HAWAII RANGE COMPLEX

REQUEST FOR
LETTER OF AUTHORIZATION
FOR THE INCIDENTAL HARASSMENT
OF MARINE MAMMALS RESULTING FROM
NAVY TRAINING OPERATIONS
CONDUCTED WITHIN THE
HAWAII RANGE COMPLEX

Final

SUBMITTED TO

Office of Protected Resources

National Marine Fisheries Service

National Oceanic and Atmospheric Administration

PREPARED BY

Commander, U.S. Pacific Fleet
Commander, THIRD Fleet

July 2007

FINAL

REQUEST FOR LETTER OF AUTHORIZATION FOR THE INCIDENTAL HARASSMENT OF MARINE MAMMALS RESULTING FROM NAVY TRAINING OPERATIONS CONDUCTED WITHIN THE HAWAII RANGE COMPLEX

Submitted to:

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July 2007

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ACRONYMS AND ABBREVIATIONS

ADC	Acoustic Device Countermeasures
ASM	Air to Surface Missile
ASW	Anti-Submarine Warfare
ATOC	Acoustic Thermometry of Ocean Climate
BARSTUR	Barking Sands Tactical Underwater Range
BOMBEX	Bombing Exercise
CASS/GRAB	Comprehensive Acoustic System Simulation Gaussian Ray Bundle
CATM	Captive Air Training Missile
CDC	Center for Disease Control and Prevention
CIWS	Close-in Weapons System
COMNAVSURFPAC	Commander, Naval Surface Forces Pacific
CSG	Carrier Strike Group
CV	Coefficient of Variation
dB	Decibel
DEMO	Demolition
DICASS	Directional Command Activated Sonobuoy System
DOC	Department of Commerce
DON	Department of the Navy
EA/OEA	Environmental Assessment/Overseas Environmental Assessment
EER	Extended Echo Ranging
EEZ	Exclusive Economic Zone
EIS	Environmental Impact Statement
EL	Energy Flux Density Level (dB re 1μPa^2-s)
EMATT	Expendable Mobile Anti-Submarine Warfare Training Target
EPA	Environmental Protection Agency
ESA	Endangered Species Act
ESG	Expeditionary Strike Group
EXTORP	Exercise Torpedo
FAST	Floating at-sea Target
FCLP	Fleet Carrier Landing Practice
FDA	Food and Drug Administration
FEIS	Final Environmental Impact Statement
FIREX	Fire Support Exercise
FRTP	Fleet Readiness Training Plan
GRAB	Gaussian Ray Bundle
GUNEX	Gunnery Exercise
HARM	High-speed Anti-Radiation Missile
HRC	Hawaii Range Complex
IEER	Improved Extended Echo Ranging
IHA	Incidental Harassment Authorization
ISTT	Improved Surface Towed Target
IUCN	World Conservation Union
IWC	International Whaling Commission
kHz	Kilohertz
km	Kilometers

LOA	Letter of Authorization
m	Meter
MCM	Mine Countermeasures
MFA	Mid-Frequency Active
MISSILEX	Missile Exercise
MMC	Marine Mammal Commission
MMHSRP	Marine Mammal Health and Stranding Response Program
MMPA	Marine Mammal Protection Act
μPa	Micropascal
MRA	Marine Resources Assessment
MSAT	Marine Species Awareness Training
NAS	Naval Air Station or National Academies of Science
NATO	North Atlantic Treaty Organization
NDE	National Defense Exemption
nm	nautical miles
nm^2	Square Nautical Miles
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPAL	North Pacific Acoustic Laboratory
NRC	Nuclear Regulatory Commission or National Research Council
NSG	Naval Strike Group
NUWC	Naval Undersea Warfare Command
OCE	Officer-in-charge of the Exercise
OEIS/EIS	Overseas Environmental Impact Statement/Environmental Impact Statement
ONR	Office of Naval Research
OPAREA	Operating Area
PCB	Polychlorinated biphenyl
PMRF	Pacific Missile Range Facility
PTS	Permanent Threshold Shift
RCMP	Range Complex Management Plan
RDT&E	Research, Development, Test, and Evaluation
REXTORP	Recoverable Exercise Torpedo
RIMPAC	Rim of the Pacific
R_{MAX}	Impact Range
SAG	Surface Action Group
SAR	Search and Rescue
SD	Standard Deviation
SEL	Sound Exposure Level
SEPTAR	Seaborne Powered Target
SINKEX	Sinking Exercise
SOP	Standard Operating Procedure
SPAWAR	Navy’s Space and Naval Warfare System Center
SPECWAROPS	Special Warfare Operations
SPL	Sound Pressure Level
SURTASS LFA	Surveillance Towed Array Sensor System Low Frequency Active

TL	Transmission Loss
TM	Tympanic Membrane
TORPEX	Torpedo Exercise
TRACKEX	Tracking Exercise
TS	Threshold Shift
TTS	Temporary Threshold Shift
TTS_2	TTS measured two minutes after exposure
UME	Unusual Mortality Events
U.S.C.	United States Code
USWEX	Undersea Warfare Exercise
UXO	Unexploded Ordnance

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EXECUTIVE SUMMARY

With this submittal, the U.S. Navy (Navy) requests a five-year Letter of Authorization (LOA) for the incidental harassment of marine mammals incidental to the training events within the Hawaii Range Complex (HRC) for the period July 2008 through July 2013, as permitted by the Marine Mammal Protection Act (MMPA) of 1972, as amended. The training events may expose certain marine mammals that may be present within the HRC to sound from hull-mounted mid-frequency active tactical sonar or to pressures from underwater detonations.

In order to estimate acoustic exposures from the HRC anti-submarine warfare (ASW) training events, acoustic sources to be used were examined with regard to their operational characteristics. An analysis was conducted for HRC training events, modeling the potential interaction of mid-frequency active sonar and underwater explosives, with marine mammals in the Hawaiian Islands Operating Area (OPAREA).

The potential sonar exposures outlined in Chapter 6 represent the estimated annual maximum number of exposures to marine mammals that may result in incidental harassment of marine mammals during Navy training and testing in the HRC. Based on the regulatory framework established under the MMPA, the Navy has worked with the National Marine Fisheries Service (NMFS) to develop criteria and methodology for evaluating when sound exposure might constitute incidental harassment. The MMPA defines two types of harassment, and Level A (potential injury) and Level B (disturbance), evaluated here as follows:

- Level A: Consistent with prior actions, permanent physiological effects are considered injury, and energy flux density level (EL) is appropriate for evaluating when a sound exposure may cause a permanent physiological effect to marine mammals. EL exposures at or above the lowest threshold at which the onset of a permanent physiological effect may occur are used to define potential Level A harassment (215 dB re 1 μPa^2-s [EL]).
- Level B: Consistent with prior actions, temporary, recoverable physiological effects are considered to potentially result in disturbance of marine mammals. Exposures below 215 dB re 1 μPa^2-s (EL) and at or above the lowest exposures at which temporary physiological effects may occur (195 dB re 1 μPa^2-s) are used to define potential Level B harassment.
- Level B: In addition to considering temporary physiological effects that may cause disturbance, this action also considers the potential for behavioral and physiological responses (e.g., stress) to behaviorally disturb marine mammals. Based on comments received on prior Navy actions, a dose function is used to determine when these responses might be considered Level B harassment.

In addition to Level A and Level B harassment, the potential for mortality may also be considered in impacts to marine mammals for LOA authorizations.

The conservative analysis used to estimate the maximum number of marine mammals that could be exposed annually by Navy training operations will overestimate the potential effects. Behavioral effects modeling using the dose function methodology indicates between 47,129 (No Action Alternative) to 63,468 (Alternative 2) expected annual acoustic exposures that exceed the sound pressure level (SPL) dose function thresholds and potentially result in behavioral harassment for mid-frequency sonar. The modeling also indicates between 1281 (No Action Alternative) to 1,788 (Alternative 2) annual exposures that exceed the temporary threshold shift (TTS) threshold. The total potential annual exposures from mid-frequency active sonar using the Dose Function and TTS is 65,256 (Level B harassment) for Alternative 2, the Preferred Alternative. The modeling indicates that sound levels that may cause a permanent threshold shift (Level A harassment) are not likely to reach marine mammals. However, when Level A exposures are summed for an entire year for all sonar training, the result is one Level A exposure for humpback whale and one Level A exposure for striped dolphin. .Modeling indicates that 61 marine mammals may be exposed to pressure from underwater detonations that could cause TTS (Level B harassment) but none would be exposed to pressures that would cause injury (Level A harassment) or mortality.

The numbers of marine mammals predicted to be exposed are given without taking into consideration the use of mitigation measures. The Navy routinely employs a number of mitigation measures, outlined in Chapter 11, which will substantially decrease the number of animals potentially exposed and affected.

The potential explosive exposures outlined in Chapter 6 represent the maximum expected number of cetaceans and pinnipeds that could be affected from underwater explosives for mine countermeasures, demolition of underwater obstacles, missile exercises, bombing exercises, gunnery exercises, and ship sinking exercises. For underwater detonations, the threshold for potential TTS is at 182 dB re 1 μPa^2-s or at 23 pounds per square inch (psi). Level A thresholds are 50 percent tympanic membrane rupture, or onset of slight lung injury. The fatality threshold is onset of extensive lung injury. As with the acoustic impacts from sonar activities, the conservative analysis used to estimate the maximum number of marine mammals that could be affected by Navy training operations will overestimate the potential exposures.

Level B harassment in the context of military readiness activities is defined as any act that disturbs or is likely to disturb a marine mammal or marine mammal stock in the wild by causing disruption of natural behavioral patterns including, but not limited to, migration, surfacing, nursing, breeding, feeding, or sheltering to a point where such behavioral patterns are abandoned or significantly altered. This estimate of total predicted marine mammal sound exposures potentially constituting Level B harassment is presented without consideration of mitigation measures. In addition, the assessment of whether temporary physiological effects or behavioral responses may cause behavioral patterns to be abandoned or significantly altered is considered in the context of an analytical framework for active sonar. This framework acknowledges that only a subset of exposures are likely to result in Level B harassment, and that multiple exposures of the same individual have a higher likelihood of disturbance than single exposures. All predicted acoustic exposures are presented in this analytical framework to support NMFS assessment of those exposures that may result in Level B harassment.

The incidental harassment of marine mammals associated with the proposed Navy action will have no more than negligible impacts on marine mammal species or stocks. For species listed and protected under the Endangered Species Act (ESA), modeling indicates that fin whales, humpback whales, sei whales, sperm whales and Hawaiian monk seals may be exposed to sound levels that may affect these species. The ongoing ESA Section 7 consultation will examine the anticipated responses and any associated fitness consequences for these ESA-listed species to determine if MMPA incidental harassment authorization is required for a certain subset of the predicted exposures. However, given implementation of mitigation measures, it is unlikely that training operations would adversely affect these species. Based on the widely dispersed geography of the training operations and evaluation of the potential for physiological and behavioral disturbance coupled with the reduction of potential effects attributed to the robust mitigation measures to be executed, the interpretation of the modeling indicates that only Level B harassment is anticipated for all marine mammal species in the HRC. In all cases, the conclusions are that Level B harassment to a small number of marine mammals would have a negligible impact on marine mammal species or stocks.

In a letter from NMFS to Navy dated October 2006, NMFS indicated that Section 101(a)(5)(A) authorization is appropriate for mid-frequency active sonar activities because it allows NMFS to consider the potential for incidental mortality. NMFS' letter indicated; "Because mid-frequency sonar has been implicated in several marine mammal stranding events including some involving serious injury and mortality, and because there is no scientific consensus regarding the causal link between sonar and stranding events, NMFS cannot conclude with certainty the degree to which mitigation measures would eliminate or reduce the potential for serious injury of mortality." In addition, given the frequency of naturally occurring marine mammal strandings in Hawaii (e.g., natural mortality), it is conceivable that a stranding could co-occur with a Navy exercise even though the stranding is actually unrelated to and not caused by Navy activities. Accordingly, the Navy's LOA application will include requests for take, by mortality, of the most commonly stranded non ESA-listed species.

Evidence from five beaked whale strandings, all of which have taken place outside the HRC, and have occurred over approximately a decade, suggests that the exposure of beaked whales to mid-frequency sonar in the presence of certain conditions (e.g., multiple units using tactical sonar, steep bathymetry, constricted channels, strong surface ducts, etc.) may result in strandings, potentially leading to mortality. Although these physical factors believed to contribute to the likelihood of beaked whale strandings are not present, in their aggregate, in the Hawaiian Islands, scientific uncertainty exists regarding what other factors, or combination of factors, may contribute to beaked whale strandings. Accordingly, to allow for scientific uncertainty regarding contributing causes of beaked whale strandings and the exact mechanisms of the physical effects, the Navy will also request authorization for take, by mortality, of the beaked whale species present in the Hawaiian Islands.

Neither NMFS nor the Navy anticipates that marine mammal strandings or mortality will result from the operation of mid-frequency sonar during Navy exercises within the HRC. However, by authorizing a very small number of mortalities for beaked whales and commonly stranded species, if a single individual of these species is found dead coincident with Navy activities (a statistically likely event, as an average of two wash up per month in Hawaii), a potentially lengthy investigation of the cause(s) of the death would not unnecessarily interfere with Navy training exercises.

Additionally, through the MMPA process (which allows for adaptive management), NMFS and the Navy will determine the appropriate way to proceed in the unlikely event that a causal relationship were to be found between Navy activities and a future stranding. The Navy's LOA application requests the take, by serious injury or mortality, of 2 each of 10 species (bottlenose dolphin, Kogia *spp*., melon-headed whale, pantropical spotted dolphin, pygmy killer whale, short-finned pilot whale, striped dolphin, Cuvier's, Longman's, and Blainville's beaked whales), however, these numbers may be modified through the MMPA process, based on available data.

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1. DESCRIPTION OF ACTIVITIES

This Chapter describes the mission activities conducted within the Hawaii Range Complex (HRC) that could result in Level B harassment and possibly Level A harassment, under the Marine Mammal Protection Act (MMPA) of 1972, as amended in 1994. The actions are U.S. Navy (Navy) training exercises involving mid-frequency active tactical sonar and underwater detonations with the potential to affect marine mammals that may be present within the HRC (Table 1-1).

1.1 Background

The Navy's mission is to maintain, train, and equip combat-ready naval forces capable of winning wars, deterring aggression, and maintaining freedom of the seas. Title 10, U.S. Code (U.S.C.) 5062 directs the Chief of Naval Operations to train all naval forces for combat. The Chief of Naval Operations meets that direction, in part, by conducting at-sea training exercises and ensuring naval forces have access to ranges, operating areas (OPAREAs) and airspace where they can develop and maintain skills for wartime missions and conduct research, development, test, and evaluation (RDT&E) of naval weapons systems. For purposes of this Letter of Authorization (LOA), exercises and training include only those events conducted as part of the training cycle and as part of major multinational exercises.

The Proposed Action is to support and conduct current and emerging training and RDT&E operations in the HRC. The decision to be made by the Assistant Secretary of the Navy (Installations & Environment) is to determine both the level and mix of training to be conducted and the range capabilities enhancements to be made within the HRC that best meets the needs of the Navy.

The HRC complex consists of targets and instrumented areas, airspace, surface OPAREAs, and land range facilities. The activities analyzed in this Letter of Authorization (LOA) include current and future proposed Navy training and RDT&E operations within Navy-controlled OPAREAs, airspace, and ranges, and Navy-funded range capabilities enhancements (including infrastructure improvements).

The HRC is one of thirteen Navy range complexes used for training and testing. Four ranges support the Pacific Fleet, headquartered at Naval Station Pearl Harbor. These naval ranges contain some common capabilities, but each range contains distinctive individual capabilities as well. The enhancement of each range complex will be analyzed separately for potential environmental impacts. All ranges, including the HRC, will require adequate capabilities and the flexibility to enhance and sustain Navy training and testing. This document analyzes activities that may affect marine mammals that are present in the HRC.

The HRC has the infrastructure to support a large number of forces in a location both remote and under U.S. control. Centrally located in the Pacific Ocean between the west coast of the United States and the naval stations in the western Pacific, and surrounding the most isolated islands in the world, the HRC has extensive existing range assets and training capabilities. The range surrounds the major homeport of Naval Station Pearl Harbor, enabling re-supply and repairs to submarines and surface ships alike. The range is important to unit level training for the many forces stationed in Hawaii. The closeness of the Hawaiian Islands land masses to the remote and extensive marine training sites of the HRC allow use of onshore medical facilities when the dangerous work of military training results in injury, and land-based airfields for aircraft diversion during difficult training maneuvers or in case of emergency.

Table 1-1. Summary of Training and RDT& E Operations that will Occur in the HRC and which Operations were Modeled for Sonar or Underwater Detonation Exposures

Training Operations	Research, Development, Testing, and Evaluation (RDT&E) Operations
Exercises Involving Explosives and Potential Impacts on Marine Mammals [1]	**RDT&E Operations with no Potential for Impacts to Marine Mammals from Explosives or Sonar**
• Naval Surface Fire Support Exercise [1]	• Testing and Evaluation Operations
• Surface-to-Surface Gunnery Exercise (S-S GUNEX) [1]	• Anti-air Warfare RDT&E
• Surface-to-Surface Missile Exercise (S-S MISSILEX) [1]	• Antisubmarine Warfare
• Air-to-Surface Missile Exercise (A-S MISSILEX) [1]	• Combat System Ship Qualification Trial
• Bombing Exercise (BOMBEX) (Sea) [1]	• Electronic Combat/Electronic Warfare
• Sink Exercise (SINKEX) [1]	• High Frequency
• Mine Neutralization[1]	• Missile Operations
Exercises Involving Sonar with Potential Impacts on Marine Mammals [2]	• Missile Defense
• Antisubmarine Warfare (ASW) Tracking Exercise[2]	• Shipboard Electronic Systems Evaluation Facility (SESEF) Quick Look
• Antisubmarine Warfare Torpedo Exercise[2]	• SESEF System Performance Test
• Major Integrated ASW Training Exercise[2]	• Additional Chemical Simulant (Alternative 1)
Other Exercises with no Potential Impacts on Marine Mammals from Explosives or Sonar	• Intercept Targets Launched into Pacific Missile Range Facility (PMRF) Controlled Area (Alternative 1)
• Anti-surface Warfare Torpedo Exercise (Submarine-Surface)	• Launched SM-6 from Sea-Based Platform (AEGIS) (Alternative 1)
• Air-to-Surface Gunnery Exercise (A-S GUNEX)	• Test Unmanned Surface Vehicles (Alternative 1)
• Air-to-Air Missile Exercise	• Test Unmanned Aerial Vehicles (Alternative 1)
• Surface-to-Air Gunnery Exercise (S-A GUNEX)	• Test Hypersonic Vehicles (Alternative 1)
• Surface-to-Air Missile Exercise (S-A MISSILEX)	• Portable Undersea Tracking Range (Alternative 1)
• Mine Countermeasures Exercise	• Large Area Tracking Range Upgrade (Alternative 1)
• Submarine Operations	• Enhanced Electronic Warfare Training (Alternative 1)
• Swimmer Insertion/Extraction	• Expanded Training Capability for Transient Air
• Command and Control (C2) (Sea)	• Direct Energy (Alternative 2)
• Demolition Exercises (Sea)	• Advanced Hypersonic Weapon (Alternative 2)
• IEER-EER SSQ-110	
• Air Combat Maneuver	
• Electronic Combat Operations	
• Chaff Exercise (CHAFFEX)	
• Visit, Board, Search, and Seizure	

Notes: 1. Modeled for explosives 2. Modeled for sonar

The isolation of the range offers an invaluable facility on which to conduct missile testing and training. Able to link with the U.S. Army's Pohakalua Training Area, as well as U.S. Air Force and U.S. Marine Corps bases where aircraft basing and amphibious operations may occur, the HRC provides a superior joint training environment for all the services and advanced missile testing capability.

Among the important assets of the HRC is the Pacific Missile Range Facility (PMRF). PMRF is the world's largest instrumented, multi-environment, military test range capable of supporting subsurface, surface, air, and space operations. It consists of instrumented underwater ranges, controlled airspace, and a temporary operating area covering 2.1 million square nautical miles (nm^2) of ocean area. PMRF provides major range services for training, tactics development, and evaluation of air, surface, and subsurface weapons systems for the Navy, other Department of Defense (DoD) agencies, foreign military forces, and private industry. It also maintains facilities and provides services to support naval operations, and other activities and units designated by the Chief of Naval Operations.

Hawaii provides an environment virtually unconstrained by encroachment challenges. The HRC ocean areas where Rim of the Pacific (RIMPAC), Undersea Warfare Exercise (USWEX) and other testing and training are conducted have significantly less commercial shipping traffic than other ranges because trans-Pacific shipping routes are generally far north or south of the area. Due to increasing commercial airline traffic in Southern California, scheduling the necessary amount of airspace required for a multi-national force to meet exercise objectives would not be possible at the Southern California range but is easily accommodated in Hawaii.

The open ocean of the HRC presents a realistic environment for strike warfare training, including amphibious, nearshore, and anti-submarine warfare. Training may be conducted within a few miles of land masses so that battle situations may be realistically simulated. There is room and space to operate within proximity of land but at safe distances from other simultaneous training activities. This allows both training of locally-based units and the necessary build-up of capability through training that culminates in multi-force training in Hawaii as naval forces transit the Pacific.

Hawaii stands out as a cost-effective, cost-efficient, and time-efficient en route training location for units deploying to the western Pacific Ocean from the U.S. west coast. Its proximity to the western Pacific theater allows expeditionary forces to train on the way west as part of sustainment training: continued training of certified personnel to be better prepared for entering potential battle areas. Such training may include the conduct of undersea warfare exercises in Hawaii on the way to the potential battle area, single ship training, planned events, and response to simulated events simultaneously. The Navy must have the flexibility and capacity to quickly surge required combat power in the event of a national crisis or contingency operation. An enhanced HRC provides that capacity.

Training for sustained deployment at the HRC, rather than at ranges on the west coast, saves 10 transit days to the western Pacific from the west coast of the United States. Given its training mandate and legal responsibilities, the Navy cannot afford to lose the 14 days it would take to reach the western Pacific from the west coast. As training is mandatory, as it must be unconstrained by operational timing requirements to the extent possible, and as it must be realistic and thereby near land, the HRC becomes an ideal location for increased training activities and site enhancement.

The HRC is well-suited to accommodate the Navy's training and testing responsibilities, both geographically and strategically. The specific value of the HRC and its superiority to alternative ranges is defined by its location in the Pacific Ocean, its proximity to Hawaii-based forces, its presence on the route of transiting forces from the west coast of the United States to operations in the western Pacific, and its central location for nations around the rim of the Pacific.

The Navy has conducted a thorough review of all continuing/ongoing training conducted in the HRC, in addition to those proposed training and RDT&E operations to determine whether there is a potential for harassment of marine mammals. The following discussion provides an overview of those training and RDT&E operations that would result in the generation of sound in the water, either through the use of sonar or from the use of live ordnance, including the detonation of explosives in the water.

1.2 Proposed Training Operations

A number of training operations within the HRC have the potential to impact marine mammals.

1.2.1 ASW Training Operations

The types of anti-submarine warfare (ASW) training conducted within the HRC involve the use of ships, submarines, aircraft, non-explosive exercise weapons, and other training-related devices. ASW training involves the use of active and passive devices with training operations occurring in offshore (<12 nm from shore) and open ocean (>12 nm from shore) areas. A description of ASW operations and the sonar devices is provided below.

Tracking Exercise (TRACKEX)

A TRACKEX tests the Naval Strike Group's (NSG) ability to locate and track an unknown or hostile submarine over a predetermined time. TRACKEX training occurs throughout the year. Average training operation duration is 10.9 hours. This operation tests the NSG's ability to coordinate the positioning of assets including surface, air, and subsurface, and the effective communication and turnover of responsibility for maintaining coverage of the unknown submarine. Potential harassment would be from active sonar sources as shown on Table 1-2.

Sensors that are part of this exercise include:

Torpedo Exercise (TORPEX)

Anti-submarine Warfare Torpedo Exercises (ASW TORPEX) operations train crews in tracking and attack of submerged targets, firing one or two exercise torpedoes (EXTORPs; recoverable but having no engine) or recoverable exercise torpedoes (REXTORPs). TORPEX training occurs throughout the year. Average training operation duration is 14.3 hours. TORPEX targets used in the Offshore Areas include actual submarines, MK-30 ASW training targets, and/or MK-39 Expendable Mobile ASW Training Targets (EMATT). The target may be non-evading while

Table 1-2. Sonar Sources by Exercise Type

Exercise	Source	Total Sonar Modeled Per Year
TRACKEX (200 exercises per year)		
	Source	**Modeled**
	53C	1,592 hours
	Dipping	NA
	Sonobuoy	1,061 buoys
	MK-48	NA
TORPEX (300 exercises per year)		
	Source	**Modeled**
	53C	414 hours
	Dipping	NA
	Sonobuoy	428 buoys
	MK-48	365 runs
RIMPAC (2 Carrier, 1 exercise every other year)		
	Source	**Modeled**
	53C	1,064 hours
	Dipping	673 dips
	Sonobuoy	959 buoys
	MK-48	8 runs
USWEX (6 exercises per year)		
	Source	**Modeled**
	53C	1,167 hours
	Dipping	577 dips
	Sonobuoy	767 buoys
	MK-48	NA
Multiple Strike Group (1 exercise per year)		
	Source	**Modeled**
	53C	945 hours
	Dipping	240 dips
	Sonobuoy	326 buoys
	MK-48	NA

operating on a specified track, or it may be fully evasive, depending on the training requirements of the operation.

Submarines periodically conduct torpedo firing training exercises within the Hawaii Offshore OPAREA. Typical duration of a submarine TORPEX operation is 22.7 hours, while air and surface ASW platform TORPEX operations are considerably shorter. The sonar portion of the exercise is approximately 11 hours. Potential harassment would be from active sonar sources as shown on Table 1-2.

Rim of the Pacific (RIMPAC)

RIMPAC is a combined force exercise where submarines, surface ships, and aircraft conduct many different exercise events including ASW against opposition submarine targets. RIMPAC occurs during the summer over a 1-month period every other year. Submarine targets include real submarines, targets that simulate the operations of an actual submarine including those described previously under TORPEX, and virtual submarines interjected into the training events by exercise controllers. ASW training events are complex and highly variable. For RIMPAC, the primary event involves a Surface Action Group (SAG), consisting of one to five surface ships equipped with sonar, with one or more helicopters, and a P-3 aircraft searching for one or more submarines. There will be approximately four SAGs for a typical RIMPAC. For the purposes of analysis, each SAG event is counted as an ASW operation. There will be approximately 44 ASW operations during RIMPAC with an average event length of approximately 12 hours.

One or more ASW events may occur simultaneously within the Hawaiian Islands OPAREA. Each event was identified and modeled separately. If a break of more than one hour in ASW operations occurred, then the subsequent event was modeled as a separate event. Training event durations ranged from 2 hours to 24 hours. The preferred alternative includes eight SAGs using mid-frequency active sonar. Potential harassment would be from active sonar sources as shown on Table 1-2.

In addition, RIMPAC includes training operations that involve underwater detonations as described in Section 1.2.3, including Sinking Exercise, Air-to-Surface Gunnery Exercise, Surface-to-Surface Gunnery Exercise, Naval Surface Fire Support, Air-to-Surface Missile Exercise, Surface-to-Surface Missile Exercise, Bombing Exercise, Mine Neutralization Exercise, and IEER/EER Exercise. These exercises do not occur at the same place and time and do not overlap with sonar exercises. Explosives from RIMPAC have been included in the training operations described in Section 1.2.3.

Undersea Warfare Exercise (USWEX)

Carrier Strike Groups (CSGs) and Expeditionary Strike Groups (ESGs) that deploy from the west coast of the United States will experience realistic submarine combat conditions and assess submarine warfare training postures in the Hawaii Range Complex prior to their deployment to a theater of operations. Hawaii Range Complex training areas, test ranges, and ocean operating areas would be utilized to fully support the Fleet Readiness Training Plan (FRTP). As a combined force, submarines, surface ships, and aircraft will conduct ASW against opposition submarine targets. Submarine targets include real submarines, targets that simulate the operations of an actual submarine, and virtual submarines interjected into the training events by exercise controllers. ASW training events are complex and highly variable. The primary event involves from one to five surface ships equipped with sonar, with one or more helicopters, and a

P-3 aircraft searching for one or more submarines. A total of six exercises using mid-frequency active sonar would occur throughout the year for USWEX. Each USWEX occurs over a 3- to 4-day period. Potential harassment would be from active sonar sources as shown on Table 1-2.

In addition, USWEX includes training operations that involve underwater detonations as described in Section 1.2.3, including Air-to-Surface Gunnery Exercise, Air-to-Surface Missile Exercise, and Bombing Exercise. These exercises do not occur at the same place and time and do not overlap with sonar exercises. Explosives from USWEX have been included in the training operations described in Section 1.2.3.

Multiple Strike Group Exercise

A Multiple Strike Group Exercise consists of operations that involve Navy assets engaging in a schedule of events battle scenario, with U.S. forces (blue forces) pitted against a notional opposition force (red force). Participants use and build upon previously gained training skill sets to maintain and improve the proficiency needed for a mission-capable, deployment-ready unit. The exercise would occur over a 5- to 10-day period at any time during the year. As described above for USWEX, as a combined force, submarines, surface ships, and aircraft will conduct ASW against opposition submarine targets. Potential harassment would be from active sonar sources as shown on Table 1-2.

In addition, the Multiple Strike Group Exercise includes training operations that involve underwater detonations as described in Section 1.2.3, including Sinking Exercise, Air-to-Surface Missile Exercise, Mine Neutralization Exercise, and EER/IEER Exercise. These exercises do not occur at the same place and time and do not overlap with sonar exercises. Explosives from the Multiple Strike Group Exercise have been included in the training operations described in Section 1.2.3.

1.2.2 Active Acoustic Devices

Tactical military sonars are designed to search for, detect, localize, classify, and track submarines. There are two types of sonars, passive and active:

- Passive sonars only listen to incoming sounds and, since they do not emit sound energy in the water, lack the potential to acoustically affect the environment.
- Active sonars generate and emit acoustic energy specifically for the purpose of obtaining information concerning a distant object from the received and processed reflected sound energy.

Modern sonar technology has developed a multitude of sonar sensor and processing systems. In concept, the simplest active sonars emit omni-directional pulses ("pings") and time the arrival of the reflected echoes from the target object to determine range. More sophisticated active sonar emits an omni-directional ping and then rapidly scans a steered receiving beam to provide directional, as well as range, information. More advanced sonars transmit multiple preformed beams, listening to echoes from several directions simultaneously and providing efficient detection of both direction and range.

The tactical military sonars to be deployed in during testing and training in the HRC are designed to detect submarines in tactical operational scenarios. This task requires the use of the sonar mid-frequency range (1 kilohertz [kHz] to 10 kHz) predominantly.

The types of tactical acoustic sources that would be used in training events are discussed in the following paragraphs.

- **Surface Ship Sonars.** A variety of surface ships participate in testing and training events. Some ships (e.g., aircraft carriers, amphibious assault ships) do not have any onboard active sonar systems, other than fathometers. Others, like guided missile cruisers, are equipped with active as well as passive tactical sonars for mine avoidance and submarine detection and tracking. For purposes of the analysis, all surface ship sonars were modeled as equivalent to SQS-53 having the nominal source level of 235 decibels (dB) re 1 µPa @ 1 m. Since the SQS-53 hull-mounted sonar is the Navy's most powerful surface ship hull-mounted sonar, modeling this source is a conservative assumption tending towards an overestimation of potential effects. Sonar ping transmission durations were modeled as lasting 1 second per ping and omni-directional, which is a conservative assumption that will overestimate potential effects. Actual ping durations will be less than 1 second. The SQS-53 hull-mounted sonar transmits at center frequencies of 2.6 kHz and 3.3 kHz. Effects analysis modeling used frequencies that are required in tactical deployments such as those during RIMPAC and USWEX. Details concerning the tactical use of specific frequencies and the repetition rate for the sonar pings is classified but was modeled based on the required tactical training setting.

- **Submarine Sonars.** Submarine sonars are used to detect and target enemy submarines and surface ships. Because submarine active sonar use is very rare and in those rare instances, very brief, it is extremely unlikely that use of active sonar by submarines would have any measurable effect on marine mammals. Therefore, this type of sonar was not modeled for the HRC.

- **Aircraft Sonar Systems.** Aircraft sonar systems that would operate in the HRC include sonobuoys and dipping sonar. Sonobuoys may be deployed by maritime patrol aircraft or helicopters; dipping sonars are used by carrier-based helicopters. A sonobuoy is an expendable device used by aircraft for the detection of underwater acoustic energy and for conducting vertical water column temperature measurements. Most sonobuoys are passive, but some can generate active acoustic signals, as well as listen passively. Dipping sonar is an active or passive sonar device lowered on cable by helicopters to detect or maintain contact with underwater targets. During ASW training, these systems active modes are only used briefly for localization of contacts and are not used in primary search capacity. Because active mode dipping sonar use is very brief, it is extremely unlikely its use would have any effect on marine mammals. However, the AN/AQS-22 dipping sonar was modeled based on estimated use during Major Exercises within the HRC.

- **Torpedoes.** Torpedoes are the primary ASW weapon used by surface ships, aircraft, and submarines. The guidance systems of these weapons can be autonomous or electronically controlled from the launching platform through an attached wire. The autonomous guidance systems are acoustically based. They operate either passively, exploiting the emitted sound energy by the target, or actively, ensonifying the target and using the received echoes for guidance. Potential impacts from the use of torpedoes on the PMRF range areas were analyzed in the PMRF Environmental Impact Statement (EIS) and, consistent with the National Oceanic and Atmospheric Administration's

(NOAA's) June 3, 2002, Endangered Species Act (ESA) Section 7 letter to the Navy for RIMPAC 2002 and the RIMPAC 2006 Biological Opinion, the Navy determined that the activities are not likely to adversely affect ESA listed species under the jurisdiction of the National Marine Fisheries Service (NMFS). The MK-48 torpedo was modeled for active sonar transmissions during specified training operations within the HRC.

- **Acoustic Device Countermeasures (ADC).** ADCs are, in effect, submarine simulators that make sound to act as decoys to avert localization and/or torpedo attacks. Previous classified analysis has shown that, based on the operational characteristics (source output level and/or frequency) of these acoustic sources, the potential to affect marine mammals was unlikely.
- **Training Targets.** ASW training targets consisting of MK-30 and/or MK-39 EMATT are used to simulate opposition submarines. They are equipped with one or a combination of the following devices: (1) acoustic projectors emanating sounds to simulate submarine acoustic signatures; (2) echo repeaters to simulate the characteristics of the echo of a particular sonar signal reflected from a specific type of submarine; and (3) magnetic sources to trigger magnetic detectors. Based on the operational characteristics (source output level and/or frequency) of these acoustic sources, the potential to affect marine mammals is unlikely, and therefore they were not modeled for this analysis. Consistent with NOAA's June 3, 2002, ESA Section 7 letter to the Navy for RIMPAC 2002 and the RIMPAC 2006 Biological Opinion, the Navy determined that the activities are not likely to adversely affect ESA listed species under the jurisdiction of NMFS.
- **Range Sources.** Range pingers are active acoustic devices that allow each of the in-water platforms on the range (e.g., ships, submarines, target simulators, and exercise torpedoes) to be tracked by the PMRF range hydrophones. In addition to passively tracking the pinger signal from each range participant, the range transducer nodes also are capable of transmitting acoustic signals for a limited set of functions. These functions include submarine warning signals, acoustic commands to submarine target simulators (acoustic command link), and occasional voice or data communications (received by participating ships and submarines on range). Based on the operational characteristics (source output level and/or frequency) of these acoustic sources, the potential to affect marine mammals is unlikely, and therefore they were not modeled for this analysis. Consistent with NOAA's June 3, 2002, ESA Section 7 letter to the Navy for RIMPAC 2002 and the RIMPAC 2006 Biological Opinion, the Navy determined that the activities are not likely to adversely affect ESA listed or MMPA protected species under the jurisdiction of NMFS.

1.2.3 Non-Sonar Operations-Underwater Detonations

Underwater detonation activities can occur at various depths depending on the activity (sinking exercise [SINKEX] and mine neutralization), but may also include activities which may have detonations at or just below the surface (SINKEX, gunnery exercise [GUNEX], or missile exercise [MISSILEX]). When the weapons hit the target, there is no explosion in the water, and so a "hit" is not modeled. When a live weapon misses, it is modeled as exploding below the water surface at 1 ft (5-inch naval gunfire, 76mm rounds), 2 meters (Maverick, Harpoon, MK-82, MK-83, MK-84), or 50-ft (MK-48 torpedo) as shown in Appendix A, Table A-7. For a

SINKEX, a specific sequence of weapons firing is assumed. Appendix A, Table A-8 provides the sequence of hits and misses that were modeled for a SINKEX. For all other activities (Naval Surface Fire Support, GUNEX, MISSILEX, BOMBEX), all weapons are modeled as detonating under water at the depths listed above. Mine neutralization activities are modeled with a detonation depth near the seafloor. Training operations that involve explosives and underwater detonations occur throughout the year and are presented in Table 1-3.

Table 1-3. Training Operations Involving Explosives and Underwater Detonation

Training Operation	Explosive Source	Location	Number of Exercises per Year	Number of Live Rounds per Year	Average Length (Hours)
Mine Neutralization	1 to 20-lb Demolition charge	Puuloa Underwater Range, Lima Landing, Naval Inactive Ship Maintenance Facility, Open ocean areas	68	68	6
Air to Surface Missile Exercise	Penguin Maverick	Warning Area W-188	50	50	5.5
Surface to Surface Missile Exercise	Harpoon	Warning Area W-188	12	75	5
Bombing Exercise	Mk82, Mk83, Mk84	PMRF, Hawaii Offshore	38	38	6
Sinking Exercise	Multiple sources as described below	PMRF, Hawaii Offshore	6	6	14.5
Surface to Surface Gunnery Exercise	5 inch round, 76-mm round	Warning Areas W-188, W-191, 192, 193, 194, 196, and Mela South	91	3,822	3.5
Naval Surface Fire Support	5 inch round, 76-mm round	Warning Area W-188	28	644	8.1

Sinking Exercise (SINKEX)

In a SINKEX, a specially prepared, deactivated vessel is deliberately sunk using multiple weapons systems. The exercise provides training to ship and aircraft crews in delivering both live and inert ordnance on a real target. These target vessels are empty, cleaned, and environmentally-remediated. A SINKEX target is towed to sea and set adrift at the SINKEX location. The duration of a SINKEX is unpredictable since it ends when the target sinks, sometimes immediately after the first weapon impact and sometimes only after multiple impacts by a variety of weapons. Typically, the exercise lasts for 4 to 8 hours over 1 to 2 days. SINKEXs typically occur only once or twice a year in the HRC. Potential harassment would be from underwater detonation. Some or all of the following weapons may be employed in a SINKEX:

- Three HARPOON surface-to-surface and air-to-surface missiles
- Two to eight air-to-surface Maverick missiles

- Two to four MK-82 General Purpose Bombs
- Two Hellfire air-to-surface missiles
- One SLAM-ER air-to-surface missile
- Two-hundred and fifty rounds for a 5-inch gun
- One MK-48 heavyweight submarine-launched torpedo

Air-to-Surface Gunnery Exercise (A-S GUNEX)

Air-to-Surface GUNEX operations are conducted by rotary-wing aircraft against stationary targets (Floating at-sea Target [FAST] and smoke buoy). Rotary-wing aircraft involved in this operation would include a single SH-60 using either 7.62-mm or .50-caliber door-mounted machine guns. A typical GUNEX will last approximately one hour and involve the expenditure of approximately 400 rounds of 50-caliber or 7.62-mm ammunition. Due to them being inert and the small size of the rounds, they are not considered to have an underwater detonation impact.

Surface-to-Surface Gunnery Exercise (S-S GUNEX)

Surface gunnery exercises (GUNEX) take place in the open ocean to provide gunnery practice for Navy and Coast Guard ship crews. GUNEX training operations conducted in the Offshore OPAREA involve stationary targets such as a MK-42 FAST or a MK-58 marker (smoke) buoy. The gun systems employed against surface targets include the 5-inch, 76 millimeter (mm), 25-mm chain gun, 20-mm Close-in Weapon System (CIWS), and .50 caliber machine gun. Typical ordnance expenditure for a single GUNEX is a minimum of 21 rounds of 5-inch or 76-mm ammunition, and approximately 150 rounds of 25-mm or .50-caliber ammunition. Both live and inert training rounds are used. After impacting the water, the rounds and fragments sink to the bottom of the ocean. A GUNEX lasts approximately 2 to 4 hours, depending on target services and weather conditions. The live 5-inch and 76-mm rounds are considered in the underwater detonation modeling. Potential harassment would be from underwater detonation.

Naval Surface Fire Support Exercise

Navy surface combatants conduct fire support exercise (FIREX) operations at PMRF on a virtual range against “Fake Island”, located on Barking Sands Tactical Underwater Range (BARSTUR). Fake Island is unique in that it is a virtual landmass simulated in three dimensions. Ships conducting FIREX training against targets on the island are given the coordinates and elevation of targets. PMRF is capable of tracking fired rounds to an accuracy of 30 feet. The live 5-inch and 76-mm rounds fired into ocean during this exercise are considered in the underwater detonation modeling. Potential harassment would be from underwater detonation.

Air-to-Surface Missile Exercise (A-S MISSILEX)

The air-to-surface missile exercise (MISSILEX [A-S]) consists of the attacking platform releasing a forward-fired, guided weapon at the designated towed target. The exercise involves locating the target, then designating the target, usually with a laser.

MISSILEX (A-S) training that does not involve the release of a live weapon can take place if the attacking platform is carrying a captive air training missile (CATM) simulating the weapon involved in the training. The CATM MISSILEX is identical to a live-fire exercise in every aspect except that a weapon is not released. The operation requires a laser-safe range as the target is designated just as in a live-fire exercise.

From 1 to 16 aircraft, carrying live, inert, or CATMs, or flying without ordnance (dry runs) are used during the exercise. At sea, seaborne powered targets (SEPTARs), Improved Surface Towed Targets (ISTTs), and decommissioned hulks are used as targets. MISSILEX (A-S) assets include helicopters and/or 1 to 16 fixed wing aircraft with air-to-surface missiles and anti-radiation missiles (electromagnetic radiation source seeking missiles). When a high-speed anti-radiation missile (HARM) is used, the exercise is called a HARMEX. Targets include SEPTARs, ISTTs, and excess ship hulks. Potential harassment would be from underwater detonation.

Surface-to-Surface Missile Exercise (S-S MISSILEX)

Surface-to-surface missile exercise (MISSILEX [S-S]) involves the attack of surface targets at sea by use of cruise missiles or other missile systems, usually by a single ship conducting training in the detection, classification, tracking and engagement of a surface target. Engagement is usually with Harpoon missiles or Standard missiles in the surface-to-surface mode. Targets could include virtual targets or the SEPTAR or ship deployed surface target. MISSILEX (S-S) training is routinely conducted on individual ships with embedded training devices.

A MISSILEX (S-S) could include 4 to 20 surface-to-surface missiles, SEPTARs, a weapons recovery boat, and a helicopter for environmental and photo evaluation. All missiles are equipped with instrumentation packages or a warhead. Surface-to-air missiles can also be used in a surface-to-surface mode. MISSILEX (S-S) activities are conducted within PMRF Warning area W-188. Each exercise typically lasts 5 hours. Future MISSILEX (S-S) could range from 4 to 35 hours. Potential harassment would be from underwater detonation.

Bombing Exercise (BOMBEX)

Fixed-wing aircraft conduct bombing exercise (BOMBEX [Sea]) operations against stationary targets (MK-42 FAST or MK-58 smoke buoy) at sea. An aircraft will clear the area, deploy a smoke buoy or other floating target, and then set up a racetrack pattern, dropping on the target with each pass. At PMRF, a range boat might be used to deploy the target for an aircraft to attack. A BOMBEX may involve either live or inert ordnance. Potential harassment would be from underwater detonation.

Mine Neutralization

Mine Neutralization operations involve the detection, identification, evaluation, rendering safe, and disposal of mines and unexploded ordnance (UXO) that constitutes a threat to ships or personnel. Mine neutralization training can be conducted by a variety of air, surface and sub-surface assets. Potential harassment would be from underwater detonation.

Tactics for neutralization of ground or bottom mines involve the diver placing a specific amount of explosives, which when detonated underwater at a specific distance from a mine results in neutralization of the mine. Floating, or moored, mines involve the diver placing a specific amount of explosives directly on the mine. Floating mines encountered by Fleet ships in open-ocean areas will be detonated at the surface. In support of an expeditionary assault, divers and Navy marine mammal assets deploy in very shallow water depths (10 to 40 feet) to locate mines and obstructions. Divers are transported to the mines by boat or helicopter. Inert dummy mines are used in the exercises. The total net explosive weight used against each mine ranges from less than 1 pound to 20 pounds.

Various types of surveying equipment may be used during mine detection. Examples include the Canadian Route Survey System that hydrographically maps the ocean floor using multi-beam side scan sonar and the Bottom Object Inspection Vehicle used for object identification. These units can help in supporting mine detection prior to Special Warfare Operations (SPECWAROPS) and amphibious exercises.

Mine neutralization operations take place offshore in the Puuloa Underwater Range (called Keahi Point in earlier documents); Naval Inactive Ship Maintenance Facility; Lima Landing; and in open-ocean areas.

All demolition activities are conducted in accordance with Commander, Naval Surface Forces Pacific (COMNAVSURFPAC) Instruction 3120.8F, Procedures for Disposal of Explosives at Sea/Firing of Depth Charges and Other Underwater Ordnance (Department of the Navy [DON], 2003).

Before any explosive is detonated, divers are transported a safe distance away from the explosive. Standard practices for tethered mines in Hawaiian waters require ground mine explosive charges to be suspended 10 feet below the surface of the water.

EER/IEER SSQ-110A

The Extended Echo Ranging and Improved Extended Echo Ranging (EER/IEER) Systems are airborne ASW systems used in conducting “large area” searches for submarines. These systems are made up of airborne avionics ASW acoustic processing and sonobuoy types that are deployed in pairs. The IEER System's active sonobuoy component, the AN/SSQ-110A Sonobuoy, would generate a sonar "ping" and the passive AN/SSQ-101 ADAR Sonobuoy would "listen" for the return echo of the sonar ping that has been bounced off the surface of a submarine. These sonobuoys are designed to provide underwater acoustic data necessary for naval aircrews to quickly and accurately detect submerged submarines. The sonobuoy pairs are dropped from a fixed-wing aircraft into the ocean in a predetermined pattern with a few buoys covering a very large area. The AN/SSQ-110A Sonobuoy Series is an expendable and commandable sonobuoy. Upon command from the aircraft, the bottom payload is released to sink to a designated operating depth. A second command is required from the aircraft to cause the second payload to release and detonate generating a “ping”. There is only one detonation in the pattern of buoys at a time.

Mitigation measures and modeling approaches are still being coordinated between the Navy and NMFS. Standard practice is that EER/IEER are not and will not be used during the winter months when humpback whales and other mysticetes are present. In addition, buoys are not dropped or activated if marine species are observed or marine mammals are acoustically detected.

For a separate but otherwise identical action, modeling of exposures from EER/IEER was undertaken for analysis of the Composite Training Unit Exercise/Joint Task Force Exercise COMPTUEX /JTFEX series of exercises in the waters of Southern California. Based on the results from modeling for Southern California where the densities of marine mammals are three orders of magnitude higher than in the HRC, there were only a few exposures resulting from the modeling. For the HRC where the density of marine mammals is much less, incorporating seasonal restrictions during the winter months when humpback and other mysticetes are present, along with the standard operating procedure (SOP) mitigation measures (such as command detonating the buoys only when marine mammals are not observed in the area or heard acoustically), it is very unlikely there will be any exposures exceeding the current regulatory thresholds or of consequence to marine species, and potential harassment is not anticipated. This conclusion will be confirmed through subsequent review and modeling or otherwise revised as necessary. Results will be provided to NMFS and will be included in the Final HRC EIS.

1.2.4 Proposed Action and Alternatives

No-Action Alternative (Current Baseline)

The No-Action Alternative includes the current level of training and test activities (which includes RIMPAC exercises). These or similar activities have been taking place in the HRC for decades. Under the No-Action Alternative, the current baseline of activities includes over 3,400 training and RDT&E operations (includes ASW and missile operations, occurs mostly at PMRF and Naval Undersea Warfare Command [NUWC] ranges) conducted in the Hawaii Range Complex annually. Under the No-Action Alternative, training operations, RDT&E activities, and Major Exercises would continue at the baseline levels (which include RIMPAC and USWEX exercises). The No-Action Alternative includes the activities implemented pursuant to the 1998 PMRF Final EIS, the additional PMRF programs analyzed since December 1998, and the activities described in the RIMPAC 2002 Programmatic Environmental Assessment (EA) and the supplements to that document in 2004 and 2006.

Alternative 1

Alternative 1 includes the activities described in the No-Action Alternative with the addition of increased training necessary to support the FRTP, Hawaii Range Complex Management Plan (RCMP) investments, planned RDT&E activities, and necessary force structure changes. Under Alternative 1, the Navy proposes to increase the tempo and frequency of training exercises in the HRC. The Navy proposes to continue RIMPAC and USWEX exercises described in the No-action Alternative. Under Alternative 1, RIMPAC would include two Strike Groups, and Fleet Carrier Landing Practices (FCLPs) would occur in association with transiting Strike Groups participating in Major Exercises. For RIMPAC under Alternative 1, the marine mammal exposure modeling included 1,064 hours of AN/SQS-53C (53C) surface ship sonar and associated dipping sonar, sonobuoys, and MK-48 torpedoes. For USWEX under Alternative 1, the marine mammal exposure modeling included 1,167 hours of 53C surface ship sonar and associated dipping sonar, and sonobuoys. For TRACKEX under Alternative 1, the marine mammal modeling included 1,440 hours of 53C surface ship sonar and associated sonobuoys. For TORPEX under Alternative 1, the marine mammal modeling included 356 hours of 53C surface ship sonar and associated sonobuoys.

Alternative 2 (Preferred Alternative)

Alternative 2 would include all of the activities described in Alternative 1 with the addition of Major Exercises, such as supporting a three strike group training exercise, increasing the tempo of training exercises, and additional RDT&E programs at PMRF. For RIMPAC under Alternative 2, the marine mammal exposure modeling included 1,064 hours of 53C surface ship sonar and associated dipping sonar, sonobuoys, and MK-48 torpedoes. For USWEX under Alternative 2, the marine mammal exposure modeling included 1,167 hours of 53C surface ship sonar and associated dipping sonar, and sonobuoys. For the three strike group training exercise under Alternative 2, the marine mammal exposure modeling included 944 hours of 53C surface ship sonar and associated dipping sonar, sonobuoys, and MK-48 torpedoes. For TRACKEX under Alternative 2, the marine mammal modeling included 1,592 hours of 53C surface ship sonar and associated sonobuoys. For TORPEX under Alternative 1, the marine mammal modeling included 414 hours of 53C surface ship sonar and associated sonobuoys. Under Alternative 2 the Navy proposes to increase the tempo and frequency of training exercises (above Alternative 1 levels) and compress the tempo of training exercises in the HRC. For example, instead of an exercise lasting 5 days, the same operations would be completed in 3 days. The frequency of exercises would also be increased.

2. DURATION AND LOCATION OF ACTIVITIES

Hawaii Range Complex (HRC) training events, including tracking exercises (TRACKEX), torpedo exercises (TORPEX), undersea warfare exercise (USWEX), and Multi Strike Group exercise would take place throughout the year from July 2008 through July 2013. Rim of the Pacific (RIMPAC) exercises occur every other year in the summer.

The Hawaii Range Complex consists of 235,000 square nautical miles (nm^2) of ocean, generally from 17 to 26 degrees north latitude and from 154 to 162 west longitude (Figure 2-1). The HRC is divided into open ocean and offshore areas:

- Open Ocean Area – air, surface, and subsurface areas of the HRC that lie outside of 12 nautical miles (nm) from land.
- Offshore Area – air, surface, and subsurface ocean areas within 12 nm of the Hawaiian Islands.

There are several range areas in the HRC that would be in use during HRC training that include ocean areas where marine mammals may be found (Figure 2-1). Most of the anti-submarine warfare (ASW) sonar exercises, including RIMPAC and USWEX, will occur in the open ocean area (beyond 12 nautical miles [nm]) and the Pacific Missile Range Facility (PMRF). Several of the underwater detonation events such as sinking exercises (SINKEX), bombing exercises (BOMBEX) and gunnery exercises (GUNEX) will also occur in the open ocean area and PMRF.

Underwater detonation events may occur in shallow water ranges such as Lima Landing or Pu'uloa Underwater Range on Oahu. Live-fire events (surface or just below surface detonations) or underwater detonations may occur at several nearshore areas with sparse marine mammal use such as Kaula Island, Kauai and underwater detonations may occur at nearshore areas with sparse marine mammal use such as Ewa Training Minefield, and within Pearl Harbor Channel on Oahu.

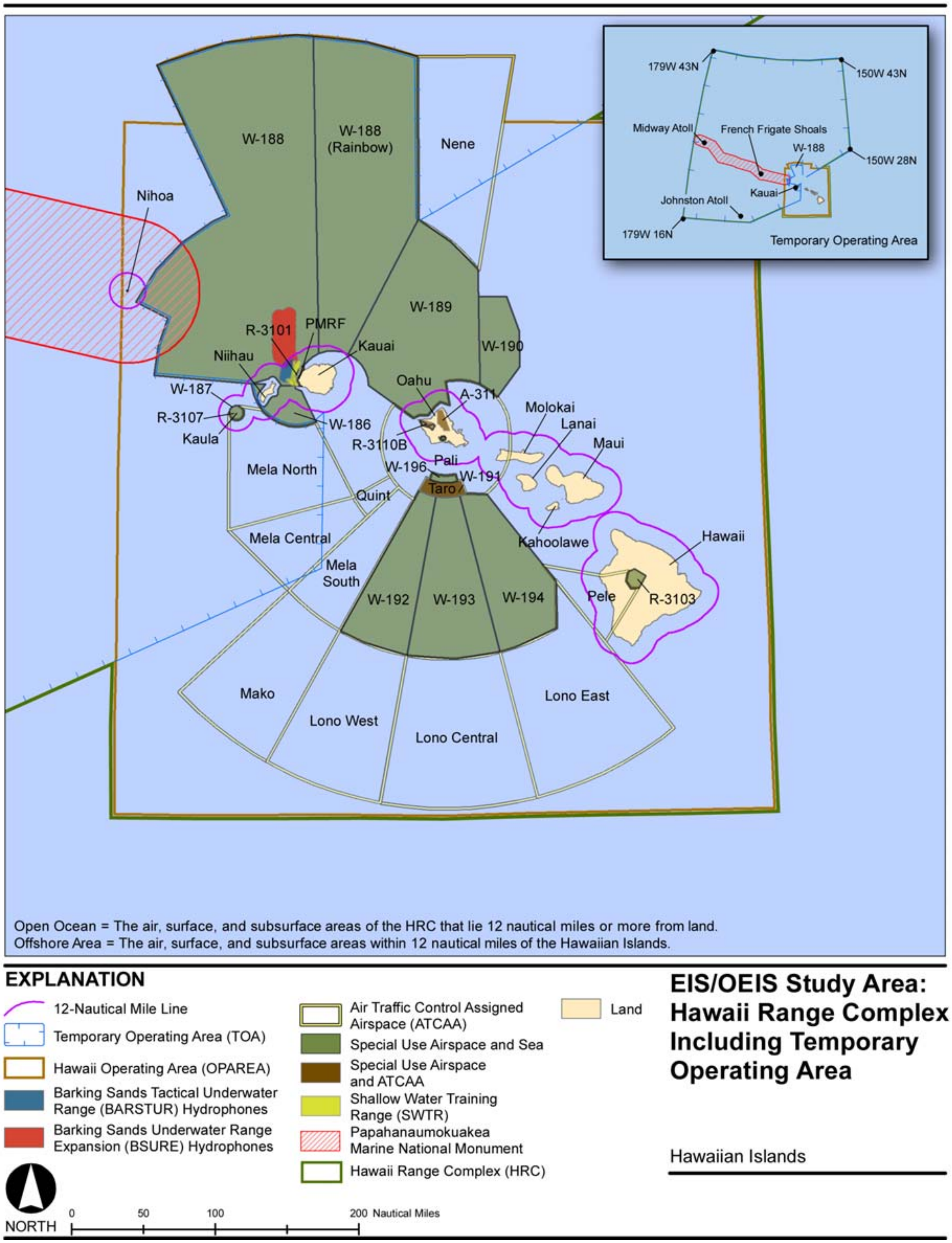


Figure 2-1. Map of the Hawaii Range Complex

3. MARINE MAMMAL SPECIES AND NUMBERS

The information contained in this Chapter relies heavily on the data gathered in the Marine Resources Assessment (MRA) for the Hawaiian Islands Operating Area (OPAREA) (Department of the Navy [DON], 2005). In addition, literature searches were conducted using the search engines: Biosis, Cambridge Abstract's Aquatic Sciences, University of California Melvyl, Biosis, and Zoological Record Plus. Searches were also conducted on peer review journals that regularly publish marine mammal related articles (e.g., Marine Mammal Science, Canadian Journal of Zoology, Journal of Acoustical Society of America, Journal of Zoology, Aquatic Mammals). References were also obtained from previous environmental documents from applicants or resource agencies, and mitigation or monitoring reports etc.

There are 27 marine mammal species with possible or confirmed occurrence in the Hawaiian Islands OPAREA. As shown in Table 3-1, there are 25 cetacean species (whales, dolphins, and porpoises) and two pinnipeds (seals).

3.1 Marine Mammal Occurrence

The MRA data, supplemented with other resources and more recent references, were used to provide a regional context for each species. The data were compiled from available sighting records, literature, satellite tracking, and stranding and bycatch data. The most abundant marine mammals are rough-toothed dolphins, dwarf sperm whales, and Fraser’s dolphins; the most abundant large whales are sperm whales (Barlow, 2003; 2006). There are three seasonally migrating baleen whale species that winter in Hawaiian waters including minke, fin, and humpback whales.

Seven marine mammal species listed as Federally-endangered under the Endangered Species Act (ESA), occur in the area: blue whale, fin whale, Hawaiian monk seal, humpback whale, North Pacific right whale, sei whale, and sperm whale. A separate consultation is underway with National Marine Fisheries Service (NMFS) to evaluate potential effects to these species under the ESA.

3.2 Estimated Marine Mammal Densities

Quantification of marine mammal distribution and abundance was accomplished by evaluating the spatial and temporal distribution and abundance of marine mammals throughout the Hawaiian Islands OPAREA. Marine mammal survey data for the offshore area beyond 25 nautical miles (nm) (Barlow, 2003; 2006) and survey data for nearshore areas (within 25 nm; Mobley et. al., 2000; Mobley, 2004) and data for monk seals (Carretta, 2005) provided marine mammal species density for modeling (Table 3-1).

The Mobley (2004) densities are applicable for areas within 25 nm of land, and the densities from Barlow are appropriate for areas beyond 25 nm. To determine how to use the different densities, each modeling area was examined to determine what percentage of the Hawaiian Islands OPAREA was within 25 nm of land. This was accomplished by using Nobeltec, a commercial visual navigational tool. The location of each anti-submarine warfare (ASW) modeling area was placed on a map overlay. Circles with 25 nm radii were drawn from locations on the closest land masses. The percentage of the ASW modeling area within 25 nm of land was calculated. Table 3-1 presents these results. In the final calculation of the exposure estimates, the densities were applied with the same percentages.

Table 3-1. Summary of Marine Mammal Species, Status, and Abundance in the HRC

Order Cetacea	Scientific Name	Status	Occurs[1]	Group Size[2]	Detection Probability[3] Group 1-20	Group >20	Overall Abundance
ESA SPECIES							
Blue whale	*Balaenoptera musculus*	E	Rare				UNK
Fin whale	*Balaenoptera physalus*	E	Rare	2.6	0.90	0.90	236 [4]
Humpback whale	*Megaptera novaeangliae*	E	Regular	1.7			4,491
No. Pacific right whale	*Eubalaena japonica*	E	Rare				UNK
Sei whale	*Balaenoptera borealis*	E	Rare	3.4	0.90	0.90	236 [4]
Sperm whale	*Physeter macrocephalus*	E	Regular	7.3	0.87	0.87	6,919
Hawaiian monk seal	*Monachus schauinslandi*	E	Regular				1,252 (52)[5]
MYSTICETES (baleen whales)							
Bryde's whale	*Balaenoptera edeni/brydei**		Regular	1.5	0.90	0.90	469
Minke whale	*Balaenoptera acutorostrata*		Rare				UNK
ODONTOCETES (toothed whales)							
Blainville's beaked whale	*Mesoplodon densirostris*		Regular	2.3	0.45	0.45	2,872
Bottlenose dolphin	*Tursiops truncatus*		Regular	9.0	0.76	1.00	3,215
Cuvier's beaked whale	*Ziphius cavirostris*		Regular	2.0	0.23	0.23	15,242
Dwarf sperm whale	*Kogia sima*		Regular	2.3	0.35	0.35	17,519
False killer whale	*Pseudorca crassidens*		Regular	10.3	0.76	1.00	236
Fraser's dolphin	*Lagenodelphis hosei*		Rare	286.3	0.76	1.00	10,226
Killer whale	*Orcinus orca*		Regular	6.5	0.90	0.90	349
Longman's beaked whale	*Indopacetus pacificus*		Regular	17.8	0.76	0.96	1,007
Melon-headed whale	*Peponocephala electra*		Regular	89.2	0.76	1.00	2,950
Pantropical spotted dolphin	*Stenella attenuata*		Regular	60.0	0.76	1.00	8,978
Pygmy killer whale	*Feresa attenuata*		Regular	14.4	0.76	1.00	956
Pygmy sperm whale	*Kogia breviceps*		Regular	1.0	0.35	0.35	7,138
Risso's dolphin	*Grampus griseus*		Regular	15.4	0.76	1.00	2,372
Rough-toothed dolphin	*Steno bredanensis*		Regular	14.8	0.76	1.00	8,709
Short-finned pilot whale	*Globicephala macrorhynchus*		Regular	22.5	0.76	1.00	8,870
Spinner dolphin	*Stenella longirostris*		Regular	31.7	0.76	1.00	3,351
Striped dolphin	*Stenella coeruleoalba*		Regular	37.3	0.76	1.00	13,143
PINNIPEDS (seals, sea lions, walruses)							
Northern elephant seal	*Mirounga angustirostris*		Rare				

Source: U.S. Department of the Navy 2005a; Barlow, 2003; 2006; Mobley, 2004; Carretta, 2005
Notes: Taxonomy follows Rice (1998) for pinnipeds and sirenians and the International Whaling Commission (2004) for cetaceans
[1] Occurrence: **Regular** = A species that occurs as a regular or normal part of the fauna of the area, regardless of how abundant or common it is; **Rare** = A species that only occurs in the area sporadically; *includes more than one species, but nomenclature is still unsettled.
[2] Mean group sizes are the geometric mean of best estimates from multiple observers and have not been corrected for bias.
[3] Barlow (2003)
[4] For analysis purposes, density was assumed to be the same as for false killer whale which has a similar population size to fin and sei whales.
[5] Most monk seals inhabit the Northwest Hawaiian Islands outside of the HRC, only 52 monk seals have been counted in the Main Hawaiian Islands within the HRC.
E = Endangered
UNK = Unknown

Barlow (2003) gave population estimates of 77 for the sei whale and 174 for the fin whale but later removed those estimates because the survey was conducted at the end of the period when fin and sei whales are present in the Hawaiian Islands (Barlow, 2006). Although there are no current population numbers for these species in the Hawaii Range Complex (HRC), they do occur during the winter. Therefore, for exposure analysis purposes, the density of fin and sei whales was assumed to be similar to false killer whales which have a similar population size (236 false killer whales; Barlow, 2006).

