INCIDENTAL HARASSMENT AUTHORIZATION APPLICATION FOR TESTING THE AN/AQS-20A MINE RECONNAISSANCE SONAR SYSTEM IN THE NSWC PCD TESTING RANGE

Submitted To:

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LIST OF ACRONYMS, ABBREVIATIONS, AND SYMBOLS

°C	Degrees Celsius
°F	Degrees Fahrenheit
°N	Degrees North
°S	Degrees South
μPa	Micropascal
3-D	Three-Dimensional
ABR	Auditory Brainstem Response
AFB	Air Force Base
ASW	Anti-Submarine Warfare
CASS-GRAB	Comprehensive Acoustic Simulation System/Gaussian Ray Bundle
CETAP	Cetacean and Turtle Assessment Program
CFR	Code of Federal Regulations
cm	Centimeters
COMPTUEX	Composite Training Unit Exercises
CPA	Closest Points of Approach
dB	Decibels
DBDBV	Digital Bathymetry Data Base Variable Resolution
dB re 1 μPa	Decibels Referenced to 1 Micropascal
dB re 1 μPa^2-s	Decibels Referenced to 1 Micropascal Squared Second
DOC	Department of Commerce
DON	Department of the Navy
EA	Environmental Assessment
EEZ	Exclusive Economic Zone
EFD	Energy Flux Density
EFDL	Energy (Flux Density) Level
EIS	Environmental Impact Statement
EIS/OEIS	Environmental Impact Statement/Overseas Environmental Impact Statement
EL	Energy Flux Density Level
EMF	Electromagnetic Field
ESA	Endangered Species Act
ETP	Eastern Tropical Pacific
FDA	Food and Drug Administration
FEIS	Final Environmental Impact Statement
FM	Frequency Modulated
ft	Feet
ft/s	Feet per Second
ft^2	Square Feet
ft^3	Cubic Feet
FWC	Florida Fish and Wildlife Conservation Commission
FY	Fiscal Year
GDEM	Generalized Digital Environmental Model
GIS	Geographic Information System
GOM	Gulf of Mexico
GRAB	Gaussian Ray Bundle
HE	High Explosive
HFBL	High-Frequency Bottom Loss
HPA	Hypothalamic-Pituitary-Adrenal

HRC	Hawaii Range Complex
Hz	Hertz
IHA	Incidental Harassment Authorization
in	Inches
in-lb/in^2	Inch Pounds per Square Inch
IWC	International Whaling Commission
J/m^2	Joule per Square Meter
JTFEX	Joint Task Force Exercises
kg	Kilograms
kg/m^3	Kilograms per Cubic Meter
kHz	Kilohertz
km	Kilometers
km/hr	Kilometers per Hour
km^2	Square Kilometers
kt	Knots
lb	Pounds
LCS	Littoral Combat Ship
LFA	Low-Frequency Active
LFBL	Low-Frequency Bottom Loss
LIDAR	Light Imaging Detection and Ranging
LLS	Laser Line Scan
L_{max}	Highest Sound Level Measured During a Single Noise Event
LOA	Letter of Authorization
LWAD	Littoral Warfare Advanced Development
m	Meters
m/sec	Meters per Second
m^2	Square Meters
m^3	Cubic Meters
MCM	Mine Countermeasures
MFA	Mid-Frequency Active
MHz	Megahertz
mi^2	Square Miles
MLO	Mine-like Object
mm	Millimeters
MMPA	Marine Mammal Protection Act
MMS	Minerals Management Service
MRA	Marine Resources Assessment
MSAT	Marine Species Awareness Training
msec	Millisecond
NATO	North Atlantic Treaty Organization
NEPA	National Environmental Policy Act
NEW	Net Explosive Weight
NIPTS	Noise-induced Permanent Threshold Shift
NM	Nautical Miles
nm	Nanometer
NM^2	Square Nautical Miles
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council

NSA PC	Naval Support Activity Panama City
NSWC PCD	Naval Surface Warfare Center Panama City Division
OEA	Overseas Environmental Assessment
ONR	Office of Naval Research
OPAREAs	Operating Areas
p	Pressure
PBR	Potential Biological Removal
PC	Panama City
PCD	Panama City Division
PL	Public Law
p_{rms}	RMS Pressure
psi	Pounds per Square Inch
psi-msec	Pounds per Square Inch per Millisecond
PTS	Permanent Threshold Shift
Q-20	AN/AQS-20A Mine Reconnaissance Sonar System
RDT&E	Research, Development, Test, and Evaluation
RIMPAC	Rim of the Pacific
rms	Root Mean Square
SAB	St. Andrew Bay
sec	Seconds
SEL	Sound Exposure Level
SI	Source Intensity
SL	Source Level
SNS	Sympathetic Nervous System
SOA	Sonar Operating Area
SPL	Sound Pressure Level
SURTASS	Surveillance Towed Array Sensor System
SVP	Sound Velocity Profile
TM	Tympanic Membrane
TNT	Trinitrotoluene
TS	Threshold Shift
TTS	Temporary Threshold Shift
UME	Unusual Mortality Events
U.S.	United States
USC	United States Code
USEPA	U.S. Environmental Protection Agency
USS	United States Ship
USWEX	Undersea Warfare Exercise
UUV	Underwater Unmanned Vehicle
VEM	Versatile Exercise Mine
W	Watts

1. DESCRIPTION OF ACTIVITIES

1.1 INTRODUCTION

The Department of the Navy (DON) has prepared this request for a Incidental Harassment Authorization (IHA) in accordance with provisions of Section 101 (a)(5)(D) of the Marine Mammal Protection Act (MMPA) to cover the incidental taking by harassment of marine mammals from testing the AN/AQS-20A Mine Reconnaissance Sonar System (hereafter referred to as the Q-20) in the Naval Surface Warfare Center, Panama City Division (NSWC PCD) Testing Range. The Q-20 test activities will be conducted in the non-territorial waters of the U.S. (beyond 12 nautical miles) (Figure 2-1).

The Marine Mammal Protection Act (MMPA) of 1972, as amended (16 United States Code (USC) Section (§) 101(a)(5)(D)), authorizes the issuance of IHAs for the incidental taking of marine mammals by a specified activity for a period of not more than one year. The issuance occurs when the Secretary of Commerce, after notice has been published in the Federal Register and opportunity for comment has been provided, finds 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. The National Marine Fisheries Service (NMFS) has promulgated implementing regulations under 50 Code of Federal Regulations (CFR) § 216.101–106 that 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 (FY) 2004 (Public Law [PL] 108-136). The basis of this request is the analysis of spatial and temporal distributions of marine mammals in the Q-20 Study Area, a review of Q-20 test activities that have the potential to affect marine mammals, and a technical risk assessment to determine the likelihood of effects to marine mammals from the Q-20 test activities.

This section describes Q-20 test activities conducted by the United States (U.S.) Navy that could expose marine mammals to sound likely to result in Level B harassment (i.e., behavioral effects) under the MMPA of 1972. The Navy requests NMFS authorize the incidental taking of marine mammals pursuant to the MMPA, with the issuance of an IHA by April, 2012.

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 Combat Ship (LCS). Testing would include component, subsystem-level, and full-scale system testing in the operational environment.

The need for the Proposed Action is to support the timely deployment of the Q-20 to the operational Navy for Mine Countermeasure (MCM) activities abroad, allowing the Navy to meet its statutory 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.

1.3 DESCRIPTION OF THE PROPOSED ACTION

The Proposed Action is to test the Q-20 from the RMMV and from surrogate platforms such as a small surface vessel or helicopter. The RMMV or surrogate platforms will be deployed from the Navy’s new LCS or its surrogates. The Navy is evaluating potential environmental effects associated with the Q-20 test activities proposed for the Q-20 Study Area, which includes non-territorial waters of military warning area W-151 (includes Panama City Operating Area). Q-20 test activities occur at sea in the waters present within the Q-20 Study Area. No hazardous waste is generated at sea during Q-20 test activities. This IHA request will evaluate only the at-sea activities related to Q-20 test activities conducted within the Q-20 Study Area and will not address routine shore side management functions performed by the supporting ashore Navy facility.

1.3.1 Basis for Operations Addressed in this IHA Request

This document addresses only mission components analyzed in the Testing the AN/AQS-20A in the NSWC PCD Testing Range, 2012-2014 Overseas Environmental Assessment (Q-20 OEA) that may result in the incidental taking of marine mammal species. Test activities that have been identified which have the potential to affect the underwater environment in regions inside and outside of the Q-20 Study Area, include surface and sonar operations. Laser operations and mine field deployment and retrieval operations are eliminated from further discussion in this IHA because these actions would not take marine mammal species as discussed in the Q-20 OEA. This request includes only the test activities that have potential to affect the underwater environment in the Q-20 Study Area.

1.3.2 Q-20 Test Activities

Surface Operations

A significant portion of Q-20 test activities rely on surface operations to successfully complete missions. Q-20 test activities involving surface operations may result in incidental harassment of marine mammals by collision. The Proposed Action includes up to 420 hours of surface operations per year in the Q-20 Study Area. Three subcategories make up surface operations:

support activities; tows; and deployment and recovery of equipment. Testing requiring 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 is support activities, which are required by nearly all of the testing missions within the Q-20 Study Area. Acting as a support platform for testing, these vessels are utilized to carry test equipment and personnel to and from the test sites and are also used to secure and monitor the designated test area. Normally, these vessels remain on site and return to port following the completion of the test; occasionally, however, they remain on station throughout the duration of the test cycle (a maximum of ten sonar hours per day) for guarding sensitive equipment in the water.

The remaining subcategories of additional support include tows, and 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 ashore 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 as a means of demonstrating the system’s software capability to detect, locate, and characterize mine-like objects under various environmental conditions. The data collected is used to validate the sonar systems’ effectiveness and capability to meet its mission.

As sound travels through water, it creates a series of pressure disturbances. Frequency is the number of complete cycles a sound or pressure wave occurs per unit of time (measured in cycles per second, or hertz [Hz]). The Navy has characterized low, mid, or high frequency as follows:

- **Low frequency** – Below 1 kilohertz (kHz) (low frequency will not be used during any Q-20 test operations)
- **Mid-frequency** – From 1 to 10 kHz (mid frequency will not be during any Q-20 test operations)
- **High frequency** – Above 10 kHz (Q-20 test operations would use high frequency sound sources)

The Q-20 sonar systems proposed to be tested within the Q-20 Study Area range in frequencies from 35 kHz to > 200 kHz. The sonar systems that operate at very high frequencies (i.e., >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 sonar systems that require analysis in this document range from between 207 decibels (dB) re 1 micro pascal (µPa) at 1 meter (m) to 212 dB re 1 µPa at 1 m. Operating parameters of the Q-20 sonar systems can be found in Appendix A, Supplemental Information for Underwater Noise Analysis.

2. DURATION AND LOCATION OF THE ACTIVITIES

This Q-20 IHA request 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 Military Warning Area 151 (W-151), an area within the Gulf of Mexico (GOM) subject to military operations which also encompasses the Panama City Operating Area (Figure 2-1). The Q-20 test activities will be conducted in the non-territorial waters of the U.S. (beyond 12 nautical miles). The locations and environments include:

- Wide coastal shelf to 183 meters (m) [600 feet (ft)].
- Water temperature range of 27 degrees Celsius (°C) [80 degrees Fahrenheit (°F)] in summer to 10 °C (50 °F) in winter.
- Mostly sandy bottom and good underwater visibility.
- Seas less than 0.91 m (3 ft) 80 percent of the time in summer and 50 percent of the time in winter.

This IHA request is for a time period of one year beginning April, 2012. Forty-two RDT&E test days will be conducted with a maximum sonar operation of 10 hours per test day.

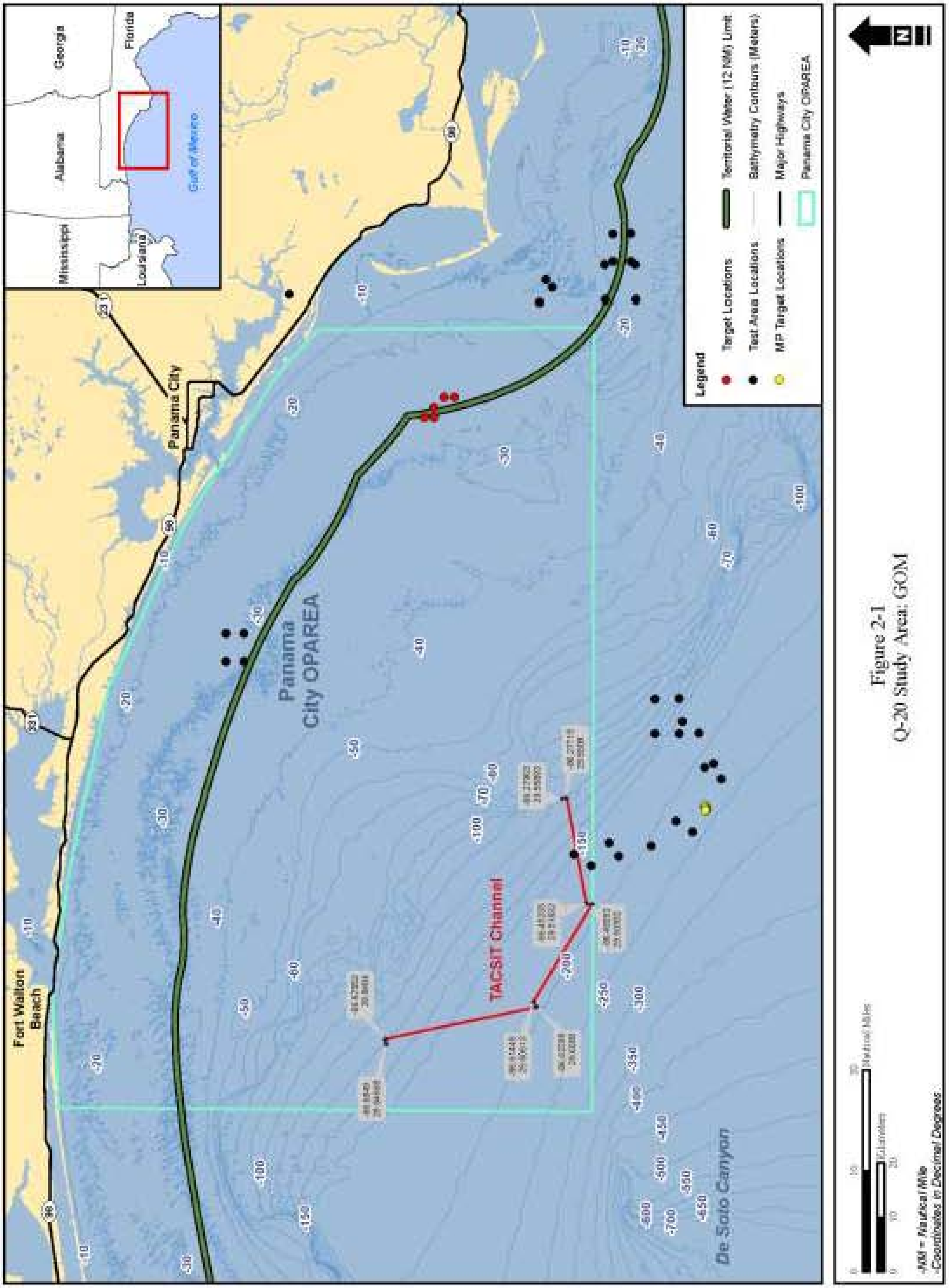

Figure 2-1. Existing TTS Data for Cetaceans

3. MARINE MAMMAL SPECIES AND NUMBERS

The Marine Mammal Protection Act (MMPA), which is administered by the National Marine Fisheries Service (NMFS) and the U.S. Fish and Wildlife Service (USFWS), protects all marine mammals in United States (U.S.) waters. Twenty-nine marine mammal species may occur in the Q-20 Study Area. Twenty-two of these species regularly occur here. Of the 29 species potentially occurring in the Q-20 Study Area, six species are currently listed as endangered under the Endangered Species Act. The discussion below describes all of the species whose ranges include the Gulf of Mexico (GOM) and identifies which are most likely to occur in the Study Area.

Marine Mammal Occurrence

Marine mammals are generally defined as mammals that depend upon the sea for all or most of their life needs. Cetaceans may be further categorized as mysticetes or odontocetes. Mysticetes use baleen plates to filter small prey items from the water column whereas odontocetes use teeth to capture prey.

Cetaceans inhabit most marine environments, from deep ocean canyons to shallow estuarine waters. However, they are not randomly distributed. Marine mammal distribution is affected by demographic, evolutionary, ecological, habitat-related, and anthropogenic factors (Bjørge, 2002; Forcada, 2002; Stevick et al., 2002). Species occurring off the continental shelf are often associated with physical features that tend to concentrate prey, such as banks, canyons, or the shelf edge. Cetacean movements are often related to breeding or feeding (Stevick, 2002). Cetacean occurrence and movement has also been linked to indirect prey indicators such as temperature variations, sea surface chlorophyll *a* concentrations, and features such as bottom depth (Fiedler, 2002). Occurrence may also be related to oceanographic features such as upwelling events or warm core rings. The increased nutrient concentrations associated with upwelling results in areas of high primary productivity. These areas of high primary production cause a cascading effect on the trophic dynamics of marine animals; upwelling areas are generally associated with higher-than-average levels of consumers such as copepods, fish, and cetaceans. Marine mammals have also been associated with warm core rings that have pinched off the Gulf Stream current. Many species, including sperm whales (*Physeter macrocephalus*), were associated with the periphery of Gulf Stream warm-core rings, probably due to the increased productivity and presence of prey species around the rings (Waring et al, 2001; Griffin, 1999).

Some baleen whale species, such as humpback and North Atlantic right whales, make extensive annual migrations to low-latitude mating and calving grounds in the winter and to high-latitude feeding grounds in the summer (Corkeron and Connor, 1999). These migrations undoubtedly occur during these seasons due to the presence of highly productive waters and associated cetacean prey species at high latitudes and warm water temperatures at low latitudes (Corkeron and Connor, 1999; Stern, 2002). Not all baleen whales, however, migrate. Some individual fin (*B. physalus*) and blue (*B. musculus*) whales may stay year-round in a specific area. The timing of migration is often a function of age, sex, and reproductive class. Females tend to migrate earlier than males and adults earlier than immature animals (Stevick et al., 2002). Since most toothed whales do not have the fasting capability of the baleen whales, toothed whales probably either follow seasonal shifts in preferred prey or are opportunistic feeders, taking advantage of whatever prey happens to be in the area (Department of the Navy [DON], 2007).

A variety of marine mammals occur in the GOM. Most of the cetaceans occurring in the GOM are odontocetes. Very few baleen whales exist in the GOM and all species except the Bryde's whale would not be expected to occur within the Q-20 Study Area since they are rarely seen in the GOM. Fourteen species of oceanic dolphins, five species of beaked whales, and fourteen species of whales belonging to four families inhabit or migrate through the eastern GOM. Of the fifteen whale species, six species are listed under the ESA as endangered. Five of these six whales have been only rarely sighted in the eastern GOM. They include the North Atlantic right whale, the humpback whale, the sei whale, the fin whale, and the blue whale.

Cetaceans considered to be common in the GOM include the Atlantic bottlenose dolphin (*Tursiops truncatus*), the pantropical spotted dolphin (*Stenella attenuata*), the Atlantic spotted dolphin (*Stenella plagiodon*), and the striped dolphin (*Stenella coeruleoalba*). Of all whale species in the GOM, the endangered sperm whales (*Physeter macrocepalus*) are the most abundant (Waring et al., 2007). Table 3-1 presents the cetaceans sighted within the GOM as determined in a Navy technical report (DON, 2007).

Table 3-1. Marine Mammals with Sighting Records in the GOM

Common Name	Scientific Name	Status
Suborder Mysticeti (baleen whales)		
Family Balaenopteridae (rorquals)		
North Atlantic right whale	*Eubalaena glacialis*	Endangered
Humpback whale	*Megaptera novaeangliae*	Endangered
Sei whale	*Balaenoptera borealis*	Endangered
Fin whale	*Balaenoptera physalus*	Endangered
Blue whale	*Balaenoptera musculus*	Endangered
Bryde's whale	*Balaenoptera edeni*	
Minke whale	*Balaenoptera acutorostrata*	
Suborder Odontoceti (toothed whales)		
Family Physeteridae (sperm whale)		
Sperm whale	*Physeter macrocephalus*	Endangered
Family Kogiidae		
Pygmy sperm whale	*Kogia breviceps*	
Dwarf sperm whale	*Kogia sima*	
Family Ziphiidae (beaked whales)		
Cuvier's beaked whale	*Ziphius cavirostris*	
Gervais' beaked whale	*Mesoplodon europaeus*	
Blainville's beaked whale	*Mesoplodon densirostris*	
Sowerby's beaked whale	*Mesopolodon bidens*	
True's beaked whale	*Mesopolodon mirus*	
Family Delphinidae (dolphins)		
Rough-toothed dolphin	*Steno bredanensis*	
Atlantic bottlenose dolphin	*Tursiops truncatus*	
Pantropical spotted dolphin	*Stenella attenuata*	
Atlantic spotted dolphin	*Stenella frontalis*	

Common Name	Scientific Name	Status
Spinner dolphin	*Stenella longirostris*	
Clymene dolphin	*Stenella clymene*	
Striped dolphin	*Stenella coeruleoalba*	
Fraser's dolphin	*Lagenodelphis hosei*	
Risso's dolphin	*Grampus griseus*	
Melon-headed whale	*Peponocephala electra*	
Pygmy killer whale	*Feresa attenuata*	
False killer whale	*Pseudorca crassidens*	
Killer whale	*Orcinus orca*	
Short-finned pilot whale	*Globicephala macrorhynchus*	

Source: DON, 2007

Of the approximately 29 species with occurrence records in the Q-20 Study Area, 22 species regularly occur here. The other seven species are extralimital and are excluded from further consideration of impacts from Q-20 test activities. Table 3-2 provides an overview of the best and minimum population estimates for marine mammal stocks by region in the Q-20 Study Area, which are calculated by NMFS officials in their Stock Assessment Reports (SAR). The most current SARs were used for the population estimates. If the population estimates were listed as unknown the last SAR with population estimates was used. This table addresses only the species that are potentially expected to be in the Q-20 Study Area and that were analyzed in this document. Stocks and regions are provided because some species, in this case the Atlantic bottlenose dolphin, have been divided by NMFS officials into different stocks based on their anatomical, genetic, and/or behavioral characteristics.

Table 3-2. Best and Minimum Population Estimates for Marine Mammals in the Q-20 Study Area Calculated by NMFS

Species	Stock	Best Population Estimate	Minimum Population Estimate	SAR Date
Bryde's Whale	Northern GOM	15	5	2009
Sperm Whale	Northern GOM	1,665	1,409	2010
Kogia sp. (Dwarf and Pygmy Sperm Whale)	Northern GOM	453	340	2009
Mesoplodon sp. (Blainville's & Gervais Beaked Whales)	Northern GOM	57	24	2009
Cuvier's Beaked Whale	Northern GOM	65	39	2009
Sowerby's Beaked Whale	Western North Atlantic	NA	NA	2009
Rough-toothed Dolphin	Northern GOM	2,653	1,890	2008
Atlantic Bottlenose Dolphin	Coastal, Eastern GOM	7,702	6,551	2010
Atlantic Bottlenose Dolphin	Continental Shelf & Slope	17,777	13,667	2008
Atlantic Bottlenose Dolphin	GOM Oceanic	3,708	2,641	2009
Atlantic Bottlenose Dolphin	Northern GOM Coastal	2,473	2,004	2010
Pantropical Spotted Dolphin	Northern GOM	34,067	29,311	2009
Atlantic Spotted Dolphin	Northern GOM	37,611	29,844	2008
Spinner Dolphin	Northern GOM	1,989	1,356	2009
Clymene Dolphin	Northern GOM	6,575	4,901	2009
Striped Dolphin	Northern GOM	3,325	2,266	2009
Fraser's Dolphin	Northern GOM	726	427	2005

Risso's Dolphin	Northern GOM	1,589	1,271	2010
Melon Headed Whale	Western North Atlantic	2,283	1,293	2009
Pygmy Killer Whale	Northern GOM	323	203	2009
False Killer Whale	Northern GOM	777	501	2009
Killer Whale	Northern GOM	49	28	2010
Short-finned pilot whale	Northern GOM	716	542	2009

NA Not applicable, only one sighting available for estimate; OCS = Outer Continental Shelf
Source: NMFS Stock Assessment Reports

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

Cetaceans have a number of anatomical and physiological adaptations to the aquatic environment. Compared to terrestrial mammals, body heat conservation is more efficient due to the presence of blubber and the circulatory adjustments made to minimize heat loss. Many marine mammals are also capable of prolonged and deep dives. Characteristics that enable such dives include flexible ribs that allow the lungs to collapse, thickened tissue in the middle ear, slowed heart rate, reduced oxygen consumption, and shunting of blood to essential tissues during dives. Sensory abilities also vary somewhat from those of terrestrial mammals. Hearing is extremely important to cetaceans because sound travels further in water than in air. In addition, light attenuation in water decreases the distance of the visual range of marine mammals and therefore, marine mammals use hearing in place of vision. Vocalization is used to navigate, forage, and socialize. Produced sound often extends above and below the range of human hearing. Baleen whales primarily use low frequencies (0.20 to 3 kilohertz [kHz]). Odontocetes typically use high frequencies, but produce a wide range of frequencies. Direct experimental data on cetacean hearing ability are sparse, particularly for the larger species. It is generally believed that these animals should at least be sensitive to the frequencies of their own vocalizations. Scientists have determined auditory thresholds for a few dolphin species in captivity. Studies of the anatomy of cetacean inner ears and models of the structural properties provide an indication of possible sensitivity to various sound frequencies. The ears of small, toothed whales appear to be optimized to hear high frequencies, while baleen whale ears are likely most sensitive to low frequencies.

This section provides detailed information on the population characteristics for the affected species in the Q-20 Study Area. Descriptions include the distribution of animals in the Q-20 Study Area and abundance estimates. As defined in Section 2, Q-20 test activities take place in the non-territorial waters of W-151 (includes Panama City OPAREA) in the Gulf of Mexico (GOM). Of the approximately 29 species with occurrence records in the Q-20 Study Area, 21 species regularly occur here. The other seven species are extralimital and are excluded from further consideration of impacts from Q-20 test activities. The following sections describe marine mammal occurrence in the Q-20 Study Area.

The Navy Marine Resources Assessment (MRA) program was implemented by the Commander, United States (U.S.) Fleet Forces Command, to collect data and information on the protected and commercial marine resources found in the Department of the Navy's (DON's) operating areas. Specifically, the goal of the MRA program is to describe and document the marine resources present in each of the Navy's Operating Areas. As such, an MRA has been completed for the GOM Testing and Training Areas, which comprise three adjacent Operating Areas, one of which is the Panama City Operating Area (DON, 2007). The DON 2007 is the most current MRA for the GOM.

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 (2003) reports, including stock assessment reports, recovery plans, and survey reports. The MRAs summarize the physical environment (e.g., marine geology, circulation and currents, hydrography, and plankton and primary productivity) for each test area. In addition, an in-depth discussion of the biological environment (marine mammals, sea turtles, fish, and EFH), as well as fishing grounds (recreational and commercial) and other areas of interest (e.g., maritime boundaries, navigable waters, marine managed areas, recreational diving sites) are also provided. Where applicable, the information contained in the Marine Resources Assessment (MRA) was used for this Incidental Harassment Authorization (IHA).

The MRA uses a particular convention to describe marine mammal occurrence throughout the Navy's OPAREAs. The specific terms used and their corresponding meanings are as follows:

- **Expected occurrence** is defined as the area encompassing the expected distribution of a species based on what is known of its habitat preferences, life history, and the available stranding, sighting, and fisheries' incidental by-catch data.

- **Extralimital occurrence** is defined as the area where species occasionally occur in very small numbers.

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

- **Occurrence not expected** is the area where a species is not expected to be encountered.

The MRA data were used to provide a regional context for each species. The data were compiled from available sighting records, literature, satellite tracking, and stranding and by-catch data.

4.1 MYSTICETES

The following mysticetes have probable or confirmed occurrence in the Q-20 Study Area in the GOM.

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. The taxonomy of the baleen whale group formerly known as sei and Bryde's whales is currently confused and highly controversial.

Status – The best estimate of abundance for Bryde's whales within the Northern GOM Stock is 15, with a minimum population size estimate of 5 whales (NMFS, 2009a). 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 (NMFS, 2009a). The NOAA Stock Assessment Report 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° 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. Additional information on reproductive areas and seasons for this species is not available.

Diving Behavior – Bryde's whales are lunge-feeders, feeding primarily on fish, but they also take small crustaceans. Bryde's whales might dive as long as 20 min.

Acoustics and Hearing **–** Bryde's whales produce low frequency tonal and swept calls similar to those of other rorquals. Calls vary regionally, yet all but one of the call types have a fundamental frequency below 60 Hz. They last from 0.25 sec to several seconds; and they are produced in extended sequences. While no data on hearing ability for this species are available, Ketten (1997) hypothesized that mysticetes have acute infrasonic hearing.

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 coast of the Gulf. 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.

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. 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.

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.

Status – Sperm whales are classified as endangered under the ESA, although they are globally not in any immediate danger of extinction. They are 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. In the GOM, the best abundance estimate for sperm whales is 1,665, with a minimum population estimate of 1,409 (NMFS, 2010a). Abundance information, population dynamics, and trends are extremely limited for sperm whale populations in U.S. waters (Lowry et al., 2007).

Distribution **–** Sperm whales are found from tropical to polar waters in all oceans of the world between approximately 70°N and 70°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, 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 NM); these are among the longest documented movements for female sperm whales.

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 go 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.

Diving Behavior – Sperm whales forage during deep dives that routinely exceed a depth of 400 m (1,312 ft) and 30 min duration. Sperm whales are capable of diving to depths of over 2,000 m (6,56 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 hours 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 meters per second (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).

Acoustics and Hearing **–** Sperm whales typically produce short-duration (<30 ms), repetitive broadband clicks used for communication and echolocation. These clicks range in frequency from 0.1 to 30 kHz, with dominant frequencies between the 2 to 4 kHz and 10 to 16 kHz ranges. When sperm whales are socializing, they tend to repeat series of group-distinctive clicks (codas), which follow a precise rhythm and may last for hours. Codas are shared between individuals of a social unit and are considered to be primarily for intra-group communication. Recent research in the South Pacific suggests that in breeding areas the majority of codas are produced by mature females. Coda repertoires have also been found to vary geographically and are categorized as dialects, similar to those of killer whales. For example, significant differences in coda repertoire have been observed between sperm whales in the Caribbean and those in the Pacific. Furthermore, the clicks of neonatal sperm whales are very different from those of adults. Neonatal clicks are of low-directionality, long-duration (2 to 12 ms), and low-frequency (dominant frequencies around 0.5 kHz) with estimated source levels between 140 and 162 dB re 1 μPa-m root mean square (rms) and are hypothesized to function in communication with adults. Source levels from adult sperm whale's highly directional (possible echolocation), short (100 μs) clicks have been estimated up to 236 dB re 1 μPa-m rms. Creaks (rapid sets of clicks) are heard most frequently when sperm whales are engaged in foraging behavior in the deepest portion of their dives with intervals between clicks and source levels being altered during these behaviors. It has been shown that sperm whales may produce clicks during 81 percent of their dive period; specifically, 64 percent of the time during their descent phases. In addition to producing clicks, sperm whales, in some regions like Sri Lanka and the Mediterranean Sea, have been recorded making what are called trumpets at the beginning of dives just before commencing click production.

The anatomy of the sperm whale's inner and middle ear indicates an ability to best hear high frequency to ultrasonic frequency sounds. They may also possess better low-frequency hearing than other odontocetes, although not as low as many baleen whales. The auditory brainstem response (ABR) technique used on a stranded neonatal sperm whale indicated it could hear sounds from 2.5 to 60 kHz with best sensitivity to frequencies between 5 and 20 kHz.

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.

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.

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.

There has also been recent extensive work on the movements and habitat use of sperm whales in the northern Gulf of Mexico, such as the studies conducted by the Sperm Whale Acoustic Monitoring Program (SWAMP) and the Sperm Whale Seismic Study (SWSS). These studies include habitat cruises, physical oceanographic analyses, and long term satellite tag deployments. Several satellite tags have operated for over 12 months and indicate movements generally along the shelf break (700-1,000 m depth) throughout the Gulf, with some animals (more frequently males) using deeper oceanic waters. (NMFS, 2011).

Based on the analysis of largely the same data set compiled in the GOM MRA (DoN 2007) and used to estimate “sightings per unit effort,” sperm whales have a zero probability of being seen in the vicinity of the proposed test area except during spring (April-July). The low (non-zero) probability of occurrence during spring reflects a lone sighting as shown in the stock assessment report (NMFS, 2010a).

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*.

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). The best abundance estimate for pygmy and dwarf sperm whales in the Northern GOM is 453 animals with a minimum population of 340 (NMFS, 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.

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.

Acoustics and Hearing – The only sound recordings for the pygmy sperm whale are from a stranded individual that produced echolocation clicks ranging from 60 to 200 kHz, with a dominant frequency of 120 to 130 kHz. Recently, a dwarf sperm whale was recorded producing clicks at 13 to 33 kHz with durations of 0.3 to 0.5 sec. A study completed on a stranded pygmy sperm whale indicated a hearing range of 90 to 150 kHz. No information on sound production or hearing is available for the dwarf sperm whale.

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) isobath.

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. Occurrence is assumed to be the same for all four seasons.

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 and three members of the genus *Mesoplodon* (Gervais', Blainville's, and Sowerby's beaked whales).

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); Gervais' beaked whale males reach lengths of at least 4.5 m (15 ft), while females reach at least 5.2 m (17 ft); and Sowerby's beaked whale males and females attain lengths of at least 5.5 and 5.1 m (18 and 17 ft), respectively. 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. Northern bottlenose whales are 7 to 9 m (23.0 to 29.5 ft) in length and have rotund bodies, large bulbous heads, and small, well-defined beaks.

Status **–** The best abundance estimate for Cuvier's beaked whales in the northern GOM is 65 individuals, with a minimum population estimate for the northern GOM of 39 Cuvier's beaked whales (NMFS, 2009c). It is not possible to determine the minimum population estimate of only Cuvier's beaked whales. The best abundance estimate for *Mesoplodon* species in the northern GOM is 106 animals. The minimum population estimate for *Mesoplodon* species in the northern GOM is 76.

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. Information on reproductive areas and seasons is not available for these species.

Sowerby's beaked whales and True's beaked whales are the most northerly species, occurring in northern, temperate waters of the North Atlantic; in the GOM they are currently considered extralimital. 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. 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. Tagged Cuvier's beaked whale dive durations as long as 87 minutes and dive depths of up to 1,990 m (6,529 ft) have been recorded. 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 minutes to depths greater than 800 m (2,625 ft), with one long dive occurring on average every two hours; (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.

Acoustics and Hearing **–** Sounds recorded from beaked whales are divided into two categories: whistles and pulsed sounds (clicks); whistles likely serve a communicative function and pulsed sounds are important in foraging and/or navigation. Whistle frequencies are about 2 to 12 kHz, while pulsed sounds range in frequency from 300 Hz to 135 kHz; however, higher frequencies may not be recorded due to equipment limitations. Whistles recorded from free-ranging Cuvier's beaked whales off Greece ranged in frequency from 8 to 12 kHz, with an upsweep of about 1 sec, while pulsed sounds had a narrow peak frequency of 13 to 17 kHz, lasting 15 to 44 sec in duration. Short whistles and chirps from a stranded sub adult Blainville's beaked whale ranged in frequency from slightly <1 to almost 6 kHz. Recent studies incorporating digital acoustic recording tags (known commonly as DTAGs) attached to both Blainville's and Cuvier's beaked whales in the Ligurian Sea (arm of the Mediterranean Sea) recorded high-frequency echolocation clicks (duration: 175 µs for Blainville's and 200 to 250 µs for Cuvier's) with dominant frequency ranges from about 20 to over 40 kHz (limit of recording system was 48 kHz) and only at depths greater than 200 m. The source levels of the Blainville's beaked whales' clicks were estimated to range from 200 to 220 dB re 1 µPa-m, while they were 214 dB re 1 µPa-m for the Cuvier's beaked whale.

From anatomical examination of their ears, it is presumed that beaked whales are predominantly adapted to best hear ultrasonic frequencies. Beaked whales have well-developed semi-circular canals (typically for vestibular function but may function differently in beaked whales) compared to other cetacean species, and they may be more sensitive than other cetaceans to low frequency sounds. The only direct measure of beaked whale hearing is from using auditory evoked potential techniques on a stranded juvenile Gervais' beaked whale. The hearing range was 5 to 80 kHz, with greatest sensitivity at 40 and 80 kHz.

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.

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.

Status **–** The best estimate of abundance for rough-toothed dolphins is 2,653 in the northern GOM. The minimum population estimate for the same area is 1,890 rough-toothed dolphins (NMFS, 2008a). There is no information on stock differentiation for the western North Atlantic stock of this species.

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 (ETP) 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.

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. 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).

Acoustics and Hearing **–** The rough-toothed dolphin produces a variety of sounds, including broadband echolocation clicks and whistles. Echolocation clicks (duration <250 microseconds [μsec]) typically have a frequency range of 0.1 to 200 kHz, with a dominant frequency of 25 kHz. Whistles (duration <1 sec) have a wide frequency range of 0.3 to greater than 24 kHz but dominate in the 2 to 14 kHz range. There has been no data collected on rough-toothed dolphin hearing ability. However, odontocetes are generally adapted to hear high frequencies.

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.

Bottlenose Dolphin (*Tursiops truncatus*)

Description – Bottlenose dolphins (genus *Tursiops*) are large, relatively robust dolphins with striking regional variation in body size; adult body length ranges from 1.9 to 3.8 m (6.2 to 12.5 ft). *Tursiops* are opportunistic feeders, taking a wide variety of fish, cephalopods, and shrimp. *Tursiops* use a wide variety of feeding strategies, including feeding in association with shrimp trawls.

Scientists recognize a near shore (coastal) and an offshore form of the bottlenose dolphin, which may be distinguished by external morphology, hematology, cranial morphology, diet, and parasite load. Both "coastal" and "offshore" forms of bottlenose dolphins occur in the GOM (NMFS, 2008b).

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 (NMFS, 2008b).

In the northern GOM, there are three 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. The best estimate of abundance along the GOM continental shelf and slope is 17,777, with a minimum population estimate of 13,667 bottlenose dolphins (NMFS, 2008b).

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 NM) to Monterey Bay.

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.

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 – 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 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.

Acoustics and Hearing – Sounds emitted by bottlenose dolphins have been classified into two broad categories: pulsed sounds (including clicks and burst-pulses) and narrow-band continuous sounds (whistles), which usually are frequency modulated. Clicks and whistles have a dominant frequency range of 110 to 130 kHz and a source level of 218 to 228 dB re 1 µPa-m and 3.4 to 14.5 kHz and 125 to 173 dB re 1 µPa-m, respectively. Whistles are primarily associated with communication and can serve to identify specific individuals (i.e., signature whistles). Up to 52 percent of whistles produced by bottlenose dolphin groups with mother-calf pairs can be classified as signature whistles. Sound production also is influenced by group type (single or multiple individuals), habitat, and behavior. Bray calls (low-frequency vocalizations; majority of energy below 4 kHz), for example, are used when capturing fish, specifically sea trout (*Salmo trutta*) and Atlantic salmon (*Salmo salar*), in some regions (i.e., Moray Firth, Scotland). Additionally, whistle production has been observed to increase while feeding. Furthermore, both whistles and clicks have been demonstrated to vary geographically in terms of overall vocal activity, group size, and specific context (e.g., feeding, milling, traveling, and socializing). For example, preliminary research indicates that characteristics of whistles from populations in the northern GOM significantly differ (i.e., in frequency and duration) from those in the western north Atlantic.

Bottlenose dolphins can typically hear within a broad frequency range of 0.04 to 160 kHz. Electrophysiological experiments suggest that the bottlenose dolphin brain has a dual analysis system: one specialized for ultrasonic clicks and another for lower-frequency sounds, such as whistles. Scientists have reported a range of highest sensitivity between 25 and 70 kHz, with peaks in sensitivity at 25 and 50 kHz. Recent research, on the same individuals, indicates that auditory thresholds obtained by electrophysiological methods correlate well with those obtained in behavior studies, except at the some lower (10 kHz) and higher (80 and 100 kHz) frequencies. Temporary threshold shifts (TTS) in hearing have been experimentally induced in captive bottlenose dolphins using a variety of noises (i.e., broad-band, pulses). For example, TTS has been induced with exposure to a 3 kHz, one-second pulse with sound exposure level (SEL) of 195 dB re 1 µPa2-s, one-second pulses from 3 to 20 kHz at 192 to 201 dB re 1µPa-m, and octave band noise (4 to 11 kHz) for 50 minutes at 179 dB re 1 µPa-m. Preliminary research indicates that TTS and recovery after noise exposure are frequency dependent and that an inverse relationship exists between exposure time and sound pressure level associated with exposure. Observed changes in behavior were induced with an exposure to a 75 kHz one-second pulse at 178 dB re 1 µPa-m. TTS has been measured to be between 8 and 16 kHz (negligible or absent at higher frequencies) after 30 min of noise exposure (4 to 11 kHz) at 160 dB re 1 µPa-m (Nachtigall et al., 2004).

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 western extent of the map area.

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.

Pantropical and Atlantic Spotted Dolphins (*Stenella attenuata* and *Stenella frontalis*)

Description – The pantropical spotted dolphin is a generally slender dolphin. Adults may reach up to 2.6 m (8.5 ft) in length. Pantropical spotted dolphins are born spotless and develop spots as they age although the degree of spotting varies geographically. Some populations may be virtually unspotted. Pantropical spotted dolphins prey on epipelagic fish, squid, and crustaceans, with some take of mesopelagic animals.

The Atlantic spotted dolphin tends to resemble the bottlenose dolphin more than it does the pantropical spotted dolphin. In body shape, it is somewhat intermediate between the two, with a moderately long but rather thick beak. Adults are up to 2.3 m (7.5 ft) long and 143 kilogram (kg) (315 pounds [lb]) in weight. Atlantic spotted dolphins are born spotless and develop spots as they age. Some Atlantic spotted dolphin individuals become so heavily spotted that the dark cape and spinal blaze are difficult to see. There is marked regional variation in adult body size of the Atlantic spotted dolphin. There are two forms: a robust, heavily spotted form that inhabits the continental shelf, usually found within 250 to 350 km (135 to 189 NM) of the coast, and a smaller, less spotted form that inhabits offshore waters. The largest body size is exhibited by the coastal form, which occurs in waters over the continental shelf of North America (U.S. East Coast, GOM, and Central America). The smallest Atlantic spotted dolphins are those around oceanic islands, such as the Azores, and on the high seas in the western North Atlantic. Atlantic spotted dolphins feed on small cephalopods, fish, and benthic invertebrates, and in the GOM have been seen feeding cooperatively and are known to feed in association with shrimp trawls.

Where the Atlantic spotted dolphin and the pantropical spotted dolphin co-occur, the offshore form of the Atlantic spotted dolphin and the pantropical spotted dolphin can be difficult to differentiate at sea. (NMFS, 2008c and 2009d).

Status – The best estimate of abundance for Atlantic spotted dolphins in the northern GOM is 37,611, with a minimum population estimate of 29,894 dolphins (NMFS, 2008c).

The pantropical spotted dolphin is the most abundant and commonly-seen cetacean in deep waters of the northern GOM. The best estimate of abundance for pantropical spotted dolphins in the northern GOM is 34,067, with a minimum population of 29,311 dolphins (NMFS, 2009d).

Distribution – The pantropical spotted dolphin is distributed in tropical and subtropical waters worldwide, generally occurring in oceanic waters beyond the shelf break. *Stenellid* dolphins have been sighted within the Gulf Stream, which is consistent with the oceanic distribution of pantropical spotted dolphins and their preference for warm waters. 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).

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 northern 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 NM) 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.

Diving Behavior – Pantropical spotted dolphins 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 ETP and off Hawaii. 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).

Acoustics and Hearing – Pantropical spotted dolphin whistles have a frequency range of 3.1 to 21.4 kHz. Clicks typically have two frequency peaks (bimodal) at 40 to 60 kHz and 120 to

140 kHz with estimated source levels up to 220 dB re 1 μPa peak-to-peak. No direct measures of hearing ability are available for pantropical spotted dolphins, but ear anatomy has been studied and indicates that this species should be adapted to hear the lower range of ultrasonic frequencies (<100 kHz).

A variety of sounds including whistles, echolocation clicks, squawks, barks, growls, and chirps have been recorded for the Atlantic spotted dolphin. Whistles have dominant frequencies below 20 kHz (range: 7.1 to 14.5 kHz) but multiple harmonics extend above 100 kHz, while burst pulses consist of frequencies above 20 kHz (dominant frequency of approximately 40 kHz. Other sounds, such as squawks, barks, growls, and chirps, typically range in frequency from 0.1 to 8 kHz. Recently recorded echolocation clicks have two dominant frequency ranges at 40 to 50 kHz and 110 to 130 kHz, depending on source level (i.e., lower source levels typically correspond to lower frequencies and higher frequencies to higher source levels. Echolocation click source levels as high as 210 dB re 1 μPa-m peak-to-peak have been recorded. There are no empirical hearing data for Atlantic spotted dolphins.

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 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.

The pantropical spotted dolphin is an oceanic species and is the most common cetacean in the oceanic northern GOM and is found in the deeper waters off the continental shelf. 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.

Spinner Dolphin (*Stenella longirostris*)

Description – This is a very slender dolphin that has a very long and slender beak and can reach lengths of 2.4 m (7.9 ft). This species has a three-part color pattern (dark gray cape, light gray sides, and white belly). There are four known subspecies of spinner dolphins and probably other undescribed ones. Spinner dolphins feed primarily on small mesopelagic fish, squid, and sergestid shrimp, diving to at least 200 to 300 m (656 to 984 ft). Many of these organisms become available to spinner dolphins when the deep-scattering layer moves toward the surface at night.

Status – The best estimate of abundance for spinner dolphins in the northern GOM is 1,989. The minimum population estimate for the northern GOM is 1,356 spinner dolphins (NMFS, 2009e).

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 U.S. 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.

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.

Acoustics and Hearing – Pulses, whistles, and clicks have been recorded from this species. Pulses and whistles have dominant frequency ranges of 5 to 60 kHz and 8 to 12 kHz, respectively. Spinner dolphins consistently produce whistles with frequencies as high as 16.9 to 17.9 kHz with a maximum frequency for the fundamental component at 24.9 kHz. Clicks have a dominant frequency of 60 kHz. The burst pulses are predominantly ultrasonic, often with little or no energy below 20 kHz. Source levels between 195 and 222 dB re 1 µPa-m have been recorded for spinner dolphin clicks. Other research indicates that this species produces whistles in the range of 1 to 22.5 kHz with the dominant frequency being 6.8 to 17.9 kHz, although their full range of hearing may extend down to 1 kHz or below as reported for other small odontocetes (Nedwell et al., 2004).

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. Occurrence is assumed to be similar throughout the year.

Clymene Dolphin (*Stenella clymene*)

Description – The Clymene dolphin is easily confused with the spinner dolphin (and the short-beaked common dolphin) due to its similar appearance. The Clymene dolphin, however, is smaller and more robust, with a much shorter and stockier beak. The Clymene dolphin can reach at least 2 m (7 ft) in length and weights of at least 85 kg (187 lb). Available information on feeding habits is limited to the stomach contents of two individuals and one observation of free ranging dolphins; Clymene dolphins feed on small fish and squid.

Status **–** For animals in the GOM, the best estimate of abundance for Clymene's dolphins is 6,575, with a minimum population estimate of 4,901 dolphins (NMFS, 2009f).

Distribution **–** 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 (NMFS, 2009f). 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 are found in deep waters with a mean bottom depth of 1,870 m (6,135 ft). Additional information on reproductive areas and seasons is not available for this species.

Diving Behavior – There is no diving information available for this species.

Acoustics and Hearing – The only data available for this species is a description of their whistles. Clymene dolphin whistle structure is similar to that of other stenellids, but it is generally higher in frequency (range of 6.3 to 19.2 kHz). There is no empirical data on the hearing ability of Clymene dolphins; however, the most sensitive hearing range for odontocetes generally includes high frequencies.

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.

Striped Dolphin (*Stenella coeruleoalba*)

Description **–** The striped dolphin is a uniquely marked dolphin, which is relatively robust and reaches 2.6 m (8.5 ft) in length. Striped dolphins often feed in pelagic or benthopelagic zones along or seaward of the continental slope. Small, midwater fish (in particular, myctophids or lantern fish) and squid are the dominant prey.

Status **–** The best abundance estimate for striped dolphins in the northern GOM is 3,325, with a minimum population estimate of 2,266 striped dolphins (NMFS, 2009g).

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.

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.

Acoustics and Hearing – Striped dolphin whistles range from 6 to greater than 24 kHz, with dominant frequencies ranging from 8 to 12.5 kHz. A single striped dolphin's hearing range, determined by using standard psycho-acoustic techniques, was from 0.5 to 160 kHz with best sensitivity at 64 kHz.

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.

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.

Status – The best estimate of abundance for Fraser's dolphins in the northern GOM is 726, with a minimum population estimate of 427 animals (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. 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.

Acoustics and Hearing – Very little is known of the acoustic abilities of the Fraser's dolphin. Fraser's dolphin whistles have a frequency range of 7.6 to 13.4 kHz. There are no hearing data for this species.

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 sightings in the Q-20 Study Area and the known habitat preferences of this species. Fraser's dolphins have been sighted 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) isobath.

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.

Status –The best abundance estimate for Risso's dolphins in the northern GOM is 1,589, with a minimum population estimate of 1,271 dolphins (NMFS, 2010b).

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 10 degrees Celsius (ºC) (50 degrees Fahrenheit [°F]). In the western North Atlantic, this species is found from Newfoundland southward to the GOM, throughout the Caribbean, and around the equator. A number of studies have noted that the Risso's dolphin is found along the continental slope. 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. 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.

Acoustics and Hearing – Risso's dolphin vocalizations include broadband clicks, barks, buzzes, grunts, chirps, whistles, and combined whistle and burst-pulse sounds that range in frequency from 0.4 to 22 kHz and in duration from less than a second to several seconds. The combined whistle and burst pulse sound (2 to 22 kHz, mean duration of 8 sec) appears to be unique to Risso's dolphin. Risso's dolphins also produce echolocation clicks (40 to 70 µs duration) with a dominant frequency range of 50 to 65 kHz and estimated source levels up to 222 dB re 1 µPa-m peak-to-peak.

Baseline research on the hearing ability of this species was conducted in a natural setting (included natural background noise) using behavioral methods on one older individual. This individual could hear frequencies ranging from 1.6 to 100 kHz and was most sensitive between 8 and 64 kHz. Hearing in a stranded infant has also been measured. This individual could hear frequencies ranging from 4 to 150 kHz, with best sensitivity at 90 kHz. This study demonstrated that this species can hear higher frequencies than previously reported.

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.

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.

Status **–** The best estimate of abundance for melon-headed whales in the northern GOM is 2,283, with a minimum population estimate of 1,293 melon-headed whales (NMFS, 2009h).

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. 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 up to 1,500 m (4,921 ft) deep, suggesting that feeding takes place deep in the water column.

Acoustics and Hearing – The only published acoustic information for melon-headed whales is from the southeastern Caribbean. Sounds recorded included whistles and click sequences. Whistles had dominant frequencies around 8 to 12 kHz; higher-level whistles were estimated at no more than 155 dB re 1 μPa-m. Clicks had dominant frequencies of 20 to 40 kHz; higher-level click bursts were judged to be about 165 dB re 1 μPa-m. No data on hearing ability for this species are available.

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) isobath. 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.

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.

Status **–** The best estimate of abundance for pygmy killer whales in the northern GOM is 323. The minimum population estimate for the northern GOM is 203 pygmy killer whales (NMFS, 2009i).

Distribution **–** This species has a worldwide distribution in deep tropical, subtropical, and warm temperate oceans. Pygmy killer whales generally do not range north of 40°N or south of 35°S.

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.

Diving Behavior – There is no diving information available for this species.

Acoustics and Hearing – The pygmy killer whale emits short duration, broadband signals similar to a large number of other delphinid species. Clicks produced by pygmy killer whales have centered frequencies between 70 and 85 kHz; there are bimodal peak frequencies between 45 and 117 kHz. The estimated source levels are between 197 and 223 dB re 1 μPa-m. These clicks possess characteristics of echolocation clicks. There are no hearing data available for this species.

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. Additional information on reproductive areas and seasons is not available for this species.

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 **–** The best estimate of abundance for false killer whales in the northern GOM is 777. The minimum population estimate for the northern GOM is 501 false killer whales (NMFS, 2009j).

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. 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.

Acoustics and Hearing – Dominant frequencies of false killer whale whistles are from 4 to 9.5 kHz, and those of their echolocation clicks are from either 20 to 60 kHz or 100 to 130 kHz depending on ambient noise and target distance. Click source levels typically range from 200 to 228 dB re 1 μPa-m. Recently, false killer whales recorded in the Indian Ocean produced echolocation clicks with dominant frequencies of about 40 kHz and estimated source levels of 201-225 dB re 1 μPa-m. False killer whales can hear frequencies ranging from approximately 2 to 115 kHz with best hearing sensitivity ranging from 16 to 64 kHz. Additional behavioral audiograms of false killer whales support a range of best hearing sensitivity between 16 and 24 kHz, with peak sensitivity at 20 kHz, peaking at 22.5 kHz.

Occurrence in 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 the 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-20Study 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.

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 in height [3.3 to 5.9 ft]). Killer whales feed on bony fish, elasmobranches, cephalopods, seabirds, sea turtles, and other marine mammals.

Status – The best estimate of abundance for killer whales in the northern GOM is 49, with a minimum population estimate of 28 (NMFS, 2010c).

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.

In the western North Atlantic, killer whales are known from the polar pack ice southward to Florida, the Lesser Antilles, and the GOM. 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. Little is known of the movement patterns of killer whales in this region. 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.

Acoustics and Hearing – Killer whales produce a wide-variety of clicks and whistles, but most of this species' social sounds are pulsed, with frequencies ranging from 0.5 to 25 kHz (dominant frequency range: 1 to 6 kHz). Echolocation clicks recorded for this species indicate source levels ranging from 195 to 224 dB re 1 µPa-m peak-to-peak, dominant frequencies ranging from 20 to 60 kHz, and durations of 80 to 120 µs. Source levels associated with social sounds have been calculated to range from 131 to 168 dB re 1 µPa-m and have been demonstrated to vary with vocalization type (e.g., whistles: average source level of 140.2 dB re 1 µPa-m, variable calls: average source level of 146.6 dB re 1 µPa-m, and stereotyped calls: average source level 152.6 dB re 1 µPa-m). Additionally, killer whales modify their vocalizations depending on social context or ecological function (i.e., short-range vocalizations [<10 km, or 6.2 mile, range]) are typically associated with social and resting behaviors and long-range vocalizations [10 to 16 km, or 6.2 to 9.9 mile, range] associated with travel and foraging.

Acoustic studies of resident killer whales in British Columbia have found that they possess dialects, which are highly stereotyped, repetitive discrete calls that are group-specific and are shared by all group members. These dialects are likely used to maintain group identity and cohesion and may serve as indicators of relatedness that help in the avoidance of inbreeding between closely related whales. Dialects have been documented in northern Norway and southern Alaskan killer whales populations and likely occur in other regions as well. Both behavioral and ABR techniques indicate killer whales can hear a frequency range of 1 to 100 kHz and are most sensitive at 20 kHz, which is one the lowest maximum-sensitivity frequency known among toothed whales.

Occurrence in Q-20 Study Area – Killer whale sightings in the northern GOM are generally clumped 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. Occurrence patterns are assumed to be similar for all seasons.

Short-Finned Pilot Whale (*Globicephala macrorhynchus*)

Description **–** Pilot whales are among the largest members of the dolphin family. The short-finned pilot whale (*G. macrorhynchus*) may attain lengths of 5.5 m (18 ft) (females) and 6.1 m (20 ft) (males). The closely related long-finned pilot whale (*Globicephala melas*) is not known to occur in the GOM.

Status **–** For short-finned pilot whales in the GOM, the best estimate of abundance is 716, with a minimum population estimate of 542 animals (NMFS, 2009k).

Distribution **–**The short-finned pilot whale usually does not range north of 50ºN or south of 40ºS. Pilot whales are found in both near shore and offshore environments. 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. 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) are recorded. Pilot whales are able to stay submerged for up to 40 min.

Acoustics and Hearing **–** Short-finned pilot whale whistles and clicks have a dominant frequency range of 2 to 14 kHz and 30 to 60 kHz, respectively, at an estimated source level of 180 dB re 1 μPa-m. There are no hearing data available for either pilot whale species.

Occurrence in Q-20 Study Area **–** The identifications of many pilot whale specimen records in the GOM, and most or all sightings, have not been unequivocally shown to be of the short-finned pilot whale. There are no confirmed records of long-finned pilot whales in the GOM. 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.

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) isobath. Pilot whales do have an oceanic distribution, and the few shipboard surveys that have occurred past the 2,000 m (6,562 ft) isobath have occasionally recorded pilot whales.

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 (DON, 2007). 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.

4.3 SUMMARY OF SPECIES INCLUDED IN THIS ANALYSIS

Table 4-1 identifies the species included in the analysis and provides a basis for the species that are eliminated from further discussion in this IHA.

Table 4-1. Marine Mammals in the GOM

Species	Included in analysis	Reason for dismissal
North Atlantic right whale *Eubalaena glacialis*		Right whales are considered extralimital to the Q-20 Study Area. The species is dismissed from further discussion and analysis.
Humpback whale *Megaptera novaeangliae*		Humpback whales are considered extralimital to the Q-20 Study Area; therefore, the species is dismissed from further examination.
Sei whale *Balaenoptera borealis*		Sei whales are considered extralimital to the Q-20 Study Area. Thus, the species is dismissed from further discussion and analysis.
Fin whale *Balaenoptera physalus*		Fin whales are considered extralimital to the Q-20 Study Area. They are dismissed from further examination.
Blue whale *Balaenoptera musculus*		Blue whales are considered extralimital to the Q-20 Study Area; therefore, the species is dismissed from further discussion and analysis.
Bryde's whale *Balaenoptera edeni*	X	
Sperm whale *Physeter macrocephalus*	X	
Minke whale *Balaenoptera acutorostrata*		Low occurrence in the GOM, with no distribution expected in the Q-20 Study Area. Thus, the species is dismissed from further discussion and analysis.
Pygmy sperm whale *Kogia breviceps*	X	
Dwarf sperm whale *Kogia simus*	X	
Cuvier's beaked whale *Ziphius cavirostris*	X	
Gervais' beaked whale *Mesoplodon europaeus*	X	
Blainville's beaked whale *Mesoplodon densirostris*	X	
Sowerby's beaked whale *Mesoplodon bidens*		Sowerby's beaked whales are considered extralimital to the LCS Q-20 Study Area; therefore the species is dismissed from further discussion and analysis.
True's beaked whale *Mesoplodon mirus*		True's beaked whales are considered extralimital to the LCS Q-20 Study Area; therefore the species is dismissed from further discussion and analysis.
Rough-toothed dolphin *Steno bredanensis*	X	
Atlantic bottlenose dolphin *Tursiops truncatus*	X	
Pantropical spotted dolphin *Stenella attenuata*	X	

Assessment of Marine Mammal Species or Stocks that could potentially be Affected

Species	Included in analysis	Reason for dismissal
Atlantic spotted dolphin *Stenella frontalis*	X	
Spinner dolphin *Stenella longirostris*	X	
Clymene dolphin *Stenella clymene*	X	
Striped dolphin *Stenella coeruleoalba*	X	
Fraser's dolphin *Lagenodelphis hosei*	X	
Risso's dolphin *Grampus griseus*	X	
Melon-headed whale *Peponocephala electra*	X	
Pygmy killer whale *Feresa attenuata*	X	
False killer whale *Pseudorca crassidens*	X	
Killer whale *Orcinus orca*	X	
Short-finned pilot whale *Globicephala macrorhynchus*	X	

Source: DON, 2007

[a] FE = Federal endangered

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5. HARASSMENT AUTHORIZATION REQUESTED

The United States (U.S.) Navy requests an Incidental Harassment Authorization (IHA) commencing March 2012 for the incidental harassment of marine mammals pursuant to Section 101(a)(5)(D) of the Marine Mammal Protection Act (MMPA). The Navy's request includes authorization for:

- Level B harassment from behavior by sonar activities.

It is understood that an IHA is applicable for up to one year, is renewable, and is appropriate where authorization for harassment, but not serious injury or mortality of marine mammals is requested. Section 6 provides details on the species and numbers of takes requested.

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

Marine Mammal Species	Level A	Level B (TTS)	Level B (Behavioral)
Bottlenose dolphin	0	0	399
Pantropical spotted dolphin	0	0	126
Atlantic spotted dolphin	0	0	315
Spinner dolphin	0	0	126
Clymene dolphin	0	0	42
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 Marine Mammal Protection Act (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 MMPA Level A and Level B as applicable to military readiness activities. The following sections discuss the potential for ship strikes to occur from surface operations and 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 EIS/OEIS and associated documents.

6.1 SURFACE OPERATIONS

6.1.1 Introduction and Approach to Analysis

Typical operations occurring at the surface includes the deployment or towing of Mine Countermeasures (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. In an effort to reduce the likelihood of a ship strike, the protective measures mentioned in Section 11 will be implemented.

6.1.2 Non-territorial Waters

Collisions with commercial and U.S. Navy ships can cause major wounds and may occasionally cause fatalities to marine mammals. 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). 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. More specifically, from 1975 through 1996, there were 31 dead whale strandings involving four large whales along the Gulf of Mexico (GOM) coastline. Stranded animals included two sei whales, four minke whales, eight Bryde’s whales, and 17 sperm whales. Only one of the stranded animals, a sperm whale with propeller wounds found in Louisiana on 9 March 1990, was identified as a result of a possible ship strike (Laist et al., 2001). In addition, from 1999 through 2003, there was only one stranding involving a false killer whale in the northern GOM (Alabama 1999) (Waring et al., 2006). According to a 2010 Draft Stock Assessment Report (NMFS 2010e), during 2009 there was one known Bryde’s whale mortality as a result of a ship strike. Otherwise, no other marine mammal that is likely to occur in the northern GOM has been reported as either seriously or fatally injured from 1999 through 2009 (Waring et al., 2007).

It is unlikely that activities in non-territorial waters will result in a ship strike because of the nature of the operations and size of the vessels. For example, the hours of surface operations take into consideration operation times for multiple vessels during each test event. These vessels range in size from small Rigid Hull Inflatable Boat (RHIB) to surface vessels of approximately 420 feet. The majority of these vessels are small RHIBs and medium-sized vessels. A large proportion of the timeframe for the AN/AQS-20A Mine Reconnaissance System (hereafter referred to as Q-20) test events include periods when ships remain stationary within the test site. The greatest time spent in transit for tests includes navigation to and from the sites. At these times, the Navy follows standard operating procedures (SOPs). The captain and other crew members keep watch during ship transits to avoid objects in the water. In addition, the proposed Navy SOPs and protective measures listed in Section 11 will ensure that no ship strikes occur to marine mammals in non-territorial waters. The 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 in the high-frequency ranges. The following subsections present the background information for evaluation of potential exposures marine mammals from active sonar at the Q-20 Study Area.