4. AFFECTED SPECIES STATUS AND DISTRIBUTION

Marine mammals inhabit most marine environments from deep ocean canyons to shallow estuarine waters. They are not randomly distributed. Marine mammal distribution is affected by demographic, evolutionary, ecological, habitat-related, and anthropogenic factors (Bowen et al., 2002; Bjørge, 2002; Forcada, 2002; Stevick et al., 2002). Section 4.1 includes a general description of the marine mammals that may occur within the Hawaii Range Complex (HRC). Endangered marine mammals are presented first, with the remaining species following the order presented in Table 3-1.

Marine mammal movements are often related to feeding or breeding activity (Stevick et al., 2002). A migration is the periodic movement of all, or significant components of an animal population from one habitat to one or more other habitats and back again. Migration is an adaptation that allows an animal to monopolize areas where favorable environmental conditions exist for feeding, breeding, and/or other phases of the animal's life history. Some baleen whale species, such as humpback 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). Cetacean movements can also reflect the distribution and abundance of prey (Gaskin, 1982; Payne et al., 1986; Kenney et al., 1996). Cetacean movements have also been linked to indirect indicators of prey, such as temperature variations, sea-surface chlorophyll-*a* concentration, and features such as bottom depth (Fiedler, 2002). Oceanographic conditions such as upwelling zones, eddies, and turbulent mixing can create regionalized zones of enhanced productivity that are translated into zooplankton concentrations, and/or entrain prey.

The oceanic waters surrounding the Hawaiian Islands do not contain a true continental shelf, and therefore no true shelf break—the region in which there is a sharp break in the slope of the island shelf (Kennett, 1982; Thurman, 1997). Rather, the Hawaiian Islands Operating Area (OPAREA) and vicinity is composed of a series of volcanic seamounts, several of which have broken the surface to form the Hawaiian Islands. Seamount topography has been previously correlated with enhanced production due to the formation of vortices capable of mixing nutrients to the surface and entraining phytoplankton in the overlying waters (reviewed by Rogers, 1994).

In addition, the passage of the North Equatorial Current through the Hawaiian archipelago is capable of creating regions of enhanced turbulence. Passage of the current of the North Equatorial Current can initiate the formation of eddies on the lee side of the islands (Wolanski et al., 2003); these are capable of entraining phytoplankton and creating localized regions of enhanced primary production. Passage of currents through a narrow channel (as found in the Alenuehaha Channel between Hawaii and Maui) can also create localized zones of turbulent flow capable of mixing nutrients into the surface layer to fuel primary production (Gilmartin and Revelante, 1974; Simpson et al., 1982).

4.1 Threatened and Endangered Marine Mammals of the Hawaii Range Complex

There are seven marine mammal species that are listed as endangered under the Endangered Species Act (ESA) with confirmed or possible occurrence in the study area. These include the blue whale, fin whale, Hawaiian monk seal, humpback whale, North Pacific right whale, sei whale, and sperm whale. The humpback whale, sperm whale, and the Hawaiian monk seal are expected to regularly occur in the Hawaiian Islands OPAREA. Definitive information on sei and fin whales is lacking, and based on limited observations, their occurrence was assumed although considered unlikely. Each marine mammal species is described below with available stock, status, distribution, diving behavior and acoustic information.

4.1.1 Blue Whale (*Balaenoptera musculus*)

Stock. Western North Pacific

Status. The blue whale is listed as endangered under the ESA and as a depleted and strategic stock under the Marine Mammal Protection Act (MMPA). The National Marine Fisheries Service (NMFS) considers blue whales found in Hawaii as part of the Western North Pacific stock (Carretta et al., 2005) due to differences in call types with the Eastern North Pacific stock (Stafford et al., 2001; Stafford, 2003). The blue whale was severely depleted by commercial whaling in the twentieth century (NMFS, 1998). There is no designated critical habitat for this species in the North Pacific. There is no information on the population trend of blue whales.

Distribution. Blue whales are distributed from the ice edges to the tropics in both hemispheres (Jefferson et al., 1993). Blue whales migrate to high latitudes in the summer and move into the subtropics and tropics during the winter for calving season (Yochem and Leatherwood, 1985). Data from both the Pacific and Indian Oceans, however, indicate that some individuals may remain in low latitudes year-round, such as over the Costa Rican Dome (Wade and Friedrichsen, 1979; Reilly and Thayer, 1990). The productivity of the Costa Rican Dome may allow blue whales to feed during their winter calving/breeding season and not fast, like humpback whales (Mate et al., 1999).

The only reliable sighting report of this species in the central North Pacific was a sighting made from a scientific research vessel about 216 nm northeast of Hawaii in January 1964 (NMFS, 1998). There is a rare occurrence for the blue whale throughout the year throughout the entire HRC. Blue whale calls have been recorded off Midway and Oahu (Northrop et al., 1971; Thompson and Friedl, 1982; McDonald and Fox, 1999); these provide evidence of blue whales occurring within several hundred kilometers of these islands (NMFS, 1998). The recordings made off Oahu showed bimodal peaks throughout the year, suggesting that the animals were migrating into the area during summer and winter (Thompson and Friedl, 1982; McDonald and Fox, 1999). The greatest likelihood of encountering blue whales would be in waters greater than 100 m, based on observations in locales that blue whales are seen regularly (Schoenherr, 1991).

Diving Behavior. Blue whales spend more than 94 percent of their time below the water's surface (Lagerquist et al., 2000). Croll et al. (2001) determined that blue whales dived to an average of 462 ft. and for 7.8 minutes (min) when foraging and to 222 ft. and for 4.9 min when not foraging. Calambokidis et al. (2003) deployed tags on blue whales and collected data on dives as deep as about 164 fathoms.

Acoustics. Blue and fin whales produce calls with the lowest frequency and highest source levels of all cetaceans. Blue whale vocalizations are long, patterned low-frequency sounds with durations up to 36 sec (Richardson et al., 1995) repeated every 1 to 2 min (Mellinger and Clark, 2003). Their frequency range is 12 to 400 hertz (Hz), with dominant energy in the infrasonic range at 12 to 25 Hz (Ketten, 1998; Mellinger and Clark, 2003). Source levels are up to 188 decibels (dB) re 1 µPa-m (Ketten, 1998; McDonald et al., 2001). During the Magellan II Sea Test (at-sea exercises designed to test systems for antisubmarine warfare), off the coast of

California in 1994, blue whale vocalization source levels at 17 Hz were estimated in the range of 195 dB re 1 µPa-m (Aburto et al., 1997).

Vocalizations of blue whales appear to vary among geographic areas (Rivers, 1997), with clear differences in call structure suggestive of separate populations for the western and eastern regions of the North Pacific (Stafford et al., 2001). Stafford et al. (2005) recorded the highest calling rates when blue whale prey was closest to the surface during its vertical migration. Wiggins et al. (2005) reported the same trend of reduced vocalization during daytime foraging and then an increase in vocalizations at dusk as prey move up into the water column and disperse. Blue whales make seasonal migrations to areas of high productivity to feed and vocalize less in the feeding grounds than during the migration (Burtenshaw et al., 2004). Oleson et al. (2007) reported higher calling rates in shallow diving (<100 ft) whales while deeper diving whales (> 165 ft) were likely feeding and calling less. While no data on hearing ability for this species are available, Ketten (1997) hypothesized that mysticetes have acute infrasonic hearing.

4.1.2 Fin Whale (*Balaenoptera physalus*)

Stock. Hawaiian

Status. The fin whale is listed as endangered under the ESA and as a depleted and strategic stock under the MMPA. There is no designated critical habitat for this species in the North Pacific. The International Whaling Commission (IWC) recognizes two management stocks in the North Pacific: a single widespread stock in the North Pacific and a smaller stock in the East China Sea (Donovan, 1991). The National Oceanic and Atmospheric Administration (NOAA) stock assessment report recognizes three stocks of fin whales in the North Pacific: (1) the Hawaii stock; (2) the California/Oregon/Washington stock; and (3) the Alaska stock (Carretta et al., 2005). There is no information on the population trend of fin whales.

Abundance and Distribution. Barlow (2006) did not give a density estimate for fin whales in Hawaii because the survey (originally analyzed in Barlow 2003) was not conducted during the peak period of abundance. Therefore, for the analysis undertaken in support of this Letter of Authorization (LOA), it was assumed that the number and density of fin whales did not exceed that of the small population of false killer whales (236 false killer whales in Hawaii). There is no information on the population trend of fin whales. Fin whales are broadly distributed throughout the world's oceans, usually in temperate to polar latitudes, and less commonly in the tropics (Reeves et al., 2002). Fin whales are distributed across the North Pacific during the summer (May through October) from the southern Chukchi Sea (69°N) south to the Sub-arctic Boundary (approximately 42°N) and to 30°N in the California Current (Mizroch et al., 1999). They have been observed during the summer in the central Bering Sea (Moore et al., 2000).

Fin whales are not common in the Hawaiian Islands. Sightings were reported north of Oahu in May 1976, the Kauai Channel in February 1979, and north of Kauai during February 1994 (Shallenberger, 1981; Mobley et al., 1996). Thompson and Friedl (1982) suggested that fin whales migrate into Hawaiian waters mainly during fall and winter, based on acoustic recordings off the islands of Oahu and Midway (Northrop et al., 1971; McDonald and Fox, 1999). Primary occurrence is expected seaward of the 330 feet (ft) isobath during the fall-winter period to account for possible stragglers migrating through the area. There is a rare occurrence for the fin whale from the shore to the 330 ft isobath. There is a rare occurrence of fin whales throughout the Hawaiian Islands during the spring-summer period.

Diving Behavior. Fin whales typically dive for 5 to 15 min, separated by sequences of 4 to 5 blows at 10 to 20 sec intervals (Cetacean and Turtle Assessment Program, 1982; Stone et al., 1992; Lafortuna et al., 2003). Kopelman and Sadove (1995) found significant differences in blow intervals, dive times, and blows per hour between surface feeding and non-surface-feeding fin whales. Croll et al. (2001) determined that fin whales dived to 53.5 fathoms (Standard Deviation [SD] = ± 17.82) with a duration of 6.3 min (SD = ± 1.53 min) when foraging and to 32.4 fathoms (SD = ± 16.22 fathoms) with a duration of 4.2 min (SD = ± 1.67 min) when not foraging. Goldbogen et al. (2006) reported that fin whales in California made foraging dives to a maximum of 748-889 ft and dive durations of 6.2-7.0 min. Fin whale dives exceeding 82 fathoms and coinciding with the diel migration of krill were reported by Panigada et al. (1999).

Acoustics. Fin and blue whales produce calls with the lowest frequency and highest source levels of all cetaceans. Infrasonic, pattern sounds have been documented for fin whales (Watkins et al., 1987; Clark and Fristrup, 1997; McDonald and Fox, 1999). Fin whales produce a variety of sounds with a frequency range up to 750 Hz. The long, patterned 15 to 30 Hz vocal sequence is most typically recorded; only males are known to produce these (Croll et al., 2002). The most typical fin whale sound is a 20 Hz infrasonic pulse (actually an FM sweep from about 23 to 18 Hz) with durations of about 1 sec and can reach source levels of 184 to 186 dB re 1 µPa-m (maximum up to 200) (Richardson et al., 1995; Charif et al., 2002). Croll et al. (2002) recently suggested that these long, patterned vocalizations might function as male breeding displays, much like those that male humpback whales sing. The source depth, or depth of calling fin whales, has been reported to be about 162 ft (Watkins et al., 1987). While no data on hearing ability for this species are available, Ketten (1997) hypothesized that mysticetes have acute infrasonic hearing.

4.1.3 Humpback Whale (*Megaptera novaeangliae*)

Stock. Central North Pacific. Evidence suggests that some humpback whales may move between the waters of Japan in the Western North Pacific (Darling and Cerchio, 1993; Salden, et al., 1999; Calambokidis et al., 2001; Witteveen et al., 2004).

Status. The humpback whale is listed as endangered under the ESA and as a depleted and strategic stock under the MMPA (Carretta et al., 2005). There is no designated critical habitat for this species in the North Pacific.

Abundance and Distribution. While the NOAA Hawaiian Islands Humpback Whale National Marine Sanctuary website and local newspapers speculate that there are as many as 10,000 humpback whales in Hawaiian waters, the only scientifically verifiable abundance estimate comes from the 2006 NMFS Stock Assessment for the Central North Pacific. Based on Mobley (2004) the stock assessment determines there are 4,491 humpback whales in the Hawaiian Islands in the winter. Humpback whales use Hawaiian waters as a major breeding ground during winter and spring (November through April). Calambokidis et al. (1997) estimated that up to half of the North Pacific population of humpback whales migrates to the Hawaiian Islands during the winter. Peak abundance around the Hawaiian Islands is from late February through early April (Mobley et al., 2001; Carretta et al., 2005). During the fall-winter period, primary occurrence is expected from the coast to 50 nm offshore, which takes into consideration both the available sighting data and the preferred breeding habitat (shallow waters) (Herman and Antinoja, 1977; Mobley et al., 1999, 2000, 2001). The greatest densities of humpback whales (including calves) are in the four-island region consisting of Maui, Molokai, Kahoolawe, and

Lanai, as well as Penguin Bank (Baker and Herman, 1981; Mobley et al., 1999; Maldini, 2003) and around Kauai (Mobley, 2005). Secondary occurrence is expected from seaward of this area, past the HRC boundaries. Humpback whales are not expected to be in Pearl Harbor, though an anomalous sighting of an adult and calf was reported during 1998 and 2003 (DON, 2005). The occurrence of humpback whales in deeper waters is based on work in the Caribbean (the breeding ground for humpback whales in the North Atlantic), where humpback whale calls were acoustically detected over deep water, far from any banks or islands (Swartz et al., 2002).

During the spring–summer period, secondary occurrence is expected offshore out to 50 nm, mainly to account for the possible occurrence of humpback whales during the end of the breeding season (April). Occurrence further offshore, as well as in Pearl Harbor, is expected to be rare.

The Hawaiian Islands Humpback Whale National Marine Sanctuary was signed into law in November 1992. The Final Environmental Impact Statement (FEIS)/Management Plan was released in March 1997, and the final rule was published in November 1999. Activities allowed within the Sanctuary are all classes of military activities, internal or external to the Sanctuary, that were being, or have been, conducted before the effective date of the regulations, as identified in the Final EIS/Management Plan. The sanctuary includes specific areas from the coast of the Hawaiian Islands seaward to the 600 ft isobath.

<u>Diving Behavior</u>. Humpback whale diving behavior depends on the time of year (Clapham and Mead, 1999). In summer, most dives last less than 5 min; those exceeding 10 min are atypical. In winter (December through March), dives average 10 to 15 min; dives of greater than 30 min have been recorded (Clapham and Mead, 1999). Although humpback whales have been recorded to dive as deep as about 1,638 ft (Dietz et al., 2002), on the feeding grounds they spend the majority of their time in the upper 400 ft of the water column (Dolphin, 1987; Dietz et al., 2002). Humpback whales on the wintering grounds do dive deeply; Baird et al. (2000) recorded dives to 577 ft.

<u>Acoustics</u>. Humpback whales are known to produce three classes of vocalizations: (1) “songs” in the late fall, winter, and spring by solitary males; (2) sounds made within groups on the wintering (calving) grounds; and (3) social sounds made on the feeding grounds (Richardson et al., 1995). The best-known types of sounds produced by humpback whales are songs, which are thought to be breeding displays used only by adult males (Helweg et al., 1992). Singing is most common on breeding grounds during the winter and spring months, but is occasionally heard outside breeding areas and out of season (Matilla et al., 1987; Clark and Clapham, 2004). There is geographical variation in humpback whale song, with different populations singing different songs, and all members of a population using the same basic song. However, the song evolves over the course of a breeding season, but remains nearly unchanged from the end of one season to the start of the next (Payne et al., 1983). Social calls are from 50 Hz to over 10 kilohertz (kHz), with the highest energy below 3 kHz (Silber, 1986). Female vocalizations appear to be simple; Simão and Moreira (2005) noted little complexity. The male song, however, is complex and changes between seasons. Components of the song range from under 20 Hz to 4 kHz and occasionally 8 kHz, with source levels of 144 to 174 dB re 1 µPa m, with a mean of 155 dB re 1 µPa-m (Thompson et al., 1979; Payne and Payne 1985). Au et al. (2001) recorded high-frequency harmonics (out to 13.5 kHz) and source level (between 171 and 189 dB re 1 µPa-m) of humpback whale songs. Songs have also been recorded on feeding grounds (Mattila et al., 1987; Clark and Clapham, 2004).

The main energy lies between 0.2 and 3.0 kHz, with frequency peaks at 4.7 kHz. Feeding calls, unlike song and social sounds, are highly stereotyped series of narrow-band trumpeting calls. They are 20 Hz to 2 kHz, less than 1 sec in duration, and have source levels of 175 to 192 dB re 1 µPa-m. The fundamental frequency of feeding calls is approximately 500 Hz (D'Vincent et al., 1985).

No tests on humpback whale hearing have been made. Houser *et al*. (2001) constructed a humpback audiogram using a mathematical model based on the internal structure of the ear. The predicted audiogram indicates sensitivity to frequencies from 700 Hz to 10 kHz, with maximum relative sensitivity between 2 and 6 kHz. Maybaum (1989) reported that humpback whales showed a mild response to a hand held sonar marine mammal detection and location device (frequency of 3.3 kHz at 219 dB re 1µPa @ 1 meter or frequency sweep of 3.1-3.6 kHz) although this system is very different from the Navy's haul mounted sonars. In addition, the system had some low frequency components (below 1 kHz) which may be an artifact of the acoustic equipment. This may have affected the response of the whales to both the control and sonar playbacks. Humpback whales also stop singing in response to playbacks of the singing or social sounds of conspecifics (Tyack, 1983). Miller et al. (2000) reported that humpback whales sang longer during playbacks of low-frequency active sonar which is much lower in frequency than the mid-frequency active sonar proposed in this EIS. Recent information on the songs of humpback whales suggests that their hearing may extend to frequencies of at least 24 kHz and source levels of 151-173 dB re 1µPa (Au et al., 2006).

4.1.4 North Pacific Right Whale (*Eubalaena japonica*)

Stock. Eastern North Pacific

Status. The north Pacific right whale is listed as endangered under the ESA and as a depleted and strategic stock under the MMPA (Carretta et al., 2005). Until recently, right whales in the North Atlantic and North Pacific were classified together as a single species, referred to as the "northern right whale." Genetic data indicate that these two populations represent separate species: the North Atlantic right whale (*Eubalaena glacialis*) and the North Pacific right whale (*Eubalaena japonica*) (Rosenbaum et al., 2000) and NOAA has proposed to officially recognize *E. japonica* as a separate species (NMFS, 2006).

The North Pacific right whale is perhaps the world's most endangered large whale species (Perry et al., 1999; IWC, 2001). North Pacific right whales are classified as endangered both under the ESA and on the World Conservation Union (IUCN) Red List (Reeves et al., 2003). There are insufficient genetic or resighting data to address whether there is support for the traditional separation into eastern and western stocks (Brownell et al., 2001); however, Clapham et al. (2004) noted that north–south migratory movements support the hypothesis of two largely discrete populations of right whales in the eastern and western North Pacific. No reliable population estimate presently exists for this species; the population in the eastern North Pacific is considered to be very small, perhaps only in the tens of animals (NMFS, 2002; Clapham et al., 2004), while in the western North Pacific, the population may number at least in the low hundreds (Brownell et al., 2001; Clapham et al., 2004). There is no proposed or designated critical habitat for the North Pacific right whale in the HRC.

Abundance and Distribution. Right whales occur in sub-polar to temperate waters. The North Pacific right whale historically occurred across the Pacific Ocean north of 35 degrees north, with concentrations in the Gulf of Alaska, eastern Aleutian Islands, south-central Bering Sea, Sea of

Okhotsk, and the Sea of Japan (Omura et al., 1969; Scarff, 1986; Clapham et al., 2004). Presently, sightings are extremely rare, occurring primarily in the Okhotsk Sea and the eastern Bering Sea (Brownell et al., 2001; Shelden et al., 2005). Prior to 1996, right whale sightings were very rare in the eastern North Pacific (Scarff, 1986; Brownell et al., 2001). Recent summer sightings of right whales in the eastern Bering Sea represent the first reliable consistent observations in this area since the 1960s (Tynan et al., 2001; LeDuc, 2001). Neither the west coast of North America nor the Hawaiian Islands constituted a major calving ground for right whales within the last 200 years (Scarff, 1986). No coastal calving grounds for right whales have been found in the western North Pacific either (Scarff, 1986). Mid-ocean whaling records of right whales in the winter suggest that right whales may have wintered and calved far offshore in the Pacific (Scarff, 1986; 1991; Clapham et al., 2004). Such pelagic calving would appear to be inconsistent with the records of offshore calving grounds in other locales for the other right whale species.

There are very few recorded sightings from the Hawaiian Islands; they are from both shallow and deep waters (Herman et al., 1980; Rowntree et al., 1980; Salden and Mickelsen, 1999). Secondary occurrence is expected from the coastline to seaward of the HRC boundaries. Right whales are not expected to make their way into lagoons or busy harbors; therefore, occurrence in Pearl Harbor is expected to be rare (DON, 2005). Right whale occurrence patterns are assumed to be similar throughout the year. Based on migration patterns and whaling data, the Hawaiian Islands may have been a breeding ground for North Pacific right whales in the past (Clapham et al., 2004).

Diving Behavior. Dives of 5 to 15 min or even longer have been reported (Winn et al., 1995; Mate et al., 1997; Baumgartner and Mate, 2003). Baumgartner and Mate (2003) found that the average depth of a North Atlantic right whale dive was strongly correlated with both the average depth of peak copepod abundance and the average depth of the bottom mixed layer's upper surface. North Atlantic right whale feeding dives are characterized by a rapid descent from the surface to a particular depth between 262 and 574 ft, remarkable fidelity to that depth for 5 to 14 min and then rapid ascent back to the surface (Baumgartner and Mate, 2003). Longer surface intervals have been observed for reproductively active females and their calves (Baumgartner and Mate, 2003).

Acoustics. North Pacific right whale calls are classified into five categories: (1) up; (2) down-up; (3) down; (4) constant; and (5) unclassified (McDonald and Moore, 2002). The 'up' call is the predominant type (McDonald and Moore, 2002; Mellinger et al., 2004). Typically, the 'up' call is a signal sweeping from about 90 to 150 Hz in 0.7 sec (McDonald and Moore, 2002; Wiggins et al., 2004). Right whales commonly produce calls in a series of 10 to 15 calls lasting 5 to 10 min, followed by silence lasting an hour or more; some individuals do not call for periods of at least 4 hours (McDonald and Moore, 2002). This calling pattern is similar to the 'moan cluster' reported for North Atlantic right whales by Matthews et al. (2001). Vocalization rates of North Atlantic right whales are also highly variable, and individuals have been known to remain silent for hours (Gillespie and Leaper, 2001).

Frequencies of these vocalizations are between 50 and 500 Hz (Matthews et al., 2001; Laurinolli et al., 2003); typical sounds are in the 300 to 600 Hz range with up- and down-sweeping modulations (Vanderlaan et al., 2003). Vanderlaan et al. (2003) found that lower (<200 Hz) and higher (>900 Hz) frequency sounds are relatively rare. Source levels have been estimated only for pulsive calls of North Atlantic right whales, which are 172 to 187 dB, with a reference pressure of one micropascal (µP) at one meter (dB re 1 µPa-m) (Richardson et al., 1995).

Morphometric analyses of the inner ear of right whales resulted in an estimated hearing frequency range of approximately 10 Hz to 22 kHz, based on established marine mammal models (Parks et al., 2004). Research by Nowacek et al. (2004) on North Atlantic right whales suggests that received sound levels of only 133 to 148 dB re 1 µPa-m for the duration of the sound exposure are likely to disrupt feeding behavior. The authors did note, however, that a return to normal behavior within minutes of when the source is turned off would be expected. While some of the upper frequencies approach those of mid-frequency active sonar, the signal is not similar because they were either too low in frequency range or longer and contains a down sweep signal 4500 – 500 Hz.

4.1.5 Sei Whale (*Balaenoptera borealis*)

Stock. Hawaiian

Status. The sei whale is listed as endangered under the ESA and as a depleted and strategic stock under the MMPA (Carretta et al., 2005). The IWC designates the entire North Pacific Ocean as one sei whale stock unit (Donovan, 1991), although some evidence exists for multiple stocks (NMFS, 1998; Carretta et al., 2005). For the NOAA stock assessment reports, sei whales within the Pacific exclusive economic zone (EEZ) are divided into three discrete, non-contiguous areas: (1) the Hawaiian stock; (2) California/ Oregon/Washington stock; and (3) the Eastern North Pacific (Alaska) stock (Carretta et al., 2005).

The taxonomy of the baleen whale group formerly known as sei and Bryde's whales is currently confused and highly controversial (see Reeves et al., 2004) for a recent review, also see the Bryde's whale species account below for further explanation).

Abundance and Distribution. Barlow (2006) did not give a density estimate for sei whales in Hawaii because the survey (originally analyzed in Barlow, 2003) was not conducted during the peak period of abundance. Therefore, for the analysis undertaken in support of this LOA, it was assumed that the number and density of sei whales did not exceed that of the small population of false killer whales (236 false killer whales in Hawaii). There is no information on the population trend of sei whales. Sei whales have a worldwide distribution, but are found primarily in cold temperate to sub-polar latitudes, rather than in the tropics or near the poles (Horwood, 1987). Sei whales are also known for occasional irruptive occurrences in areas followed by disappearances for sometimes decades (Horwood, 1987; Schilling et al., 1992; Clapham et al., 1997).

Sei whales spend the summer months feeding in the sub-polar higher latitudes and return to the lower latitudes to calve in winter. There is some evidence from whaling catch data of differential migration patterns by reproductive class, with females arriving at and departing from feeding areas earlier than males (Horwood, 1987; Perry et al., 1999). For the most part, the location of winter breeding areas remains a mystery (Rice, 1998; Perry et al., 1999). In the North Pacific, sei whales are thought to occur mainly south of the Aleutian Islands. They are present all across the temperate North Pacific north of 40°N (NMFS, 1998b) and are seen at least as far south as 20°N (Horwood, 1987). In the east, they range as far south as Baja California, Mexico, and in the west, to Japan and Korea (Reeves et al., 1999). As noted by Reeves et al. (1999), reports in the literature from any time before the mid-1970s are suspect, because of the frequent failure to distinguish sei from Bryde's whales, particularly in tropical to warm temperate waters where Bryde's whales are generally more common than sei whales.

The sei whale is considered to be rare in Hawaiian waters based on reported sighting data and the species' preference for cool, temperate waters. Secondary occurrence is expected seaward of the 9,840 ft isobath on the north side of the islands only. This pattern was based on sightings made during the NMFS–Southwest Fisheries Science Center shipboard survey assessment of Hawaiian cetaceans (Barlow et al., 2004). Sei whales are expected to be rare throughout the remainder of the HRC. Occurrence patterns are expected to be the same throughout the year (DON, 2005).

Diving Behavior. There are no reported diving depths or durations for Sei whales.

Acoustics. Sei whale vocalizations have been recorded only on a few occasions. They consist of paired sequences (0.5 to 0.8 sec, separated by 0.4 to 1.0 sec) of 7 to 20 short (4 milliseconds [msec]) frequency modulated sweeps between 1.5 and 3.5 kHz; source level is not known (Richardson et al. 1995). Sei whales in the Antarctic produced broadband "growls" and "whooshes" at frequency of 433 ±192 kHz and source level of 156 ±3.6 dB re 1 µPa at 1 m (Mc Donald et al., 2005).

While no data on hearing ability for this species are available, Ketten (1997) hypothesized that mysticetes have acute infrasonic hearing.

4.1.6 Sperm Whale (*Physeter macrocephalus*)

Stock. Hawaiian

Status. The sperm whale is listed as endangered under the ESA and as a depleted and strategic stock under the MMPA (Carretta et al., 2005). There is no designated critical habitat for this species in the North Pacific. Although many sperm whale populations have been depleted to varying degrees by past whaling activities, sperm whales remain one of the more globally common great whale species. In fact, in some areas, they are actually quite abundant. For example, there are estimated to be about 21,200 to 22,700 sperm whales in the eastern tropical Pacific Ocean (Wade and Gerrodette, 1993).

For management purposes, the IWC has divided the North Pacific into two management regions defined by a zigzag line which starts at 150°W at the equator, is at 160°W between 40° to 50°N, and ends up at 180°W north of 50°N (Donovan, 1991). Preliminary genetic analyses reveal significant differences between sperm whales off the coast of California, Oregon, and Washington and those sampled offshore to the Hawaiian Islands (Mesnick et al., 1999; Carretta et al., 2005). The NOAA stock assessment report divides sperm whales within the U.S. Pacific EEZ into three discrete, noncontiguous areas: (1) waters around the Hawaiian Islands, (2) California, Oregon, and Washington waters, and (3) Alaskan waters (Carretta et al., 2005). The best available abundance estimate for the Hawaiian Islands stock of the sperm whale is 7,082 (coefficient of variation [CV] = 0.30) individuals (Barlow, 2003; Carretta et al., 2005). Sperm whale abundance in the eastern temperate North Pacific is estimated to be 32,100 individuals and 26,300 individuals by acoustic and visual detection methods, respectively (Barlow and Taylor, 2005).

Abundance and Distribution. The best available estimate of abundance for the Hawaiian stock of the sperm whale is 6,919 (CV = 0.81) individuals (Barlow, 2006). Sperm whales are found from tropical to polar waters in all oceans of the world between approximately 70°N and 70°S (Rice, 1998). Females use a subset of the waters where males are regularly found. Females are normally restricted to areas with sea surface temperatures greater than approximately 15°C, whereas males, especially the largest males, can be found in waters as far poleward as the pack ice within approximately to the 40° parallels (50° in the North Pacific) (Whitehead, 2003).

Sperm whales are widely distributed throughout the Hawaiian Islands year-round (Rice, 1960; Shallenberger, 1981; Lee, 1993; and Mobley et al., 2000). Sperm whale clicks recorded from hydrophones off Oahu confirm the presence of sperm whales near the Hawaiian Islands throughout the year (Thompson and Friedl, 1982). Globally, sperm whales are typically distributed in waters over the shelf break and continental slope. The primary area of occurrence for the sperm whale is seaward of the shelf break in the HRC. There is a rare occurrence of sperm whales from the shore to the shelf break. This occurrence prediction is based on the possibility of this typically deepwater species being found in insular shelf waters that are in such close proximity to deep water. Mating behavior occurs from winter through summer and calving from spring through fall (DON, 2005a). Occurrence patterns are assumed to be similar throughout the year.

Diving Behavior. Sperm whales forage during deep dives that routinely exceed a depth of 1,314 ft and 30 min duration (Watkins et al., 2002). Sperm whales are capable of diving to depths of over 6,564 ft with durations of over 60 min (Watkins et al., 1993). Sperm whales spend up to 83 percent of daylight hours underwater (Jaquet et al., 2000; Amano and Yoshioka, 2003). Males do not spend extensive periods of time at the surface (Jaquet et al. 2000). In contrast, females spend prolonged periods of time at the surface (1 to 5 hours daily) without foraging (Whitehead and Weilgart, 1991; Amano and Yoshioka 2003). The average swimming speed is estimated to be 0.7 m/sec (Watkins et al., 2002). Dive descents averaged 11 min at a rate of 1.52 m/sec, and ascents averaged 11.8 min at a rate of 1.4 m/sec (Watkins et al., 2002).

Acoustics. Sperm whales produce short-duration (generally less than 3 sec), broadband clicks. These clicks range in frequency from 100 Hz to 30 kHz, with dominant energy in two bands (2 to 4 kHz and 10 to 16 kHz). Generally, most of the acoustic energy is present at frequencies below 4 kHz, although diffuse energy up to past 20 kHz has been reported (Thode et al., 2002). The source levels can be up to 236 dB re 1 µPa-m (Møhl et al., 2003). Thode et al. (2002) suggested that the acoustic directivity (angular beam pattern) from sperm whales must range between 10 and 30 dB in the 5 to 20 kHz region. The clicks of neonate sperm whales are very different from usual clicks of adults in that they are of low directionality, long duration, and low-frequency (centroid frequency between 300 and 1,700 Hz) with estimated source levels between 140 and 162 dB re 1 µPa-m (Madsen et al., 2003). Clicks are heard most frequently when sperm whales are engaged in diving/foraging behavior (Whitehead and Weilgart, 1991; Miller et al., 2004; Zimmer et al., 2005). These may be echolocation clicks used in feeding, contact calls (for communication), and orientation during dives. When sperm whales are socializing, they tend to repeat series of clicks (codas), which follow a precise rhythm and may last for hours (Watkins and Schevill, 1977). Codas are shared between individuals of a social unit and are considered to be primarily for intragroup communication (Weilgart and Whitehead, 1997; Rendell and Whitehead, 2004).

The anatomy of the sperm whale's ear indicates that it hears high-frequency sounds (Ketten 1992). Anatomical studies also suggest that the sperm whale has some ultrasonic hearing, but at a lower maximum frequency than many other odontocetes (Ketten, 1992). The sperm whale may also possess better low-frequency hearing than some other odontocetes, although not as extraordinarily low as many baleen whales (Ketten, 1992). Auditory brainstem response in a neonatal sperm whale indicated highest sensitivity to frequencies between 5 and 20 kHz (Ridgway and Carder, 2001).

4.1.7 Hawaiian Monk Seal (*Monachus schauinslandi*)

Stock. Hawaiian

Status. The Hawaiian monk seal is listed as endangered under the ESA and as a depleted and strategic stock under the MMPA (Ragen and Lavigne, 1999; Carretta et al., 2005). Hawaiian monk seals are managed as a single stock, although there are six main reproductive subpopulations at French Frigate Shoals, Laysan Island, Lisianski Island, Pearl and Hermes Reef, Midway Island, and Kure Atoll (Ragen and Lavigne, 1999; Carretta et al., 2005). Genetic comparisons between the Northwestern and Main Hawaiian Islands seals have not yet been conducted, but observed interchange of individuals among the regions is extremely rare, suggesting that these may be more appropriately designated as separate stocks; further research is needed (Carretta et al., 2005).

Critical habitat for the Hawaiian monk seal is designated from the shore out to 120 ft in 10 areas of the Northwestern Hawaiian Islands (NMFS, 1988). The eastern-most island is located on the northwestern edge of the HRC. A revised recovery plan, which included species status, threats to the population and recommendations to prevent extinction, was issued in 2006 (NMFS, 2006).

Abundance and Distribution. The best estimate of the total population size is 1,252 individuals in the Hawaiian Islands Archipelago (Carretta et al., 2006). There are an estimated 52 seals in the Main Hawaiian Islands (Baker and Johanos, 2004; DON, 2005; Carretta et al., 2005). The vast majority of the population is present in the Northwestern Hawaiian Islands. The trend in abundance for the population over the past 20 years has mostly been negative (Baker and Johanos, 2004; Carretta et al., 2005). A self-sustaining subpopulation in the Main Hawaiian Islands may improve the monk seal's long-term prospects for recovery (Marine Mammal Commission [MMC], 2003; Baker and Johanos, 2004; Carretta et al., 2005).

The Hawaiian monk seal occurs only in the central North Pacific. Until recently, this species occurred almost exclusively at remote atolls in the Northwestern Hawaiian Islands where six major breeding colonies are located: French Frigate Shoals, Laysan and Lisianski Islands, Pearl and Hermes Reef, Midway Island, and Kure Atoll. In the last decade, however, sightings of Hawaiian monk seals in the Main Hawaiian Islands have increased considerably (Baker and Johanos, 2004; Carretta et al., 2005). Most monk seal haulout events in the Main Hawaiian Islands have been on the western islands of Niihau and Kauai (Baker and Johanos, 2004; Carretta et al., 2005), although sightings or births have now been reported for all of the Main Hawaiian Islands, including Lehua and Kaula (MMC, 2003; Baker and Johanos, 2004). Hawaiian monk seals wander to Maro Reef and Gardner Pinnacles and have occasionally been sighted on nearby island groups such as Johnston Atoll, Wake Island, and Palmyra Atoll (Rice, 1998).

Hawaiian monk seals may give birth throughout the year but most births occur between February and August with a peak from March to June (Gilmartin and Forcada, 2002). Hawaiian monk seals show very high site fidelity to natal (birthing) islands, with only about 10 percent of individuals moving to another island in their lifetime (Gilmartin and Forcada, 2002). While monk seals do move between islands, long-distance movements are not common. Seals move distances of up to 135 nm on a regular basis, but longer distances have been recorded (e.g., from

Laysan to Molokai) (Johanos & Baker, 2002). Primary occurrence of monk seals within the HRC is expected in a continuous band between Nihoa, Kaula, Niihau, and Kauai. This band extends from the shore to around 1,638 ft and is based on the large number of sightings and births recorded in this area (Westlake and Gilmartin, 1990; Ragen and Finn, 1996; MMC, 2003; Baker and Johanos, 2004). An area of secondary occurrence is expected from 1,638 ft to 3,282 ft around Nihoa, Kaula, Niihau, and Kauai. A continuous area of secondary occurrence is also expected from the shore to 3,282 ft around the other Main Hawaiian Islands, taking into account sighting records, the location of deep sea corals, and the ability of monk seals to forage in water deeper than about 1,638 ft (Parrish et al., 2002; Severns and Fiene Severns, 2002; Kona Blue Water Farms, 2003; Kubota, 2004; Anonymous 2005 [from Honolulu Star Bulletin]; Fujimori, 2005). The Pearl Harbor entrance is included in the area of secondary occurrence based on sightings of this species near the entrance of the harbor (DON, 2001a). There is a rare occurrence of the monk seal seaward of the 3,281-ft isobath. Occurrence patterns are expected to be the same throughout the year (DON, 2005).

Diving Behavior. Monk seals feed on a variety of benthic and mid water fish and invertebrates (Goodman-Lowe, 1998; Parrish et al., 2000). Adult seals at French Frigate Shoals forage at depths of 984-1,640 ft in coral beds; and juveniles forage at depths of about 33 to 96 ft and to 162 to 330 ft at underwater sand fields (Parrish et al., 2002; 2005).

Acoustics. The range of underwater hearing in monk seals is 12 to 70 kHz with best hearing from 12 to 28 kHz and 60-70 kHz (Thomas et al., 1990). This audiogram was from only one animal and the high upper frequency range, which is high for a phocid, may not be indicative of the species.

There is no information on underwater sounds. In air sounds are low frequency sounds (below 1,000 Hz) such as "soft liquid bubble", short duration guttural expiration, a roar and belching/coughing sound (Miller and Job, 1992). A pup produces a higher frequency call (1.4 kHz) that presumably is use to call its mother.

4.2 Non-Endangered or Threatened Species

Mysticetes

4.2.1 Bryde's Whale (*Balaenoptera edeni brydei*)

Stock. Hawaiian

Status. The Bryde's whale is not listed as endangered under the ESA and is not a depleted or strategic stock under the MMPA (Carretta et al., 2005). Bryde's whales can be easily confused with sei whales. It is not clear how many species of Bryde's whales there are, but genetic analyses suggest the existence of at least two species (Rice, 1998; Kato, 2002). The taxonomy of the baleen whale group formerly known as sei and Bryde's whales is currently confused and highly controversial (see Reeves et al., 2004).

The IWC recognizes three management stocks of Bryde's whales in the North Pacific: western North Pacific, eastern North Pacific, and East China Sea (Donovan, 1991). There is currently no biological basis for defining separate stocks of Bryde's whales in the central North Pacific (Carretta et al., 2005). For the NOAA stock assessment reports, Bryde's whales within the U.S. Pacific EEZ are divided into two areas: (1) Hawaiian waters, and (2) the eastern tropical Pacific (east of 150°W and including the Gulf of California and waters off California) (Carretta et al., 2005).

Abundance and Distribution. The best available estimate of abundance for the Hawaiian stock of the Bryde's whale is 469 (CV = 0.34) individuals (Barlow, 2006; Carretta et al., 2005). The Bryde's whale is found in tropical and subtropical waters, generally not moving poleward of 40° in either hemisphere (Jefferson et al., 1993). Long migrations are not typical of Bryde's whales, though limited shifts in distribution toward and away from the equator, in winter and summer, respectively, have been observed (Cummings, 1985). In summer, the distribution of Bryde's whales in the western North Pacific extends as far north as 40°N, but many individuals remain in lower latitudes, as far south as about 5°N. Data also suggest that winter and summer grounds partially overlap in the central North Pacific (Kishiro, 1996; Ohizumi et al., 2002). Bryde's whales are also distributed in the central North Pacific in summer; the southernmost summer distribution of Bryde's whales inhabiting the central North Pacific is about 20°N (Kishiro, 1996). Some whales remain in higher latitudes (around 25°N) in both winter and summer (Kishiro, 1996).

Bryde's whales are seen year-round throughout tropical and subtropical waters (Kato, 2002) and are also expected in the HRC year-round (DON, 2005). It should be noted that more sightings are reported for the Northwest Hawaiian Islands than in the Main Hawaiian Islands (Barlow et al., 2004; Carretta et al., 2005). Bryde's whales have been reported to occur in both deep and shallow waters globally. There is a secondary occurrence of Bryde's whales seaward of the 162 ft isobath in the HRC. Bryde's whales are sometimes seen very close to shore and even inside enclosed bays (Best et al., 1984). Occurrence is expected to be rare inshore of this area (DON, 2005).

Diving Behavior. Bryde's whales are lunge-feeders, feeding on fish and krill (Nemoto and Kawamura, 1977). Cummings (1985) reported that Bryde's whales might dive as long as 20 min.

Acoustics. Bryde's whales produce low frequency tonal and swept calls similar to those of other rorquals (Oleson et al., 2003). 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 (Oleson et al., 2003). Heimlich et al. (2005) recently described five tone types. While no data on hearing ability for this species are available, Ketten (1997) hypothesized that mysticetes have acute infrasonic hearing.

4.2.2 Minke Whale (*Balaenoptera acutorostrata*)

Stock. Hawaiian

Status. The minke whale is not listed as endangered under the ESA and is not a depleted or strategic stock under the MMPA (Carretta et al., 2005). The IWC recognizes three stocks of minke whales in the North Pacific: one in the Sea of Japan/East China Sea, one in the rest of the western Pacific west of 180°N, and one in the remainder of the Pacific (Donovan, 1991). For the NOAA stock assessment report, there are three stocks of minke whales within the U.S. Pacific EEZ: (1) a Hawaiian stock; (2) a California/Oregon/Washington stock; and (3) an Alaskan stock (Carretta et al., 2005).

Abundance and Distribution. There currently is no abundance estimate for the Hawaiian stock of minke whales, which appears to occur seasonally (approximately November through March) around the Hawaiian Islands (Carretta et al., 2005). Mating is thought to occur in winter or early spring (Stewart and Leatherwood, 1985).

Minke whales are distributed in polar, temperate, and tropical waters (Jefferson et al., 1993); they are less common in the tropics than in cooler waters. Minke whales are present in the North Pacific from near the equator to the Arctic (Horwood, 1990). The summer range extends to the Chukchi Sea (Perrin and Brownell, 2002). In the winter, minke whales are found south to within 2° of the equator (Perrin and Brownell, 2002). The distribution of minke whale vocalizations (specifically, "boings") suggests that the winter breeding grounds are the offshore tropical waters of the North Pacific Ocean (Rankin and Barlow, 2003). There is no obvious migration from low-latitude, winter breeding grounds to high-latitude, summer feeding locations in the western North Pacific, as there is in the North Atlantic (Horwood, 1990); however, there are some monthly changes in densities in both high and low latitudes (Okamura et al., 2001). In the northern part of their range, minke whales are believed to be migratory, whereas they appear to establish home ranges in the inland waters of Washington and along central California (Dorsey et al., 1983) and exhibit site fidelity to these areas between years (Borggaard et al., 1999).

The minke whale is expected to occur seasonally in the HRC (Barlow, 2003). Abundance is expected to be higher between November and March (Carretta et al., 2005). Therefore, an area of secondary occurrence is seaward of the shoreline during the fall-winter period. Both visual and acoustic detections of minke whales have been reported for this area (Balcomb, 1987; Thompson and Friedl, 1982; Barlow et al., 2004; Carretta et al., 2005; Norris et al., 2005). The occurrence pattern takes into account both sightings in shallow waters in some locales globally as well as the anticipated oceanic occurrence of this species (DON, 2005). "Boings" were recorded in waters with a bottom depth of approximately 700 to 2,100 fathoms (Norris et al., 2005). Norris et al. *(*2005) reported sighting a minke whale 58 mi southwest of Kauai, in waters with a bottom depth of approximately 8,400 ft (DON, 2005). During the spring-summer period, there is a rare occurrence for the minke whale throughout the entire HRC although recent evidence from passive acoustic monitoring suggests that there may be more minke whales in the HRC than previously thought (Rankin and Barlow, 2005; Barlow, 2006).

Diving Behavior. Stern (1992) described a general surfacing pattern of minke whales consisting of about four surfacings, interspersed by short-duration dives averaging 38 sec. After the fourth surfacing, there was a longer duration dive ranging from approximately 2 to 6 min. Minke whales are "gulpers," like the other rorquals (Pivorunas, 1979). Hoelzel et al. (1989) reported on different feeding strategies used by minke whales. In the North Pacific, major food items include krill, Japanese anchovy, Pacific saury, and walleye Pollock (Perrin and Brownell, 2002).

Acoustics. Recordings in the presence of minke whales have included both high-and low-frequency sounds (Beamish and Mitchell, 1973; Winn and Perkins, 1976; Mellinger et al., 2000). Mellinger et al. (2000) described two basic forms of pulse trains that were attributed to minke whales: a "speed up" pulse train with energy in the 200 to 400 Hz band, with individual pulses lasting 40 to 60 msec, and a less-common "slow-down" pulse train characterized by a decelerating series of pulses with energy in the 250 to 350 Hz band. Recorded vocalizations from minke whales have dominant frequencies of 60 Hz to greater than 12,000 Hz, depending on vocalization type (Richardson et al. 1995). Recorded source levels, depending on vocalization type, range from 151 to 175 dB re 1 µPa-m (Ketten, 1998). Gedamke et al. (2001) recorded a complex and stereotyped sound sequence ("star-wars vocalization") in the Southern Hemisphere that spanned a frequency range of 50 Hz to 9.4 kHz. Broadband source levels between 150 and

165 dB re 1 µPa-m were calculated. "Boings," recently confirmed to be produced by minke whales and suggested to be a breeding call, consist of a brief pulse at 1.3 kHz, followed by an amplitude-modulated call with greatest energy at 1.4 kHz, with slight frequency modulation over a duration of 2.5 sec (Anonymous, 2002; Rankin and Barlow, 2003). While no data on hearing ability for this species are available, Ketten (1997) hypothesized that mysticetes have acute infrasonic hearing.

Odontocetes

4.2.3 Blainville's Beaked Whale (*Mesoplodon densirostris*)

Stock. Hawaiian

Status. The Blainville's beaked whale is not listed as endangered under the ESA and is not a depleted or strategic stock under the MMPA (Carretta et al., 2005).

Abundance and Distribution. The best available estimate of abundance for the Hawaiian stock of the Blainville's beaked whale is 2,872 individuals (CV = 1.25) (Barlow, 2006). There is no information on the population trend of Blainville's beaked whales.

The Blainville's beaked whale occurs in temperate and tropical waters of all oceans (Jefferson et al., 1993). The distribution of *Mesoplodon* species in the western North Atlantic may relate to water temperature, with Blainville's beaked whale generally occurring in warmer southern waters (Mead, 1989; MacLeod 2000). In the eastern Pacific, where there are about a half-dozen *Mesoplodon* species known, the Blainville's beaked whale is second only to the pygmy beaked whale (*Mesoplodon peruvianus*) in abundance in tropical waters (Wade and Gerrodette, 1993). Baird et al. (2006) reported the presence of a Blainville's beaked whale in at the northern edge of the Kaulakahi Channel between the islands of Kauai and Niihau. Mobley et al., (2006) reported the presence of a Blainville's beaked whale in the Alenuihaha Channel area between the islands or Maui and Hawaii during the RIMPAC 06 exercise. The same individuals had been observed multiple times off of the west coast of the Island of Hawaii during a 15-year period suggesting an island-associated population (McSweeney et al., 2007). Recent information shows that *Mesoplodon* beaked whales may not always inhabit deep ocean areas and may be found over the continental slope (Ferguson et al., 2006).

Diving Behavior. Analysis of stomach contents from captured and stranded individuals suggests that beaked whales are deep-diving animals, feeding by suction (Heyning and Mead, 1996). Another species of beaked whales, the Baird's beaked whale, feeds mainly on benthic fishes and cephalopods, but occasionally on pelagic fish such as mackerel, sardine, and saury (Kasuya, 2002; Walker et al., 2002; Ohizumi et al., 2003). Baird et al. (2006) reported on the diving behavior of four Blainville's beaked whales off the west coast of Hawaii. The four beaked whales foraged in deep ocean areas (2,270-9,855ft) with a maximum dive to 4,619 ft. Dives ranged from at least 13 min (lost dive recorder during the dive) to a maximum of 68 min (Baird et al. 2006).

Acoustics. MacLeod (1999) suggested that beaked whales use frequencies of between 300 Hz and 129 kHz for echolocation, and between 2 and 10 kHz, and possibly up to 16 kHz, for social communication. Blainville's beaked whales echolocation clicks were recorded at frequencies from 20 to 40 kHz (Johnson et al., 2004) and Cuvier's beaked whales at frequencies from 20 to 70 kHz (Zimmer et al. 2005).

Recent information on the hearing abilities of beaked whales (Blainville's, Cuvier's and Gervais' beaked whales) show that they are most sensitive from 40 to 80 kHz with an overall range of 5 to 80 kHz (Johnson et al., 2004; Zimmer et al., 2005; Cook et al., 2006).

4.2.4 Bottlenose Dolphin (*Tursiops truncatus*)

Stock. Hawaiian

Status. The bottlenose dolphin is not listed as endangered under the ESA and is not a depleted or strategic stock under the MMPA (Carretta et al., 2005). There is no information on the population trend of bottlenose dolphins.

Genetic analyses of biopsied bottlenose dolphins in the Main Hawaiian Islands suggested the possibility of two species of bottlenose dolphins in Hawaiian waters (DON, 2005). In the meantime, however, information is presented on the one confirmed *Tursiops* species for this LOA.

Abundance and Distribution. The best available estimate of abundance for the Hawaiian stock of the bottlenose dolphin is 3,215 (CV = 0.59) individuals (Barlow, 2006; Carretta et al., 2005).

The overall range of *Tursiops* is worldwide in tropical to temperate waters. *Tursiops* generally do not range poleward of 45°, except around the United Kingdom and northern Europe (Jefferson et al., 1993).

Bottlenose dolphins are found in nearshore waters around the Main Hawaiian Islands and are island-associated, with all sightings occurring in relatively nearshore and shallow waters (<200 m), and no apparent movement between the islands (Baird et al., 2002, 2003). Baird et al. (2003) noted the possibility of a second population of bottlenose dolphins in the Hawaiian Islands, based on sighting data, with a preference for deeper (bottom depth of 1,312 to 2,952 ft) waters.

Bottlenose dolphins are regularly found around the Main Hawaiian Islands in both nearshore and offshore waters (Rice, 1960; Shallenberger, 1981; Mobley et al., 2000; Baird et al., 2003). Based on photo-identification studies and sighting data, there is a possibility of separate island populations with different preferences for shallow (<650 ft) and deep (about 1,314 to 2,952 ft) waters (Baird *et* al., 2003; Baird et al., 2006). Therefore, an area of primary occurrence is expected from the shore to the 3,282 ft isobath in the HRC, excluding Nihoa due to no survey effort. This area is continuous between Niihau and Kauai and between Oahu, Molokai, Lanai, Maui, and Kahoolawe to account for possible movements between islands. There is a secondary occurrence seaward of the 3,282 ft isobath and seaward from the shoreline of Nihoa. Mead and Potter (1990) suggested that for the Atlantic species, there is a calving period of spring through fall with a peak in the spring. Occurrence patterns are expected to be the same throughout the year (DON, 2005).

Diving Behavior. Pacific coast bottlenose dolphins feed primarily on surf perches (Family Embiotocidae) and croakers (Family Sciaendae) (Norris and Prescott, 1961; Walker, 1981; Schwartz et al., 1992; Hanson and Defran, 1993), and also consume squid (*Loligo opalescens*) (Schwartz et al., 1992). Navy bottlenose dolphins have been trained to reach maximum diving depths of about 164 fathoms (Ridgway et al., 1969). Reeves et al. (2002) noted that the presence of deep-sea fish in the stomachs of some offshore individual bottlenose dolphins suggests that they dive to depths of more than 1,638 ft. Dive durations up to 15 min have been recorded for trained individuals (Ridgway et al., 1969). Typical dives, however, are more shallow and of a much shorter duration.

<u>Acoustics</u>. 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 (FM). 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 (Au, 1993) and 3.5 to 14.5 kHz and 125 to 173 dB re 1 μPa-m, respectively (Ketten, 1998). Generally, whistles range in frequency from 0.8 to 24 kHz (Richardson et al., 1995).

The bottlenose dolphin has a functional high-frequency hearing limit of 160 kHz (Au, 1993) and can hear sounds at frequencies as low as 40 to 125 Hz (Turl, 1993). Inner ear anatomy of this species has been described (Ketten, 1992). Electrophysiological experiments suggest that the bottlenose dolphin brain has a dual analysis system: one specialized for ultrasonic clicks and the other for lower-frequency sounds, such as whistles (Ridgway, 2000). The audiogram of the bottlenose dolphin shows that the lowest thresholds occurred near 50 kHz at a level around 45 dB re 1 μPa-m (Nachtigall et al., 2000). Below the maximum sensitivity, thresholds increased continuously up to a level of 137 dB at 75 Hz. Above 50 kHz, thresholds increased slowly up to a level of 55 dB at 100 kHz, then increased rapidly above this to about 135 dB at 150 kHz. Scientists have reported a range of best sensitivity between 25 and 70 kHz, with peaks in sensitivity occurring at 25 and 50 kHz at levels of 47 and 46 dB re 1 μPa-m (Nachtigall et al., 2000).

Temporary threshold shifts (TTS) in hearing have been experimentally induced in captive bottlenose dolphins (Ridgway et al., 1997; Schlundt et al., 2000; Nachtigall et al., 2003). Ridgway et al. (1997) observed changes in behavior at the following minimum levels for 1 sec tones: 186 dB at 3 kHz, 181 dB at 20 kHz, and 178 dB at 75 kHz (all re 1 μPa-m). TTS levels were 194 to 201 dB at 3 kHz, 193 to 196 dB at 20 kHz, and 192 to 194 dB at 75 kHz (all re 1 μPa-m). Schlundt et al. (2000) exposed bottlenose dolphins to intense tones (0.4, 3, 10, 20, and 75 kHz); the animals demonstrated altered behavior at source levels of 178 to 193 dB re 1 μPa-m, with TTS after exposures generally between 192 and 201 dB re 1 μPa-m (though one dolphin exhibited TTS after exposure at 182 dB re 1 μPa-m). Nachtigall et al. (2003) determined threshold for a 7.5 kHz pure tone stimulus. No shifts were observed at 165 or 171 dB re 1 μPa-m, but when the sound level reached 179 dB re 1 μPa-m, the animal showed the first sign of TTS. Recovery apparently occurred rapidly, with full recovery apparently within 45 min following sound exposure. TTS measured between 8 and 16 kHz (negligible or absent at higher frequencies) after 30 min of sound exposure (4 to 11 kHz) at 160 dB re 1 μPa-m (Nachtigall et al., 2004).

4.2.5 Cuvier's Beaked Whale (*Ziphius cavirostris*)

<u>Status</u>. The Cuvier's beaked whale is not listed as endangered under the ESA and is not a depleted or strategic stock under the MMPA (Carretta et al., 2005). There is no information on the population trend of Cuvier's beaked whales.

<u>Abundance and Distribution</u>. The best available estimate of abundance for the Hawaiian stock of the Cuvier's beaked whale is 15,242 (CV = 1.43) individuals (Barlow, 2006). Recent information collected from photo identification studies of Cuvier's beaked whale shows a degree of site fidelity near the Island of Hawaii (Baird et al., 2006). The same individuals had been observed multiple times off of the west coast of the Island of Hawaii during a 15-year period

suggesting an island-associated population (McSweeney et al., 2007). A tagged Cuvier's beaked whale shows a degree of site fidelity near the Island of Hawaii (Baird et al. 2006). Mobley et al. (2006) report the presence of a Cuvier's beaked whale in the Alenuihaha Channel area between the islands of Maui and Hawaii during the RIMPAC 2006 exercise. There is no information on the population trend of Cuvier's beaked whales.

Diving Behavior. Cuvier's beaked whales are generally sighted in waters with a bottom depth greater than about 650 ft and are frequently recorded at depths of 3,282 ft or more (Gannier, 2000; MacLeod, et al. 2004). They are commonly sighted around seamounts, escarpments, and canyons. In the eastern tropical Pacific Ocean, the mean bottom depth for Cuvier's beaked whales is approximately 11,154 ft, with a maximum depth of over 16,732 ft. (Ferguson, 2005). Recent studies by Baird et al., (2006) show that Cuvier's beaked whales dive deeply (maximum of 4,757 ft) and for long periods (maximum dive duration of 68.7 min) but also spent time at shallow depths. Gouge marks were observed on mud volcanoes on the sea floor at 5,580–6,564, and Woodside et al. (2006) speculated that they were caused by Cuvier's beaked whales foraging on benthic prey.

Acoustics. MacLeod (1999) suggested that beaked whales use frequencies of between 300 Hz and 129 kHz for echolocation, and between 2 and 10 kHz, and possibly up to 16 kHz, for social communication. Blainville's beaked whales echolocation clicks were recorded at frequencies from 20 to 40 kHz (Johnson et al., 2004) and Cuvier's beaked whales at frequencies from 20 to 70 kHz (Zimmer et al., 2005). Cook et al. (2006) reported that the Gervais beaked whale (*Mesoplodon europeus*) could hear in the range of 5 to 80 kHz although no measurements were attempted above 80 kHz.

4.2.6 Dwarf Sperm Whale (*Kogia sima*)

Status. The difficulty in identifying pygmy and dwarf sperm whales is exacerbated by their avoidance reaction towards ships and change in behavior towards approaching survey aircraft (Würsig et al., 1998). Based on the cryptic behavior of these species and their small group sizes (much like that of beaked whales), as well as similarity in appearance, it is difficult to identify these species in sightings at sea. Neither species of *Kogia* is listed as endangered under the ESA or considered depleted under the MMPA.

Abundance and Distribution. Dwarf sperm whales within the U.S. Pacific EEZ are each divided into two discrete, non-contiguous areas: (1) Hawaiian waters, and (2) waters off California, Oregon, and Washington (Carretta et al., 2005). The best available estimate of abundance for the Hawaiian stock of the dwarf sperm whale is 17,519 individuals (CV = 0.74) (Barlow, 2006). Both *Kogia* species have a worldwide distribution in tropical and temperate waters (Jefferson et al., 1993).

Both species of *Kogia* generally occur in waters along the continental shelf break and over the continental slope (e.g., Baumgartner et al., 2001; McAlpine, 2002; Baird, 2005). The primary occurrence for *Kogia* is seaward of the shelf break in the HRC and in deep water with a mean depth of 4,675 ft (Baird, 2005). This takes into account their preference for deep waters. There is a rare occurrence for *Kogia* inshore of the area of primary occurrence. Occurrence is expected to be the same throughout the year. Dwarf sperm whales showed a high degree of site fidelity, determined from photo identification over several years, in area of west of the island of Hawaii (Baird et al., 2006).

Diving Behavior. *Kogia* feed on cephalopods and, less often, on deep-sea fishes and shrimps (Caldwell and Caldwell, 1989; Baird et al., 1996; Willis and Baird, 1998; Wang et al., 2002). Willis and Baird (1998) reported that *Kogia* make dives of up to 25 min. Median dive times of around 11 min have been documented for *Kogia* (Barlow, 1999). 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 (Scott et al., 2001). Most sightings of *Kogia* are brief; these whales are often difficult to approach and they actively avoid aircraft and vessels (Würsig et al., 1998).

Acoustics. There is no information available on dwarf sperm whale vocalizations or hearing capabilities. Pygmy sperm whale clicks range from 60 to 200 kHz, with a dominant frequency of 120 kHz (Richardson et al., 1995). An auditory brainstem response study indicates that pygmy sperm whales have their best hearing between 90 and 150 kHz (Ridgway and Carder, 2001).

4.2.7 False Killer Whale (*Pseudorca crassidens*)

Status. This stock is listed as a strategic stock by NMFS because the estimated level of serious injury and mortality from the Hawaii-based tuna and swordfish long-line fishery is greater than the potential biological removal (Carretta et al., 2005). Genetic evidence suggests that the Hawaiian stock might be a reproductively isolated population from false killer whales in the eastern tropical Pacific (Chivers et al., 2003).

Baird et al. (2005) noted that more work was needed to determine if false killer whales using coastal waters might even be a discrete population from those in offshore waters and waters off the Northwest Hawaiian Islands.

Abundance and Distribution. The best available estimate of abundance for the Hawaiian stock of the false killer whale is 236 (CV = 1.13) individuals (Barlow, 2006). False killer whales are found in tropical and temperate waters, generally between 50°S and 50°N latitude with a few records north of 50°N in the Pacific and the Atlantic (Odell and McClune, 1999). Seasonal movements in the western North Pacific may be related to prey distribution (Odell and McClune, 1999). Baird et al. (2005) noted considerable inter-island movements of individuals in the Hawaiian Islands.

False killer whales are commonly sighted in offshore waters from small boats and aircraft, as well as offshore from long-line fishing vessels (e.g., Mobley et al., 2000; Baird et al., 2003; Walsh and Kobayashi, 2004). Baird et al. (2005) reported that false killer whales in the Hawaiian Islands occur in waters from about 132 to 13,122 ft. There is an area of primary occurrence for the false killer whale from the shore to 6,564 ft, with the exception of Pearl Harbor, where there is a rare occurrence for this species. There is an additional area of primary occurrence seaward of 13,122 ft on the south side of the islands, which takes into account false killer whale sighting and incidental catch data in the southwestern portion of the HRC (Forney, 2004; Walsh and Kobayashi, 2004; Carretta et al., 2005). The area of secondary occurrence includes a narrow band between 6,564 ft and 13,122 ft south of the islands and the entire area north of the islands seaward of 6,564 ft. It has been suggested that false killer whales using coastal waters might be a discrete population from those in offshore waters and waters off the Northwest Hawaiian Islands (Baird et al., 2005; Carretta et al., 2005). The area of secondary occurrence takes into account the possibility of two different stocks, with a possible hiatus in their distribution (DON, 2005). There is no evidence of a seasonal calving period (Jefferson et al., 1993). Occurrence patterns are assumed to be the same throughout the year.

Diving Behavior. False killer whales primarily eat deep-sea cephalopods and fish (Odell and McClune, 1999), but they have been known to attack other cetaceans, including dolphins (Perryman and Foster, 1980; Stacey and Baird, 1991), sperm whales (Palacios and Mate, 1996), and baleen whales.

Acoustics. The dominant frequencies of false killer whale whistles are 4 to 9.5 kHz; those of their clicks are 25 to 30 kHz and 95 to 130 kHz (Thomas et al., 1990; Richardson et al., 1995). The source level is 220 to 228 dB re 1 µPa-m (Ketten, 1998). Best hearing sensitivity measured for a false killer whale was around 16 to 64 kHz (Thomas et al., 1988, 1990). Yuen et al. (2005) tested a stranded false killer whale using auditory evoke potentials produce an audiogram in the range of 4-44 kHz and with best sensitivity at 16-24 kHz.