MMPA Level A and Level B Harassment

Categorizing potential effects as either physiological or behavioral effects allows them to be related to the harassment definitions. For military readiness activities, 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 is the destruction or loss of biological tissue (DON, 2006; DON, 2006a; NOAA, 2006). 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, the Q-20 Incidental Harassment Authorization (IHA) assumes that all injury is qualified as a physiological effect and, to be consistent with prior actions and policy (DON, 2006; DON, 2006a; NOAA, 2006), all injuries (slight to severe) are considered Level A harassment.

Public Law (PL) 108-136 (2004) amended the definition of Level B harassment under the MMPA for military readiness activities, such as this action (and also for scientific research on marine mammals conducted by or on the behalf of the federal government). For military readiness activities, Level B harassment is now defined as “any act that disturbs or is likely to disturb a marine mammal or marine mammal stock in the wild by causing disruption of natural behavioral patterns including, but not limited to, migration, surfacing, nursing, breeding, feeding, or sheltering to a point where such behavioral patterns are abandoned or significantly altered.” Unlike Level A harassment, which is solely associated with physiological effects, both physiological and behavioral effects may cause Level B harassment.

The amended definition of Level B harassment serves to clarify and codify National Marine Fisheries Service (NMFS's) existing interpretation of Level B harassment. The intent of the unique definition of harassment for military readiness activities and specific scientific activities was to provide greater clarity for DoD and the regulatory agencies. In addition the definition now takes a more science-based approach by properly focusing on activities that result in significant behavioral changes in biologically important activities, rather than activities with *de minimus* effects. Replacement of the threshold standard "potential" with "likely" eliminates from consideration those activities that have a mere "potential" to have effects. Unlike Level A harassment, which is solely associated with physiological effects, both physiological and behavioral effects may cause Level B harassment.

Some physiological effects can occur that are non-injurious but that can potentially disrupt the behavior of a marine mammal. These include temporary distortions in sensory tissue that alter physiological function but that are fully recoverable without the requirement for tissue replacement or regeneration. For example, an animal that experiences a temporary reduction in hearing sensitivity suffers no injury to its auditory system but may not perceive some sounds due to the reduction in sensitivity. As a result, the animal may not respond to sounds that would normally produce a behavioral reaction. This lack of response qualifies as a temporary disruption of normal behavioral patterns; the animal is impeded from responding in a normal manner to an acoustic stimulus. The analysis presented in this document assumes all temporary hearing impairment (slight to severe) is considered Level B harassment, even if the effect from the temporary impairment is biologically insignificant.

The harassment status of slight behavioral disruption (without physiological effects) has been addressed in previous actions and policies (DON, 2006). The conclusion is that a certain momentary behavioral reaction of an animal to a brief, time-isolated acoustic event does not qualify as Level B harassment. A more general conclusion, that Level B harassment occurs only when there is "a potential for a significant behavioral change or response in a biologically important behavior or activity," is found in recent actions and policies (DON, 2006).

Although the temporary lack of response discussed above may not result in abandonment or significant alteration of natural behavioral patterns, to be conservative, the inputs to the acoustic model were based on the assumption that temporary hearing impairment (slight to severe) would result in Level B harassment. The above conclusions and definitions of harassment, including the 2004 amendments to the definitions of harassment, were considered in the context of the proposed Q-20 test activities in developing conservative thresholds for behavioral disruptions. As a result, the actual incidental harassment of marine mammals associated with this action may be less than that calculated.

MMPA Exposure Zones

Two acoustic modeling approaches were used to account for both physiological and behavioral effects to marine mammals. This subsection on exposure zones is specific to the modeling of total energy. When using a threshold of accumulated energy, the volumes of ocean in which Level A and Level B harassment were predicted to occur are called "exposure zones." As a conservative estimate, all marine mammals predicted to be in an exposure zone were considered exposed over time to accumulated sound levels that may result in harassment within the applicable Level A or Level B harassment categories. Figure 6-1 illustrates exposure zones extending from a hypothetical, directional sound source.

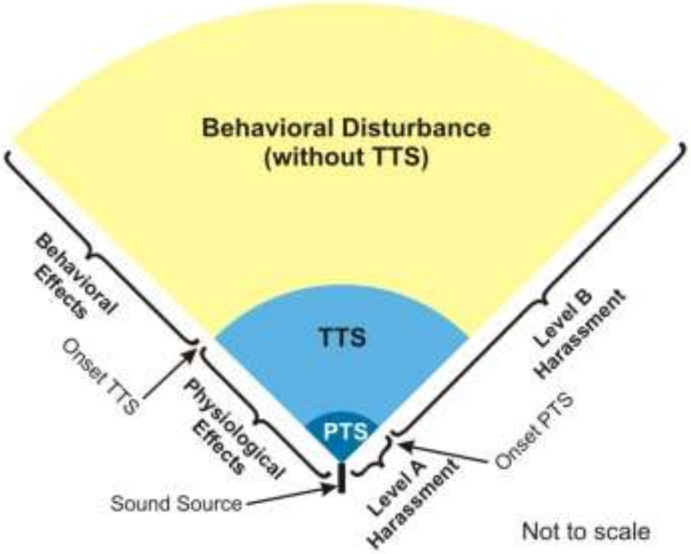


Figure 6-1. Illustration of the Acoustic Effect Framework Used in this IHA

The Level A exposure zone extends from the source out to the distance and exposure at which the slightest amount of injury is predicted to occur. The acoustic exposure that produces the slightest degree of injury is therefore the threshold value defining the outermost limit of the Level A exposure zone. Use of the threshold associated with the onset of slight injury as the most distant point and least-injurious exposure takes into account all more serious injuries within the Level A exposure zone.

The Level B exposure zone begins just outside the point of slightest injury and extends outward from that point to include all animals that may possibly experience Level B harassment. Physiological effects extend beyond the range of slightest injury to a point where slight temporary distortion of the most sensitive tissue occurs, but without destruction or loss of that tissue. The animals predicted to be in this zone are assumed to experience Level B harassment by virtue of temporary impairment of sensory function (altered physiological function) that can disrupt behavior.

Auditory Tissues as Indicators of Physiological Effects

Exposure to continuous-type sound may cause a variety of physiological effects in mammals. For example, exposure to very high sound levels may affect the function of the visual system, vestibular system, and internal organs (Ward, 1997). Exposure to high-intensity, continuous type sounds of sufficient duration may cause injury to the lungs and intestines (e.g., Dalecki et al., 2002). Sudden, intense sounds may elicit a “startle” response and may be followed by an orienting reflex (Ward, 1997; Jansen, 1998). The primary physiological effects of sound, however, are on the auditory system (Ward, 1997).

The mammalian auditory system consists of the outer ear, middle ear, inner ear, and central nervous system. Sound waves are transmitted through the middle ears to fluids within the inner ear, except in cetaceans. The inner ear contains delicate electromechanical hair cells that convert the fluid motions into neural impulses that are sent to the brain. The hair cells within the inner ear are the most vulnerable to overstimulation by sound exposure (Yost, 1994).

Very high sound levels may rupture the eardrum or damage the small bones in the middle ear (Yost, 1994). Lower level exposures of sufficient duration may cause permanent or temporary hearing loss; such an effect is called a sound-induced threshold shift, or simply a threshold shift (TS) (Miller, 1974). A TS may be either temporary (TTS) or permanent (PTS). PTS does not equal permanent hearing loss; it is more correctly described as a permanent loss of hearing sensitivity, usually over a subset of the animal's hearing range. Similarly, TTS is a temporary hearing sensitivity loss, usually over a subset of the animal's hearing range. Still lower levels of sound may result in auditory masking, which may interfere with an animal's ability to hear other concurrent sounds.

Because the tissues of the ear appear to be the most susceptible to the physiological effects of sound and TSs tend to occur at lower exposures than other more serious auditory effects, PTS and TTS are used here as the biological indicators of physiological effects. TTS is the first indication of physiological non injurious change and is not physical injury. The remainder of this section is, therefore, focused on TSs, including PTSs and TTSs. Since masking (without a resulting TS) is not associated with abnormal physiological function, it is not considered a physiological effect for this assessment but rather a potential behavioral effect.

Sound-Induced Threshold Shifts

The amount of TS depends on the amplitude, duration, frequency, and temporal pattern of the sound exposure. Threshold shifts generally increase with the amplitude and duration of sound exposure. For continuous sounds, exposures of equal energy lead to approximately equal effects (Ward, 1997). For intermittent sounds, less TS occurs than from a continuous exposure with the same energy (some recovery will occur between exposures) (Kryter et al., 1966; Ward, 1997).

The magnitude of a TS normally decreases with the amount of time post-exposure (Miller, 1974). The amount of TS just after exposure is called the initial TS. If the TS activity returns to zero (the threshold returns to the pre-exposure value), the TS is a TTS. Since the amount of TTS depends on the time post-exposure, it is common to use a subscript to indicate the time in minutes after exposure (Quaranta et al., 1998). For example, TTS_2 means a TTS measured two minutes after exposure. If the TS does not return to zero but leaves some finite amount of TS, then that remaining TS is a PTS. The distinction between PTS and TTS is based on whether there is a complete recovery of a TS following a sound exposure. Figure 6-2 shows two hypothetical TSs: one that completely recovers (a TTS) and one that does not completely recover, leaving some PTS.

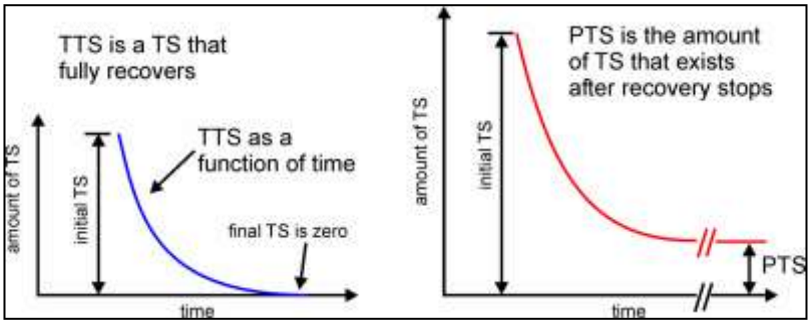


Figure 6-2. Hypothetical Temporary and Permanent Threshold Shifts

PTS, TTS and Exposure Zones

PTS is nonrecoverable and 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.

TTS is recoverable and, as in recent rulings (NOAA, 2001; 2002a), 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. This follows from the concept that hearing loss potentially affects an animal’s ability to react normally to the sounds around it. Therefore, in this IHA, the potential for TTS is considered as a Level B harassment that is mediated by physiological effects upon the auditory system.

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 are then presented. This is followed by discussions of sound energy flux density level (EL), the relationship between EL and sound pressure level (SPL), and the use of SPL and EL in previous 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 dB. EL is stated in dB re 1 µPa^2-s for underwater sound and dB re 20 µPa^2-s for airborne sound.

SPL is a measure of the root mean square, or “effective,” sound pressure in decibels. SPL is expressed in dB re 1 µPa for underwater sound and dB re 20 µPa for airborne sound.

TTS in Marine Mammals

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 exposed to one second tones. This paper also includes a re-analysis of preliminary TTS data released in a technical report by Ridgway et al. (1997). At frequencies of 3, 10, and 20 kilohertz (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.

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 seconds. 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. (2003a, 2004) measured TTS in a bottlenose dolphin exposed to octave-band sound centered at 7.5 kHz. Nachtigall et al. (2003a) reported TTSs of about 11 dB measured 10 to 15 minutes after exposure to 30 to 50 minutes 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 minutes after exposure to 30 to 50 minutes 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. (2003a). 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 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, northern elephant seal, and a Pacific harbor seal exposed to continuous underwater sounds at levels of 80 and 95 dB Sensation Level (SL) at 2.5 and 3.5 kHz for up to 50 minutes. 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.

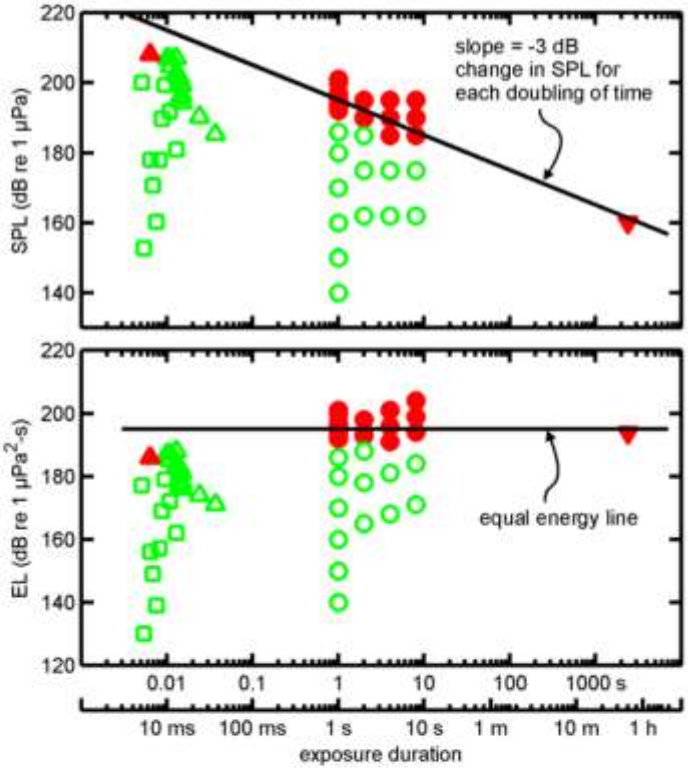
Figure 6-3 shows the existing TTS data for cetaceans (dolphins and beluga whales). Individual exposures are shown in terms of SPL versus exposure duration (upper panel) and EL versus exposure duration (lower panel). Exposures that produced TTS are shown as filled symbols. Exposures that did not produce TTS are represented by open symbols. The squares and triangles represent impulsive test results from Finneran et al., 2000 and 2002, respectively. The circles show the 3, 10, and 20 kHz data from Schlundt et al. (2000) and the results of Finneran et al. (2003). The inverted triangle represents data from Nachtigall et al. (2004).

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 second. 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.

In summary, the existing marine mammal TTS data show that, for the species studied and sounds (nonimpulsive) of interest, the following is 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. Threshold shifts 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.



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

Relationship Between TTS and PTS

Since marine mammal PTS data do not exist, onset-PTS levels for these animals must be estimated using TTS data and relationships between TTS and PTS. Much of the early human TTS work was directed towards relating TTS_2 after 8 hours of sound exposure to the amount of PTS that would exist after years of similar daily exposures (e.g., Kryter et al., 1966). Although it is now acknowledged that susceptibility to PTS cannot be reliably predicted from TTS measurements, TTS data do provide insight into the amount of TS that may be induced without a PTS. Experimental studies of the growth of TTS may also be used to relate changes in exposure level to changes in the amount of TTS induced. Onset-PTS exposure levels may therefore be predicted by:

- Estimating the largest amount of TTS that may be induced without PTS. Exposures causing a TS greater than this value are assumed to cause PTS.
- Estimating the additional exposure, above the onset-TTS exposure, necessary to reach the maximum allowable amount of TTS that, again, may be induced without PTS. This is equivalent to estimating the growth rate of TTS, or how much additional TTS is produced by an increase in exposure level.

Experimentally induced TTSs in marine mammals have generally been limited to around 2 to 10 dB, well below TSs that result in some PTS. Experiments with terrestrial mammals have used much larger TSs and provide more guidance on how high a TS may rise before some PTS results. Early human TTS studies reported complete recovery of TTSs as high as 50 dB after exposure to broadband sound (Ward, 1960; Ward et al., 1958, 1959). Ward et al. (1959) also reported slower recovery times when TTS_2 approached and exceeded 50 dB, suggesting that 50 dB of TTS_2 may represent a “critical” TTS. Miller et al. (1963) found PTS in cats after exposures that were only slightly longer in duration than those causing 40 dB of TTS. Kryter et al. (1966) stated: “A TTS_2 that approaches or exceeds 40 dB can be taken as a signal that danger to hearing is imminent.” These data indicate that TSs up to 40 to 50 dB may be induced without PTS, and that 40 dB is a reasonable upper limit for TS to prevent PTS.

The small amounts of TTS produced in marine mammal studies also limit the applicability of these data to estimates of the growth rate of TTS. Fortunately, data do exist for the growth of TTS in terrestrial mammals. For moderate exposure durations (a few minutes to hours), TTS_2 varies with the logarithm of exposure time (Ward et al., 1958, 1959; Quaranta et al., 1998). For shorter exposure durations, the growth of TTS with exposure time appears to be less rapid (Miller, 1974; Keeler, 1976). For very long-duration exposures, increasing the exposure time may fail to produce any additional TTS, a condition known as asymptotic threshold shift (Saunders et al., 1977; Mills et al., 1979).

Ward et al. (1958, 1959) provided detailed information on the growth of TTS in humans. Ward et al. presented the amount of TTS measured after exposure to specific SPLs and durations of broadband sound. Since the relationship between EL, SPL, and duration is known, these same data could be presented in terms of the amount of TTS produced by exposures with different ELs.

Figure 6-4 shows results from Ward et al. (1958, 1959) plotted as the amount of TTS_2 versus the exposure EL. The data in Figure 6-4(a) are from broadband (75 hertz [Hz] to 10 kHz) sound exposures with durations of 12 to 102 minutes (Ward et al., 1958). The symbols represent mean TTS_2 for 13 individuals exposed to continuous sound. The solid line is a linear regression fit to all but the two data points at the lowest exposure EL. The experimental data are fit well by the regression line (R2 = 0.95). These data are important for two reasons: (1) they confirm that the amount of TTS is correlated with the exposure EL; and (2) the slope of the line allows one to estimate the additional amount of TTS produced by an increase in exposure. For example, the slope of the line in Figure 6-4(a) is approximately 1.5 dB TTS_2 per dB of EL. This means that each additional dB of EL produces 1.5 dB of additional TTS_2.

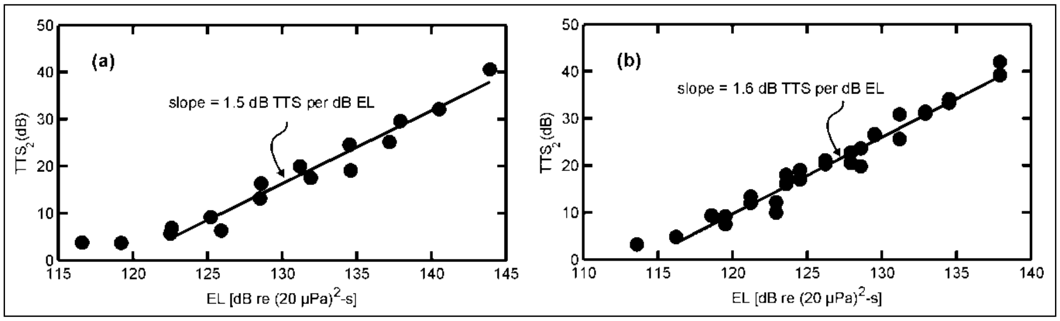


Figure 6-4. Growth of TTS Versus the Exposure EL
(from Ward et al. [1958, 1959])

The data in Figure 6-4(b) are from octave-band sound exposures (2.4 to 4.8 kHz) with durations of 12 to 102 minutes (Ward et al., 1959). The symbols represent mean TTS for 13 individuals exposed to continuous sound. The linear regression was fit to all but the two data points at the lowest exposure EL. The results are similar to those shown in Figure 6-4(a). The slope of the regression line fit to the mean TTS data was 1.6 dB TTS_2/dB EL. A similar procedure was carried out for the remaining data from Ward et al. (1959), with comparable results. Regression lines fit to the TTS versus EL data had slopes ranging from 0.76 to 1.6 dB TTS_2/dB EL, depending on the frequencies of the sound exposure and hearing test.

An estimate of 1.6 dB TTS_2 per dB increase in exposure EL is the upper range of values from Ward et al. (1958, 1959) and gives the most conservative estimate; it predicts a larger amount of TTS from the same exposure compared to the lines with smaller slopes. The difference between onset-TTS (6 dB) and the upper limit of TTS before PTS (40 dB) is 34 dB. To move from onset-TTS to onset-PTS, therefore, requires an increase in EL of 34 dB divided by 1.6 dB/dB, or approximately 21 dB. An estimate of 20 dB between exposures sufficient to cause onset-TTS and those capable of causing onset-PTS is a reasonable approximation. To summarize:

- In the absence of marine mammal PTS data, onset-PTS exposure levels may be estimated from marine mammal TTS data and PTS/TTS relationships observed in terrestrial mammals. This involves:
- Estimating the largest amount of TTS that may be induced without PTS. Exposures causing a TS greater than this value are assumed to cause PTS.

- Estimating the growth rate of TTS, i.e., determining how much additional TTS is produced by an increase in exposure level.
- A variety of terrestrial mammal data sources point toward 40 dB as a reasonable estimate of the largest amount of TS that may be induced without PTS. A conservative estimate is that continuous-type exposures producing TSs of 40 dB or more always result in some amount of PTS.
- Data from Ward et al. (1958, 1959) reveal a linear relationship between TTS2 and exposure EL. A 1.6 dB TTS2 per dB increase in EL is a conservative estimate of how much additional TTS is produced by an increase in exposure level for continuous-type sounds.
- There is a 34 dB TS difference between onset-TTS (6 dB) and onset-PTS (40 dB). The additional exposure above onset-TTS that is required to reach PTS is therefore 34 dB divided by 1.6 dB/dB, or approximately 21 dB.
- Exposures with ELs 20 dB above those producing TTS may be assumed to produce a PTS. This number is used as a conservative simplification of the 21 dB number derived above.

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. (2003a, 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 EL 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:

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

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 second.
- Two pings with SPL = 189 dB re 1 µPa and duration = 2 seconds.

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 MFA/HFA Sources

Background

Based on available evidence, marine animals are likely to exhibit any of a suite of potential behavioral responses or combinations of behavioral responses upon exposure to sonar transmissions. Potential behavioral responses include, but are not limited to: avoiding exposure or continued exposure; behavioral disturbance (including distress or disruption of social or foraging activity); habituation to the sound; becoming sensitized to the sound; or not responding to the sound.

Existing studies of behavioral effects of human-made sounds in marine environments remain inconclusive, partly because many of those studies have lacked adequate controls, applied only to certain kinds of exposures (which are often different from the exposures being analyzed in the study), and had limited ability to detect behavioral changes that may be significant to the biology of the animals that were being observed. These studies are further complicated by the wide variety of behavioral responses marine mammals exhibit and the fact that those responses can vary significantly by species, individuals, and the context of an exposure. In some circumstances, some individuals will continue normal behavioral activities in the presence of high levels of human-made noise. In other circumstances, the same individual or other individuals may avoid an acoustic source at much lower received levels (Richardson et al., 1995; Wartzok et al., 2003). These differences within and between individuals appear to result from a complex interaction of experience, motivation, and learning that are difficult to quantify and predict.

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 two 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 Report 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 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). It is also likely that stranding is a behavioral response to a sound under certain contextual conditions and that the subsequently observed physiological effects of the strandings (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).

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 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 received levels of MFA sonar. The mathematical function is derived from a solution in Feller (1968) as defined in the SURTASS LFA Sonar Final OEIS/EIS (U.S. Department of the Navy, 2001), and relied on in the Supplemental SURTASS LFA Sonar EIS (U.S. Department of the Navy, 2007a) for the probability of MFA sonar risk for MMPA Level B behavioral harassment with input parameters modified by NMFS for MFA sonar for mysticetes and odontocetes (National Marine Fisheries Service, 2008). The same risk function and input parameters will be applied to high frequency active (HFA) (>10 kHz) sources until applicable data becomes 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; and
- The function should be reasonably convenient for algebraic manipulations.

As described in U.S. Department of the Navy (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) (explained in 3.1.4.3).

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 title *Input Parameters for the Risk Function*, the values used in this analysis are based on three sources of data: TTS experiments conducted at SSC and documented in Finneran, et al., (2001, 2003, and 2005; Finneran and Schlundt, 2004); reconstruction of sound fields produced by the USS Shoup associated with the behavioral responses of killer whales observed in Haro Strait and documented in Department of Commerce (National Marine Fisheries Service, 2005); U.S. Department of the Navy (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 MFA sound signals needs to be better defined using controlled experiments. 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 MFA sonar. 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 is available, NMFS and the Navy have determined that the following three data sets are most applicable for the direct use in developing risk function parameters for MFA/HFA sonar. These data sets represent the only known data that specifically relate altered behavioral responses to exposure to MFA sound sources.

<u>Data from SSC's Controlled Experiments:</u> 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, and 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 micropascal (μPa) root mean square (rms), and beluga whales did so at received levels 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-second (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/hertz [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.

<u>Data from Studies of Baleen (Mysticetes) Whale Responses:</u> The only mysticete data available resulted from a field experiments in which baleen whales (mysticetes) were exposed to a range frequency 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-minutes of exposure consisting of three 2-minute 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. 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 between 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 received levels ranged from 133 to 148 dB re 1μPa.

Observations of Killer Whales in Haro Strait in the Wild: In May 2003, killer whales (Orcinus orca) were observed exhibiting behavioral responses while the USS Shoup was engaged in MFA sonar operations in the Haro Strait in the vicinity 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 MFA sonar.

> 3. U.S. Department of Commerce (National Marine Fisheries, 2005); U.S. Department of the Navy (2004); Fromm (2004a, 2004b) documented reconstruction of sound fields produced by the USS Shoup associated with the behavioral response of killer whales observed in Haro Strait. Observations from this reconstruction included an approximate closest approach time which was correlated to a reconstructed estimate of received level at an approximate whale location (which ranged from 150 to 180 dB), with a mean value of 169.3 dB.

Limitations of the Risk Function Data Sources

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 Navy have determined are the best available science at this time. The 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 MFA sonar 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 Navy believes the SSC San Diego data is the most rigorous and applicable for the following reasons:

- The data represents 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 MFA sonar bandwidth.

However, the Navy and NMFS do 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: trained 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 MFA sonar.
- The behavioral responses of marine mammals that were observed in the wild are based solely on an estimated received level 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; or
  - 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 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 µPa2-s).
- The animals were not exposed in the open ocean but in a shallow bay or pool.

<u>North Atlantic Right Whales in the Wild Data Set:</u>

- The observations of behavioral response were from exposure to alert stimuli that contained mid-frequency components but were not similar to a MFA sonar ping. The alert signal was 18 minutes of exposure consisting of three 2-minute 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-minute alert stimuli 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.

<u>Killer Whales in the Wild Data Set:</u>

- 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 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 received level (RL) below which the risk of significant change in a biologically important behavior approaches zero for the MFA/HFA 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 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 MFA/HFA sonar has a negligible impact on the subsequent calculations, because the risk function does not attain appreciable values at received levels that low.

The K Parameter

NMFS and the Navy used the mean of the following values to define the midpoint of the function: (1) the mean of the lowest received levels (185.3 dB) at which individuals responded with altered behavior to 3 kHz tones in the SSC data set; (2) the estimated mean received level value of 169.3 dB produced by the reconstruction of the USS Shoup incident in which killer whales exposed to MFA sonar (range modeled possible received levels: 150 to 180 dB); and (3) the mean of the 5 maximum received levels 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 receive level. 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 Navy use A=10 as the value for odontocetes (Figure 6-5) (National Marine Fisheries Service, 2008). This is the same value of A that was used for the SURTASS LFA sonar analysis. As stated in the SURTASS LFA Sonar Final OEIS/EIS (U.S. Department of the Navy, 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 LFA Sonar Final OEIS/EIS to make conservative assumptions when extrapolating from other data sets (see Subchapter 1.4.3 and Appendix D of the SURTASS LFA Sonar EIS).

Based on NMFS' direction, the Navy will use a value of A=8 for mysticetes to allow for greater consideration of potential harassment at the lower received levels based on Nowacek et al., 2004 (Figure 6-6). (National Marine Fisheries Service, 2008)

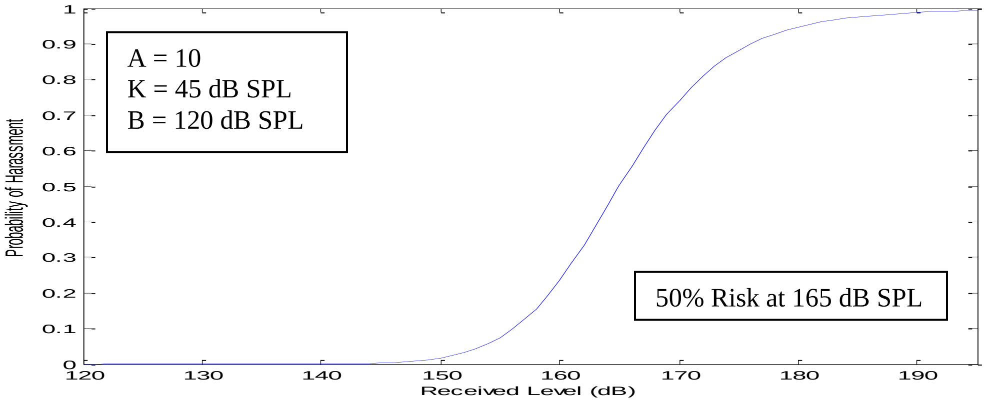


Figure 6-5. Risk Function Curve for Odontocetes (Toothed Whales)

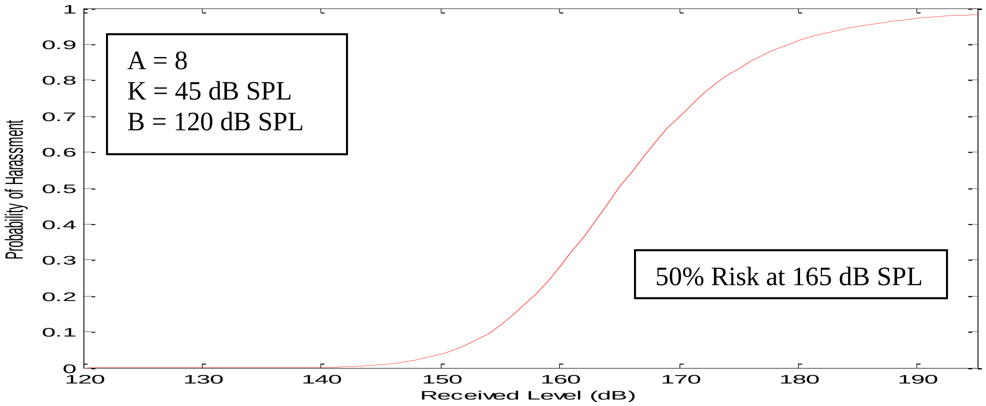


Figure 6-6. Risk Function Curve for Mysticetes (Baleen Whales)

Basic Application of the Risk Function

Relation of the Risk Function to the Current Regulatory Scheme

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 Navy's testing and training with MFA sonar) at a given received level 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 Navy/NMFS applies that by estimating that 50 percent of the individuals exposed at that received level 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 received level 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 received level, 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, 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 received levels (120-135 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 received levels, such as those approaching the onset of TTS (180-195 dB). Generally speaking, 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 received levels.

It is worth noting that 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 received level, 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 received levels and at greater distances from the exercises would be less likely to contribute to population level effects.

Analytical Framework for Assessing Marine Mammal Response to Active Sonar

Marine mammals respond to various types of man-made sounds introduced into the ocean environment. Responses are typically subtle and can include shorter surfacings, shorter dives, fewer blows per surfacing, longer intervals between blows (breaths), ceasing or increasing vocalizations, shortening or lengthening vocalizations, and changing frequency or intensity of vocalizations (National Research Council of the National Academies [NRC], 2005). However, it is not known how these responses relate to significant effects (e.g., long-term effects or population consequences) (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. The Navy enlisted the expertise of NMFS as the cooperating agency in the preparation of this IHA.

In estimating the potential for marine mammals to be exposed to an acoustic source, the following actions were completed:

- Evaluated potential effects within the context of existing and current regulations, thresholds, and criteria.
- Identified all acoustic sources that will be used during active sonar activities.
- Identified the location, season, and time of the action to determine which marine mammal species are likely to be present.
- Determined the estimated number of marine mammals (i.e., density) of each species that will likely be present in the Q-20 Study Area during active sonar activities.