4.2.8 Fraser's Dolphin (*Lagenodelphis hosei*)

Status. The Fraser's dolphin is not listed as endangered under the ESA and is not a depleted or strategic stock under the MMPA (Carretta et al., 2005). There is no information on the population trend of Fraser's dolphins.

Abundance and Distribution. The best available estimate of abundance for the Hawaiian stock of the Fraser's dolphin is 10,226 (CV = 1.16) individuals (Barlow, 2006).

The Fraser's dolphin is found in tropical and subtropical waters around the world, typically between 30°N and 30°S (Jefferson et al., 1993). Strandings in temperate areas are usually associated with anomalously warm-water temperatures (Perrin et al., 1994b). As noted by Reeves et al. (1999), the documented distribution of this species is skewed towards the eastern Pacific, which may reflect the intensity of research associated with the tuna fishery rather than an actual higher density of occurrence there than in other tropical regions.

Fraser's dolphins have only recently been documented in Hawaiian waters (Carretta et al., 2005). Sightings have been recorded in the Northwest Hawaiian Islands but not within the Main Hawaiian Islands (Barlow, 2003). There is a rare occurrence of the Fraser's dolphin from the shore to seaward of the HRC that takes into account that this is an oceanic species that can be found closer to the coast, particularly in locations where the shelf is narrow and deep waters are nearby. There is no evidence of a seasonal calving season (DON, 2005). Occurrence patterns are assumed to be the same throughout the year (DON, 2005).

Diving Behavior. There is no information available on their diving behavior.

Acoustics. Little is known of the acoustic abilities of Fraser's dolphins. Their whistles have a range of 7.6-13.4 kHz (Leatherwood et al. 1993). There are no audiograms or other information on the hearing of Fraser's dolphins.

4.2.9 Killer Whale (*Orcinus orca*)

Status. The killer whale is not listed as endangered under the ESA and is not a depleted or strategic stock under the MMPA (Carretta et al., 2005). There is no information on the population trend of killer whales.

Abundance and Distribution. The best available estimate of abundance for the Hawaiian stock of the killer whale is 349 (CV = 0.98) individuals (Barlow, 2006). Genetic analysis of a biopsy sample taken from a killer whale in Hawaii (during the NMFS Hawaiian Islands Cetacean and Ecosystem Assessment Survey) was most closely related to mammal-eating killer whales in Alaska (Baird et al., 2003).

The killer whale is a cosmopolitan species found throughout all oceans and contiguous seas, from equatorial regions to the polar pack-ice zones. This species has sporadic occurrence in most regions (Ford, 2002). Though found in tropical waters and the open ocean, killer whales as a species are most numerous in coastal waters and at higher latitudes (Mitchell, 1975; Miyazaki and Wada, 1978; Dahlheim et al., 1982). Sightings in most tropical waters, although not common, are widespread (Visser and Bonoccorso, 2003).

Killer whales in general are uncommon in most tropical areas (DON, 2005). The distinctiveness of this species would lead it to be reported more than any other member of the dolphin family, if it occurs in a certain locale. Killer whales are infrequently sighted and found stranded around the Hawaiian Islands (Shallenberger, 1981; Tomich, 1986; Mobley et al., 2001b; Baird et al., 2003), though with increasing numbers of boaters, sightings each year could be expected (Baird et al., 2006). Because the killer whale has a sporadic occurrence in tropical waters and can be found in both coastal areas and the open ocean, there is a rare occurrence of this species in the HRC from the shoreline to seaward of the HRC boundaries. Occurrence patterns are assumed to be the same throughout the year (DON, 2005)

Diving Behavior. The maximum depth recorded for free-ranging killer whales diving off British Columbia is about 864 ft (Baird et al., 2005). On average, however, for seven tagged individuals, less than 1 percent of all dives examined were to depths greater than about 16 fathoms (Baird et al., 2003). The longest duration of a recorded dive from a radio-tagged killer whale was 17 min (Dahlheim and Heyning, 1999).

Acoustics. The killer whale produces a wide variety of clicks and whistles, but most of its sounds are pulsed and at 1 to 6 kHz (Richardson et al., 1995). Source levels of echolocation signals range between 195 and 224 dB re 1 μPa-m (Au et al., 2004). The source level of social vocalizations ranges between 137 to 157 dB re 1 μPa-m (Veirs, 2004). Acoustic studies of resident killer whales in British Columbia have found that there are dialects, in their highly stereotyped, repetitive discrete calls, which are group-specific and shared by all group members (Ford, 2002). These dialects likely are 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 (Ford, 2002). Dialects also have been documented in killer whales occurring in northern Norway, and likely occur in other locales as well (Ford, 2002). The killer whale has the lowest frequency of maximum sensitivity and one of the lowest high frequency hearing limits known among toothed whales (Szymanski et al., 1999). The upper limit of hearing is 100 kHz for this species. The most sensitive frequency, in both behavioral and in auditory brainstem response audiograms, has been determined to be 20 kHz (Szymanski et al., 1999).

4.2.10 Longman's Beaked Whale (*Indopacetus pacificus*)

Status. The Longman's beaked whale is not listed as endangered under the ESA and is not a depleted or strategic stock under the MMPA (Carretta et al., 2005). There is no information on the population trend of Longman's beaked whale.

Abundance and Distribution. The best available estimate for the Hawaiian stock of the Longman's beaked whale is 1,007 (CV = 1.26) individuals (Barlow, 2006). Beaked whales may be expected to occur in the area including around seaward of the shelf break. There is a low or unknown occurrence of beaked whales on the shelf between the 162 ft isobath and the shelf break, which takes into account that deep waters come very close to the shore in this area. In some locales, beaked whales can be found in waters over the shelf, so it is possible that beaked whales have similar habitat preferences here. Occurrence patterns are expected to be the same throughout the year (DON, 2005).

Longman's beaked whale is not as rare as previously thought. However, the frequency with which it has been sighted in the eastern and western tropical Pacific oceans (MacLeod et al., 2004) suggests that it is probably not as common as the Cuvier's and Mesoplodon beaked whales (Ferguson and Barlow, 2001). Recent information shows that Cuvier's and *Mesoplodon* beaked whales may not always inhabit deep ocean areas and may be found over the continental slope (Ferguson et al., 2006).

Diving Behavior. Analysis of stomach contents from captured and stranded individuals suggests that beaked whales are deep-diving animals, feeding by suction (Heyning and Mead, 1996). Another species of beaked whales, the Baird's beaked whale, feed mainly on benthic fishes and cephalopods, but occasionally on pelagic fish such as mackerel, sardine, and saury (Kasuya, 2002; Walker et al., 2002; Ohizumi et al., 2003). Prolonged dives by the Baird's beaked whales for periods of up to 67 min have been reported (Kasuya, 2002), though dives of about 84 to 114 ft are typical, and dives of 45 min are not unusual (Balcomb, 1989; Von Saunder and Barlow, 1999).

Acoustics. MacLeod (1999) suggested that beaked whales use frequencies of between 300 Hz and 129 kHz for echolocation, and between 2 and 10 kHz, and possibly up to 16 kHz, for social communication. Blainville's beaked whales echolocation clicks were recorded at frequencies from 20 to 40 kHz (Johnson et al., 2004) and Cuvier's beaked whales at frequencies from 20 to 70 kHz (Zimmer et al., 2005).

There is no direct information available on the exact hearing abilities of Longman's beaked whales (MacLeod, 1999) but some information is available for other beaked whales. Recent information on the hearing abilities of beaked whales (Blainville's, Cuvier's and Gervais' beaked whales) show that they are most sensitive from 40 to 80 kHz with an overall range of 5 to 80 kHz (Johnson et al., 2004; Zimmer et al., 2005; Cook et al., 2006).

4.2.11 Melon-headed Whale (*Peponocephala electra*)

Status. The melon headed whale is not listed as endangered under the ESA and is not a depleted or strategic stock under the MMPA (Carretta et al., 2005). There is no information on the population trend of melon headed whales.

Abundance and Distribution. The best available estimate of abundance for the Hawaiian stock of the melon-headed whale is 2,950 (CV = 1.17) individuals (Barlow, 2006). Melon-headed whales are found worldwide in tropical and subtropical waters. They have occasionally been reported from higher latitudes, but these sightings are often associated with incursions of warm water currents (Perryman et al., 1994). Preliminary results from photo-identification work in the Main Hawaiian Islands suggest inter-island movements by some individuals (e.g., between the islands of Kauai and Hawaii) as well as some residency by other individuals (e.g., at the island of Hawaii (DON, 2005).

The melon-headed whale is an oceanic species. Melon-headed whales are primarily expected to occur from the shelf break to seaward of the HRC and vicinity. There is a rare sighting occurrence from the shore to the shelf break. Occurrence patterns are assumed to be the same throughout the year (DON, 2005).

Diving Behavior. There is no information on the diving behavior of melon headed whales.

Acoustics. Melon headed whales produce whistles in the range of 8-12 kHz and clicks in the range of 20-40 kHz (Watkins et al. 1997).

4.2.12 Pantropical Spotted Dolphin (*Stenella attenuata*)

Status. The pantropical spotted dolphin is not listed as endangered under the ESA and is not a depleted or strategic stock under the MMPA (Carretta et al., 2005). There is no information on the population trend of pantropical spotted dolphins.

Abundance and Distribution: The best available estimate of abundance for the pantropical spotted dolphin within the Hawaiian Islands EEZ is 8,978 (CV = 0.48) individuals (Barlow, 2006).

The pantropical spotted dolphin is distributed in tropical and subtropical waters worldwide (Perrin and Hohn, 1994). Range in the central Pacific is from the Hawaiian Islands in the north to at least the Marquesas in the south (Perrin and Hohn, 1994).

Based on known habitat preferences and sighting data, the primary occurrence for the pantropical spotted dolphin is between the 330 ft and 13,122 ft throughout the HRC. This area of primary occurrence also includes a continuous band connecting all the Main Hawaiian Islands, Nihoa, and Kaula, taking into account possible inter-island movements. Secondary occurrence is expected from the shore to 330 ft, as well as seaward of 13,122 ft. Pantropical spotted dolphins are expected to be rare in Pearl Harbor. In the eastern tropical Pacific there are two calving periods, one in the spring and one in the fall (Perrin and Hohn, 1994). Occurrence patterns are the same throughout the year (DON, 2005).

Diving Behavior: Results from various tracking and food habit studies suggest that pantropical spotted dolphins in the eastern tropical Pacific and off Hawaii feed primarily at night on epipelagic species and on mesopelagic species which rise towards the water's surface after dark (Robertson and Chivers, 1997; Scott and Cattanach, 1998; Baird et al., 2001). Dives during the day generally are shorter and shallower than dives at night; rates of descent and ascent are higher at night than during the day (Baird et al., 2001). Similar mean dive durations and depths have been obtained for tagged pantropical spotted dolphins in the eastern tropical Pacific and off Hawaii (Baird et al., 2001).

Acoustics. Pantropical spotted dolphin whistles have a dominant frequency range of 6.7 to 17.8 kHz (Ketten, 1998). Click source levels between 197 and 220 dB re 1 μPa-m have been recorded for pantropical spotted dolphins (Schotten et al., 2004). There are no published hearing data for pantropical spotted dolphins (Ketten, 1998). Anatomy of the ear of the pantropical spotted dolphin has been studied; Ketten (1992, 1997) found that they have a Type II cochlea, like other delphinids.

4.2.13 Pygmy Killer Whale (*Feresa attenuata*)

Status. The pygmy killer whale is not listed as endangered under the ESA and is not a depleted or strategic stock under the MMPA (Carretta et al., 2005). There is no information on the population trend of pygmy killer whales.

Abundance and Distribution. The best available estimate of abundance for the Hawaiian stock of the pygmy killer whale is 956 (CV = 0.83) individuals (Barlow, 2006). This species has a worldwide distribution in deep tropical and subtropical oceans. Pygmy killer whales generally do not range north of 40°N or south of 35°S (Jefferson et al., 1993). Reported sightings suggest that this species primarily occurs in equatorial waters, at least in the eastern tropical Pacific (Perryman et al., 1994). Most of the records outside the tropics are associated with strong, warm western boundary currents that effectively extend tropical conditions into higher latitudes (Ross and Leatherwood, 1994).

Pygmy killer whales regularly occur in the HRC. Pygmy killer whales are easily confused with false killer whales and melon-headed whales, which are two species that also have expected occurrence in the HRC. The pygmy killer whale is primarily expected to occur from the shelf break to seaward of the HRC boundaries. There is a rare sighting occurrence from the shore to the shelf break. Occurrence patterns are assumed to be the same throughout the year. Pygmy killer whales off the island of Hawaii demonstrate tremendous site fidelity to the island (DON, 2005).

Diving Behavior. There is no information on the diving behavior of pygmy killer whales.

Acoustics. The pygmy killer whale produces clicks in the range of 45-117 kHz with the main energy in the range of 70-85 kHz (Madsen et al. 2004). There is no information on the hearing of pygmy killer whales.

4.2.14 Pygmy Sperm Whale (*Kogia breviceps*)

Status. The pygmy sperm whale is not listed as endangered under the ESA and is not a depleted or strategic stock under the MMPA (Carretta et al., 2005). There is no information on the population trend of pygmy sperm whales.

The difficulty in identifying pygmy and dwarf sperm whales is exacerbated by their avoidance reaction towards ships and change in behavior towards approaching survey aircraft (Würsig et al., 1998). Based on the cryptic behavior of these species and their small group sizes (much like that of beaked whales), as well as similarity in appearance, it is difficult to identify these species in sightings at sea. Neither species of *Kogia* is listed as endangered under the ESA or considered depleted under the MMPA.

Abundance and Distribution. The best available estimate of abundance for the Hawaiian stock of the pygmy sperm whale is 7,138 (CV = 1.12) individuals (Barlow 2006). Both *Kogia* species have a worldwide distribution in tropical and temperate waters (Jefferson et al., 1993).

Both species of *Kogia* generally occur in waters along the continental shelf break and over the continental slope (Baumgartner et al., 2001; McAlpine, 2002; Baird, 2005). The primary occurrence for *Kogia* is seaward of the shelf break in the HRC and in deep water with a mean depth of 4,675 ft (Baird, 2005). This takes into account their preference for deep waters. There is a rare occurrence for *Kogia* inshore of the area of primary occurrence. Dwarf sperm whales showed a high degree of site fidelity, determined from photo identification over several years, in area of west of the island of Hawaii (Baird et al., 2006). Occurrence is expected to be the same throughout the year (DON, 2005).

Diving Behavior. *Kogia* feed on cephalopods and, less often, on deep-sea fishes and shrimps (Caldwell and Caldwell, 1989; Baird et al., 1996; Willis and Baird, 1998; Wang et al., 2002). Willis and Baird (1998) reported that *Kogia* make dives of up to 25 min. Median dive times of around 11 min have been documented for *Kogia* (Barlow, 1999). 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 (Scott et al., 2001). Most sightings of *Kogia* are brief; these whales are often difficult to approach and they actively avoid aircraft and vessels (Würsig et al., 1998).

Acoustics. Pygmy sperm whale clicks range from 60 to 200 kHz, with a dominant frequency of 120 kHz (Richardson et al., 1995). There is no information available on dwarf sperm whale vocalizations or hearing capabilities. An auditory brainstem response study indicates that pygmy sperm whales have their best hearing between 90 and 150 kHz (Ridgway and Carder, 2001).

4.2.15 Risso's Dolphin (*Grampus griseus*)

Status. The Risso's dolphin is not listed as endangered under the ESA and is not a depleted or strategic stock under the MMPA (Carretta et al., 2005). There is no information on the population trend of Risso's dolphins.

Abundance and Distribution. The best available estimate of abundance for the Hawaiian stock of the Risso's dolphin is 2,372 (CV = 0.65) individuals (Barlow, 2006). The Risso's dolphin is distributed worldwide in tropical to warm-temperate waters, roughly between 60°N and 60°S, where surface water temperature is usually greater than 10°C (Kruse et al., 1999). Water temperature appears to be a factor that affects the distribution of Risso's dolphins in the Pacific (Kruse et al., 1999). Changes in local distribution and abundance along the California coast are probably in response to protracted or unseasonable warm-water events, such as El Niño events (Shane, 1994).

There is an area of secondary occurrence between 330 ft and 16,400 ft based on the known habitat preferences of this species, as well as the paucity of sightings even though there is extensive aerial and boat-based survey coverage near the islands. There is a narrow band of rare occurrence from the shore out to 330 ft, including Pearl Harbor that takes into consideration the possibility that this species, with a preference for waters with steep bottom topography, might swim into areas where deep water is close to shore. Risso's dolphins are expected to be rare seaward of 16,400 ft isobath. Occurrence patterns are assumed to be the same throughout the year.

Diving Behavior. They may remain submerged on dives for up to 30 min (Kruse et al., 1999). Cephalopods are the primary prey (Clarke, 1996).

Acoustics. Risso's dolphin vocalizations include broadband clicks, barks, buzzes, grunts, chirps, whistles, and simultaneous whistle and burst-pulse sounds (Corkeron and Van Parijs, 2001). The combined whistle and burst pulse sound appears to be unique to Risso's dolphin (Corkeron and Van Parijs, 2001). Corkeron and Van Parijs (2001) recorded five different whistle types, ranging in frequency from 4 to 22 kHz. Broadband clicks had a frequency range of 6 to greater than 22 kHz. Low-frequency narrowband grunt vocalizations had a frequency range of 0.4 to 0.8 kHz. A recent study established empirically that Risso's dolphins echolocate; estimated source levels were up to 216 dB re 1 μPa-m (Philips et al., 2003).

The range of hearing in Risso's dolphins is 1.6-122.9 kHz with maximum sensitivity occurring between 8 and 64 kHz (Nachtigall et al., 1995).

4.2.16 Rough-Toothed Dolphin (*Steno bredanensis*)

Status. The rough-toothed dolphin is not listed as endangered under the ESA and is not a depleted or strategic stock under the MMPA (Carretta et al., 2005). There is no information on the population trend of rough-toothed dolphins. Nothing is known about stock structure for the rough-toothed dolphin in the North Pacific (Carretta et al., 2005).

Abundance and Distribution. The best available estimate of abundance for the Hawaiian stock of the rough-toothed dolphin is 8,709 (CV = 0.45) individuals (Barlow, 2006).

Rough-toothed dolphins are found in tropical to warm-temperate waters globally, rarely ranging north of 40°N or south of 35 S (Miyazaki and Perrin, 1994). In the Main Hawaiian Islands, this species appears to demonstrate site fidelity to specific islands (Baird, et al., 2006).

Primary occurrence for the rough-toothed dolphin is from the shelf break to seaward of the HRC boundaries. There is also an area of rare occurrence of rough-toothed dolphins from the shore to the shelf break. Baird et al. (2003) noted that rough-toothed dolphins are rarely seen in offshore waters of the Main Hawaiian Islands. Occurrence patterns are expected to be the same throughout the year (DON, 2005).

Diving Behavior. They are deep divers, and can dive for up to 15 min (Reeves et al., 2002). They usually inhabit deep waters (Davis et al. 1998), where they prey on fish and cephalopods (Reeves et al., 2002). Rough-toothed dolphins may stay submerged for up to 15 min and are known to dive as deep as 230 ft, but can probably dive much deeper (Miyazaki and Perrin, 1994).

Acoustics. The vocal repertoire of the rough-toothed dolphin includes broad-band clicks, barks, and whistles (Yu et al. 2003). Echolocation clicks of rough-toothed dolphins are in the frequency range of 0.1 to 200 kHz, with a peak of about 25 kHz (Miyazaki and Perrin 1994; Yu et al., 2003). Whistles show a wide frequency range: 0.3 to >24 kHz (Yu et al. 2003). There is no published information on hearing ability of this species.

4.2.17 Short-finned Pilot Whale (*Globicephala macrorhynchus*)

Status. Stock structure of short-finned pilot whales has not been well-studied in the North Pacific Ocean, except in Japanese waters (Carretta et al., 2005). Two stocks have been identified in Japan based on pigmentation patterns and differences in the head shape of adult males (Kasuya et al., 1988). Pilot whales in Hawaiian waters are similar morphologically to the Japanese southern form (Carretta et al., 2005). Genetic analyses of tissue samples collected near the Main Hawaiian Islands indicate that the Hawaiian population is reproductively isolated from short-finned pilot whales found in the eastern North Pacific Ocean (Carretta et al., 2005).

Abundance and Distribution. The best available estimate of abundance for the Hawaiian stock of the short-finned pilot whale is 8,870 (CV = 0.38) individuals (Barlow, 2006; Carretta et al., 2005). The short-finned pilot whale is found worldwide in tropical to warm-temperate seas, generally in deep offshore areas. The short-finned pilot whale usually does not range north of 50°N or south of 40°S (Jefferson et al., 1993). The long-finned pilot whale is not known to presently occur in the North Pacific (Kasuya, 1975); the range of the short-finned pilot whale appears to be expanding to fill the former range of the long-finned pilot whale (Bernard and Reilly, 1999). Pilot whales are sighted throughout the Hawaiian Islands (Shallenberger, 1981).

Short-finned pilot whales are expected to occur year-round throughout the HRC. They are commonly found in deep waters with steep bottom topography, including deepwater channels between the Main Hawaiian Islands, such as the Alenuihaha Channel between Maui and Hawaii (Balcomb, 1987). The area of primary occurrence for this species is between 654 and 13,122 ft.

Considering the narrow insular shelf and deep waters in proximity to the shore, secondary occurrence is between 162 and 654 ft. Another area of secondary occurrence extends from 13,122 ft to seaward of the HRC boundaries. Short-finned pilot whales are expected to be rare between the shore and 162 ft. Occurrence patterns are assumed to be the same throughout the year. Photo-identification work suggests a high degree of site fidelity around the island of Hawaii (Shane and McSweeney, 1990).

Diving Behavior. Pilot whales are deep divers; the maximum dive depth measured is about 3,186 ft (Baird et al., 2002). Pilot whales feed primarily on squid, but also take fish (Bernard and Reilly, 1999). Pilot whales are not generally known to prey on other marine mammals; however, records from the eastern tropical Pacific suggest that the short-finned pilot whale does occasionally chase, attack, and may eat dolphins during fishery operations (Perryman and Foster, 1980), and they have been observed harassing sperm whales in the Gulf of Mexico (Weller et al., 1996).

Acoustics. Short-finned pilot whale whistles and clicks have a dominant frequency range of 2 to 14 kHz and a source level of 180 dB re 1 µPa-m (Fish and Turl, 1976; Ketten, 1998). There are no published hearing data available for this species.

4.2.18 Spinner Dolphin (*Stenella longirostris*)

Status. The spinner dolphin is not listed as endangered under the ESA and is not a depleted or strategic stock under the MMPA (Carretta et al., 2005). There is no information on the population trend of spinner dolphins.

Abundance and Distribution. The best available estimate of abundance for the Hawaiian stock of the spinner dolphin is 3,351 (CV = 0.74) individuals (Barlow, 2006).

The spinner dolphin is found in tropical and subtropical waters worldwide. Limits are near 40°N and 40 S (Jefferson et al., 1993). Spinner dolphins occur near islands such as the Hawaiian Islands, the Mariana Islands, the South Pacific, the Caribbean, and Fernando de Noronha Island off Brazil. Spinner dolphins have been documented to travel distances of about 25 mi between the Main Hawaiian Islands (Maldini, 2003). In the Hawaiian Islands, spinner dolphins occur along the leeward coasts of all the major islands and around several of the atolls northwest of the main island chain. Long-term site fidelity has been noted for spinner dolphins along the Kona coast of Hawaii, along Oahu, and off the island of Moorea in the Society Islands (Norris et al., 1994; Östman 1994; Poole, 1995; Marten and Psarakos, 1999), with some individuals being sighted for up to 12 years at Moorea (Poole, 1995). Recent data suggests that spinner dolphins do not readily move between islands as determined by genetic analysis (Andrews et al., 2006). Monitoring for RIMPAC 2006 showed that spinner dolphins are seen daily in the offshore area of Kekaha Beach, Kauai (near PMRF, Barking Sands) despite being regularly accompanied by tour boats (DON, 2006).

Spinner dolphins occur year-round throughout the HRC, with primary occurrence from the shore to 13,122 ft. This takes into account offshore resting habitat and offshore feeding areas. Spinner dolphins are expected to occur in shallow water (about 162 ft or less) resting areas throughout the middle of the day, moving into deep waters offshore during the night to feed. Primary resting areas are along the west side of Hawaii, including Makako Bay, Honokohau Bay, Kailua Bay, Kealakekua Bay, Honaunau Bay, Kauhako Bay, and off Kahena on the southeast side of the island (Östman-Lind et al., 2004). Along the Waianae coast of Oahu, spinner dolphins rest along

Makua Beach, Kahe Point, and Pokai Bay during the day (Lammers, 2004). Kilauea Bay in Kauai is also a popular resting bay for Hawaiian spinner dolphins (DON, 2005). There is an area of secondary occurrence seaward of 13,122 ft. Although sightings have been recorded around the mouth of Pearl Harbor (Lammers, 2004), spinner dolphin occurrence is expected to be rare. Occurrence patterns are assumed to be the same throughout the year. It is currently not known whether individuals move between islands or island groups (Carretta et al., 2005) but recent data on the genetic comparison of animals from each suggest there is little movement between the islands (Andrews et al., 2006).

Spinner dolphins in Tahiti showed a pattern of being present in their resident area a higher percentage of time on the weekend compared to weekdays despite the higher tourist traffic and encounter rate (Gannier and Petiau, 2007).

Diving Behavior. Spinner dolphins feed primarily on small mesopelagic fishes, squids, and sergestid shrimps and they dive to at least 654 to 984 ft (Perrin and Gilpatrick, 1994). Foraging takes place primarily at night when the mesopelagic prey migrates vertically towards the surface and also horizontally towards the shore (Benoit-Bird et al., 2001; Benoit-Bird and Au, 2004; Dollar et al., 2003).

Acoustics. There is little information on the acoustic abilities of the spinner dolphin. They produce whistles in the range of 1 to 22.5 kHz with the dominant frequency being 6.8 to 17.9 kHz, above that of the active sonar frequencies, although their full range of hearing may extend down to 1 kHz or below as reported for other small odontocetes (Richardson et al., 1995; Nedwell et al., 2004). They also display pulse burst sounds in the range of 5 to 60 kHz. Their echolocation clicks range up to at least 65 kHz (Richardson et al., 1995).

4.2.19 Striped Dolphin (*Stenella coeruleoalba*)

Status. The striped dolphin is not listed as endangered under the ESA and is not a depleted or strategic stock under the MMPA (Carretta et al., 2005). There is no information on the population trend of striped dolphins.

Abundance and Distribution. The best available estimate of abundance for the Hawaiian stock of the striped dolphin is 13,143 (CV 0.46) individuals (Barlow, 2006). The striped dolphin has a worldwide distribution in cool-temperate to tropical waters. This species is well documented in both the western and eastern Pacific off the coasts of Japan and North America (Perrin et al., 1994a); the northern limits are the Sea of Japan, Hokkaido, Washington State, and along roughly 40°N across the western and central Pacific (Reeves et al., 2002). Scattered records exist from the South Pacific as well (Perrin et al., 1994a).

The striped dolphin regularly occurs throughout the HRC. There is a primary occurrence for the striped dolphin seaward of 3,282 ft based on sighting records and the species' known preference for deep waters. Striped dolphins are occasionally sighted closer to shore (Mobley et al., 2000); therefore, an area of secondary occurrence is expected from 330 to 3,282 ft. Occurrence patterns are assumed to be the same throughout the year.

Diving Behavior. Striped dolphins often feed in pelagic or benthopelagic zones along the continental slope or just beyond oceanic waters. A majority of the prey possess luminescent organs, suggesting that striped dolphins may be feeding at great depths, possibly diving to about 109 to 383 fathoms to reach potential prey (Archer and Perrin, 1999). Striped dolphins may feed at night, in order to take advantage of the deep scattering layer's diurnal vertical movements.

Small, mid-water fishes (in particular, myctophids or lanternfish) and squids are the dominant prey (Perrin et al., 1994).

Acoustics. Striped dolphin whistles range from 6 to at least 24 kHz, with dominant frequencies ranging from 8 to 12.5 kHz (Richardson et al., 1995). The striped dolphin's range of most sensitive hearing (defined as the frequency range with sensitivities within 10 dB of maximum sensitivity) was determined to be 29 to 123 kHz using standard psycho-acoustic techniques; maximum sensitivity occurred at 64 kHz (Kastelein et al., 2003). Hearing ability became less sensitive below 32 kHz and above 120 kHz (Kastelein et al., 2003).

Pinniped

4.2.20 Northern Elephant Seal (*Mirounga angustirostris*)

Status. The northern elephant seal is not listed as endangered under the ESA and is not a depleted or strategic stock under the MMPA (Carretta et al., 2005).

Abundance and Distribution. The northern elephant seal population has recovered dramatically after being reduced to several dozen to perhaps no more than a few animals in the 1890s (Bartholomew and Hubbs, 1960; Stewart et al., 1994). Although movement and genetic exchange continues between rookeries, most elephant seals return to their natal rookeries when they start breeding (Huber et al., 1991). The population size has to be estimated since all age classes are not ashore at any one time of the year (Carretta et al., 2005). There is a conservative minimum population estimate of 60,547 elephant seals in the California stock (Carretta et al., 2005). Based on trends in pup counts, abundance in California is increasing by around 6 percent annually, but the Mexican stock is evidently decreasing slowly (Stewart et al., 1994; Carretta et al., 2005).

Breeding and molting habitat for northern elephant seals is characterized by sandy beaches, mostly on offshore islands, but also in some mainland locations along the coast (Stewart et al., 1994). When on shore, seals will also use small coves and sand dunes behind and adjacent to breeding beaches. They rarely enter the water during the breeding season, but some seals will spend short periods in tide pools and alongshore; these are most commonly weaned pups that are learning to swim (Le Boeuf et al., 1972).

The northern elephant seal is endemic to the North Pacific Ocean, occurring almost exclusively in the eastern and central North Pacific. However, vagrant individuals do sometimes range to the western North Pacific. Northern elephant seals occur in Hawaiian waters only rarely as extralimital vagrants. The most far-ranging individual appeared on Nijima Island off the Pacific coast of Japan in 1989 (Kiyota et al., 1992). This demonstrates the great distances that these animals are capable of covering.

There is a rare occurrence of northern elephant seals throughout the HRC year-round. There are several unconfirmed reports of elephant seals at Midway Atoll, Pearl and Hermes Reef, and Kure Atoll (DON, 2005). The first confirmed sighting of a northern elephant seal in the Hawaiian Islands was a female found on Midway Island in 1978 that had been tagged earlier at San Miguel Island (off the coast of southern California) (Northwest and Alaska Fisheries Center, 1978). The first sighting of an elephant seal in the Main Hawaiian Islands occurred on the Kona coast of Hawaii in January 2002; a juvenile male was sighted hauled out at Kawaihae Beach and later at the Kona Village Resort (Fujimori, 2002;). Based on these sightings and documented long-distance movements as far west as Japan (Northwest and Alaska Fisheries Center, 1978;

Antonelis and Fiscus, 1980; Tomich, 1986; Kiyota et al., 1992; Fujimori, 2002), rare encounters with northern elephant seals in the HRC are possible.

Diving Behavior. Feeding habitat is mostly in deep, offshore waters of warm temperate to sub-polar zones (Stewart and DeLong, 1995; Stewart, 1997; Le Boeuf et al., 2000). Some seals will move into subtropical or tropical waters while foraging (Stewart and DeLong, 1995).

Both sexes routinely dive deep (up to 4,500 ft) (Le Boeuf et al., 2000); dives average 15–25 min, depending on time of year, and surface intervals between dives are 2–3 min. The deepest dives recorded for both sexes are over 5,000 ft (e.g., Le Boeuf et al., 2000; Schreer et al., 2001). Females remain submerged about 86–92 percent of the time and males about 88–90 percent (Le Boeuf et al., 1989; Stewart and Delong, 1995).

Feeding juvenile northern elephant seals dive for slightly shorter periods (13–18 min), but they dive to similar depths (978 to 1,500 ft) and spend a similar proportion (86–92 percent) of their time submerged (Le Boeuf et al., 2000).

Acoustics. The northern elephant seal produces loud, low-frequency in-air vocalizations (Bartholomew and Collias, 1962). The mean fundamental frequencies are in the range of 147 to 334 Hz for adult males (Le Boeuf and Petrinovich, 1974). The mean source level of the male-produced vocalizations during the breeding season is 110 dB re 20 μPa (Sanvito and Galimberti, 2003). In-air calls made by aggressive males include: (1) snoring, which is a low intensity threat; (2) a snort (0.2 to 0.6 kHz) made by a dominant male when approached by a subdominant male; and (3) a clap threat (<2.5 kHz) which may contain signature information at the individual level (Richardson et al., 1995). These sounds appear to be important social cues (Shipley et al., 1992). The mean fundamental frequency of airborne calls for adult females is 500 to 1,000 Hz (Bartholomew and Collias, 1962). In-air sounds produced by females include a <0.7 kHz belch roar used in aggressive situations and a 0.5 to 1 kHz bark used to attract the pup (Bartholomew and Collias, 1962). As noted by Kastak and Schusterman (1999), evidence for underwater sound production by this species is scant. Except for one unsubstantiated report), none have been definitively identified (Fletcher et al., 1993; Burgess et al., 1998). Burgess et al. (1998) detected possible vocalizations in the form of click trains that resembled those used by males for communication in air.

The audiogram of the northern elephant seal indicates that this species is well-adapted for underwater hearing; sensitivity is best between 3.2 and 45 kHz, with greatest sensitivity at 6.4 kHz and an upper frequency cutoff of approximately 55 kHz (Kastak and Schusterman, 1999).

5. HARASSMENT AUTHORIZATION REQUESTED

The Navy requests a Letter of Authorization (LOA) for the incidental harassment of marine mammals pursuant to Section 101 (a)(5)(A) of the Marine Mammal Protection Act (MMPA). The authorization requested is for the incidental harassment of marine mammals by behavioral disruption. However, it is understood that an LOA is applicable for up 5 years, and is appropriate where authorization for serious injury or mortality of marine mammals is requested. The request is for exercises and training events conducted within the Hawaii Range Complex (HRC). These include operations that use active mid-frequency sonar or involve underwater detonations. The request is for a 5-year period commencing in July 1, 2008.

The acoustic modeling approach taken in the HRC Environmental Impact Statement/Overseas Environmental Impact Statement and this LOA request attempts to quantify potential exposures to marine mammals resulting from operation of mid-frequency active sonar and underwater detonations. Results from this conservative modeling approach are presented without consideration of mitigation measures employed per Navy standard operating procedures. For example, securing or turning off an active sonar when an animal approaches closer than a specified distance reduces potential exposure since the sonar is no longer transmitting.

Modeling results from the analysis does not predict any marine mammal mortalities. Modeling results do predict that for this LOA request, one (1) humpback whale and one (1) striped dolphin could be exposed to sonar in excess of permanent threshold shift (PTS) threshold indicative of Level A injury. However, given standard mitigation measures presented in Chapter 11, and the increased likelihood that humpback whales and striped dolphins (since they occur in large pods) can be readily detected, a single Level A exposure to these species is less likely to occur.

To reiterate an important point, the history of Navy activities in the HRC and analysis in this document indicate that military readiness activities are not expected to result in any sonar–induced Level A injury or mortalities to marine mammals.

There are natural and manmade sources of mortality other than sonar and underwater detonation that may contribute to stranding events as described in the Cetacean Stranding Section (Section 6.2.10). Documented marine mammal strandings are a regular occurrence within the Hawaiian Islands since early record keeping began in the 1930's (Mazzuca et al., 1999, Maldini et al., 2005). For instance, 22 cetacean and 14 Hawaiian monk seal strandings or boat strikes were reported in Hawaiian waters during 2006 (NMFS-PIR, 2007). Of these 22 stranding, 17 are attributed to either vessel strikes or fisheries interaction. In a review of mass strandings within Hawaii, approximately two-thirds occurred during the summer (Mazzuca et al., 1999). The actual cause of a particular stranding may not be immediately apparent when there is little evidence of physical trauma, especially in the case of disease or age-related mortalities. These events require careful scientific investigation by a collaborative team of subject matter experts to determine actual cause of death.

Given the frequency of naturally occurring marine mammal strandings in Hawaii (e.g., natural mortality), it is conceivable that a stranding could co-occur with a Navy exercise even though the stranding is actually unrelated to and not caused by Navy activities. Species that are most commonly stranded within Hawaii are bottlenose dolphin, Kogia *spp*., melon-headed whale, pantropical spotted dolphin, pygmy killer whale, short-finned pilot whale, striped dolphin, Hawaiian monk seal, sperm whale, and humpback whale (Mazzuca et al., 1999, Maldini et al., 2005; NMFS-PIR, 2007).

In a letter from NMFS to Navy dated October 2006, NMFS indicated that Section 101(a)(5)(A) authorization is appropriate for mid-frequency active sonar activities because it allows NMFS to consider the potential for incidental mortality. NMFS' letter indicated; "Because mid-frequency sonar has been implicated in several marine mammal stranding events including some involving serious injury and mortality, and because there is no scientific consensus regarding the causal link between sonar and stranding events, NMFS cannot conclude with certainty the degree to which mitigation measures would eliminate or reduce the potential for serious injury of mortality." Accordingly, the Navy's LOA application will include requests for take, by mortality, of the most commonly stranded non ESA-listed species.

Evidence from five beaked whale strandings, all of which have taken place outside the HRC, and have occurred over approximately a decade, suggests that the exposure of beaked whales to mid-frequency sonar in the presence of certain conditions (e.g., multiple units using tactical sonar, steep bathymetry, constricted channels, strong surface ducts, etc.) may result in strandings, potentially leading to mortality. Although these physical factors believed to contribute to the likelihood of beaked whale strandings are not present, in their aggregate, in the Hawaiian Islands, scientific uncertainty exists regarding what other factors, or combination of factors, may contribute to beaked whale strandings. Accordingly, to allow for scientific uncertainty regarding contributing causes of beaked whale strandings and the exact mechanisms of the physical effects, the Navy will also request authorization for take, by mortality, of the beaked whale species present in the Hawaiian Islands.

Neither NMFS nor the Navy anticipates that marine mammal strandings or mortality will result from the operation of mid-frequency sonar during Navy exercises within the HRC. However, by authorizing a very small number of mortalities for beaked whales and commonly stranded species, if a single individual of these species is found dead coincident with Navy activities (a statistically likely event, as an average of two wash up per month in Hawaii), a potentially lengthy investigation of the cause(s) of the death would not unnecessarily interfere with Navy training exercises. Additionally, through the MMPA process (which allows for adaptive management), NMFS and the Navy will determine the appropriate way to proceed in the unlikely event that a causal relationship were to be found between Navy activities and a future stranding. The Navy's LOA application requests the take, by serious injury or mortality, of 2 each of 10 species (bottlenose dolphin, Kogia *spp*., melon-headed whale, pantropical spotted dolphin, pygmy killer whale, short-finned pilot whale, striped dolphin, Cuvier's, Longman's, and Blainville's beaked whales), however, these numbers may be modified through the MMPA process, based on available data.

6. NUMBERS AND SPECIES EXPOSED

The National Marine Fisheries Service (NMFS) application 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 Marine Mammal Protection Act (MMPA), and Section 6.2.1 below defines MMPA Level A and Level B as applicable to military readiness activities. Section 6.2.1 presents how the Level A and Level B harassment definitions were relied on to develop the quantitative acoustic analysis methodologies used to assess the potential for the proposed action to affect marine mammals.

6.1 Non-Acoustic Effects

The Hawaii Range Complex Environmental Impact Statement/Overseas Environmental Impact Statement (2007) concluded that the non-acoustic activities associated with training activities would not have a significant impact on marine mammals, and that non-acoustic effects would not result in the take of MMPA-protected species.

Collisions with commercial ships, Navy ships, and vessels engaged in whale watching 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., sperm whale). Accordingly, the Navy has adopted standard operating procedures to reduce the potential for collisions with surfaced marine mammals. These standard operating procedures include: (1) use of lookouts trained to detect all objects on the surface of the water, including marine mammals; (2) reasonable and prudent actions to avoid the close interaction of Navy assets and marine mammals; and (3) maneuvering to keep away from any observed marine mammal. Based on these standard operating procedures, collisions with marine mammals are not expected.

6.2 Acoustic Exposures

6.2.1 Analytical Framework for Assessing Marine Mammal Response to Active Sonar

As summarized by the National Academies of Science (NAS), the possibility that human-generated sound could harm marine mammals or significantly interfere with their "normal" activities is an issue of increasing concern (National Research Council [NRC], 2005). This section of the authorization request evaluates the potential for the specific Navy acoustic sources used in the HRC to result in harassment of marine mammals.

Assessing whether a sound may disturb or injure a marine mammal involves understanding the characteristics of the acoustic sources, the marine mammals that may be present in the vicinity of the sound, and the effects that sound may have on the physiology and behavior of those marine mammals. Although it is known that sound is important for marine mammal communication, navigation and foraging (NAS, 2003; NRC, 2005), there are many unknowns in assessing the effects and significance of marine mammals responses to sound exposures. For this reason, the Navy enlisted the expertise of National Marine Fisheries Service (NMFS) as the cooperating agency. Their input assisted the Navy in developing a conceptual analytical framework for evaluating what sound levels marine mammals might receive as a result of Navy training actions in HRC, whether marine mammals might respond to these exposures, and whether that response might have a mode of action on the biology or ecology of marine mammals such that the response should be considered a potential harassment. From this framework of evaluating the potential for harassment incidents to occur, an assessment of whether acoustic sources might impact populations, stocks or species of marine mammals can be conducted.

The conceptual analytical framework (Figure 6-1) presents an overview of how the mid-frequency active sonar sources used during training are assessed to evaluate the potential for marine mammals to be exposed to an acoustic source, the potential for that exposure to result in a physiological effect or behavioral response by an animal, and the assessment of whether that response may result in a consequence that constitutes harassment in accordance with MMPA definitions.

The first step in the conceptual model is to estimate the potential for marine mammals to be exposed to a Navy acoustic source. Three questions are answered in this "acoustic modeling" step:

1. **What action will occur?** This requires identification of all acoustic sources that would be used in the exercises and the specific outputs of those sources. This information is provided in Appendix A.
2. **Where and when will the action occur?** The place and season of the action are important to determine which marine mammal species are likely to be present. Species occurrence and density data (Section 4.1 and 4.2) are used to determine the subset of marine mammals that may be present when an acoustic source is operational (abundance and density estimates from Mobley 2004 and Barlow 2006).
3. **Predict the underwater acoustic environment that would be encountered**. The acoustic environment here refers to environmental factors that influence the propagation of underwater sound. Acoustic parameters influenced by the place, season, and time are described in Appendix A.
4. **How many marine mammals are predicted to be exposed to sound from the acoustic sources?** Sound propagation models are used to predict the received exposure level from an acoustic source, and these are coupled with species distribution and density data to estimate the accumulated received energy and sound pressure level that might be received at a level that could be considered as potential harassment. Appendix A describes the acoustic modeling and Section 6.3 present the number of exposure incidents predicted by the modeling.

The next steps in the analytical framework evaluate whether the sound exposures predicted by the acoustic model might cause a response in a marine mammal, and if that response might be considered harassment of the animal. Harassment includes the concepts of potential injury (Level A Harassment) and behavioral disturbance (Level B harassment). The response assessment portion of the analytical framework examines the following question:

1. **Which potential acoustic exposures might result in harassment of marine mammals**?

The predicted acoustic exposures are first considered within the context of the species biology (e.g., can a marine mammal detect the sound, and is that mammal likely to respond to that sound?). Next, if a response is predicted, is that response potentially 'harassment' in accordance

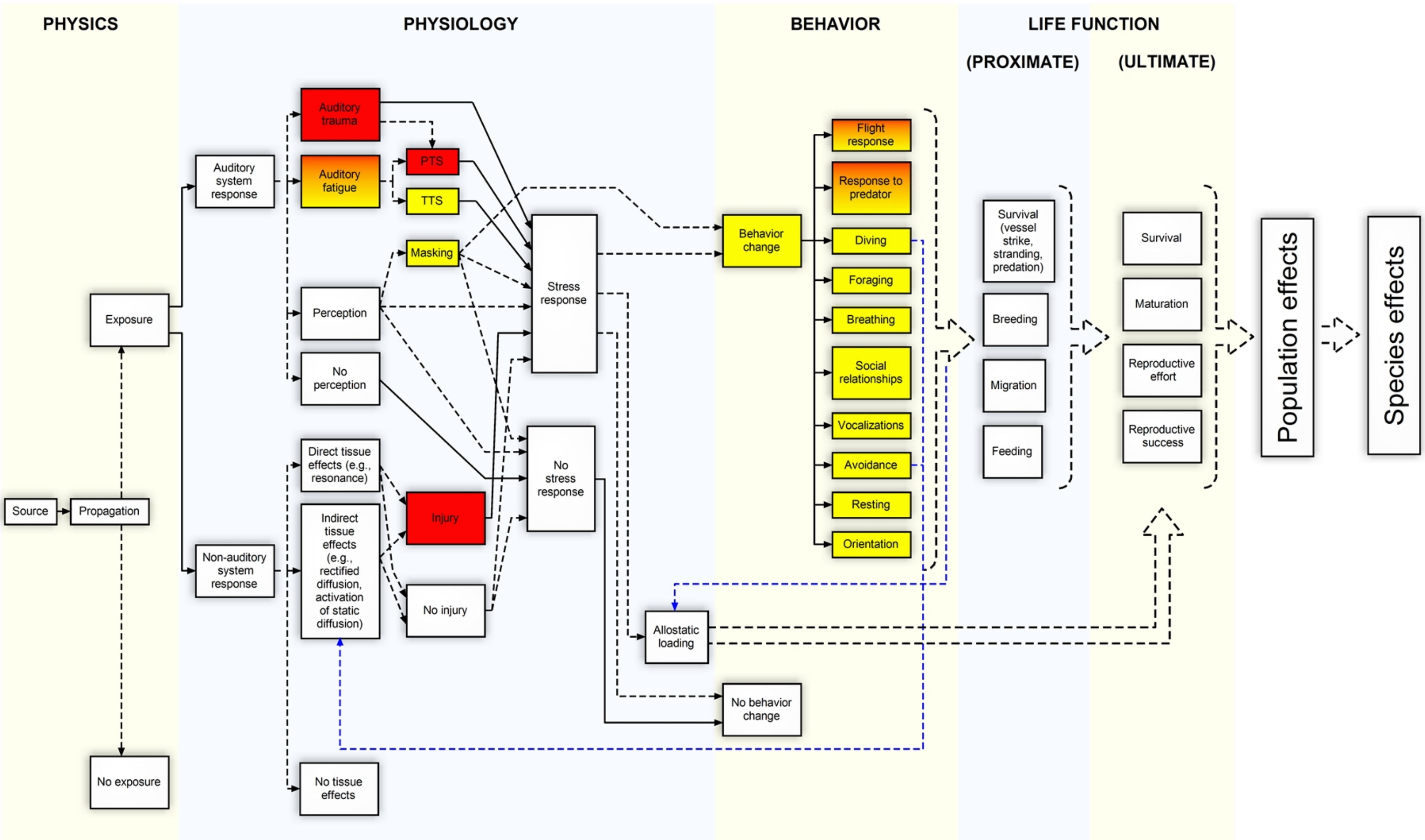


Figure 6-1. MMPA Analytical Framework for Exposure to Sound (on the left) and Responses Progressing to the Right to Population and Species Level Effects

with MMPA harassment definitions? For example, if a response to the acoustic exposure has a mode of action that results in a consequence for an individual, such as interruption of feeding, that response or repeated occurrence of that response could be considered "abandonment or significant alteration of natural behavioral patterns," and therefore the exposure(s) would cause Level B harassment.

Section 6.2.2 reviews the regulatory framework and premises for the Navy/NMFS marine mammal response analytical framework. Section 6.3 present the analysis by species/stock, presenting relevant information about the species biology and ecology to provide a context for assessing whether modeled exposures might result in incidental harassment. The potential for harassment incidents is then considered 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 impact on species or stocks.

6.2.2 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 model for estimating potential acoustic effects from HRC anti-submarine warfare (ASW) training activities on cetacean species makes use of the methodology that was developed in cooperation with the 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 Undersea Warfare Training Range (USWTR) received from NMFS dated January 30, 2006, NMFS concurred with the use of Energy Flux Density Level (EL) for the determination of physiological effects to marine mammals. Therefore, this methodology is used to estimate the annual exposure of marine mammals that may be considered Level A harassment or Level B harassment as a result of temporary, recoverable physiological effects.

In addition, the approach for estimating potential acoustic effects from HRC training activities on marine mammal makes use of the comments received on the Navy's Draft *Overseas Environmental Impact Statement/Environmental Impact Statement, Undersea Warfare Training Range (OEIS/EIS)* (DON, 2005) and the 2006 Rim of the Pacific (RIMPAC) Supplemental Overseas Environmental Assessment (DON, 2006). NMFS and others who commented recommended the use of an alternate methodology to evaluate when sound exposures might result in behavioral effects without corresponding physiological effects. As a result of these comments, this analysis uses a dose function approach to evaluate the potential for behavioral effects. The dose-function is further explained in Section 6.2.6.

A number of Navy actions and NOAA rulings have helped to qualify possible events deemed as "harassment" under the MMPA. As stated previously, "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). NMFS also includes mortality as a possible outcome to consider in addition to Level A and Level B harassment. The acoustic effects analysis and exposure calculations are based on the following premises:

- Harassment that may result from Navy operations described in the HRC EIS/OEIS is unintentional and incidental to those operations.
- This HRC LOA request uses an unambiguous definition of injury as defined in the RIMPAC OEA (DON, 2006) and in previous rulings (NOAA, 2001; 2002a): injury occurs when any biological tissue is destroyed 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 (defined below) harassment categories can overlap and are not necessarily mutually exclusive. However, consistent with prior ruling (NOAA, 2001; 2006b), this HRC LOA request assumes that Level A and B do not overlap so as to preclude circular definitions of harassment.
- An individual animal predicted to experience simultaneous multiple injuries, multiple disruptions, or both, is counted as a single take (see NOAA, 2001; 2006b). 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. Based on the consideration of two different acoustic modeling methodologies to assess the potential for sound exposures that might result in behavioral disturbance, it is possible that an animal could simultaneously experience multiple disruptions (e.g., a temporary threshold shift and a resultant stress response), may be counted as multiple Level B harassment incidents (i.e., a potential overlap of 5 percent). Although this approach overestimates the potential for behavioral disturbance incidents, it is considered conservative because the actual incidents of disturbance are expected to be much lower.
- The acoustic effects analysis is based on primary exposures only. Secondary, or indirect effects, such as susceptibility to predation following injury and injury resulting from disrupted behavior, while possible, can only be reliably predicted in circumstances where the responses have been well documented. Consideration of secondary effects would result in much 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. However, for beaked whales, where a connection between behavioral disruption by mid-frequency active sonar and injury to beaked whales is considered a possibility under specific operational and environmental parameters, a probability of secondary effect leading to serious injury is considered (See Section 6.2.8).

6.2.3 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 Sections 6.2.4 and 6.2.5 is used to develop specific numerical exposure thresholds and dose function exposure estimations. Exposure thresholds are combined with sound propagation models and species distribution data to estimate the potential exposures, as presented in Section 6.2.7.

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 proposed 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 impact may not be observable over short periods of observation. Ecological information is considered in the analysis of the effects of individual species (see Section 6.3.3 and 6.3.4).

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. A physiological effect may range from the most significant of impacts (i.e., mortality and serious injury) to lesser effects that would define the lower end of the physiological impact range, such as the non-injurious distortion of auditory tissues. This latter physiological effect is important to the integration of the biological and regulatory frameworks and will receive 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 endangered species act (ESA).

In this authorization request 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 acoustic sources. As a result, this authorization request uses the following definitions:

- A **physiological effect** is a variation in an animal's respiratory, endocrine, hormonal, circulatory, neurological, or reproductive activity and processes, beyond the animal's normal range of variability, in response to human activity or to an exposure to a stimulus such as active sonar.
- A **behavioral effect** is a variation in the pattern of an animal's breathing, feeding, resting, migratory, intraspecific behavior (such as reproduction, mating, territorial, rearing, and agonistic behavior), and interspecific beyond the animal's normal pattern of

variability in response to human activity or to an exposure to a stimulus such as active sonar.

The definitions of physiological effect and behavioral effect used here are specific to this LOA request and should not be confused with more global definitions applied to the field of biology or to existing Federal law. 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 6-2 shows the relationship between severity of effects, source distance, and exposure level, as defined in this authorization request.

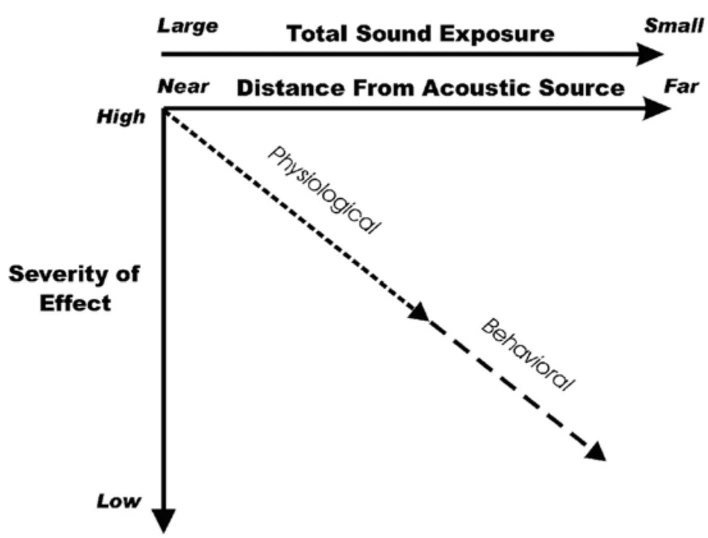


Figure 6-2. Relationship Between Severity of Effects, Source Distance, and Exposure Level

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, as defined in the HRC EIS/OEIS and previous rulings (NOAA, 2001; 2002a), is the destruction or loss of biological tissue. The destruction or loss of biological tissue will result in an alteration of physiological function that exceeds the normal daily physiological variation of the intact tissue. For example, increased localized histamine production, edema, production of scar tissue, activation of clotting factors, white blood cell response, etc., may be expected following injury. Therefore, this authorization request assumes that all injury is qualified as a physiological effect and, to be consistent with prior actions and rulings (NOAA, 2001), all injuries (slight to severe) are considered Level A harassment.

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

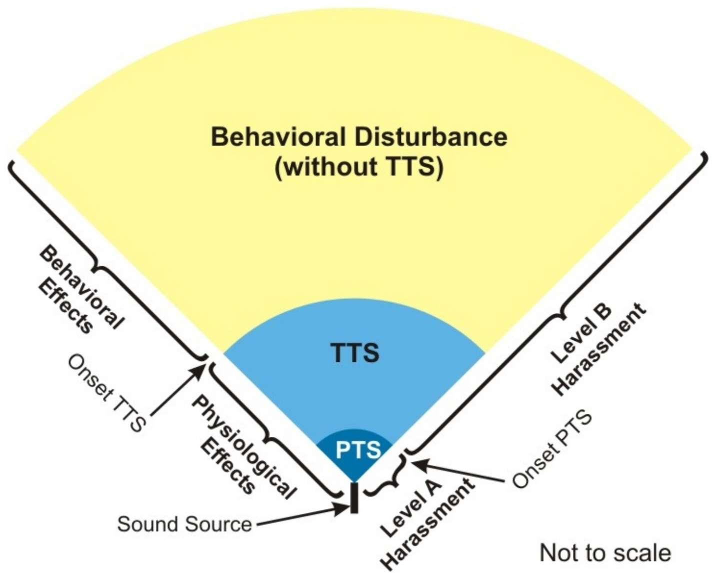
For example, some physiological effects can occur that are non-injurious but that can potentially disrupt the behavior of a marine mammal. These include temporary distortions in sensory tissue that alter physiological function, but that are fully recoverable without the requirement for tissue replacement 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 harassment status of slight behavior disruption has been addressed in workshops, previous actions, and rulings (NOAA, 2001; DON, 2001a). The conclusion is that a 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 rulings (NOAA, 2002a). Public Law 108-136 (2004) amended the definition of Level B harassment for military readiness activities, which applies to this action. For military readiness activities, Level B harassment is defined as "any act that disturbs or is likely to disturb a marine mammal or marine mammal stock by causing disruption of natural behavioral patterns…to a point where such behaviors are abandoned or significantly altered."

Although the temporary lack of response discussed above may not result in abandonment or significant alteration of natural behavioral patterns, the acoustic effect inputs used in the acoustic model assume that temporary hearing impairment (slight to severe) is considered Level B harassment. Although modes of action are appropriately considered, as outlined in Figure 6-1, the conservative assumption used here is to consider all hearing impairment as harassment. As a result, the actual incidental harassment of marine mammals associated with this action may be less than predicted via the analytical framework.

MMPA Exposure Zones

Two acoustic modeling approaches are used to account for both physiological and behavioral effects to marine mammals. This subsection of harassment zones is specific to the modeling of total energy (EL), described in more detail in Appendix A. When using a threshold of accumulated energy (EL) the volumes of ocean in which Level A and Level B harassment are predicted to occur are described as exposure zones. As a conservative estimate, all marine mammals predicted to be in a zone are considered exposed to accumulated sound levels that may result in harassment within the applicable Level A or Level B harassment categories. Figure 6-3 illustrates harassment zones extending from a hypothetical, directional sound source.



This figure is for illustrative purposes only and does not represent the sizes or shapes of the actual exposure zones.

Figure 6-3. Harassment Zones Extending from a Hypothetical, Directional Sound Source

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 account of all more serious injuries by inclusion within the Level A harassment zone. The threshold used to define the outer limit of the Level A exposure zone is given in Figure 6-3.

The **Level B exposure zone** begins just beyond 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 (such as occurs with inner ear hair cells subjected to temporary threshold shift) . 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. The criterion and threshold used to define the outer limit of the Level B exposure zone for the on-set of certain physiological effects are given in Figure 6-3. Due to the Level B exposure zone developed using accumulated energy, there is a partial overlap with the consideration of potential behavioral disturbance assessed using the dose function, which is a received sound pressure level, described in Section 6.2.6. This overlap is considered conservative in that it may 'double-count' potential exposures, and ensures both physiological and behavioral effects are sufficiently considered.

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 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 over-stimulation 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 noise-induced threshold shift, or simply a threshold shift (TS) (Miller, 1974). A TS may be either permanent, in which case it is called a permanent threshold shift (PTS), or temporary, in which case it is called a temporary threshold shift (TTS). Still lower levels of sound may result in auditory masking (described in Section 6.2.7), 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 in this authorization request, but rather a potential behavioral effect. Descriptions of other potential physiological effects, including acoustically mediated bubble growth and air cavity resonance, are described in the HRC EIS/OEIS.

Noise-Induced Threshold Shifts

The amount of TS depends on the amplitude, duration, frequency, 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) (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 eventually 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, TTS2 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 6-4 shows two hypothetical TSs: one that completely recovers, a TTS, and one that does not completely recover, leaving some PTS.

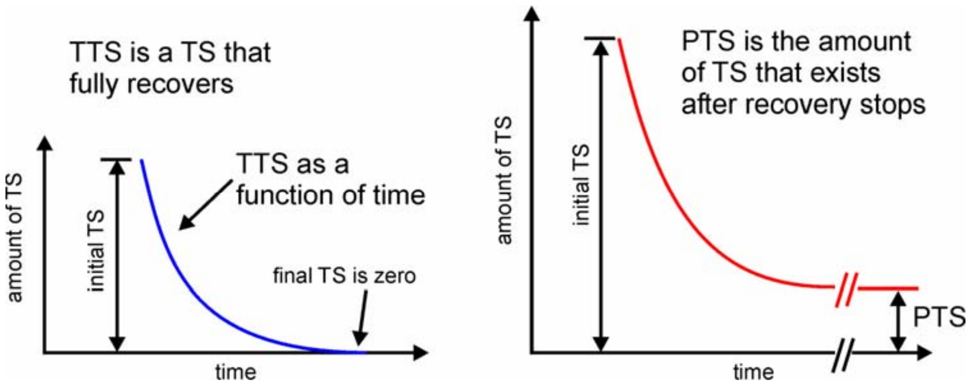


Figure 6-4. Hypothetical Temporary and Permanent Threshold Shifts

PTS, TTS, and Exposure Zones

PTS is non-recoverable and, by definition, must result from the destruction of tissues within the auditory system. PTS therefore qualifies as an injury and is classified as Level A harassment under the wording of the MMPA. In the HRC, 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 HRC, 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 the HRC, the potential for TTS is considered as a Level B harassment that is mediated by physiological effects on the auditory system.

6.2.4 Criteria and Thresholds for Physiological Effects (Sensory Impairment)

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. Section 6.2.4 identified the tissues of the ear as being 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.

Marine mammal ears are functionally and structurally similar to terrestrial mammal ears; however, there are important differences (Ketten, 1998). The most appropriate information from which to develop PTS/TTS criteria for marine mammals would be 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. Because of the ethical issues presented, PTS data do not exist for marine mammals and are unlikely to be obtained. Therefore, PTS criteria must be extrapolated using 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 authorization request 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

Energy Flux Density Level (EL) is 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 $\mu Pa)^2$-s for airborne sound.

Sound Pressure Level (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 (for example, Schlundt et al., 2000). The existing cetacean TTS data are summarized in the following bullets.

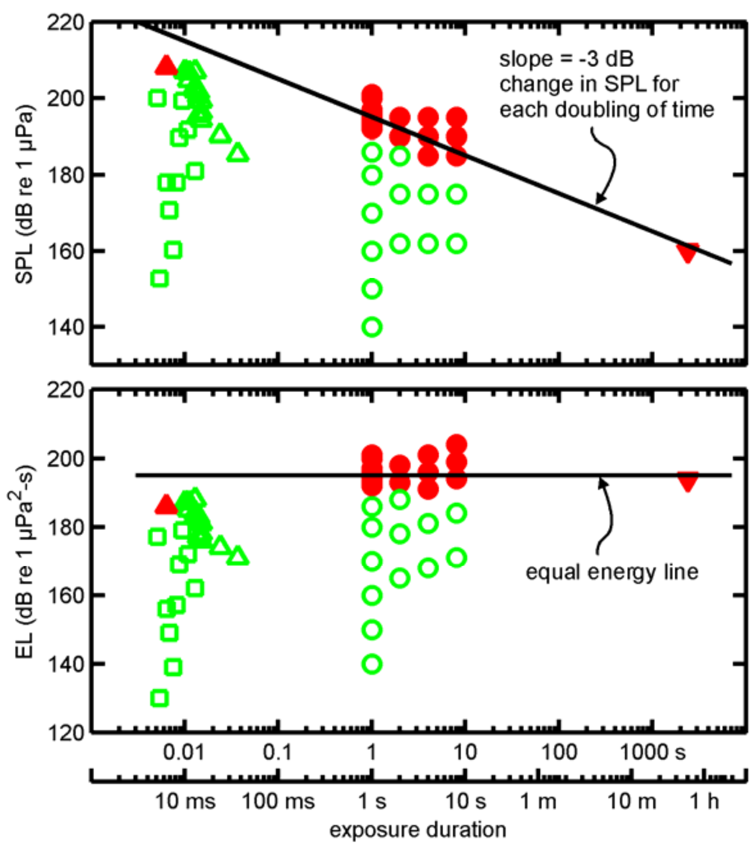
- **Schlundt** et al. **(2000)** reported the results of TTS experiments conducted with bottlenose dolphins and white whales exposed to 1-second tones. This paper also includes a reanalysis of preliminary TTS data released in a technical report by Ridgway et al. (1997). At frequencies of 3, 10, and 20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

- **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. **(2003)** 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. (2003b) 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 white whales exposed to impulsive sounds similar to those produced by distant underwater explosions and seismic water guns. 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 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 6-5 shows the existing TTS data for cetaceans (dolphins and white 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. (2003b).