- Applied the applicable acoustic threshold criteria to the predicted sound exposures from the proposed activity. The results of this effort were then evaluated to determine whether the predicted sound exposures from the acoustic model might be considered harassment.
- Considered potential harassment within the context of the affected marine mammal population, stock, or species to assess potential population viability. Particular focus on recruitment and survival are provided to analyze whether the effects of the action can be considered to have negligible effects to species or stocks.

The following flow chart (Figure 6-7) is a representation of the general analytical framework utilized in applying specific thresholds. The framework presented in the flow chart is organized from left to right and is compartmentalized according to the phenomena that occur within each. These include the physics of sound propagation (Physics), the potential physiological processes associated with sound exposure (Physiology), the potential behavioral processes that might be affected as a function of sound exposure (Behavior), and the immediate impacts these changes may have on functions the animal is engaged in at the time of exposure (Life Function – Proximate). These compartmentalized effects are extended to longer-term life functions (Life Function – Ultimate) and into population and species effects. Throughout the flow chart, dotted and solid lines are used to connect related events. Solid lines designate those effects that “will” happen; dotted lines designate those that “might” happen but must be considered (including those hypothesized to occur but for which there is no direct evidence).

Some boxes contained within the flow chart are colored according to how they relate to the definitions of harassment under the MMPA. Red boxes correspond to events that are injurious. By prior ruling and usage, these events would be considered as Level A harassment under the MMPA. Yellow boxes correspond to events that have the potential to qualify as Level B harassment under the MMPA. Based on prior ruling, the specific instance of TTS is considered as Level B harassment. Boxes that are shaded from red to yellow have the potential for injury and behavioral disturbance.

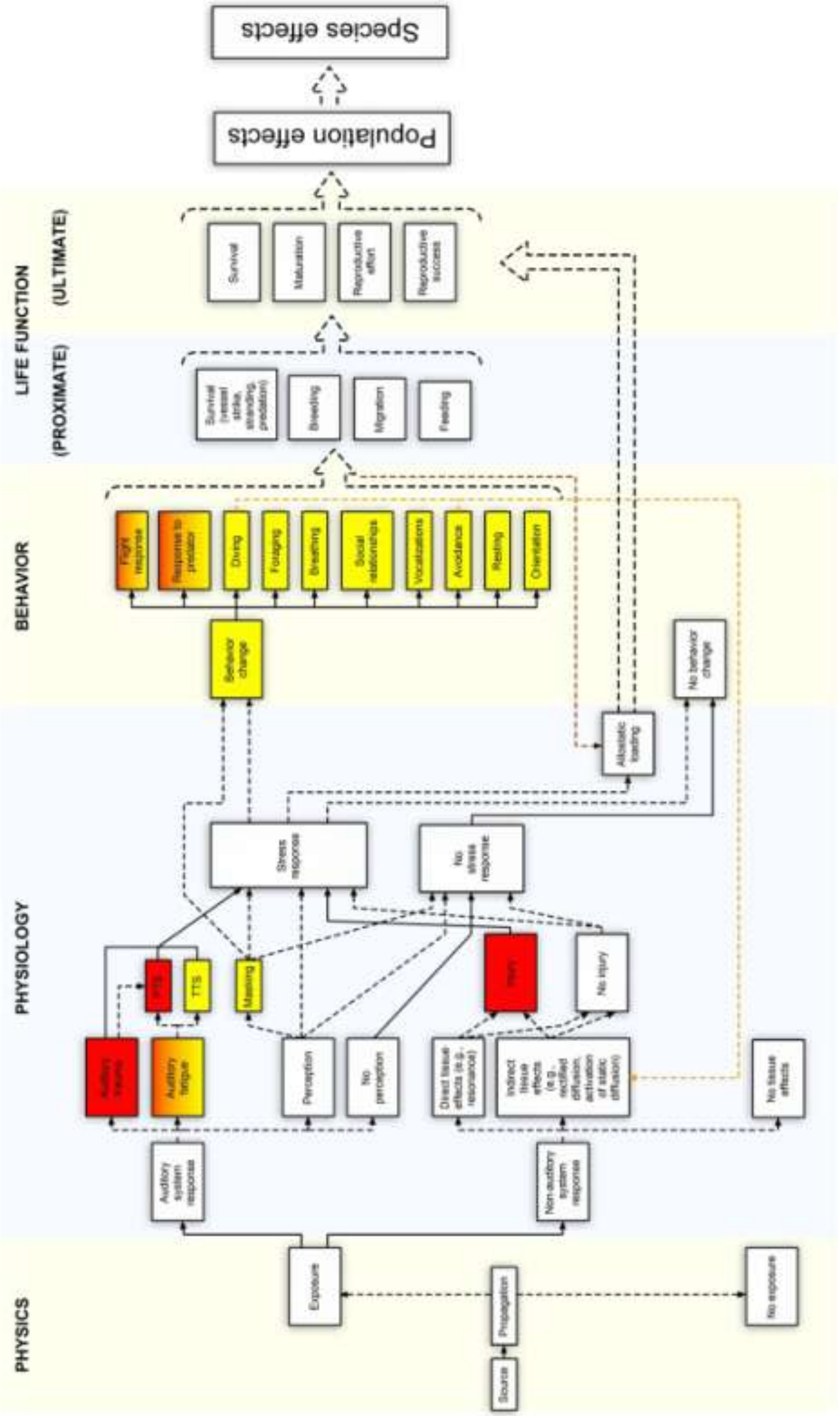


Figure 6-7. Analytical Framework Flow Chart

Physics

Starting with a sound source, the attenuation of an emitted sound due to propagation loss is determined. Uniform animal distribution is overlaid onto the calculated sound fields to assess if animals are physically present at sufficient received sound levels (e.g., above ambient) to be considered "exposed" to the sound. If the animal is determined to be exposed, two possible scenarios must be considered with respect to the animal's physiology, effects on the auditory system and effects on non-auditory system tissues. These are not independent pathways and both must be considered since the same sound could affect both auditory and nonauditory tissues. Note that the model does not account for any animal response; rather, the animals are considered stationary, accumulating energy until the threshold is tripped.

Physiology

Potential impacts to the auditory system are assessed by considering the characteristics of the received sound (e.g., amplitude, frequency, duration) and the sensitivity/susceptibility of the exposed animals. Some of these assessments can be numerically based (e.g., TTS, PTS, perception). Others will be necessarily qualitative, due to lack of information, or will need to be extrapolated from other species for which information exists. Potential physiological responses to the sound exposure are ranked in descending order, with the most severe impact (auditory trauma) occurring at the top and the least severe impact (the sound is not perceived) occurring at the bottom.

1. Auditory trauma represents 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 is always injurious but could be temporary and not result in PTS. Auditory trauma is always assumed to result in a stress response.

2. Auditory fatigue refers to a loss of hearing sensitivity after sound stimulation. The loss of sensitivity persists, sometimes long after, the cessation of the sound. The mechanisms responsible for auditory fatigue differ from auditory trauma and would primarily consist of metabolic exhaustion of the hair cells and cochlear tissues. The features of the exposure (e.g., amplitude, frequency, duration, temporal pattern) and the individual animal's susceptibility would determine the severity of fatigue and whether the effects were temporary (TTS) or permanent (PTS). Auditory fatigue (PTS or TTS) is always assumed to result in a stress response.

3. Perception – Sounds with sufficient amplitude and duration to be detected among the background ambient noises are considered to be "perceived." This category includes sounds from the threshold of audibility through the normal dynamic range of hearing (i.e., not capable of producing fatigue). To determine whether an animal perceives the sound, the received level, frequency, and duration of the sound are compared to what is known of the species' hearing sensitivity.

   Since audible sounds may interfere with an animal's ability to detect other sounds at the same time, perceived sounds have the potential to result in auditory masking. Unlike auditory fatigue, which always results in a stress response because the sensory tissues are being stimulated beyond their normal physiological range, masking may or may not result in a stress response, depending on the degree and duration of the masking effect. Masking may also result in a unique circumstance where an animal's ability to detect other sounds is compromised without the animal's knowledge. This could conceivably result in sensory impairment and subsequent behavior change; in this case, the change in behavior is the lack of a response that would normally be made if sensory impairment did not occur. For this reason, masking also may lead directly to behavior change without first causing a stress response.

The features of perceived sound (e.g., amplitude, duration, temporal pattern) are also used to judge whether the sound exposure is capable of producing a stress response. Factors to consider in this decision include the probability of the animal being naïve or experienced with the sound (i.e., what are the known/unknown consequences of the exposure).

4. Not perceived – The received level is not of sufficient amplitude, frequency, and duration to be perceptible by the animal. By extension, this does not result in a stress response.

Potential impacts to tissues other than those related to the auditory system are assessed by considering the characteristics of the sound (e.g., amplitude, frequency, duration) and the known or estimated response characteristics of nonauditory tissues. Some of these assessments can be numerically based (e.g., exposure required for rectified diffusion). Others will be necessarily qualitative, due to lack of information. Each of the potential responses may or may not result in a stress response.

1. Direct tissue effects – Direct tissue responses to sound stimulation may range from tissue shearing (injury) to mechanical vibration with no resulting injury. Any tissue injury would produce a stress response, whereas noninjurious stimulation may or may not.

2. Indirect tissue effects – Based on the amplitude, frequency, and duration of the sound, it must be assessed whether exposure is sufficient to indirectly affect tissues. For example, the hypothesis that rectified diffusion occurs is based on the idea that bubbles that naturally exist in biological tissues can be stimulated to grow by an acoustic field. Under this hypothesis, one of three things could happen: (1) bubbles grow to the extent that tissue hemorrhage occurs (injury); (2) bubbles develop to the extent that a complement immune response is triggered or nervous 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.

3. No tissue effects – The received sound is insufficient to cause either direct (mechanical) or indirect effects to tissues. No stress response occurs.

The Stress Response

The acoustic source is considered a potential stressor if, by its action on the animal, via auditory or nonauditory means, it may produce a stress response in the animal. The term "stress" has taken on an ambiguous meaning in the scientific literature, but with respect to Figure 6-7 and the later discussions of allostasis and allostatic loading, the term "stress response" will refer to an increase in energetic expenditure that results from exposure to the stressor and which is predominantly characterized by either the stimulation of the sympathetic nervous system (SNS) or the hypothalamic-pituitary-adrenal (HPA) axis (Reeder and Kramer, 2005). The SNS response to a stressor is immediate and acute and is characterized by the release of the catecholamine neurohormones norepinephrine and epinephrine (i.e., adrenaline). These hormones produce elevations in the heart and respiration rate, increase awareness, and increase the availability of glucose and lipids for energy. The HPA response is ultimately defined by increases in the secretion of the glucocorticoid steroid hormones, predominantly cortisol in mammals. The amount of increase in circulating glucocorticoids above baseline may be an indicator of the overall severity of a stress response (Hennessy et al., 1979). Each component of the stress response is variable in time, e.g., adrenalines are released nearly immediately and are used or cleared by the system quickly, whereas cortisol levels may take long periods of time to return to baseline.

The presence and magnitude of a stress response in an animal depends on a number of factors. These include the animal's life history stage (e.g., neonate, juvenile, adult), the environmental conditions, reproductive or developmental state, and experience with the stressor. Not only will these factors be subject to individual variation, but they will also vary within an individual over time. In considering potential stress responses of marine mammals to acoustic stressors, each of these should be considered. For example, is the acoustic stressor in an area where animals engage in breeding activity? Are animals in the region resident and likely to have experience with the stressor (i.e., repeated exposures)? Is the region a foraging ground or are the animals passing through as transients? What is the ratio of young (naïve) to old (experienced) animals in the population? It is unlikely that all such questions can be answered from empirical data; however, they should be addressed in any qualitative assessment of a potential stress response as based on the available literature.

The stress response may or may not result in a behavioral change, depending on the characteristics of the exposed animal. However, provided a stress response occurs, we assume that some contribution is made to the animal's allostatic load. Allostasis is the ability of an animal to maintain stability through change by adjusting its physiology in response to both predictable and unpredictable events (McEwen and Wingfield, 2003). The same hormones associated with the stress response vary naturally throughout an animal's life, providing support for particular life history events (e.g., pregnancy) and predictable environmental conditions (e.g., seasonal changes). The allostatic load is the cumulative cost of allostasis incurred by an animal and is generally characterized with respect to an animal's energetic expenditure. Perturbations to an animal that may occur with the presence of a stressor, either biological (e.g., predator) or anthropogenic (e.g., construction), can contribute to the allostatic load (Wingfield, 2003). Additional costs are cumulative and additions to the allostatic load over time may contribute to reductions in the probability of achieving ultimate life history functions (e.g., survival, maturation, reproductive effort and success) by producing pathophysiological states. The contribution to the allostatic load from a stressor requires estimating the magnitude and duration of the stress response, as well as any secondary contributions that might result from a change in behavior (see the Behavior section, below).

If the acoustic source does not produce tissue effects, is not perceived by the animal, or does not produce a stress response by any other means, Figure 6-7 assumes that the exposure does not contribute to the allostatic load. Additionally, without a stress response or auditory masking, it is assumed that there can be no behavioral change. Conversely, any immediate effect of exposure that produces an injury (i.e., red boxes on the flow chart in Figure 6-7) is assumed to also produce a stress response and contribute to the allostatic load.

Behavior

Acute stress responses may or may not cause a behavioral reaction. However, all changes in behavior are expected to result from an acute stress response. This expectation is based on the idea that some sort of physiological trigger must exist to change any behavior that is already being performed. An exception to this rule is the case of masking. The presence of a masking sound may not produce a stress response, but may interfere with the animal’s ability to detect and discriminate biologically relevant signals. The inability to detect and discriminate biologically relevant signals hinders the potential for normal behavioral responses to auditory cues and is thus considered a behavioral change.

Numerous behavioral changes can occur as a result of stress response, and Figure 6-7 lists only those that might be considered the most common types of response for a marine animal. For each potential behavioral change, the magnitude in the change and the severity of the response needs to be estimated. Certain conditions, such as stampeding (i.e., flight response) or a response to a predator, might have a probability of resulting in injury. For example, a flight response, if significant enough, could produce a stranding event. Under the MMPA, such an event would be considered a Level A harassment. Each altered behavior may also have the potential to disrupt biologically significant events (e.g., breeding or nursing) and may need to be qualified as Level B harassment. All behavioral disruptions have the potential to contribute to the allostatic load. This secondary potential is signified by the feedback from the collective behaviors to allostatic loading.

Special considerations are given to the potential for avoidance and disrupted diving patterns. Due to past incidents of beaked whale strandings associated with sonar operations, feedback paths are provided between avoidance and diving and indirect tissue effects. This feedback accounts for the hypothesis that variations in diving behavior and/or avoidance responses can possibly result in nitrogen tissue supersaturation and nitrogen off-gassing, possibly to the point of deleterious vascular bubble formation. Although hypothetical in nature, the potential process is currently popular and hotly debated.

Life Function

Proximate Life Functions

Proximate life history functions are the functions that the animal is engaged in at the time of acoustic exposure. The disruption of these functions, and the magnitude of the disruption, is something that must be considered in determining how the ultimate life history functions are affected. Consideration of the magnitude of the impact to each of the proximate life history functions is dependent upon the life stage of the animal. For example, an animal on a breeding ground that is sexually immature will suffer relatively little consequence to disruption of breeding behavior when compared to an actively displaying adult of prime reproductive age.

Ultimate Life Functions

The ultimate life functions are those that enable an animal to contribute to the population (or stock, or species, etc.). The impact to ultimate life functions will depend on the nature and magnitude of the perturbation to proximate life history functions. Depending on the severity of the response to the stressor, acute perturbations may have nominal to profound impacts on ultimate life functions. For example, unit-level use of sonar by a vessel transiting through an area that is utilized for foraging, but not for breeding, may disrupt feeding by exposed animals for a brief period of time. Because of the brevity of the perturbation, the impact to ultimate life functions may be negligible. By contrast, weekly training over a period of years may have a more substantial impact because the stressor is chronic. Assessment of the magnitude of the stress response from the chronic perturbation would require an understanding of how and whether animals acclimate to a specific, repeated stressor and whether chronic elevations in the stress response (e.g., cortisol levels) produce fitness deficits.

The proximate life functions are loosely ordered in decreasing severity of impact. Mortality (survival) has an immediate impact, in that no future reproductive success is feasible and there is no further addition to the population resulting from reproduction. Severe injuries may also lead to reduced survivorship (longevity) and prolonged alterations in behavior. The latter may further affect an animal’s overall reproductive success and reproductive effort. Disruptions of breeding have an immediate impact on reproductive effort and may impact reproductive success. The magnitude of the effect will depend on the duration of the disruption and the type of behavior change that was provoked. Disruptions to feeding and migration can affect all of the ultimate life functions; however, the impacts to reproductive effort and success are not likely to be as severe or immediate as those incurred by mortality and breeding disruptions.

Application of the Framework

For each species in the region of a proposed action, the density and occurrence of the species in the region relative to the timing of the proposed action should be determined. The probability of exposing an individual will be based on the density of the animals at the time of the action and the acoustic propagation loss. Based upon the calculated exposure levels for the individuals, or proportions of the population, an assessment for auditory and nonauditory responses should be made. Based on the available literature on the bioacoustics, physiology, dive behavior, and ecology of the species, Figure 6-7 should be used to assess the potential impact of the exposure to the population and species.

Regulatory Framework

The MMPA prohibits the unauthorized harassment of marine mammals and provides the regulatory processes for authorization for any such harassment that might occur incidental to an otherwise lawful activity.

The regulatory framework for estimating potential acoustic effects from Q-20 test activities on marine mammal species makes use of the methodology that was developed in cooperation with National Oceanic and Atmospheric Administration (NOAA) for the Navy's Draft *Overseas Environmental Impact Statement/Environmental Impact Statement, Undersea Warfare Training Range (OEIS/EIS)* (DON, 2005). Via response comment letter to USWTR received from NMFS January 30, 2006, NMFS concurred with the use of EL for the determination of physiological effects to marine mammals. Therefore, this methodology was used to estimate the annual exposure of marine mammals that may be considered Level A harassment (sound level threshold of 215 dB or above) or Level B harassment (sound levels below 215 dB down to 195 dB) as a result of temporary, recoverable physiological effects.

In addition, 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 NOAA for the Navy's USWTR Draft OEIS/EIS (2005), Undersea Warfare Exercise (USWEX) EA/OEA (DON, 2005a, 2007a), RIMPAC EA/OEA (DON, Commander Third Fleet, 2006a), Composite Training Unit Exercises (COMPTUEX)/ Joint Task Force Exercises (JTFEX) and COMPTUEX/JTFEX EA/OEA (DON, 2007b), and HRC Draft EIS (DON, 2007c). 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.

A number of Navy actions and NMFS rulings have helped to qualify possible activities deemed as "harassment" under the MMPA. "Harassment" under the MMPA includes both potential injury (Level A) and disruptions of natural behavioral patterns to a point where they are abandoned or significantly altered (Level B). The acoustic effects analysis and exposure calculations are based on the following premises:

- Harassment that may result from Navy operations described in the Testing the AN/AQS-20A Mine Reconnaissance System in the NSWC PCD Testing Range, 2012-2014 Overseas Environmental Assessment (Q-20 OEA) is unintentional and incidental to those operations.
- This IHA uses an unambiguous definition of injury as defined in the Undersea Warfare Training Range Draft OEIS/DEIS (DON, 2005) and in previous rulings (NOAA, 2001, 2002a): injury occurs when any biological tissue is damaged or lost as a result of the action.
- Behavioral disruption might result in subsequent injury and injury may cause a subsequent behavioral disruption, so Level A and Level B harassment categories (defined below in Section 4.7.3.1) can overlap and are not necessarily mutually exclusive. However, based on prior ruling (NOAA, 2001, 2006c), this IHA assumes that Level A and B do not overlap.
- An individual animal predicted to experience simultaneous multiple injuries, multiple disruptions, or both is counted as a single take (see NOAA, 2001, 2006a). An animal whose behavior is disrupted by an injury has already been counted as a Level A harassment and will not also be counted as a Level B harassment.

- The acoustic effects analysis is based on primary exposures to the action. Secondary or indirect effects, such as susceptibility to predation following injury and injury resulting from disrupted behavior may not be readily determined unless directly observed, or the risk of occurrence concluded from previous well documented examples. Consideration of secondary effects would result in some Level A harassment being considered Level B harassment, and vice versa, since much injury (Level A harassment) has the potential to disrupt behavior (Level B harassment), and much temporary physiological or behavioral disruption (Level B) could be conjectured to have the potential for injury (Level A). Consideration of secondary effects would lead to circular definitions of harassment.
- Animals are uniformly distributed and remain stationary during the active sonar events; therefore, the model does not account for any animal response.

Integration of Regulatory and Biological Frameworks

This section presents a biological framework within which potential effects can be categorized and then related to the existing regulatory framework of injury (Level A) and behavioral disruption (Level B). The information presented in the subsections below was used to develop specific numerical exposure thresholds and risk function estimations. Exposure thresholds were combined with sound propagation models and species distribution data to estimate the potential exposures.

Physiological and Behavioral Effects

Sound exposure may affect multiple biological traits of a marine animal; however, the MMPA as amended directs which traits should be used when determining effects. Effects that address injury are considered Level A harassment under MMPA. Effects that address behavioral disruption are considered Level B harassment under MMPA.

The biological framework discussed here is structured according to potential physiological and behavioral effects resulting from sound exposure. The range of effects may then be assessed to determine which qualify as injury or behavioral disturbance under MMPA regulations. Physiology and behavior are chosen over other biological traits because:

- They are consistent with regulatory statements defining harassment by injury and harassment by disturbance.
- They are components of other biological traits that may be relevant.
- They are a more sensitive and immediate indicator of effect.

For example, ecology is not used as the basis of the framework because the ecology of an animal is dependent on the interaction of an animal with the environment. The animal’s interaction with the environment is driven both by its physiological function and its behavior, and an ecological effect may not be observable over short periods of observation. Ecological information is considered in the analysis of the effects to individual species.

A “physiological effect” is defined here as one in which the “normal” physiological function of the animal is altered in response to sound exposure. Physiological function is any of a collection of processes ranging from biochemical reactions to mechanical interaction and operation of organs and tissues within an animal. Physiological effects may range from the most significant of effects (i.e., mortality and serious injury) to lesser effects that define the lower end of the physiological effects range, such as the noninjurious distortion of auditory tissues. This latter physiological effect is important to the integration of the biological and regulatory frameworks and receives additional attention in later sections.

A “behavioral effect” is one in which the “normal” behavior or patterns of behavior of an animal are overtly disrupted in response to an acoustic exposure. Examples of behaviors of concern can be derived from the harassment definitions in the MMPA and the ESA.

In this IHA, the term “normal” is used to qualify distinctions between physiological and behavioral effects. Its use follows the convention of normal daily variation in physiological and behavioral function without the influence of anthropogenic (e.g., man-made) acoustic sources. As a result, this Q-20 IHA request uses the following definitions.

- A physiological effect is a variation in an animal’s physiology that results from an anthropogenic acoustic exposure and exceeds the normal daily variation in physiological function.
- A behavioral effect is a variation in an animal’s behavior or behavior patterns that results from an anthropogenic acoustic exposure and exceeds the normal daily variation in behavior but arises through normal physiological process.
- The definitions of physiological effect and behavioral effect used here are specific to this document and should not be confused with more global definitions applied to the field of biology.

It is reasonable to expect some physiological effects to result in subsequent behavioral effects. For example, a marine mammal that suffers a severe injury may be expected to alter diving or foraging to the degree that its variation in these behaviors is outside that which is considered normal for the species. If a physiological effect is accompanied by a behavioral effect, the overall effect is characterized as a physiological effect; physiological effects take precedence over behavioral effects with regard to their ordering. This approach provides the most conservative ordering of effects with respect to severity, provides a rational approach to dealing with the overlap of the definitions, and avoids circular arguments.

The severity of physiological effects generally decreases with decreasing sound exposure and/or increasing distance from the sound source. The same generalization does not consistently hold for behavioral effects because they do not depend solely on the received sound level. Behavioral responses also depend on an animal’s learned responses, innate response tendencies, motivational state, the pattern of the sound exposure, and the context in which the sound is presented. However, to provide a tractable approach to predicting acoustic effects that is relevant to the terms of behavioral disruption described in the MMPA, it is assumed here that the severities of behavioral effects also decrease with decreasing sound exposure and/or increasing distance from the sound source. Figure 6-8 shows the relationship between severity of effects, source distance, and exposure level, as defined in this IHA.

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, Supplemental Information for Underwater Noise Analysis. The following section provides an overview of the methods used to conduct the analysis.

The quantitative analysis was based on conducting sonar operations in 13 different geographical regions, or provinces. Using combined marine mammal density and depth estimates, which is detailed later in this section, acoustical modeling was conducted to calculate the actual exposures. Refer to Appendix B, Geographic Description of Environmental Provinces, for additional information on provinces. Refer to Appendix C, Definitions and Metrics for Acoustic Quantities, for additional information regarding the acoustical analysis.

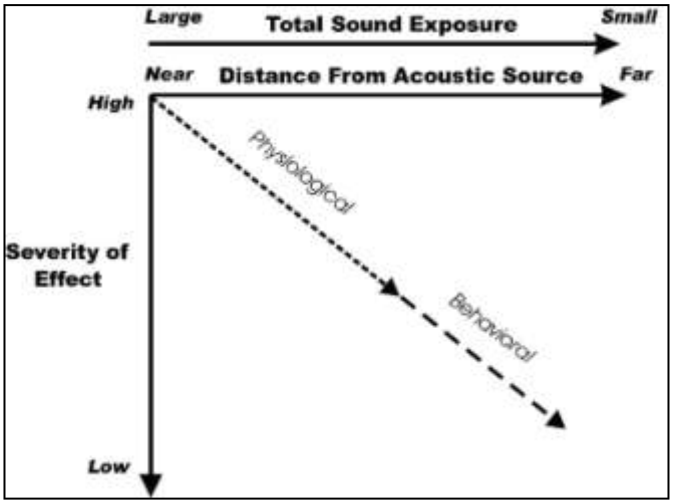


Figure 6-8. Relationship Between Severity of Effects, Source Distance, and Exposure Level

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 NOAA for the Navy's USWTR Draft OEIS/EIS (2005), Undersea Warfare Exercise (USWEX) Environmental Assessment (EA)/Overseas Environmental Assessment (OEA) (U.S. DON, 45, 2007a), RIMPAC EA/ OEA (DON, Commander Third Fleet, 2006a), Composite Training Unit Exercises (COMPTUEX)/Joint Task Force Exercises (JTFEX) EA/OEA (DON, 2007b), and HRC Draft EIS (DON, 2007c). 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 Navy modeled the following systems:

- AN/AQS-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, Supplemental Information for Underwater Noise Analysis.

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 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-Frequency Bottom Loss geo-acoustic provinces and two High-Frequency Bottom Loss classes. These are addressed by defining eight fundamental 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 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 calculations must be made for each, in both seasons. The transmission loss is predicted using Comprehensive Acoustic Simulation System/Gaussian Ray Bundle (CASS-GRAB) sound modeling software.

Step 3. Exposure Volumes. The transmission loss, combined with the source characteristics, gives the energy field of a single ping. The energy of over 10 hours 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 ten hours, 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 reliable 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 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 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.

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

Marine Mammal Density

The density estimates that were used in previous Navy environmental documents were updated to provide a compilation of the most recent data and information on the occurrence, distribution, and density of marine mammals and sea turtles in the southeast OPAREAs. The updated density estimates presented in this IHA are derived from the *Navy OPAREA Density Estimates (NODE) for the GOMEX OPAREA* report (DON, 2007e).

Density estimate calculations for cetaceans in 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; 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 NOAA stock assessment report (SAR) (Waring et al., 2007). In the Q-20 Study Area which includes the GOMEX OPAREA, density estimates were derived via abundance estimates found in the NOAA stock assessment report (Waring et al., 2007) based on Mullin and Fulling (2004).

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, sea surface temperature (SST), and chlorophyll *a* (chl *a*) concentration was formulated using generalized additive models (GAMs). 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 GOMEX, all analyses for cetaceans were based on data collected through NMFS-SEFSC 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 NOAA SAR to ensure consistency. All spatial models and density estimates were reviewed by NMFS technical staff.

A list of each species and how their density was 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 report 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, 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 U.S. 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 SARs. These surveys may also extend beyond U.S. waters. Both stock abundance and survey abundance are used in this IHA to determine a density of marine mammal species within the Q-20 Study Area. That some portion of the animals range may extend beyond the Q-20 Study Area or U.S. 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 effects to 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
Sperm whale (*Physeter macrocephalus*)
Dwarf/Pygmy sperm whale (Family Kogiidae)
Beaked Whales (Family Ziphiidae)
Rough-toothed dolphin (*Steno bredanensis*)
Bottlenose dolphin (*Tursiops truncatus*)
Pantropical spotted dolphin (*Stenella attenuata*)
Atlantic spotted dolphin (*Stenella frontalis*)
Striped dolphin (*Stenella coeruleoalba*)
Spinner dolphin (*Stenella longirostris*)
Risso's dolphin (*Grampus griseus*)
SAR or Literature-Derived Density Estimates
Bryde’s whale (*Balaenoptera brydei/edeni*)
Clymene dolphin (*Stenella clymene*)
Fraser’s dolphin (*Lagenodelphis hosei*)
Killer whale (*Orcinus orca*)
False killer whale (*Pseudorca crassidens*)
Pygmy killer whale (*Feresa attenuata*)
Melon-headed Whale (*Peponocephala electra*)
Short-finned pilot whale *(Globicephala macrorhynchus)*

Source: DON, 2007e

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

Common Name	Winter Density/km^2	Summer Density/km^2
MYSTICETES		
Bryde’s whale	0.00003495	0.00003495
ODONTOCETES		
Sperm whale	0.0003024	0.0003345
Dwarf/Pygmy sperm whale	0.0003810	0.0003810
All beaked whales	0.000001294	0.000001291
Rough-toothed dolphin	0.0003885	0.0003885
Bottlenose dolphin	0.1223	0.1223
Pantropical spotted dolphin	0.03989	0.04287
Atlantic spotted dolphin	0.1057	0.1057
Spinner dolphin	0.03810	0.03810
Clymene dolphin	0.01516	0.01516
Striped dolphin	0.009272	0.009272
Fraser’s dolphin	0.0006344	0.0006344
Risso’s dolphin	0.003632	0.003632
Melon-headed whale	0.003015	0.003015
Pygmy killer whale	0.0003566	0.0003566
False killer whale	0.0009070	0.0009070
Killer whale	0.0001162	0.0001162
Short-finned pilot whale	0.002087	0.002087

Depth Distribution

There are limited depth distribution data for most marine mammals. This is especially true for cetaceans, as they must be tagged at-sea by using a tag that either must be implanted in the skin/blubber in some manner or adhere to the skin. 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. 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. Depth information can also be collected via satellite tags, sonic tags, digital 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-11.

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 include 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.

Density and Depth Distribution Combined

Density is nearly always reported for an area (e.g., animals/km^2). Analyses of survey results using distance sampling techniques 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

Acoustically Mediated Bubble Growth

One suggested cause of injury to marine mammals is rectified diffusion, which is the process of increasing the size of a bubble by exposing it to a sound field (Crum and Mao, 1996). This process 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). Conversely, studies have shown that marine mammal lung structure (both pinnipeds and cetaceans) facilitates collapse of the lungs at depths below approximately 50 m (162 ft) (Kooyman et al., 1970). Collapse of the lungs would force air into the nonair exchanging areas of the lungs (into the bronchioles away from the alveoli) thus significantly decreasing nitrogen diffusion into the body. Deep-diving pinnipeds such as the northern elephant (*Mirounga angustirostris*) and Weddell seals (*Leptonychotes weddellii*) typically exhale before long deep dives, further reducing air volume in the lungs (Kooyman et al., 1970). 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.