Figure 6-5 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 6-5 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 + 10log10 (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* – 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 non-impulsive data) very well, despite differences in exposure duration, SPL, experimental methods, and subjects.



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

Figure 6-5. Existing TTS Data for Cetaceans

In summary, the existing cetacean TTS data show that, for the species studied and sounds (non-impulsive) of interest, the following is true:

- **The growth and recovery of TTS are analogous 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) (Kryter et al., 1965; 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 energy flux density level of 195 dB re 1 µPa^2-s is the most appropriate predictor for onset-TTS from a single, continuous exposure.

Relationship between TTS and PTS

Since 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 TTS2 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 – 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 TTS2 approached and exceeded 50 dB, suggesting that 50 dB of TTS2 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 TTS2 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), TTS2 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 6-6 shows results from Ward et al. (1958, 1959) plotted as the amount of TTS2 versus the exposure EL. The data in Figure 6-6(a) are from broadband (75 Hz to 10 kHz) sound exposures with durations of 12 to 102 minutes (Ward et al., 1958). The symbols represent mean TTS2 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 in additional amount of TTS produced by an increase in exposure. For example, the slope of the line in Figure 6-5(a) is approximately 1.5 dB TTS2 per dB of EL. This means that each additional dB of EL produces 1.5 dB of additional TTS2.

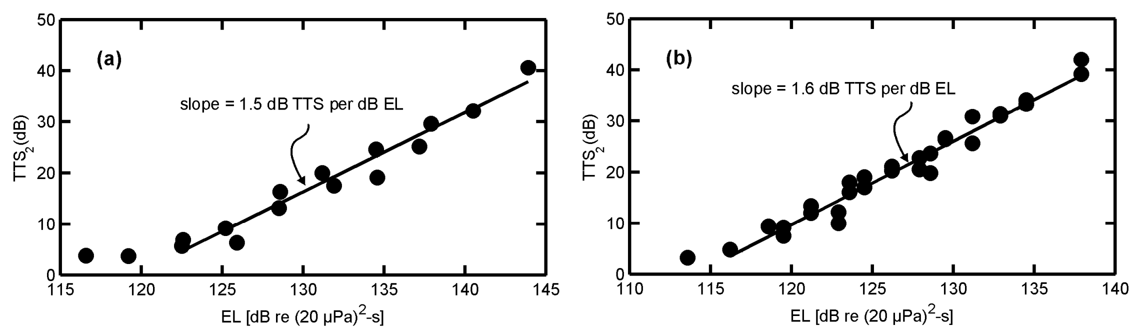


Figure 6-6. Growth of TTS versus the Exposure EL (from Ward et al. [1958, 1959])

The data in Figure 6-6(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 6-6(a). The slope of the regression line fit to the mean TTS data was 1.6 dB TTS2/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 TTS2/dB EL, depending on the frequencies of the sound exposure and hearing test.

An estimate of 1.6 dB TTS2 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 – 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 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 value of 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 text 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 a 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. 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. Analyses for each individual species are presented in Sections 6.3.3 and 6.3.4.

Derivation of Effect Threshold

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, 2003) and the long-duration sound data from Nachtigall et al. (2003a, b). 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:

$$EL = SPL + 10\log10(\text{duration})$$

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.
- A single ping with SPL = 192 dB re 1 μPa and duration = 2 seconds.
- Two pings with SPL = 192 dB re 1 μPa and duration = 1 second.
- Two pings with SPL = 189 dB re 1 μPa and duration = 2 seconds.

Comparison to Surveillance Towed Array Sensor System Low Frequency (SURTASS LFA) Active Risk Functions

The physiological effect thresholds described in this authorization request should not be confused with criteria and thresholds used for the Navy's Surveillance Towed Array Sensor

System Low Frequency Active (SURTASS LFA) sonar. SURTASS LFA features pings lasting many tens of seconds. The sonars of concern for use during within the HRC emit pings lasting a few seconds at most. SURTASS LFA risk functions were expressed in terms of the received "single ping equivalent" SPL. Physiological effect thresholds in this authorization request are expressed in terms of the total received EL. The SURTASS LFA risk function parameters cannot be directly compared to the effect thresholds used in this LOA request and the HRC EIS/OEIS. Comparisons must take into account the differences in ping duration, number of pings received, and method of accumulating effects over multiple pings.

Previous Use of EL for Physiological Effects

Energy measures have been used as a part of dual criteria for cetacean auditory effects in shock trials, which only involve impulsive-type sounds (DON, 1997, 2001a). These actions used 192 dB re 1 μPa^2-s as a reference point to derive a TTS threshold in terms of EL. A second TTS threshold, based on peak pressure, was also used. If either threshold was exceeded, effect was assumed.

The 192 dB re 1 μPa^2-s reference point differs from the threshold of 195 dB re 1 μPa^2-s used in this HRC LOA request and EIS/OEIS. The 192 dB re 1 μPa^2-s value was based on the minimum observed by Ridgway et al. (1997) and Schlundt et al. (2000) during TTS measurements with bottlenose dolphins exposed to 1-second tones. At the time, no impulsive test data for marine mammals were available and the 1-second tonal data were considered to be the best available. The minimum value of the observed range of 192 to 201 dB re 1 μPa^2-s was used to protect against misinterpretation of the sparse data set available. The 192 dB re 1 μPa^2-s value was reduced to 182 dB re 1 μPa^2-s to accommodate the potential effects of pressure peaks in impulsive waveforms.

The additional data now available for onset-TTS in small cetaceans confirm the original range of values and increase confidence in it (Finneran et al., 2001, 2003; Nachtigall et al., 2003a, 2003b). The HRC EIS/OEIS, therefore, uses the more complete data available and the mean value of the entire Schlundt et al. (2000) data set (195 dB re 1 μPa^2-s), instead of the minimum of 192 dB re 1 μPa^2-s. From the standpoint of statistical sampling and prediction theory, the mean is the most appropriate predictor—the "best unbiased estimator"—of the EL at which onset-TTS should occur; predicting the number of exposures in future actions relies (in part) on using the EL at which onset-TTS will most likely occur. When that EL is applied over many pings in each of many sonar exercises, that value will provide the most accurate prediction of the actual number of exposures by onset-TTS over all of those exercises. Use of the minimum value would overestimate the number of exposures because many animals counted would not have experienced onset-TTS. Further, there is no logical limiting minimum value of the distribution that would be obtained from continued successive testing. Continued testing and use of the minimum would produce more and more erroneous estimates.

Summary of Physiological Effects Criteria

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. The application of the model results to estimate marine mammal exposures for each species is discussed in Sections 6.3.3 and 6.3.4. In this authorization request, sound exposure thresholds for onset TTS and PTS are as presented in the following text box:

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

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

6.2.5 Criteria and Thresholds for Behavioral Effects

Section 6.2.4 categorized the potential effects of sound into physiological effects and behavioral effects. Criteria and thresholds for physiological effects are discussed in Section 6.2.4. This Section presents the effect criterion and threshold for behavioral effects of sound leading to behavioral disturbance without accompanying physiological effects. Since TTS is used as the biological indicator for a physiological effect leading to behavioral disturbance, the behavioral effects discussed in this section may be thought of as behavioral disturbance occurring at exposure levels below those causing TTS.

A large body of research on terrestrial animal and human response to airborne sound exists, but results from those studies are not readily extendible to the development of effect criteria and thresholds for marine mammals. For example, "annoyance" is one of several criteria used to define impact to humans from exposure to industrial sound sources. Comparable criteria cannot be developed for marine mammals because there is no acceptable method for determining whether a non-verbal animal is annoyed. Further, differences in hearing thresholds, dynamic range of the ear, and the typical exposure patterns of interest (e.g., human data tend to focus on 8-hour-long exposures) make extrapolation of human sound exposure standards inappropriate.

Behavioral observations of marine mammals exposed to anthropogenic sound sources exist, however, there are few observations and no controlled measurements of behavioral disruption of cetaceans caused by sound sources with frequencies, waveforms, durations, and repetition rates comparable to those employed by the tactical sonars to be used in the HRC. At the present time there is no consensus on how to account for behavioral effects on marine mammals exposed to continuous-type sounds (NRC, 2003).

This application uses behavioral observations of trained cetaceans exposed to intense underwater sound under controlled circumstances to develop a criterion and threshold for behavioral effects of sound. These data are described in detail in Schlundt et al. (2000) and Finneran and Schlundt (2004). These data, because they are based on controlled, tonal sound exposures within the tactical sonar frequency range, are the most applicable.

History of Assessing Potential Harassment from Behavioral 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. The application of the model results to estimate marine mammal exposures for each species is discussed in Sections 6.3.3 and 6.3.4. In this authorization request, sound exposure thresholds for onset TTS and PTS are as presented in the following text box:

As described above, behavioral observations of trained cetaceans exposed to intense underwater sound under controlled circumstances are an important data set in evaluating and developing a criterion and threshold for behavioral effects of sound. These behavioral response data are an important foundation for the scientific basis of the Navy's prior threshold of onset behavioral effects because of the: (1) finer control over acoustic conditions; (2) greater quality and confidence in recorded sound exposures; and (3) the exposure stimuli closely match those of interest for the mid-frequency active sonar used proposed in HRC. Since no comparable controlled exposure data for wild animals exist, or are likely to be obtained in the near-term, the relationship between the behavioral results reported by Finneran and Schlundt (2004) and wild animals is not known. Although experienced, trained subjects may tolerate higher sound levels than inexperienced animals; it is also possible that prior experiences and resultant expectations may have made some trained subjects less tolerant of sound exposures. However, in response to USWTR comments, potential differences between trained subjects and wild animals were considered by the Navy in conjunction with NMFS in the Navy's application for harassment authorization for RIMPAC 2006. At that time, NMFS recommended the Navy include analysis of this threshold based on NMFS' evaluation of behavioral observations of marine mammals under controlled conditions, plus NMFS' interpretation of two additional studies on reactions to vessel sound (Nowacek et al., 2004) and analysis for the *U.S.S. SHOUP* event (NMFS, 2005). For that exercise, a conservative threshold for effect was derived compared to the regulatory definition of harassment, and the Navy agreed to the use of the 173 dB re 1 μPa^2-s threshold for the RIMPAC incidental harassment authorization (IHA) request.

Rationale for using energy flux density for evaluation of behavioral effects included:

- **EL effect exposures account for both the exposure SPL and duration into account.** Both SPL and duration of exposure affect behavioral responses to sound, so a behavioral effect threshold based on EL accounts for exposure duration.
- **EL takes into account the effects of multiple pings.** Effect thresholds based on SPL predict the same effect regardless of the number of received sounds. Previous actions using SPL-based criteria included implicit methods to account for multiple pings, such as the single-ping equivalent used in the surveillance towed array sensor system low frequency active (SURTASS LFA) (DON, 2001b).
- **EL allows a rational ordering of behavioral effects with physiological effects.** The effect thresholds for physiological effects are stated in terms of EL because experimental data described above showed that the observed effects (TTS and PTS) are correlated best with the sound energy, not the SPL. Using EL for behavioral effects allows the behavioral and physiological effects to be placed on a single exposure scale, with behavioral effects occurring at lower exposures than physiological effects.

Subsequent to issuance of the RIMPAC IHA, additional public comments were received and considered. Based on this input, the Navy continued to coordinate with NMFS to determine whether an alternate approach to energy flux density could be used to evaluate when a marine mammal may behaviorally be affected by mid-frequency sonar sound exposures. Coordination between the Navy and NMFS produced the adoption of dose function for evaluation of behavioral effects. The dose function approach for evaluating behavioral effects is described in below, and fully considers the controlled, tonal sound exposure data in addition to comments received from the regulatory, scientific and the public regarding concerns with the use of EL for evaluating the effects of sound on wild animals.

6.2.6 Estimating the Probable Behavioral Responses of Marine Mammals to Active Sonar

To assess the potential effects on marine mammals of active sonar that is used during training activities, the U.S. Navy began with a series of mathematical models that estimate the number of times individuals of the different species of marine mammal might be exposed to mid-frequency active (MFA) sonar at different received levels. These exposure analyses assumed that the potential consequences of exposure to MFA sonar on individual animals would be a function of the intensity (measured in both sound pressure level in decibels and frequency), duration, and frequency of the animal’s exposure to the mid-frequency transmissions. These exposure analyses assume that MFA sonar poses no risk to marine mammals if they are not exposed to sound pressure levels from the mid-frequency active sonar above some critical value. Though, active sonar could have various indirect, adverse effects on marine mammals by disrupting marine food chains, a species’ predators, or a species’ competitors; however, the Navy and NMFS did not identify situations where this concern might apply to marine mammals under the National Marine Fisheries Service’s jurisdiction.

The second step of the assessment procedure requires the U.S. Navy and NMFS to identify how marine mammals are likely to respond when and if they are exposed to active sonar. Marine mammals can experience a variety of responses to sound including death, sensory impairment (permanent and temporary threshold shifts and acoustic masking), physiological responses (particular stress responses), behavioral responses, and social responses that might result in reducing the fitness of individual marine mammals.

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 introduce sound into the marine environment. Although many of these mass stranding events have been correlated with sonar exposures, sonar exposure has been identified as a contributing cause of five specific mass stranding events: Greece in 1996; the Bahamas in March 2000; Madeira, Spain in 2000; and the Canary Islands in 2002 and 2004 (Advisory Committee Report 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, investigators have identified two 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).

Acoustic exposures can also result in noise induced hearing loss that is a function of the interactions of several factors, including individual hearing sensitivity and exposure amplitude, exposure duration, frequency, and other variables that have not been studied very well (e.g., kurtosis, temporal pattern, directionality). Loss of hearing sensitivity is referred to as a "threshold shift"; the extent and duration of threshold shifts depend on a combination of several acoustic features and is specific to particular species. A shift in hearing sensitivity may be temporary (temporary threshold shift or TTS) or it may be permanent (permanent threshold shift or PTS) depending on how the frequency, amplitude and duration of the exposure combine to produce damage and if that change is reversible.

Based on the evidence available, marine animals are likely to exhibit any of a suite of behavioral responses or combinations of behavioral responses upon exposure to sonar transmissions: they will try to avoid exposure or continue exposure, they will experience behavioral disturbance (including distress or disruption of social or foraging activity), they will habituate to the sound, they will become sensitized to the sound, or they will not respond. In experimental trials with trained marine mammals, behavioral changes typically involved 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). Dolphins exposed to 1-second intense tones exhibited short-term changes in behavior above received sound levels of 178 to 193 dB re 1 μPa rms and belugas did so at received levels of 180 to 196 dB and above. Test animals sometimes vocalized after 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).

Existing studies of behavioral effects of man-made sounds in marine environments remain inconclusive, partly because many of those studies have lacked adequate controls, apply only to certain kinds of exposures (which are often different from the exposures being analyzed), and have 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 man-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. 2004). 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.

In the past, the Navy and NMFS have only used "acoustic thresholds" to identify the number of marine mammals that might experience hearing losses or behavioral harassment upon being exposed to active sonar (see Figure 6-7 right panel). These acoustic 'thresholds" have been represented by either sound exposure level (related to sound energy, abbreviated as SEL), sound pressure level (abbreviated as SPL), or other metrics such as peak pressure level and acoustic impulse (not considered for sonar in this document). The general approach has been to apply these threshold functions such that a marine mammal is counted as behaviorally harassed or experiencing hearing loss (depending on which threshold) by received sound levels above the threshold and not counted as behaviorally harassed or experiencing hearing loss otherwise. For example, previous Navy EISs, environmental assessments, and permit applications, and NMFS MMPA permits used 195 dB re 1 $\mu Pa^2 s$ as the energy threshold level for temporary hearing degradation for cetaceans. If the transmitted sonar energy received by a whale was above 195 dB re 1 $\mu Pa^2 s$, then the animal was considered to have experienced a temporary loss in the sensitivity of its hearing. If the received energy level was below 195 dB re 1 $\mu Pa^2 s$, then the animal was not treated as having experienced a temporary loss in the sensitivity of its hearing.

The right panel in Figure 6-7 illustrates a typical step-function or threshold that might also relate a sonar exposure to the probability of a response. As this figure illustrates, acoustic thresholds the Navy and NMFS used in the past assumed that every marine mammal above a particular received level (for example, to the right of the red vertical line in the figure) would exhibit identical responses to a sonar exposure. This assumed that the responses of marine mammals would not be affected by differences in acoustic conditions, differences between species and populations, differences in gender, age, reproductive status, social behavior, or the prior experience of the individuals.

Both the Navy and NMFS are aware that the studies of marine mammals in the wild and in experimental settings do not support these assumptions — different species of marine mammals and different individuals of the same species respond differently to sonar exposure. Further, there are geographic differences in the response of marine mammals to sonar that suggest that different populations may response differently to sonar exposure, and studies of animal physiology suggest that gender, age, reproductive status, and social behavior, among other variables, probably affects how marine mammals respond to sonar exposures. However, neither agency had the data necessary to implement alternatives to discrete acoustic thresholds.

Over the past several years, the U.S. Navy and the NMFS have worked on developing acoustic “dose-functions” to replace the acoustic thresholds used in the past to estimate the probability of marine mammals being behaviorally harassed by received levels of mid-frequency active sonar (the Navy and NMFS will continue to use acoustic thresholds to estimate the probability of temporary or permanent threshold shifts and for behavioral responses to explosives using SEL as the appropriate metric). Unlike acoustic thresholds, acoustic dose-functions (which are also called “exposure-response functions,” “dose-response functions,” or “stress-response functions” in other risk assessment contexts) assume that the probability of a response depends first on the “dose” (in this case, the received level of sound) and that the probability of a response increases as the “dose” increases. It is important to note that the probabilities associated with acoustic dose functions do not represent an individual’s probability of responding, they identify the proportion of an exposed population that is likely to respond to an exposure.

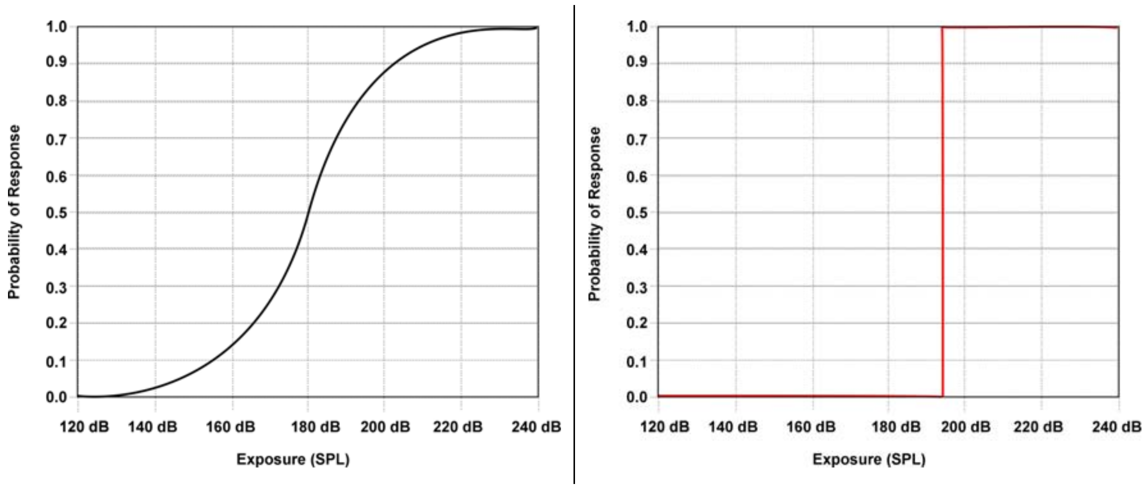


Figure 6-7. The left panel illustrates a typical dose-function with the probability of a response on the y-axis and exposure on the x-axis. The right panel illustrates a typical step function using the same axes. SPL is "Sound Pressure Level" in decibels referenced to 1 microPascal (1 μPa rms)

The left panel in Figure 6-7 illustrates a typical acoustic dose-function that might relate an exposure, as sound pressure level in decibels referenced to 1 microPascal (1 μPa), to the probability of a response. As the exposure or "dose" increases in this figure, the probability of a response increases as well but the relationship between an exposure and a response is "linear" only in the center of the curve (that is, unit increases in exposure would produce unit increases in the probability of a response only in the center of a dose-function curve). In the "tails" of an acoustic dose-function curve, unit increases in exposure produce smaller increases in the probability of a response. Using the illustration as an example, increasing an exposure from 190 dB to 200 dB would have greater effect on the probability of a response than increasing an exposure from 160 dB to 170 dB or from 210 dB to 220 dB (the upper and lower "tails" of the dose-function, respectively). Based on observations of various animals, including humans, the relationship represented by an acoustic dose-function is a more robust predictor of the probable behavioral responses of marine mammals to sonar and other acoustic sources.

The particular acoustic dose-functions the Navy and NMFS developed for this EIS estimate the probability of behavioral responses that NMFS would classify as harassment for the purposes of the Marine Mammal Protection Act given exposure to specific received levels of mid-frequency active sonar. In the example illustrated in Figure 6-8, about 50% of the marine mammals exposed to mid-frequency active sonar at a received level of 180 dB would be expected to exhibit behavioral responses that NMFS would classify as harassment for the purposes of the MMPA.

Because the Navy and NMFS will use acoustic dose-functions to estimate the proportion of marine mammals that would be expected to exhibit behavioral responses that would be classified as "harassment" for the purposes of the MMPA, the Navy and NMFS now use two methods to estimate the number of marine mammals that might be "taken," as that term is defined by the MMPA, during training exercises. The agencies will use acoustic dose-functions to estimate the

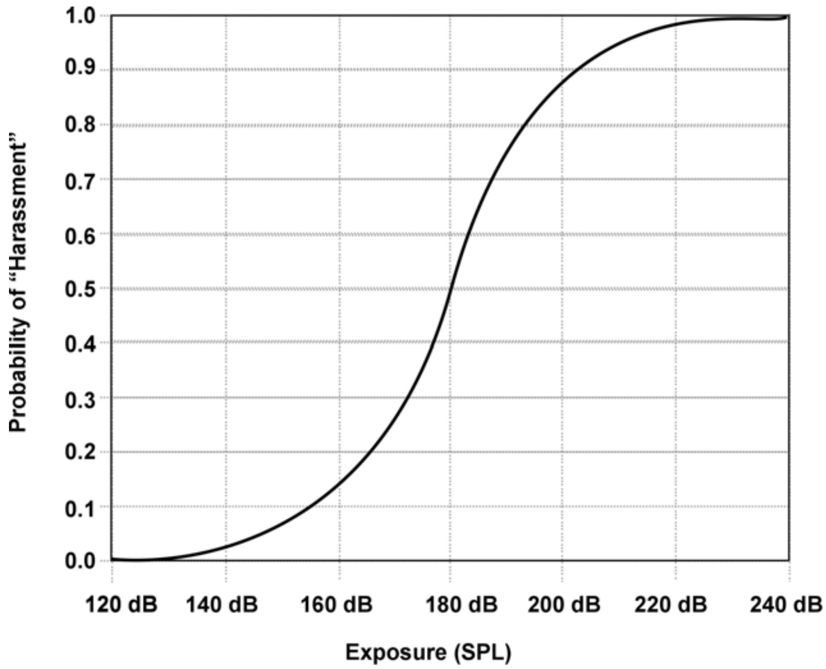


Figure 6-8 Illustration of a dose-function developed to estimate a marine mammal's probability of being "harassed" which we define as its probability of exhibiting a behavioral response that NMFS would classify as "harassment" for the purposes of the Marine Mammal Protection Act (see text). SPL is "Sound Pressure Level" in decibels referenced to 1 microPascal (1 μPa rms)

number of marine mammals that might be "taken" by behavioral harassment as a result of being exposed to mid-frequency active sonar. The agencies will continue to use acoustic thresholds ("step-functions") to estimate the number of marine mammals that might be "taken" through sensory impairment as a result of being exposed to mid-frequency active sonar and to estimate the number of marine mammals that might be "taken" during exercises that use explosives (for example, sinking exercises). Using both of these methods to predict the number of marine mammals that might be "taken" by mid-frequency active sonar during training exercises will over-estimate the number of marine mammals by between approximately 5 and 10 percent.

Although the Navy has not used acoustic dose-functions in previous assessments of the potential effects of mid-frequency active sonar on marine mammals, dose-functions are not new concepts for risk assessments. They are common elements of the process of developing criteria for air, water, radiation, and ambient noise and for assessing the effects of sources of air, water, and noise pollution. The Environmental Protection Agency uses dose-functions to develop water quality criteria and to regulate pesticide applications (EPA 1998); the Nuclear Regulatory Commission uses dose-functions to estimate the consequences of radiation exposures (see NRC 1997 and 10 CFR 20.1201); the Centers for Disease Control and Prevention and the Food and Drug Administration use dose-functions as part of their assessment methods (for example, see Centers for Disease Control and Prevention, 2003, FDA and others 2001); and the Occupational Safety and Health Administration uses dose-functions to assess the potential effects of noise and chemicals in occupational environments on the health of people working in those environments (for examples, see Federal Register 61:56746-56856, 1996; Federal Register 71:10099-10385, 2006).

The U.S. Navy and NMFS have also used variants of acoustic dose-functions to estimate the probable responses of marine mammals to acoustic exposures for other training and research programs and were used in Navy EISs on the Surveillance Towed Array Sonar System – Low Frequency Active (SURTASS-LFA; DON, 2001); and the North Pacific Acoustic Laboratory experiments conducted off the Island of Kaua'i (ONR, 2001).

The Data Used to Develop Acoustic Dose-Functions

The acoustic dose-functions can be generated using data from experiments conducted in the field and controlled settings or data extracted from observations not associated with an experiment (that is, opportunistic observations). To qualify as a sample that would be appropriate for use in an acoustic dose-function, an observation would have to satisfy the following minimal set of information: (a) the species of marine mammals observed, (b) the number of individuals of a species observed; (c) a measurement or estimate of the sound field (in terms of frequency and received level) to which the individuals were exposed; (d) the circumstances and context of the exposure, which includes the date, location, site, time of day, duration, oceanographic and bathymetric conditions under which the exposure occurred; and (e) a report (or other record) of the behavioral response of individual animals given an exposure; this might include a variety of responses when individuals are observed as members of a group.

Over time, as the amount of data available to generate acoustic dose-functions increases, the Navy and NMFS expect to develop a suite of dose-functions that reflect differences in species, populations, sound sources, how a sound source is operated, and bathymetric conditions among other variables. If and when that kind of data becomes available, acoustic dose-functions will be generated from data that represent equivalent sound sources (for sonar systems, this would include equivalent operations), equivalent environmental conditions, and equivalent species or populations. Because the data that is currently available is limited, the data used to generate the current set of acoustic dose-functions had to originate from sound sources in frequency ranges that were equivalent to those of the mid-frequency active sonar that would be used in during the training exercises proposed in this document.

The data that were used to generate acoustic dose-functions for the training exercises proposed in this document originated with two sources: a series of experiments conducted by researchers at the Space and Naval Warfare Systems Center San Diego in California (SSC San Diego), the University of California Santa Cruz (for example, Kastak et al., 1999; Schlundt et al., 2000; Finneran et al., 2000a; Finneran et al., 2002) and opportunistic observations collected while a Navy vessel was operating mid-frequency active sonar in Haro Strait, in the Pacific Northwest.

The series of experiments that provided the primary source of the data used to generate acoustic dose-functions for mid-frequency active sonar resulted from observations of the behavioral responses of trained marine mammals during investigations into the effects of acoustic exposures on the hearing sensitivity of trained marine mammals. These behavioral responses included attempts to avoid sites of previous noise exposures (e.g., Schlundt et al., 2000), attempts to avoid an exposure in progress (e.g., Kastak et al., 1999); aggressive behavior or refusal to further participate in tests (Schlundt et al., 2000).

Schlundt et al. (2000; see also Finneran et al. 2001, 2003, 2005) provided a detailed summary of the behavioral responses of trained marine mammals during TTS tests conducted at SSC San Diego with 1-second tones. Schlundt et al. (2000) reported eight individual TTS experiments. Fatiguing stimuli durations were 1 second; exposure frequencies were 0.4, 3, 10, 20, 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.

Finneran et al. (2001, 2003, 2005) conducted TTS experiments using tones at 3 kHz. The test method was similar to that of Schlundt et al. except the tests were conducted in a pool with a very low ambient noise level (below 50 dB re 1 μPa2/Hz), and no masking noise was used. Two separate experiments were conducted using 1-second 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.

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, 2005) experiments featuring 1-second tones. These included observations from 193 exposure sessions (fatiguing stimulus level > 141 dB re 1 μPa) 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 acoustic dose-functions for mid-frequency active sonar were generated using data collected during experimental trials that exposed marine mammals to sound sources in the 3 - 10 kHz range.

USS SHOUP Analyses

In May 2003, killer whales (*Orcinus orca*) were observed exhibiting behavioral responses while the U.S.S. SHOUP was engaged in sonar operations in the Haro Strait in the vicinity of Puget Sound, Washington. Those observations have been documented in three reports developed by Navy and NMFS (Fromm, 2004a, 2004b; DON 2003). 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 U.S.S. SHOUP provide the only data set available of the behavioral responses of wild, non-captive animal upon exposure to SQS-53 sonar.

The U.S.S. SHOUP sonar data observations and analyses are complex, and some of the relevant information (especially the SQS 53 sonar source level versus transmit angle) is classified. Nevertheless, analyses of the U.S.S. SHOUP observations were made public in 2004 (Fromm 2004) and the observations qualify as a sample that can be used to generate acoustic dose-functions.

The Method Used to Calculate Acoustic Dose-Functions

To generate the acoustic dose-functions used to estimate behavioral exposures in this document, (see Tables 6-1 and 6-2), the Navy used "probit" analyses, which fit a normal distribution function to the transformed empirical data in Finneran *et al.* (2004)). To produce acoustic dose-functions for odontocetes, the Navy's probit analyses fit normal distribution function parameters to the 25, 50, and 75 percentiles of the data produced by SSC San Diego with an additional data point from the U.S.S. SHOUP incident. The acoustic dose-functions for mid-frequency active sonar presented in this document only used observations associated with sound sources in the 3 kHz range (which would be comparable to the range of the mid-frequency active sonar the U.S. Navy uses in its exercises).

Table 6-1. Sound Pressure Level Acoustic Dose-Functions for Behavioral Disturbance from Sonars and Projectors

Animal	Center Frequency For Sonar or Projector	Dose-Function Mean (SPL)	Dose-Function Standard Deviation (SPL)	Cutoff (Sigma)
Small odontocetes (except beaked whales and harbor porpoises)	2 - 6 kHz	189 dB//µPa	12 dB//µPa	-3 (153 dB)
Beaked whales	2 – 6 kHz	189 dB//µPa	12 dB//µPa	-4 (141 dB)
Mysticetes	2 - 30 kHz	175 dB//µPa	10 dB//µPa	-3 (145 dB)
Pinnipeds	2 - 30 kHz	180 dB//µPa	10 dB//µPa	-3 (150 dB)
Small odontocetes (except beaked whales and harbor porpoises)	6 – 15 kHz	182 dB//µPa	10 dB//µPa	-3 (152 dB)
Beaked whales	6 – 15 kHz	182 dB//µPa	10 dB//µPa	-4 (142 dB)

Table 6-2. Sound Pressure Level Acoustic Dose-Functions for Behavioral Disturbance from non-MFA Sonars and Projectors

Animal	Center Frequency For Sonar or Projector	Dose-Function Mean (SPL)	Dose-Function Standard Deviation (SPL)	Cutoff (Sigma)
Small odontocetes (except beaked whales and harbor porpoises)	15 – 30 kHz	189 dB//µPa	12 dB//µPa	-3 (153 dB)
Beaked whales	15 – 30 kHz	189 dB//µPa	12 dB//µPa	-4 (141 dB)
Small odontocetes (except beaked whales and harbor porpoises)	30 - 100 kHz	180 dB//µPa	12 dB//µPa	-3 (144 dB)
Beaked whales	30 - 100 kHz	180 dB//µPa	12 dB//µPa	-4 (136 dB)
Mysticetes	30 - 100 kHz	175 dB//µPa	10 dB//µPa	-3 (145 dB)
Pinnipeds	30 - 100 kHz	180 dB//µPa	10 dB//µPa	-3 (150 dB)

For cases other than the 2 - 6 kHz sonars and odontocetes, the same general approach was used as that for odontocetes exposed to MFA sound sources; namely, fit a normal distribution to the transformed data in Finneran *et al.* (2004) and modify the mean, standard deviation, and cutoff (low end) for each case. Parameters for odontocetes for non-MFA sonars and projectors are given in Table 6-2.

'Cutoffs' at – 3 and – 4 standard deviations were also based on rough estimates of range from a powerful sonar source (especially the SQS 53 shipboard sonar) at which an animal might be behaviorally harassed. For spherical spreading and a frequency range of 2 kHz to 6 kHz, the distance from the source for the cutoff threshold are of order 10 km for –3 standard deviations, and 30 km for –4 standard deviations. There are no controlled data to test these assumptions, but the approach accounts for behavioral responses out to 30 km for beaked whales. SPLs at the cutoff are shown in the tables, and range from 136 to 153 dB re 1 μPa. The acoustic dose-function thus accounts for very low level exposures that have the potential for behavioral harassment.

The values the Navy used to develop acoustic dose-functions for Mysticetes in this document relied on values used in previous assessments (such as the series of NEPA documents that Navy prepared for the Littoral Warfare and Defense program; Office of Naval Research, 1999a and 1999b) and supplemented with observations discussed in Richardson *et al*. 1995 (citing, *inter alia*, Malme *et al*., 1983 and 1984). TTS experiments on pinnipeds conducted by Kastak *et al*. (1996 – 1999) were included in the development of acoustic dose-functions for pinnipeds although, because the experiments were not designed as behavioral studies.

As explained above, the Navy's original approach to developing acoustic dose function calculations was to fit normal distribution function parameters to the 25, 50, and 75 percentiles of the data produced by SSC San Diego (2004) with an additional data point from the U.S.S. SHOUP incident. Calculations generated using this original approach are reflected in tables 6-1 and 6-2. NMFS conducted a technical review of this approach and suggested an alternative, namely that the acoustic dose-function be calculated based on the direct empirical data from the SSC San Diego experiments and the U.S.S. SHOUP data described in the previous section of this document. While the Navy's original approach to calculating acoustic dose function was used to estimate marine mammal exposures in this draft EIS, the Navy and NMFS are planning to utilize the NMFS approach to calculating acoustic dose-functions for the final EIS. Because the original Navy approach and the NMFS approach use the same data set, the two curves may be similar, but the methodology used to arrive at the curves will differ. The following section outlines NMFS' recommended approach to calculating acoustic dose-functions.

NMFS Recommended Approach to Calculating Acoustic Dose-Functions

To prepare the behavioral observations produced by the experimental studies and from the U.S.S. SHOUP for analysis, the Navy and NMFS will code behavioral observations associated with a received level as "1" (for "yes, NMFS would classify this behavioral response as harassment") or "0" (for "no, NMFS would not classify this behavioral response as harassment"). To develop acoustic dose-functions for mid-frequency active sonar, the Navy and NMFS will only use observations associated with sound sources in the 3 – 10 kHz range (which would be comparable to the range of the mid-frequency active sonar the U.S. Navy uses in its exercises).

Acoustic dose-functions will be developed from the resulting series of 1s and 0s using probit analysis (using the probit model) and logistic regression (using the logit model), which are designed to use binary data to estimate the probability of a response variable given a predictor variable (in this case, sound pressure level or SPL). Both of these statistical procedures produce s-shaped dose-functions, such as those illustrated in Figures 6-7 and 6-8, and both produce results that are similar to one another. Box 6-1 summarizes the specific models used for both probit and logit analyses. Those interested in detailed technical explanations of probit and logit analyses should refer to texts such as Dobson (2002), Hoffman (2004), McCullagh and Nedler (1989), McCulloch and Searle (2001), and Nedler and Wedderburn (1972).

These analyses treat a "1" as equivalent to "there is a 100 percent probability that NMFS would classify this response as harassment for the purposes of the MMPA" and a "0" as equivalent to "there is a 0 percent probability that NMFS would classify this response as harassment for the purposes of the MMPA". It is possible to envision a range of probabilities between these two extremes (for example, "there is a 10, 20, 30, 50, or 90 percent probability that an animal would exhibit behavior responses that NMFS would classify as harassment for the purposes of the MMPA"). The dose-functions the Navy and NMFS will develop convert these binary data into probabilities that form a continuous range between 100 percent and 0 percent.

As discussed in the introduction to this sub-section, the Navy and NMFS agreed to use sound pressure level (or SPL) rather than sound exposure level (or SEL) as the appropriate metric for behavioral disturbance (NOAA/NMFS 2007). This is a change from previous environmental analyses the Navy has conducted for training activities that use mid-frequency active sonar, which relied on SEL to assess the potential effects of mid-frequency sonar exposures on marine mammals. Sound exposure level may be a better metric for estimating the potential effects of sonar exposures on an animal's hearing because it represents an accumulation of energy and the sensitivity of the mammalian ear degrades as energy accumulates. However, the behavioral responses of marine mammals to sonar exposures seem to reflect the amplitude of the sound animals receive more than the accumulation of energy. As a result, for most behavioral functions of hearing, SPL is a more appropriate measure of exposure.

Animals use hearing to detect signals in noise. They listen for echoes from their echolocation signals, for communication calls of conspecifics, for sounds of prey or predators. One of the ways in which anthropogenic sound can disrupt behavior is by impairing or "masking" an animal's ability to detect an important signal. Another way that anthropogenic sound can disrupt behavior is by triggering reactions such as avoidance or causing the animal to break off from an activity such as feeding. For the purpose of producing acoustic dose-functions for behavioral harassment, using SPL rather than SEL makes more data available. Nearly all studies of behavioral effects of anthropogenic sound on marine mammals have reported SPL not SEL, and it would be difficult to estimate SEL based upon the information provided in these reports.

Box 6-1. The probit and logit models

Generalized linear models are generalizations of the classic linear regression model that assumes that a dependent variable is a linear function of a set of independent variables (and that the dependent variable is continuous). The classic linear regression model is limited because it only provides an accurate model when the data have a linear trend. Generalized linear models are a family of models developed for regressions when classic linear regression is not appropriate.

Generalized linear models rely on a linear relationship between the x's and a linear predictor, defined below as η:

$$\eta = \sum_{k=1}^{K} \beta_K X_K$$

Where *X* is an independent variable, such as a behavioral response upon exposure to a received level of mid-frequency sonar, β_k is the slope on the X_k axis. Generalized linear models are designed to create linear relationships between a set of Xs and η and then "linking" η and μ (the dependent variable). Many functions can provide this "link," but the underlying distribution of the data usually helps identify the most appropriate links.. In this instance, the underlying data are binary (0 and 1), so the probit, or logit, models provide the most appropriate "link."

The probit model is typically represented as

$$\eta = \Phi^{-1}(\mu)$$

where the symbol Φ (pronounced *phi*) represents the standard normal distribution. In this model, the superscript -1 indicates the inverse of the standardized normal distribution, which provides the link between the Xs and η. Probit analysis transforms probabilities of an event into z-scores (number of standard deviations from the mean) of the cumulative standard normal distribution.

The logit model is typically represented as

$$\eta = \log_e \left| \frac{\mu}{1-\mu} \right|$$

where the $\log_e$ represents the natural or Naperian logarithm. In application of this equation, the symbol μ represents the probability of a response that NMFS would classify as harassment for the purposes of the MMPA. The logit model estimates the probability of such a response by assuming the natural logarithm of the odds of "1" to the odds of "0" are linearly related to exposure level

The U.S. Navy and NMFS are analyzing the behavioral observations made during the hearing sensitivity experiments and during the U.S.S. SHOUP incident in Haro Strait to determine whether NMFS would classify the behavioral responses as harassment for the purposes of the MMPA (responses coded as "1" or "0"). These data will be analyzed using the probit and logit procedures discussed in Box 6-1 to produce the acoustic dose functions and to estimate the probabilities of "harassment" given sonar exposures.

There are several important limitations to this procedure. First, the number of samples available for these analyses remains very small, which affects the level of confidence that can be assigned to acoustic dose-functions based on those samples. Second, the acoustic dose-functions are based on data from a small number of individuals representing three marine mammal species. The responses of those individuals may not be representative of the responses of populations of the same species and different populations may exhibit different responses to the same stimulus. Similarly, the responses of the three species for which data available may not be representative of the responses of other species, some of which may be more or less sensitive than bottlenose dolphins, beluga whales, or killer whales. Fourth, the limited data prevents these models from estimating effects on different behavioral activities such as feeding, reproduction, changes in diving behavior, etc. Finally, the data available do not allow us to assess the consequences of multiple or long-duration exposures.

It is important to note that the data the Navy and NMFS will use to produce the acoustic dose-functions for the FEIS are still being subjected to internal technical review and may be subjected to formal peer review. Those reviews may cause some of the specific data points to be removed from or added to the data set that has been used to produce the existing acoustic dose-function. Any change in the dose-function is likely to change the number of marine mammals that have been estimated to be "taken" (in the form of harassment) for the purposes of the Marine Mammal Protection Act that are presented in this document. Based on reviews that have been conducted thus far, the acoustic dose-functions are not expected to change substantially, but even fractional changes in percentages would increase or decrease the number of marine mammals that are estimated to be "taken." As a result, the "take" estimates for the different marine mammals presented might increase or decrease slightly between the draft EIS and the final EIS on this action.

Interpretation of Acoustic Dose-Function

The Navy developed acoustic dose-functions to estimate the probability of marine mammals being "harassed" (or of marine mammals exhibiting behavioral responses that NMFS would classify as harassment) given exposure to different received levels of mid and high frequency acoustic sources. There are, however, several important limitations to the analyses that affect how the dose-function for small odontocetes is interpreted. First, the number of samples available for these analyses was very small, which affects the level of confidence that can be assigned to dose-functions generated from those samples. Second, the dose-functions were generated from observations of a small number of individuals representing only three species of marine mammal; the responses of those individuals may not be representative of the responses of populations of the same species and different populations may exhibit different responses to the same stimulus. Similarly, the responses of the three species for which data are available may not be representative of the responses of other species, some of which may be more or less sensitive than bottlenose dolphins, beluga whales, or killer whales. Fourth, the data were not sufficient to estimate potential relationships between acoustic exposures and specific behavioral activities (such as feeding, reproduction, changes in diving behavior, etc.). Finally, the data available did not allow the Navy to assess the consequences of multiple or long-duration exposures. The data used for the analyses of other taxa may have additional limitations.

These limitations affect how the acoustic dose-functions are interpreted because probit regression models the Navy used to generate the dose-functions, like all generalized linear models, assume that the effects of independent variables other than received level have been controlled (Liao 1994). That is, probit models assume that variables that are not included in the models — such variables as bathymetry, acoustic waveguides, differences in individuals, populations, or species, or the prior experiences, reproductive state, hearing sensitivity, or age of the marine mammals, among many others — do not influence the behavioral responses of marine mammals that might be exposed to MFA sonar.

Application of Uncertainty Factors to the Dose-Functions

As discussed in the preceding paragraph, the model's assumption that "all other things being equal" is not valid for the current set of acoustic dose-functions. Because that assumption is not valid and that invalid assumption has uncertain effect on the acoustic dose-functions, the Navy applied uncertainty factors to the dose-functions. These uncertainty factors modify the acoustic dose-functions to compensate for the biases inherent in the data that were used to generate the dose-functions (for additional background on uncertainty factors, see Dorne *et al*. 2005 and Krewski *et al*. 1984, Suter *et al*. 1993).

To comply with the requirements of the MMPA and ESA, NMFS may impose additional "uncertainty" factors on the Navy's existing acoustic dose-functions to compensate for uncertainties about the probable responses of beaked whales, baleen whales, and pinnipeds to MFA sonar exposures.

Beaked whales

Acoustic dose-functions will be interpreted carefully for beaked whales — particularly Cuvier's, Gervais', and Blainville's beaked whales, which have historically been involved in mass stranding events more than any other species of beaked whale — because these whales appear to be more sensitive to MFA sonar and may experience more serious consequences as a result of an exposure than other marine mammals. In training situations that include bathymetric circumstances that provide limited ability for beaked whales to avoid continued exposure, where the exercises occur proximate to a continental slope, where there is canyon-like bathymetry, where multiple sonar sources are operating in the area,, and where there is a high probability of acoustic wave-guides (a significant surface duct), the Navy interpreted the results of acoustic dose-functions based on an assumption that they are likely to underestimate (a) the probability of behavioral responses that would be classified as harassment and (b) the severity of the behavioral responses of beaked whales to MFA sonar.

To account for these uncertainties, the Navy will adjust the estimates produced by the dose-functions for beaked whale in circumstances that might increase the probability of beaked whale stranding. These circumstances include: limited egress opportunities for the whales, proximity to the continental slope, presence of a significant surface duct, canyon-like bathymetry, and multiple sonar operations (of the SQS 53 and 56 types) in close proximity. One possible adjustment that the Navy and NMFS are considering for these special circumstances is assuming that 1% of the animals that are expected to be behaviorally harassed would be mortalities.

Harbor Porpoises
Data reviewed by Houser (2007) suggests that the threshold level at which both captive and wild animals responded to sound is very low (e.g., 120 dB SPL re 1 μPa), although the biological significance of the disturbances is uncertain. Nonetheless, the Navy's estimates treated harbor porpoises as special cases based on these data.

NMFS Interpretation of Acoustic Dose-Functions

As discussed previously, the acoustic dose-functions make it possible to estimate the probability of marine mammals exhibiting behavioral responses that NMFS would classify as harassment given exposure to different received levels of mid-frequency active sonar. In practice, the Navy and NMFS will use these probabilities to estimate the proportion of marine mammals that would be expected to exhibit behavioral responses that would be classified as "harassment" for the purposes of the MMPA.

As more observations become available and more research is conducted, those data would be added to the dataset that is currently used to generate acoustic dose-functions and dose-functions would be re-estimated based on the entire dataset. Until then, acoustic dose-functions will be interpreted to compensate for the biases and uncertainties that are inherent in the data used to produce them.

Specifically, the Navy and NMFS will apply "uncertainty" factors to acoustic dose-functions to compensate for the fact that the data that was used to generate those dose-functions primarily reflect the behavioral responses of (a) bottlenose dolphins and, to a lesser degree, beluga whales and (b) those species were represented by captive animals that had been trained to participate in acoustic trials. It is uncertain whether and to what degree the behavioral responses would be representative of individuals of the same species that had not been trained to participate in acoustic trials, the same species in the wild, other small cetaceans in the wild, or other species of marine mammals (pinnipeds and baleen whales, in particular) that have different hearing sensitivities than small, toothed whales.

For example, acoustic dose-functions need to be interpreted carefully for beaked whales because they appear to be more sensitive to mid-frequency sonar and may experience more serious consequences as a result of an exposure than other marine mammals. In training situations that include bathymetric circumstances that provide limited ability for beaked whales to avoid continued exposure, where the exercises occur proximate to a continental slope, where there is canyon-like bathymetry, multiple sonar operations, and a high probability of acoustic wave-guides, the results of acoustic dose-functions need to be interpreted carefully. That is, they should be interpreted based on an assumption that they are likely to underestimate (a) the probability of behavioral responses that would be classified as harassment and (b) the severity of the behavioral responses of beaked whales to mid-frequency sonar.

The Navy and NMFS will address these differences by applying "uncertainty" factors to the set of acoustic dose-functions. These uncertainty factors will modify the acoustic dose-functions to compensate for the biases inherent in the data that were used to generate the dose-functions (for

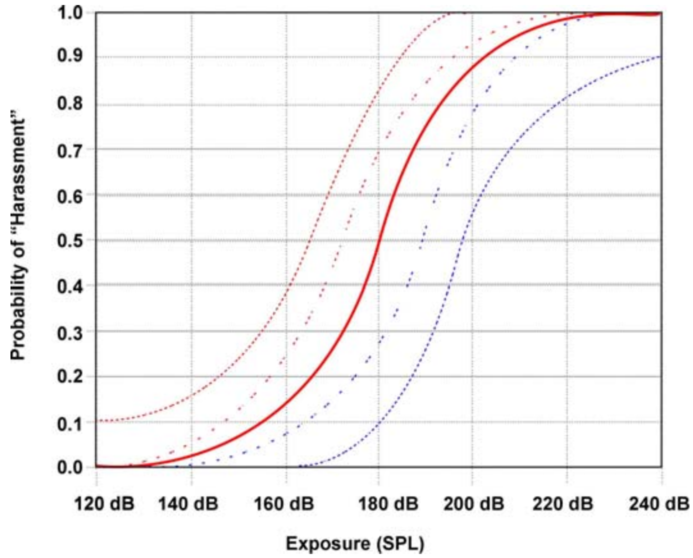


Figure 6-9. Illustration of a dose-function (solid line) with uncertainty factors (dashed lines) applied. The dashed lines to the left of the dose-function would be interpreted to mean that a species has a greater probability of responding at the same received level while the dashed lines to the right of the dose-function would be interpreted to mean that a species has a smaller probability of responding to the same received level of mid-frequency sonar.

additional background on safety or uncertainty factors, see Dorne et al. 2005 and Krewski et al. 1984, Suter et al. 1993; see Figure 6-9 for an illustration of the effects of apply uncertainty factors to a dose-function). For beaked whales — particularly Cuvier's, Gervais', and Blainville's beaked whales which have historically been involved in substantially larger numbers of mass stranding events than any other species of beaked whale — uncertainty factors would be designed to minimize the probability of assuming that beaked whales would not experience significant adverse consequences given exposure to mid-frequency sonar when such consequences are likely. For pinnipeds and baleen whales, uncertainty factors would adjust the acoustic dose-function for small, toothed cetaceans to reflect the lower sensitivity of pinnipeds and baleen whales to mid-frequency sound sources.

6.2.7 Other Effects Considered

Stress

A possible stressor for marine mammals exposed to sound, including mid-frequency active sonar, is the effect on health and physiological stress (Review by Fair and Becker, 2000). A stimulus may cause a number of behavioral and physiological responses such as an elevated heart rate, increases in endocrine and neurological function, and decreased immune function, particularly if the animal perceives the stimulus as life threatening (Seyle, 1950; Moberg, 2000, Sapolsky et al., 2005). The primary response to the stressor is to move away to avoid continued exposure. Next, the animal's physiological response to a stressor is to engage the autonomic nervous system with the classic "fight or flight" response. This includes changes in the cardiovascular system (increased heart rate), the gastrointestinal system (decrease digestion), the exocrine glands (increased hormone output), and the adrenal glands (increased nor-epinephrine). These physiological and hormonal responses are short lived and may not have significant long-term effects on an animal's health or fitness. Generally these short term responses are not detrimental to the animal except when the health of the animal is already compromised by disease, starvation or parasites; or the animal is chronically exposed to a stressor.

Exposure to chronic or high intensity sound sources can cause physiological stress. Acoustic exposures and physiological responses have been shown to cause stress responses (elevated respiration and increased heart rates) in humans (Jansen, 1998). Jones (1998) reported on reductions in human performance when faced with acute, repetitive exposures to acoustic disturbance. Trimper et al. (1998) reported on the physiological stress responses of osprey to low-level aircraft noise. Krausman et al. (2004) reported on the auditory (TTS) and physiology stress responses of endangered Sonoran pronghorn to military overflights. Smith et al. (2004a, 2004b) recorded sound-induced physiological stress responses in a hearing-specialist fish that was associated with TTS and PTS. Welch and Welch (1970) reported physiological and behavioral stress responses that accompanied damage to the inner ears of fish and several mammals.

Most of these responses to sound sources or other stimuli have been studied extensively in terrestrial animals but are much more difficult to determine in marine mammals. Increases in heart rate are common reaction to acoustic disturbance in marine mammals (Miksis et al., 2001) as are small increases in the hormones norepinephrine, epinephrine, and dopamine (Romano et al., 2002; 2004). Increases in cortical steroids are more difficult to determine because blood collection procedures will also cause stress (Romano et al., 2002; 2004). A recent study, Chase Encirclement Stress Studies (CHESS), was conducted by NMFS on chronic stress effects in small odontocetes affected by the eastern tropical Pacific (ETP) tuna fishery (Forney et al., 2002). Analysis was conducted on blood constituents, immune function, reproductive parameters, heart rate and body temperature of small odontocetes that had been pursued and encircled by tuna fishing boats. Some effects were noted, including lower pregnancy rates, increases in norepinephrine, dopamine, ACTH and cortisol levels, heart lesions and an increase in fin and surface temperature when chased for over 75 minutes but with no change in core body temperature (Forney et al., 2002). These stress effects in small cetaceans that were actively pursued (sometimes for over 75 minutes) were relatively small and difficult to discern. It is unlikely that marine mammals exposed to mid-frequency active sonar would be exposed at long as the cetaceans in the CHESS study and would not be pursued by the Navy ships, therefore stress effects would be minimal from the short term exposure to sonar.

Acoustically Mediated Bubble Growth

One suggested cause of injury to marine mammals is by rectified diffusion (Crum and Mao, 1996).The process of increasing the size of a bubble by exposing it to a sound field. 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 (remainder of air is about 21 percent oxygen with some carbon dioxide). 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 (for example, beaked whales) are theoretically predicted to induce greater super saturation (Houser et al., 2001). Conversely, studies have shown that marine mammal lung structure (both pinnipeds and cetaceans) facilitates collapse of the lungs at depths deeper than approximately 162 ft (Kooyman et al., 1970). Collapse of the lungs would force air in to the non-air exchanging areas of the lungs (in to the bronchioles away from the alveoli) thus significantly decreasing nitrogen diffusion in to 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 super saturation 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 would be long enough to drive bubble growth to any substantial size, if such a phenomenon occurs. However, an alternative but related hypothesis has also been suggested. Stable 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 and exposed to a continuous sound source 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 but requires further investigation. Conversely Fahlman et al. (2006) suggested 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 in Hawaii (Baird et al. 2006) and in the Ligurian Sea in Italy (Tyack et al., 2006) showed that while these species do dive deeply (regularly exceed depths of 2,624 ft) 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 in response to sonar should not cause decompression sickness. Currently it is not known if beaked whales do rapidly ascend in response to sonar or other disturbances. It may be that deep diving animals would be better protected diving to depth to avoid predators, such as killer whales, rather than ascending to the surface where they may be more susceptible to predators.

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, 2003). 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 and complicating factors associated with introduction of gas in to the venous system during necropsy. Because evidence supporting it is debatable, no marine mammals addressed in this EIS/OEIS are given special treatment due to the possibility for acoustically mediated bubble growth. Beaked whales are, however, assessed differently from other species to account for factors that may have contributed to prior beaked whale strandings as set out in the previous section.

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—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 (for example, 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 Navy mid-frequency active sonar caused resonance effects in beaked whales that eventually led to their stranding (DOC and DON, 2001). The conclusions of that group were that resonance in air-filled structures the frequencies at which resonance were predicted to occur were below the frequencies utilized by the sonar systems employed. Furthermore, air cavity vibrations due to the resonance effect were not considered to be of sufficient amplitude to cause tissue damage.

Likelihood of Prolonged Exposure

The proposed ASW activities within the HRC would not result in prolonged exposure because the vessels are constantly moving, and the flow of the activity in the HRC when ASW training occurs reduces the potential for prolonged exposure. The implementation of the mitigation measures described in Chapter 11 would further reduce the likelihood of any prolonged exposure.

Likelihood of 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 manmade sources (for example, 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 proposed HRC ASW areas are away from harbors but may include heavily traveled shipping lanes, although shipping lanes are a small portion of the overall range complex. The loudest mid-frequency underwater sounds in the Proposed Action area are those produced by hull-mounted mid-frequency active tactical sonar. 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, the total number of hours of operation per year small, and these hull-mounted mid-frequency active tactical 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.

Long-Term Effects

Navy activities are conducted in the same general areas throughout the HRC, so marine mammal populations could be exposed to repeated activities over time. However, as described earlier, short-term non-injurious sound exposure levels predicted to cause TTS or temporary behavioral disruptions qualify as Level B harassment. Application of this criterion assumes an effect even though it is highly unlikely that all behavioral disruptions or instances of TTS will result in long term significant impacts.

Humpback whales are increasing within the HRC (Carretta et al., 2005) and several island associated resident populations of cetaceans are found within the HRC including the bottlenose dolphin, spinner dolphin, false killer whale, humpback whale, Blainville's beaked whale, short-finned pilot whale and melon-headed whales (Baird et al., 2006). The Hawaiian monk population is declining although most monk seals inhabit the North West Hawaiian Islands which are outside of the HRC (Regan and Lavigne, 1999).

Long-term monitoring programs for the HRC are being developed by the Navy to assess population trends and responses of marine mammals to Navy activities. Short-term monitoring programs for exercises (e.g., undersea warfare exercise (USWEX)) are being developed to assess mitigation measures and responses of marine mammals to Navy activities.

6.2.8 Application of Exposure Thresholds to Other Species

Mysticetes

Information on auditory function in mysticetes is extremely lacking. Sensitivity to low-frequency sound by baleen whales has been inferred from observed vocalization frequencies, observed reactions to playback of sounds, and anatomical analyses of the auditory system. Baleen whales are estimated to hear from 15 Hz to 20 kHz, with good sensitivity from 20 Hz to 2 kHz (Ketten, 1998). Filter-bank models of the humpback whale's ear have been developed from anatomical features of the humpback's ear and optimization techniques (Houser et al., 2001). The results suggest that humpbacks are sensitive to frequencies between 40 Hz and 16 kHz, but best sensitivity is likely to occur between 100 Hz and 8 kHz. However, absolute sensitivity has not been modeled for any baleen whale species. Furthermore, there is no indication of what sorts of sound exposure produce threshold shifts in these animals.

The criteria and thresholds for PTS and TTS developed for odontocetes for this activity are also used for mysticetes. This generalization is based on the assumption that the empirical data at hand are representative of both groups until data collection on mysticete species shows otherwise. For the frequencies of interest for this action, there is no evidence that the total amount of energy required to induce onset-TTS and onset-PTS in mysticetes is different than that required for odontocetes.

Beaked Whales

Recent beaked whale strandings have prompted inquiry into the relationship between high-amplitude continuous-type sound and the cause of those strandings. For example, in the stranding in the Bahamas in 2000, the Navy mid-frequency sonar was identified as the only contributory cause that could have lead to the stranding. The Bahamas exercise entailed multiple ships using mid-frequency sonar during transit of a long constricted channel. The Navy participated in an extensive investigation of the stranding with the NMFS. The "Joint Interim Report, Bahamas Marine Mammal Stranding Event of 15-16 March 2000" concluded that the variables to be considered in managing future risk from tactical mid-range sonar were "sound propagation characteristics (in this case a surface duct), unusual underwater bathymetry, intensive use of multiple sonar units, a constricted channel with limited egress avenues, and the presence of beaked whales that appear to be sensitive to the frequencies produced by these sonars." (DOC and DON, 2001).

The Navy analyzed the known range of operational, biological, and environmental factors involved in the Bahamas stranding and focused on the interplay of these factors to reduce risks to beaked whales from ASW training operations. Mitigation measures based on the Bahamas investigation are presented in Chapter 6.1.3. The confluence of these factors do not occur in the Hawaiian Islands. Beaked whales are present at PMRF and a there are a few individual beaked whales that appear to be resident in the area off of the island of Hawaii and the Alenuihaha Channel between the island of Hawaii and Maui where ASW sonar operations occur regularly (Baird et al. 2006; McSweeney et al. 2007). Although beaked whales are visually and acoustically detected in areas where sonar use routinely takes place, there has not been a stranding of beaked whales in the Hawaiian Islands associated with the 30-year use history of the present sonar systems.

This history would suggest that the simple exposure of beaked whales to sonar is not enough to cause beaked whales to strand. Brownell et al (2004), have suggested that the high number of beaked whale strandings in Japan between 1980 and 2004 may be related to U.S. Navy sonar use in those waters given the presence of U.S. Naval Bases and exercises off Japan. The Center for Naval Analysis complied the history of naval exercises taking place off Japan and found there to be no correlation in time for any of the stranding events presented in Brownell et al (2004). Like the situation in Hawaii, there are clearly beaked whales present in the waters off Japan (as evidenced by the strandings) however, there is no correlation in time to strandings and sonar use. Sonar did not causing the strandings provided by Brownell et al. (2004) and more importantly, this suggests sonar use in the presence of beaked whales over two decades has not resulted in strandings related to sonar use.

As suggested by the known presence of beaked whales in waters sonar use has historically taken place, it is likely that beaked whales have been occasionally exposed to sonar during the 30 year history of sonar use in the Hawaiian Islands and yet there is no indication of any adverse impact on beaked whales from exposure to sonar in Hawaiian waters. Therefore, the continued use of sonar in the HRC is not likely to result in effects to beaked whales.

Since the exact causes of the stranding events are unknown, separate, meaningful impact thresholds cannot be derived specifically for beaked whales. The Navy, in consideration of the repetitive use of mid-frequency active sonar proposed for HRC operations is taking a conservative approach and has extended the Dose Function cut off to 141 dB (extended to 4 s.d., or about 30 km in most cases in comparison to other odontocetes).

Pinniped

The information on the hearing abilities of the Hawaiian monk seal is limited. The range of underwater hearing in monk seals is 12 to 70 kHz with best hearing from 12 to 28 kHz and 60-70 kHz (Thomas et al., 1990). This audiogram was from only one animal and the high upper frequency range, which is high for a phocid, may not be indicative of the species. There is no information on underwater sounds and in air sounds are low frequency sounds (below 1000 Hz) such as “soft liquid bubble”, short duration guttural expiration, a roar and belching/coughing sound (Miller and Job, 1992). A pup produces a higher frequency call (1.4 kHz) that presumably is use to call its mother.

The audiogram of the Hawaiian monk seal suggests they hear above mid-frequency active sonar although the in air sounds they produce are below mid-frequency active sonar.

6.2.9 Marine Mammal Mitigation Measures Related To Acoustic Effects

Effective training in the HRC dictates that ship, submarine, and aircraft participants utilize their sensors and train with their weapons to their optimum capabilities as required by the mission. The Navy recognizes that such use has the potential to cause behavioral disruption of some marine mammal species in the vicinity of an exercise. As part of their standard operating procedures, the Navy has developed mitigation measures that would be implemented to protect marine mammals and ESA listed species during ASW operations. These mitigation measures include the establishment of a safety zone and procedures to power down or shut off sonar if animals are detected within the safety zone and are a part of the No-Action Alternative. For a detailed list of mitigation measures, see Chapter 11.

During ASW events, Navy ships always have two, although usually more, personnel on watch serving as lookouts. In addition to the qualified lookouts, the bridge team, at a minimum, also includes an Officer of the Deck and one Junior Officer of the Deck whose responsibilities also include observing the waters in the vicinity of the ship. At night, personnel engaged in ASW events may also employ the use of night vision goggles and infrared detectors, as appropriate, which can also aid in the detection of marine mammals. Passive acoustic detection of vocalizing marine mammals is also used to alert bridge lookouts to the potential presence of marine mammals in the vicinity. Navy lookouts undergo extensive training in order to qualify as a watchstander. This training includes on-the-job instruction under the supervision of an experienced watchstander, followed by completion of the Personal Qualification Standard program. The Navy includes marine species awareness as part of its training for its bridge lookout personnel on ships and submarines as required training for Navy lookouts. This training addresses the lookout’s role in environmental protection, laws governing the protection of marine species, Navy stewardship commitments, and general observation information to aid in avoiding interactions with marine species.