It is unlikely that the short duration of sonar pings will 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 bubbles could be destabilized by high-level sound exposures such that bubble growth then occurs 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.

Another hypothesis suggests that rapid ascent to the surface following exposure to a startling sound might produce tissue gas saturation sufficient for the evolution of nitrogen bubbles (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. Cox et al. (2006), with experts in the field of marine mammal behavior, diving, physiology, respiration physiology, pathology, anatomy, and bio-acoustics considered this to be a plausible hypothesis that requires further investigation. Conversely Fahlman et al. (2006) suggested by formulation of a mathematical model that diving bradycardia (reduction in heart rate and circulation to the tissues), lung collapse, and slow ascent rates would reduce nitrogen uptake and thus reduce the risk of decompression sickness by 50 percent in models of marine mammals. Recent information on the diving profiles of Cuvier’s (*Ziphius cavirostris*) and Blainville’s (*Mesoplodon densirostris*) beaked whales (Baird et al., 2006) in the Ligurian Sea in Italy (Tyack et al., 2006) showed that while these species do dive deeply (regularly exceed depths of 800 m [.5 mi]) and for long periods (48–68 minutes), they have significantly slower ascent rates than descent rates. This fits well with Fahlman et al., (2006) model of deep and long duration divers that would have slower ascent rates to reduce nitrogen saturation and reduce the risk of decompression sickness. Therefore, if nitrogen saturation remains low, then a rapid ascent should not cause decompression sickness. Currently, it is not known if beaked whales rapidly ascend in response to sonar or other disturbances. Deep diving animals may be better protected by diving to depth to avoid predators, such as killer whales, rather than ascending to the surface where they may be more susceptible to predators, subsequently eliminating a rapid ascent.

Although theoretical predictions suggest the possibility for acoustically mediated bubble growth, there is considerable disagreement among scientists as to its likelihood (Piantadosi and Thalmann, 2004; Evans and Miller, 2004). To date, ELs predicted to cause *in vivo* bubble formation within diving cetaceans have not been evaluated (NOAA, 2002b). Further, although it has been argued that traumas from recent beaked whale strandings are consistent with gas emboli- and bubble-induced tissue separations (Jepson et al., 2003), there is no conclusive evidence of this occurrence. In addition, there may be complicating factors associated with introduction of gas into the venous system during necropsy. Because evidence supporting it is debatable, no marine mammals addressed in this IHA are given special treatment due to the possibility for acoustically mediated bubble growth.

Resonance

Another suggested cause of injury in marine mammals is air cavity resonance due to sonar exposure. 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 and geometry of an air cavity determine the frequency at which the cavity will resonate. Displacement of the cavity boundaries during resonance has been suggested as a cause of injury. Large displacements have the potential to tear tissues that surround the air space (e.g., lung tissue).

Understanding resonant frequencies and the susceptibility of marine mammal air cavities to resonance is important in determining whether certain sonars have the potential to affect different cavities in different species. In 2002, NMFS convened a panel of government and private scientists to address this issue (NOAA, 2002b). They modeled and evaluated the likelihood that U.S. Navy MFA sonar caused resonance effects in beaked whales that eventually led to their stranding (Department of Commerce [DOC] and DON, 2001). The conclusions of that group were that frequencies predicted to cause resonance in air-filled structures were below the frequencies produced by the sonar systems in use. Furthermore, air cavity vibrations due to the resonance effect were not considered to be of sufficient amplitude to cause tissue damage. The Q-20 OEA and this IHA request assumes that similar phenomenon will not be problematic in other cetacean species.

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.

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 a wide frequency band and are long in duration.

The majority of proposed Q-20 test activities is 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, the duty cycle low, and these active sonars 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 (*Tursiops truncatus*), Atlantic spotted dolphin (*Stenella frontalis*), pantropical spotted dolphin (*Stenella attenuata*), striped dolphin (*Stenella coeruleoalba*), spinner dolphin (S*tenella longirostris*), and Clymene dolphin (*Stenella clymene*). 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.

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)
Bryde's whale	0	0	0
Sperm whale	0	0	0
Dwarf/Pygmy sperm whale	0	0	0
All beaked whales	0	0	0
Rough-toothed dolphin	0	0	0
Bottlenose dolphin	0	0	399
Pantropical spotted dolphin	0	0	126
Atlantic spotted dolphin	0	0	315
Spinner dolphin	0	0	126
Clymene dolphin	0	0	42

Marine Mammal Species	Level A	Level B (TTS)	Level B (Behavioral)
Striped dolphin	0	0	42
Fraser’s dolphin	0	0	0
Risso’s dolphin	0	0	0
Melon-headed whale	0	0	0
Pygmy killer whale	0	0	0
False killer whale	0	0	0
Killer whale	0	0	0
Short-finned pilot whale	0	0	0

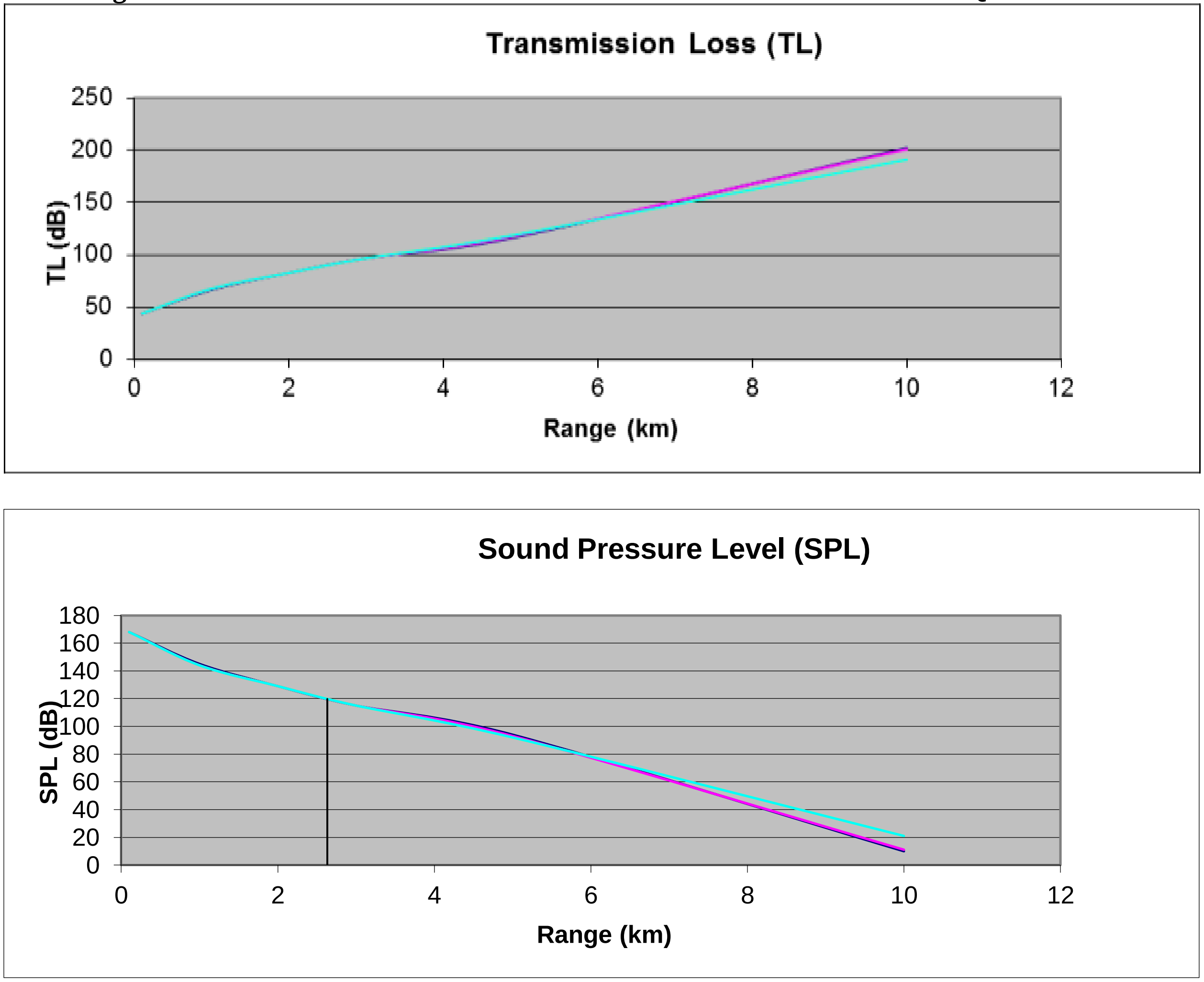
Potential for Long-Term Effects

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 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 transmission losses and received sound pressure levels (SPLs) from the Q-20 when operating in the test area. Specifically, four radials out towards De Soto Canyon were calculated. The results (Figure 6-9), indicate the relatively rapid attenuation of sound pressure levels with distance from the source, which is not surprising given the high frequency of the source. Figure 6-10 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 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 nm) 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 6-9 and 6-10, that DeSoto Canyon is well beyond the distance at which sound pressure levels from the Q-20 attenuate to zero.

Figure 6-9. Attenuation of Sound Pressure Levels with Distance from the Q-20 Source



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

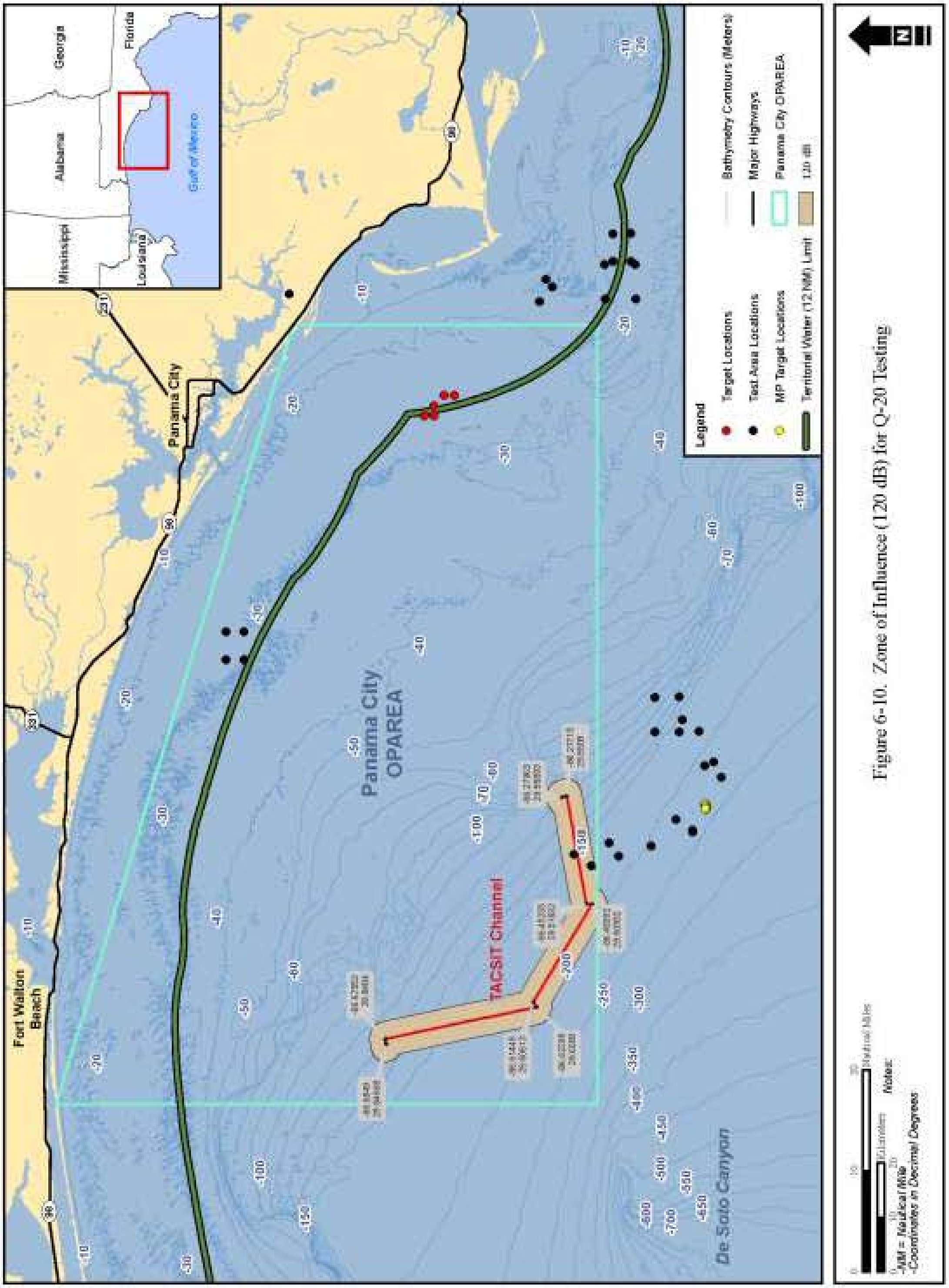


Figure 6-10. Zone of Influence (120 dB SPL) for Q-20 Testing

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 high-frequency sonar operations.

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.

Bottlenose Dolphin

As previously mentioned, the best estimate of abundance for bottlenose dolphins along the GOM continental shelf and slope is 17,777, with a minimum population estimate of 13,667 bottlenose dolphins (NMFS, 2008b). The risk function and 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 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.

Atlantic Spotted Dolphin

As previously mentioned, the best estimate of abundance for Atlantic spotted dolphins in the northern GOM is 37,611, with a minimum population estimate of 29,844 dolphins (NMFS, 2008c). The risk function and 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 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

The best estimate of abundance for pantropical spotted dolphins in the northern GOM is 34,067, with a minimum population of 29,311 dolphins (NMFS, 2009d). The risk function and 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, 0.0.37 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 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 3,325, with a minimum population estimate of 2,266 striped dolphins (NMFS, 2009g). The risk function and Navy post-modeling analysis estimates that 42 striped dolphins will exhibit behavioral responses that NMFS will classify as harassment under the MMPA. Based on this 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 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 is 1,989. The minimum population estimate for the northern GOM is 1,356 spinner dolphins (NMFS, 2009e). The risk function and Navy post-modeling analysis estimates that 126 spinner dolphins will exhibit behavioral responses that NMFS will classify as harassment under the MMPA. Based on this 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 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 6,575, with a minimum population estimate of 4,901 animals (NMFS, 2009). The risk function and Navy post-modeling analysis estimates that 42 Clymene dolphins will exhibit behavioral responses that NMFS will classify as harassment under the MMPA. Based on this 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 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.

Table 6-4 summarizes the requested takes by marine mammal species.

Table 6-4. Requested Takes by Marine Mammal Species

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

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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 behavioral effects zones (Level B harassment).
- Although the estimated exposure numbers represent estimated harassment under the Marine Mammal Protection Act (MMPA), as described above, they are conservative estimates of harassment by behavioral disturbance. In addition, the model calculates harassment without taking into consideration standard protective measures, and is 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 the National Marine Fisheries Service (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 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 mission 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 take any marine mammals in non-territorial waters.

7.2 SONAR

No takings by death or injury of marine mammals are anticipated from missions that test sonar in the Gulf of Mexico (GOM). Six species of marine mammals may be taken by incidental harassment in non-territorial waters. They include the bottlenose dolphin (*Tursiops truncatus*), Atlantic spotted dolphin (*Stenella frontalis*), pantropical spotted dolphin (*Stenella attenuata*), striped dolphin (*Stenella coeruleoalba*), spinner dolphin (*Stenella longirostris*), and Clymene dolphin (*Stenella clymene*). Because sonar testing in the Q-20 Study Area results in temporary and intermittent takings by incidental harassment, there will be a negligible effect to affected species or stocks.

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8. IMPACT ON SUBSISTENCE USE

Potential impacts resulting from the proposed activity will be limited to individuals of marine mammal species located in the Gulf of Mexico (GOM). No subsistence uses exist for cetacean species occurring in waters affected by the Proposed Action. Therefore, no impacts on the availability of species or stocks available for subsistence use are considered.

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

The Testing the AN/AQS-20A Mine Reconnaissance System in the NSWC PCD Testing Range, 2012-2014 Overseas Environmental Assessment (Q-20 OEA) considered the sources that could affect marine mammal habitat. Sources that may affect marine mammal habitat include introduction of sound into the water column, and transiting vessels. Each of these components was considered in the Q-20 OEA and was determined to have no effect on marine mammal habitat. A summary of the conclusions are included in subsequent sections. Changes in the amount and distribution of prey were also analyzed relative to these operations to determine whether effects to marine mammal habitat would occur. Marine mammal habitat would not be affected.

9.1 SOUND IN THE ENVIRONMENT

The potential cumulative impact issue associated with active sonar activities is the addition of underwater sound to oceanic ambient noise levels, which in turn could have potential effects on marine animals. Anthropogenic sources of ambient noise that are most likely to have contributed to increases in ambient noise levels are commercial shipping, offshore oil and gas exploration and drilling, and naval and other use of sonar (Department of the Navy [DON], 2007a). The potential impact that high-frequency sonars may have on the overall oceanic ambient noise level are reviewed in the following contexts:

- Recent changes to ambient sound levels in the Gulf of Mexico (GOM);
- Operational parameters of the sonar operating during RDT&E activities, including proposed mitigation;
- The contribution of active sonar activities to oceanic noise levels relative to other human generated sources of oceanic noise; and
- Cumulative impacts and synergistic effects.

Very few studies have been conducted to determine ambient sound levels in the ocean. However, ambient sound levels for the Eglin Gulf Test and Training Range, located in the GOM, generally range from approximately 40 decibels (dB) to about 110 dB (United States [U.S.] Air Force, 2002). In a study conducted by Andrew et al. (2002), ocean ambient sound from the 1960s was compared to ocean ambient sound from the 1990s for a receiver off the coast of California (DON, 2007d). The data showed an increase in ambient noise of approximately 10 dB in the frequency range of 20 to 80 hertz (Hz) and 200 and 300 Hz, and about 3 dB at 100 Hz over a 33-year period (DON, 2007d).

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, there are approximately 20,000 large commercial vessels at sea worldwide at any given time. The 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, the National Oceanic and Atmospheric Administration (NOAA) hosted a symposium entitled, “Shipping Noise and Marine Mammals.” During Session I, Trends in the Shipping Industry and Shipping Noise, statistics were presented that indicate foreign waterborne trade into the United States has increased 2.45 percent each year over a 20-year period (1981-2001) (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 National Research Council (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 in order to define subsurface geological structure. The resultant seismic data are necessary for determining drilling location and currently seismic surveys are 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 seconds, but for very deep water surveys, 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 from zero-to-peak are typical for a full-scale array. The most powerful arrays have source levels as high as 260 dB, zero-to-peak with air gun volumes of 130 L (7,900 cubic inches). Smaller arrays have SLs of 235 to 246 dB, zero-to-peak.

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. Also, the ships use thrusters to stay in the same location rather than anchoring. Auxiliary noise is produced during drilling activities, such as helicopter and supply boat noises. Offshore drilling structure emplacement creates some localized noise for brief periods of time, and emplacement activities can last for a few weeks and occur worldwide. Additional noise is created during other oil production activities, such as borehole logging, cementing, pumping, and pile driving. Although sound pressure levels 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 occur year-round (not individual surveys, but collectively) and are usually operational 24 hours per day and seven days a week.

There are both military and commercial sonars: military sonars are used for target detection, localization, and classification; and commercial sonars are typically higher in frequency and lower in power and are used for depth sounding, bottom profiling, fish finding, and detecting obstacles in the water. 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 be more than one time, the intermittent nature of the sonar signal, its low duty cycle, and because both the vessel and animal are moving 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 anthropogenic oceanic noise. Protective measures will be employed during Q-20 test activities to minimize potential effects to marine mammals to the greatest extent practicable. As such, it was determined that there would be no significant impact to marine mammals from sound in the environment.

9.2 TRANSITING VESSELS

Collisions with commercial and U.S. Navy ships can cause major wounds and may occasionally cause fatalities to marine mammals. 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). These species are primarily large, slow moving whales. Smaller marine mammals, for example Atlantic bottlenose and Atlantic spotted dolphins, move quickly throughout the water column and are often seen riding the bow wave of large ships. Marine mammal responses may include avoidance and changes in dive pattern (NRC, 2003).

Accordingly, the U.S. Navy has adopted standard operating procedures and protective measures to reduce the potential for collisions 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 Navy assets and 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, Research Vessel (R/V) Mr. Offshore, several 4.0 to 7.6 m (13 to 25 ft) outboard motor boats, a 9.1 m (30 ft) rigid hull inflatable boat (RHIB), 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 and are stationary for a large proportion of operations. Thus, effects to marine mammal habitat from these vessels would be negligible.

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

Based on the previous discussion in this Incidental Harassment Authorization (IHA) request, there will be no impacts to 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 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 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 Navy must develop a robust capability using realistic conditions to research, develop, test, and evaluate systems within the Q-20 Study Area. The Navy recognizes that such developments have the potential to cause behavioral disruption of some marine mammal species in the vicinity of research, development, test, and evaluation (RDT&E) activities. This section presents the 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 Navy, which have been in place since 2004.

11.2.1 Personnel Training

Marine mammal mitigation training for those who participate in the active sonar activities is a key element of the protective measures. The goal of this training is for key personnel onboard Navy platforms in the Q-20 Study Area to understand the protective measures and be competent to carry them out. 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, Navy stewardship, and general observation information including more detailed information for spotting marine mammals. Marine mammal observer training will be provided before active sonar testing begins. MSAT has been reviewed by the National Marine Fisheries Service (NMFS) and acknowledged as suitable training. Marine observers 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 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 sector. 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 so the horizon is in the top third of the field of vision and direct the eyes just below the horizon. The lookout will scan for approximately five seconds in as many small steps as possible across the field seen through the binoculars. They will search the entire sector in approximately five-degree steps, pausing between steps for approximately five seconds to scan the field of view. At the end of the sector search, the glasses will be lowered to allow the eyes to rest for a few seconds, 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.
- 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. 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 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. 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. 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

Proposed Monitoring for this Incidental Harassment Authorization

The RDT&E Monitoring Program, proposed by the Navy as part of this Incidental Harassment Authorization (IHA), 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. 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 National Marine Fisheries Service (NMFS) stranding response network and NMFS Regional Office. Reporting requirements of this IHA will be included in the Naval Surface Warfare Center Panama City Division (NSWC PCD) Mission Activities Final Environmental Impact Statement/Overseas Environmental Impact Statement Annual Activity report as required by its Final Rule (DON, 2009; NMFS, 2010d).

Ongoing Monitoring

The Navy has an existing Monitoring Plan that provides for site-specific monitoring for Marine Mammal Protection Act and Endangered Species Act listed species, primarily marine mammals within the Gulf of Mexico including marine water areas of the Q-20 Study Area (DON, 2009; NMFS, 2010d). This monitoring plan was initially developed in support of the NSWC PCD Mission Activities Final Environmental Impact Statement/Overseas Environmental Impact Statement and subsequent Final Rule by the National Marine Fisheries Service (DON, 2009; NMFS, 2010d). The primary goals of monitoring are to evaluate trends in marine species distribution and abundance in order to assess potential population effects from Navy training and testing events and determine the effectiveness of the Navy's mitigation measures. The monitoring plan, adjusted annually in consultation with NMFS includes aerial and ship based visual observations, acoustic monitoring, and other efforts such as oceanographic observations. The 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 Navy sponsors a significant portion of research concerning the effects of human generated sound on marine mammals. World-wide, the Navy funded over $33 million in marine mammal research in 2010. Major topics of 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 RDT&E 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 by academic institutions have been augmented with additional funding from the Navy. The 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 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 Navy will continue to fund ongoing marine mammal research, and plans to coordinate long-term monitoring/studies of marine mammals on various established ranges and operating areas. The Navy will continue to research and contribute to university/external research to improve the state of the science regarding marine species biology and acoustic effects. 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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14. LIST OF PREPARERS

This Incidental Harassment Authorization (IHA) was prepared for the U.S. Navy by Naval Surface Warfare Center Panama City Division. A list of key preparation and review personnel is included.

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15. REFERENCES

Advisory Committee on Acoustic Impacts on Marine Mammals, 2006. Report to the U.S. Marine Mammal Commission. Marine Mammal Commission; Bethesda, Maryland.

Baird, R. W., D. L. Webster, D. J. McSweeney, A. D. Ligon, G. S. Schorr, and J. Barlow, 2006. Diving behaviour of Cuvier's (*Ziphius cavirostris*) and Blainville's (*Mesoplodon densirostris*) beaked whales in Hawai'i. *Canadian Journal of* Zoology, Vol 84, pp 1120–1128.

Corkeron, P.J., and R.C. Connor, 1999. Why do baleen whales migrate? Marine Mammal Science 15(4):1228-1245.

Cox, T. M., T. J. Ragen, A. J. Read, E. Vos, R. W. Baird, K. Balcomb, J. Barlow, J. Caldwell, T. Ranford, L. Crum, A. D'amico, G. D'spain, A. Fernández, J. Finneran, R. Gentry, W. Gerth, F. Gulland, J. Hildebrand, D. Houser, T. Hullar, P. D. Jepson, D. Ketten, C. D. Macleod, P. Miller, S. Moore, D. C. Mountain, D. Palka, P. Ponganis, S. Rommel, T. Rowles, B. Taylor, P. Tyack, D. Wartzok, R. Gisiner, J. Meads, L. Benner, 2006. Understanding the impacts of anthropogenic sound on beaked whales. *Journal of Cetacean Research Management*, Vol 7, pp 177–187.

Crum, L.A., and Y. Mao, 1996. "Acoustically enhanced bubble growth at low frequencies and its implications for human diver and marine mammal safety." *Journal of the Acoustical Society of America* 99:2898-2907.

Dalecki, D., S. Z. Child, and C. H. Raeman, 2002. Lung damage from exposure to low-frequency underwater sound. *Journal of the Acoustical Society of America*, Vol 111, pp 2462A.

Department of the Navy (DON), 2005. Draft Overseas Environmental Impact Statement/Environmental Impact Statement for Undersea Warfare Training Range. Department of the Navy. October 2005.

————, 2005a. Undersea Warfare Exercise (USWEX) Programmatic Environmental Assessment/Overseas Environmental Assessment. United States Pacific Fleet.

————, 2006. Mid-Frequency Active Sonar Effects Analysis Interim Policy. Office of the Chief of Naval Operations. Washington, DC. March 6, 2006.

————, 2006a. 2006 Supplement to the 2002 Rim of the Pacific (RIMPAC) Programmatic Environmental Assessment. Third Fleet. May 2006.

————, 2007. Marine Resources Assessment for the Gulf of Mexico. Prepared for the Department of the Navy, U.S. Fleet Forces Command, Norfolk, Virginia. Contract #N62470-02-D-9997, CTO 0030. Prepared by Geo-Marine, Inc., Hampton, Virginia.

————, 2007a. Undersea Warfare Exercise (USWEX) Programmatic Environmental Assessment/Overseas Environmental Assessment. United States Pacific Fleet.

————, 2007b. Final Supplement to the Final Comprehensive Overseas Environmental Assessment for Major Atlantic Fleet Training Exercises. United States Fleet Forces Command. May 2007.

————, 2007c. Hawaii Range Complex Draft Environmental Impact Statement/Overseas Environmental Impact Statement. United States Pacific Fleet. August 2007.

————, 2007d. Final Comprehensive Report for the Operation of the Surveillance Towed Array Sensor System Low Frequency Active (SURTASS LFA) Sonar Onboard the R/V Cory Chouest and USNS IMPECCABLE (T-AGOS 23) Under the National Marine Fisheries Service Regulations 50 CFR 216 Subpart Q. National Marine Fisheries Service (NMFS)/National Oceanic and Atmospheric Administration (NOAA).

————, 2007e. *Navy OPAREA Density Estimate (NODE) for the GOMEX OPAREA. Prepared for the Department of the Navy, U.S. Fleet Forces Command, Norfolk, Virginia*. Contract #N62470-02-D-9997, CTO 0030. Prepared by Geo-Marine, Inc., Hampton, Virginia, Dolar, M. L. L., 2002. Fraser's dolphin. Pp. 485-487 In: WF Perrin, B Wursig and JGM Thewissen (eds) *Encyclopedia of Marine Mammals*. Academic Press: San Diego. 1414 pp.

————, 2009. Department of the Navy, *Final Environmental Impact Statement/Overseas Environmental Impact Statement NSWC PCD Mission Activities*. Naval Surface Warfare Center Panama City Division, Panama City, FL. September 2009.

Evans, D.L., and G.R. England, 2001. "Joint Interim Report Bahamas Marine Mammal Stranding Event of 15-16 March 2000," (Department of Commerce), pp. 1-66.

Evans, G. H., and L. A. Miller, 2004. Proceedings of the Workshop on Active Sonar and Cetaceans. *European Cetacean Society Newsletter,* No. 42 Special Issue – February 2004.

Fahlman, A., A. Olszowka, B. Bostrom, and D. R. Jones, 2006. Deep diving mammals: dive behavior and circulatory adjustments contribute to bends avoidance. *Respiratory Physiology & Neurobiology* 153:66-77.

Feller, W., 1968. Introduction to probability theory and its application. Vol. 1. 3rd ed. John Wilay & Sons, NY, NY.

Fernández, A., J. Edwards, V. Martín, F. Rodríguez, A. Espinosa de los Monteros, P. Herráez, P. Castro, J. R. Jaber, and M. Arbelo, 2005. ""Gas and fat embolic syndrome" involving a mass stranding of beaked whales exposed to anthropogenic sonar signals," Journal of Veterinary Pathology 42, 446-457.

Fiedler, P.C., 2002. Ocean environment. Pages 824-830 in Perrin, W.F., B. Würsig, and J.G.M. Thewissen, eds. Encyclopedia of marine mammals. San Diego, California: Academic Press.

Finneran, J. J., and C. E. Schlundt, 2004. *Effects of Intense Pure Tones on the Behavior of Trained Odontocetes.* SPAWAR Systems Center, San Diego, California. September 2003.

Finneran, J. J., C. E. Schlundt, D. A. Carder, J. A. Clark, J. A. Young, J. B. Gaspin, and S. H. Ridgway, 2000. Auditory and behavioral responses of bottlenose dolphins (*Tursiops truncatus*) and a beluga whale (*Delphinapterus leucas*) to impulsive sounds resembling distant signatures of underwater explosions. *Journal of the Acoustical Society of America*, Vol 108, No 1, pp 417–431.

Finneran, J. J., D. A. Carder, and S. H. Ridgway, 2001. Temporary threshold shift (TTS) in bottlenose dolphins (*Tursiops truncatus*) exposed to tonal signals. 142nd Meeting of the Acoustical Society of America, Fort Lauderdale, Florida, December 2001. *Journal of the Acoustical Society of America*, Vol 110, No 5, p 2749(A).

————, 2002. Temporary shift in masked hearing thresholds in odontocetes after exposure to single underwater impulses from a seismic watergun. *Journal of the Acoustical Society of America*, Vol 111, No 6, pp 2929–2940.

————, 2003. Temporary threshold shift (TTS) measurements in bottlenose dolphins (*Tursiops truncatus*), belugas (*Delphinapterus leucas*), and California sea lions (*Zalophus californianus*). Environmental Consequences of Underwater Sound (ECOUS) Symposium, San Antonio, Texas. 12–16 May 2003.

———, 2005. Temporary threshold shift in bottlenose dolphins (*Tursiops truncatus*) exposed to mid-frequency tones. *Journal of the Acoustical Society of America*, Vol 118, pp 2696–2705.

Forcada, J., 2002. Distribution. Pages 327-333 in W.F. Perrin, B. Würsig, and J.G.M. Thewissen, eds. Encyclopedia of marine mammals. San Diego: Academic Press.

Fromm, D., 2004a. "Acoustic Modeling Results of the Haro Strait For 5 May 2003." Naval Research Laboratory Report, Office of Naval Research, 30 January 2004.

Fromm, D., 2004b. "EEEL Analysis of Shoup Transmissions in the Haro Strait on 5 May 2003," Naval Research Laboratory briefing of 2 September 2004.