Operating procedures are implemented to maximize the ability of personnel to recognize instances when marine mammals are close aboard and avoid adverse effects. These procedures include measures such as decreasing the source level and then shutting down active tactical sonar operations when marine mammals are encountered in the vicinity of a training event. Although these mitigation measures are standard operating procedures, their use is also reinforced through promulgation of an Environmental Annex to the Operational Order for an exercise. Sonar operators on ships, submarines, and aircraft utilize both passive and active sonar detection indicators of marine mammals as a measure of estimating when marine mammals are close. When marine mammals are detected in close vicinity, all ships, submarines, and aircraft engaged in ASW would reduce mid-frequency active sonar power levels in accordance with specific guidelines developed for each type of training event.

If a stranding were to occur in the HRC where there was clear and credible available evidence implicating active sonar in the stranding event, the Navy will cease use of active sonar events in the vicinity of the stranding.

NMFS and the Navy will continue coordination on the "Communications and Response Protocol for Stranded Marine Mammal Events During Navy Operations in the Pacific Islands Region" that was prepared by NMFS Pacific Region PIRO to facilitate communication during RIMPAC 2006. The Navy will continue to coordinate with the Hawaii NMFS Stranding Coordinator for any unusual marine mammal behavior, including stranding, beached live or dead cetacean(s), floating marine mammals, or out-of-habitat/milling live cetaceans that may occur during or shortly after Navy activities in the vicinity of the stranding.

6.2.10 Cetacean Stranding Events

The Navy is very concerned and thoroughly investigates each marine mammal stranding to better understand the events surrounding strandings (Norman 2006). Strandings can be a single animal or several to hundreds. An event where animals are found out of their normal habitat is considered a stranding even though animals do not necessarily end up beaching (such as the July 2004 Hanalei Mass Stranding Event; Southall et al., 2006). Several hypotheses have been given for the mass strandings which include the impact of shallow beach slopes on odontocete sonar, disease or parasites, geomagnetic anomalies that affect navigation, following a food source in close to shore, avoiding predators, social interactions that cause other cetaceans to come to the aid of stranded animals, and human actions. Generally, inshore species do not strand in large numbers but generally just as a single animal. This may be due to their familiarity with the coastal area whereas pelagic species that are unfamiliar with obstructions or sea bottom tend to strand more often in larger numbers (Woodings, 1995). The Navy has studied several stranding events in detail that may have occurred in association with Navy sonar activities. To better understand the causal factors in stranding events that may be associated with Navy sonar activities, the main factors, including bathymetry (i.e. steep drop offs), narrow channels (less than 35 nm), environmental conditions (e.g. surface ducting), and multiple sonar ships (see Section on Stranding Events Associated with Navy Sonar) were compared between the different stranding events.

In a review of 70 reports of mass stranding events between 1960 and 2006, 48 (68 percent) involved beaked whales, 3 (4 percent) involved dolphins, and 14 (20 percent) involved whale species. Cuvier's beaked whales were involved in the greatest number of these events (48 or 68 percent), followed by sperm whales (7 or 10 percent), and Blainville's and Gervais' beaked whales (4 each or 6 percent). Naval operations that might have involved tactical sonars are reported to have coincided with 9 (13 percent) or 10 (14 percent) of those stranding events. Between the mid-1980s and 2003 (the period reported by the IWC), we identified reports of 44 mass cetacean stranding events of which at least 7 have been correlated with naval operations that were using mid-frequency active sonar.

RIMPAC exercises have occurred every other year since 1968 and ASW operations have occurred in each of the 19 exercises that have occurred thus far. If the mid-frequency active sonar employed during those exercises killed or injured whales whenever the whales encountered the sonar, it seems likely that some mass strandings would have occurred at least once or twice over the 38-year period since 1968. With one possible exception, there is little evidence of a pattern in the record of strandings reported for the main Hawaiian Islands.

What is a Stranded Marine Mammal?

When a marine mammal swims or floats onto shore and becomes "beached" or stuck in shallow water, it is considered a "stranding" (MMPA section 410 (16 USC section 1421g; NMFS, 2007a). NMFS explains that "a cetacean is considered stranded when it is on the beach, dead or alive, or in need of medical attention while free-swimming in U.S. waters. A pinniped is considered to be stranded either when dead or when in distress on the beach and not displaying normal haul-out behavior" (NMFS, 2007b).

There are three general categories of strandings: single, mass, and unusual mortality events. The most frequent type of stranding is a single stranding, which involves one animal per event, or a mother/calf pair, and are most often the result of illness or injury (NMFS, 2007f) or natural causes like old age.

Mass strandings involve two or more marine mammals of the same species coming ashore at the same time and place (other than a female and her calf), and can sometimes result in the death of a large number of animals. There are only a few species in North America that typically strand in groups of 15 or more: sperm whales, pilot whales, false killer whales, Atlantic white-sided dolphins, white-beaked dolphins, and rough-toothed dolphins. A few other species occasionally strand in smaller numbers: pygmy killer whales, common dolphins, *Stenella* spp. and Frasier's dolphins (Geraci et al., 2005). Some species, such as pilot whales, false-killer whales, and melon-headed whales occasionally strand in groups of 50 to 150 or more (Geraci et al., 1999). All of these species are sociable and usually less accustomed to inshore waters than other coastal marine mammal species like the bottlenose dolphin or the harbor porpoise (Geraci et al., 2005). Sometimes these animals can be saved by releasing each member of the group out to sea all at the same time; however, studies have shown that stranded marine mammals that are returned to water have a tendency to re-strand themselves someplace else (NMFS, 2007f; 2005b). In all cases of mass strandings, NMFS coordinates stranding response and necropsy examination with partners around the country to try to determine the circumstance and cause for the stranding (NMFS, 2006).

Unusual mortality events (UMEs) are strandings and/or mortalities that occur under unusual circumstances. These are usually unexpected, infrequent, and may involve a significant number of marine mammal mortalities. Unusual environmental conditions are probably responsible for most UMEs and marine mammal die-offs (Geraci et al., 1999). Because these events require an immediate response, special teams are assembled to determine the cause (NMFS, 2007b). UMEs may occur for a variety of reasons ranging from diseases, to harmful algal blooms, to environmental conditions such as El Niño (NMFS, 2007e).

While an animal may be either dead or alive when it strands, a majority of stranded animals are dead. Many times, the animal has died of natural causes and is then washed ashore from wind and tides. Usually, animals that are alive when stranded are in need of medical attention, or are free-swimming but can't return to their natural habitat without assistance (NMFS, 2007b). In some cases when an animal is found alive, it may be possible to transport them to a rehabilitation center to receive further care, and even possibly returned to the wild. Unfortunately, statistics on strandings show that most marine mammals that are alive when they strand will not survive. In most cases the cause of the stranding is not clear. Some identified causes include parasites, disease, interactions with fishing gear, and starvation, to name a few (NMFS, 2007a).

Stranding Data

Stranding events, though unfortunate, can be useful to scientists and resource managers because they can provide information that is not accessible at sea or through any other means. Necropsies are useful in attempting to assess a reason for the stranding, and are performed on stranded animals when the situation allows. Stranded animals have provided us with the opportunity to gain insight into the lives of marine mammals such as their natural history, seasonal distribution, population health, reproductive biology, environmental contaminant levels, types of interactions with humans, and the prevalence of disease and parasites. The only existing information on some cetacean species has been discovered from stranding events (NMFS, 2007b).

Currently the government agency responsible for responding to strandings is the Marine Mammal Health and Stranding Response Program (MMHSRP) within NMFS. The National Marine Mammal Stranding Network, which is one part of the more comprehensive MMHSRP, is made up of smaller organizations partnered with NMFS to investigate marine mammal strandings. These stranding networks are established in all coastal states and consist of professionals and volunteers from nonprofit organizations, aquaria, universities, and state and local governments who are trained in stranding response. NMFS authorizes, coordinates, and participates in response activities and personnel training (NMFS, 2007b). NMFS oversees stranding response via a National Coordinator and a regional coordinator in each of the NMFS regions. There are currently over 400 organizations that are authorized by NMFS to respond to marine mammal strandings (NMFS, 2007c).

Stranding reporting and response efforts over time have been inconsistent and have been increasing over the past three decades, making any trends hard to interpret (NMFS, 2007c). Over the past decade (1990 – 2000), approximately 40,000 stranded marine mammals have been reported by the regional stranding networks, averaging 3,600 strandings reported per year (NMFS, 2007e). The highest number of strandings were reported between the years 1992-1993 and 1997-1998, with a peak in the number of reported strandings in 1998 totaling 5,708 (NMFS, 2007e; 2007c). These have since been determined to have been El Niño years, which for a variety of reasons can have a drastic effect on marine mammals (see Table 6-3).

Effort has been more consistent since 1994. Between 1994 and 1998 a total of 19,130 strandings were reported, with an average of 3,826 per year (NMFS, 2007c). The composition of animals involved in strandings varies by region. For example, the southwest always has more pinniped strandings, while the southeast always has the highest number of cetacean strandings (NMFS, 2007c). Table 6-3 presents the numbers and composition of reported strandings during the five year period 1994 – 1998 (taken from NMFS, 2007c).

Table 6-3. Summary of the Number of Cetacean and Pinniped Strandings by Region for Five Years From 1994 To 1998

Region	# of Cetaceans	# of Pinnipeds
Southeast	3,683	44
Northeast	1,013	1,768
Southwest	624	10,147
Northwest	119	1,098
Alaska	462	172
Five Year Totals	**5,901**	**13,229**

Peak years for cetacean strandings were in 1994 and 1999, and can be attributed to two UMEs. In 1994, 220 bottlenose dolphins stranded off Texas, which represented almost double the annual average (NMFS, 2007e). It has been determined that the probable cause for these strandings was a morbillivirus outbreak. In 1999, 223 harbor porpoises stranded from Maine to North Carolina, representing a four-fold increase over the annual average (NMFS, 2007e). The most likely cause for these strandings was inter-specific aggression due to sea surface temperatures and a shift in prey species in the Mid-Atlantic (NMFS, 2007e).

Causes of Strandings

Marine mammal strandings have been occurring as long as man has been recording scientific observations. The cause of the strandings was not clear in Aristotle's day, and in most cases, the reason is not clear now. Current science suggests that there are multiple factors, both natural and manmade, that may be acting alone or in combination. Most stranded animals are already dead or in a weakened state. An animal may suffer from one ailment and then become susceptible to various other dilemmas because of its weakened condition, making it difficult to determine a primary cause. Therefore, anything that leads to mortality, weakness, confusion, or injury in an animal could be considered a potential factor in influencing stranding. The physical injuries that may occur during a stranding can hasten death, but the stranding itself is not usually the underlying cause (Geraci et al., 1999). While data collection and necropsies attempt to find a possible cause, it is difficult to pinpoint exactly one factor that can be blamed for any given stranding. In many stranding cases, scientists never learn the exact cause of the stranding (NOAA, 2006a).

Natural Causes

Marine mammals have been found stranded throughout human history and therefore many strandings can be attributed to natural and environmental causes. Marine mammals die every single day from weakness resulting from trauma, predation, starvation, and disease (Geraci et al., 1999), or simply from old age (NOAA, 2006). Natural mortality in marine mammals is highest in the youngest and oldest age classes, which is typical of many large mammals (Geraci et al., 1999). Certain factors such as infections and environmental conditions can sometimes lead to the deaths of large numbers of marine mammals in a short period of time (Geraci et al., 1999). Because most stranded marine mammals come ashore either already dead or in a weakened state, it is believed that the original cause of death or weakness occurs at sea, and the animal is then brought to shore with the currents, tides, and wind.

Disease

Marine mammals frequently suffer from a variety of diseases resulting from viral, bacterial, parasite, or worm infections (NOAA, 2006a).

Microparasites are small and can reproduce within their hosts, such as bacteria, viruses, and other microorganisms including yeasts (Geraci et al., 1999). These types of organisms flourish in marine mammal habitats and usually pose little threat to a healthy animal (Geraci et al., 1999). For example, morbillivirus infection without mortality is endemic in certain marine mammal populations, such as in long-finned pilot whales of the western North Atlantic ocean (Geraci et al., 1999). This infection is presumed to be widespread but of little consequence because they have gained immunity through repeated exposure (Geraci et al., 1999). New viruses are continuously being discovered, many with little or no known effects (Geraci et al., 1999).

The most notable role of viruses has been in their association with marine mammal die-offs. The first mass mortality attributed to a virus (Influenza A) happened between December 1979 and October 1980 along the New England coast (Geraci et al., 1999). Since 1980, viruses have been implicated in almost all marine mammal mass mortalities attributed to infectious diseases (Geraci et al., 1999). For example, a UME in 1993 and 1994 involving bottlenose dolphins was caused by morbillivirus – this UME started along the Florida Panhandle and spread westward with most of the mortalities occurring in Texas (NMFS, 2005f).

Opportunistic species can invade and overwhelm those animals already weakened for other reasons such as malnutrition or infection (Geraci et al., 1999). It is hard to determine if a microparasite is the primary pathogen, or if it shows up later as a secondary infection in an already weakened animal (Geraci et al., 1999), thus making it difficult to determine the true cause of a stranding.

Macroparasites are usually large and require an intermediate host (Geraci et al., 1999). A wide range of different macroparasites can be found within marine mammals, and even heavy burdens of these organisms may have little effect on the animal unless it is also suffering from other illness, injury, or weakened by starvation (Geraci et al., 1999). Nasitrema, a trematode (parasitic flatworm) commonly found in the cranial sinuses of cetaceans, is fairly non-threatening to the animal (Geraci et al., 1999). But sometimes one of these organisms finds its way to the brain, critically damaging tissues as it moves (Geraci et al., 1999). This worm is one of the few that has been directly linked to strandings (Geraci et al., 1999).

Naturally Occurring Toxins

In Florida, "red tides" are created by a dinoflagellate (*Karenia brevis*) that blooms annually, and has been doing so since at least the mid 1800s (NMFS, 2007m). *K. brevis* is distributed primarily throughout the Gulf of Mexico, and occasionally along the mid- and southern Atlantic coasts (NMFS, 2007m). This dinoflagellate produces a form of neurotoxin, known as brevetoxin, which affects public health and causes significant animal mortalities (NMFS, 2007m).

Red tides resulting from *K. brevis* are responsible for annual mass mortalities of thousands of fish, and in some years they cause mass mortalities of marine mammals, birds, and sea turtles (NMFS, 2007m). Over the years, the effects of red tide have been responsible for many marine mammal strandings.

Several species of diatoms (microscopic marine plants) have the ability to produce a toxin called domoic acid (NMFS, 2007m). These diatoms are widespread and can be found on the east and west coasts of the United States as well as in the Gulf of Mexico (NMFS, 2007m). Domoic acid has also been known to have serious effects on public health and a variety of marine species (NMFS, 2007m). Since 1987, domoic acid has been identified as the cause of mass mortalities of seabirds and marine mammals off the coast of California, and whale deaths off of Georges Bank (NMFS, 2007m).

Between March 10 and April 13, 2004, 107 bottlenose dolphins were found dead and stranded on the Florida Panhandle, along with hundreds of dead fish and marine invertebrates (NMFS, 2007n). This event was declared a UME. Analyses of the dolphins found brevetoxins at high levels within the dolphin stomach contents, and at variable levels within their tissues (NMFS, 2007n). Low levels of domoic acid were also detected in some of the dolphins, and a diatom that produces domoic acid (Pseudo-nitzschia delicatissima) was present in low to moderate levels in water samples (NMFS, 2007n). In the Gulf of Mexico, two other UMEs associated with red tide involving bottlenose dolphins occurred previously in 1996, and between 1999 and 2000 (NMFS, 2005f).

Predation

Many species of marine mammal serve as prey to other animals and forms of marine life, including sharks and even other marine mammals. Predation from sharks is considered to be a contributing factor in the decline of the Hawaiian monk seal (Geraci et al., 1999). A stranded marine mammal will sometimes show signs of interactions with predators such as bites, teeth marks, and other injuries, which occasionally are bad enough to have been the primary cause of injury, death, and stranding.

Traveling Inshore

Inshore waters are certainly shallower than the waters of the open ocean, which may be a contributing factor in stranding events. Local coastal geography may be related to stranding events. Areas with gentle slopes and broad flats, extreme tidal changes, and strong or unusual currents may serve as “whale traps” (Geraci et al., 1999).

The presence of prey species close to the coast may result in bringing pelagic marine mammals, probably not familiar with the shoreline, closer to the coast than usual to feed (Chambers et al., 2005). Certain species of marine mammal follow their prey inshore, like Atlantic white-sided dolphins in the Bay of Fundy, or long-finned pilot whales seeking squid and herring close to Cape Cod, Massachusetts. Most of the time this is an uneventful activity, but occasionally a group hits land (Geraci et al., 2005). Between 1981 and 1991, at least 10 separate pilot whale mass stranding events occurred within a 20-mile radius on Cape Cod. The strandings totaled more than 475 animals between the months of September and December (Geraci et al., 2005).

Sometimes even coastal species are caught by an outgoing tide. Occasionally beluga whales that feed on salmon in Cook Inlet, Alaska, strand in large numbers due to unusually low tides. Most of the time, these animals seem to suffer little damage from the temporary grounding and are able to swim away with a higher tide and resume normal activities (Geraci et al., 2005).

Echolocation Malfunction in Shallow Water

Some researchers believe that some pelagic species of marine mammals may run aground because their echolocation is impaired in shallow waters (Geraci et al., 1999). When stranded cetaceans are determined to be free of disease or parasitic infection, it has been hypothesized that echolocation malfunction could be a possible cause of mass strandings on shallow beaches (Chambers et al., 2005). For a cetacean, echolocation signal reflections contain important information on the location of a shoreline (Chambers et al., 2005). A gently sloping beach may present major difficulties to the navigational systems of some cetaceans, and in some instances may even be undetectable to echolocation. Navigational errors leading to incorrect or non-detection of a shoreline could result in confusion and disorientation, possibly causing a stranding (Chambers et al., 2005). In some cases, successful detection of a shoreline might happen too late, at a point where stranding becomes imminent (Chambers et al., 2005).

Chambers et al. (2005) explored this possibility as a cause of mass cetacean strandings in Geographe Bay in south-western Australia. Geographe Bay, a gently-sloping sandy bottomed beach, has been the location of several live mass strandings over the past 15 years, involving large groups (five or more) of apparently healthy, toothed cetaceans that utilize echolocation as a means of navigation (Chambers et al., 2005). They believe that a mechanism called "sonar termination" was a major factor in these strandings. Sonar termination occurs when an echolocation click is directed towards the coast, but then attenuates to a point to where the reflections are not detectable (Chambers et al., 2005).

Chambers et al. (2005) suggest that there are two factors that contribute to sonar termination; first, a gently sloping shore, and second, tiny micro-sized bubbles within the water column. Active echolocation detection of a shallow coast is hindered by a large amount of reflection loss due to gently sloping bathymetry (Chambers et al., 2005). They believe that the combined effect of reflection loss and microbubble attenuation can mask the presence of a shoreline or degrade an echolocation signal to a point where a navigational error may be made (Chambers et al., 2005).

It is widely accepted that small bubbles are continuously being created at the water's surface by rain and surface waves, with tidal and wave motions thoroughly mixing these microbubbles in shallow water (Chambers et al., 2005). These microbubbles can stay within the water column from a few hours up to a few days, and their presence contributes directly to sonar termination by having an attenuative effect on echolocation (Chambers et al., 2005). They have a detrimental effect on the successful detection of a shallow shoreline by absorbing energy emitted from a marine mammal's echolocation signals.

It is important to review weather data and underwater geography when researching possible causes of a stranding to determine if a cetacean's active echolocation mechanisms could have been adversely affected. A windy period could have created an unusual amount of microbubbles in the water, or the marine mammal's echolocation may have had difficulty detecting a gently sloping coastline.

Weather Events and Climate Patterns

Even though marine mammals as a group have adapted to deal with varying and sometimes extreme environmental conditions, events such as severe storms or prolonged cold can have a big impact, and many individual animals may die as a direct result (Geraci et al., 1999). Sometimes mass strandings coincide with unusual weather events and abnormal environmental conditions. For example, in 1999 in the British Virgin Islands, it is believed that severe hurricanes may have been responsible for the stranding of five pygmy killer whales (Geraci et al., 2005). And along southern Newfoundland, wind-driven ice sometimes forces groups of blue whales and white-beaked dolphins ashore (Geraci et al., 1999).

Weather events can also have an indirect effect on marine mammals by shifting or depleting food resources (Geraci et al., 1999). Some researchers have investigated the correlation of stranding frequency with changes in the oceanic currents or periods of climatic warming that may alter the distribution of prey, therefore altering the movement of predatory marine mammals. It is possible that these events may bring animals unfamiliar with the coastline closer to shore and into risky shallow territory, thus increasing the chance that some may run aground (Geraci et al., 2005).

Bradshaw et al. (2006) examined stranding events in the southeastern region of Australia including Tasmania, considered to be one of the world's stranding "hotspots" (Bradshaw et al., 2006). Bradshaw et al. believe that the variability in the distribution and availability of food resources is what dictates the patterns in animal migration, survival, fecundity, and population size. They therefore believe that if movement of nutrient-rich waters is responsible for bringing marine mammals closer to land, the probability of stranding at those times will be higher (Bradshaw et al., 2006). Their analyses of stranding data for the area found cycles in the number of stranding events (occurring about every 12–14 years) and that these pulses in stranding activity were related to measurable changes in climate patterns (Bradshaw et al., 2006). They found that a good predictor for an increase in stranding frequency was to watch for increases in zonal meridional winds that result in colder and possibly more nutrient-rich water moving closer to southern Australian landmasses (Bradshaw et al., 2006). They put this hypothesis to test when their model predicted that the 2004–2005 austral summer would be a peak year for strandings in the area, which it was (Bradshaw et al., 2006). Bradshaw et al. conclude that while climatic and other models can provide broad-scale mechanisms for predicting stranding frequency at a given location, the exact mechanisms for individual stranding events are likely to vary widely.

It is also possible that the sudden disappearance of prey due to an extreme weather event could have a sudden and dramatic effect throughout a marine mammal population (Geraci et al., 1999). Food resources dramatically decrease during El Niño years which have a strong impact on pinnipeds, especially affecting the very young - pups may be abandoned while weanlings and juveniles starve (NMFS, 2007e).

Earth's Magnetic Field

The Earth's magnetic field provides a stable source of positional and directional information. It is now known that many animals detect the geomagnetic field and use it as a compass and a map to navigate, especially over long distances when it may not be possible to use other navigational abilities (Walker et al., 1992). This has been demonstrated in birds along their seasonal migration routes and in pigeon homing behavior. Fish and honeybees have also been conditioned to respond to various magnetic field stimuli (Walker et al., 1992).

Some scientists believe that marine mammals may also use this magnetic sensing, and there is some evidence that cetaceans are using magnetic information to guide their movements. Alternating bands of magnetism run north to south parallel to the mid-ocean rift. If whales are able to detect these alterations in the magnetic field, it is possible that they may be able to use the magnetic patterns as north-south highways on their annual migrations (Wartzok et al., 1999). Underwater disturbances or anomalies in the magnetic field may then disrupt movements of marine mammals by causing them to misinterpret the geomagnetic information, leading them astray by providing incorrect direction and location.

In 2000, over 150 false killer whales stranded themselves on Mexico’s Yucatan peninsula (Tracey, 2000). In relation to this stranding event, Dr. Randall Reeves, chairman of the IUCN Species Survival Commission’s Cetacean Specialist Group, explained that the exact reason for the strandings is unknown. He mentioned that one hypothesis to explain the strandings involves magnetic irregularities in certain places that make it difficult for the whales to navigate, and that magnetic disturbances in some areas have been linked to mass stranding occurrences (Tracey, 2000).

Klinowska (1985) hypothesized that seemingly healthy whales that strand themselves alive must have made a serious navigational mistake. She plotted live stranding positions on top of magnetic field maps for the coast of Great Britain. Klinowska observed an association between live stranding positions and levels within the magnetic field. She found that in all cases, live strandings occurred at locations where magnetic minima, or lows in the magnetic fields, intersect the coastline. The results suggest that cetaceans possess some type of magnetic sensory system. There was no such correlation between magnetic data and strandings of dead cetaceans, which had most likely been washed ashore by currents (Klinowska, 1985).

Others have expanded upon this research. Kirschvink and his colleagues (1986, 1990) extended Klinowska’s study to the United States, testing the hypothesis that cetaceans use anomalies in the geomagnetic field as cues for orientation and navigation. Stranding positions were plotted on a map of magnetic data for the east coast of the United States, and they were able to develop associations between stranding sites and locations where magnetic minima intersected the coast. They found highly significant tendencies for cetaceans to beach themselves near these coastal areas. Even small variations in total intensity were sufficient to influence stranding location (Kirschvink et al., 1986; Kirschvink, 1990). Again, these results suggest that cetaceans may have a magnetic sensory system comparable to that in other migratory animals, and that marine magnetic topography and patterns may play an important role in guiding long-distance movements (Kirschvink et al., 1986).

Walker et al. (1992) studied the locations of where free-swimming fin whales had been observed over the continental shelf off the northeastern United States. They found that migrating animals associated themselves with lows in the geometric gradient or intensity. Their results suggested that fin whales do in fact recognize and associate with features in the geomagnetic field independent of other geophysical stimuli, and this association is correlated with seasonal migration patterns. These results are consistent with earlier analyses of live whale strandings, the occurrence of which happened most often on coastlines that intersected areas characterized by low magnetic field gradients and intensities. It also supports the notion that fin whales, and possibly other mysticete species, possess a magnetic sense that assists in migration (Walker et al., 1992).

To support these theories, there is anatomical evidence that some species of cetaceans have crystals of magnetite in the soft tissue of their brains that may be to sense the Earth's magnetic field (Geraci et al., 2005) (Wartzok et al., 1999).

Intentionally

There is debate as to why a marine mammal would intentionally strand. Some suggestions include to seek the safety of land, to rest, or to rub their skin (NMFS, 2007f). Some have even suggested that it may be because they are distracted, for sensory stimulation, or a regression to instinctive behaviors (Bradshaw et al., 2006). Many cetaceans exhibit a strong kinship within social structures, which appears to be especially important in the group structure of some of the larger toothed whale species. Mass strandings have a tendency to involve those species with strong social bonds, which appear extraordinarily strong at times (Wells et al., 1999). Many individual animals within a mass stranding come ashore in seemingly good health (Geraci et al., 1999), with only a small proportion of animals within the group showing any indication of illness or injury. This suggests that social cohesion may contribute to bringing the entire group ashore – a force that is strong enough to make others in the pod likely to follow just a few (Geraci et al., 1999). Removal or loss of the injured members has led to the successful return of the rest of the group to sea (Wells et al., 1999). In September of 1975, 200 long-finned pilot whales stranded off Newfoundland. 125 died, and the rest of the animals returned to sea on the next tide (Geraci et al., 1999).

Anthropogenic Causes

Over the past few decades, there has been an increase in marine mammal mortalities believed to be caused by a variety of human activities (Geraci et al., 1999), such as gunshots, collisions with vessels (NOAA, 2006a), and other trauma and mutilations.

- Gunshot injuries are the most common manmade cause of strandings in sea lions and seals on the U.S. West Coast (NMFS, 2007c).
- Every year a few northern right whales are killed within shipping lanes along the U.S. Atlantic coast, which may be enough to jeopardize stock recovery (Geraci et al., 1999).
- In 1998, two bottlenose dolphins and a calf were killed by vessel strikes in the Gulf of Mexico (NMFS, 2005f).
- In 1999, there was one report of a stranded false killer whale on the Alabama coast that was classified as likely caused by fishery interactions or other human interaction due to limb mutilation (the fins and flukes of the animal had been amputated) (NMFS, 2005c).
- 1,377 bottlenose dolphins were found stranded in the Gulf of Mexico from 1999 through 2003. 73 animals (11 percent) showed evidence of human interactions as the cause of death (e.g., gear entanglement, mutilations, gunshot wounds) (NMFS, 2005f).

Data from strandings in which there was evidence of human interaction is available for the years 1999 – 2000. Table 6-4 provides the number of stranded marine mammals (cetaceans and pinnipeds) during this period that displayed evidence of human interactions (NMFS, 2007e). (Stranding data for the California region for the year 1999 is unavailable; therefore numbers are for stranded animals in 2000 only. Similarly, data is unavailable for the year 2000 in the Alaska region; numbers provided represent strandings for 1999 only).

Fisheries Interactions/Marine Debris Entanglement

The incidental catch of marine mammals in commercial fisheries is a significant threat to many populations of marine mammals. Interactions between fisheries and marine mammals have been occurring for centuries, and are currently on the rise due to increases in the human population, fishery industrialization, and fishery expansion into new areas (Read et al., 2006). Interactions with fisheries and/or entanglement in discarded or lost gear continue to be a major factor in marine mammal deaths worldwide (Geraci et al., 1999). Marine mammals can not only get caught in gear that is actively being fished but they can become entangled in netting and other fishing gear that has been thrown away or lost and is floating around in the oceans of the world. Baleen whales and pinnipeds have been found entangled in nets, ropes, monofilament line, and other fishing gear that has been discarded out at sea (Geraci et al., 1999). To address these issues there are a variety of Federal laws that regulate commercial and recreational fishing activities, and gear restrictions and usage.

Table 6-4. Summary of Marine Mammal Strandings by Cause for Each Region for Two Years From 1999 to 2000

Interaction	Southeast	Northeast	Northwest	California	Alaska
Fisheries	89	75	10	31	16
Vessel Strike	9	6	1	11	2
Gun Shot	6	6	12	19	4
Blunt Trauma	-	1	-	-	-
Mutilation	4	17	-	-	-
Plastic Ingestion	1	3	-	-	-
Power Plant Entrapment	1	11	-	12	-
Harassment	-	9	-	-	-
Arrow Wound	-	-	1	-	-
Harpoon Wound	-	-	2	-	-
Hit by Car	-	-	1	-	-
Hit by Train	-	-	1	-	-
Debris Entanglement	-	-	1	3	-
Total	**110**	**128**	**27**	**97**	**22**

Entangled marine mammals may die as a result of drowning, escape with pieces of gear still attached to their bodies, or manage to be set free either of their own accord or by fishermen. Many large whales carry off gear after becoming entangled (Read et al., 2006). Many times when a marine mammal swims off with gear attached, the end result can be fatal. The gear may be become too cumbersome for the animal, or it can be wrapped around a crucial body part and tighten over time. Stranded marine mammals frequently exhibit signs of previous fishery interaction, such as scarring or gear attached to their bodies, and the cause of death for many stranded marine mammals is often attributed to such interactions. Because marine mammals that die or are injured in fisheries may not wash ashore and not all animals that do wash ashore exhibit clear signs of interactions, stranding data probably underestimate fishery-related mortality and serious injury (NMFS, 2005a).

From 1993 through 2003, 1,105 harbor porpoises were reported stranded from Maine to North Carolina, many of which had cuts and body damage suggestive of net entanglement (NMFS, 2005e). In 1999 it was possible to determine that the cause of death for 38 of the stranded porpoises was from fishery interactions, with one additional animal having been mutilated (right flipper and fluke cut off) (NMFS, 2005e). In 2000, one stranded porpoise was found with monofilament line wrapped around its body (NMFS, 2005e). And in 2003, nine stranded harbor porpoises were attributed to fishery interactions, with an additional three mutilated animals (NMFS, 2005e).

Read et al. (2006) attempted to estimate the magnitude of marine mammal bycatch in U.S. and global fisheries. Data on marine mammal bycatch within the United States was obtained from fisheries observer programs, reports of entangled stranded animals, and fishery logbooks, and was then extrapolated to estimate global bycatch by using the ratio of U.S. fishing vessels to the total number of vessels within the world's fleet (Read et al., 2006). Within U.S. fisheries, between 1990 and 1999 the mean annual bycatch of marine mammals was 6,215 animals, with a standard error of +/- 448 (Read et al., 2006). 84 percent of cetacean bycatch occurred in gill-net fisheries, with dolphins and porpoises constituting most of the cetacean bycatch (Read et al., 2006). Over the decade there was a 40 percent decline in marine mammal bycatch, which was significantly lower from 1995-1999 than it was from 1990-1994 (Read et al., 2006). Read et al. (2006) suggests that this is primarily due to effective conservation measures that were implemented during this time period.

Read et al. (2006) then extrapolated this data for the same time period and calculated an annual estimate of 653,365 of marine mammals globally, with most of the world's bycatch occurring in gill-net fisheries. With global marine mammal bycatch likely to be in the hundreds of thousands every year, bycatch in fisheries will be the single greatest threat to many marine mammal populations around the world (Read et al., 2006).

Ingestion of Plastic Objects and Other Marine Debris

For many marine mammals, debris in the marine environment is a great hazard and can be harmful to wildlife. Not only is debris a hazard because of possible entanglement, animals may mistake plastics and other debris for food (NMFS, 2007g). There are certain species of cetaceans, along with Florida manatees, that are more likely to eat trash, especially plastics, which is usually fatal for the animal (Geraci et al., 1999).

Between 1990 through October 1998, 215 pygmy sperm whales stranded along the U.S. Atlantic coast from New York through the Florida Keys (NMFS, 2005a). Remains of plastic bags and other debris were found in the stomachs of 13 of these animals (NMFS, 2005a). During the same time period, 46 dwarf sperm whale strandings occurred along the U.S. Atlantic coastline between Massachusetts and the Florida Keys (NMFS, 2005d). In 1987 a pair of latex examination gloves was retrieved from the stomach of a stranded dwarf sperm whale (NMFS, 2005d). 125 pygmy sperm whales were reported stranded from 1999 – 2003 between Maine and Puerto Rico; in one pygmy sperm whale found stranded in 2002, red plastic debris was found in the stomach along with squid beaks (NMFS, 2005a).

Toxic Pollution Exposure and Ingestion, Poisoning

High concentrations of potentially toxic substances within marine mammals along with an increase in new diseases have been documented in recent years. Scientists have begun to consider the possibility of a link between pollutants and marine mammal mortality events. NMFS takes part in a marine mammal bio-monitoring program not only to help assess the health and contaminant loads of marine mammals, but also to assist in determining anthropogenic impacts on marine mammals, marine food chains and marine ecosystem health. Using strandings and bycatch animals, the program provides tissue/serum archiving, samples for analyses, disease monitoring and reporting, and additional response during disease investigations (NMFS, 2007d).

The manmade chemical PCB (polychlorinated biphenyl), and the pesticide DDT (dichlorodiphyenyltrichloroethane), are both considered persistent organic pollutants that are currently banned in the United States for their harmful effects in wildlife and humans (NMFS, 2007c). Despite having been banned for decades, the levels of these compounds are still high in marine mammal tissue samples taken along U.S. coasts (NMFS, 2007c). Both compounds are long-lasting, reside in marine mammal fat tissues (especially in the blubber), and can be toxic causing effects such as reproductive impairment and immunosuppression (NMFS, 2007c).

Both long-finned and short-finned pilot whales have a tendency to mass strand throughout their range. Short-finned pilot whales have been reported as stranded as far north as Rhode Island, and long-finned pilot whales as far south as South Carolina (NMFS, 2005b). For U.S. east coast stranding records, both species are lumped together and there is rarely a distinction between the two because of uncertainty in species identification (NMFS, 2005b). Since 1980 within the Northeast region alone, between 2 and 120 pilot whales have stranded annually either individually or in groups (NMFS, 2005b). Between 1999 and 2003 from Maine to Florida, 126 pilot whales were reported to be stranded, including a mass stranding of 11 animals in 2000 and another mass stranding of 57 animals in 2002, both along the Massachusetts coast (NMFS, 2005b).

It is unclear how much of a role human activities play in these pilot whale strandings, and toxic poisoning may be a potential human-caused source of mortality for pilot whales (NMFS, 2005b). Moderate levels of PCBs and chlorinated pesticides (such as DDT, DDE, and dieldrin) have been found in pilot whale blubber (NMFS, 2005b). Bioaccumulation levels have been found to be more similar in whales from the same stranding event than from animals of the same age or sex (NMFS, 2005b). Numerous studies have measured high levels of toxic metals (mercury, lead, and cadmium), selenium, and PCBs in pilot whales in the Faroe Islands (NMFS, 2005b). Population effects resulting from such high contamination levels are currently unknown (NMFS, 2005b).

Habitat contamination and degradation may also play a role in marine mammal mortality and strandings. Some events caused by man have direct and obvious effects on marine mammals, such as oil spills (Geraci et al., 1999). But in most cases, effects of contamination will more than likely be indirect in nature, such as effects on prey species availability, or by increasing disease susceptibility (Geraci et al., 1999).

Anthropogenic Sound

There is evidence that manmade sounds (such as explosions, drilling, construction, and certain types of sonar) (NOAA, 2006a) that occur underwater may have an impact on marine mammals, and in some cases is believed to be a possible contributing factor in stranding events. Behavioral and physiological responses of marine mammals to various sound sources remain highly misunderstood (NMFS, 2007k).

There is data to indicate that some active sonar systems are audible to a variety of marine mammal species over considerable distances (NMFS, 2007k). The effect that sonar may have on marine mammals remains scientifically uncertain (NMFS, 2007k), and the answers as to how sonar can contribute to a stranding remain unclear. Our comprehension of the type and magnitude of any behavioral or physiological responses from marine mammals to active sonar, and how these responses may contribute to strandings, is rudimentary at best (NMFS, 2007k).

Stranding Events Associated with Navy Sonar

Greece Stranding Event, May 12 – 13, 1996

On the morning of May 12, 1996, Cuvier's beaked whales began to strand alive in different locations of Kyparissiakos Gulf, Greece, and continued through the afternoon of May 13 (Frantzis, 2004; ICES, 2005). The Gulf is a long sandy beach in the west coast of the Peloponnese, along the Hellenic Trench (Frantzis, 2004). A total of twelve whales were reported stranded alive, spread across 38.2 kilometers of coastline and separated by a mean distance of 3.5 km (Frantzis, 1998). The Greek Seas occupy the northern part of the eastern Mediterranean and are characterized by long and highly irregular coastlines with rich geomorphology (Frantzis, 2004). There are depressions and deep trenches that surround Greece, which are good habitats for deep diving cetaceans close to the coastline (Frantzis, 2004).

From May 11 through May 15, North Atlantic Treaty Organization (NATO) research vessels were conducting sound-detecting system trials by transmitting to both low and medium frequencies (Cox et al., 2006). The period of time and the location where the tests had been carried out both encompassed the time and location of the marine mammal stranding coordinates (Frantzis, 2004).

Findings

Necropsies of eight of the animals were performed, but were limited to basic external examination and sampling of stomach contents, blood, and skin. No ears or organs were collected, and no histological samples were preserved because of problems related to permits, lack of trained specialists, and lack of facilities and means (ICES, 2005).

- At least 12 of the 14 animals stranded alive in an atypical way (ICES, 2005). The spread of strandings were also atypical in location and time, as mass-strandings usually occur at the same place and at the same time (Frantzis, 1998).
- No apparent abnormalities or wounds were found (Frantzis, 2004).
- Examination of photos of the animals revealed that the eyes of at least four of the individuals were bleeding. Photos were taken soon after their death (Frantzis, 2004).
- Stomach contents contained the flesh of cephalopods, indicating that feeding had recently taken place (Frantzis, 1998).

- No unusual environmental events occurred before or during the stranding (Frantzis, 2004).

Conclusions

All available information regarding the conditions associated with this stranding were compiled, and many potential causes were examined including major pollution events, important tectonic activity, unusual physical or meteorological events, magnetic anomalies, epizootics, and conventional military activities (ICES, 2005). However, none of these potential causes coincided in time with the mass stranding, or could explain its characteristics (ICES, 2005). The robust condition of the animals, plus the recent stomach contents, is not consistent with pathogenic causes (Frantzis, 2004). In addition, environmental causes can be ruled out as there were no unusual environmental circumstances or events before or during this time period (Frantzis, 2004).

It was determined that because of the rarity of this mass stranding of Cuvier's beaked whales in the Kyparissiakos Gulf (first one in history), the probability for the two events (the military exercises and the strandings) to coincide in time and location, while being independent of each other, was extremely low (Frantzis, 1998).

Because full necropsies had not been conducted, and no abnormalities were noted, the cause of the strandings cannot be precisely determined (Cox et al., 2006). The analysis of this stranding event provided support for, but no clear evidence for, the cause-and-effect relationship of sonar operations and beaked whale strandings (Cox et al., 2006).

Bahamas Marine Mammal Stranding Event, March 15-16, 2000

On March 15-16, 2000, seventeen marine mammals comprised of four different species (Cuvier's beaked whales, Blainville's beaked whales, Minke whales, and one spotted dolphin) stranded along the Northeast and Northwest Providence Channels of the Bahamas Islands (NMFS, 2001a; DON/DOC, 2001). The strandings occurred within 24 hours of Navy ships using active mid-frequency active sonar for an extended period while passing through the Northeast and Northwest Providence Channels (NMFS, 2001a).

Because of the unusual nature and situation surrounding these strandings, a comprehensive investigation into every possible cause was quickly launched (DON/DOC, 2001).

Strandings were first reported at the southern end of the channels, and proceeded northwest throughout March 15, 2000 (DON/DOC, 2001). It is probable that all of the strandings occurred on March 15, even though some of the animals weren't found or reported until March 16 (DON/DOC, 2001). Seven of the animals died, while ten animals were returned to the water alive; however, it is unknown if these animals survived or died at sea at a later time (DON/DOC, 2001).

The animals that are known to have died include five Cuvier's beaked whales, one Blainville's beaked whale, and the single spotted dolphin (DON/DOC, 2001). Six necropsies were performed, but only three out of the six (one Cuvier's beaked whale, one Blainville's beaked whale, and the spotted dolphin) were fresh enough to examine any lesions clearly. Results from the spotted dolphin necropsy revealed that the animal died with systemic debilitation disease, and is considered unrelated to the rest of the mass stranding (DON/DOC, 2001).

Findings

Based on necropsies performed on the other five beaked whales, it was preliminarily determined that they had experienced some sort of acoustic or impulse trauma which led to their stranding and ultimate demise (DON/DOC, 2001). Detailed microscopic tissue studies followed in order to determine the source of the acoustic trauma and the mechanism by which trauma was caused.

- All five necropsied beaked whales were in good body condition, showing no signs of infection disease, ship strike, blunt trauma, or fishery related injuries, and three still had food remains in their stomachs. (DON/DOC, 2001).
- Auditory structural damage was discovered in four of the whales, specifically bloody effusions or hemorrhaging around the ears (DON/DOC, 2001).
- Bilateral intra-cochlear and unilateral temporal region subarachnoid hemorrhage with blood clots in the lateral ventricles were found in two of the whales (DON/DOC, 2001).
- Three of the whales had small hemorrhages in their acoustic fats (located along the jaw and in the melon) (DON/DOC, 2001).
- Passive acoustic monitor recordings within the area during the time of the stranding showed no signs of an explosion or other geological event such as an earthquake (DON/DOC, 2001).
- The beaked whales showed signs of overheating, physiological shock, and cardiovascular collapse, all of which commonly result in death following a stranding (DON/DOC, 2001).

Conclusions

The physiological trauma resulting from stranding is the mostly likely immediate cause of death, but the offshore acoustic event within a specific environment is what triggered this series of events (DON/DOC, 2001).

The actual mechanism by which sonar could have caused tissue damage or caused the animals to strand remains unknown. The report concluded that the cause of the Bahamas stranding was the confluence of mid-frequency sonar with the variables which included sound propagation characteristics (in this case a surface duct), unusual underwater bathymetry, intensive use of multiple sonar units, a constricted channel with limited egress avenues, and the presence of beaked whales that appear to be sensitive to the frequencies produced by these sonars (DON/DOC, 2001)..

May 10–14, 2000 Stranding Event, Madeira Island, Portugal

From May 10–14, 2000, three Cuvier's beaked whales were found stranded on two islands in the Madeira archipelago, Portugal (Cox et al., 2006) – two on Porto Santo Island, and one on the northeast coast of Madeira Island (Freitas, 2004). A fourth animal was reported floating in the Madeiran waters by fisherman, but did not come ashore (Woods Hole Oceanographic Institution [WHOI], 2005).

Joint NATO amphibious training peacekeeping exercises involving participants from 17 countries took place in Portugal during May 2–15, 2000. The exercises were conducted across an area that stretched from the Island of Madeira to the Gulf of Gascony, and was named "Linked Seas 2000" (NATO, 2000). It involved Greek, British, Spanish, Portuguese, French, Romanian, and U.S. forces, and included 80 warships and several thousand men landing on the beaches (USACE, 2001). The NATO exercises occurred concurrently with this atypical mass stranding of beaked whales (Freitas, 2004).

Findings

The bodies of the three stranded whales were examined post mortem (WHOI, 2005). Two heads were taken to be examined, one intact and the other partially seared from a fire started by locals during an attempt to dispose of the corpse (WHOI, 2005). Only one of the stranded whales was fresh enough (24 hours after stranding) to be necropsied (Cox et al. 2006).

- Results from the necropsy revealed evidence of hemorrhage and congestion in the right lung and both kidneys (Cox et al., 2006).
- There was also evidence of inter-cochlear and intracranial hemorrhage similar to that which was observed in the whales that stranded in the Bahamas event (Cox et al., 2006).
- There were no signs of blunt trauma, and no major fractures (WHOI, 2005).
- The cranial sinuses and airways were found to be quite clear with little or no fluid deposition, which may indicate good preservation of tissues (WHOI, 2005).

Conclusions

Several observations on the Madeira stranded beaked whales, such as the pattern of injury to the auditory system, are the same as those observed in the Bahamas strandings (WHOI, 2005). Blood in and around the eyes, kidney lesions, pleural hemorrhages, and congestion in the lungs are particularly consistent with the pathologies from the whales stranded in the Bahamas, and are consistent with stress and pressure related trauma (WHOI, 2005). The similarities in pathology and stranding patterns between these two events suggest that a similar pressure event may have precipitated or contributed to the strandings at both sites (WHOI, 2005).

Even though no causal link can be made between the stranding event and naval exercises, certain conditions may have existed in the exercise area that, in their aggregate, may have contributed to the marine mammal strandings (Freitas, 2004).

- Operations were conducted in areas of at least 1,000 m depth near a shoreline where there is a rapid change in bathymetry on the order of 1,000 – 6,000 m occurring a cross a relatively short horizontal distance (Freitas, 2004).
- Multiple ships were operating around Madeira. It is not known if mid-frequency active sonar was used, and the specifics of the sound sources used the Linked Seas 2000 exercises, and their propagation characteristics, are unknown (Cox et al. 2006, Freitas, 2004).
- Exercises took place in an area surrounded by landmasses separated by less than 35 nm and at least 10 nm in length, or in an embayment. Operations involving multiple ships employing mid-frequency active near land may produce sound directed towards a channel or embayment that may cut off the lines of egress for marine mammals (Freitas, 2004).

September 24, 2002 Canary Islands Stranding Event

The southeastern area within the Canary Islands is well known for aggregations of beaked whales due to its ocean depths of greater than 1,000 m within a few hundred meters of the coastline (Fernandez et al., 2005). On September 24, 2002, 14 beaked whales were found stranded on Fuerteventura and Lanzaote Islands in the Canary Islands (ICES, 2005). Seven whales died while the remaining seven live whales were returned to deeper waters (Fernandez et al., 2005). Four beaked whales were found stranded dead over the next 3 days either on the coast or floating offshore.

These strandings occurred within near proximity of an international naval exercise named Neo-Tapon 2002 that involved numerous surface warships and several submarines. Spanish naval sources indicated that tactical mid-frequency active sonar was utilized during the exercises, but no explosions occurred (Fernandez et al., 2005). Strandings began about 4 hours after the onset of the use of mid-frequency active sonar activity (ICES, 2005; Fernandez et al., 2005).

Findings

Eight Cuvier's beaked whales, one Blainville's beaked whale, and on Gervais' beaked whale were necropsied, six of which were considered to be very fresh (Jepson et al., 2003).

- No pathogenic bacteria were isolated from the carcasses (Jepson et al., 2003)
- The animals displayed severe vascular congestion and hemorrhage especially around the tissues in the jaw, ears, brain, and kidneys, displaying marked disseminated microvascular hemorrhages associated with widespread fat emboli (Jepson et al., 2003; ICES, 2005).
- Several organs contained intravascular bubbles, although definitive evidence of gas embolism in vivo is difficult to determine after death (Jepson et al., 2003).
- The livers of the necropsied animals were the most consistently affected organ, which contained macroscopic gas-filled cavities and had variable degrees of fibrotic encapsulation. In some animals, cavitary lesions had extensively replaced the normal tissue (Jepson et al., 2003).
- Stomachs contained a large amount of fresh and undigested contents, which suggests a rapid onset of disease and death (Fernandez et al., 2005).
- Head and neck lymph nodes were enlarged and congested, and parasites were found in the kidneys of all animals (Fernandez et al., 2005).

Conclusions

There are similarities between this mass stranding and other strandings. The oceanographic features are characteristic of steep-slope regions, the species involved have been predominantly beaked whales, and they were temporally associated with naval maneuvers that employed low or mid-frequency range sonar signals (Fernandez et al., 2005). This leads to the observation that beaked whales that are found in association with certain oceanographic features may be behaviorally or physiologically susceptible to the effects of a variety of sound exposures, including certain types of anthropogenic sonar systems (Fernandez et al., 2005).

There are several different theories as to how gas bubble formation may occur in marine mammals, and how it might be related to strandings. One theory suggests that bubble formations such as the ones found in the animals involved in the Canary Islands stranding might result from behavioral changes to normal diving behavior, such as an accelerated ascent rate (Jepson et al. 2003; Fernandez et al., 2005).

Another theory suggests that gas bubble formation within the subcutaneous adipose tissue, and widespread vascular embolization of fat material, caused sudden spikes in the blood and tissue levels of PCBs or other related xenobiotics (Di Guardo et al., 2005). The liver is one of several sites where accumulation of PCBs occurs in cetaceans, and PCBs are known to act as immunosuppressors and as endocrine disruptors that are associated with morphologic changes in several of the hormone-producing glands (such as the adrenal and thyroid glands) (Di Guardo et al., 2005). A similar pathogenic mechanism may have been involved in three delphinids and one beaked whale found stranded in the United Kingdom between 1992 and 2003, which displayed gas-filled cystic cavities in their livers and other organs (Di Guardo et al., 2005).

However, at this point in time there is no definitive answer to the issue of how bubble formation (like those in the Canary Islands animals) may or may not be associated with marine mammal strandings, and how military sonar may or may not be involved. Aside from their bacteriologic status, there is no other data regarding the age or any pre-existing health of the whales that stranded in the Canary Islands, such as levels of pollutants in tissues (i.e., PCBs) (Di Guardo et al. 2005). A number of acute and chronic disease factors and mechanisms, either acting alone or in combination, may have also been involved in the deaths of the whales in the Canary Islands (Di Guardo et al., 2005).

May 5, 2003 U.S.S. SHOUP Washington State

On May 5, 2003 at 8:55 in the morning, the *U.S.S. SHOUP* got underway from the pier at Naval Station Everett, Washington. The *U.S.S. SHOUP* then transited from Everett through Admiralty Inlet to the west side of Whidbey Island, where at 10:30 a.m. it began a training exercise. Use of *U.S.S. SHOUP*'s mid-frequency tactical active sonar began at 10:40 a.m. At 2:20p.m., the *U.S.S. SHOUP* entered the Haro Strait at a speed of 18 knots. *U.S.S. SHOUP* terminated active sonar use at 2:38 p.m.

Between May 2 and June 2, 2003, approximately 16 strandings involving 15 harbor porpoise and one Dall's porpoise were reported to the Northwest Marine Mammal Stranding Network. *U.S.S. SHOUP* was accused of having caused these strandings by use of its sonar. NMFS noted that the number of strandings in 2003 was one below the previously recorded high (NMFS, 2003:5). The annual stranding of harbor porpoise in Puget Sound is a known and expected seasonal phenomenon, with strandings occurring more frequently in May, and 70 percent of all annual strandings occurring between the months of March and June. Other cited causes of strandings include toxins (such as "red tide") and contaminants (NMFS 2003; e.g., release of 40 tons of raw sewage in Admiralty Inlet on 3 May 2003 by a cruise liner; AP, 2003).

For a historical perspective, since 1992 the San Juan Stranding Network has documented an average of 5.8 porpoise strandings per year. In 1997 there were 12 strandings in the San Juan Islands with over 30 strandings throughout the general Puget Sound area. On May 20, 2003, Dr. Richard Osborne, Research Director for The Whale Museum on San Juan Island wrote that he believed that he was observing a normal pattern of porpoise strandings (Osborne, 2003).

While these data and trends analysis from Dr. Osborne appear to conflict with the NMFS necropsy report abstract which noted a higher rate of strandings in 2003 than the six per year, they can be reconciled when accounting for several factors (NMFS, 2003). First, Dr. Osborne and NMFS point to the repeated and intense level of media attention focused on the strandings which increased reporting efforts (Osborne, 2003; NMFS, 2003). NMFS noted in its report that the "sample size is too small and biased to infer a specific relationship with respect to sonar usage and subsequent strandings (NMFS, 2003). In addition, although NMFS has characterized 2003 as having "an abnormally high number" of strandings, it is actually less than the maximum previously recorded (15 strandings in 2001; NMFS, 2003). Finally, given the reported average of 6.0 (strandings annually) and the standard deviation of 6.1, a large variation in the number of annual strandings should be expected (NMFS, 2003).

Of the 16 strandings *U.S.S. SHOUP* was accused of potentially having caused, seven mammals died prior to *U.S.S. SHOUP* departing the pier at Everett on May 5, 2003. Of these seven, one, discovered on May 5, 2003 was in a state of moderate decomposition indicating it died well before May 5, 2003. Its cause of death was salmonella septicemia and no evidence of acoustic trauma. Another porpoise, discovered at Port Angeles on May 6, 2003, was in a state of moderate decomposition indicating that this porpoise died prior to May 5, 2003. One stranded harbor porpoise discovered fresh at Dungeness on May 6, 2003 is the only animal that could potentially be linked in time to *U.S.S. SHOUP*'s May 5, 2003 active sonar use. Necropsy results for this porpoise found no evidence of acoustic trauma. Both the Port Angeles and Dungeness locations are known common harbor porpoise stranding sites. The remaining eight strandings were discovered one to three weeks after *U.S.S. SHOUP*'s May 5, 2003 Haro Strait transit and, therefore, cannot be causally linked in time. Two of the eight died from blunt trauma injury. A third suffered from parasitic infestation possibly contributing to its death (NMFS, 2003). Of the remaining five, NMFS was unable to identify the causes of death.

As a result of the allegations regarding *U.S.S. SHOUP*, NMFS initiated a necropsy study involving 11 of the stranded animals discovered between May 2 and June 2, 2003. The purposes of these examinations were to provide scientific data on the causes of death and to investigate whether physical evidence could be found to link the stranding events to "naval sonar activity" (NMFS, 2003). The necropsies took place at the National Marine Mammal Laboratory in Seattle.

Findings

- None of the 11 necropsied harbor porpoise showed signs of acoustic trauma (NMFS, 2003).
- One of the animals had fibrinous peritonitis, one had salmonellosis, and another had profound necrotizing pneumonia (Norman et al., 2004).
- Two of the five had perimortem blunt trauma injury with associated broken bones in their head (NMFS, 2003)
- No cause of death could be determined for the remaining six animals, which is consistent with the expected percentage in most marine mammal necropsies from the region (NMFS, 2003).

Conclusions

Examination and test results from 11 of the 15 harbor porpoises did not reveal any definitive signs of acoustic trauma associated with the mid-range active sonar on May 5, 2003 (Norman et al. 2004).

It is noted that this stranding event is quite different from other events in which sonar may have played a role. In contrast to the event in the Bahamas, there were no strandings of live harbor porpoises and animals were recovered sporadically over a period of one month (Norman et al. 2004). In addition, lesions associated with possible trauma from active sonar have not been seen previously in harbor porpoises (Norman et al., 2004).

July 3, 2004, Hanalei Bay, Kauai Stranding Event

The majority of the following information on the stranding event was provided by Dr. Robert Braun, NMFS Pacific Islands Fisheries Science Center in Honolulu, Hawaii. At Hanalei Bay, Kauai on the morning of July 3, 2004, two individuals attending a canoe blessing ceremony noted that as the ceremony began (on time at 7:00 a.m.); melon-headed whales were seen entering the bay (Braun, 2005). They reported that the whales entered across the center of the bay in a "wave" as if they were chasing fish (Braun, 2005). The whales were moving fast, but not at maximum speed.

At 6:45 a.m. on July 3, 2004, approximately 25 nm from Hanalei Bay, active sonar was tested briefly prior to the start of an ASW event; this was about 15 minutes before the whales were observed in Hanalei Bay. At the nominal swim speed for melon-headed whales (5 to 6 knots), the whales had to be within 1.5 to 2 nm of Hanalei Bay before the sonar at PMRF was activated. The whales were not in their open ocean habitat but had to be close to shore at 6:45 a.m. when the sonar was activated, to have been observed inside Hanalei Bay from the beach by 7:00 a.m. (Hanalei Bay is very large area).

The whales stopped in the southwest portion of the bay grouping tightly with lots of spy hopping and tail slapping. As people went in the water among the whales, spy hopping increased and the pod separated into two groups with individual animals moving between the two clusters (Braun, 2005). This continued through most of the day, with the animals slowly moving south and then southeast within the bay (Braun, 2005). By about 3 p.m. police arrived and kept people from interacting with the animals. At 4:45 p.m. on July 3, 2004, the RIMPAC Battle Watch Captain received a call from a NMFS representative in Honolulu, Hawaii, reporting the sighting of as many as 200 melon-headed whales in Hanalei Bay. At 4:47 p.m., out of caution, the Battle Watch Captain directed all ships in the area to cease all active sonar transmissions.

A NMFS representative arrived at Hanalei Bay at 7:20 p.m. on July 3, 2004, and observed a tight single pod 75 yards from the southeast side of the bay (Braun, 2005). The pod was circling in a tight group and there was frequent tail slapping and minimal spy hopping. Occasionally one or two sub-adult sized animals broke from the tight pod and came nearer the shore to apparently chase fish and be in the shore break (Braun, 2005). The pod stayed in the bay through the night of July 3, 2004.

On July 4, 2004, a 700–800-foot rope was constructed by weaving together beach morning glory vines. This vine rope was tied between two canoes and with the assistance of 30 to 40 kayaks, the pod was coaxed out of the bay by about 11:30 a.m. on July 4, 2004 (Braun, 2005).

The following morning on July 5, 2004, a very young melon-headed whale was found stranded dead on the beach at Hanalei. NMFS necropsied the animal to attempt to determine cause of death. Preliminary findings indicated the cause of death was starvation (Farris, 2004) and this was later confirmed upon completion of the NMFS stranding report (Southall et al., 2006).

Findings

- Observers reported the whales entered across the center of the bay in a "wave" as if they were chasing fish (Braun, 2005).
- A simultaneous "stranding" of 500-700 melon headed whales and Risso's dolphins occurred at Sasanhaya Bay, Rota, in the Northern Marianas Islands on the same morning as the Hanalei stranding. A pod of melon-headed whales entered Hilo Bay in the 1870s in a manner similar to the occurrence at Hanalei Bay in July 2004. Therefore, while very rare, the presence of melon headed whales occurring near shore is not unknown.
- There was a full moon, which may affect the behavior and distribution of prey species, and a squid run on the evening before the stranding.
- There was no evidence of unusual harmful algal blooms (NMFS, 2007j).
- A newborn melon-headed whale was found stranded dead on the beach at Hanalei after the whales were coaxed from the bay. Necropsy found the cause of death was starvation

Conclusions

The calculated received level at Hanalei Bay from the sonar at PMRF was approximately 147.5 dB re 1 μPa^2-s at 1 m. Although it is not impossible, it is unlikely that the sound level from the sonar caused the whales to enter the bay. The area between the islands of Oahu and Kauai, and the PMRF training range have been used in past RIMPAC exercises and are used year-round for ASW training using mid-frequency active sonar. Melon-headed whales inhabiting the waters around Kauai are likely not naïve to the sound of sonar and there has never been another stranding event associated in time with ASW training at Kauai or in the Hawaiian Islands.

Marine mammal strandings in Hawaii (approximately two per month) are relatively rare when compared with other locations. Two melon-headed whales stranded at Hauula Beach on Oahu in August, 2003 (Honolulu Advertiser July 6, 2004). A report of a pod entering Hilo Bay in the 1870s indicates that on at least one other occasion, melon-headed whales entered a bay in a manner similar to the occurrence at Hanalei Bay in July 2004. The simultaneous "stranding" of 500-700 melon headed whales and Risso's dolphins at Sasanhaya Bay, Rota, in the Northern Marianas Islands on the same morning as the 2004 Hanalei stranding (Jefferson et al., 2006), suggests melon-headed whales entering shallow embayments may be an infrequent but not extraordinary event.

There are many possible causes for whales appearing in Hanalei Bay (such as following prey as initial reports suggested) and many possible causes for stranding, including sick individual members of a pod. Clearly the starvation death of a newborn whale was not caused by RIMPAC naval operations. There will be no definitive answers to why the whales entered Hanalei Bay on the morning of July 3, 2004. NMFS produced a report on this stranding in April 2006 (Southall et al., 2006). That report concluded that sonar use was a, "plausible, if not likely, contributing factor in what may have been a confluence of events" (Southall et al., 2006). Since that time the primary author has attempted to clarify that the NMFS Hanalei Report, "did not conclude that active military sonar caused this event" (Southall, 2006). The authors of the NMFS report were unaware, at the time of publication, of the simultaneous Rota stranding and had partially based their "plausible, if not likely" finding on the "anomalous nature of the stranding" and "the absence of other compelling causative explanation" (Southall et al., 2006). In light of the simultaneous Rota stranding, the Hanalei stranding is no longer anomalous in nature. In addition, the presence of a full moon on the date of the stranding as subsequently noted by Southall (2006) and the whales having entering Hanalei Bay as if they were chasing fish, it would seem that in retrospect there are other more compelling explanations for why this event occurred, as opposed to a few minutes of sonar use 25 mi to the north as likely being causal.

North Carolina Marine Mammal Mass Stranding Event, January 15-16, 2005

On January 15 and 16, 2005, 36 marine mammals comprised of three separate species (33 short-finned pilot whales, one minke whale, and two dwarf sperm whales) stranded alive on the beaches of North Carolina (NMFS, 2007h; Hohn et al., 2006) distributed over a 111-km area between the northern part of the state down to Cape Hatteras (NMFS, 2007i). Thirty-one different species of marine mammals have been known to strand along the North Carolina coast since 1992; all three of the species involved in this stranding occasionally strand in this area (NMFS, 2007i). This stranding event was determined to be a UME because live strandings of three different species in one weekend in North Carolina is extremely rare; in fact, it is the only stranding of offshore species to occur within a 2-3 day period in the region on record (NMFS, 2007h; Hohn et al., 2006).

The Navy indicated that they were conducting tactical mid-frequency active sonar operations from individual surface vessels over short durations and on a small scale within the general area and time period investigated (NMFS, 2007h); these kinds of transmissions are not unusual for the area or time of year (NMFS, 2007i). Marine mammal observers located on the Navy vessels reported that they did not detect any marine mammals (NMFS, 2007h).

Findings

On January 16 and 17, 2005, two dwarf sperm whales, 27 pilot whales, and the single minke whale were necropsied and sampled. Because of the uniqueness of the stranding, 9 locations of interest within 25 stranded cetacean heads were examined closely. The only common finding in all of the heads was a form of sinusitis (NMFS, 2007h).

- The pilot whales and the dwarf sperm whale were not considered to be emaciated, even though none of them had recently-eaten food in their stomachs (NMFS, 2007h).
- The minke whale was emaciated, and it is believed that this was a dependant calf that got separated from its mother, and was not a part of the other strandings (NMFS, 2007h).
- Most biochemistry abnormalities indicated deteriorating conditions from being on land for an extended amount of time, and are believed to be a result of the stranding itself (NMFS, 2007h).
- Three pilot whales showed signs of pre-existing systemic inflammation (NMFS, 2007h).
- Lesions involving all organ systems were seen, but consistent lesions were not observed across species (NOAA, 2006a; Hohn et al., 2006).
- Cardiovascular disease was present in one pilot whale and one dwarf sperm whale, while musculoskeletal disease was present in two pilot whales (NMFS, 2007h).
- Parasites were found and collected from 26 pilot whales and two dwarf sperm whales; parasite loads were considered to be within normal limits for free-ranging cetaceans (NMFS, 2007h).

- There were no harmful algal blooms present along the coastline during the months prior to the strandings (NMFS, 2007h; Hohn et al., 2006).
- Environmental conditions that are consistent with conditions under which other mass strandings have occurred were present (a gently sloping shore, strong winds, and changes in up-welling to down-welling conditions) (NMFS, 2007h).

Conclusions

Several whales had pre-existing conditions that may have contributed to the stranding, but were not determined to be the cause of the stranding event (Hohn et al., 2006; NMFS, 2007i). The actual cause of death for many of the whales was determined to be a result of the stranding itself (NMFS, 2007i). NMFS concluded that this mass stranding event occurred simultaneously in time and space with active mid-frequency active sonar naval activities, and has several features in common with other possible sonar-related stranding events (NMFS, 2007h). For this reason, along with the rarity of the event, NMFS believes that it is possible that there exists a causal rather than a coincidental association between naval sonar activity and the stranding event (NMFS, 2007h). But they also acknowledge that there are differences in operational and environmental characteristics between this event and other possible sonar-related stranding events (NMFS, 2007h), such as constricted channels (NMFS, 2007i).

Even though the stranding occurred while active military sonar was being utilized off the North Carolina coast, the investigation team was unable to determine what role, if any, military activities played in the stranding events (Hohn et al., 2006). If mid-frequency active sonar played a part in the strandings, sound propagation models indicated that received acoustic levels would depend heavily on the position of the whales relative to the source; however, because the exact location of the cetaceans is unknown it is impossible to estimate the level of their exposure to active sonar transmissions (NMFS, 2007h). Evidence to support a definitive association is lacking, and consistent lesions across species and individuals that could indicate a single cause of the stranding were not found (NMFS, 2007h).

Based on the physical evidence, it cannot be definitively determined if there is a causal link between the strandings and anthropogenic sonar activity and/or environmental conditions, or a combination of both (NMFS, 2007h).

January 26, 2006, Spain

The Spanish Cetacean Society reported an atypical mass stranding of four beaked whales that occurred January 26, 2006, on the southeast coast of Spain, near Mojacar (Gulf of Vera) in the Western Mediterranean Sea. According to the report, two of the whales were discovered the evening of January 26 and were found to be still alive. Two other whales were discovered during the day on January 27, but had already died. A following report stated that the first three animals were located near the town of Mojacar and were examined by a team from the University of Las Palmas de Gran Canarias, with the help of the stranding network of Ecologistas en Acción Almería-PROMAR and others from the Spanish Cetacean Society. The fourth animal was found dead on the afternoon of January 27, a few km north of the first three animals.

From January 25-26, 2006, Standing NATO Response Force Maritime Group Two (five of seven ships including one U.S. ship under NATO OPCON) had conducted active sonar training against a Spanish submarine within 50 nm of the stranding site.

Findings

Veterinary pathologists necropsied the two male and two female beaked whales (*Ziphius cavirostris*, family Ziphiidae).

Conclusions

According to the pathologists, the most likely primary cause of this type of beaked whale mass stranding event is anthropogenic acoustic activities, most probably anti-submarine mid-frequency active sonar used during the military naval exercises. However, no positive acoustic link was established as a direct cause of the stranding.

Even though no causal link can be made between the stranding event and naval exercises, certain conditions may have existed in the exercise area that, in their aggregate, may have contributed to the marine mammal strandings (Freitas, 2004).

- Operations were conducted in areas of at least 1,000 m depth near a shoreline where there is a rapid change in bathymetry on the order of 1,000 – 6,000 m occurring a cross a relatively short horizontal distance (Freitas, 2004).
- Multiple ships (in this instance, five) were operating (in this case, mid-frequency active sonar) in the same area over extended periods of time (in this case, 20 hours) in close proximity.
- Exercises took place in an area surrounded by landmasses, or in an embayment. Operations involving multiple ships employing mid-frequency active sonar near land may produce sound directed towards a channel or embayment that may cut off the lines of egress for marine mammals (Freitas, 2004).

Causal Associations for Stranding Events

Several stranding events have been associated with Navy sonar activities but relatively few of the total stranding events that have been recorded occurred spatially or temporally with Navy sonar activities. While sonar may be a contributing factor under certain rare conditions, the presence of sonar it is not a necessary condition for stranding events to occur.

A review of past stranding events associated with sonar suggest that the potential factors that may contribute to a stranding event are steep bathymetry changes, narrow channels, multiple sonar ships, surface ducting and the presence of beaked whales that may be more susceptible to sonar exposures. The most important factors appear to be the presence of a narrow channel (e.g. Bahamas and Madeira Island, Portugal) that may prevent animals from avoiding sonar exposure and multiple sonar ships within that channel. There are no narrow channels (less than 35 nm wide and 10 nm in length) in the HRC and the ships would be spread out over a wider area allowing animals to move away from sonar activities if they choose. In addition, beaked whales may not be more susceptible to sonar but may favor habitats that are more conducive to sonar effects.

The RIMPAC exercises have been conducted every other year since 1968 in the HRC, and along with other ASW training events have only been implicated in one stranding event which may have been simply animals following prey in to a bay (Braun, 2005; Southall et al., 2006). Given the large military presence and private and commercial vessel traffic in the Hawaiian waters, it is likely that a mass stranding event would be detected. Therefore, it is unlikely that the conditions that may have contributed to past stranding events involving Navy sonar would be present in the HRC.

6.2.11 Estimated Effects Modeling

Modeling of the effects of mid-frequency sonar and underwater detonations was conducted using methods described in brief below. A detailed description of the representative modeling areas, sound sources, model assumptions, acoustic and oceanographic parameters, underwater sound propagation and transmission models, and diving behavior of species modeled are presented in Appendix A.

Acoustic Source Modeling

The approach for estimating potential acoustic effects from HRC ASW training activities on cetacean species makes use of the methodology that was developed in cooperation with NOAA for the Navy's USWEX EA/OEA (DON, 2007), RIMPAC EA/OEA (2006) and Composite Training Unit Exercise/Joint Task Force Exercise (COMPTUEX/JTFEX) EA/OEA (2007), as well as additional cooperative work with NMFS for analyzing behavioral effects to marine mammals. The methodology is provided here to determine the number and species of marine mammals for which incidental take authorization is requested.

In order to estimate acoustic effects from the HRC ASW operations, acoustic sources to be used were examined with regard to their operational characteristics. Systems with acoustic source levels below 205 dB re 1 µPa @ 1 m were not included in the analysis given that at this source level or below, a 1-second ping would attenuate below 175 dB received level within a distance of about 1,000 yards (yd), which is the Navy's current sonar mitigation safety zone. As additional verification, sources at this level were examined typically using simple spreadsheet calculations to ensure that they did not need to be considered further. For example, a sonobuoy's typical use yielded an exposure area that produced 0 marine mammal exposures based on the maximum marine mammal density. Such a source was designated non-problematic and was not modeled in the sense of running its parameters through the environmental model (CASS), generating an acoustic footprint, etc.

In addition, systems with an operating frequency greater than 100 kHz were not analyzed in the detailed modeling as these signals attenuate rapidly (due to the frequency) resulting in very short propagation distances for a received level exceeding the acoustic thresholds of concern.

Based on the information above, only hull-mounted mid-frequency active tactical sonar, Directional Command Activated Sonobuoy System (DICASS) sonobuoy, MK 48 torpedo, and AN/AQS 22 (dipping sonar) were determined to have the potential to affect marine mammals protected under the MMPA and ESA during HRC ASW training events.

For modeling purposes, sonar parameters (source levels, ping length, the interval between pings, output frequencies, etc.) were based on records from training events, previous exercises, and preferred ASW tactical doctrine to reflect the sonar use expected to occur during events in the HRC. The actual sonar parameters such as output settings, distance between ASW surface, subsurface, and aerial units, their deployment patterns, and the coordinated ASW movement (speed and maneuvers) across the exercise area are classified, however, modeling used to calculate exposures to marine mammals employed actual and preferred parameters to which the participants are trained and have in the past, used during ASW events in the HRC.

For discussion purposes surface ship sonars can be considered as having the nominal source level of 235 decibels (dB) re 1 μPa^2-s @ 1 m, transmitting a 1 second omnidirectional ping at center frequencies of 2.6 kHz and 3.3 kHz, with 30 seconds between pings.

Every active sonar operation includes the potential to harass marine animals in the vicinity of the source. The number of animals exposed to potential harassment 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).

Modeling Physiological Effects

For the HRC, the relevant measure of potential physiological effects to marine mammals due to sonar training is the accumulated (summed over all source emissions) energy flux density level received by the animal over the duration of the activity.

The modeling for estimating received energy flux density level from surface ship active tactical sonar occurred in five broad steps, listed below. Results were calculated based on the typical ASW activities planned for the HRC. Acoustic propagation and mammal population data are analyzed for both the summer (May to October) and winter (November to April) timeframe. Marine mammal survey data for the offshore area beyond 25 nm (Barlow, 2006) and survey data for nearshore areas within 25 nm (Mobley et al., 2000) provided marine mammal species density for modeling.

- **Step 1**. Environmental Provinces. The HRC operating area is divided into six marine modeling areas, and each has a unique combination of environmental conditions. 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 HRC operating areas. 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 eight environments, separate transmission loss calculations must be made for each, in both seasons. The transmission loss is predicted using Comprehensive Acoustic System Simulation 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. Repeating this calculation for each environment in each season gives the hourly ensonified volume, by depth, for each environment and season.
- **Step 4**. Marine Mammal Densities. The marine mammal densities were given in two dimensions, but using sources such as the North Pacific Acoustic Laboratory EIS, the depth regimes of these marine mammals are used to project the two dimensional densities into three dimensions.

- **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 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. Calculated exposures above 0.5 were counted as one exposure.

The movement of various units during an ASW event is largely unconstrained and dependent on the developing tactical situation presented to the commander of the forces.

Only when all exposures for all training is summed for the year does the model indicate the potential for exposure in excess of 215 dB re 1 μPa^2-s. This summation for the year results in 0.66 of an exposure (rounded up to one (1)) counting as one incident of exposure for humpback whale and 0.53 of an exposure counted as one exposure for striped dolphin. However, the likelihood of exposures above the thresholds for Level A harassment is considered highly improbable. In addition, mitigation measures that will be implemented during the proposed activities would reduce the potential for these two Level A exposures to occur.

Modeling Behavioral Effects

For the HRC, the relevant measure of potential behavioral disturbance effects to marine mammals due to sonar training is the maximum sound pressure level (SPL) received by the animal over the duration of the activity (or over each day).

The modeling for estimating received energy flux density from surface ship active tactical sonar is analogous to the modeling for energy flux density level, discussed above. However, the SPL metric yields the maximum SPL (and not the sum of energies).

Results were calculated based on the typical ASW activities planned for the HRC. Acoustic propagation and mammal population data are analyzed for both the summer (May to October) and winter (November to April) timeframe. Marine mammal survey data for the offshore area beyond 25 nm (Barlow, 2006) and survey data for nearshore areas within 25 nm (Mobley et al., 2004) provided marine mammal species density for modeling (see Appendix A, Table A-52).

Explosive Source Modeling

Explosive Source Criteria

The criterion for mortality for marine mammals used in the *CHURCHILL FEIS* (DON, 2001) is "onset of severe lung injury." This is conservative in that it corresponds to a 1 percent chance of mortal injury, and yet any animal experiencing onset severe lung injury is counted as a lethal exposure.

- The threshold is stated in terms of the Goertner (1982) modified positive impulse with value "indexed to 31 psi-ms.'" Since the Goertner approach depends on propagation, source/animal depths, and animal mass in a complex way, the actual impulse value corresponding to the 31-psi-ms index is a complicated calculation. Again, to be conservative, *CHURCHILL* used the mass of a calf dolphin (at 12.2 kg), so that the threshold index is 30.5 psi-ms (Table 6-5).

Table 6-5. Effects Analysis Criteria for Underwater Detonations for Explosives < 2000 lbs Net Explosive Weight

	Criterion	Threshold
Mortality	Onset of Severe Lung Injury	Goertner Modified Positive Impulse Indexed to 31 psi-ms
Level A Harassment Injury	Tympanic membrane rupture Onset of slight lung injury	50% rate of rupture; 205 dB re 1 μPa^2-s (Energy Flux Density) Goertner Modified Positive Impulse Indexed to 13 psi-ms
Level B Harassment Non-Injury	Onset Temporary Threshold Shift	182 dB re 1 μPa^2-s (Energy Flux Density) in any 1/3-octave band at frequencies above 100 Hz for all toothed whales (e.g. sperm whales, beaked whales); above 10 Hz for all baleen whales
Level B Harassment Non-Injury	Onset Temporary Threshold Shift	23 psi peak pressure level (for small explosives)

Source: Based on CHURCHILL FEIS (DON, 2001) and Eglin Air Force Base IHA (NMFS, 2005h) and LOA (NMFS, 2006b)

Two criteria are used for injury: onset of slight lung hemorrhage and 50 percent eardrum rupture (tympanic membrane [TM] rupture). These criteria are considered indicative of the onset of injury (Table 6-5).

- The threshold for onset of slight lung injury is calculated for a small animal (a dolphin calf weighing 27 lb), and is given in terms of the "Goertner modified positive impulse," indexed to 13 psi-ms in the (DON, 2001a). This threshold is conservative since the positive impulse needed to cause injury is proportional to animal mass, and therefore, larger animals require a higher impulse to cause the onset of injury.
- The threshold for TM rupture corresponds to a 50 percent rate of rupture (i.e., 50 percent of animals exposed to the level are expected to suffer TM rupture); this is stated in terms of an EL value of 205 dB re 1 μPa^2-s. The criterion reflects the fact that TM rupture is not necessarily a serious or life-threatening injury, but is a useful index of possible injury that is well correlated with measures of permanent hearing impairment (e.g., Ketten, 1998 indicates a 30 percent incidence of permanent threshold shift [PTS] at the same threshold).

Two criteria are considered for non-injurious harassment temporary threshold shift (TTS), which is a temporary, recoverable, loss of hearing sensitivity (NMFS, 2001; DON, 2001a).

- The first criterion for TTS is 182 dB re 1 μPa^2-s maximum EL level in any 1/3-octave band at frequencies.
- A second criterion for estimating TTS threshold has also been developed. A threshold of 12 pounds per square inch (psi) peak pressure was developed for 10,000 pound charges as part of the *CHURCHILL Final EIS* (DON, 2001a, [FR70/160, 19 Aug 05; FR 71/226, 24 Nov 06]). It was introduced to provide a more conservative safety zone for TTS when the explosive or the animal approaches the sea surface (for which case the explosive energy is reduced but the peak pressure is not). Navy policy is to use a 23 psi criterion for explosive charges less than 2,000 lb and the 12 psi criterion for explosive charges

larger than 2,000 lb. This is below the level of onset of TTS for an odontocete (Finneran et al., 2002), All explosives modeled for the HRC EIS are less than 1,500 lbs.

Explosive Source and Live Fire Procedures

As part of the official Navy clearance procedure before an underwater detonation or live fire exercise, the target area must be inspected visually (from vessels and available aircraft) and determined to be clear. The required clearance zone at the target areas, and operations within controlled ranges, minimizes the risk to marine mammals. Open ocean clearance procedures are the same for live or inert ordnance. Whenever ships and aircraft use the ranges for missile and gunnery practice, the weapons are used under controlled circumstances involving clearance procedures to ensure cetaceans, pinnipeds, or sea turtles are not present in the target area. These involve, at a minimum, a detailed visual search of the target area by aircraft reconnaissance, range safety boats, and range controllers and passive acoustic monitoring.

Ordnance cannot be released until the target area is determined clear. Operations are immediately halted if cetaceans, pinnipeds, or sea turtles are observed within the target area. Operations are delayed until the animal clears the target area. All observers are in continuous communication in order to have the capability to immediately stop the operations. The operation can be modified as necessary to obtain a clear target area. If the area cannot be cleared, the event is canceled. All of these factors serve to avoid the risk of harming cetaceans, pinnipeds, or sea turtles. Post event monitoring of underwater detonation locations have not observed any injured marine species.

The weapons used in most missile and live fire exercises pose little risk to marine mammals unless they were to be near the surface at the point of impact. Machine guns (0.50 caliber), 5-in guns, 76mm guns, and close-in weapons systems (anti missile systems) exclusively fire non-explosive ammunition. The same applies to larger weapons firing inert ordnance for training operations. The rounds pose an extremely low risk of a direct hit and potential to directly affect a marine species. Target area clearance procedures would again reduce this risk.

A sinking exercise (SINKEX) uses a variety of live fire weapons; many of these are guided "smart" weapons. The intention is for the ordnance to hit the target vessel and not the water. Target area clearance procedures would again reduce this risk. Modeling results of the potential exposures of marine mammals to underwater sound from a SINKEX is included in the summary presented in Section 6.3.2 (Table 6-10).

The Navy has developed a mitigation plan to maximize the probability of sighting any ships or protected species in the vicinity of an operation. In order to minimize the likelihood of taking any threatened or endangered species that may be in the area, the following monitoring plan would be adhered to:

- All weapons firing would be conducted during the period 1 hour after official sunrise to 30 minutes before official sunset.
- Extensive range clearance operations would be conducted in the hours prior to commencement of the operation, ensuring that no shipping is located within the hazard range of the longest-range weapon being fired for that event.
- An exclusion zone with a radius of 1 nm would be established around each target. This exclusion zone is based on calculations using a 990 lb net explosive weight high explosive source detonated 5 feet below the surface of the water, which yields a distance

of 0.85 nm (cold season) and 0.89 nm (warm season) beyond which the received level is below the 182 dB re: 1 µPa^2-s threshold established for the *WINSTON S. CHURCHILL* (DDG 81) shock trials. An additional buffer of 0.5 nm would be added to account for errors, target drift, and animal movements. Additionally, a safety zone, which extends from the exclusion zone at 1 nm out an additional 0.5 nm, would be surveyed. Together, the zones extend out 2 nm from the target.

A series of surveillance over-flights would be conducted within the exclusion and the safety zones, prior to and during the operation, when feasible. Survey protocol would be as follows:

- All visual surveillance operations would be conducted by Navy personnel trained in visual surveillance. In addition to the over flights, the exclusion zone would be monitored by passive acoustic means, when assets are available.
- If a protected species observed within the exclusion zone is diving, firing would be delayed until the animal is re-sighted outside the exclusion zone, or 30 minutes has elapsed. After 30 minutes, if the animal has not been re-sighted it would be assumed to have left the exclusion zone. This is based on a typical dive time of 30 minutes for traveling listed species of concern. The officer-in-charge of the exercise (OCE) would determine if the ESA listed species is in danger of being adversely affected by commencement of the operation.

6.3 Estimated Effects on Marine Mammals

This section includes summary tables for sonar and underwater detonation exposures. Table 6-6 and 6-9 (in Section 6.3.2) represent the total number of Level A and Level B harassments without mitigation measures. Note that Table 6-6 sums the Level B harassment authorization requested based on the dose function and the 195 dB onset TTS threshold is based on energy flux density level. Only species expected to be present in the HRC were evaluated for this LOA request.

When analyzing the results of the acoustic exposure modeling to provide an estimate of effects, it is important to understand that there are limitations to the ecological data used in the model, and that the model results must be interpreted within the context of a given species' ecology. When reviewing the acoustic effects modeling results, it is also important to understand that the estimates of marine mammal sound exposures are presented without consideration of standard mitigation operating procedures or the fact that there have been no confirmed acoustic effects on any marine species in previous HRC exercises or from any other mid-frequency active sonar training events within the HRC.

All Level B harassment would be short term and temporary in nature. In addition, the short-term non- injurious exposures predicted to cause TTS or temporary behavioral disruptions are considered Level B harassment in this LOA even though it is highly unlikely that the disturbance would be to a point where behavioral patterns are abandoned or significantly altered. The modeling for HRC analyzed the potential interaction of mid-frequency active tactical sonar and underwater detonations with marine mammals that occur in the HRC.

The annual estimated number of exposures for mid-frequency active sonar and underwater detonations (mine neutralization, Missile exercise (MISSILEX), bombing exercise (BOMBEX), and gunnery exercise (GUNEX)) are given for each species. The modeled exposure is the probability of a response that NMFS would classify as harassment under the MMPA. These exposures are calculated for all activities modeled and represent the total exposures per year and are not based on a per day basis.

Due to wind and swell conditions in Hawaii and the cryptic nature of some marine mammal species, detection of marine mammals during training events can be challenging. A detailed description of the mitigation measures for mid-frequency sonar and underwater detonation activities are presented in Sections 11.1 and 11.2.

6.3.1 Sonar Exposure Summary

Behavioral effects modeling for mid-frequency active sonar using the dose function methodology predicts 63,468 annual acoustic exposures that result in behavioral harassment. The modeling also indicates between 1,788 annual exposures that exceed the TTS threshold. The summary of modeled sonar exposure harassment numbers by species are presented in Table 6-6 and represent potential harassment without implementation of mitigation measures.

For each of the 5 types of exercises marine mammals are exposed to mid -frequency sonar from several sources. Table 6-7 provides the number of exposures modeled based on dose function, the TTS threshold (195 dB), and the PTS threshold (215 dB). The values given for dose function and TTS are further subdivided based on the type of sonar. For PTS, the numbers are so small that only the total values are given. Each source is modeled separately and then the exposures are summed to get the number of exposures requested in this LOA. This is a conservative approach in that if the more powerful 53C sonar overlaps one of the other sonars then the lesser sonar would not actually produce an exposure. However, for modeling purposes all sonar exposures were counted.

Table 6-6. Summary of Level A and B Exposures from All ASW Sonar

Species	Level B Sonar Exposures		Level A Sonar Exposures
	Dose Function	TTS 195-215 dB re 1 μPa^2-s	PTS >215 dB re 1 μPa^2-s
ESA Species			
Blue whale	N/A	N/A	N/A
Fin whale	82	5	0
Humpback whale	34,797	482	1
North Pacific right whale	N/A	N/A	N/A
Sei whale	82	5	0
Sperm whale	1,154	35	0
Hawaiian monk seal	570	9	0
Mysticetes			
Bryde's whale	273	3	0
Minke whale	N/A	N/A	N/A
Odontocetes			
Blainville's beaked whale	613	23	0
Bottlenose dolphin	1,348	67	0
Cuvier's beaked whale	1,593	20	0
Dwarf sperm whale	2,565	134	0
False killer whale	82	5	0
Fraser's dolphin	1,556	81	0
Killer whale	82	5	0
Longman's beaked whale	176	6	0
Melon-headed whale	1,015	52	0
Pantropical spotted dolphin	4,184	196	0
Pygmy killer whale	328	19	0
Pygmy sperm whale	1,048	55	0
Risso's dolphin	846	44	0
Rough-toothed dolphin	1,348	70	0
Short-finned pilot whale	3,046	157	0
Spinner dolphin	524	27	0
Striped dolphin	6,106	287	1
Unidentified beaked whale	51	1	0
Pinnipeds			
Northern elephant seal	N/A	N/A	N/A
Total	63,468	1,788	2

N/A The species was not modeled because the abundance and density are not known

Table 6-7. Sonar Exposures by Exercise Type and Sonar Source Type

Exercise	Source	Modeled	PTS (Total for Humpback & Striped Dolphin)	TTS	Dose Function
TRACKEX	53C	1,592 hours		504	15952
	Dipping	1,061 dips		0.0003	18
	Sonobuoy	NA		NA	NA
	MK-48	NA		NA	NA
		Total	0.31	504	15,970
TORPEX	**Source**	**Modeled**	**PTS**	**TTS**	**Dose Function**
	53C	1,064 hours		132	4302
	Dipping	673 dips		NA	NA
	Sonobuoy	959 buoys		0.0001	8
	MK-48	8 runs		22	392
		Total	0.09	154	4,702
RIMPAC (2 Carrier)					
	Source	**Modeled**	**PTS**	**TTS**	**Dose Function**
	53C	1,064 hours		274	5330
	Dipping	673 dips		0.03	14
	Sonobuoy	959 buoys		0.0002	8
	MK-48	8 runs		0.2	1
		Total	0.11	274	5,353
USWEX (6 exercises)					
	Source	**Modeled**	**PTS**	**TTS**	**Dose Function**
	53C	1,167 hours		556	25901
	Dipping	577 dips		0.05	30
	Sonobuoy	767 buoys		0.0003	27
	MK-48	NA		NA	NA
		Total	0.47	556	25,958
Multiple Strike Group					
	Source	**Modeled**	**PTS**	**TTS**	**Dose Function**
	53C	945 hours		298	11463
	Dipping	240 dips		0.01	11
	Sonobuoy	326 buoys		0	6
	MK-48	NA		NA	NA
		Total	0.19	297	11,480

The number of hours of sonar (or number of dips, number of sonobuoys, or number of MK-48 torpedoes) within each of the six modeling areas was determined for each type of exercise. Table 6-8 provides the percentage breakdown for each exercise type within each of the six modeling areas.

Table 6-8. Percentage of Sonar Modeling by Area and Time of Year by Exercise Type

	Percentage of Sonar Modeled Within Each Modeling Area						**Time of Year**	
Exercise Type	1	2	3	4	5	6	Summer	Winter
TRACKEX	45%	15%	5%	1%	19%	15%	60%	40%
TORPEX	95%	3%	0%	0%	2%	0%	60%	40%
RIMPAC	2%	53%	14%	3%	8%	20%	100%	0%
USWEX	8%	8%	8%	27%	4%	45%	50%	50%
3 Carrier	15%	3%	0%	2%	40%	40%	0%	100%

It is highly unlikely that a marine mammal would experience any long-term effects because the large HRC training areas makes individual mammals' repeated and/or prolonged exposures to high-level sonar signals unlikely. Specifically, mid-frequency active sonars have limited marine mammal exposure ranges and relatively high platform speeds. The number of exposures that exceed the PTS threshold and result in Level A harassment from sonar is two (one for humpback whale and one for striped dolphin). Therefore, long term effects on individuals, populations or stocks are unlikely.

When analyzing the results of the acoustic exposure modeling to provide an estimate of effects, it is important to understand that there are limitations to the ecological data (diving behavior, migration or movement patterns and population dynamics) used in the model, and that the model results must be interpreted within the context of a given species' ecology.

When reviewing the acoustic exposure modeling results, it is also important to understand that the estimates of marine mammal sound exposures are presented without consideration of mitigation measures. Section 11.1 presents details of the mitigation measures currently used for ASW activities including detection of marine mammals and power down procedures if marine mammals are detected within one of the safety zones. The Navy will work through the MMPA incidental harassment regulatory process to discuss the mitigation measures and their potential to reduce the likelihood for incidental harassment of marine mammals.

As described previously, this authorization request assumes that short-term non-injurious sound exposure levels predicted to cause TTS or temporary behavioral disruptions qualify as Level B harassment. This approach is overestimating because there is no established scientific correlation between mid-frequency active sonar use and long term abandonment or significant alteration of behavioral patterns in marine mammals.

Because of the time delay between pings, and platform speed, an animal encountering the sonar will accumulate energy for only a few sonar pings over the course of a few minutes. Therefore, exposure to sonar would be a short-term event, minimizing any single animal's exposure to sound levels approaching the harassment thresholds.

6.3.2 Explosive Exposure Summary

The modeled exposure harassment numbers for all training operations involving explosives are presented by species in Table 6-9. The modeling indicates 61 annual exposures to pressure from underwater detonations that could result in TTS (Level B Harassment). The modeling indicates no exposures from pressure from underwater detonations that could cause injury.

Table 6-9. Summary of Level A and Level B Exposures from Underwater Detonations

Species	Level B Exposures		Level A Exposures
	TTS 182 dB/23 psi	50% TM Rupture 203 dB Slight Lung Injury 23 dB-ms	Onset Massive Lung Injury 31dB-ms
ESA Species			
Blue whale	N/A	N/A	N/A
Fin whale	0	0	0
Humpback whale	15	0	0
North Pacific right whale	N/A	N/A	N/A
Sei whale	0	0	0
Sperm whale	5	0	0
Hawaiian monk seal	0	0	0
Mysticetes			
Bryde's whale	0	0	0
Minke whale	N/A	N/A	N/A
Odontocetes			
Blainville's beaked whale	2	0	0
Bottlenose dolphin	0	0	0
Cuvier's beaked whale	10	0	0
Dwarf sperm whale	9	0	0
False killer whale	0	0	0
Fraser's dolphin	4	0	0
Killer whale	0	0	0
Longman's beaked whale	0	0	0
Melon-headed whale	0	0	0
Pantropical spotted dolphin	2	0	0
Pygmy killer whale	0	0	0
Pygmy sperm whale	4	0	0
Risso's dolphin	0	0	0
Rough-toothed dolphin	3	0	0
Short-finned pilot whale	2	0	0
Spinner dolphin	2	0	0
Striped dolphin	3	0	0
Unidentified beaked whale	0	0	0
Pinnipeds			
Northern elephant seal	N/A	N/A	N/A
Total	61	0	0

N/A The species was not modeled because the abundance and density are not known

Training operations involving explosives include Mine Neutralization, Air to Surface Missile Exercise, Surface to Surface Missile Exercise, Bombing Exercise, Sinking Exercise, Surface to Surface Gunnery exercise, and Naval Surface Fire Support. In a SINKEX, weapons are typically fired in order of decreasing range from the source with weapons fired until the target is sunk. Since the target may sink at any time during the exercise, the actual number of weapons used can vary widely. In the representative case, however, all of the ordnances are assumed expended; this represents the worst case of maximum exposure. The sequence of weapons firing for the representative SINKEX is described in Appendix A, Table A-8. Guided weapons are nearly 100 percent accurate and are modeled as hitting the target (that is, no underwater acoustic effect) in all but two cases: (1) the Maverick is modeled as a miss to represent the occasional miss, and (2) the MK-48 torpedo intentionally detonates in the water column immediately below the hull of the target. Unguided weapons are more frequently off-target and are modeled according to the statistical hit/miss ratios. Note that these hit/miss ratios are artificially low in order to demonstrate a worst-case scenario; they should not be taken as indicative of weapon or platform reliability.

For all other training operations each explosive round is modeled individually and all rounds are assumed to enter the water and detonate. The explosive source, and number of rounds modeled for each training operation involving explosives is provided in Table 6-10. The total number of exposures for each type of training operation is also provided. As noted previously there are no Level B exposures that reach the threshold of 50% TM Rupture (203 dB) or Slight Lung Injury (23 dB-ms) and there are no Level A exposures.

Table 6-10. Explosive Source Exposures

Training Operation	Explosive Source	Location	Number of Rounds	Exposures (TTS 182 dB, 23 psi)
Mine Neutralization	1 to 20-lb Demolition charge	Puuloa Underwater Range, Lima Landing, Naval Inactive Ship Maintenance Facility, Open Ocean Areas	68	1
Air to Surface Missile Exercise	Penguin Maverick	Warning Area W-188	50	0
Surface to Surface Missile Exercise	Harpoon	Warning Area W-188	75	0
Bombing Exercise	Mk82, Mk83, Mk84	PMRF, Hawaii Offshore	38	29
Sinking Exercise	Multiple sources as described below	PMRF, Hawaii Offshore	6	21
Surface to Surface Gunnery Exercise	5 inch round, 76 mm round	Warning Areas W-188, W-191, 192, 193, 194, 196, and Mela South	3,822	9
Naval Surface Fire Support	5 inch round	W-188	644	1

These exposure modeling results are estimates of marine mammal underwater detonation sound exposures without consideration of standard mitigation and monitoring procedures. The implementation of the mitigation and monitoring procedures presented in Section 11.2 will minimize the potential for marine mammal exposure and harassment through range clearance procedures. The Navy will work through the MMPA incidental harassment regulatory process to discuss the mitigation and monitoring measures and their potential to reduce the likelihood for injury and incidental harassment of marine mammals.

6.3.3 Assessment of Marine Mammal Response to Acoustic Exposures

Section 6.2.1 presented the concept that potential effects of sound include both physiological effects and behavioral effects. Section 6.2.4 and 6.2.7 provide information on how physiological effects and behavioral responses are considered in development of acoustic modeling.

Acoustic exposures are evaluated based on their potential direct effects on marine mammals, and these effects are then assessed in the context of the species biology and ecology to determine if there is a mode of action that may result in the acoustic exposure warranting consideration as a harassment level effect. A large body of research on terrestrial animal and human response to airborne sound exists, but results from those studies are not readily extendible to the development of effect criteria and thresholds for marine mammals. For example, “annoyance” is one of several criteria used to define impact to humans from exposure to industrial sound sources. Comparable criteria cannot be developed for marine mammals because there is no acceptable method for determining whether a non-verbal animal is annoyed. Further, differences in hearing thresholds, dynamic range of the ear, and the typical exposure patterns of interest (e.g., human data tend to focus on 8-hour-long exposures) make extrapolation of human sound exposure standards inappropriate. Behavioral observations of marine mammals exposed to anthropogenic sound sources exist, however, there are few observations and no controlled measurements of behavioral disruption of cetaceans caused by sound sources with frequencies, waveforms, durations, and repetition rates comparable to those employed by the tactical sonars to be used in the HRC. At the present time there is no consensus on how to account for behavioral effects on marine mammals exposed to continuous-type sounds (NRC, 2003).

This application uses behavioral observations of trained cetaceans exposed to intense underwater sound under controlled circumstances to develop a criterion and threshold for behavioral effects of sound. These data are described in detail in Schlundt et al. (2000) and Finneran and Schlundt (2004). These data, because they are based on controlled, tonal sound exposures within the tactical sonar frequency range, are the most applicable.

When analyzing the results of the acoustic effect modeling to provide an estimate of harassment, it is important to understand that there are limitations to the ecological data used in the model, and to interpret the model results within the context of a given species’ ecology.

Limitations in the model include:

- Density estimates (May be limited in duration and time of year and are modeled to derive density estimates).
- When reviewing the acoustic effect modeling results, it is also important to understand that the estimates of marine mammal sound exposures are presented without

consideration of mitigation which may reduce the potential for estimated sound exposures to occur.

- Overlap of TTS and dose function.

Potential Injury

As described previously, with respect to the acoustic model, the model inputs included the lowest sound level at which a response might occur. For example, the model considered the potential of onset of PTS in estimating exposures that might result in permanent tissue damage. Other effects postulated as permanent damage to marine mammal tissues also are considered in evaluating the potential for the estimated acoustic exposures to actually result in tissue damage. Resonance, rectified diffusion and decompression sickness were describe above the arguments for and against were presented with the conclusion that these effects are unlikely to occur.

Behavioral Disturbance

TTS used as an onset of physiological response but not at the level of injury. This response is easily measured in a laboratory situation but is difficult to predict in free ranging animals expose to sound. Because it is an involuntary response, it is easier to predict than behavioral responses. The dose function methodology considers other exposures which may include a variety of modes of action that could result in behavioral responses.

Limited information from literature on the proximal responses specific to mid-frequency active sonar and marine mammals require the use of information from other species and from other types of acoustic sources to build a conceptual model for considering issues such as allostatic loading, spatial disorientation, impaired navigation and disrupted life history events, disrupted communication, or increased energy costs. The dose function methodology assumes a range of responses from very low levels of exposure for certain individuals (with some individuals being more reactive then others depending on the situation – i.e., foraging, breeding, migrating), with increasing probability of response as the received sound level increases. The result is estimate of probability that the range of physiological and behavioral responses that might occur are accounted for in determining the number of harassment incidents. The predicted responses using the dose function and TTS methodology are conservatively estimated to result in the disruption of natural behavioral patterns although it is assumed that such behavioral patterns are not abandoned or significantly altered.

No Harassment

Although a marine mammal may be exposed to mid-frequency active sonar, it may not respond or may only show a mild response, which may not rise to the level of harassment. In using the dose function it is assumed that the response of animals is variable, depending on their activity, gender or age, and that higher sound levels would elicit a greater response. Each exposure, using the Dose Function methodology, represents the probability of a response that NMFS would classify as harassment under the MMPA. The ESA listed species that may be exposed to mid-frequency active sonar in the HRC include the blue whale, fin whale, humpback whale, sei whale, sperm whale, and Hawaiian monk seal. The exposure modeling was completed using the same methodology as that for non-ESA listed species. A different analytical framework will be used to discuss potential exposure and affects to ESA-listed species because the ESA consultation process is interested in population level effects (severely depleted or endangered populations) rather than stocks or species effects.

Marine Mammals

The best scientific information on the status, abundance and distribution, behavior and ecology, diving behavior and acoustic abilities are provided for each species expected to be found within the HRC (Sections 4.1 and 4.2). Information was reviewed on the response of marine mammals to other sound sources such as seismic air guns or ships but these sources tend to be longer in the period of exposure or continuous in nature. The response of marine mammals to those sounds, and mid-frequency active sonar, are variable with some animals showing no response or moving toward the sound source while others may move away (Review by Richardson et al. 1995; Andre et al. 1997; Nowacek et al. 2004). The analytical framework shows the range of physiological and behavioral responses that can occur when an animal is exposed to an acoustic source. Physiological effects include auditory trauma (TTS, PTS, and tympanic membrane rupture), stress or changes in health and bubble formation or decompression sickness. Behavioral responses may occur due to stress in response to the sound exposure. Behavioral responses may include flight response, changes in diving, foraging or reproductive behavior, changes in vocalizations (may cease or increase intensity), changes in migration or movement patterns or the use of certain habitats. Whether an animal responds, the types of behavioral changes, and the magnitude of those changes may depend on the intensity level of the exposure and the individual animal's prior status or behavior. Little information is available to determine the response of animals to mid-frequency active sonar and its effects on ultimate and proximate life functions or at the population or species level.

6.3.4 Estimated Effects on ESA Species

The endangered species that may be affected as a result of implementation of the HRC activities include the blue whale (*Balaenoptera musculus*), fin whale (*Balaenoptera physalus*), humpback whale (*Megaptera novaeangliae*), north Pacific right whale (*Eubalaena japonica*), sei whale (*Balaenoptera borealis*), sperm whale (*Physeter macrocephalus*) and Hawaiian monk seal (*Monachus schauinslandi*).

Blue Whale (*Balaenoptera musculus*)

There is no density information available for blue whales in Hawaiian waters given they have not been seen during any surveys. Given they are so few in number, it is unlikely that HRC mid-frequency active sonar training events will result in the exposure of any blue whales to accumulated acoustic energy in excess of any energy flux threshold or a SPL in excess of 145 dB. No blue whales would be exposed to impulsive sound or pressures from underwater detonations that would cause TTS or physical injury.

Given the large size (up to 98 ft [30 m]) of individual blue whales (Leatherwood et al., 1982), pronounced vertical blow, and aggregation of approximately two to three animals in a group (probability of track line detection = 0.90 in Beaufort Sea States of 6 or less; Barlow 2003), it is very likely that lookouts would detect a group of blue whales at the surface. Additionally, mitigation measures call for continuous visual observation during operations with active sonar; therefore, blue whales that migrate into the operating area would be detected by visual observers. Implementation of mitigation measures and probability of detecting a large blue whale reduces the likelihood of exposure, such that effects would be discountable.

In the unlikely event that blue whales are exposed to mid-frequency sonar, the anatomical information available on blue whales suggests that they are not likely to hear mid-frequency (1 kHz–10 kHz) sounds (Ketten, 1997). There are no audiograms of baleen whales, but blue whales tend to react to anthropogenic sound below 1 kHz (e.g., seismic air guns), and most of their vocalizations are also in that range, suggesting that they are more sensitive to low frequency sounds (Richardson et al., 1995; Croll, 2002). Based on this information, if they do no hear these sounds, they are not likely to respond physiologically or behaviorally to those received levels.

Based on the model results, behavioral patterns, acoustic abilities of blue whales, results of past training exercises, and the implementation of mitigation measures presented in sections 11.1 for sonar and 11.2 for underwater detonations, the Navy finds that the HRC training events would not likely result in any harassment to blue whales.

Fin Whale (*Balaenoptera physalus*)

There is no density information for fin whales in the Hawaiian Islands (Barlow, 2006). For purposes of acoustic effects analysis estimates, it was assumed that the number and density of fin whales did not exceed that of false killer whales and the modeled number of exposures for both species would therefore be the same.

The modeling results for behavioral effects were calculated using the dose-function methodology documented in Section 6.2.5. Combining all non-explosive sources, the annual number of fin whales predicted to be behaviorally harassed from testing and training in the HRC is 82 (Table 6-6).

Modeling also indicates, there would be 5 exposures to accumulated acoustic energy between 195 dB and 215 dB re 1 μPa^2-s, which is the threshold established indicative of onset TTS. Modeling indicates no exposures for fin whales to accumulated acoustic energy above 215 dB re 1 μPa^2-s, which is the threshold indicative of onset PTS. No fin whales would be exposed to impulsive sound or pressures from underwater detonations that would cause TTS or physical injury (Table 6-9).

Given the large size (up to 78 ft [24m]) of individual fin whales (Leatherwood et al., 1982), pronounced vertical blow, mean aggregation of three animals in a group (probability of trackline detection = 0.90 in Beaufort Sea States of 6 or less; Barlow, 2003) it is very likely that lookouts would detect a group of fin whales at the surface. Additionally, mitigation measures call for continuous visual observation during operations with active sonar, therefore, fin whales in the vicinity of operations would be detected by visual observers. Implementation of mitigation measures and probability of detecting a large fin whale reduces the likelihood of exposure, such that effects would be discountable.

In the unlikely event that fin whales are exposed to mid-frequency sonar, the anatomical information available on fin whales suggests that they are not likely to hear mid-frequency (1 kHz–10 kHz) sounds (Richardson et al., 1995; Ketten, 1997). Fin whales primarily produce low frequency calls (below 1 kHz) with source levels up to 186 dB re 1µPa at 1 m, although it is possible they produce some sounds in the range of 1.5 to 28 kHz (review by Richardson et al., 1995; Croll et al. 2002). There are no audiograms of baleen whales, but they tend to react to anthropogenic sound below 1 kHz, suggesting that they are more sensitive to low frequency sounds (Richardson et al., 1995). Based on this information, if they do no hear these sounds, they are not likely to respond physiologically or behaviorally to those received levels.

In the St. Lawrence estuary area, fin whales avoided vessels with small changes in travel direction, speed and dive duration, and slow approaches by boats usually caused little response (MacFarlane, 1981). Fin whales continued to vocalize in the presence of boat sound (Edds and Macfarlane, 1987). Even though any undetected fin whales transiting the HRC may exhibit a reaction when initially exposed to active acoustic energy, field observations indicate the effects would not cause disruption of natural behavioral patterns to a point where such behavioral patterns would be abandoned or significantly altered.

Based on the model results, behavioral patterns, acoustic abilities of fin whales, results of past HRC training, and the implementation of procedure mitigation measures presented in sections 11.1 for sonar and 11.2 for underwater detonations, the Navy finds that the HRC training events would likely not result in any death or injury to fin whales, but some Level B behavioral harassment may occur.

An ESA consultation is ongoing, and includes the finding that the proposed ASW exercises may affect fin whales. Should consultation under the ESA conclude that the estimated exposures of fin whales can be avoided via mitigation measures or that the received sound is not likely to adversely affect fin whales, authorization for the predicted exposures would not be requested under MMPA. At this time, this application requests authorization for the annual harassment of 87 fin whales by Level B harassment from potential exposure to mid-frequency active sonar.

Humpback Whale (*Megaptera novaeangliae*)

The modeling results for behavioral effects were calculated using the dose-function methodology documented in Section 6.2.5. Combining all non-explosive sources, the annual number of humpback whales predicted to be behaviorally harassed from testing and training in the HRC is 34,797 (Table 6-6).

Modeling indicates there would be 482 exposures to accumulated acoustic energy between 195 dB and 215 dB re 1 µPa^2-s, which is the threshold established indicative of onset TTS. Modeling indicates one exposure for humpback whales to accumulated acoustic energy above 215 dB re 1 µPa^2-s, which is the threshold indicative of onset PTS.

Without consideration of clearance procedures, there would be 15 exposures from impulsive sound or pressures from underwater detonations that would exceed the TTS threshold and none that would exceed the onset of slight injury threshold and no exposure that would exceed the onset of massive lung injury threshold (Table 6-9). Target and demolition area clearance procedures would make sure there are no humpback whales within the safety zone and therefore potential exposure of humpback whales to sound levels that exceed TTS or injury levels are highly unlikely Given the mitigation measures detailed in Chapter 11, most ASW exercises take place in offshore waters and with the knowledge of the nearshore areas of humpback whale breeding aggregations, the Navy would likely avoid those nearshore areas regularly used by breeding humpback. This makes it is unlikely that mother calf pairs would be disturbed to the point of separation or the cessation of reproductive behaviors.

Given the large size (up to 53 ft [16m] of individual humpback whales (Leatherwood et al., 1982), and pronounced vertical blow, it is very likely that lookouts would detect humpback whales at the surface. Additionally, mitigation measures call for continuous visual observation during operations with active sonar, therefore, humpback whales that are present in the vicinity of ASW operations would be detected by visual observers reducing the likelihood of exposure, such that effects would be discountable.

There are no audiograms of baleen whales, but they tend to react to anthropogenic sound below 1 kHz, suggesting that they are more sensitive to low frequency sounds (Richardson et al., 1995). Based on this information, if they do not hear these sounds, they are not likely to respond physiologically or behaviorally to those received levels, such that effects would be insignificant. A single study suggested that humpback whales responded to mid-frequency sonar (3.1-3.6 kHz re 1 μPa^2-s) sound (Maybaum, 1989). The hand held sonar system had a sound artifact below 1,000 Hz which caused a response to the control playback (a blank tape) and may have affected the response to sonar (i.e. the humpback whale responded to the low frequency artifact rather than the mid-frequency active sonar sound). Au et al. (2001) recorded high-frequency harmonics (out to 13.5 kHz) and source level (between 171 and 189 dB re 1 µPa-m) of humpback whale songs. Humpback whale mother-calf pairs are generally in the shallow protected waters and ASW mid-frequency active sonar activities takes place throughout the extensive HRC but the areas inhabited by humpback whales represents only a small portion of the HRC.

The response of mother-calf pairs of humpback and other baleen whales, to lower frequency sounds such as seismic air guns, vessels or the LFA sound source have been documented. Humpback whales responded to small vessels (often whale watching boats; low frequency sound) by changing swim speed, respiratory rates and social interactions depending on proximity to the vessel and vessel speed, with responses varying by social status and gender (Watkins et al., 1981; Bauer, 1986; Bauer and Herman, 1986). Animals may even move out of the area in response to vessel noise (Salden 1988). The NRC (2005) reported that gray whale mother-calf pairs are sensitive to whale watching boats (low frequency sound) along the coast of California and in the calving lagoons of Mexico (NRC, 2005). Frankel and Clark (2000; 2002) reported that there was only a minor response by humpback whales to the Acoustic Thermometry of Ocean Climate (ATOC) sound source (low frequency below 100 Hz) and that response was variable with some animals being found closer to the sound source during operation. Humpback whale mother-calf pairs avoided an active seismic survey vessel (impulse sound with a frequency output of less than 1,000 Hz) by at least three km away (McCauley et al., 2000). Gray whale mother-calf pairs declined by 48% in the Baja Mexico calving lagoons in response to airgun playback experiments (Jones et al., 1986).

Based on the model results, behavioral patterns, acoustic abilities of humpback whales, results of past training, and the implementation of procedure mitigation measures presented in sections 11.1 for sonar and 11.2 for underwater detonations, the Navy finds that the HRC training events would not likely result in any death or injury to humpback whales, and the one predicted exposure to Level A harassment is not considered probable. Modeling does indicate the potential for Level B harassment, indicating the proposed ASW exercises may affect humpback whales.

An ESA consultation is ongoing, and includes the finding that the proposed ASW exercises may affect humpback whales. Should consultation under the ESA conclude that the estimated exposures of humpback whales can be avoided via mitigation measures or that the received sound is not likely to adversely affect humpback whales, authorization for the predicted exposures would not be requested under MMPA. At this time, this application requests authorization for the annual harassment of 35,284 humpback whales by Level B harassment

(35,279 from mid-frequency active sonar and 15 from underwater detonations) and one humpback whale by Level A harassment from potential exposure to mid-frequency active sonar.

North Pacific Right Whale (*Eubalaena japonica*)

There is no density information available for North Pacific right whales in Hawaiian waters since they have not been seen during survey. Given they are so few in number, it is unlikely that HRC mid-frequency active sonar training events will result in the exposure of any right whales to accumulated acoustic energy in excess of any energy flux threshold or a SPL in excess of 145 dB. No right whales would be exposed to impulsive sound or pressures from underwater detonations that would cause TTS or physical injury.

Given their large size (up to 56 ft [17m]) of individual North Pacific right whales (Leatherwood et al. 1982), surface behavior (e.g., breaching), pronounced blow, and mean group size of approximately three animals (probability of trackline detection = 0.90 in Beaufort Sea States of 6 or less; Barlow 2003), it is very likely that lookouts would detect a group of North Pacific right whales at the surface. Additionally, mitigation measures call for continuous visual observation during operations with active sonar; therefore, large whales that are present in the operating area would be detected by visual observers. Implementation of mitigation measures and probability of detecting a large North Pacific right whale reduces the likelihood of exposure, such that effects would be discountable.

In the unlikely event that North Pacific right whales are exposed to mid-frequency sonar, the information available on North Pacific right suggests that they may hear the lower range of mid-frequency (1 kHz–10 kHz) sounds (Richardson et al., 1995; Ketten 1997). There are no audiograms for baleen whales but they are estimated to hear from 15 Hz to 20 kHz with good sensitivity from 20 Hz to 2 kHz (Ketten, 1998).

Active sonars may temporarily mask some sounds in the range of North Pacific right whale hearing and may also cause a temporary behavioral response (i.e., diving or swimming away from the sound source). Even though any undetected North Pacific right whales transiting HRC may exhibit a reaction when initially exposed to active acoustic energy, these observations indicate the effects would not cause disruption of natural behavioral patterns to a point where such behavioral patterns would be abandoned or significantly altered.

Based on the model results, behavioral patterns, acoustic abilities of North Pacific right whales, results of past training, and the implementation of procedure mitigation measures presented in sections 11.1 for sonar and 11.2 for underwater detonations, the Navy finds that the HRC training events would not likely result in any death or injury to North Pacific right whales.

Sei Whale (*Balaenoptera borealis*)

For purposes of the acoustic effects analysis, the same assumptions made previously regarding fin whales are also made for sei whales. It was therefore assumed that the number and density of sei whales did not exceed that of false killer whales and the modeled number of exposures for both species would therefore be the same.

The modeling results for behavioral effects were calculated using the dose-function methodology documented in Section 6.2.5. Combining all non-explosive sources, the annual number of sei whales predicted to be behaviorally harassed from testing and training in the HRC is 82 (Table 6-6).

Modeling also predicts 5 exposures to accumulated acoustic energy between 195 dB and 215 dB re 1 µPa^2-s, which is the threshold established indicative of onset TTS. Modeling predicts no exposures for sei whales to accumulated acoustic energy above 215 dB re 1 µPa^2-s, which is the threshold indicative of onset PTS. No sei whales would be exposed to impulsive sound or pressures from underwater detonations that would cause TTS or physical injury (Table 6-9).

Given the large size (up to 53 ft [16m}) of individual sei whales (Leatherwood et al. 1982), pronounced vertical blow, aggregation of approximately three animals (probability of trackline detection = 0.90 in Beaufort Sea States of 6 or less; Barlow, 2003), it is very likely that lookouts would detect a group of sei whales at the surface. Additionally, mitigation measures call for continuous visual observation during operations with active sonar, therefore, sei whales that migrate into the operating area would be detected by visual observers. Implementation of mitigation measures and probability of detecting a large sei whale reduces the likelihood of exposure, such that effects would be discountable.

There is little information on the acoustic abilities of sei whales or their response to human activities. The only recorded sounds of sei whales are frequency modulated sweeps in the range of 1.5 to 3.5 kHz (Thompson et al., 1979) but it is likely that they also vocalized at frequencies below 1 kHz as do fin whales. There are no audiograms of baleen whales but they tend to react to anthropogenic sound below 1 kHz suggesting that they are more sensitive to low frequency sounds (Richardson et al., 1995). Sei whales were more difficult to approach than were fin whales and moved away from boats but were less responsive when feeding (Gunther, 1949).

Based on the model results, behavioral patterns, acoustic abilities of sei whales, results of past training, and the implementation of procedure mitigation measures presented in sections 11.1 for sonar and 11.2 for underwater detonations, the Navy finds that the HRC training events would not likely result in any death or injury to sei whales, but some Level B behavioral harassment may occur.

An ESA consultation is ongoing, and includes the finding that the proposed ASW exercises may affect sei whales. Should consultation under the ESA conclude that the estimated exposures of sei whales can be avoided via mitigation measures or that the received sound is not likely to adversely affect sei whales, authorization for the predicted exposures would not be requested under MMPA. At this time, this application requests authorization for the annual harassment of 87 sei whales by Level B harassment from potential exposure to mid-frequency active sonar.

Sperm Whales (*Physeter macrocephalus*)

The modeling results for behavioral effects were calculated using the dose-function methodology documented in Section 6.2.5. Combining all non-explosive sources, the annual number of sperm whales expected to be behaviorally harassed from testing and training in the HRC is 1,154 (Table 6-6).

Modeling predicts 35 exposures to accumulated acoustic energy between of 195 dB and 215 dB re 1 µPa^2-s, which is the threshold established indicative of onset TTS. Modeling predicts there will be no exposures for sperm whales to accumulated acoustic energy above 215 dB re 1 µPa^2-s, which is the threshold indicative of onset PTS.

Without consideration of clearance procedures, there would be 5 exposures from impulsive sound or pressures from underwater detonations that would exceed the TTS threshold (Table 6-9). Target and demolition area clearance procedures would make sure there are no sperm whales within the safety zone, and therefore potential exposure of sperm whales to sound levels that exceed TTS are highly unlikely.

Given the large size (up to 56 ft [17m]) of individual sperm whales (Leatherwood et al. 1982), pronounced blow (large and angled), mean group size of approximately seven animals (probability of trackline detection = 0.87 in Beaufort Sea States of 6 or less; Barlow 2003; 2006), it is very likely that lookouts would detect a group of sperm whales at the surface. Sperm whales can make prolonged dives of up to two hours making detection more difficult but passive acoustic monitoring can detect and localize sperm whales from their calls (Watwood et al., 2006). Additionally, mitigation measures call for continuous visual observation during operations with active sonar; therefore, sperm whales that migrate into the operating area would be detected by visual observers. Implementation of mitigation measures and probability of detecting a large sperm whale reduces the likelihood of exposure, such that effects would be discountable.

In the unlikely event that sperm whales are exposed to mid-frequency sonar, the information available on sperm whales exposed to received levels of active mid-frequency sonar suggests that the response to mid-frequency (1 kHz to 10 kHz) sounds is variable (Richardson et al. 1995). While Watkins et al. (1985) observed that sperm whales exposed to 3.25 kHz to 8.4 kHz pulses interrupted their activities and left the area, other studies indicate that, after an initial disturbance, the animals return to their previous activity. During playback experiments off the Canary Islands, André et al. (1997) reported that foraging whales exposed to a 10 kHz pulsed signal did not exhibit any general avoidance reactions. When resting at the surface in a compact group, sperm whales initially reacted strongly but then ignored the signal completely (André et al., 1997).

Based on the model results, behavioral patterns, acoustic abilities of sperm whales, results of past training, and the implementation of procedure mitigation measures presented in sections 11.1 for sonar and 11.2 for underwater detonations, the Navy finds that the HRC training events would not result in any death or injury to sperm whales, but some Level B behavioral harassment may occur.

An ESA consultation is ongoing, and includes the finding that the proposed ASW exercises may affect sperm whales. Should consultation under the ESA conclude that the estimated exposures of sperm whales can be avoided via mitigation measures or that the received sound is not likely to adversely affect sperm whales, authorization for the predicted exposures would not be requested under MMPA. At this time, this application requests authorization for the annual harassment of 1,194 sperm whales by Level B harassment (1,189 from mid-frequency active sonar and five from underwater detonations).

Hawaiian Monk Seal (*Monachus schauinslandi*)

The modeling results for behavioral effects were calculated using the dose-function methodology documented in Section 6.2.5. Combining all non-explosive sources, the annual number of monk seals predicted to be behaviorally harassed from testing and training in the HRC is 570 (Table 6-6).

Modeling predicts 9 exposures to accumulated acoustic energy between 195 dB and 215 dB re 1 μPa^2-s, which is the threshold established indicative of onset TTS. Modeling predicts no exposures for monk seals to accumulated acoustic energy above 215 dB re 1 μPa^2-s, which is the threshold indicative of onset PTS. These exposures were modeled using the entire Hawaiian monk seal population which is primarily found in the Northwestern Hawaiian Islands which is outside of the HRC. The population of monk seals within the Main Hawaiian Islands is estimated to be 52 seals (Baker and Johanos, 2004), therefore the exposure estimate is grossly overestimated.

Without consideration of clearance procedures, there would be no exposures from impulsive sound or pressures from underwater detonations that would exceed the TTS threshold and no exposures that exceed the injury threshold (Table 6-9). Target and demolition area clearance procedures would make sure there are no monk seals within the safety zone, and therefore potential exposure of monk seals to sound levels that exceed TTS is highly unlikely.

Additionally, mitigation measures call for continuous visual observation during operations with active sonar; therefore, Hawaiian monk seals that move into the operating area would be insignificant. Critical habitat was designated 1986 as the area extending out to the 10 fathom depth (60 ft) for the Northwest Hawaiian Islands (NMFS, 1986). Critical habitat was extended out to the 20-fathom depth in 1988 (NMFS, 1988) but is outside of the HRC.

Based on the model results, behavioral patterns, acoustic abilities of monk seals, results of past training, and the implementation of procedure mitigation measures presented in sections 11.1 for sonar and 11.2 for underwater detonations, the Navy finds that the training events would not likely result in any death or injury to Hawaiian monk seals, but some Level B behavioral harassment may occur.

An ESA consultation is ongoing, and includes the finding that the proposed ASW exercises may affect Hawaiian monk seals. Should consultation under the ESA conclude that the estimated exposures of Hawaiian monk seals can be avoided via mitigation measures or that the received sound is not likely to adversely affect Hawaiian monk seals, authorization for the predicted exposures would not be requested under MMPA. At this time, this application requests authorization for the annual harassment of 579 Hawaiian monk seals by Level B harassment from mid-frequency active sonar.

6.3.5 Estimated Exposures for Non-ESA Species

Bryde's Whale (*Balaenoptera edeni brydei*)

The modeling results for behavioral effects were calculated using the dose-function methodology documented in Section 6.2.5. Combining all non-explosive sources, the annual number of Bryde's whales predicted to be behaviorally harassed from testing and training in the HRC is 273 (Table 6-6).

Modeling indicates there would 3 exposures to accumulated acoustic energy between of 195 dB and 215 dB re 1 µPa^2-s, which is the threshold established indicative of onset TTS. Modeling for all Alternatives indicates that no Bryde's whales would be exposed to accumulated acoustic energy at or above 215 dB re 1 µPa^2-s, which is the threshold indicative of onset PTS. No Bryde's whales would be exposed to impulsive sound or pressures from underwater detonations that would cause physical injury (Table 6-9).

Given the large size (up to 46 ft. [14 m]) of individual Bryde's whales, pronounced blow, and mean group size of approximately 1.5 animals and (probability of trackline detection = 0.87 in Beaufort Sea States of 6 or less; Barlow 2003; 2006), it is very likely that lookouts would detect a group of Bryde's whales at the surface. Additionally, mitigation measures call for continuous visual observation during operations with active sonar, therefore, minke whales that migrate into the operating area would be detected by visual observers. Implementation of mitigation measures and probability of detecting a minke whale reduces the likelihood of exposure, such that effects would be discountable.

Based on the model results, behavioral patterns, acoustic abilities of Bryde's whales, results of past training, and the implementation of procedure mitigation measures presented in sections 11.1 for sonar and 11.2 for underwater detonations, the Navy finds that the HRC training events would not result in any death or injury to Bryde's whales. At this time, this application requests authorization for the annual harassment of 276 Bryde's whales to potential Level B harassment from mid-frequency active sonar.

Minke Whale (*Balaenoptera acutorostrata*)

There is no density information available for minke whales in Hawaiian waters given they have rarely been seen during surveys. Given they are so few in number, it is unlikely that HRC mid-frequency active sonar training events will result in the exposure of any minke whales to accumulated acoustic energy in excess of any energy flux threshold or a SPL in excess of 145 dB (Table 6-6). No minke whales would be exposed to impulsive sound or pressures from underwater detonations that would cause TTS or physical injury (Table 6-9).

Minke whales are difficult to spot visually but can be detected using passive acoustic monitoring. Additionally, mitigation measures call for continuous visual observation during operations with active sonar, therefore, minke whales that migrate into the operating area would be detected by visual observers. Implementation of mitigation measures and probability of detecting a minke whale reduces the likelihood of exposure, such that effects would be discountable.

Based on the model results, behavioral patterns, acoustic abilities of minke whales, results of past training, and the implementation of procedure mitigation measures presented in sections 11.1 for sonar and 11.2 for underwater detonations, the Navy finds that the HRC training events would not result in any death or injury to minke whales.

Blainville's Beaked Whale (*Mesoplodon densirostris*)

The modeling results for behavioral effects were calculated using the dose-function methodology documented in Section 6.2.5. Combining all non-explosive sources, the annual number of Blainville's beaked whales predicted to be behaviorally harassed from testing and training in the HRC is 613 (Table 6-6).

Modeling indicates 23 exposures to accumulated acoustic energy between of 195 dB and 215 dB re 1 µPa^2-s, which is the threshold established indicative of onset TTS. Modeling for all Alternatives indicates that no Blainville's beaked whales would be exposed to accumulated acoustic energy at or above 215 dB re 1 µPa^2-s, which is the threshold indicative of onset PTS. Modeling indicates there would 2 exposures to impulsive sound or pressures from underwater detonations of 182 dB or 23 psi, which is the threshold indicative of onset TTS, and no exposures to impulsive sound or pressures from underwater detonations that would cause physical injury (Table 6-9).

Given the size (up to 15.5 ft. [4.7 m]) of individual Blainville's beaked whales, aggregation of 2.3 animals, it is likely that lookouts would detect a group of Blainville's beaked whales at the surface although beaked whales make prolonged dives that can last up to an hour (Baird et al., 2004). Additionally, mitigation measures call for continuous visual observation during operations with active sonar, therefore, Blainville's beaked whales that migrate into the operating area would be detected by visual observers. Implementation of mitigation measures and probability of detecting a large sei whale reduces the likelihood of exposure, such that effects would be discountable.

Based on the model results, behavioral patterns, acoustic abilities of Blainville's beaked whales, results of past training, and the implementation of procedure mitigation measures presented in sections 11.1 for sonar and 11.2 for underwater detonations, the Navy finds that the HRC training events would not result in any death or injury to Blainville's beaked whales. At this time, this application requests authorization for the annual harassment of 638 Blainville's beaked whales to potential Level B harassment (636 from mid-frequency active sonar and two from underwater detonations).