Griffin, R. B., 1999. Sperm whale distributions and community ecology associated with a warm-core ring off Georges Bank. Marine Mammal Science 15(1):33-51.

Hennessy, M. B., J. P. Heybach, J. Vernikos, AND S. Levine, 1979. Plasma corticosterone concentrations sensitively reflect levels of stimulus intensity in the rat. Physiology and Behavior 22:821–825.

Houser, D.S., D. A. Helweg, and P. W. B. Moore, 2001. A bandpass filter-bank model of auditory sensitivity in the humpback whale. *Aquatic Mammals* Vol 27,pp 82–91.

Jansen, G., 1998. "Physiological effects of noise," In *Handbook of Acoustical Measurements and Noise Control, 3rd Edition,* New York: Acoustical Society of America.

Jepson, P. D., M. Arbelo, R. Deaville, I. A. P. Patterson, P. Castro, J. R. Baker, E. Degollada, H. M. Ross, P. Herráez, A. M. Pocknell, F. Rodríguez, F. E. Howie, A. Espinosa, R. J. Reid, J. R. Jaber, V. Martin, A. A. Cunningham, and A. Fernández, 2003. Gas-bubble lesions in stranded cetaceans. *Nature*, Vol 425, pp 575.

Jepson, P. D., R. Deaville, I. A. P. Patterson, A. M. Pocknell, H. M. Ross, J. R. Baker, F. E. Howie, R. J. Reid, A. Colloff, and A. A. Cunningham, 2005. "Acute and chronic gas bubbles lesions in cetaceans stranded in the United Kingdom," *Veterinary Pathology*, 42:291-305.

Jochens, A., D. Biggs, D. Engelhaupt, J. Gordon, N. Jaquet, M. Johnson, R. Leben, B. Mate, P. Miller, J. Ortega-Ortiz, A. Thode, P. Tyack, J. Wormuth, and B. Würsig, 2006. Sperm whale seismic study in the Gulf of Mexico, Summary Report, 2002-2004. OCS Study MMS 2006-034. New Orleans, Louisiana: Minerals Management Service.

Kastak, D., R. J. Schusterman, B. L. Southall, and C. J. Reichmuth, 1999. Underwater temporary threshold shift induced by octave-band noise in three species of pinniped. *Journal of the Acoustical Society of America*, Vol 106, No 2, pp 1142–1148.

Kastak D., B. L. Southall, R. J. Schusterman, and C. R. Kastak, 2005. "Underwater temporary threshold shift in pinnipeds: Effects of noise level and duration," *Journal of the Acoustical Society of America*, 118:3154–3163.

Kastelein, R. A., Rippe, H. T., Vaughan, N., Schooneman, N. M., Verboom, W. C., & de Haan, D., 2000. The effects of acoustic alarms on the behavior of harbor porpoises in a floating pen. Marine Mammal Science 16:46-64.

Keeler, J. S., 1976. Models for noise-induced hearing loss. In: *Effects of Noise on Hearing*, ed. Henderson et al., 361–381. New York: Raven Press.

Ketten, D. R., 1997. Structure and Function in Whale Ears, *Bioacoustics*, vol.8, no. 1, pp. 103-136.

————, 1998. Marine mammal auditory systems: *A summary of audiometric and anatomical data and its implications for underwater acoustic impacts.* NOAA-TM-NMFSSWFSC-256, Department of Commerce.

————, 2005. Annex K: Report of the standing working group on environmental concerns. Appendix 4. Marine mammal auditory systems: a summary of audiometric and anatomical data and implications for underwater acoustic impacts. Journal of Cetacean Research and Management 7:286 - 289.

Kooyman, G. L., D. D. Hammond, and J. P. Schroeder, 1970. Brochograms and tracheograms of seals under pressure. *Science*, Vol 169, pp 82–84.

Kryter K. D., W. D. Ward, J. D. Miller, and D. H. Eldredge, 1966. Hazardous exposure to intermittent and steady-state noise. *Journal of the Acoustical Society of America*, Vol 39, pp 451–464.

Laist, D. W., A. R. Knowlton, J. G. Mead, A. S. Collet, and M. Podesta, 2001. Collisions between ships and whales. Marine Mammal Science, Vol 17, No 1, pp 35–75.

Lowry, M. S., J. V. Carretta, K. A. Forney, M. M. Muto, J. Barlow, J. Baker, and B. Hanson, 2007. U.S. Pacific marine mammal stock assessments: 2006. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-SWFSC-398.

Malme, C. I., P. R. Miles, C. W. Clark, P. Tyack, and J. E. Bird, 1984. Investigations of the potential effects of underwater noise from petroleum industry activities on migrating gray whale behavior/Phase II*:* January 1984 migration. BBN Rep. 5586. Rep. From Bolt Beranek and Newman, Inc., Cambridge, MA, for U.S. Minerals Manage. Serv., Anchorage, AK. Var. pag. NTIS PB86-218377.

McEwen, Bruce S. and Wingfield, John C., 2003. The concept of allostasis in biology and biomedicine. Hormones and Behavior, 43, 2-15.

Mead, J. G., 2002. Beaked whales, overview. pp. 81-4. In: W.F. Perrin, B. Wursig and G.M. Thewissen (eds.) Encyclopedia of Marine Mammals. San Diego, California: Academic Press.

Miller, J. D., 1974. Effects of noise on people. *Journal of the Acoustical Society of America*, Vol 56, pp 729–764.

Miller, J. D., C. S. Watson, and W. P. Covell, 1963. Deafening effects of noise on the cat. *Acta Oto-Laryngologica* Supplement Vol 176, pp 1–91.

Mills, J. H., R. M. Gilbert, and W. Y. Adkins, 1979. “Temporary threshold shifts in humans exposed to octave bands of noise for 16 to 24 hours,” Journal of the Acoustical Society of America, 65:1238–1248.

Mullin, K. D. and G. L. Fulling, 2003. Abundance of cetaceans in the southern U.S. North Atlantic Ocean during summer 1998. *Fishery Bulletin*, Vol 101, pp. 603-613.

Mullin, K. D. and G. L. Fulling, 2004. Abundance of cetaceans in the oceanic northern Gulf of Mexico, 1996-2001. *Marine Mammal Science* 20(4): 787-807.

Nachtigall, P. E., J. L. Pawloski, and W. W. L. Au, 2003a. “Temporary threshold shift and recovery following noise exposure in the Atlantic bottlenosed dolphin (*Tursiops truncates*),” *Journal of the Acoustical Society of America*, 113:3425-3429.

Nachtigall, P. E., A. Supin, J. L. Pawloski, and W. W. L. Au, 2004. “Temporary threshold shift after noise exposure in bottlenosed dolphin (*Tursiops truncates*) measured using evoked auditory potential,” *Marine Mammal Science*, 20:673-687.

National Marine Fisheries Service (NMFS), 2005. Assessment of Acoustic Exposures on Marine Mammals in Conjunction with USS Shoup Active Sonar Transmissions in the Eastern Strait of Juan de Fuca and Haro Strait, National Marine Fisheries Service, Office of Protected Resources, Washington, 5 May 2003.

National Marine Fisheries Service (NMFS), 2005. Stock Assessment Report, Fraser’s Dolphin (*Lagenodelphis hosei*) Northern Gulf of Mexico Stock. December. Available online at http://www.nmfs.noaa.gov/pr/sars/species.htm.

————, 2008a. Stock Assessment Report, Rough-toothed Dolphin (*Steno bredanensis*) Northern Gulf of Mexico Stock. October. Available online at http://www.nmfs.noaa.gov/pr/sars/species.htm.

————, 2008b. Stock Assessment Report, Bryde’s Whale (*Balaanoptera edeni*) Northern Gulf of Mexico Stock. December. Available online at http://www.nmfs.noaa.gov/pr/sars/species.htm.

————, 2008c. Stock Assessment Report, Atlantic Spotted Dolphin (*Stenella frontalis*) Northern Gulf of Mexico Stock. October. Available online at http://www.nmfs.noaa.gov/pr/sars/species.htm.

————, 2009a. Stock Assessment Report, Bryde's Whale (*Balaanoptera edeni*) Northern Gulf of Mexico Stock. December. Available online at http://www.nmfs.noaa.gov/pr/sars/species.htm.

————, 2009b. Stock Assessment Report, Dwarf Sperm Whale (*Kogia sima*) Northern Gulf of Mexico Stock. December. Available online at http://www.nmfs.noaa.gov/pr/sars/species.htm.

————, 2009c. Stock Assessment Report, Cuvier's Beaked Whale (*Ziphius cavirostris*) Northern Gulf of Mexico Stock. December. Available online at http://www.nmfs.noaa.gov/pr/sars/species.htm.

————, 2009d. Stock Assessment Report, Pantropical Spotted Dolphin (*Stenella attenuata*) Northern Gulf of Mexico Stock. December. Available online at http://www.nmfs.noaa.gov/pr/sars/species.htm.

————, 2009e. Stock Assessment Report, Spinner Dolphin (*Stenella longirostris*) Northern Gulf of Mexico Stock. December. Available online at http://www.nmfs.noaa.gov/pr/sars/species.htm.

————, 2009f. Stock Assessment Report, Clymene Dolphin (*Stenella clymene*) Northern Gulf of Mexico Stock. December. Available online at http://www.nmfs.noaa.gov/pr/sars/species.htm.

————, 2009g. Stock Assessment Report, Striped Dolphin (*Stenella coeruleoalba*) Northern Gulf of Mexico Stock. December. Available online at http://www.nmfs.noaa.gov/pr/sars/species.htm.

————, 2009h. Stock Assessment Report, Melon-headed Whale (*Peponocephala electra*) Northern Gulf of Mexico Stock. December. Available online at http://www.nmfs.noaa.gov/pr/sars/species.htm.

————, 2009i. Stock Assessment Report, Pygmy Killer Whale (*Feresa attenuata*) Northern Gulf of Mexico Stock. December. Available online at http://www.nmfs.noaa.gov/pr/sars/species.htm.

————, 2009j. Stock Assessment Report, False Killer Whale (*Pseudorca crassidens*) Northern Gulf of Mexico Stock. December. Available online at http://www.nmfs.noaa.gov/pr/sars/species.htm.

————, 2009k. Stock Assessment Report, Short-Finned Pilot Whale (*Globicephala macrorhynchus*) Northern Gulf of Mexico Stock. December. Available online at http://www.nmfs.noaa.gov/pr/sars/species.htm.

————, 2010a. Stock Assessment Report, Sperm Whale (*Physeter macrocephalus*) Northern Gulf of Mexico Stock. November. Available online at http://www.nefsc.noaa.gov/publications/tm/tm219/.

————, 2010b. Stock Assessment Report, Risso's Dolphin (*Grampus griseus*) Northern Gulf of Mexico Stock. November. Available online at http://www.nmfs.noaa.gov/pr/sars/species.htm.

————, 2010c. Stock Assessment Report, Killer Whale (*Orcinus orca*) Northern Gulf of Mexico Stock. November. Available online at http://www.nmfs.noaa.gov/pr/sars/species.htm.

————, 2010d. Taking and Importing Marine Mammals; U.S. Naval Surface Warfare Center Panama City Division Mission Activities; Final Rule, *Federal Register*, Vol 75, No 13, pp 3395–3426, 21 January 2010.

————, 2010e. Draft Stock Assessment Report, Bryde's Whale (*Balaanoptera edeni*) Northern Gulf of Mexico Stock. December. Available online at http://www.nmfs.noaa.gov/pr/pdfs/sars/ao2011_gulf_draft.pdf.

————, 2011. Endangered Species Act Section 7 Consultation Biological Opinion for U.S. Navy research, development, test, and evaluation (RDT&E) activities at the U.S. Naval Surface Warfare Center, Panama City, Florida, from January 2011 to January 2012.

National Oceanic and Atmospheric Administration (NOAA), 2001. Final Rule for the Shock Trial of the WINSTON S. CHURCHILL (DDG-81), Federal Register, Department of Commerce; NOAA Fisheries, FR 66, No. 87, 22450-67, 4 May.

————, 2002a. *Final Rule SURTASS LFA Sonar*. Federal Register, Department of Commerce, NOAA Fisheries. 16 July 2002. Federal Register (FR) 67, No 136, pp 46712–89

————, 2002b. *Report of the workshop on acoustic resonance as a source of tissue trauma in cetaceans*. NOAA Fisheries, Silver Spring, Maryland. April 2002.

————, 2006. Small takes of marine mammals incidental to specified activities, Rim of the Pacific antisubmarine warfare exercise training events within the Hawaiian Islands Operation Area. Federal Register 71:38710-38738, 7 Jul 06.

————, 2006a. Proposed Rule. Taking and Importing Marine Mammals; Taking Marine Mammals Incidental to the Explosive Removal of Offshore Structures in the Gulf Of Mexico, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Commerce, Federal Register, Vol. 71, No. 67, pp. 17790-17804, 7 April 2006.

National Research Council (NRC), 2003. Ocean Noise and Marine Mammals. The National Academies Press, Washington, DC.

————, 2005. Marine Mammal Populations and Ocean Noise: Determining When Noise Causes Biologically Significant Effects. The National Academic Press, Washington D.C. 126 pp.

Nedwell, J. R., B. Edwards, A.W. H. Turnpenny, and J. Gordon. 2004. Fish and Marine Mammal Audiograms: A Summary of Available Information. 3 September 2004.

Nowacek, D. P., M. P. Johnson, and P. L. Tyack, 2004. North Atlantic right whales (*Eubalaena glacialis*) ignore ships but respond to alerting stimuli. Proceedings of the Royal Society B: Biological Sciences 271:227-231.

Piantadosi, C. A. and E. D. Thalmann, 2004. Whales, sonar, and decompression sickness. Nature. 15 April 2004.

Quaranta, A., P. Portalatini, and D. Henderson, 1998. “Temporary and permanent threshold shift: An overview,” *Scandinavian Audiology,* 27:75–86.

Reeder, D. M. and K. M. Kramer, 2005. “Stress in free-range mammals: Integrating physiology, ecology, and natural history,” *Journal of Mammalogy.* 86(2): 225-235.

Richardson, W. J., C. R. Green, Jr., C. I. Malme, and D. H. Thomson, 1995. *Marine Mammals and Noise*, Academic Press, Inc., San Diego, CA.

Ridgway, S. H., and R. Howard, 1979. Dolphin lung collapse and intramuscular circulation during free diving: evidence from nitrogen washout. *Science,* Vol 206, pp 1182–1183.

Ridgway, S. H., D. A. Carder, R. R. Smith, T. Kamolnick, C. E. Schlundt, and W. R. Elsberry, 1997. Behavioral responses and temporary shift in masked hearing threshold of bottlenose dolphins, Tursiops truncatus, to 1-second tones of 141 to 201 dB re 1 µPa. Technical Report 1751, Revision 1. San Diego: Naval Sea Systems Command.

Saunders, J. C., J. H. Mills, and J. D. Miller, 1977. “Threshold shift in the chinchilla from daily exposure to noise for six hours,” Journal of the Acoustical Society of America, 61:558–570.

Schlundt, C. E., J. J. Finneran, D. A. Carder, and S. H. Ridgway, 2000. Temporary threshold shift in masked hearing thresholds of bottlenose dolphins, *Tursiops truncatus*, and white whales, *Delphinapterus leucas*, after exposure to intense tones. *Journal of the Acoustical Society of America*, Vol 107, pp 3496–3508.

Scowcroft, G., K. Vigness Raposa, C. Knowlton, and J. Johnen, 2006. *Discovery of Sound in the Sea*. University of Rhode Island.

Simmonds, M. P., and L. F. Lopez-Jurado, 1991. "Whales and the military," Nature 351, 448.

Southall, B., 2005. Shipping Noise and Marine Mammals: A Forum for Science, Management and Technology. National Oceanographic and Atmospheric Administration. 40 pp.

Southall, B. L., A. E. Bowles, W. T. Ellison, J. J. Finneran, R. L. Gentry, C. R. Greene Jr., D. Kastak, D. R. Ketten, J. H. Miller, P. E. Nachtigall, W. J. Richardson, J. A. Thomas, and P. L. Tyack, 2007. Marine mammal noise exposure criteria: initial scientific recommendations. *Aquatic Mammals*, Vol 33, No 4, pp 411-521.

Stern, S. J., 2002. Migration and movement patterns. Pages 742-748 in Perrin, W.F., B. Würsig, and J.G.M. Thewissen, eds. Encyclopedia of marine mammals. San Diego, California: Academic Press.

Stevick, P. T., B. J. McConnell, and P. S. Hammond. 2002. Patterns of movement. Pages 185-216 in Hoelzel, A. R., ed. Marine mammal biology: An evolutionary approach. Oxford, United Kingdom: Blackwell Science.

Tyack, P. L., M. Johnson, N. Aguilar Soto, A. Sturlese, and P. T. Madsen, 2006. Extreme diving of beaked whales. *Journal of Experimental Biology*, Vol 209, pp 4238–4253.

Urian, Kim W., Aleta A. Hohn and Larry J. Hansen, 1999. Status of the photo-identification catalog of coastal bottlenose dolphins of the western North Atlantic: report of a workshop of catalog contributors. U.S. Department of Commerce, Beaufort, NC. (NOAA Administrative Report NMFS-SEFSC-425) 24p. SH11.A3441a no.425.

Ward, W. D., 1960. Recovery from high values of temporary threshold shift. *Journal of the Acoustical Society of America*, Vol 32, pp 497–500.

Ward, W. D., 1997. Effects of high-intensity sound. *Encyclopedia of Acoustics*, ed. M.J. Crocker, Wiley: New York, New York, pp 1497–1507.

Ward, W. D., A. Glorig, and D. L. Sklar, 1958. Dependence of temporary threshold shift at 4 kc on intensity and time. *Journal of the Acoustical Society of America*, Vol 30, pp 944–954.

————, 1959. Temporary threshold shift from octave-band noise: Applications to damage-risk criteria. *Journal of the Acoustical Society of America*, Vol 31, pp 522–528.

Walsh, M. T., R. Y. Ewing, D. K. Odell, and G. D. Bossart 2001. "Mass Strandings of Cetaceans," in Marine Mammal Medicine, edited by L. A. Dierauf, and F. M. D. Gulland (CRC Press, Boca Raton), pp. 83-96.

Waring, G., D. Belden, M. Vecchione, and R. Gibbons, 2003. Mid-water prey in beaked whale and sperm whale deep-water habitat south of Georges Bank. In *Abstracts, Fifteenth Biennial Conference on the Biology of Marine Mammals 14–19 December 2003*, p 172. Greensboro, North Carolina.

Waring, G. T., E. Josephson, C. P. Fairfield, and K. Maze-Foley, editors., 2006. *U.S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments -- 2005*. NOAA Technical Memorandum NMFS-NE-194:1-346.

————, 2007. *U.S. Atlantic and Gulf of Mexico Marine Mammal Stock Assessments—2006*. NOAA Technical Memorandum, NMFS-NE-201. April 2007.

Wartzok, D., A. N. Popper, J. Gordon, and J. Merrill, 2003. Factors affecting the responses of marine mammals to acoustic disturbance. *Marine Technology Society Journal* 37(4):6-15.

Wingfield, J. C., 2003. Control of behavioural strategies for capricious environments. Animal Behavior, Vol 66, No 5, pp 807–816(10).

Yost, W. A., 1994. Fundamentals of Hearing: An Introduction. Academic Press: San Diego, California.

APPENDIX A

SUPPLEMENTAL INFORMATION FOR UNDERWATER NOISE ANALYSIS

SUPPLEMENTAL INFORMATION FOR UNDERWATER NOISE ANALYSIS

A.1 ACOUSTIC SOURCES

The AN/AQS-20A Mine Reconnaissance System (hereafter referred to as 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 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

Operations in the Q-20 Study Area involves 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. This analysis focuses on the loudest of these sources and demonstrates that even these sources yield few potential exposures (the Kingfisher being the lone significant exception). Exposure estimates are calculated on a 24 hour basis. Table A-1 presents the frequency class of the source. Tables A-2 and A-3 gives an overview of the number of operating hours for the systems in non-territorial waters, respectively.

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 hrs 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: $10 \log_{10} (360 / \text{horizontal beam width})$
  - Vertical directivity correction: $10 \log_{10} (2 / [\sin(\theta_1) - \sin(\theta_2)])$, where θ_1 and θ_2 are the 3-decibel (dB) down points on the main lobe.

- Source depth – Depth of the source in meters.
- Nominal frequency – Typically the center band of the source emission. These are frequencies that have been reported 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

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

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 the following table:

Table A-4. 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 = decibels; sec = seconds; m = meters; ° = degrees

A.2 IMPACT VOLUMES AND IMPACT RANGES

Naval 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, transmission loss (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 transmission loss 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-Frequency Bottom Loss geo-acoustic provinces and two High-Frequency Bottom Loss 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 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 calculations must be made for each, in both seasons. The transmission loss is predicted using CASS-GRAB sound modeling software.

- Step 3. Exposure Volumes. The transmission loss, combined with the source characteristics, gives the energy field of a single ping. The energy of over 10 hours 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 ten hours, 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 three-dimensional 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 Gaussian Ray Bundle (GRAB) propagation loss model (Keenan, 2000). The use of GRAB is predicated on the following factors:

- GRAB is certified as a Navy-standard transmission loss 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 transmission loss suffered along the eigenray path.

The frequency TL inputs are specified in Table A-6 for the Volume Search Sonar (VSS). It has been used as a worst case to model potential effects of the Q-20 sonars since it operates at 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-6. 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-7. Note that these parameters are a function of the TL input frequency; Table A-7 can be used to map them to a particular sonar source.

Table A-7. 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 NM)	5 m (16.4 ft)

kHz = kilohertz; ft = feet; km = kilometers; NM = nautical miles; m = meters

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 accumulate energy at grid points in each depth layer is compared to the specified threshold. If the accumulate 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 transmission loss 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 ten 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.

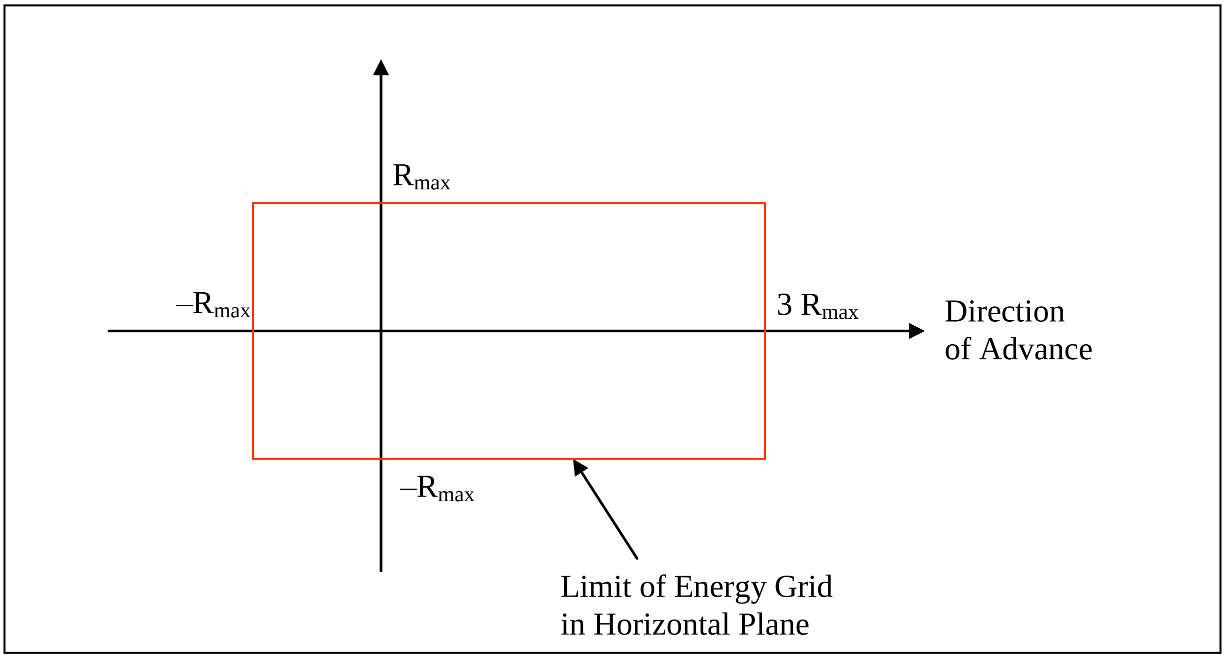


Figure A-1. Horizontal Plane of Volumetric Grid for Omni-Directional Source

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.

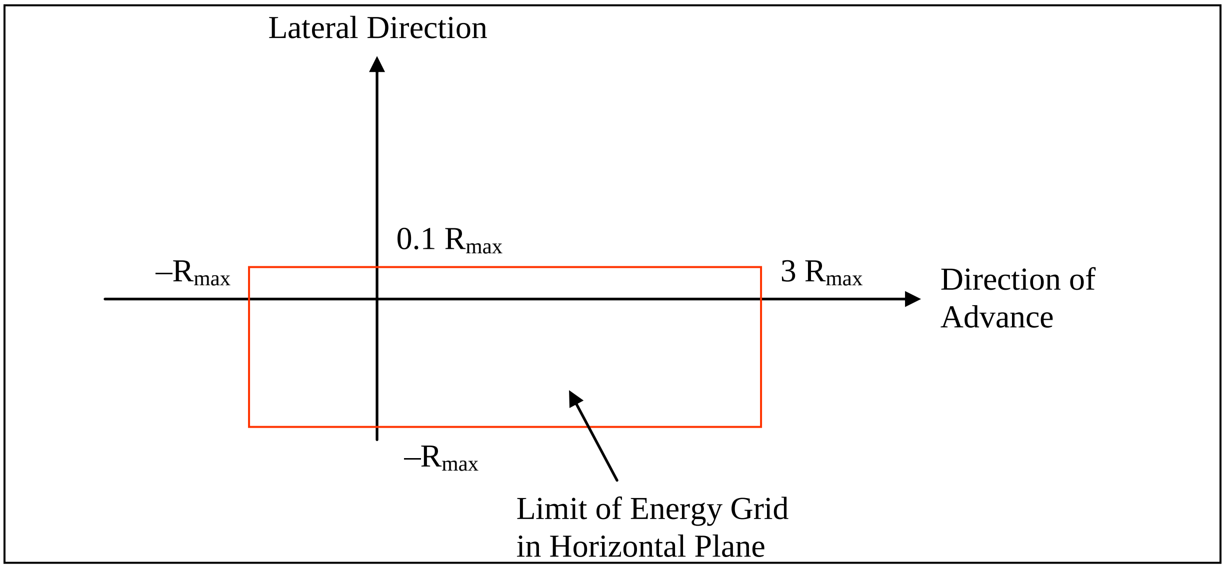


Figure A-2. Horizontal Plane of Volumetric Grid for Starboard Beam Source

Once the extent of the grid is established, the grid sampling can be defined. In the 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 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, as depicted in the following figure.

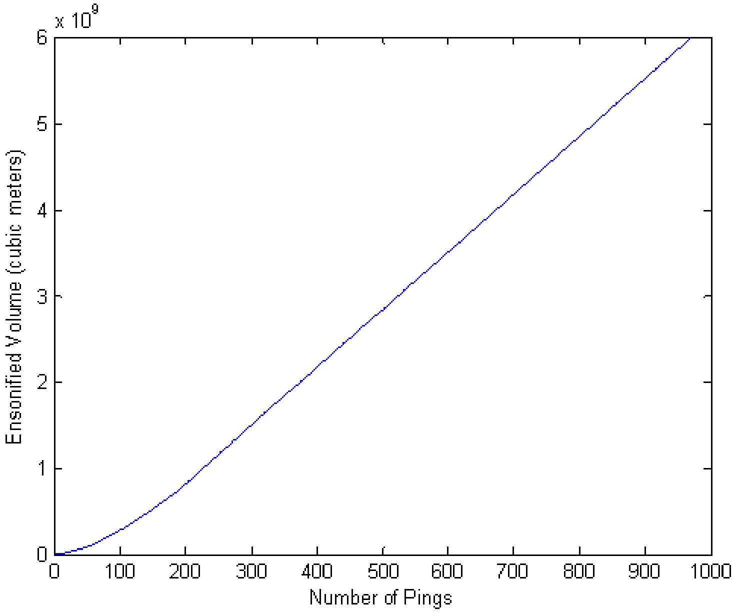


Figure A-3. 53C Impact Volume by Ping

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-4 provides an example of an hourly impact volume vector for a particular environment.

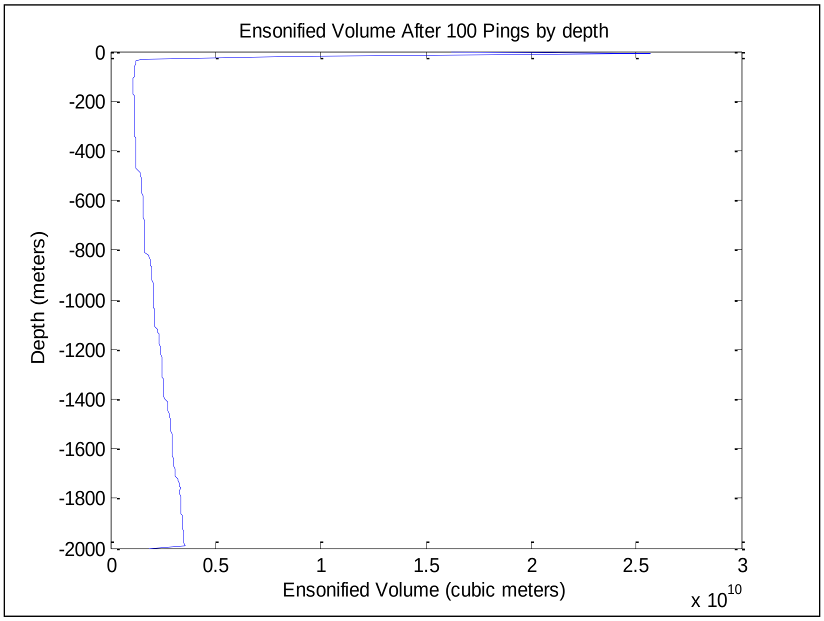


Figure A-4. Example of an Impact Volume Vector

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,

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

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 (124 miles x 124 miles), or 40,000 km^2 (15,444 square miles), 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. 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 sound pressure level 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 sound pressure level of the source and the TL curve, the sound pressure level is calculated on a volumetric grid. For a given depth, volume associated with a sound pressure level interval is calculated. Then this volume is multiplied by the probability that an animal will be affected by that sound pressure level. 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 sound pressure levels are segregated into a sequence of bins that cover the range encountered in the area. The sound pressure levels 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 sound pressure level at each *x-y* plane grid point is calculated using the sound pressure level of the source, the TL curve, the horizontal beam pattern of the source, and the vertical beam patterns of the source. The sound pressure levels in this grid become the bins in the volume histogram. Figure A-5 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-6 is an example of the impact volume as a function of depth at a water depth of 100 m (328 ft).