Bottlenose Dolphin (*Tursiops truncatus*)

The modeling results for behavioral effects were calculated using the dose-function methodology documented in Section 6.2.5. Combining all non-explosive sources, the annual number of bottlenose dolphins predicted to be behaviorally harassed from testing and training in the HRC is 1,348 (Table 6-6).

Modeling indicates 67 exposures to accumulated acoustic energy between of 195 dB and 215 dB re 1 μPa^2-s, which is the threshold established indicative of onset TTS. Modeling for all Alternatives indicates that no bottlenose dolphins would be exposed to accumulated acoustic energy at or above 215 dB re 1 μPa^2-s, which is the threshold indicative of onset PTS. No bottlenose dolphins would be exposed to impulsive sound or pressures from underwater detonations that would cause physical injury (Table 6-9).

Given the frequent surfacing, aggregation of approximately 9 animals (probability of trackline detection = 0.76 in Beaufort Sea States of 6 or less; Barlow, 2003), it is very likely that lookouts would detect a group of bottlenose dolphins at the surface. Additionally, mitigation measures call for continuous visual observation during operations with active sonar, therefore, bottlenose dolphins that migrate into the operating area would be detected by visual observers. Implementation of mitigation measures and probability of detecting bottlenose dolphins reduces the likelihood of exposure, such that effects would be discountable.

Based on the model results, behavioral patterns, acoustic abilities of bottlenose dolphins, results of past training, and the implementation of procedure mitigation measures presented in sections 11.1 for sonar and 11.2 for underwater detonations, the Navy finds that the HRC training events would not result in any death or injury to bottlenose dolphins. At this time, this application requests authorization for the annual harassment of 1,415 bottlenose dolphins to potential Level B harassment from mid-frequency active sonar.

Cuvier's Beaked Whale (*Ziphius cavirostris*)

The modeling results for behavioral effects were calculated using the dose-function methodology documented in Section 6.2.5. Combining all non-explosive sources, the annual number of Cuvier's beaked whales predicted to be behaviorally harassed from testing and training in the HRC is 1,593 (Table 6-6).

Modeling indicates 20 exposures to accumulated acoustic energy between of 195 dB and 215 dB re 1 µPa^2-s, which is the threshold established indicative of onset TTS. Modeling for all Alternatives indicates that no Cuvier's beaked whales would be exposed to accumulated acoustic energy at or above 215 dB re 1 µPa^2-s, which is the threshold indicative of onset PTS. Modeling indicates there would 10 exposures to impulsive sound or pressures from underwater detonations of 182 dB or 23 psi, which is the threshold indicative of onset TTS and no exposures to impulsive sound or pressures from underwater detonations that would cause slight physical injury (Table 6-9).

Given the medium size (up to 23 ft. [7.0 m]) of individual Cuvier's beaked whales, aggregation of approximately two animals (Barlow, 2006), it is likely that lookouts would detect a group of Cuvier's beaked whales at the surface although beaked whales make prolonged dives that can last up to an hour (Baird et al. 2004). Additionally, mitigation measures call for continuous visual observation during operations with active sonar, therefore, Blainville's beaked whales that migrate into the operating area would be detected by visual observers. Implementation of mitigation measures and probability of detecting a large sei whale reduces the likelihood of exposure, such that effects would be discountable.

Based on the model results, behavioral patterns, acoustic abilities of Cuvier's beaked whales, results of past training, and the implementation of procedure mitigation measures presented in sections 11.1 for sonar and 11.2 for underwater detonations, the Navy finds that the HRC training events would not result in any death or injury to Cuvier's beaked whales. At this time, this application requests authorization for the annual harassment of 1,623 Cuvier's beaked whales to potential Level B harassment (1,613 from mid-frequency active sonar and 10 from underwater detonations).

Dwarf Sperm Whale (*Kogia sima*)

The modeling results for behavioral effects were calculated using the dose-function methodology documented in Section 6.2.5. Combining all non-explosive sources, the annual number of dwarf sperm whales predicted to be behaviorally harassed from testing and training in the HRC is 2,565 (Table 6-6).

Modeling indicates 134 exposures to accumulated acoustic energy between of 195 dB and 215 dB re 1 µPa^2-s, which is the threshold established indicative of onset TTS. Modeling for all Alternatives indicates that no dwarf sperm whales would be exposed to accumulated acoustic energy at or above 215 dB re 1 µPa^2-s, which is the threshold indicative of onset PTS. Modeling indicates 9 exposures to impulsive sound or pressures from underwater detonations of 182 dB or 23 psi, which is the threshold indicative of onset TTS, and no exposures to impulsive sound or pressures from underwater detonations that would cause slight physical injury or onset of massive lung injury (Table 6-9).

Based on the model results, behavioral patterns, acoustic abilities of dwarf sperm whales, results of past training, and the implementation of procedure mitigation measures presented in sections 11.1 for sonar and 11.2 for underwater detonations, the Navy finds that the HRC training events would not result in any death or injury to dwarf sperm whale. At this time, this application requests authorization for the annual harassment of 2,708 dwarf sperm whales to potential Level B harassment (2,699 from mid-frequency active sonar and nine from underwater detonations).

False Killer Whale (*Pseudorca crassidens*)

The modeling results for behavioral effects were calculated using the dose-function methodology documented in Section 6.2.5. Combining all non-explosive sources, the annual number of false killer whales predicted to be behaviorally harassed from testing and training in the HRC is 82 (Table 6-6).

Modeling indicates 5 exposures to accumulated acoustic energy between of 195 dB and 215 dB re 1 µPa^2-s, which is the threshold established indicative of onset TTS. Modeling for all Alternatives indicates that no false killer whales would be exposed to accumulated acoustic energy at or above 215 dB re 1 µPa^2-s, which is the threshold indicative of onset PTS. No false killer whales would be exposed to impulsive sound or pressures from underwater detonations that would cause physical injury (Table 6-9).

Given their size (up to 19.7 ft [6.0 m]) and large mean group size of 10.3 animals (probability of trackline detection = 0.76 in Beaufort Sea States of 6 or less; Barlow, 2003), it is very likely that lookouts would detect a group of false killer whales at the surface. Additionally, mitigation measures call for continuous visual observation during operations with active sonar, therefore, false killer whales that migrate into the operating area would be detected by visual observers. Implementation of mitigation measures and probability of detecting large groups of false killer whales reduces the likelihood of exposure.

Based on the model results, behavioral patterns, acoustic abilities of false killer whales, results of past training, and the implementation of procedure mitigation measures presented in sections 11.1 for sonar and 11.2 for underwater detonations, the Navy finds that the HRC training events would not result in any death or injury to false killer whales. At this time, this application requests authorization for the annual harassment of 87 false killer whales to potential Level B harassment from mid-frequency active sonar.

Fraser's Dolphin (*Lagenodelphis hosei*)

The modeling results for behavioral effects were calculated using the dose-function methodology documented in Section 6.2.5. Combining all non-explosive sources, the annual number of Fraser's dolphins predicted to be behaviorally harassed from testing and training in the HRC is 1,556 (Table 6-6).

Modeling indicates 81 exposures to accumulated acoustic energy between of 195 dB and 215 dB re 1 µPa^2-s, which is the threshold established indicative of onset TTS. Modeling for all Alternatives indicates that no Fraser's dolphins would be exposed to accumulated acoustic energy at or above 215 dB re 1 µPa^2-s, which is the threshold indicative of onset PTS. Modeling indicates there would be 4 exposures to impulsive sound or pressures from underwater detonations of 182 dB or 23 psi, which is the threshold indicative of onset TTS, and no exposures to impulsive sound or pressures from underwater detonations that would cause slight physical injury or onset of massive lung injury (Table 6-9).

Given their large aggregations, mean group size of 286.3 animals (probability of trackline detection = 1.00 in Beaufort Sea States of 6 or less; Barlow, 2006), it is very likely that lookouts would detect a group of Fraser's dolphins at the surface. Additionally, mitigation measures call for continuous visual observation during operations with active sonar, therefore, Fraser's dolphins that migrate into the operating area would be detected by visual observers.

Implementation of mitigation measures and probability of detecting large groups of false killer whales reduces the likelihood of exposure.

Based on the model results, behavioral patterns, acoustic abilities of Fraser's dolphins, results of past training, and the implementation of procedure mitigation measures presented in sections 11.1 for sonar and 11.2 for underwater detonations, the Navy finds that the HRC training events would not result in any death or injury to Fraser's dolphins. At this time, this application requests authorization for the annual harassment of 1,641 Fraser's dolphins to potential Level B harassment (1,637 from mid-frequency active sonar and four from underwater detonations).

Killer Whale (*Orcinus orca*)

The modeling results for behavioral effects were calculated using the dose-function methodology documented in Section 6.2.5. Combining all non-explosive sources, the annual number of killer whales predicted to be behaviorally harassed from testing and training in the HRC is 82 (Table 6-6).

Modeling indicates 5 exposures to accumulated acoustic energy between of 195 dB and 215 dB re 1 μPa^2-s, which is the threshold established indicative of onset TTS. Modeling for all Alternatives indicates that no killer whales would be exposed to accumulated acoustic energy at or above 215 dB re 1 μPa^2-s, which is the threshold indicative of onset PTS. No killer whales would be exposed to impulsive sound or pressures from underwater detonations that would cause physical injury (Table 6-9).

Given their size (up to 23 ft [7.0 m]), conspicuous coloring, pronounce dorsal fin and large mean group size of 6.5 animals (probability of trackline detection = 0.90 in Beaufort Sea States of 6 or less; Barlow, 2003). It is very likely that lookouts would detect a group of killer whales at the surface. Additionally, mitigation measures call for continuous visual observation during operations with active sonar, therefore, killer whales that migrate into the operating area would be detected by visual observers. Implementation of mitigation measures and probability of detecting large groups of killer whales reduces the likelihood of exposure.

Based on the model results, behavioral patterns, acoustic abilities of killer whales, results of past training, and the implementation of procedure mitigation measures presented in sections 11.1 for sonar and 11.2 for underwater detonations, the Navy finds that the HRC training events would not result in any death or injury to killer whales. At this time, this application requests authorization for the annual harassment of 87 killer whales to potential Level B harassment from mid-frequency active sonar.

Longman's Beaked Whale (*Indopacetus pacificus*)

The modeling results for behavioral effects were calculated using the dose-function methodology documented in Section 6.2.5. Combining all non-explosive sources, the annual number of Longman's beaked whales predicted to be behaviorally harassed from testing and training in the HRC is 176 (Table 6-6).

Modeling indicates 6 exposures to accumulated acoustic energy between of 195 dB and 215 dB re 1 μPa^2-s, which is the threshold established indicative of onset TTS. Modeling for all Alternatives indicates that no Longman's beaked whale would be exposed to accumulated acoustic energy at or above 215 dB re 1 μPa^2-s, which is the threshold indicative of onset PTS.

No Longman's beaked whale would be exposed to impulsive sound or pressures from underwater detonations that would cause physical injury (Table 6-9).

Given the medium size (up to 24 ft. [7.5 m]) of individual Longman's beaked whale, aggregation of approximately 17.8 animals (Barlow, 2006), it is very likely that lookouts would detect a group of Longman's beaked whale at the surface although beaked whales make prolonged dives that can last up to an hour (Baird et al., 2004).. Additionally, mitigation measures call for continuous visual observation during operations with active sonar, therefore, Longman's beaked whales that migrate into the operating area would be detected by visual observers. Implementation of mitigation measures and probability of detecting a large sei whale reduces the likelihood of exposure, such that effects would be discountable.

Based on the model results, behavioral patterns, acoustic abilities of Longman's beaked whale, results of past training, and the implementation of procedure mitigation measures presented in sections 11.1 for sonar and 11.2 for underwater detonations, the Navy finds that the HRC training events would not result in any death or injury to Longman's beaked whale. At this time, this application requests authorization for the annual harassment of 182 Longman's beaked whales to potential Level B harassment from mid-frequency active sonar.

Melon-headed Whale (*Peponocephala electra*)

The modeling results for behavioral effects were calculated using the dose-function methodology documented in Section 6.2.5. Combining all non-explosive sources, the annual number of melon-headed whales predicted to be behaviorally harassed from testing and training in the HRC is 1,015 (Table 6-6).

Modeling indicates 52 exposures to accumulated acoustic energy between of 195 dB and 215 dB re 1 μPa^2-s, which is the threshold established indicative of onset TTS. Modeling for all Alternatives indicates that no melon-headed whales would be exposed to accumulated acoustic energy at or above 215 dB re 1 μPa^2-s, which is the threshold indicative of onset PTS. No melon-headed whales would be exposed to impulsive sound or pressures from underwater detonations that would cause physical injury (Table 6-9).

Given their size (up to 8.2 ft [2.5 m]) and large group size (mean of 89.2 whales) or more animals (probability of trackline detection = 1.00 in Beaufort Sea States of 6 or less; Barlow, 2003). It is very likely that lookouts would detect a group of melon-headed whales at the surface. Additionally, mitigation measures call for continuous visual observation during operations with active sonar, therefore, melon-headed whales that migrate into the operating area would be detected by visual observers. Implementation of mitigation measures and probability of detecting large groups of melon-headed whales reduces the likelihood of exposure.

Based on the model results, behavioral patterns, acoustic abilities of melon-headed whales, results of past training, and the implementation of procedure mitigation measures presented in sections 11.1 for sonar and 11.2 for underwater detonations, the Navy finds that the HRC training events would not result in any death or injury to melon-headed whales. At this time, this application requests authorization for the annual harassment of 1,067 melon-headed whales to potential Level B harassment from mid-frequency active sonar.

Pantropical Spotted Dolphin (*Stenella attenuata*)

The modeling results for behavioral effects were calculated using the dose-function methodology documented in Section 6.2.5. Combining all non-explosive sources, the annual number of pantropical spotted dolphins predicted to be behaviorally harassed from testing and training in the HRC is 4,184 (Table 6-6).

Modeling indicates 196 exposures to accumulated acoustic energy between of 195 dB and 215 dB re 1 μPa^2-s, which is the threshold established indicative of onset TTS. Modeling for all Alternatives indicates that no pantropical spotted dolphins would be exposed to accumulated acoustic energy at or above 215 dB re 1 μPa^2-s, which is the threshold indicative of onset PTS. Modeling indicates 2 exposures to impulsive sound or pressures from underwater detonations of 182 dB or 23 psi, which is the threshold indicative of onset TTS, and no exposures to impulsive sound or pressures from underwater detonations that would cause slight physical injury or massive lung injury (Table 6-9).

Given their frequent surfacing and large group size hundreds of animals (Leatherwood et al. 1982), mean group size of 60.0 animals in Hawaii and probability of trackline detection of 1.00 in Beaufort Sea States of 6 or less (Barlow, 2006) it is very likely that lookouts would detect a group of pantropical spotted dolphins at the surface. Additionally, mitigation measures call for continuous visual observation during operations with active sonar and underwater detonations, therefore, pantropical spotted dolphins that migrate into the operating area would be detected by visual observers. Implementation of mitigation measures and probability of detecting large groups of pantropical spotted dolphins reduces the likelihood of exposure.

Based on the model results, behavioral patterns, acoustic abilities of pantropical spotted dolphins, results of past training, and the implementation of procedure mitigation measures presented in sections 11.1 for sonar and 11.2 for underwater detonations, the Navy finds that the HRC training events would not result in any death or injury to pantropical spotted dolphins. At this time, this application requests authorization for the annual harassment of 4,382 pantropical spotted dolphins to potential Level B harassment (4,380 from mid-frequency active sonar and two from underwater detonations).

Pygmy Killer Whale (*Feresa attenuata*)

The modeling results for behavioral effects were calculated using the dose-function methodology documented in Section 6.2.5. Combining all non-explosive sources, the annual number of pygmy killer whales predicted to be behaviorally harassed from testing and training in the HRC is 328 (Table 6-6).

Modeling indicates 19 exposures to accumulated acoustic energy between of 195 dB and 215 dB re 1 μPa^2-s, which is the threshold established indicative of onset TTS. Modeling for all Alternatives indicates that no pygmy killer whales would be exposed to accumulated acoustic energy at or above 215 dB re 1 μPa^2-s, which is the threshold indicative of onset PTS. No pygmy killer whales would be exposed to impulsive sound or pressures from underwater detonations that would cause physical injury (Table 6-9).

Given their size (up to 8.5 ft [2.6 m]) and mean group size of 14.4 animals (probability of trackline detection = 0.76 in Beaufort Sea States of 6 or less; Barlow, 2003), it is very likely that lookouts would detect a group of pygmy killer whales at the surface. Additionally, mitigation measures call for continuous visual observation during operations with active sonar, therefore, pygmy killer whales that migrate into the operating area would be detected by visual observers. Implementation of mitigation measures and probability of detecting large groups of pygmy killer whales reduces the likelihood of exposure.

Based on the model results, behavioral patterns, acoustic abilities of to pygmy killer whales, results of past training, and the implementation of procedure mitigation measures presented in sections 11.1 for sonar and 11.2 for underwater detonations, the Navy finds that the HRC training events would not result in any death or injury to pygmy killer whales. At this time, this application requests authorization for the annual harassment of 347 pygmy killer whales to potential Level B harassment from mid-frequency active sonar.

Pygmy Sperm Whale (*Kogia breviceps*)

The modeling results for behavioral effects were calculated using the dose-function methodology documented in Section 6.2.5. Combining all non-explosive sources, the annual number of pygmy sperm whales predicted to be behaviorally harassed from testing and training in the HRC is 1,048 (Table 6-6).

Modeling indicates 55 exposures to accumulated acoustic energy between of 195 dB and 215 dB re 1 µPa^2-s, which is the threshold established indicative of onset TTS. Modeling for all Alternatives indicates that no pygmy sperm whales would be exposed to accumulated acoustic energy at or above 215 dB re 1 µPa^2-s, which is the threshold indicative of onset PTS. Modeling indicates 4 exposures to impulsive sound or pressures from underwater detonations of 182 dB or 23 psi, which is the threshold indicative of onset TTS and no exposures to impulsive sound or pressures from underwater detonations that would cause slight physical injury (Table 6-9).

Given their size (up to 10 ft [3 m]) and behavior of resting at the surface (Leatherwood et al., 1982), it is very likely that lookouts would detect a pygmy sperm whale at the surface. Additionally, mitigation measures call for continuous visual observation during operations with active sonar and underwater detonations, therefore, pygmy sperm whales that migrate into the operating area would be detected by visual observers. Implementation of mitigation measures and probability of detecting large groups of pygmy sperm whales reduces the likelihood of exposure.

Based on the model results, behavioral patterns, acoustic abilities of pygmy sperm whale, results of past training, and the implementation of procedure mitigation measures presented in sections 11.1 for sonar and 11.2 for underwater detonations, the Navy finds that the HRC training events would not result in any death or injury to pygmy sperm whale. At this time, this application requests authorization for the annual harassment of 1,107 pygmy sperm whales to potential Level B harassment (1,103 from mid-frequency active sonar and four from underwater detonations).

Risso's Dolphin (*Grampus griseus*)

The modeling results for behavioral effects were calculated using the dose-function methodology documented in Section 6.2.5. Combining all non-explosive sources, the annual number of Risso's dolphins predicted to be behaviorally harassed from testing and training in the HRC is 846 (Table 6-6).

Modeling indicates 44 exposures to accumulated acoustic energy between of 195 dB and 215 dB re 1 µPa^2-s, which is the threshold established indicative of onset TTS. Modeling for all Alternatives indicates that no Risso's dolphins would be exposed to accumulated acoustic energy at or above 215 dB re 1 μPa^2-s, which is the threshold indicative of onset PTS. No Risso's dolphins would be exposed to impulsive sound or pressures from underwater detonations that would cause physical injury (Table 6-9).

Given their frequent surfacing, light coloration and large group size of up to several hundred animals (Leatherwood et al. 1982), mean group size of 15.4 dolphins in Hawaii and probability of trackline detection of 0.76 in Beaufort Sea States of 6 or less (Barlow, 2006), it is very likely that lookouts would detect a group of Risso's dolphins at the surface. Additionally, mitigation measures call for continuous visual observation during operations with active sonar and underwater detonations, therefore, Risso's dolphins that migrate into the operating area would be detected by visual observers. Implementation of mitigation measures and probability of detecting large groups of Risso's dolphins reduces the likelihood of exposure.

Based on the model results, behavioral patterns, acoustic abilities of Risso's dolphins, results of past training, and the implementation of procedure mitigation measures presented in sections 11.1 for sonar and 11.2 for underwater detonations, the Navy finds that the HRC training events would not result in any death or injury to Risso's dolphins. At this time, this application requests authorization for the annual harassment of 890 Risso's dolphins to potential Level B harassment from mid-frequency active sonar.

Rough-Toothed Dolphin (*Steno bredanensis*)

The modeling results for behavioral effects were calculated using the dose-function methodology documented in Section 6.2.5. Combining all non-explosive sources, the annual number of rough-toothed dolphins predicted to be behaviorally harassed from testing and training in the HRC is 1,348 (Table 6-6).

Modeling indicates 70 exposures to accumulated acoustic energy between of 195 dB and 215 dB re 1 μPa^2-s, which is the threshold established indicative of onset TTS. Modeling for all Alternatives indicates that no rough-toothed dolphins would be exposed to accumulated acoustic energy at or above 215 dB re 1 μPa^2-s, which is the threshold indicative of onset PTS. Modeling indicates there would 3 exposures to impulsive sound or pressures from underwater detonations of 182 dB or 23 psi, which is the threshold indicative of onset TTS and no exposures to impulsive sound or pressures from underwater detonations that would cause slight physical injury or massive lung injury (Table 6-9).

Given their frequent surfacing and mean group size of 14.8 animals (probability of trackline detection = 0.76 in Beaufort Sea States of 6 or less; Barlow 2006), it is very likely that lookouts would detect a group of rough-toothed dolphins at the surface. Additionally, mitigation measures call for continuous visual observation during operations with active sonar and underwater detonations, therefore, rough-toothed dolphins that migrate into the operating area would be detected by visual observers. Implementation of mitigation measures and probability of detecting groups of rough-toothed dolphins reduces the likelihood of exposure.

Based on the model results, behavioral patterns, acoustic abilities of rough-toothed dolphins, results of past training, and the implementation of procedure mitigation measures presented in sections 11.1 for sonar and 11.2 for underwater detonations, the Navy finds that the HRC training events would not result in any death or injury to rough-toothed dolphins. At this time, this application requests authorization for the annual harassment of 1,421 rough-toothed dolphins to potential Level B harassment (1,418 from mid-frequency active sonar and three from underwater detonations).

Short-finned Pilot Whale (*Globicephala macrorhynchus*)

The modeling results for behavioral effects were calculated using the dose-function methodology documented in Section 6.2.5. Combining all non-explosive sources, the annual number of short-finned pilot whales predicted to be behaviorally harassed from testing and training in the HRC is 3,046 (Table 6-6).

Modeling indicates 157 exposures to accumulated acoustic energy between of 195 dB and 215 dB re 1 µPa^2-s, which is the threshold established indicative of onset TTS. Modeling for all Alternatives indicates that no short-finned pilot whales would be exposed to accumulated acoustic energy at or above 215 dB re 1 µPa^2-s, which is the threshold indicative of onset PTS. Modeling indicates there would 2 exposures to impulsive sound or pressures from underwater detonations of 182 dB or 23 psi, which is the threshold indicative of onset TTS and no exposures to impulsive sound or pressures from underwater detonations that would cause slight physical injury or massive lung injury (Table 6-9).

Given their size (up to 20 ft [6.1 m]), and large mean group size of 22.5 animals (probability of trackline detection = 0.76 in Beaufort Sea States of 6 or less; Barlow 2006). It is very likely that lookouts would detect a group of short-finned pilot whales at the surface. Additionally, mitigation measures call for continuous visual observation during operations with active sonar, therefore, short-finned pilot whales that migrate into the operating area would be detected by visual observers. Implementation of mitigation measures and probability of detecting groups of short-finned pilot whales reduces the likelihood of exposure.

Based on the model results, behavioral patterns, acoustic abilities of short-finned pilot whale, results of past training, and the implementation of procedure mitigation measures presented in sections 11.1 for sonar and 11.2 for underwater detonations, the Navy finds that the HRC training events would not result in any death or injury to short-finned pilot whale. At this time, this application requests authorization for the annual harassment of 3,205 short-finned pilot whales to potential Level B harassment (3,203 from mid-frequency active sonar and two from underwater detonations).

Spinner Dolphin (*Stenella longirostris*)

The modeling results for behavioral effects were calculated using the dose-function methodology documented in Section 6.2.5. Combining all non-explosive sources, the annual number of spinner dolphins predicted to be behaviorally harassed from testing and training in the HRC is 524 (Table 6-6).

Modeling indicates 27 exposures to accumulated acoustic energy between of 195 dB and 215 dB re 1 µPa^2-s, which is the threshold established indicative of onset TTS. Modeling for all Alternatives indicates that no spinner dolphins would be exposed to accumulated acoustic energy at or above 215 dB re 1 µPa^2-s, which is the threshold indicative of onset PTS. Modeling indicates there would be two exposures to impulsive sound or pressures from underwater detonations of 182 dB or 23 psi, which is the threshold indicative of onset TTS and no exposures to impulsive sound or pressures from underwater detonations that would cause slight physical injury massive lung injury (Table 6-9).

Given their frequent surfacing, aerobatics and large mean group size of 31.7 animals (probability of trackline detection = 1.00 in Beaufort Sea States of 6 or less; Barlow 2006), it is very likely that lookouts would detect a group of spinner dolphins at the surface. Additionally, mitigation measures call for continuous visual observation during operations with active sonar, therefore, spinner dolphins that migrate into the operating area would be detected by visual observers. Implementation of mitigation measures and probability of detecting groups of spinner dolphins reduces the likelihood of exposure.

Based on the model results, behavioral patterns, acoustic abilities of spinner dolphins, results of past training, and the implementation of procedure mitigation measures presented in sections 11.1 for sonar and 11.2 for underwater detonations, the Navy finds that the HRC training events would not result in any death or injury to spinner dolphins. At this time, this application requests authorization for the annual harassment of 553 spinner dolphins to potential Level B harassment (551 from mid-frequency active sonar and two from underwater detonations).

Striped Dolphin (*Stenella coeruleoalba*)

The modeling results for behavioral effects were calculated using the dose-function methodology documented in Section 6.2.5. Combining all non-explosive sources, the annual number of striped dolphins predicted to be behaviorally harassed from testing and training in the HRC is 6,106 (Table 6-6).

Modeling indicates 287 exposures to accumulated acoustic energy between of 195 dB and 215 dB re 1 µPa^2-s, which is the threshold established indicative of onset TTS. Modeling for all Alternatives indicates one exposure to accumulated acoustic energy at or above 215 dB re 1 µPa^2-s, which is the threshold indicative of onset PTS. Modeling indicates three exposures to impulsive sound or pressures from underwater detonations of 182 dB or 23 psi, which is the threshold indicative of onset TTS and no exposures to impulsive sound or pressures from underwater detonations that would cause slight physical injury or massive lung injury (Table 6-9).

Given their frequent surfacing, aerobatics and large mean group size of 37.3 animals (probability of trackline detection = 1.00 in Beaufort Sea States of 6 or less; Barlow 2006), it is very likely that lookouts would detect a group of striped dolphins at the surface. Additionally, mitigation measures call for continuous visual observation during operations with active sonar, therefore, striped dolphins that migrate into the operating area would be detected by visual observers. Implementation of mitigation measures and probability of detecting groups of striped dolphins reduces the likelihood of exposure.

Based on the model results, behavioral patterns, acoustic abilities of striped dolphins, results of past training, and the implementation of procedure mitigation measures presented in sections 11.1 for sonar and 11.2 for underwater detonations, the Navy finds that the HRC training events would not result in any death or injury to striped dolphins. At this time, this application requests authorization for the annual harassment of 6,396 striped dolphins to potential Level B harassment (6,393 from mid-frequency active sonar and three from underwater detonations).

Unidentified Beaked Whales

The modeling results for behavioral effects were calculated using the dose-function methodology documented in Section 6.2.5. Combining all non-explosive sources, the annual number of unidentified beaked whales predicted to be behaviorally harassed from testing and training in the HRC is 51 (Table 6-6).

Modeling indicates 1 exposure to accumulated acoustic energy between of 195 dB and 215 dB re 1 µPa^2-s, which is the threshold established indicative of onset TTS. Modeling for all Alternatives indicates that no unidentified beaked whales would be exposed to accumulated acoustic energy at or above 215 dB re 1 µPa^2-s, which is the threshold indicative of onset PTS. No unidentified beaked whales would be exposed to impulsive sound or pressures from underwater detonations that would cause physical injury (Table 6-9).

Based on the model results, behavioral patterns, acoustic abilities of unidentified beaked whales, results of past training, and the implementation of procedure mitigation measures presented in sections 11.1 for sonar and 11.2 for underwater detonations, the Navy finds that the HRC training events would not result in any death or injury to unidentified beaked whales. At this time, this application requests authorization for the annual harassment of 52 unidentified beaked whales to potential Level B harassment from mid-frequency active sonar.

7. IMPACTS TO MARINE MAMMAL SPECIES OR STOCKS

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

- Most acoustic harassments are within the non-injurious temporary threshold shift (TTS) or behavioral effects zones (Level B harassment). Only two exposures to sound levels causing permanent threshold shift (PTS)/injury (Level A harassment) resulted from the summation of the modeling, but these two exposures are not expected to occur.
- Although the numbers presented in Tables 6-6 and 6-9 represent estimated harassment under the Marine Mammal Protection Act (MMPA), as described above, they are conservative estimates of harassment, primarily by behavioral disturbance. In addition, the model calculates harassment without taking into consideration standard mitigation measures, and is not indicative of a likelihood of either injury or harm.
- Additionally, the mitigation measures described in Chapter 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 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 that the total taking is not likely to reduce annual rates of adult survival or recruitment (i.e., offspring survival, birth rates). Based on each species' life history information, the expected behavioral patterns in the Hawaii Range Complex (HRC) training and exercise locations, and an analysis of the behavioral disturbance levels in comparison to the overall population, an analysis of the potential impacts of the Proposed Action on species recruitment or survival is presented in Section 6.3 for each species. These species-specific analyses support the conclusion that proposed HRC training events would have a negligible impact on marine mammals.

8. IMPACT ON SUBSISTENCE USE

Potential impacts resulting from the Proposed Action will be limited to individuals of marine mammal species located in the Hawaiian Islands Operating Area that have no subsistence requirements. Therefore, no impacts on the availability of species or stocks for subsistence use are considered.

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

The primary source of potential marine mammal habitat impact is acoustic exposures resulting from anti-submarine warfare (ASW) activities. However, the exposures do not constitute a long-term physical alteration of the water column or bottom topography, as the occurrences are of limited duration and are intermittent in time. Surface vessels associated with the activities are present in limited duration and are intermittent as they are continuously and relatively rapidly moving through any given area. Underwater detonations activities such as bombing exercises (BOMBEX), gunnery exercises (GUNEX), missile exercises (MISSILEX), and sinking exercises (SINKEX) do not constitute a long-term physical alteration of the water column or bottom topography, as the occurrences are of limited duration and are intermittent in time. Underwater detonations for mine or obstruction clearance and amphibious landings occur in sandy shallow areas and will not affect foraging or haul-out habitats.

Other sources that may affect marine mammal habitat were considered and potentially include the introduction of fuel, debris, ordnance, and chemical residues into the water column. The effects of each of these components were considered in the Hawaii Range Complex (HRC) Environmental Impact Statement/Overseas Environmental Impact Statement (EIS/OEIS) and were determined to not likely adversely affect protected marine species. Marine mammal habitat would not be affected.

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

Based on the discussions in Chapter 9, there will be no impacts to marine mammals resulting from loss or modification of marine mammal habitat.

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

Effective training in the Hawaii Range Complex (HRC) dictates that ship, submarine, and aircraft participants utilize their sensors and exercise weapons to their optimum capabilities as required by the mission. The Navy recognizes that such use has the potential to cause behavioral disruption of some marine mammal species in the vicinity of an exercise (as outlined in Chapter 6). Although any disruption of natural behavioral patterns is not likely to be to a point where such behavioral patterns are abandoned or significantly altered, this Chapter presents the Navy's mitigation measures, outlining steps that would be implemented to protect marine mammals and Federally-ESA listed species during operations. It should be noted that these mitigation measures have been standard operating procedures for unit level anti-submarine warfare (ASW) training since 2004. In addition, the Navy coordinated with the National Marine Fisheries Service (NMFS) to further develop measures for protection of marine mammals during the period of the National Defense Exemption (NDE), and those mitigations for mid-frequency active sonar are detailed in this Section. This Chapter also presents a discussion of other measures that have been considered and rejected because they are either: (1) not feasible; (2) present a safety concern; (3) provide no known or ambiguous mitigation benefit; or (4) impact the effectiveness of the required ASW training military readiness activity.

A Letter of Instruction, Mitigation Measures Message or Environmental Annex to the Operational Order will be issued prior to each exercise to further disseminate the personnel training requirement and general marine mammal mitigation measures including monitoring and reporting. The Navy will continue to fund marine mammal research as outlined in Chapter 14.

Mitigation Measures Related to Acoustic Effects

11.1 Mid-Frequency Active Sonar Operations

11.1.1 General Maritime Mitigation Measures – Personnel Training

1. All lookouts onboard platforms involved in ASW training events will review the NMFS-approved Marine Species Awareness Training (MSAT) material prior to use of mid-frequency active sonar.
2. All Commanding Officers, Executive Officers, and officers standing watch on the Bridge will have reviewed the MSAT material prior to a training event employing the use of mid-frequency active sonar.
3. Navy lookouts will undertake extensive training in order to qualify as a watchstander in accordance with the Lookout Training Handbook (NAVEDTRA, 12968-B).
4. Lookout training will include on-the-job instruction under the supervision of a qualified, experienced watchstander. Following successful completion of this supervised training period, Lookouts will complete the Personal Qualification Standard program, certifying that they have demonstrated the necessary skills (such as detection and reporting of partially submerged objects). This does not forbid personnel being trained as lookouts from being counted as those listed in previous measures so long as supervisors monitor their progress and performance.

5. Lookouts will be trained in the most effective means to ensure quick and effective communication within the command structure in order to facilitate implementation of mitigation measures if marine species are spotted.

11.1.2 General Maritime Mitigation Measures: Lookout and Watchstander Responsibilities

6. On the bridge of surface ships, there will always be at least three people on watch whose duties include observing the water surface around the vessel.
7. All surface ships participating in ASW exercises will, in addition to the three personnel on watch noted previously, have at all times during the exercise at least two additional personnel on watch as lookouts.
8. Personnel on lookout and officers on watch on the bridge will have at least one set of binoculars available for each person to aid in the detection of marine mammals.
9. On surface vessels equipped with mid-frequency active sonar, pedestal mounted "Big Eye" (20x110) binoculars will be present and in good working order to assist in the detection of marine mammals in the vicinity of the vessel.
10. Personnel on lookout will employ visual search procedures employing a scanning methodology in accordance with the Lookout Training Handbook (NAVEDTRA 12968-B).
11. After sunset and prior to sunrise, lookouts will employ Night Lookouts Techniques in accordance with the Lookout Training Handbook.
12. Personnel on lookout will be responsible for reporting all objects or anomalies sighted in the water (regardless of the distance from the vessel) to the Officer of the Deck, since any object or disturbance (e.g., trash, periscope, surface disturbance, discoloration) in the water may be indicative of a threat to the vessel and its crew or indicative of a marine species that may need to be avoided as warranted.

11.1.3 Operating Procedures

13. A Letter of Instruction, Mitigation Measures Message or Environmental Annex to the Operational Order will be issued prior to the exercise to further disseminate the personnel training requirement and general marine mammal mitigation measures.
14. Commanding Officers will make use of marine species detection cues and information to limit interaction with marine species to the maximum extent possible consistent with safety of the ship.
15. All personnel engaged in passive acoustic sonar operation (including aircraft, surface ships, or submarines) will monitor for marine mammal vocalizations and report the detection of any marine mammal to the appropriate watch station for dissemination and appropriate action.
16. During mid-frequency active sonar operations, personnel will utilize all available sensor and optical systems (such as Night Vision Goggles to aid in the detection of marine mammals.

17. Navy aircraft participating in exercises at sea will conduct and maintain, when operationally feasible 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.
18. Aircraft with deployed sonobuoys will use only the passive capability of sonobuoys when marine mammals are detected within 200 yards of the sonobuoy.
19. Marine mammal detections will be immediately reported to assigned Aircraft Control Unit for further dissemination to ships in the vicinity of the marine species as appropriate where it is reasonable to conclude that the course of the ship will likely result in a closing of the distance to the detected marine mammal.
20. Safety Zones - When marine mammals are detected by any means (aircraft, shipboard lookout, or acoustically) within 1,000 yards of the sonar dome (the bow), the ship or submarine will limit active transmission levels to at least 6 dB below normal operating levels.

    (i) Ships and submarines will continue to limit maximum transmission levels by this 6-dB factor until the animal has been seen to leave the area, has not been detected for 30 minutes, or the vessel has transited more than 2,000 yards beyond the location of the last detection.

    (ii) Should a marine mammal be detected within or closing to inside 500 yards of the sonar dome, active sonar transmissions will be limited to at least 10 dB below the equipment's normal operating level. Ships and submarines will continue to limit maximum ping levels by this 10-dB factor until the animal has been seen to leave the area, has not been detected for 30 minutes, or the vessel has transited more than 2000 yards beyond the location of the last detection.

    (iii) Should the marine mammal be detected within or closing to inside 200 yards of the sonar dome, active sonar transmissions will cease. Sonar will not resume until the animal has been seen to leave the area, has not been detected for 30 minutes, or the vessel has transited more than 2,000 yards beyond the location of the last detection.

    (iv) Special conditions applicable for dolphins and porpoises only: If, after conducting an initial maneuver to avoid close quarters with dolphins or porpoises, the Officer of the Deck concludes that dolphins or porpoises are deliberately closing to ride the vessel's bow wave, no further mitigation actions are necessary while the dolphins or porpoises continue to exhibit bow wave riding behavior.

    (v) If the need for power-down should arise as detailed in “Safety Zones” above, Navy shall follow the requirements as though they were operating at 235 dB - the normal operating level (i.e., the first power-down will be to 229 dB, regardless of at what level above 235 sonar was being operated).
21. Prior to start up or restart of active sonar, operators will check that the Safety Zone radius around the sound source is clear of marine mammals.
22. Sonar levels (generally) - Navy will operate sonar at the lowest practicable level, not to exceed 235 dB, except as required to meet tactical training objectives.

23. Helicopters shall observe/survey the vicinity of an ASW Operation for 10 minutes before the first deployment of active (dipping) sonar in the water.
24. Helicopters shall not dip their sonar within 200 yards of a marine mammal and shall cease pinging if a marine mammal closes within 200 yards after pinging has begun.
25. Submarine sonar operators will review detection indicators of close-aboard marine mammals prior to the commencement of ASW operations involving active mid-frequency sonar.
26. Increased vigilance during major ASW training exercises with tactical active sonar when critical conditions are present.

    Based on lessons learned from strandings in Bahamas 2000, Madeiras 2000, Canaries 2002 and Spain 2006, beaked whales are of particular concern since they have been associated with mid-frequency active sonar operations. Navy should avoid planning major ASW training exercises with mid-frequency active sonar in areas where they will encounter conditions which, in their aggregate, may contribute to a marine mammal stranding event.

    The conditions to be considered during exercise planning include:

    (i) Areas of at least 1000 m depth near a shoreline where there is a rapid change in bathymetry on the order of 1000-6000 meters occurring across a relatively short horizontal distance (e.g., 5 nm).

    (ii) Cases for which multiple ships or submarines ($\geq$ 3) operating mid-frequency active sonar in the same area over extended periods of time ($\geq$ 6 hours) in close proximity ($\leq$ 10 nm apart).

    (iii) An area surrounded by land masses, separated by less than 35 nm and at least 10 nm in length, or an embayment, wherein operations involving multiple ships/subs ($\geq$ 3) employing mid-frequency active sonar near land may produce sound directed toward the channel or embayment that may cut off the lines of egress for marine mammals.

    (iv) Though not as dominant a condition as bathymetric features, the historical presence of a significant surface duct (i.e. a mixed layer of constant water temperature extending from the sea surface to 100 or more feet).

    If the Major Exercise must occur in an area where the above conditions exist in their aggregate, these conditions must be fully analyzed in environmental planning documentation. Navy will increase vigilance by undertaking the following additional mitigation measure:

    A dedicated aircraft (Navy asset or contracted aircraft) will undertake reconnaissance of the embayment or channel ahead of the exercise participants to detect marine mammals that may be in the area exposed to active sonar. Where practical, advance survey should occur within about two hours prior to mid-frequency active sonar use, and periodic surveillance should continue for the duration of the exercise. Any unusual conditions (e.g., presence of sensitive species, groups of species milling out of habitat, any stranded animals) shall be reported to the Office in Tactical Command (OTC), who should give consideration to delaying, suspending or altering the exercise.

All safety zone power down requirements described above apply.

The post-exercise report must include specific reference to any event conducted in areas where the above conditions exist, with exact location and time/duration of the event, and noting results of surveys conducted.

11.1.4 Coordination and Reporting

27. Navy will coordinate with the local NMFS Stranding Coordinator for any unusual marine mammal behavior and any stranding, beached live/dead or floating marine mammals that may occur at any time during or within 24 hours after completion of mid-frequency active sonar use associated with ASW training activities.
28. Navy will submit a report to the Office of Protected Resources, NMFS, within 120 days of the completion of a Major Exercise. This report must contain a discussion of the nature of the effects, if observed, based on both modeled results of real-time events and sightings of marine mammals. Monitoring reports provided to NMFS, unless classified, also shall be provided to the California Coastal Commission.
29. If a stranding occurs during an ASW exercise, NMFS and Navy will coordinate to determine if mid-frequency active sonar should be temporarily discontinued while the facts surrounding the stranding are collected.

11.1.5 Alternative Mitigation Measures Considered but Eliminated

Potential marine mammal acoustic exposures that may result in harassment and/or a behavioral reaction or rarely injury (tissue damage or permanent threshold shift (PTS)) are further reduced by the mitigation measures described above. Therefore, the Navy concludes that the Proposed Action and mitigation measures achieve the least practical adverse impact on species or stocks of marine species.

Several additional measures were analyzed and dismissed from primary consideration given unknown, questionable, or limited effectiveness as a mitigation measure, known or likely detrimental consequences to personnel safety and the effectiveness of the military readiness activity, and based on the practicality of implementation. These measures include:

- Using non-Navy personnel onboard Navy vessels to provide surveillance of ASW or other exercise events.
  - Security clearance issues would have to be overcome to allow non-Navy observers onboard exercise participants.
  - Use of non-Navy observers is not necessary given that Navy lookouts are extensively trained in spotting items at or near the water surface. Navy lookouts receive more hours of training, and utilize their skills more frequently, than many third party trained personnel.
  - Use of Navy lookouts is the most effective means to ensure quick and effective communication within the command structure and facilitate implementation of mitigation measures if marine species are spotted. A critical skill set of effective Navy training is communication. Navy lookouts are trained to act swiftly and decisively to ensure that information is passed to the appropriate supervisory personnel.

- Navy and NMFS have not developed the necessary lengthy and detailed procedures that would be required to facilitate the integration of information from non-Navy observers into the command structure.
- Some training events will span one or more 24-hour period with operations underway continuously in that timeframe. It is not feasible to maintain non-Navy surveillance of these operations given the number of non-Navy observers that would be required onboard.
- Surface ships having active mid-frequency sonar have limited berthing capacity. Exercise planning includes careful consideration of this limited capacity in the placement of exercise controllers, data collection personnel, and Afloat Training Group personnel on ships involved in the exercise. Inclusion of non-Navy observers onboard these ships would require that in some cases, there would be no additional berthing space for essential Navy personnel required to fully evaluate and efficiently use the training opportunity to accomplish the exercise objectives.

- Visual monitoring or surveillance using non-Navy observers from non-military aircraft or vessels to survey before, during, and after exercise events.
  - Use of non-Navy observers in the air or on civilian vessels compromises security due to the requirement to provide advance notification of specific times/locations of Navy platforms (this information is Classified).
  - The areas where training events will mainly occur (the representative areas modeled) covers approximately 200,000 nm^2. Contiguous ASW events may cover many hundreds of square miles. The number of civilian ships and/or aircraft required to monitor the area of these events would be considerable. It is, thus, not feasible to survey or monitor the large exercise areas in the time required to ensure these areas are devoid of marine mammals. In addition, marine mammals may move into or out of an area, if surveyed before an event, or an animal could move into an area after an exercise took place. Given that there are no adequate controls to account for these or other possibilities and there are no identified research objectives, there is no utility to performing either a before or an after-the-event survey of an exercise area.
  - Survey during an event raises safety issues with multiple, slow civilian aircraft operating in the same airspace as military aircraft engaged in combat training activities. In addition, most of the training events take place far from land, limiting both the time available for civilian aircraft to be in the exercise area and presenting a concern should aircraft mechanical problems arise.
  - Scheduling civilian vessels or aircraft to coincide with training events would impact training effectiveness since exercise event timetables can not be precisely fixed and are instead based on the free-flow development of tactical situations. Waiting for civilian aircraft or vessels to complete surveys, refuel, or be on station would slow the unceasing progress of the exercise and impact the effectiveness of the military readiness activity.
  - The vast majority of HRC training events involve a Navy aerial asset with crews specifically training to hone their detection of objects in the water. The capability

  of sighting from both surface and aerial platforms provides excellent survey capabilities using the Navy's existing exercise assets.
  - Multiple events may occur simultaneously in areas at opposite ends of the HRC range areas and then continue for up to 96 hours. There are not enough qualified third-party personnel to accomplish the monitoring task.
  - There is no identified research design, sampling procedures, or purpose for any survey or monitoring effort.
- Seasonal, problematic complex/steep bathymetry, or habitat avoidance.
  - The habitat requirements for most of the marine mammals in the HRC are unknown. Accordingly, there is no information available on possible alternative exercise locations or environmental factors that would otherwise be less important to marine mammals in the Southern Californian Islands. In addition, exercise locations were very carefully chosen by exercise planners based on training requirements and the ability of ships and submarines to operate safely. Moving the exercise events to alternative locations would impact the effectiveness of the training and has no known utility.
- Using active sonar with output levels as low as possible consistent with mission requirements and use of active sonar only when necessary.
  - Operators of sonar equipment are always cognizant of the environmental variables affecting sound propagation. In this regard the sonar equipment power levels are always set consistent with mission requirements.
  - Active sonar is only used when required by the mission since it has the potential to alert opposing forces to the sonar platform's presence. Passive sonar and all other sensors are used in concert with active sonar to the maximum extent practical when available and when required by the mission.
- Suspending the exercise at night, periods of low visibility, and in high sea-states when marine mammals are not readily visible.
  - It is imperative that the Navy be able to operate at night, in periods of low visibility, and in high sea-states. The Navy must train as we are expected to fight, and adopting this prohibition would eliminate this critical military readiness requirement.
- Scaling down the exercise to meet core aims.
  - Training exercises are always constrained by the availability of funding, resources, personnel, and equipment with the result being they are always scaled down to meet only the core requirements.
- Limiting the active sonar event locations.
  - Areas where events are scheduled to occur are carefully chosen to provide for the safety of operations and to allow for the realistic tactical development of the exercise scenario. Otherwise limiting the exercise to a few areas would adversely impact the effectiveness of the training.

  - Limiting the exercise areas would concentrate all sonar use, resulting in unnecessarily prolonged and intensive sound levels vice the more transient exposures predicted by the current planning that makes use of multiple exercise areas.
- Passive Acoustic Monitoring.
  - As noted in the preceding section, passive detection capabilities are used to the maximum extent practicable consistent with the mission requirements to alert exercise participants to the presence of marine mammals in an event location.
- Using ramp-up to attempt to clear an area prior to the conduct of exercises.
  - Ramp-up procedures involving slowly increasing the sound in the water to necessary levels, have been utilized in other non-Department of Defense activities. Ramp-up procedures are not a viable alternative for training exercises, as the ramp-up would alert opponents to the participants' presence and not allow the Navy to train, thus adversely impacting the effectiveness of the military readiness activity.
  - Ramp-up for sonar as a mitigation measure is also an unproven technique. The implicit assumption is that animals would have an avoidance response to the low power sonar and would move away from the sound and exercise area; however, there is no data to indicate this assumption is correct. Given there is no data to indicate that this is even minimally effective and because ramp-up would have an impact on the effectiveness of the military readiness activity, it was eliminated from further consideration.
- Reporting marine mammal sightings to augment scientific data collection.
  - Ships, submarines, aircraft, and personnel engaged in training events are intensively employed throughout the duration of the exercise. Their primary duty is accomplishment of the exercise goals, and they should not be burdened with additional duties, unrelated to that task. Any additional workload assigned that is unrelated to their primary duty would adversely impact the effectiveness of the military readiness activity they are undertaking.

11.2 Underwater Detonations

To ensure protection of marine mammals and sea turtles during underwater detonation training and Mining Operations, the operating area must be determined to be clear of marine mammals and sea turtles prior to detonation. Implementation of the following mitigation measures continue to ensure that marine mammals would not be exposed to temporary threshold shift (TTS), PTS or injury from physical contact with training mine shapes during Major Exercises.

11.2.1 Demolitions (DEMOs) and Mine Countermeasure (MCM) Operations (Up to 20 lb)

Exclusion Zones

All mine warfare and mine countermeasure (MCM) operations involving the use of explosive charges must include exclusion zones for marine mammals and sea turtles to prevent physical and/or acoustic effects to those species. These exclusion zones shall extend in a 700-yard arc radius around the detonation site.

Pre-Exercise Surveys

For MCM operations, pre-exercise survey shall be conducted within 30 minutes prior to the commencement of the scheduled explosive event. The survey may be conducted from the surface, by divers, and/or from the air, and personnel shall be alert to the presence of any marine mammal or sea turtle. Should such an animal be present within the survey area, the exercise shall be paused until the animal voluntarily leaves the area.

Post-Exercise Surveys

Surveys within the same radius shall also be conducted within 30 minutes after the completion of the explosive event.

Reporting

Any evidence of a marine mammal or sea turtle that may have been injured or killed by the action shall be reported immediately to Commander, Pacific Fleet and Commander, Navy Region Southwest, Environmental Director.

Mining Operations

Mining Operations involve aerial drops of inert training shapes on floating targets. Aircrews are scored for their ability to accurately hit the target. Although this operation does not involve live ordnance, marine mammals have the potential to be injured if they are in the immediate vicinity of a floating target; therefore, the safety zone shall be clear of marine mammals and sea turtles around the target location. Pre- and post - surveys and reporting requirements outlined for underwater detonations shall be implemented during Mining Operations. To the maximum extent feasible, the Navy shall retrieve inert mine shapes dropped during Mining Operations.

11.2.2 SINKEX, GUNEX, MISSILEX, and BOMBEX

The selection of sites suitable for sinking exercises (SINKEXs) involves a balance of operational suitability, requirements established under the MPRSA permit granted to the Navy (40 CFR 229.2), and the identification of areas with a low likelihood of encountering endangered species act (ESA) listed species. To meet operational suitability criteria, locations must be within a reasonable distance of the target vessels’ originating location. The locations should also be close to active military bases to allow participating assets access to shore facilities. For safety purposes, these locations should also be in areas that are not generally used by non-military air or watercraft. The MPRSA permit requires vessels to be sunk in waters which are at least 1000 fathoms (3000 m) deep and at least 50 nm from land.

In general, most listed species prefer areas with strong bathymetric gradients and oceanographic fronts for significant biological activity such as feeding and reproduction. Typical locations include the continental shelf and shelf-edge.

Although the siting of the location for the exercise is not regulated by a permit, the range clearance procedures used for gunnery exercise (GUNEX), missile exercise (MISSILEX), and bombing exercise (BOMBEX) are the same as those described below for a SINKEX.

Range Clearance Procedures

The Navy has developed range clearance procedures to maximize the probability of sighting any ships or protected species in the vicinity of an exercise, which are as follows:

1. All weapons firing would be conducted during the period 1 hour after official sunrise to 30 minutes before official sunset.
2. Extensive range clearance operations would be conducted in the hours prior to commencement of the exercise, ensuring that no shipping is located within the hazard range of the longest-range weapon being fired for that event.
3. Prior to conducting the exercise, remotely sensed sea surface temperature maps would be reviewed. SINKEX and air to surface missile (ASM) Operations would not be conducted within areas where strong temperature discontinuities are present, thereby indicating the existence of oceanographic fronts. These areas would be avoided because concentrations of some listed species, or their prey, are known to be associated with these oceanographic features.
4. An exclusion zone with a radius of 1.0 nm would be established around each target. This exclusion zone is based on calculations using a 449 kg H6 NEW high explosive source detonated 5 feet below the surface of the water, which yields a distance of 0.85 nm (cold season) and 0.89 nm (warm season) beyond which the received level is below the 182 dB re: 1 Pa sec^2 threshold established for the *WINSTON S. CHURCHILL* (DDG 81) shock trials. An additional buffer of 0.5 nm would be added to account for errors, target drift, and animal movements. Additionally, a safety zone, which extends from the exclusion zone at 1.0 nm out an additional 0.5 nm, would be surveyed. Together, the zones extend out 2 nm from the target.
5. A series of surveillance over-flights would be conducted within the exclusion and the safety zones, prior to and during the exercise, when feasible. Survey protocol would be as follows:
    a. Overflights within the exclusion zone would be conducted in a manner that optimizes the surface area of the water observed. This may be accomplished through the use of the Navy's Search and Rescue (SAR) Tactical Aid (TACAID). The SAR TACAID provides the best search altitude, ground speed, and track spacing for the discovery of small, possibly dark objects in the water based on the environmental conditions of the day. These environmental conditions include the angle of sun inclination, amount of daylight, cloud cover, visibility, and sea state.

    b. All visual surveillance activities would be conducted by Navy personnel trained in visual surveillance. At least one member of the mitigation team would have completed the Navy's marine mammal training program for lookouts.

    c. In addition to the overflights, the exclusion zone would be monitored by passive acoustic means, when assets are available. This passive acoustic monitoring would be maintained throughout the exercise. Potential assets include sonobuoys, which can be utilized to detect any vocalizing marine mammals (particularly sperm whales) in the vicinity of the exercise. The sonobuoys would be re-seeded as necessary throughout the exercise. Additionally, passive sonar onboard submarines may be utilized to detect any vocalizing marine mammals in the area.

The OCE would be informed of any aural detection of marine mammals and would include this information in the determination of when it is safe to commence the exercise.

d. On each day of the exercise, aerial surveillance of the exclusion and safety zones would commence two hours prior to the first firing.

e. The results of all visual, aerial, and acoustic searches would be reported immediately to the OCE (Officer Conducting the Exercise). No weapons launches or firing would commence until the OCE declares the safety and exclusion zones free of marine mammals and threatened and endangered species.

f. If a protected species observed within the exclusion zone is diving, firing would be delayed until the animal is re-sighted outside the exclusion zone, or 30 minutes has elapsed. After 30 minutes, if the animal has not been re-sighted it would be assumed to have left the exclusion zone. This is based on a typical dive time of 30 minutes for traveling listed species of concern. The OCE would determine if the listed species is in danger of being adversely affected by commencement of the exercise.

g. During breaks in the exercise of 30 minutes or more, the exclusion zone would again be surveyed for any protected species. If protected species are sighted within the exclusion zone, the OCE would be notified, and the procedure described above would be followed.

h. Upon sinking of the vessel, a final surveillance of the exclusion zone would be monitored for two hours, or until sunset, to verify that no listed species were harmed.

6. Aerial surveillance would be conducted using helicopters or other aircraft based on necessity and availability. The Navy has several types of aircraft capable of performing this task; however, not all types are available for every exercise. For each exercise, the available asset best suited for identifying objects on and near the surface of the ocean would be used. These aircraft would be capable of flying at the slow safe speeds necessary to enable viewing of marine vertebrates with unobstructed, or minimally obstructed, downward and outward visibility. The exclusion and safety zone surveys may be cancelled in the event that a mechanical problem, emergency search and rescue, or other similar and unexpected event preempts the use of one of the aircraft onsite for the exercise.

7. Every attempt would be made to conduct the exercise in sea states that are ideal for marine mammal sighting, Beaufort Sea State 3 or less. In the event of a 4 or above, survey efforts would be increased within the zones. This would be accomplished through the use of an additional aircraft, if available, and conducting tight search patterns.

8. The exercise would not be conducted unless the exclusion zone could be adequately monitored visually.

9. In the unlikely event that any listed species are observed to be harmed in the area, a detailed description of the animal would be taken, the location noted, and if possible, photos taken. This information would be provided to National Oceanic and Atmospheric

Administration (NOAA) Fisheries via the Navy's regional environmental coordinator for purposes of identification.

10. An after action report detailing the exercise's timeline, the time the surveys commenced and terminated, amount, and types of all ordnance expended, and the results of survey efforts for each event would be submitted to NOAA Fisheries.

11.3 Conservation Measures

The Navy will continue to fund ongoing marine mammal research in the Hawaiian Islands. Results of conservation efforts by the Navy in other locations will also be used to support efforts in the Hawaiian Islands. The Navy is coordinating both short and long term monitoring/studies of marine mammals on various established ranges and operating areas to determine the response of marine mammals to Navy sound sources and the effectiveness of mitigation measures:

- Coordinating with NMFS to conduct surveys within the selected Hawaiian Islands Operating Area as part of a baseline monitoring program.
- Implementing a long-term monitoring program of marine mammal populations in the Hawaiian Islands Operating Area, including evaluation of trends.
- Implementing a monitoring program of marine mammals in the HRC during training exercises.
- Continuing Navy research and Navy contribution to university/external research to improve the state of the science regarding marine species biology and acoustic effects.
- Sharing data with NMFS and via the literature for research and development efforts.

The Navy has contracted with a consortium of researchers from the University of Hawaii, LGL, Ltd., Greeneridge Scientific, University of St. Andrews, and SRS Technologies to conduct a pilot study analysis and develop a survey and monitoring plan that lays out the recommended approach for surveys (aerial/shipboard, frequency, spatial extent, etc.) and data analysis (standard line-transect, spatial modeling, etc.) necessary to establish a baseline of protected species distribution and abundance and monitor for changes that might be attributed to ASW operations within the HRC. The Research Design for the project will be utilized in implementing similar programs in the Southern California ASW operations areas.

12. MINIMIZATION OF ADVERSE EFFECTS ON SUBSISTENCE USE

Based on the discussions in Chapter 8, there are no impacts on the availability of species or stocks for subsistence use.

13. MONITORING AND REPORTING MEASURES

A Letter of Instruction, Mitigation Measures Message, or Environmental Annex to the Operational Order, will be issued prior to each exercise to further disseminate the personnel training requirement and general marine mammal mitigation measures including monitoring and reporting. The Navy will continue to fund marine mammal research as outlined in this Chapter and Chapter 14.

13.1 Marine Species Monitoring Plans

The Navy is developing two separate marine species monitoring plans: a general short-term monitoring plan that can be used for different exercises in a various locations; and long-term monitoring plans specific to a Navy range complex/geographic area. Depending on the type of exercise and the area it is conducted in, the operators can choose the appropriate monitoring elements from this plan.

13.1.1 Short-Term Exercise Monitoring Plan

The Navy is developing a monitoring program whose study design provides the power to estimate:

- The number of fin whales, humpback whales, sei whales, and sperm whales that are exposed to mid-frequency sonar within 1,000 yds (initial safety zone for 6 dB power down) during anti-submarine warfare (ASW) Exercises.
- The behavioral or other observable responses of any of these whales that are exposed to mid-frequency sonar at these received levels.
- The effectiveness of the Navy's entire suite of mitigation measures at avoiding exposing any of these whales to mid-frequency sonar.
- The effectiveness of the different measures contained in the Navy's suite of mitigation measures at avoiding exposing any of these whales to mid-frequency sonar.

This monitoring plan is being developed to address the concerns of the National Marine Fisheries Service (NMFS) and to supplement a long-term monitoring plan which is also under development. It is understood that the monitoring plans will likely require further revision in an iterative process as the methodology is refined based on the data that is returned.

The following are the specific elements that make up the short-term exercise monitoring plan.

Navy Lookout Watchstander Reports

The Navy will use its onboard lookout watchstanders as observers on Navy vessels conducting mid-frequency active sonar operations. This process is in accordance with the measures outlined in the *DoD National Defense Exemption from Requirements of the Marine Mammal Protection Act for Certain DoD Military Readiness Activities that Employ Mid-Frequency Active Sonar or Improved Extended Echo Ranging Sonobuoy*. 23 Jan 2007 (NDE), and the Navy mitigation measures as outlined in the undersea warfare exercise (USWEX) and Composite Training Unit Exercise/Joint Task Force Exercise environmental assessment/overseas environmental assessment (COMPTUEX/JTFEX EA/OEAs).

The Navy believes that due to their proximity to the sighting (i.e., on the mid-frequency active sonar ship), these reports represent the best source of sighting data when correlated to concurrent mid-frequency active sonar use. Furthermore, given the depth of individual training, supervision, and permanent presence during sonar operations, non-sonar events, and transits, the Navy believes that current lookout watchstander reporting represents the best available information source that directly answers questions as to marine mammal presence or absence on our ranges concurrent with naval ship presence, and potential response or non-response to mid-frequency active sonar. Up to five dedicated watchstanders, on duty 24/7 during an at-sea exercise, report all marine mammal sightings observed regardless of whether sonar was operational or not. While species level of detail is still broad, certain species groups are easy to identify (dolphins, pinnipeds, whales). Standard Navy Operating Procedures (SOP) as applied in an exercise specific Letter of Instruction (LOI) to participants and serves as a governing factor in both exercise specific observation reporting, and mid-frequency active sonar mitigation.

Included would be a validation of the watchstander's ability to detect and accurately determine the distance of marine mammals encountered during training exercises.

Strategic Anti-Submarine Warfare (ASW) Aerial Sighting Reports

Strategic ASW assets used during some ASW exercises include the P-3C Orion Maritime Patrol Aircraft. These planes are often equipped with advanced optical sensors and may occasionally report geo-referenced marine mammal sightings. As part of this monitoring plan, these reports when made in context of an exercise will be collected and added as additional sighting information to exercise After Action reports (AAR). While the Navy acknowledges that species level detail and proximity to mid-frequency active sonar following exposure may not be available, this information will serve as additional data points on marine mammal occurrence within the operating area associated with ASW events.

Navy Imagery Teams/Sensors Observations

Most Navy ships have a collateral duty team whose task is to respond to sightings of high valued targets and collect digital imagery for intelligence collection purposes. For this plan, the US Navy proposes to test the fly-away nature of these teams to respond to select marine mammal sightings made specifically during mid-frequency active sonar use (i.e., large whales with potential of Endangered Species Act (ESA) status, blue, fin, humpback, sei, and sperm whales. The goal would be to take imagery of animals sighted within any of the mitigation zones (200, 500, or 1,000 yards) when mid-frequency active sonar is being used or secured, and forward these to Navy or Navy-contract or marine biologists for species identification, and eventual relations to initial watchstander report.

Given a moving vessel, moving animals, and the response time need for these teams to deploy imagery gear, it is unknown if imagery can be collected in a timely manner, or will contain sufficient level of detail to enable exact species identification. Review of imagery will be conducted and reports on quality and success or failure in species identification.

Navy Range Passive Acoustic Monitoring

The Navy will use the underwater acoustic arrays at two facilities to collect marine mammal vocalizations in support of the exercise monitoring plan.