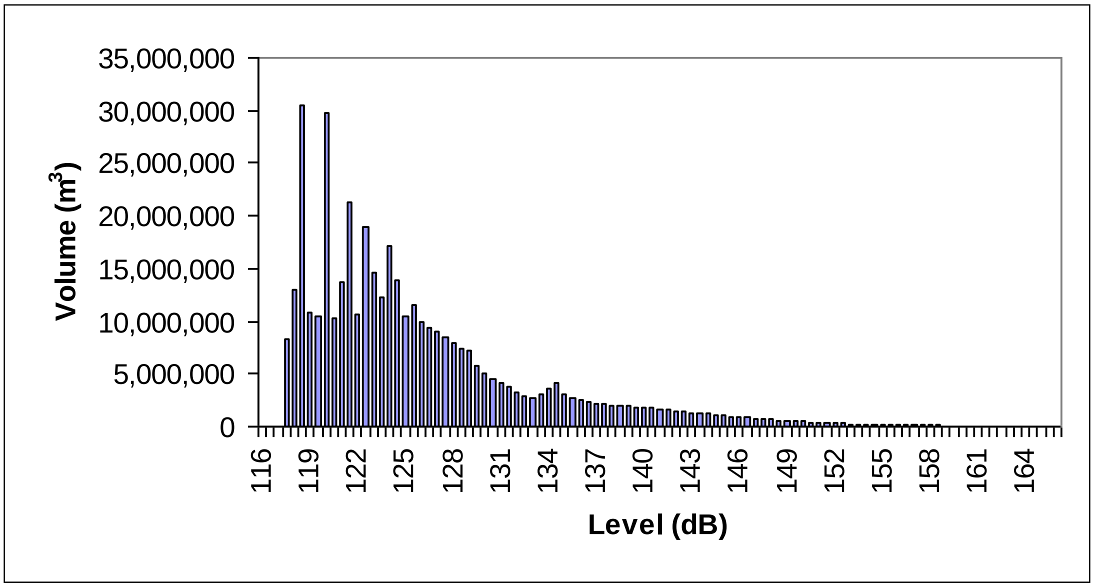


Figure A-5. Example of a Volume Histogram

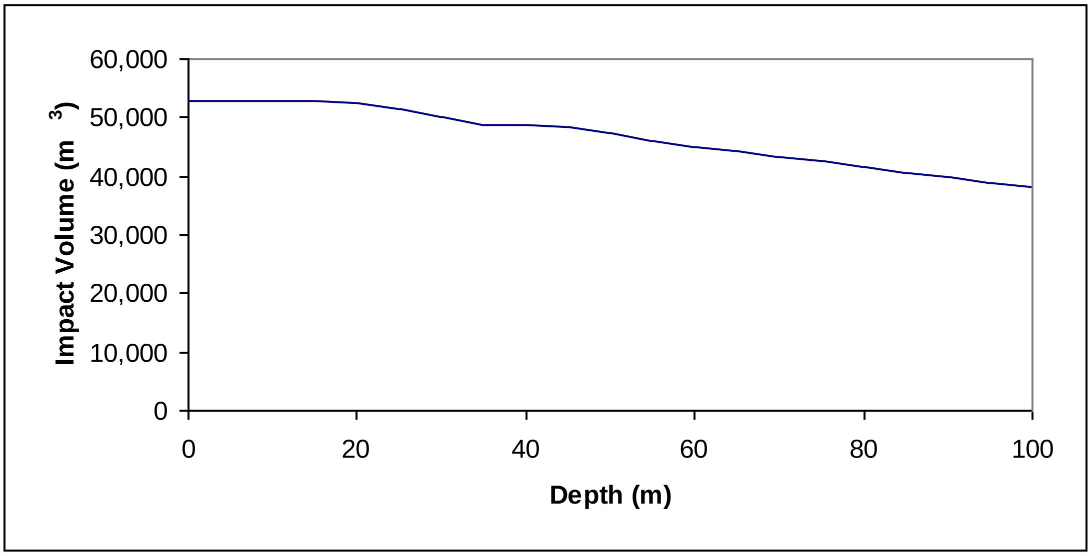


Figure A-6. Example of the Dependence of Impact Volume

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 100th 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-7, A-8, and A-9 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-7 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-8 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-9 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.

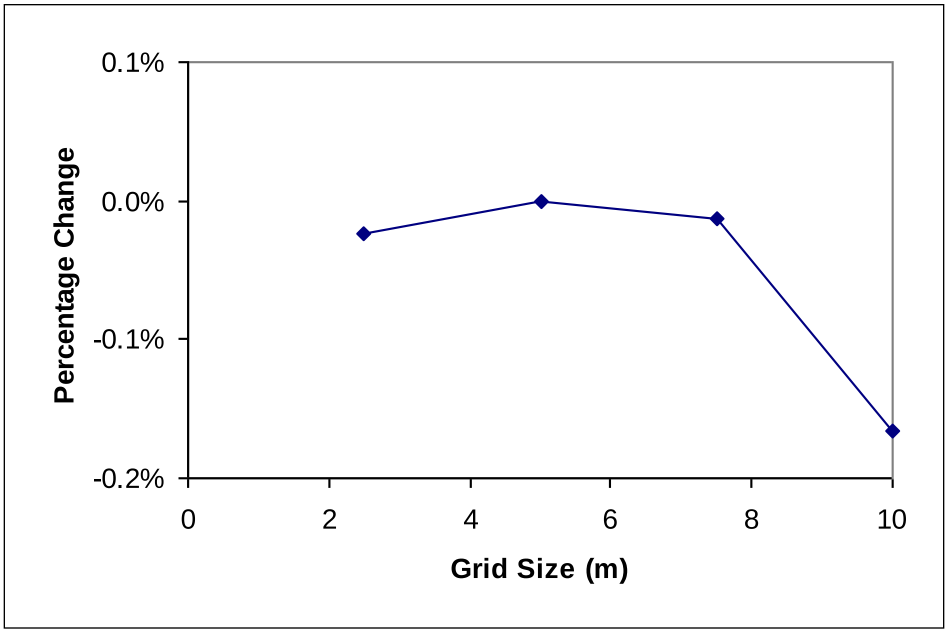


Figure A-7. Change of Impact Volume as a Function of *X* Axis Grid Size

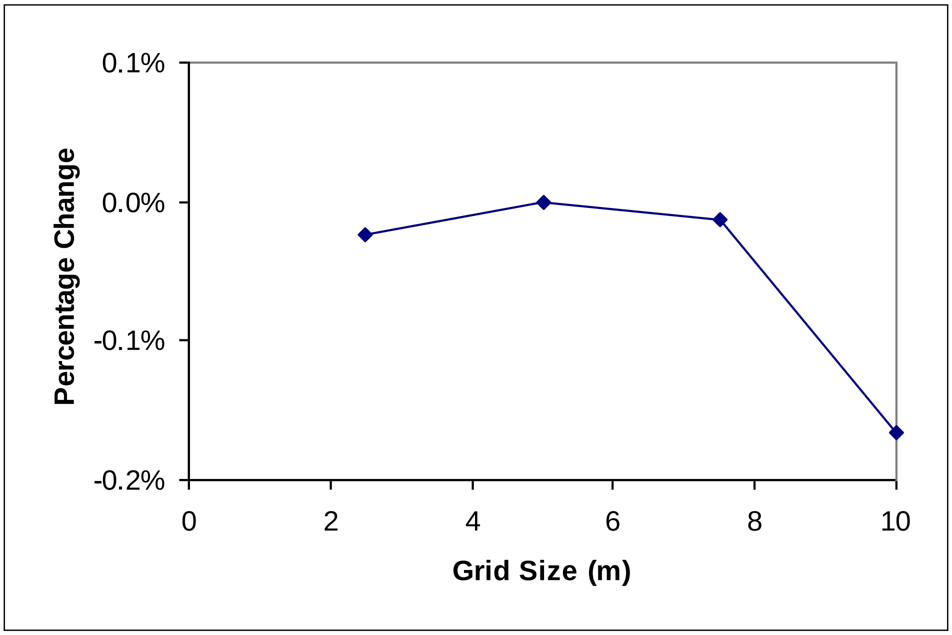


Figure A-8. Change of Impact Volume as a Function of *Y* Axis Grid Size

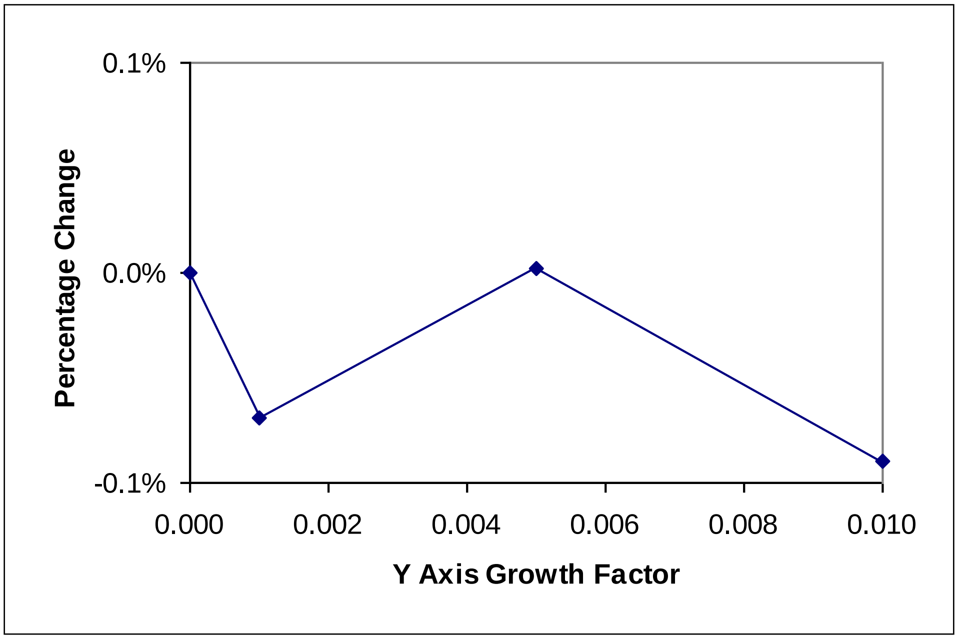


Figure A-9. Change of Impact Volume as a Function of *Y* Axis Growth Factor

Another factor influencing the accuracy of the calculation of impact volumes is the size of the bins used for sound pressure level. The sound pressure level bins extend from 100 dB (far lower than required) up to 300 dB (much higher than that expected for any sonar system). Figure A-10 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.

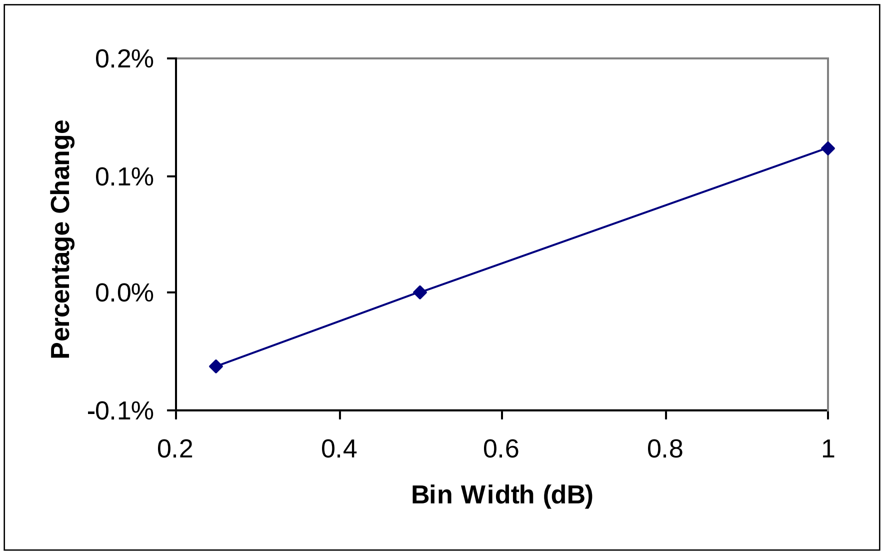


Figure A-10. Change of Impact Volume as a Function of Bin Width

Two other issues for discussion are the maximum range (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 ($10 \log_{10}(1{,}000)$). Reducing the source level by 30 dB, to get back to its original value, permits the handling of a sound pressure level threshold down to 143 dB, comparable to the minimum required. Hence, the TL calculated to support energy accumulation for 1,000 pings will also support calculation of impact volumes for the risk function metric.

The process of obtaining the maximum sound pressure level 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 sound pressure level at a grid point, the sound pressure level of the source is reduced by that TL. For the first ping, the volumetric grid is populated by the calculated sound pressure level 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 sound pressure level for each grid point is again calculated for the new source location. Since the risk function metric uses the maximum of the sound pressure levels at each grid point, the newly calculated sound pressure level at each grid point is compared to the sound pressure level 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 sound pressure level.

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-5. 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-6, 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-11 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-12 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 kilometer of track.

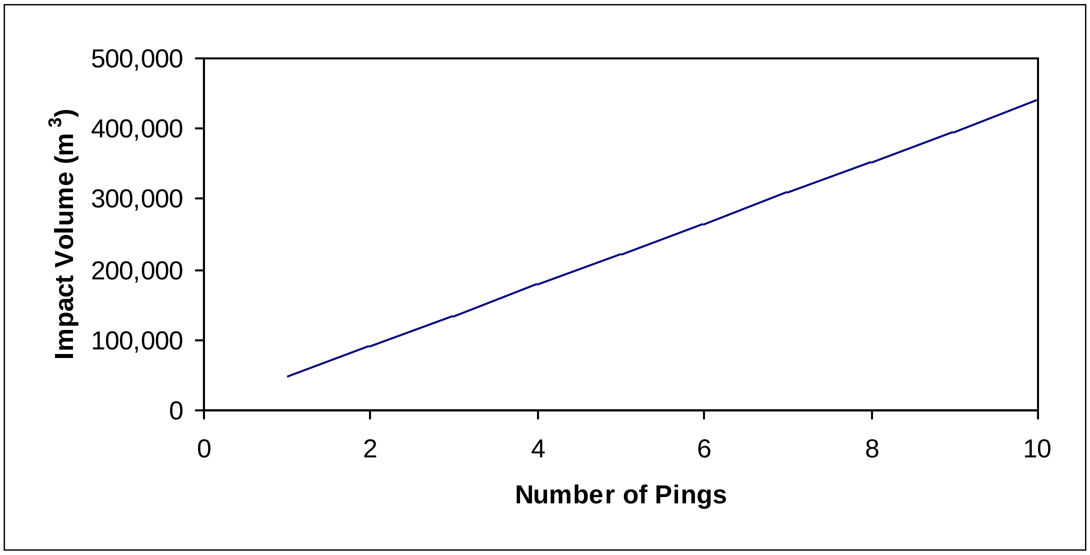


Figure A-11. Dependence of Impact Volume on the Number of Pings

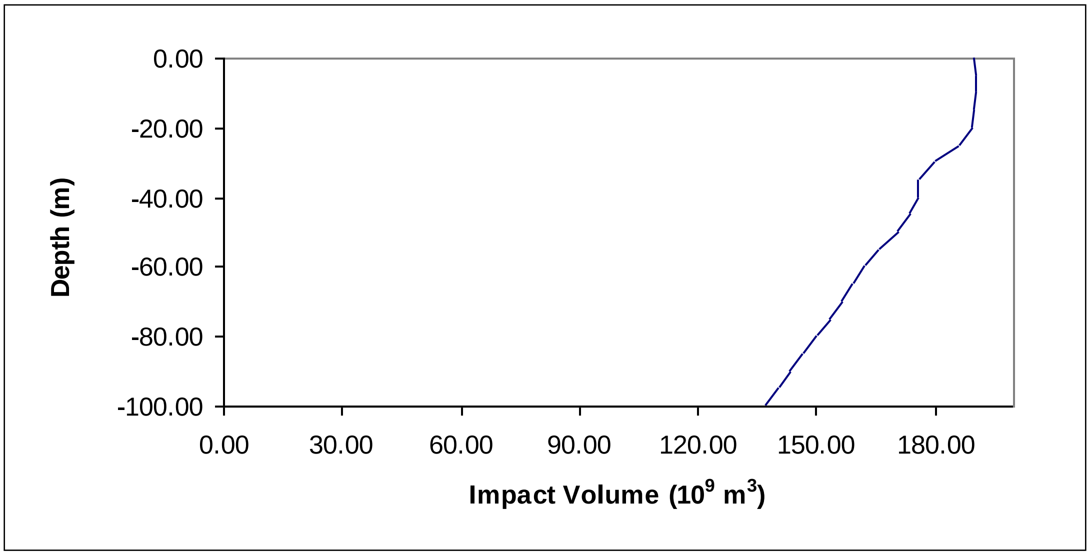


Figure A-12. Example of an Hourly Impact Volume Vector

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 hours. 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 closest point of approach (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-8 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-8. 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	Equal distribution

	exposures, land shadow	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 1000 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 closest point of approach (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% 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% 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% unharassed population
$P_0 =$local population

$$P_1 = P_0 - H$$

$$P_2 = P_1 - H\left(\frac{P_1}{P_0}\right)$$

…

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

Therefore,

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

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, 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 a sonar operating area 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.

NMFS has defined a 24 hour "refresh rate," or amount of time in which an individual can be harassed no more than once. Navy has determined that, in a 24 hour period, all sonar operations in the Q-20 Study Area transmit for a subset of that time (Table A-9).

Table A-9. Duration of Sonar Use During 24-hour Period

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

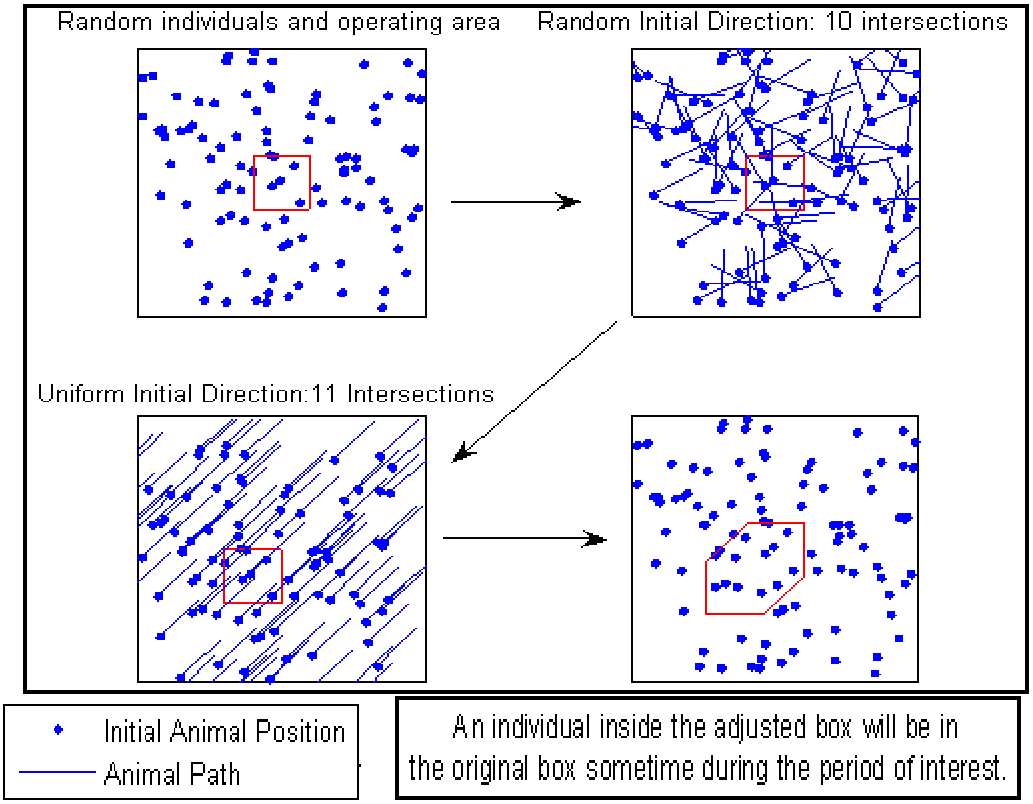
Creating the most conservative source position by assuming that a sonar transmits from each point in the SOA simultaneously can produce an upper bound on harassments for a single ping, but animal motion over the period in the above table can bring animals into range that otherwise would be out of the 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-13 illustrates an example that illustrates the overestimation, which occurs during the second arrow.



An individual inside the adjusted box will be in the original box sometime during the period of interest.

Figure A-13. Process of Overestimating Individuals Present in Area at Any Time.

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.

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

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

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 sonar operating area.

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

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

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

For the risk function and transmission loss 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-14 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.

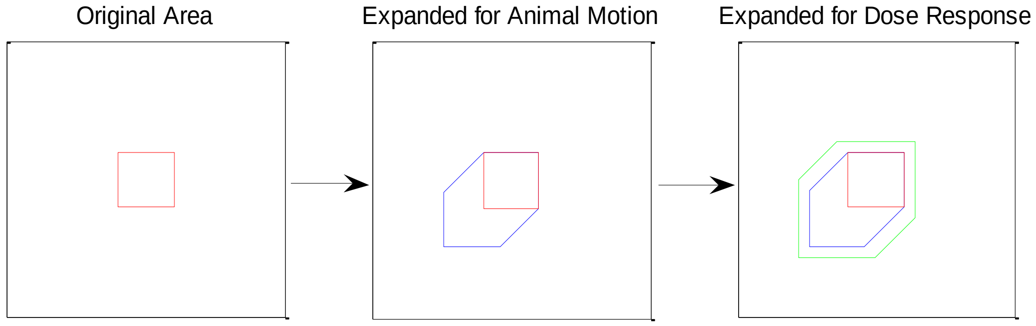


Figure A-14. Process of Expanding Area to Create Upper Bound of Harassments

Example Case

Consider a sample case for the Kingfisher sonar, the expected summer rate of harassment for pantropical spotted dolphins is 0.000097 harassments per ping, with 1200 pings per hour of operation.

Area 2 has an area of approximately 9033 square kilometers and a largest side of 300 km. Adjusting this with straight-line (upper bound) animal motion brings the total upper-bound of the affected area to 12,333 square km.

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 Kingfisher activity in Area 2 during a 24 hour period is 12,333*0.0399 = 480.1167 dolphins.

In the first ping, 0.000097 pantropical spotted dolphins will be harassed. Using the formula derive above, after one hour of continuous operation, the remaining **unharassed** population is

$$P_{1200} = P_0 \left(1 - \left(\frac{h}{P_0}\right)\right)^{1200} = 480.1167 \left(1 - \left(\frac{0.000097}{480.1167}\right)\right)^{1200} \approx 480.0003$$

So the **harassed** population will be 480.1167-480.003 = 0.1164 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 sound pressure level, or above. In the Q-20 Study Area, this occurs as far away as 65 km, 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 …,” 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 NSWC PCD Study Area, a much larger area than the Q-20 Study Area, the land shadow was calculated in reference DON 2009. 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 Gulf of Mexico (GOM) include baleen whales (mysticetes) and toothed whales (odontocetes). This section first addresses the densities used from the Navy Operating Area Density Estimates (NODE) reports and then details the depth distribution data incorporated to provide three dimensional aspect to the modeling of exposure estimates. All density information is taken directly from the GOMEX NODE report (DON, 2007).

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, and, for sperm and beaked whales, via acoustic tracking of sounds produced by the animal itself.

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-11 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

MYSTICETES

Blue whale, *Balaenoptera musculus* – Extralimital

There is no abundance or density estimate.

Fin whale, *Balaenoptera physalus* – Extralimital

There is no abundance or density estimate.

Sei whale, *Balaenoptera borealis* – Extralimital

There is no abundance or density estimate.

Bryde's whale, *Balaenoptera edeni*

Distribution and habitat preferences:

- In the GOMEX, 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 GOMEX.

Density and abundance estimates

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

Minke whale, *Balaenoptera acutorostrata* - Extralimital

There is no abundance or density estimate.

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

Sperm whale, *Physeter catodon*

- Sperm whales occur year-round in the GOMEX, aggregating along the continental slope and in canyon regions. GulfCet surveys found that most 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. Segregation between the sexes was noted during one year of survey by Jochens et al. (2006). Females and immatures showed high site fidelity to the region south of the Mississippi River Delta and Mississippi Canyon on the upper continental slope and in the western GOMEX. Males were found on the upper continental slope, but also move more often into the central GOMEX 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 GOMEX, 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.

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

- Globally, both species of *Kogia* generally occur in waters along the continental shelf break and over the continental slope.

- In the GOMEX, *Kogia* spp. are distributed mostly over the upper continental slope.

- Fulling and Fertl (2003) (as cited in DON, 2007a) reported that 67 percent of *Kogia* spp. sightings in the GOMEX 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 occur in continental shelf waters of the GOMEX, however, there were some sighting records in waters over the continental shelf.

- Fulling and Fertl (2003) (as cited in DON, 2007a) remarked on the noticeable concentration of sightings in continental slope waters near the Mississippi River Delta

Beaked whales

Three species of beaked whales may occur in the GOMEX, 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 GOMEX.

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 GOMEX. The Blainville's beaked whale is the most widely distributed of the Mesoplodon spp.; 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 GOMEX in waters off the continental shelf break. The northern GOMEX continental shelf margins recently were identified as known key areas for beaked whales. Habitat characterization modeling for the GOMEX 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 GOMEX, a few beaked whale sightings on the continental shelf are reported.

Killer whale distribution and habitat preferences:

- Globally, killer whales are found in the open sea, as well as in coastal areas.

- Killer whales are sighted year-round in the northern GOMEX. Sightings are generally clumped in a broad region south of the MS 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 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.

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 in the GOMEX 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 GOMEX are east of Mobile Bay.

Pygmy killer whale distribution and habitat preferences:

- This species does not appear to be common in the GOMEX.

- In the northern GOMEX, 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.

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 GOMEX are of the short-finned pilot whale.

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 *Globicephala spp*. coincide closely with the abundance of squid.

- Sightings in the GOMEX 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 U.S. In the GOMEX, 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 GOMEX. 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 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 this species. Most melon-headed whale sightings in the GOMEX 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.

Risso’s dolphin distribution and habitat preferences:

- A number of studies world-wide have noted that Risso’s dolphins 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 GOMEX. This correlation is most likely the result of cephalopod distribution in the same area.

Rough-toothed dolphin distribution and habitat preferences:

- In the GOMEX, 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 GOMEX, 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 [VHF]) 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.

Bottlenose dolphin

The category for bottlenose dolphins 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 GOMEX is similar to that for the species in the western North Atlantic (offshore from ≥34 km [18 NM] 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 GOMEX.
- 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 GOMEX: 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 GOMEX.
- Mullin and Fulling (2004) reported that groups of bottlenose dolphins were generally confined to the shelf break except in the northeastern GOMEX, where their distribution extended well seaward of the shelf break.

Atlantic spotted dolphin distribution and habitat preferences:

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

Pantropical spotted dolphin distribution and habitat preferences:

- Most sightings of this species in the GOMEX 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 GOMEX.

- Baumgartner et al. (2001) reported that pantropical spotted dolphins in the GOMEX 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.

Striped dolphin distribution and habitat preferences:

- 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.

- 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.

Clymene dolphin distribution and habitat preferences:

- There are more Clymene dolphin records from the GOMEX 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 GOMEX, yet there are documented sightings.

- In a study of habitat preferences in the GOMEX, 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.

Fraser's dolphin distribution and habitat preferences:

- Fraser's dolphins are not sighted regularly in the GOMEX.

- This species generally prefers oceanic waters. Sightings in the GOMEX have been seaward of the continental shelf break.

Fraser's dolphin 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.

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 20-65 m (66 – 213 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 – 500 m [328 – 1,640 ft]) of sperm whales in the Gulf of California overlapped with depth distributions (200 – 400 m [656 – 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-hour 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 – 1,500 m (3,280 – 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 34 percent. 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 – 200 m (0 – 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 – 400 m (659 – 1,312 ft), 401 – 600 m (1,316 – 1,969 ft) and 601 – 800 m (1,972 – 2,625 ft). Therefore, the depth distribution for sperm whales based on information in the Amano paper is: 31 percent in <10 m (33 ft), eight percent in 10 – 200 m (33 – 656 ft), nine percent in 201 – 400 m (659 – 1,312 ft), nine percent in 401 – 600 m (1,316 – 1,969 ft), nine percent in 601 – 800 m (1,972 – 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 Table 1 in Watwood et al. (2006) for sperm whales in the Ligurian Sea, Atlantic Ocean and Gulf of Mexico.

Pygmy and dwarf 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 (TDR) 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 sperm or Cuvier’s beaked whales. Blainville’s 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 – 71 m (7 – 233 ft), two percent at 72 – 200 m (236 – 656 ft), four percent at 201 – 400 m (659 – 1,312 ft), four percent at 401 – 600 m (1,316 – 1,969 ft), four percent at 601 – 835 m (1,972 – 2,740 ft) and 19 percent at >835 m (2,740 ft).

Unidentified beaked whales

Ziphiids feed primarily on mesopelagic squid and some fish, with most prey likely caught at >200 m (656 ft) (Pitman, 2002b). 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 whales (*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., 2006a). Depth distribution studies in Hawaii (Baird et al., 2005a; Baird et al., 2006a) 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 DTAGs 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., 2006a). 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 – 1,888 m [2,260 – 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 – 425 m [72 – 1,394 ft])
Mean number of shallow duration dives per cycle = 2 (range 0-7)
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-minute value was applied to each 200 m (656 ft) depth category from 400 – 1,070 m (1,312 – 3,510 ft); for the 2 – 220 m (7 – 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 – 220 m (7 – 722 ft), four percent at 221 – 400 m (725 – 1,312 ft), four percent at 401 – 600 m (1,316 – 1,969 ft), four percent at 601 – 800 m (1,972 – 2,625 ft), five percent at 801 – 1,070 m (2,628 – 3,510 ft) and 27 percent in >1,070 m (3,510 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 – 30 m (0 – 98 ft).

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).

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 – 30 m (0 – 98 ft).

Pilot whales including short-finned pilot whales

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 – 55 m (66 – 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 *G. melas* 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 >100m (328 ft) were far more frequent at night, likely to take advantage of vertically-migrating prey; night dives regularly went to 300 – 500 m (984 – 1,640 ft). Deepest dives were during the day, however, perhaps because prey was deeper. A diving study on G. melas 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-Jorgensen 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 – 17 m (39 – 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 – 17 m (23 – 56 ft) and four percent at 18 – 828 m (59 – 2,717 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 – 50 m (0 – 164 ft); Nighttime, 100 percent at 0 – 700 m (0 – 2,297 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 Gulf of Mexico demonstrated that Risso's 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 fed on the middle slope at depths ranging from 600 – 800 m (1,969 – 2.625 ft). Stomach content analysis from three animals elsewhere in the Mediterranean indicated that Risso's fed on species that showed greater vertical migrations than those ingested by striped dolphins (Ozturk 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 – 200 m (167 – 656 ft), 15 percent at 201 – 400 m (659 – 1,312 ft), ten percent at 401 – 600 m (1,317 – 1,969 ft) and ten percent at >600 m (1,969 ft).

Rough-toothed dolphin

Rough-toothed dolphins feed on fish and cephalopods, both oceanic and coastal species (Jefferson, 2002b). 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, 2002b). 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 – 70 m (0 – 230 ft).

Bottlenose dolphin

Bottlenose dolphins feed on a large variety of fish and squid (Wells and Scott, 2002), 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 – 13 m [23 – 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, 2002). Corkeron and Martin (2004) reported on two dolphins that spent 66 percent of time in top 5 m (16 ft) of water surface; 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 – 50 m (0 – 164 ft), four percent at >50 m (164 ft); Nighttime: 51 percent at <50 m (164 ft), eight percent at 50 – 100 m (164 – 328 ft), 19 percent at 101 – 250 m (331 – 820 ft), 13 percent at 251 – 450 m (823 – 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.

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, 2002e; 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 Gulf of Mexico. Most dives were shallow regardless of the time of day, with the deepest dives to 40 – 60 m (131 – 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 – 20 m (33 – 66 ft) and four percent at 21 – 60 m (69 – 197 ft).

Pantropical spotted dolphin

Pantropical spotted dolphins feed on small epipelagic fish, squids and crustaceans, and may vary their preferred prey seasonally (Perrin, 2002a; Wang et al., 2003). Stomach contents of dolphins collected near Taiwan indicated that the distribution of primary prey was 0 – 200 m (0 – 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 – 10 m (0 – 33 ft), most of the rest of the time was 10 – 50 m (33 – 164 ft), and the deepest dive was to 122 m (400 ft). At night, only 59 percent of time was spent from 0 – 10 m (0 – 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 – 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).

Striped dolphin

Striped dolphins feed on pelagic fish and squid and may dive during feeding to depths exceeding 200 m (656 ft) (Archer, 2002). 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).

Spinner dolphin

Spinner dolphins feed on small mesopelagic fish, and likely feed at night (Perrin, 2002d; 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 – 400 m [0 – 1,312 ft]) waters. Prey distribution during the day is estimated at 400 – 700 m (1,312 – 2,297 ft). Based on these data, the following are very rough order estimates of time at depth: Daytime: 100 percent at 0 – 50 m (0 – 164 ft); Nighttime: 100 percent at 0 – 400 m (0 – 1,312 ft).

Clymene dolphin

There is little information on the feeding habits of Clymene dolphins, and no diving studies have been carried out. They apparently feed on mesopelagic fish and squids that are vertical migrators, which indicate feeding at night. In lieu of the lack of information specific to this species, the depth distributions for spinner dolphins will be adopted for clymene: Daytime: 100 percent at 0 – 50 m (0 – 164 ft); Nighttime: 100 percent at 0 – 400 m (0 – 1,312 ft) (Benoit Bird and Au, 2003)

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 – 50 m (0 – 164 ft); Nighttime, 100 percent at 0 – 700 m (0 – 2,297 ft).

Table A-11. 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			
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)
Sei whale	*B. borealis*	53% at <20 m (66 ft); 47% at 21 – 65 m (69 – 213 ft)	Extrapolated from minke whale
Bryde's whale	*B. edeni*	53% at <20 m (66 ft); 47% at 21 – 65 m (69 – 213 ft)	Extrapolated from minke whale
Minke whale	*B. acutorostrata*	53% at <20 m (66 ft); 47% at 21 – 65 m (69 – 213 ft)	Blix and Folkow (1995)
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)
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)
ODONTOCETES - Toothed whales			
Sperm whale	*Physeter catodon*	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)
Pygmy and dwarf sperm whales	*Kogia breviceps and K. sima*	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
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

Table A-11. Summary of Depth Information for Marine Mammal Species with Densities in the NSWC PCD Study Area Cont'd

Common Name	Scientific Name	Depth Distribution	Reference
Killer whale	*Orcinus orca*	96% at 0 – 30 m (0 – 98 ft); 4% at >30 m (98 ft)	Baird et al (2003a)
False killer whale	*Pseudorca crassidens*	96% at 0 – 30 m (0 – 98 ft); 4% at >30 m (98 ft)	Extrapolated from killer whales
Pygmy killer whale	*Feresa attenuata*	96% at 0 – 30 m (0 – 98 ft); 4% at >30 m (98 ft)	Extrapolated from killer whales
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-Jorgensen et al (2002)
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 Frasier's dolphin
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)	Ozturk et al (2007)
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)
Rough-toothed dolphin	*Steno bredanensis*	100% at 0 – 70 m (0 – 230 ft)	Jefferson (2002b)
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)
Atlantic spotted dolphin	*S. 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)
Striped dolphin	*S. 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

Table A-11. Summary of Depth Information for Marine Mammal Species with Densities in the NSWC PCD Study Area Cont'd

Common Name	Scientific Name	Depth Distribution	Reference
Spinner dolphin	*S. 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)
Clymene dolphin	*S. clymene*	Daytime: 100% at 0 – 50 m (0 – 164 ft); nighttime: 100% at 0 – 400 m (0 – 1,312 ft)	extrapolated from spinner dolphin
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)

A.6 REFERENCES

Amano, M and M. Yoshioka 2003. Sperm whale diving behavior monitored using a suction-cup-attached TDR tag. *Marine Ecology Progress Series* 258: 291-295.

Archer II, F. I., 2002. Striped dolphin. Pp. 1201-1203 In: WF Perrin, B Wursig and JGM Thewissen (eds) *Encyclopedia of Marine Mammals*. Academic Press: San Diego. 1414 pp.

Baird, R. W., 2002a. False killer whale. Pp 411-412 In: WF Perrin, B Wursig and JGM Thewissen (eds) *Encyclopedia of Marine Mammals*. Academic Press: San Diego. 1414 pp.

Baird, R. W., 2002b. Risso's dolphin. Pp. 1037-1039 In: WF Perrin, B Wursig and JGM Thewissen (eds) *Encyclopedia of Marine Mammals*. Academic Press: San Diego. 1414 pp.

Baird, R. W., D. L. Webster, D. J. McSweeney, A. D. Ligon, G. S. Schorr, and J. Barlow, 2006a. Diving behaviour of Cuvier's (*Ziphius cavirostris*) and Blainville's (*Mesoplodon densirostris*) beaked whales in Hawaii. *Canadian Journal of Zoology* 84: 1120-1128.

Baird, R. W., D. L. Webster, D. J. McSweeney, A. D. Ligon, and G. S. Schorr, 2005a. Diving Behavior and ecology of Cuvier's (*Ziphius cavirostris*) and Blainville's beaked whales (*Mesoplodon densirostris*) in Hawaii. Report prepared by Cascadia Research Collective for the Southwest Fisheries Science Center. Available from www.cascadiaresearch.org.

Baird, R. W., M. B. Hanson and L. M. Dill, 2005b. Factors influencing the diving behaviour of fish-eating killer whale: Sex differences and diel and interannual variation in diving rates. *Canadian Journal of Zoology* 83(2):257-267.

Baird, R. W., M. B. Hanson, E. E. Ashe, M. R. Heithaus and G. J. Marshall, 2003a. Studies of foraging in "southern resident" killer whales during July 2002: dive depths, bursts in speed, and the use of a "crittercam" system for examining sub-surface behavior. Report prepared under Order number AB133F-02-SE-1744 for NMFS-NMML. Available from www.cascadiaresearch.org.

Baird, R. W., A. D. Ligon, S. K. Hooker and A. M. Gorgone, 2001. Subsurface and nighttime behavior of pantropical spotted dolphins in Hawaii. *Canadian Journal of Zoology* 79: 988-996.

Baird, R. W., D. J. McSweeney, M. R. Heithaus, and G. J. Marshall, 2003b. Short-finned pilot whale diving behavior: Deep feeders and day-time socialites, in *Abstracts, Fifteenth Biennial Conference on the Biology of Marine Mammals*, p 10. 14–19 December 2003. Greensboro, North Carolina.

Bannister, J. L., 2002. Baleen whales. Pp. 62-72 In: WF Perrin, B Wursig and JGM Thewissen (eds) *Encyclopedia of Marine Mammals*. Academic Press: San Diego. 1414 pp.

Baumgartner, M. F., 1997. The distribution of Risso's dolphin (*Grampus griseus*) with respect to the physiography of the northern Gulf of Mexico. *Marine Mammal Science* 13(3): 614-638.

Baumgartner, M. F, KD Mullin, LN May and TD Leming, 2001. Cetacean habitats in the northern Gulf of Mexico. *Fishery Bulletin* 99: 219-239

Baumgartner, M. F., and B. R. Mate, 2003. Summertime foraging ecology of North Atlantic right whales. *Marine Ecology Progress Series*, Vol 264, pp 123–135.

Beatson, E., 2007. The diet of pygmy sperm whales, *Kogia breviceps*, stranded in New Zealand: implications for conservation. *Rev Fish Biol Fisheries* 17:295–303.

Benoit-Bird, K. J and W. W. L. Au, 2003. Prey dynamics affect foraging by a pelagic predator (*Stenella longirotris*) over a range of spatial and temporal scales. *Behavioral Ecology and Sociobiology* 53: 364-373.

Best, P. B., 1977. Two allopatric forms of Bryde's whale off South Africa. *Rep. Int. Whal. Commn* (Spec Iss 1): 10-38.

Blanco C. and J. A. Raga, 2000. Cephalopod prey of two *Ziphius cavirostris* (Cetacea) stranded on the western Mediterranean coast. *Journal of the Marine Biological Association of the United Kingdom* 80 (2): 381-382

Blanco, C, M. A. Raduan and J. A. Raga, 2006. Diet of Risso's dolphin (*Grampus griseus*) in the western Mediterranean Sea. *Scientia Marina* 70(3): 407-411.

Blanco, C., J. Aznar and J. A. Raga, 1995. Cephalopods in the diet of the striped dolphin *Stenella coeruleoalba* from the western Mediterranean during an epizootic in 1990. *Journal of Zoology* 237 (1): 151-158.

Blix, A. S. and L. P. Folkow, 1995. Daily energy expenditure in free living minke whales. *Acta Physiologica Scandinavica* 153(1): 61-6.

Corkeron P. J. and A. R. Martin, 2004. Ranging and diving behaviour of two 'offshore' bottlenose dolphins, *Tursiops* sp., off eastern Australia. *Journal of the Marine Biological Association of the United Kingdom* 84:465-468

Davis, R. W., N. Jaquet, D. Gendron, U. Markaida, G. Bazzino and W. Gilly, 2007. Diving behavior of sperm whales in relation to behavior of a major prey species, the jumbo squid, in the Gulf of California, Mexico. *Marine Progress Series* 333: 291-302.

Davis, R. W., G. A. J. Worthy, B. Wursig and S. K. Lynn, 1996. Diving behavior and at-sea movements of an Atlantic spotted dolphin the Gulf of Mexico. *Marine Mammal Science* 12(4): 569-581.

Davis, R. W., J. G. Ortega-Ortiz, C. A. Ribic, W. E. Evans, D. C. Biggs, P. H. Ressler, R. B. Cady, R. R. Leben, K. D. Mullin, and B. Würsig, 2002. Cetacean habitat in the northern oceanic Gulf of Mexico. *Deep-Sea Research I*, Vol 49, pp 121–142.

Davis, R. W., W. E. Evans, and B. Würsig, eds., 2000. Cetaceans, sea turtles and seabirds in the northern Gulf of Mexico: Distribution, abundance and habitat associations. Volume 2: Technical report. USGS/BRD/CR-1999-0015 and OCS Study MMS 2000-003. New Orleans: Minerals Management Service.

Department of the Navy (DON), 2007. *Navy OPAREA Density Estimate (NODE) for the GOMEX OPAREA. Prepared for the Department of the Navy, U.S. Fleet Forces Command, Norfolk, Virginia*. Contract #N62470-02-D-9997, CTO 0030. Prepared by Geo-Marine, Inc., Hampton, Virginia, Dolar, M. L. L., 2002. Fraser's dolphin. Pp. 485-487 In: WF Perrin, B Wursig and JGM Thewissen (eds) *Encyclopedia of Marine Mammals*. Academic Press: San Diego. 1414 pp.

Department of the Navy (DON), 2007a. Marine resource assessment for the Gulf of Mexico. Department of the Navy, US Fleet Forces Command, Norfolk, VA. Contract #N62470-02-D-9997, CTO 0030. Prepared by Geo-Marine, Inc., Hampton, VA. Available from https://portal.navfac.navy.mil/portal/page?_pageid=181,3986942&_dad=portal&_schema=PORTAL.

Department of the Navy (DON), 2009. *Final Environmental Impact Statement/Overseas Environmental Impact Statement NSWC PCD Mission Activities*. Naval Surface Warfare Center Panama City Division, Panama City, FL. September 2009.

Dietz, R., J. Teilmann, M.-P. H. Jørgensen, and M.V. Jensen, 2002. Satellite tracking of humpback whales in West Greenland. Roskilde, Denmark: National Environmental Research Institute Technical Report 411.

Dolar, M. L. L., W.A. Walker, G.L. Kooyman and W.F. Perrin, 2003. Comparative feeding ecology of spinner dolphins (*Stenella longirostris*) and Fraser's dolphins (*Lagenodelphis hosei*) in the Sulu Sea. *Marine Mammal Science* 19(1): 1-19.

Donahue, M. A. and W. A. Perryman, 2002. Pygmy killer whale. Pp. 1009-1010 In: WF Perrin, B Wursig and JGM Thewissen (eds) *Encyclopedia of Marine Mammals*. Academic Press: San Diego. 1414 pp.

Estes, J. A., M. T. Tinker, T. M. Williams and D. F. Doak, 1998. Killer whale predation on sea otters linking oceanic and nearshore ecosystems. *Science* 282: 473-476.

Fertl, D., T. A. Jefferson, I. B. Moreno, A. N. Zerbini and K. D. Mullin, 2003. Distribution of the Clymene dolphin *Stenella clymene*. *Mammal Review* 33(3): 253-271.

Ford, J. K. B., 2002. Killer whale. Pp. 669-676 In: WF Perrin, B Wursig and JGM Thewissen (eds) *Encyclopedia of Marine Mammals*. Academic Press: San Diego. 1414 pp.

Gales, R., D. Pemberton, M. Clarke and C. C. Lu, 1992. Stomach contents of long-finned pilot whales (*Globicephala melaena*) and bottlenose dolphins (*Tursiops truncatus*) in Tasmania. *Marine Mammal Science* 8 (4): 405–413.

Gannon, D. P., A. J. Read, J. E. Craddock, K. M. Fristrup, and J. R. Nicolas, 1997. Feeding ecology of long-finned pilot whales *Globicephala melas* in the western North Atlantic. Mar. Ecol. Prog. Ser. 148:1−10.

Garrison, L., 2007. Personal communication, 9/11/07. National Marine Fisheries Center, Southwest Fisheries Science Center.

Goldbogen, J. A., J. Calambokidis, R. E. Shadwick, E. M. Oleson, M. A. McDonald, and J. A. Hildebrand, 2006. Kinematics of foraging dives and lunge-feeding in fin whales. *Journal of Experimental Biology* 209:1231-1244.

Griffin, R. B., and N. J. Griffin, 2003. Distribution, habitat partitioning, and abundance of Atlantic spotted dolphins, bottlenose dolphins, and loggerhead sea turtles on the eastern Gulf of Mexico continental shelf. *Gulf of Mexico Science*, Vol 2003, No 1, pp 23–34.

Heide-Jorgensen, M.P., Bloch, D., Stefansson, E., Mikkelsen, B., Ofstad, L.H., and Dietz, R. 2002. Diving behaviour of longfinned pilot whales Globicephala melas around the Faroe Islands. Wildl. Biol. 8: 275–281.

Heyning, J. E., 2002. Cuvier's beaked whale. Pp 305-307 In: WF Perrin, B Wursig and JGM Thewissen (eds) *Encyclopedia of Marine Mammals*. Academic Press: San Diego. 1414 pp.

Jefferson, T. A., 2002b. Rough-toothed dolphin. Pp. 1055-1059 In: WF Perrin, B Wursig and JGM Thewissen (eds) *Encyclopedia of Marine Mammals*. Academic Press: San Diego. 1414 pp.

Jefferson, T. A. and A. J. Schiro, 1997. Distribution of cetaceans in the offshore Gulf of Mexico. *Mammal. Review* 27(1): 27-50.

Jefferson and Barros, 1997. Jefferson, T. A. & N. B. Barros. 1997. Peponocephala electra. Mammal. Spec. 553: 1–6.

Jochens, A. E. and D. C. Biggs, eds., 2006. Sperm whale seismic study in the Gulf of Mexico; Annual Report: Years 3 and 4. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2006-067. 111 pp. Available from http://www.gomr.mms.gov.

Johnson, M., P. T. Madsen, W. M. X. Zimmer, N. Aguilar de Soto, and P. L. Tyack, 2004. Beaked whales echolocate on prey. *Proceedings of the Royal Society, London B* (Suppl.) 271: S383-S386.

Kato, H., 2002. Bryde's whales. Pp 171-177 In: WF Perrin, B Wursig and JGM Thewissen (eds) *Encyclopedia of Marine Mammals*. Academic Press: San Diego. 1414 pp.

Kawamura, A., 1980. Food habits of the Bryde's whales taken in the South Pacific and Indian Oceans. *Sci. Rep. Whales Res. Inst*. 32: 1-23.

Klatsky, L. J., R. S. Wells and J. C. Sweeney, 2007. Offshore bottlenose dolphins (*Tursiops truncatus*): Movement and dive behavior near the Bermuda Pedestal. *Journal of Mammalogy* 88(1):59-66.

Koen Alonso, M., S. N. Pedraza, A. C. M. Schiavini, R. N. P. Goodall and E. A. Crespo, 1999. Stomach contents of false killer whales (*Pseudorca crassidens*) stranded on the coasts of the Strait of Magellan, Tierra del Fuego. *Marine Mammal Science* 15(3): 712-724.

Ligon, A. D. and R. W. Baird, 2001. Diving behavior of false killer whales off Maui and Lana'i, Hawaii. Abstract presented at 14th Biennial Conference on the Biology of Marine Mammals, Vancouver, Canada, December, 2001. Available from www.cascadiaresearch.org.

London, J. M., 2006. Harbor seals in Hood Canal: Predators and Prey. PhD Dissertation, University of Washington.

McAlpine, D. F., L. D. Murison and E. P. Hoberg, 1997. New records for the pygmy sperm whale, *Kogia breviceps* (Physeteridae) from Atlantic Canada with notes on diet and parasites. *Marine Mammal Science* 13(4): 701-704.

Miyazaki N. and W. F. Perrin, 1994. Rough-toothed dolphin *Steno bredanensis* (Lesson, 1828). Pp 1-22 In: SH Ridgway and SR Harrison (eds.), *Handbook of Marine Mammals* Vol. 5: The first book of dolphins. Academic Press, London.

Mullin, K. D. and G. L. Fulling, 2003. Abundance of cetaceans in the southern U.S. North Atlantic Ocean during summer 1998. *Fishery Bulletin*, Vol 101, pp 603–613.

Mullin, K. D. and G. L. Fulling, 2004. Abundance of cetaceans in the oceanic northern Gulf of Mexico, 1996-2001. *Marine Mammal Science* 20(4): 787-807.

Mullin, K. D., W. Hoggard and L. J. Hansen, 2004. Abundance and seasonal occurrence of cetaceans in Outer Continental Shelf and Slope waters of the north-central and northwestern Gulf of Mexico. *Gulf of Mexico Science* 22(1): 62-73.

Nawojchik, R., D. J. St. Aubin, and A. Johnson, 2003. Movements and dive behavior of two stranded, rehabilitated long-finned pilot whales (*Globicephala melas*) in the northwest Atlantic. *Marine Mammal Science*, Vol 19, pp 232–239.

Ozturk, B., A. Salman, A. A. Ozturk and A. Tonay, 2007. Cephalopod remains in the diet of striped dolphins (*Stenella coeruleoalba*) and Risso's dolphins (*Grampus griseus*) in the eastern Mediterranean Sea. *Vie et Milieu - Life and Environment* 57(1/2): 53-59

Pauly D, Trites AW, Capuli E, Christensen V. 1998. Diet composition and trophic levels of marine mammals. Mar Mamm Sci 55:467–481.

Perrin, W. F., 2002a. Pantropical spotted dolphin. Pp. 865-867 In: W. F. Perrin, B. Wursig and J. G. M. Thewissen (eds) *Encyclopedia of Marine Mammals*. Academic Press: San Diego. 1414 pp.

Perrin, W. F., 2002d. Spinner dolphin. Pp. 1174-1178 In: W. F. Perrin, B. Wursig and J. G. M. Thewissen (eds) *Encyclopedia of Marine Mammals*. Academic Press: San Diego. 1414 pp.

Perrin, W. F., 2002e. Atlantic spotted dolphin. Pp. 49-51 In: W. F. Perrin, B. Wursig and J. G. M. Thewissen (eds) *Encyclopedia of Marine Mammals*. Academic Press: San Diego. 1414 pp.

Pitman, R. L., 2002b. Mesoplodont whales. Pp. 738-742 In: WF Perrin, B Wursig and JGM Thewissen (eds) *Encyclopedia of Marine Mammals*. Academic Press: San Diego. 1414 pp.

Richard, K. R. and M. A. Barbeau, 1994. Observations of spotted dolphins feeding nocturnally on flying fish. *Marine Mammal Science* 10(4): 473-477.

Rossbach, K. and D. Herzing, 1997. Underwater observations of benthic-feeding bottlenose dolphins (*Tursiops truncatus*) near Grand Bahama Island, Bahamas. *Marine Mammal Science* 13(3): 498-504.

Santos, R. A. and M. Haimovici, 2001. Cephalopods in the diet of marine mammals stranded or incidentally caught along southeastern and southern Brazil (21-34S). *Fisheries Research* 52(1-2): 99-112.

Santos, M. B., G. J. Pierce, J. Herman, A. Lopez, A. Guerra, E. Mente and M. R. Clarke, 2001. Feeding ecology of Cuvier's beaked whale (*Ziphius cavirostris*): a review with new information on the diet of this species. *Journal of the Marine Biological Association of the United Kingdom* 81: 687-694.

Scott M. D., A. A. Hohn, A. J. Westgate, J. R. Nicolas, B. R. Whitaker and W. B. Campbell, 2001. A note on the release and tracking of a rehabilitated pygmy sperm whale (*Kogia breviceps*). *Journal of Cetacean Research and Management* 3:87-94.

Sinclair, E. H. (1992) Stomach contents of four shortfinned pilot whales (*Globicephala macrorhynchus*) from the Southern California Bight. Mar. Mamm. Sci. 8, 76–81.

Soto, N. A., M. Johnson, P. T. Madsen, P. L. Tyack, A. Bocconcelli and J. F. Borsani, 2006. Does intense ship noise disrupt foraging in deep-diving Cuvier's beaked whales (*Ziphius cavirostris*)? *Marine Mammal Science* 22(3): 690-699.

Tyack, P. L., M. Johnson, N. Aguilar Soto, A. Sturlese and P.T. Madsen, 2006. Extreme diving of beaked whales. *Journal of Experimental Biology* 209(21):4238-4253.

Wang, M. C., W. A. Walker, K. T. Shao and L. S. Chou, 2003. Feeding habits of the pantropical spotted dolphin, *Stenella attenuata*, off the eastern coast of Taiwan. *Zoological Studies* 42(2): 368-378.

Waring, G. T., E. Josephson, C. P. Fairfield and K. Maze-Foley, 2007. *US Atlantic and Gulf of Mexico Marine Mammal Stock Assessments - 2006*. NOAA Tech Memo NMFS-NE-201. Available from http://www.nmfs.noaa.gov/pr/sars/.

Watkins, W. A., M. A. Daher, K. Fristrup and G. Notarbartolo di Sciara. 1994. Fishing and acoustic behavior of Fraser's dolphin (*Lagenodelphins hosei*) near Dominica, southeast Caribbean. *Caribbean Journal of Science* 30 (1-2): 76-82.

Watwood, S. L., P. J. O. Miller, M. Johnson, P. T. Madsen and P. L. Tyack. 2006. Deep-diving foraging behaviour of sperm whales (*Physeter macrocephalus*). *Journal of Ecology* 75: 814-825.

Wells, R. S. and M. D. Scott. 2002. Bottlenose dolphins. Pp 122-128 In: WF Perrin, B Wursig and JGM Thewissen (eds) *Encyclopedia of Marine Mammals*. Academic Press: San Diego. 1414 pp.

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APPENDIX B

GEOGRAPHIC DESCRIPTION OF ENVIRONMENTAL PROVINCES

1

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 (ASW), the 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 Navy modeling efforts.

- Water depth – Digital Bathymetry Data Base Variable Resolution (DBDBV)
- Sound speed – Generalized Digital Environmental Model (GDEM)
- Bottom loss – Low-Frequency Bottom Loss (LFBL), Sediment Thickness Database, and High-Frequency Bottom Loss (HFBL), and
- Wind speed – United States (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 Naval Surface Warfare Center, Panama City Division (NSWC PCD) 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 Naval 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 operating area 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 Navy-standard high-frequency bottom loss database in its native form is globally partitioned into nine classes. (Low-frequency bottom loss is likewise provinced in its native form, although it is not considered in this selection of environmental provinces. The sources for which low-frequency bottom loss would be of interest have limited impact ranges thus rendering bottom loss of little consequence in this analysis.) The Navy-standard sound velocity profiles database is also available as a provinced subset. Only the 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) or 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 problems 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 (16 miles per hour [mi/hr]) and the average summer wind speed is 9 knots (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 a kilometer (0.6 miles). Nearly three-fourths of the Q-20 Study Area is located on the continental shelf in waters less than 200 m (656 ft). The distribution of the bathymetry provinces over the entire Q-20 Study Area is provided in Table B-1.

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

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 about 25 meters per second (m/sec) (56 mi/hr) slower than the summer profile, as depicted in Figure B-1, and features a 50 m (164 ft) surface duct.

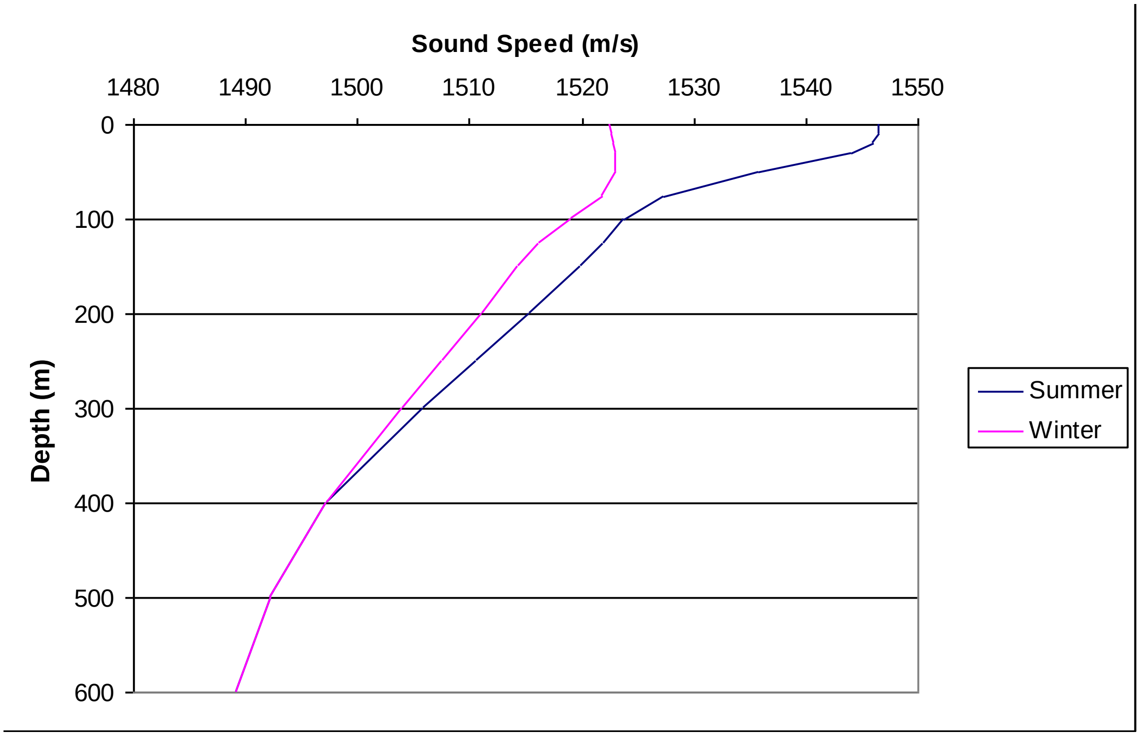

Figure B-1. Winter and Summer SVPs in the Q-20 Study Area

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 Low-Frequency Bottom Loss 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	Frequency of Occurrence
1	20 (66)	2	0	0.2 secs	12.48 %
2	40 (131)	2	0	0.2 secs	14.44 %
3	80 (262)	2	– 49*	0.57 secs	0.46 %
4	320 (1050)	2	0	0.95 secs	4.54 %
5	640 (2100)	2	– 49*	0.2 secs	4.37 %
6	40 (131)	2	– 49*	0.2 secs	2.36 %
7	80 (262)	2	13	0.2 secs	12.13 %
8	160 (525)	2	13	0.2 secs	14.20 %
9	320 (1050)	2	13	0.2 secs	0.01 %
10	40 (131)	8	– 49*	0.2 secs	0.08 %
11	80 (262)	8	0	0.2 secs	1.62 %
12	160 (525)	8	0	0.2 secs	9.43 %
13	320 (1050)	8	0	0.2 secs	17.83 %
14	640 (2100)	8	0	0.2 secs	0.01 %

* 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 between 50-800 m (164–2,625 ft) in the Gulf of Mexico (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. 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:

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-5.

The percentages given in the preceding table indicate the frequency of occurrence of each environmental province across all three Warning Areas in the Q-20 Study Area.

Table B-5. Distribution of Environmental Provinces in the Q-20 Study Area

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

* 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 between 50-800 m in the GOM, but do not necessarily cover all such areas

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APPENDIX C

DEFINITIONS AND METRICS FOR ACOUSTIC QUANTITIES

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 1026 kilogram per cubic meter (kg/m^3) (2,262 lbs per 35.3 cubic feet), or 1.026 gram per cubic centimeter (g/cm^3) (.036 ounces per .061 cubic inch). 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 .061 cubic inch) or 0.00121 g/cm^3 (4.27e-5 ounce per .061 cubic inch).

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 (MHDPM, 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 [lbs/ft^2], 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:

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

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) and others, 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 (EFD)

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 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

S*ource intensity,* I(θ,ϕ), 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, p. 29, 1975).

"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, p. 394, 1986).

Temporary (Hearing) Threshold Shift (TTS)

"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, p. 35, 1975).

Permanent (Hearing) Threshold Shift (PTS)

"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, and noise-induced permanent threshold shift (NIPTS) if it does not" (Magrab, p. 35, 1975).

C.3 DECIBELS AND SOUND LEVELS

Decibel (dB)

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 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 decibels, 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 µPa, is written 120 dB re 1 µPa.

The word "level" usually indicates decibel 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 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 $SL(\theta,\phi) = 10 \log[I(\theta,\phi)/I_0]$, 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:

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 (EFDL) Referred to Pressure^2 Time

Note that the abbreviation “EFDL” 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 EFDL 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 EFDL 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 meters per second (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} μPa (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

Length
1 NM = 1.85325 km
1 m = 3.2808 ft

Speed
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

Pressure
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 = $1.4504 \cdot 10^{-10}$ psi
1 kPa = 1000 Pa = 10^9 μPa = 0.145 psi = 20.88 psf

Power
1 W = 1 J/s = 1 Nm/s = 1 kg m^2/s^2
1 W = 10^7 erg/s

Energy (Work)

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

Acoustic Intensity

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^2s = 14.596 W/m^2
1 W/m^2 = 10^7 erg/m^2s = 10^3 erg/cm^2s

Acoustic Energy Flux Density

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

C.5 REFERENCES

Au, W. W. L., 1993. *The Sonar of Dolphins*, Springer-Verlag, New York.

Bartberger, C. L., Lecture Notes on Underwater Acoustics, NADC Report NADC-WR-6509, Naval Air Development Center, Johnsville, PA, May 17, 1965 (AD 468 869).

Beranek, L. L., 1986. *Acoustics*, American Institute of Physics, Inc., New York.

Crocker, M. J., 1997. Editor, *Encyclopedia of Acoustics*, John Wiley & Sons, Inc., New York.

Ewing, W. M., W. S. Jardetzky, and F. Press, 1957. *Elastic Waves in Layered Media*, McGraw-Hill Book Company, New York.

Fahy, F. J., 1995. *Sound Intensity*. E&FN Spon, London.

Harris, C. M. (1998). “Introduction,” in Handbook of Acoustical Measurements and Noise Control, 3rd edition (Acoustical Society of America, NY).

Kinsler, L E. and A. R. Frey, 1962. *Fundamentals of Acoustics*. John Wiley and Sons, New York.

Magrab, E. B., 1975. *Environmental Noise Control*, John Wiley and Sons, New York.

McGraw-Hill Dictionary of Physics and Mathematics (MHDPM), 1978. D. N. Lapedes (Editor in Chief), McGraw-Hill Book Company, New York.

Pierce, A. D., 1989. *Acoustics, An Introduction to Its Physical Principles and Applications*, Acoust. Soc. Am., Woodbury, NY.

Richardson, W. J, C. R. Green, Jr., C. I. Malme, and D. H. Thomson, 1995. *Marine Mammals and Noise*, Academic Press, Inc., San Diego, CA.

Ross, D., 1987. *Mechanics of Underwater Noise*, Peninsula Publishing, Los Altos, CA.

Urick, R. J., 1975 and 1983. *Principles of Underwater Sound*. McGraw-Hill, New York.

Yost, W. A. and M. Killion, 1997. Hearing Thresholds, in Crocker, 1997.