Several Navy Ranges are equipped with instrumented underwater hydrophone arrays allowing for acoustic data to be collected from large inshore and offshore areas. Hydrophones vary in acoustic response so they can be used to capture both broad band and high frequency recordings on the range. However, in order not to capture classified source signatures, the Navy will only collect data before and after exercises for validation of species present, and to note if there are statistically different changes to vocalization rates. For species with known acoustic signatures (blue, fin, humpback, and sperm whales), analysis may provide an index of abundance and records of animal movements. Data that are collected one day before and one day after the sonar operations may provide important information not apparent through other methods.

It should be noted, these underwater instrumented ranges represent only a small area of the overall ocean and exercise areas, so data collected can only be associated with events specifically scheduled on these ranges.

Third Party Visual Observations from Navy Platforms during Exercises

An independent observer will be deployed from either a mid-frequency active sonar or non mid-frequency active sonar platform on a very limited proof of concept experiment. The goal of this monitoring element would be to augment Navy lookout reports during mid-frequency active sonar operation with detailed species level identification, biological response observations, and supplementary imagery taken by the attached biologists. If species level identification of ESA-listed species can be made successfully during this event, it would add weight of evidence to discussions about mid-frequency active sonar effects or lack of effects on ESA listed species.

Of all of the Navy's proposed monitoring elements, this one will be the most difficult to consistently execute.

Berthing space on almost all mid-frequency active sonar ships is very limited, so embarking an observer is not currently proposed for mid-frequency active sonar ships during Major Exercises. With exercise lengths of one to three weeks, and given limited at sea transfer, this option would mean that even if berthing is available, a biologist would have to depart with the ship as it leaves port and stay the duration of the exercise. At best, berthing on non-mid-frequency active sonar (i.e. carrier and amphibious assault ships) may be possible but distance from mid-frequency active sonar operations may not provide the quality data desired.

Third Party Visual Observations from Navy Platforms during Unit Level Training Exercises

There may be potential for adding civilian biologist or survey teams to a vessel engage in single ship, unit-level training (DDG class ships, CG class ships) as a proof of concept demonstration. An independent observer will be deployed from either a mid-frequency active sonar or non-mid-frequency active sonar platform. The goal of this monitoring element would be to augment Navy lookout reports during mid-frequency active sonar operation with detailed species level identification, biological response observations, and supplementary imagery taken by the attached biologists.

Third Party Surface Vessel or Aerial Surveys Pre-and Post Exercise

If a sufficient geographic area for ASW events can be identified, another monitoring element to augment this plan is to conduct 3rd party surface vessel or aerial surveys either before or immediately after the exercise.

Ship-based surveys will conduct standard NMFS-protocol surveys of selected areas prior to an exercise in order to assess likely species composition encountered by exercise participants (Barlow et al. 2003). The survey could set a baseline standard of existing conditions, although within the different range areas variations of marine mammal occurrence can be anticipated due to subtle, small scale changes in oceanographic conditions and prey availability.

Aerial surveys will be conducted with a twin engine aircraft due to range, safety, and on-station time. Aircraft can cover a larger area more quickly than an observation vessel and could be used to search for potentially injured, dead, stranded animals on shore or in coastal shallow waters after an exercise.

Stranded Animal Protocol

As part of the monitoring plan, the existing stranded animal protocols will be expanded to include necropsies of stranded animals both during and outside of when exercises are conducted, a quick response to strandings to determine the cause if possible, and for live strandings be able to conduct hearing tests.

Quick mobilization of efforts to collect and necropsy stranded animals is important to determining the cause of the stranding. In warm climates animals can decompose quickly limiting the amount of data that can be collected and compromising the determination the cause of the stranding.

In addition to doing necropsies on stranded animals found during Navy exercises, necropsies would also be conducted on animals that stranded during periods of no Navy exercises. This would help to establish a baseline of stranding causes.

For many species of marine mammals, particularly for the larger whales and beaked whales, there is no audiogram information. Audiograms could be determined in live stranded animals by recording evoked potentials produced in response to an acoustic input. This procedure can be conducted non-invasively using skin electrodes and is commonly used by several researchers.

Elements not Included in the NDE

The Navy will evaluate the effectiveness of its program elements to assess the reliability its observations and the data gathered using these program elements. The data will be evaluated for:

- Ease of implementation
  - Were operators able to implement these elements effectively?
  - What were the implementation impacts on the operators (e.g., are there any national security impacts)?
- Cost of implementation
  - Is the effectiveness of the element equivalent to the cost of obtaining the data (e.g., cost benefit analysis)?

- Quality of data obtained
  - Did the elements obtain identification of species and detect animals that were exposed?
  - Were techniques beyond ones required in the NDE able to detect additional marine mammal exposure beyond the methods used in the NDE?

Additional Marine Mammal Research Sources

There are other potential marine mammal data providers in addition to the Navy that will be investigated for collaboration with this Exercise Marine Monitoring Plan. The goal is to leverage ongoing NMFS permitted studies, academic research and surveys, and new Navy detection technologies that may be of use as data augments to this plan.

Regional and Academic Research Programs

Within Hawaii and SOCAL, NMFS permitted marine mammal surveys, acoustic monitoring, and animal tagging is being conducted or planned for the next two years.

Tagging, for instance, is an important research tool for directly determining marine mammal movement, diving behavior, swim parameters (velocity, direction of travel, foraging depth), as well as potentially recording anthropogenic sound level exposure for an animal. Tagging typically allows for longer-term monitoring of individuals than visual and acoustic monitoring can provide.

In conjunction with other scientists and NMFS, the Navy will explore integrating tagging and additional survey results into the Exercise Monitoring Plan if data is available in areas associated with Navy operations.

Navy Funded R&D Technologies

New research and development technologies in marine mammal research may be considered in the future (late FY07 and FY08), but given the relatively recent nature of some technology, it is unknown at this time what value added data will be available to supplement exercise specific monitoring reports. Information from research and development technologies may, however, generate relevant biological information about marine mammal distribution and by inference impacts, or lack of impacts, from mid-frequency sonar operations. Examples include deployment of Autonomous Recording Packages (ARP) to determine presence/absence of vocalizing marine mammals, and application of various Office of Naval Research (ONR) funded marine mammal detection technologies if found to be mature enough for at-sea use (e.g. autonomous underwater gliders, surface radar detection of marine mammals, etc.).

13.1.2 Long-Term Marine Species Monitoring Plan

The Navy is developing long-term monitoring plans to determine behavioral and population level changes to marine mammals within Navy ranges. These plans will continue or initiate studies of abundance, distribution, habitat utilization, etc for sensitive species of concern using visual surveys, passive and acoustic monitoring, radar and data logging tags (satellite or radio linked to record data on acoustics, diving and foraging behavior, and movements). They will determine the geographic and temporal extent of key habitats and comprehensive baseline information to account for natural perturbations such as El Niño events as well as use observational data and baseline information to determine the spatial and temporal extent of reactions to Navy operations, or indirect effects from changes in prey availability and distribution.

The long-term monitoring plan for the Hawaii Range Complex (HRC) is currently in development.

Survey Modeling

To determine if the effects of Navy activities on marine mammal populations can be detected over an extended period (i.e. 5 years), the movements and surveys of different species groups of large marine fauna within the region of interest will be simulated. The simulations are individual-based and will model the movements of the animals at daily intervals. Because cetacean response to acoustic trials is to a large degree unknown, simulations will include several levels of response which are considered extreme. If no effect is detected under these extreme scenarios then no effect would be detectable under less extreme scenarios. Modeling will help determine the level of effort needed to detect long-term population trends.

The simulations will involve:

- Simulating the populations of interest including simulating the distribution, abundance and dynamics of the population and simulating the animals' response to acoustic activity
- Simulation of the observation process (data gathering by aerial or vessel based line transect survey)
- Analysis of the observed data.

The modeling will assist in determining how, when, and where to conduct vessel-based and aerial surveys.

Outline for the Hawaii Range Complex Long-term Marine Species Monitoring Plan

The Hawaii Range Complex (HRC) Marine Species Monitoring Plan will include the following Chapters:

Chapter 1 - Introduction

Chapter 2 - Hawaii Range Complex Background

- Description of the area and current naval activities occurring in the OPAREA

Chapter 3 – Marine Species of Concern in the Hawaii Range Complex

- Discussion of current densities of marine species (endangered and non-endangered) in the OPAREA
- Include tables for marine mammals and sea turtles in Chapter 3 detailing:
    - Common name
    - Scientific name
    - Status (Endangered/Threatened)
    - Occurrence in OPAREA (i.e., rare)

- Paragraph descriptions of animals in the OPAREA
- Discussion of other species (i.e., fish)

Chapter 4 – Monitoring Plan

- Initial paragraph in each section will provide comparison/contrast discussion that will include:
  - What species the platform will monitor best
  - What species are not expected to be monitored
  - Anticipated limitation in the OPAREA
  - Recommendation for that platform

Visual Observations

Vessel-based Surveys

Vessel-based surveys are the primary method for marine species monitoring. Surveys may also focus on a particular type of habitat or areas suspected to be used or regularly used by priority species.

Standard line-transect surveys are adaptable to weather conditions, nature and location of monitoring area, presence/absence of priority species, etc. They generally follow established standard line-transect protocols designed to obtain marine mammal density and distribution data (e.g., Kinsey et al., 2000; Ferguson and Barlow, 2001; Barlow et al., 2004).

During the surveys, the scientific team can collect general observations during transects following scan sampling protocol (e.g., Altmann, 1974; Smultea, 1991) including general behavior (i.e., behavioral state), any conspicuous individual behaviors (e.g., breach, tail slap, porpoising, etc.), orientation/direction of travel, estimated speed of movement, etc. These data would be collected during surveys without breaking from course. Thus, the accuracy and type of information collected will depend on the distance to the observed animals and is limited by the brevity of the observation time while in transit.

During surveys of marine mammals, oceanographic data (e.g., sea surface temperature, chlorophyll a, etc.) and prey abundance and distribution data would be collected to assess other environmental factors that may affect marine mammal abundance and distribution.

Upon encountering a priority species (ESA species or beaked whales), the vessel can break from transect to conduct focal behavioral observations (e.g., Altmann, 1974; Smultea, 1991); follow the focal group/animal as long as feasible (at discretion of survey leader), then return to line transect survey.

For focal and general observations, information will be collected on the species, group size, number of calves, position (lat/long), start and end times of observations, surface behavioral state activity, individual behaviors, distance from the vessel, direction and speed of travel relative to vessel, position of cetaceans, observers/recorders, photos/video taken, and visibility conditions. For focal observations, more detailed information will be collected on individual behaviors (*e.g.*, spyhop, breach, head slap, tail slap, etc.), blow and dive times for large whales, etc. Environmental parameters such as wind speed, air and water temperature, sea state, swell height, etc., will also be recorded every 30 minutes or when conditions change.

Aerial Surveys

Aerial surveys can be used before and after exercises to monitor animal distribution, occurrence, focal and scan behavior/orientation relative to exercise and related activities, etc. For safety reasons, aerial surveys may not be used in the exercise area during operations.

Aerial surveys would be conducted with a twin engine aircraft with good range otherwise it will be limited by the distance out to exercise area and time it can remain on station. A larger aircraft with greater range and safety (e.g., Twin Otter) could be used to conduct transect and focal observations in far offshore areas such as Navigator Seamounts. Aircraft can cover a larger area more quickly than an observation vessel.

Aircraft could be used to search for potentially injured, dead, stranded animals on shore and/or coastal shallow waters during and after exercise. Any observations conducted from aircraft during the exercise must be well outside the operations footprint.

Limitations of aircraft are the amount of time they can remain in the exercise area compared to a ship, can not be used for night time observations, and limited by the potentially long distances out to the exercise areas. As well, the survey speed results in missing a large proportion of long-diving animals (e.g., beaked whales, sperm whales), and species misidentification is more of a problem due to the large distance between the observers and the animals, as well as the speed of the survey platform.

Photo Identification

Photo identification (ID) is important to address longer-term aspects of the marine mammal abundance in an OPAREA. Photo ID can assess whether identified animals remain and survive/persist in an OPAREA, reproduce, etc. Comparison of photographs of the identifying marks on dorsal fins or tail flukes, rake marks, scars etc will be use to assess residency or re-sighting of individual animals (McSweeney et al., 2007).

Acoustic Monitoring

Passive Acoustic Monitoring

Acoustic monitoring is important for identifying vocalizing animals, particularly cryptic and long diving species that may not be regularly seen by visual observers. Passive acoustic monitoring provides monitoring capabilities during poor visual observation conditions and during darkness. Passive acoustics allows monitoring for presence/absence as well as changes in vocalizing behavior before, during, and after any event. Passive Acoustic Monitoring systems can detect the presence of marine mammals in an area, location, direction of travel and changes in vocalization (i.e. louder calls in response to masking).

Towed Hydrophone Arrays

Towed hydrophone arrays are capable of detecting and localizing vocalizing marine mammals for observation ship. A towed array capable of detecting low- frequency baleen whales to high-frequency beaked whales is preferable. In addition, sonobuoys could be deployed in areas where the exercise is known to use and moored acoustic buoys could be deployed in areas of potential exercise activity for several weeks at a time.

A towed hydrophone array is towed from the boat as and can detect and localize marine mammals that vocalize. The ability of the array to detect marine mammals will depend on the speed of the boat, length of the array and the frequency range of the hydrophones. The array would need to detect vocalizations in the range of very low frequency for baleen whales (< 1000 Hz; McDonald and Fox, 1999; Mellinger and Clark, 2003) to relatively high frequency for odontocetes such as sperm whales (up to 30 kHz; Watkins 1980). The use of two simultaneously deployed arrays can also allow more accurate localization and determination of diving patterns.

Use of Navy Instrumented Acoustic Range

Two Pacific Navy Ranges, the Pacific Missile Range Facility (PMRF) and Southern California ASW Range, are equipped with instrumented underwater hydrophone arrays allowing for acoustic data to be collected from large inshore and offshore areas. Hydrophones vary in acoustic response so they can be used to capture both broad and high frequency recordings on the range. However, in order not to capture classified source signatures, the Navy will only collect data before and after exercises for validation of species present, and to note if there are statistically different changes to vocalization rates. For species with known acoustic signatures (blue, fin, humpback, and sperm whales), analysis may provide an index of abundance and records of animal movements. Data that are collected one day before and one day after the sonar operations may provide important information not apparent through other methods.

It should be noted, these underwater instrumented ranges represent only a small area of the overall HRC and SOCAL ocean and exercise areas, so data collected can only be associated with events specifically scheduled on these ranges.

Procedures for collecting acoustic data at the PMRF range are already in place with two days per month of recordings being saved.

Behavioral Monitoring

Knowledge of the factors determining behavioral responses of marine mammals to E&P sound sources would provide important information for the risk assessment process for operations in sensitive areas. Data could be used for example to assist with identifying sensitive species, and planning mitigation strategies for critical habitat areas.

Changes in animal distribution, distances traveled, and foraging behavior in response to Navy sound sources compared to habitat range and natural variability would provide data needed to assess biological significance of animal avoidance/displacement reactions. Data could be used to enhance the predictive capabilities of sound exposure models by defining animal movement in response to sound sources.

Monitor animal movements in specified geographical regions of interest using visual observations of marine mammal observers (MMOs), telemetry / tagging methods, and fixed passive acoustic monitoring (PAM) systems. Determine geographic and temporal extent of behaviors to Navy operations (e.g. sonar, underwater detonations, shipping). In order to determine and quantify a significant response, it will also be necessary to establish baseline and natural variation. Measure behavioral reaction to sound exposure, including movements associated with key activities and habitat abandonment. Indirect impacts on prey distribution - track the movements of fish, squid etc in response to sound sources at different levels. Quantify foraging success. Impacts on breeding including reproductive animals moving out of critical area, decreased vocalization used in breeding behavior, dispersal of spawning events, stock recruitment or relative reproduction in following years.

Tagging of Species

Tagging is an important tool for directly determining the movement and diving behavior of cetaceans. Sensors can be used that detect swim velocity, direction of travel, foraging and record the sound level that the animal is exposed to. From position and movement data residency patterns and habitat use can be determined. In association with other techniques (biopsies, passive acoustic monitoring, photo ID, mark recapture) information of population structure can be determined.

Tagging typically allows for longer-term monitoring of individuals than visual and acoustic monitoring. Longer-term monitoring is important for assessing survival, fitness, long-term effects, resident populations, etc. (Photo ID also important for this aspect, to assess whether ID'd animals stay and survive/persist in an exercise area). Several types of tags utilizing satellite or very high frequency (VHF) tracking, the ability to record sound and various sensors to record the animals behavior or environmental parameters.

Tagging cetaceans for long periods of time (e.g., > months) is problematic due to attachment issues. Long-duration (e.g., > 1-2 months) tags on small cetaceans can typically only be deployed by capturing animals. Long-duration (e.g., > 1-2 months) tags on large cetaceans can be deployed using sub-dermal tags, with the majority of the tag body below the surface of the skin with only the antenna exposed, to reduce drag. Medium-duration tags (e.g., 1-8 weeks) that provide location-only have been remotely deployed on mid-size cetaceans, including Cuvier's beaked whales, Blainville's beaked whales (Baird et al. 2007), It is not currently possible to deploy medium-term or long-term tags on mid-size cetaceans that provide more than location-only data. Incorporating sensors that record acoustics or behavior (e.g., dive depths) is not possible on medium-term or long-term tags due to the increase in size (and thus drag), as well as transmission limitations of data to satellites.

Acoustic recording time depth recorders would be the preferred tag as these can record received sound levels the tagged animal was exposed to as well as the animal's own vocalizations or those of conspecifics, depth, time, location, orientation, etc. tagging would be problematic with long-ranging species that may migrate out of the OPAREA.

Monitoring During and After Naval Operations

Most monitoring during and directly following naval operations in the Hawaii OPAREA will be addressed in exercise-specific, short-term monitoring plans. The following is a brief discussion of pre-operation, concurrent operation, and post-operation monitoring.

The primary marine species monitoring technique to use during naval operations is vessel-based visual-acoustic surveys. Combining visual-acoustic methods maximizes the ability to detect marine mammals. For example, passive acoustic data can be collected during rough seas and darkness when visual observations are severely reduced by poor sighting conditions or are precluded altogether. Another advantage of this combined survey approach is that some cetaceans vocalize but are not seen, some are seen but do not vocalize, while others are both seen and heard. Hence, the two approaches are complimentary in nature (e.g., Smultea et al., 2004; 2005; Barlow and Taylor, 2005; Norris et al., 2005; Barlow and Gisiner, 2006; Potter et al., 2006; Weir et al., 2006). Passive acoustic monitoring techniques are described separately.

In general, the marine species of concern are considered wide-ranging in the Hawaiian Islands and elsewhere, with the possible exception of the humpback whale for short periods during the

Hawaiian wintering season. Thus, these species are unlikely to remain in the same localized area for long periods. Consequently, conducting pre-operation monitoring more than approximately 2 days prior to a scheduled operation is considered of limited value. Therefore, pre-operation monitoring would begin up to 2 days prior to the start of likely operations. Vessel-based surveys would be conducted at a speed of approximately 10 knots (18.5 kilometers/hour) or at the maximum speed possible while towing a hydrophone arrays. Surveys would follow predetermined transect lines whose start position would be randomly selected (Kinsey et al., 2000; Ferguson and Barlow, 2001; Barlow et al., 2004). Transect survey data would be used primarily to assess the presence/absence and distribution of species of interest and thus would not be required to follow the stricter protocol required for density estimates. Survey data will also be useful for assessing long-term patterns of species occurrence and distribution relative to the planned naval operations.

At the discretion of the cruise leader, the ship can go off effort and conduct focal observations on an ESA animal or group of animals that may have been effected by the training operations or had been near the exercise participants. The amount of time spent on the focal animal/group would depend on their behavior and if there was a detectable response to sonar.

The monitoring ship will remain in the area at night but would have to increase the distance to the exercise participants as dictated by concerns for safety. Monitoring would have to rely mostly on passive acoustic monitoring during the night.

Additional Research Methods

Discussion of oceanographic monitoring, other environmental factors, stranding element, etc.

Recommended Approach

Recommendations and proposed various combinations of observation platforms depending on area to be monitored, expected sea state conditions, availability of platform, availability of expertise, etc. including detailed description of what the best suite of platforms would be to accomplish OPAREA monitoring.

Chapter 5 – Research Discussion

- Description of how to evaluate data gathered during recommended survey approach
- Abundance and density from surveys
- Photo ID for historical comparisons
- Discriminant Function Analysis - acoustic
- Reporting Procedures and Protocol – Monitoring results to organization and how to submit

14. RESEARCH

The Navy will continue to fund ongoing marine mammal research in the Hawaiian Islands. Results of conservation efforts by the Navy in other locations will also be used to support efforts in the Hawaiian Islands. The Navy is planning to coordinate long-term monitoring/studies of marine mammals on various established ranges and operating areas:

- Coordinating with National Marine Fisheries Service (NMFS) to conduct surveys within the selected Hawaii Range Complex (HRC) Operating Areas as part of a baseline monitoring program. A long-term monitoring program of marine mammal populations within the HRC, including evaluation of trends.
- Continuing Navy research and Navy contribution to university/external research to improve the state of the science regarding marine species biology and acoustic effects.
- Sharing data with NMFS and via the literature for research and development efforts. The Navy has contracted with a consortium of researchers from Duke University, University of North Carolina at Wilmington, University of St. Andrews, and the NMFS Northeast Fisheries Science Center to conduct a pilot study analysis and develop a survey and monitoring plan that lays out the recommended approach for surveys (aerial/shipboard, frequency, spatial extent, etc.) and data analysis (standard line-transect, spatial modeling, etc.) necessary to establish a baseline of protected species distribution and abundance and monitor for changes that might be attributed to anti-submarine warfare (ASW) operations on the East Coast Underwater Training Range. The Research Design for the project will be utilized in implementing similar programs in the Hawaiian Islands ASW operations areas. A similar research and monitoring project has been initiated in the Hawaiian Islands and the remainder of the Pacific Fleet Operating Areas.

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Appendix A

Effects Modeling Background and Overview

A.1 Energy Flux Density and Underwater Explosives Modeling

A.1.1 BACKGROUND AND OVERVIEW

All marine mammals are protected under the Marine Mammal Protection Act (MMPA). The MMPA prohibits, with certain exceptions, the take of marine mammals in U.S. waters and by U.S. citizens on the high seas, and the importation of marine mammals and marine mammal products into the United States.

The Endangered Species Act of 1973 (ESA) provides for the conservation of species that are endangered or threatened throughout all or a significant portion of their range, and the conservation of their ecosystems. A "species" is considered endangered if it is in danger of extinction throughout all or a significant portion of its range. A species is considered threatened if it is likely to become an endangered species within the foreseeable future. There are marine mammals, already protected under MMPA, listed as either endangered or threatened under ESA, and afforded special protections. Actions involving sound in the water include the potential to harass marine animals in the surrounding waters. Demonstration of compliance with MMPA and the ESA, using best available science, has been assessed using criteria and thresholds accepted or negotiated, and described here.

Sections of the Marine Mammal Protection Act (16 United States Code [U.S.C.] 1361 et seq.) direct the Secretary of Commerce to allow, upon request, the incidental, but not intentional, taking of small numbers of marine mammals by U.S. citizens who engage in a specified activity, other than commercial fishing, within a specified geographical region. Through a specific process, if certain findings are made and regulations are issued, or if the taking is limited to harassment, notice of a proposed authorization is provided to the public for review.

Authorization for incidental takings may be granted if National Marine Fisheries Service (NMFS) finds that the taking will have no more than a negligible impact on the species or stock(s), will not have an unmitigable adverse impact on the availability of the species or stock(s) for subsistence uses, and that the permissible methods of taking, and requirements pertaining to the mitigation, monitoring, and reporting of such taking are set forth.

NMFS has defined negligible impact in 50 Code of Federal Regulations (CFR) 216.103 as an impact resulting from the specified activity that cannot be reasonably expected to, and is not reasonably likely to, adversely affect the species or stock through effects on annual rates of recruitment or survival.

Subsection 101(a)(5)(D) of the MMPA established an expedited process by which citizens of the United States can apply for an authorization to incidentally take small numbers of marine mammals by harassment. The National Defense Authorization Act of 2004 (NDAA) (Public Law 108-136) removed the small numbers limitation and amended the definition of "harassment" as it applies to a military readiness activity to read as follows:

(i) any act that injures or has the significant potential to injure a marine mammal or marine mammal stock in the wild [Level A Harassment]; or

(ii) 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 [Level B Harassment].

The primary potential impact to marine mammals from underwater acoustics is Level B harassment from noise. For explosions, in the absence of any mitigation or monitoring measures, there is a very small chance that a marine mammal could be injured or killed when exposed to the energy generated from an explosive force on the sea floor. Analysis of noise impacts to cetaceans is based on criteria and thresholds initially presented in U.S. Navy Environmental Impact Statements for ship shock trials of the Seawolf submarine and the Winston Churchill (DDG 81; U.S. Department of the Navy, 2001) and the Incidental Harassment Authorization (National Marine Fisheries Service, 2005) and the Letter of Authorization (National Marine Fisheries Service, 2006) for Eglin Air Force Base.

Non-lethal injurious impacts (Level A Harassment) are defined in those documents as tympanic membrane (TM) rupture and the onset of slight lung injury. The threshold for Level A Harassment corresponds to a 50% rate of TM rupture, which can be stated in terms of an energy flux density (EFD) value of 205 decibels (dB) re 1 micropascal squared–second (μPa^2-s). TM rupture is well-correlated with permanent hearing impairment. Ketten (1998) indicates a 30% incidence of permanent threshold shift (PTS) at the same threshold.

The criteria for onset of slight lung injury were established using partial impulse because the impulse of an underwater blast wave was the parameter that governed damage during a study using mammals, not peak pressure or energy (Yelverton, 1981). Goertner (1982) determined a way to calculate impulse values for injury at greater depths, known as the Goertner "modified" positive impulse. Those values are valid only near the surface because as hydrostatic pressure increases with depth, organs like the lung, filled with air, compress. Therefore the "modified" positive impulse thresholds vary from the shallow depth starting point as a function of depth.

The shallow depth starting points for calculation of the "modified" positive impulses are mass-dependent values derived from empirical data for underwater blast injury (Yelverton, 1981). During the calculations, the lowest impulse and body mass for which slight, and then extensive, lung injury found during a previous study (Yelverton et al., 1973) were used to determine the positive impulse that may cause lung injury. The Goertner model is sensitive to mammal weight; such that smaller masses have lower thresholds for positive impulse so injury and harassment will be predicted at greater distances from the source for them. Impulse thresholds of 13.0 and 31.0 pounds per square inch-millisecond (psi-ms), found to cause slight and extensive injury in a dolphin calf, were used as thresholds in the analysis contained in this document.

Level B (non-injurious) Harassment includes temporary (auditory) threshold shift (TTS), a slight, recoverable loss of hearing sensitivity. One criterion used for TTS is 182 dB re 1 μPa^2-s maximum EFD level in any 1/3-octave band above 100 hertz (Hz) for toothed whales (e.g., dolphins). A second criterion, 23 psi, has recently been established by NMFS to provide a more conservative range for TTS when the explosive or animal approaches the sea surface, in which case explosive energy is reduced, but the peak pressure is 1 μPa^2-s is not (Table A-1). NMFS applies the more conservative of these two.

Table A-1. Level A and B Harassment Threshold–Explosives

Threshold Type (Explosives)	Threshold Level
Level A – 50% Eardrum rupture (peak one-third octave energy)	205 dB
Temporary Threshold Shift (TTS) (peak one-third octave energy)	182 dB
Temporary Threshold Shift (TTS) (peak pressure)	23 psi
Level A – Slight lung injury (positive impulse)	13 psi-ms
Mortality – 1% Mortal lung injury (positive impulse)	31 psi-ms

For non-explosive sound sources, Level A Harassment includes marine mammals exposed to an Energy Level (EL) equal to or greater than 215 re 1 μPa^2-s. Marine mammals exposed to ELs of 195 dB re 1 μPa^2-s up to 215 dB re 1 μPa^2-s are assumed to experience TTS, which is Level B harassment (Table A-2).

Table A-2. Level A and B Harassment Threshold–Sonar

Threshold Type (Sonar)	Threshold Level
Level A – Permanent Threshold Shift (PTS)	215 dB
Level B – Temporary Threshold Shift (TTS)	195 dB

Over the past several years, the Navy and the NMFS have worked on developing "dose-functions" to replace the acoustic thresholds used in the past to estimate the probability of marine mammals being behaviorally harassed by received levels of mid-frequency active sonar. Unlike acoustic thresholds, dose-functions assume that the probability of a response depends first on the "dose" (in this case, the received level of sound) and that the probability of a response increases as the "dose" increases. It is important to note that the probabilities associated with dose functions do not represent an individual's probability of responding, they identify the proportion of an exposed population that is likely to respond to an exposure. For the HRC EIS/OEIS modeling the dose function parameters presented in Tables A-3 and A-4 were applied based on the sonar frequency and marine animals modeled.

Table A-3. SPL Dose-Function Parameters for Disturbance of Odontocetes from Sonars and Projectors

Animals	Center Frequency for Sonar or Projector	Dose-Function Mean (SPL*)	Dose-Function Standard Deviation (SPL*)	Cutoff (Standard Deviations and SPL)
Odontocetes (Except Beaked Whales and Harbor Porpoises)	2 – 6 kHz	189 dB	12 dB	-3 (153 dB)
Beaked Whales	2 – 6 kHz	189 dB	12 dB	-4 (141 dB)
Odontocetes (Except Beaked Whales and Harbor Porpoises)	6 –15 kHz	182 dB	10 dB	-3 (152 dB)
Beaked Whales	6 –15 kHz	182 dB	10 dB	-4 (142 dB)
Odontocetes (Except Beaked Whales and Harbor Porpoises)	15 –30 kHz	189 dB	12 dB	-3 (153 dB)
Beaked Whales	15 –30 kHz	189 dB	12 dB	-4 (141 dB)
Odontocetes (Except Beaked Whales and Harbor Porpoises)	30–100 kHz	180 dB	12 dB	-3 (144 dB)
Beaked Whales	30–100 kHz	180 dB	12 dB	-4 (132 dB)

Note: * re 1 μPa. Note that maximum SPL for the day is used to test for exceeding the threshold

Table A-4. SPL Dose-Function Parameters for Disturbance of Pinnipeds and Mysticetes from Sonars and Projectors

Animals	Center Frequency for Sonar or Projector	Dose-Function Mean (SPL*)	Dose-Function Standard Deviation (SPL*)	Cutoff (Standard Deviations and SPL)
Mysticetes (Except North Atlantic Right Whales)	2 –30 kHz	175 dB	10 dB	-3 (145 dB)
Pinnipeds	2 –30 kHz	180 dB	10 dB	-3 (150 dB)
Mysticetes (Except North Atlantic Right Whales)**	30–100 kHz	189 dB	12 dB	-3 (153 dB)
Pinnipeds	30–100 kHz	180 dB	10 dB	-3 (150 dB)

Notes: * re 1 μPa. The Navy used maximum or peak SPL to test for exceeding the threshold
** Because mysticetes are believed to have limited hearing sensitivity in the 30-100 kHz range, they should have behavioral disturbance thresholds no lower than those of odontocetes (who have very good hearing in that range)

The sound sources will be located in an area that is inhabited by species listed as threatened or endangered under the ESA (16 USC §§ 1531-1543). Operation of the sound sources, that is, transmission of acoustic signals in the water column, could potentially cause harm or harassment to listed species.

“Harm” defined under ESA regulations is “…an act which actually kills or injures…” (50 CFR 222.102) listed species. “Harassment” is an “intentional or negligent act or omission which creates the likelihood of injury to wildlife by annoying it to such an extent as to significantly disrupt normal behavioral patterns which include, but are not limited to, breeding, feeding, or sheltering” (50 CFR 17.3).

A.1.2 ACOUSTIC SOURCES

The Hawaii Range Complex (HRC) acoustic sources are categorized as either broadband (producing sound over a wide frequency band) or narrowband (producing sound over a frequency band that that is small in comparison to the center frequency). In general, the narrowband sources in this exercise are Anti-submarine Warfare (ASW) sonars, and the broadband sources are explosives. This delineation of source types has a couple of implications. First, the transmission loss used to determine the impact ranges of narrowband ASW sonars can be adequately characterized by model estimates at a single frequency. Broadband explosives, on the other hand, produce significant acoustic energy across several frequency decades of bandwidth. Propagation loss is sufficiently sensitive to frequency as to require model estimates at several frequencies.

Second, the types of sources have different sets of harassment metrics and thresholds. Energy metrics are defined for both types. However, explosives are impulsive sources that produce a shock wave that dictates additional pressure-related metrics (peak pressure and positive impulse). Detailed descriptions of both types of sources are provided in the following subsections.

A.1.2.1 Sonars

Operations in the HRC involve five types of narrowband sonars. Exposure estimates are calculated for each sonar according to the manner in which it operates. For example, the SQS-53C is a hull-mounted, surface ship sonar that operates for many hours at a time, so it is most useful to calculate and report 53C exposures per hour of operation. The AQS-22 is a helicopter-deployed sonar, which is lowered into the water, pings a number of times, and then moves to a new location. For the AQS-22, it is most helpful to calculate and report exposures per dip. Table A-5 presents each sonar's deployment platform, frequency class, and the metric for reporting.

Table A-5. Active Sonars Employed in the Hawaii Range Complex

Sonar	Description	Frequency Class	Exposures Reported
MK-48	Torpedo sonar	High frequency	Per torpedo
AN/SQS-53C	Surface ship sonar	Mid-frequency	Per hour
AN/SSQ-62	Sonobuoy sonar	Mid-frequency	Per sonobuoy
AN/AQS-22	Helicopter-dipping sonar	Mid-frequency	Per dip

Note that MK-48 source described here is the active pinger on the torpedo; the explosive source of the detonating torpedo is described in the next subsection.

The acoustic modeling that is necessary to support the exposure estimates for each of these sonars relies on 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 $\log_{10}$ [pulse length]), and corrected for source beam width so that it reflects the energy in the direction of the main lobe. The beam pattern correction consists of two terms:

- Horizontal directivity correction: 10 $\log_{10}$ (360 / horizontal beam width)
- Vertical directivity correction: 10 $\log_{10}$ (2 / [$\sin(\theta_1) - \sin(\theta_2)$]), where θ_1 and θ_2 are the 3-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—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 $_w$. $_s$ 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 for each of the active sonars in Table A-6.

Table A-6. Source Description of Hawaii Range Complex Active Sonars

Sonar	Source Depth	Center Freq	Source Level	Emission Spacing	Vertical Directivity	Horizontal Directivity
MK-48	27 m	20 kHz	230 dB	144 m	Omni	Omni
AN/SQS-53C	7 m	3.5 kHz	235 dB	154 m	Omni	240^o Forward-looking
AN/SSQ-62	27 m	8 kHz	201 dB	450 m	Omni	Omni
AN/AQS-22	27 m	4.1 kHz	217 dB	15 m	Omni	Omni

For the sources that are essentially stationary (AN/SSQ-62 and AN/AQS-22), emission spacing is the product of the ping cycle time and the average animal speed.

A.1.2.2 Explosives

Explosives detonated underwater introduce loud, impulsive, broadband sounds into the marine environment. The acoustic energy of an explosive is, generally, much greater than that of a sonar, so careful treatment of them is important, since they have the potential to injure. Three source parameters influence the effect of an explosive: the weight of the explosive warhead, the type of explosive material, and the detonation depth. The net explosive weight (or NEW) accounts for the first two parameters. The NEW of an explosive is the weight of only the explosive material in a given round, referenced to the explosive power of TNT (trinitrotoluene).

The detonation depth of an explosive is particularly important due to a propagation effect known as surface-image interference increasingly. For sources located near the sea surface, a distinct interference pattern arises from the coherent sum of the two paths that differ only by a single reflection from the pressure-release surface. As the source depth and/or the source frequency decreases, these two paths increasingly, destructively interfere with each other, reaching total cancellation at the surface (barring surface-reflection scattering loss). Since most HRC explosive sources are munitions that detonate essentially upon impact, the effective source depths are quite shallow and therefore the surface-image interference effect can be pronounced. In order to limit the cancellation effect (and thereby provide exposure estimates that tend toward the worst case), relatively deep detonation depths are used. Consistent with earlier

VAST/IMPASS modeling, a source depth of one foot is used for gunnery round. For the missile and bombs, a generous source depth of 2 meters (m) is used.

The MK-48 torpedo, on the other hand, detonates immediately below the target's hull. A nominal depth of 50 feet is used as its source depth in this analysis. Table A-7 gives the ordnances of interest in the Hawaii Range Complex, their NEWs, and their expected detonation depths.

Table A-7. Explosive Sources in Hawaii Range Complex

Ordnance	Net Explosive Weight	Detonation Depth
5" Naval gunfire	9.54 lbs	1 ft
76 mm Rounds	1.6 lbs	1 ft
Maverick	78.5 lbs	2 m
Harpoon	448 lbs	2 m
MK-82	238 lbs	2 m
MK-83	574 lbs	2 m
MK-84	945 lbs	2 m
MK-48	851 lbs	50 ft
Demolition Charges	20 lbs	Bottom

Note that MK-48 source described here is the explosive source of the detonating torpedo; the active pinger on the torpedo is described in the previous subsection.

The exposures expected to result from these ordnances are computed on a per in-water explosive basis. The cumulative effect of a series of explosives can often be derived by simple addition if the detonations are spaced widely in time or space, allowing for sufficient animal movement as to ensure that a different population of animals is harassed by each ordnance detonation. This is generally the case with the larger munitions that are precision guided and seldom miss their target, thus detonating above the sea surface.

The cases in which simple addition of the exposure estimates may not be appropriate are addressed by the modeling of a "representative" sink exercise (SINKEX). In a SINKEX, a decommissioned surface ship is towed to a specified deep-water location and there used as a target for a variety of weapons. Although no two SINKEXs are ever the same, a representative case derived from past exercises is described in the *Programmatic SINKEX Overseas Environmental Assessment* (March 2006) for the Western North Atlantic.

In a SINKEX, weapons are typically fired in order of decreasing range from the source with weapons fired until the target is sunk. A torpedo is used after all munitions have been expended if the target is still afloat. Since the target may sink at any time during the exercise, the actual number of weapons used can vary widely. In the representative case, however, all of the ordnances are assumed expended; this represents the worst case of maximum exposure.

The sequence of weapons firing for the representative SINKEX is described in Table A-8. Guided weapons are nearly 100% accurate and are modeled as hitting the target (that is, no underwater acoustic effect) in all but two cases: (1) the Maverick is modeled as a miss to represent the occasional miss, and (2) the MK-48 torpedo intentionally detonates in the water column immediately below the hull of the target. Unguided weapons are more frequently off-target and are modeled according to the statistical hit/miss ratios. Note that these hit/miss ratios are artificially low in order to demonstrate a worst-case scenario; they should not be taken as indicative of weapon or platform reliability.

Table A-8. Representative SINKEX Weapons Firing Sequence

Time (Local)	Event Description
0900	Range Control Officer receives reports that the exercise area is clear of non-participant ship traffic, marine mammals, and sea turtles.
0909	Hellfire missile fired, hits target.
0915	2 HARM missiles fired, both hit target (5 minutes apart).
0930	1 Penguin missile fired, hits target.
0940	3 Maverick missiles fired, 2 hit target, 1 misses (5 minutes apart).
1145	1 SM-1 fired, hits target.
1147	1 SM-2 fired, hits target.
1205	5 Harpoon missiles fired, all hit target (1 minute apart).
1300-1335	7 live and 3 inert MK 82 bombs dropped – 7 hit target, 2 live and 1 inert miss target (4 minutes apart).
1355-1410	4 MK-83 bombs dropped – 3 hit target, 1 misses target (5 minutes apart).
1500	Surface gunfire commences – 400 5-inch rounds fired (one every 6 seconds), 280 hit target, 120 miss target.
1700	MK-48 Torpedo fired, hits, and sinks target.

A.1.3 ENVIRONMENTAL PROVINCES

Propagation loss ultimately determines the extent of the Zone of Influence (ZOI) 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 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 that are accepted as standards for all Navy modeling efforts.

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

This section provides some quantitative examples 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 HRC.

A.1.3.1 Impact of Environmental Parameters

Within a typical operating area, the environmental parameter that tends to vary the most is bathymetry. It is not unusual for water depths to vary by an order of magnitude or more with the resulting impact upon ZOI calculations being significant. Bottom loss can also vary considerably over typical operating areas but its impact upon ZOI 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 ZOI 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 operating areas 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.

A.1.3.2 Environmental Provincing Methodology

The underwater acoustic environment can be quite variable over ranges in excess of 10 kilometers (km). For ASW 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 operating area, 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 (10, 20, 50, 100, 200, 500, 1,000, 2,000, and 5,000 m) provide an adequate sampling of water depth dependence.

Zone of influence volumes are then computed using propagation loss estimates derived for the representative environments. Finally, a weighted average of the ZOI 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 operating area of interest.

As discussed in the previous subsection, ZOI 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), 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 ZOI 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 on the size and complexity of the operating area, the number of environmental provinces tends to range from 5 to 20.

A.1.3.3 Description of Environmental Provinces Used in Acoustic Modeling

The HRC consists of a number of operating areas and specialized ranges located about the Hawaiian Islands. The complete collection of ranges is bounded north and south by latitudes 24°34' N and 18°36' N and east and west by meridians 161°17' W and 155° W. Within these overall boundaries, the various acoustic sources are deployed to various operating areas and ranges as defined in Section A.1.2.

This subsection describes the representative environmental provinces selected for the entire HRC. For all of these provinces, the average wind speed (winter and summer) is 13 knots. The subsequent subsections describe the representative environmental provinces for the individual Sonar Modeling Areas (SMAs) and specialized ranges.

The HRC contains a total of 32 distinct environmental provinces. These represent the various combinations of nine bathymetry provinces, three Sound Velocity Profile (SVP) provinces, and six HFBL classes. However, as discussed in the following paragraphs, 12 of the provinces are close enough to the same, or occur so infrequently, that differentiating them is inconsequential and the modeling is based on 20 environmental provinces.

The bathymetry provinces represent depths ranging from shallowest of waters (10 m) to typical deep-water depths (slightly more than 5,000 m). However, the various ranges are concentrated in the deepest bathymetry province with nearly 90% of the entire range complex represented by environmental provinces with depths in the 5,000-m province. The distribution of the bathymetry provinces over the entire HRC is provided in Table A-9.

Table A-9. Distribution of Bathymetry Provinces in Hawaii Range Complex

Province Depth (m)	Frequency of Occurrence
10	Lima Landing & Puuloa only
20	0.01 %
50	0.02 %
100	0.05 %
200	0.22 %
500	0.75 %
1,000	2.15 %
2,000	7.87 %
5,000	88.93 %

The distribution of the three sound speed provinces is presented in Table A-10.

Table A-10. Distribution of Sound Speed Provinces in Hawaii Range Complex

SVP Province	Frequency of Occurrence
81	66.07 %
88	33.41 %
98	0.52 %

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 A-1 that displays the upper 1,000 m of the winter and summer profiles.

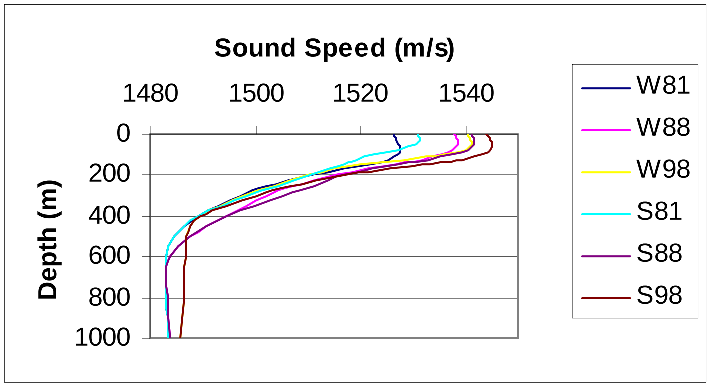

Figure A-1. Summer and Winter SVPs in the Hawaii Range Complex

The feature of the sound speed field that typically provides the most significant impact upon the size of the ZOI is the mixed layer or surface duct. Propagation loss from a source in a surface duct to points within the surface duct can be as much as 10 dB less than loss to points below the duct. The portion of the water column that enjoys this preferential propagation path (and hence longer impact ranges) is determined by the mixed layer depth. Among these profiles, the mixed layer depth (see Table A-11) is typically 50 m in both seasons.

Table A-11. Mixed Layer Depths in the Hawaii Range Complex

SVP Province	Summer Mixed Layer Depth (m)	Winter Mixed Layer Depth (m)
81	75	30
88	50	30
98	50	50

The HFBL classes represented in the HRC vary from low-loss bottoms (class 2, typically in shallow water) to high-loss bottoms (class 8). Unlike the other two types of environmental parameters, the distribution of the five HFBL classes is provided in Table A-12.

Table A-12. Distribution of High-Frequency Bottom Loss Classes in the Hawaii Range Complex

HFBL Class	Frequency of Occurrence
2	0.57 %
3	22.68 %
4	23.22 %
5	14.53 %
7	11.47 %
8	27.53 %

Given the limited variability in the sound speed field, the logic for consolidating the environmental provinces focuses upon water depth and the HFBL class. The first consideration was to ensure that all nine bathymetry provinces are represented. The four shallowest bathymetry provinces do not occur frequently in this exercise area but, nonetheless, need to be represented by at least one environmental province. Within each of these depth regimes, the predominant environmental province is selected as the representative.

Nearly 90% of the exercise is in the deepest bathymetry province; such a large area warrants the greatest partitioning. Among the 10 potential 5,000-m environmental provinces, the six most prevalent provinces are selected as representative. These span all five HFBL classes that occur at this water depth and two of the three SVP provinces (missing only SVP province 98 which is virtually indistinguishable from SVP province 88). The remaining bathymetry provinces (200, 500, 1,000, and 2,000 m) are then assigned to two or three of the most prevalent environmental provinces, ensuring that no environmental province that occurs in at least 10% of bathymetry regime is omitted. The resulting 20 environmental provinces used in the HRC acoustic modeling are described in Table A-13.

Table A-13. Distribution of Environmental Provinces in the Hawaii Range Complex

Environmental Province	Water Depth	SVP Province	HFBL Class	LFBL Province	Sediment Thickness	Frequency of Occurrence
1	20 m	81	8	– 98*	0.2 sec	0.01 %
2	50 m	81	8	– 98*	0.2 sec	0.02 %
3	100 m	81	8	– 98*	0.2 sec	0.42 %
4	200 m	81	2	52	0.2 sec	0.08 %
5	200 m	81	8	– 98*	0.23 sec	0.14 %
6	500 m	88	8	0	0.11 sec	0.11 %
7	500 m	81	8	– 98*	0.23 sec	0.56 %
8	1,000 m	81	8	52	0.22 sec	1.52 %
9	1,000 m	88	8	52	0.11 sec	0.62 %
10	2,000 m	81	8	52	0.18 sec	6.45 %
11	2,000 m	88	8	52	0.08 sec	1.43 %
12	5,000 m	81	5	13	0.22 sec	10.01 %
13	5,000 m	81	7	13	0.09 sec	10.34 %
14	5,000 m	81	4	13	0.17 sec	24.20 %
15	5,000 m	88	3	13	0.23 sec	26.21 %
16	5,000 m	81	8	13	0.13 sec	12.65 %
17	5,000 m	88	8	13	0.09 sec	5.47 %
18	500 m	88	2	– 98*	0.2 sec	0.08 %
19	100 m	81	2	52	0.2 sec	0.01 %
20	10 m	81	2	52	0.2 sec	Lima Landing / Puuloa only

* Negative province numbers indicate shallow water provinces

A.1.3.3.1 Environmental Provinces in Sonar Modeling Area 1 (SMA 1)

SMA 1 is a range located north and west of Kauai and encompasses the Barking Sands Underwater Range Expansion (BSURE), the Barking Sands Tactical Underwater Range (BARSTUR), and most of the PMRF Shallow Water Training Range (SWTR) as shown on Figure A-2.

Although SMA 1 is primarily in deep water, it does include areas that are shallower than 200 m. The distribution of bathymetry provinces in SMA 1 is described in Table A-14.

Table A-14. Distribution of Bathymetry Provinces in SMA 1

Bathymetry	Frequency of Occurrence
200	0.05%
500	0.75%
1,000	2.39%
2,000	5.10%
5,000	91.71%

SMA 1 is almost exclusively in SVP province 88 as indicated in the distribution given in Table A-15.

Table A-15. Distribution of Sound Speed Provinces in SMA 1

Sound Speed Province	Frequency of Occurrence
81	0.17%
88	99.83%

Almost all of the high-frequency bottom loss classes present in the HRC are represented in SMA 1; however, more than half of SMA 1 is a class 3 (low-loss) bottom as indicated in Table A-16.

Table A-16. Distribution of High-Frequency Bottom Loss Classes in SMA 1

High-Frequency Bottom Loss Class	Frequency of Occurrence
2	0.37%
3	54.28%
4	5.92%
5	13.32%
8	26.10%

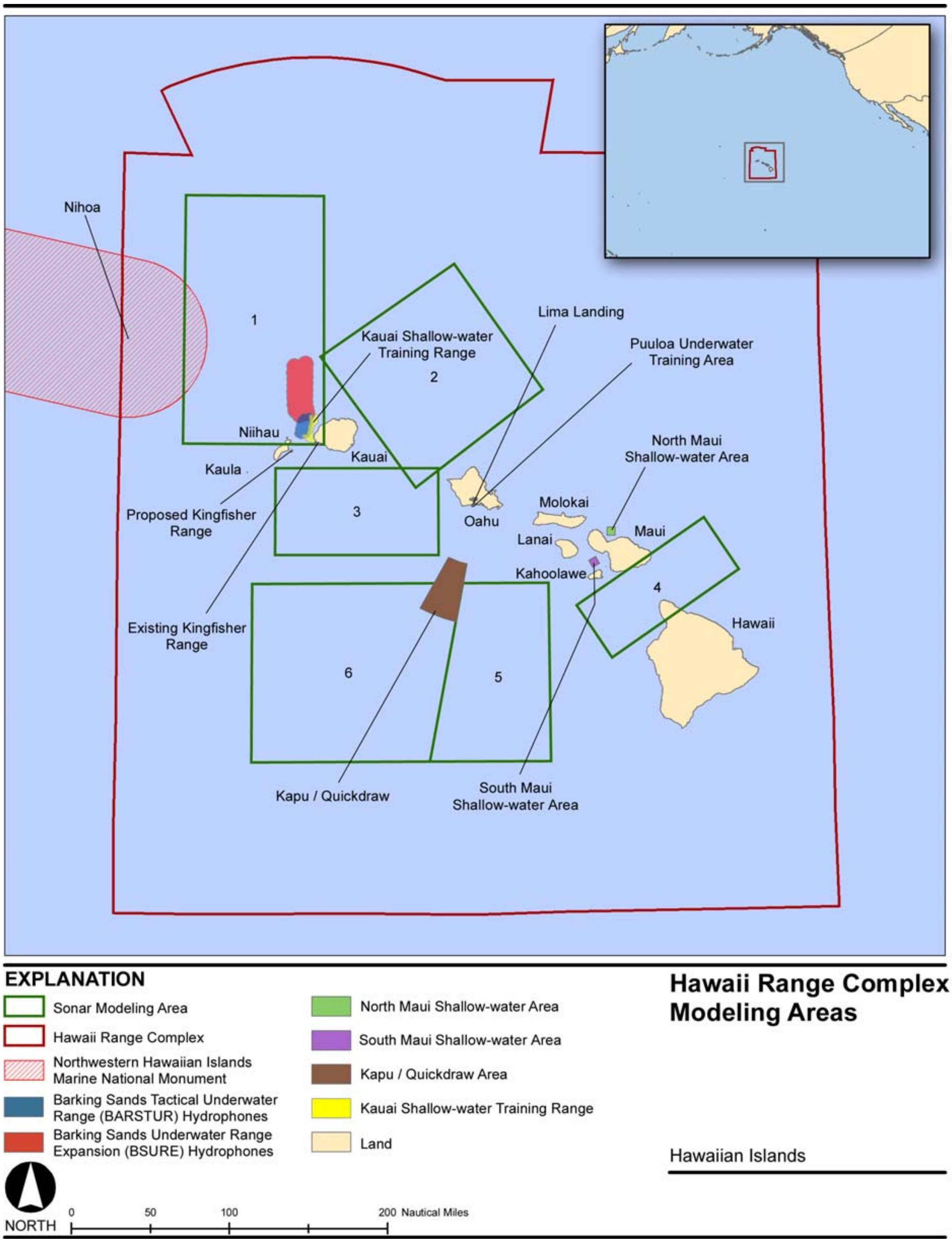

Figure A-2 Hawaii Range Complex Modeling Areas, Hawaiian Islands

For acoustic modeling purposes, the environmental variability of SMA 1 is captured by the 10 provinces listed in Table A-17. Note that the vast majority of SMA 1 is represented by two 5,000-m provinces—one with a low-loss bottom (15) and the other by with a high-loss bottom (17).

Table A-17. Distribution of Environmental Provinces in SMA 1

Environmental Province	Water Depth	SVP Province	HFBL Class	LFBL Province	Sediment Thickness	Frequency of Occurrence
4	200 m	81	2	52	0.2 sec	0.01%
5	200 m	81	8	– 98*	0.23 sec	0.04%
6	500 m	88	8	0	0.11 sec	0.37%
7	500 m	81	8	– 98*	0.23 sec	0.06%
8	1,000 m	81	8	52	0.22 sec	0.07%
9	1,000 m	88	8	52	0.11 sec	2.32%
11	2,000 m	88	8	52	0.08 sec	5.10%
15	5,000 m	88	3	13	0.23 sec	73.53%
17	5,000 m	88	8	13	0.09 sec	18.19%
18	500 m	88	2	– 98*	0.2 sec	0.31%

* Negative province numbers indicate shallow water provinces

A.1.3.3.2 Sonar Modeling Area 2 (SMA 2)

SMA 2 is located between and north of Kauai and Oahu and includes none of the smaller, specialized ranges. Although roughly equivalent in size to SMA 1, SMA 2 does not include coastal waters and thus has less environmental diversity. The bathymetry distribution is limited to depths of a kilometer or more as described in Table A-18.

Table A-18. Distribution of Bathymetry Provinces in SMA 2

Bathymetry	Frequency of Occurrence
1,000	1.84%
2,000	13.47%
5,000	84.68%

As with SMA 1, there are two SVP provinces covering SMA 2. As indicated in Table A-19, SMA 2 is nearly evenly divided between these two SVP provinces.

Table A-19. Distribution of Sound Speed Provinces in SMA 2

Sound Speed Province	Frequency of Occurrence
81	53.06%
88	46.94%

The limited environmental diversity is further demonstrated by the distribution of high-frequency bottom loss classes described in Table A-20.

Table A-20. Distribution of High-Frequency Bottom Loss Classes in SMA 2

High-Frequency Bottom Loss Class	Frequency of Occurrence
3	60.10 %
5	6.52 %
8	33.38 %

The environmental variability SMA 2 is reflected in the seven provinces listed in Table A-21.

Table A-21. Distribution of Environmental Provinces in SMA 2

Environmental Province	Water Depth	SVP Province	HFBL Class	LFBL Province	Sediment Thickness	Frequency of Occurrence
8	1,000 m	81	8	52	0.22 sec	1.84%
10	2,000 m	81	8	52	0.18 sec	13.20%
11	2,000 m	88	8	52	0.08 sec	0.28%
14	5,000 m	81	4	13	0.17 sec	20.04%
15	5,000 m	88	3	13	0.23 sec	46.57%
16	5,000 m	81	8	13	0.13 sec	17.97%
17	5,000 m	88	8	13	0.09 sec	0.31%

A.1.3.3.3 Sonar Modeling Area 3 (SMA 3)

SOA 3 is located south of Kauai and west of Oahu. It includes none of the smaller, specialized ranges. The bathymetry distribution is limited to depths of a kilometer or more as described in Table A-22.

Table A-22. Distribution of Bathymetry Provinces in SMA 3

Bathymetry	Frequency of Occurrence
1,000	0.95%
2,000	11.95%
5,000	87.10%

SMA 3 is described in its entirety by the sound speed province 81. The bottom loss classes in SMA 3 are limited to a medium-loss class (4) and a high-loss class (8) with distributions indicated in Table A-23.

Table A-23. Distribution of High-Frequency Bottom Loss Classes in SMA 3

High-Frequency Bottom Loss Class	Frequency of Occurrence
4	28.17%
8	71.83%

Table A-24 describes the four environmental provinces selected for SMA 3. The distribution of these provinces reflects the deep-water nature of this operating area.

Table A-24. Distribution of Environmental Provinces in SMA 3

Environmental Province	Water Depth	SVP Province	HFBL Class	LFBL Province	Sediment Thickness	Frequency of Occurrence
8	1,000 m	81	8	52	0.22 sec	0.95%
10	2,000 m	81	8	52	0.18 sec	11.95%
14	5,000 m	81	4	13	0.17 sec	28.17%
16	5,000 m	81	8	13	0.13 sec	58.93%

A.1.3.3.4 Sonar Modeling Area 4 (SMA 4)

SMA 4 is situated between Oahu and the island of Hawaii. It includes none of the smaller, specialized ranges but does include some shallow-water regions. The bathymetry distribution includes all eight bathymetry provinces but emphasizes deep-water with nearly 90% of the operating area in water depths of a kilometer or more as indicated in Table A-25.

Table A-25. Distribution of Bathymetry Provinces in SMA 4

Bathymetry	Frequency of Occurrence
20	0.12 %
50	0.25 %
100	0.62 %
200	2.23 %
500	7.64 %
1,000	16.84 %
2,000	40.13 %
5,000	32.17 %

SMA 4 is described in its entirety by the sound speed province 81. Bottom loss is likewise limited in variability with over 90% of the operating area characterized by a high-loss bottom (see Table A-26).

Table A-26. Distribution of High-Frequency Bottom Loss Classes in SMA 4

High-Frequency Bottom Loss Class	Frequency of Occurrence
2	6.59%
5	1.00%
7	0.01%
8	92.41%

SMA 4 is partitioned into the twelve environmental provinces listed in Table A-27. The distribution of environmental provinces is dominated by provinces with high-loss bottoms in the 1,000-, 2,000- and 5,000-m water depth regimes.

Table A-27. Distribution of Environmental Provinces in SMA 4

Environmental Province	Water Depth	SVP Province	HFBL Class	LFBL Province	Sediment Thickness	Frequency of Occurrence
1	20 m	81	8	– 98*	0.2 sec	0.13%
2	50 m	81	8	– 98*	0.2 sec	0.25%
3	100 m	81	8	– 98*	0.2 sec	0.49%
4	200 m	81	2	52	0.2 sec	0.99%
5	200 m	81	8	– 98*	0.23 sec	1.24%
7	500 m	81	8	– 98*	0.23 sec	7.64%
8	1,000 m	81	8	52	0.22 sec	16.84%
10	2,000 m	81	8	52	0.18 sec	40.13%
12	5,000 m	81	5	13	0.22 sec	1.00%
13	5,000 m	81	7	13	0.09 sec	0.01%
16	5,000 m	81	8	13	0.13 sec	31.17%
19	100 m	81	2	52	0.2 sec	0.13%

A.1.3.3.5 Sonar Modeling Area 5 (SMA 5)

Located south of Oahu and west of the island of Hawaii, SMA 5 is predominantly a deep-water region. This operating area includes none of the smaller, specialized ranges. The bathymetry distribution provided in Table A-28 includes only two bathymetry provinces, with more than 95% of the area in the 5,000-m bathymetry province.

Table A-28. Distribution of Bathymetry Provinces in SMA 5

Bathymetry	Frequency of Occurrence
2,000	3.35%
5,000	96.65%

The distribution of sound speed provinces is similarly concentrated in a single province, 81, as presented in Table A-29.

Table A-29. Distribution of Sound Speed Provinces in SMA 5

Sound Speed Province	Frequency of Occurrence
81	96.33%
98	3.67%

The distribution of bottom-loss classes is a little less concentrated as indicated in Table A-30.

Table A-30. Distribution of High-Frequency Bottom Loss Classes in SMA 5

High-Frequency Bottom Loss Class	Frequency of Occurrence
4	29.15%
7	61.94%
8	8.91%

The resulting five provinces that describe SMA 5 are presented in Table A-31 and reflect a distribution whose environmental variability is driven mainly by bottom loss.

Table A-31. Distribution of Environmental Provinces in SMA 5

Environmental Province	Water Depth	SVP Province	HFBL Class	LFBL Province	Sediment Thickness	Frequency of Occurrence
10	2,000 m	81	8	52	0.18 sec	3.35%
13	5,000 m	81	7	13	0.09 sec	55.39%
14	5,000 m	81	4	13	0.17 sec	29.15%
16	5,000 m	81	8	13	0.13 sec	8.44%
17	5,000 m	88	8	13	0.09 sec	3.67%

A.1.3.3.6 Sonar Modeling Area 6 (SMA 6)

SMA 6 is a large deep-water region located south of Kauai and Oahu, and adjacent to SMA 5 on the east. Like SMA 5, this operating area is exclusively deep-water as demonstrated in Table A-32.

Table A-32. Distribution of Bathymetry Provinces in SMA 6

Bathymetry	Frequency of Occurrence
2,000	0.56%
5,000	99.44%

SMA 6 is described in its entirety by the sound speed province 81. The ocean bottom in this region is primarily medium loss, distributed as shown in Table A-33.

Table A-33. Distribution of High-Frequency Bottom Loss Classes in SMA 6

High-Frequency Bottom Loss Class	Frequency of Occurrence
4	53.25%
5	37.04%
7	9.71%

A total of four environmental provinces are used to characterize this operating area according to the distribution given in Table A-34.

Table A-34. Distribution of Environmental Provinces in SMA 6

Environmental Province	Water Depth	SVP Province	HFBL Class	LFBL Province	Sediment Thickness	Frequency of Occurrence
10	2,000 m	81	8	52	0.18 sec	0.56%
12	5,000 m	81	5	13	0.22 sec	37.04%
13	5,000 m	81	7	13	0.09 sec	9.15%
14	5,000 m	81	4	13	0.17 sec	53.25%

A.1.3.3.7 Barking Sands Ranges

BARSTUR and the BSURE are located between and north of Niihau and Kauai. They are contained entirely within the southeast corner of SMA 1 with a bathymetry distribution as described in Table A-35.

Table A-35. Distribution of Bathymetry Provinces in Barking Sands Ranges

Bathymetry	Frequency of Occurrence
500	3.5 %
1,000	11.53 %
2,000	12.38 %
5,000	72.58 %

The Barking Sands Ranges are described in their entirety by the sound speed province 88. The ranges are fairly evenly divided between low-loss bottoms and high-loss bottoms according to the distribution described in Table A-36.

Table A-36. Distribution of High-Frequency Bottom Loss Classes in Barking Sands Ranges

High-Frequency Bottom Loss Class	Frequency of Occurrence
2	2.72 %
3	38.03 %
8	59.25 %

The various combinations of environmental properties results in the six provinces defined in Table A-37.

Table A-37. Distribution of Environmental Provinces in Barking Sands Ranges

Environmental Province	Water Depth	SVP Province	HFBL Class	LFBL Province	Sediment Thickness	Frequency of Occurrence
6	500 m	88	8	0	0.11 sec	1.34%
9	1,000 m	88	8	52	0.11 sec	11.53%
11	2,000 m	88	8	52	0.08 sec	12.38%
15	5,000 m	88	3	13	0.23 sec	38.03%
17	5,000 m	88	8	13	0.09 sec	34.56%
18	500 m	88	2	– 98*	0.2 sec	2.16%

A.1.3.3.8 South Maui Shallow-water Area and Potential MK-48 Area

The South Maui Shallow-water Area is located in shallow water between Kahoolawe, Lanai, and Maui. In addition to the Barking Sands ranges, it is one of two other areas that may be used for MK-48 training. The other area is also in shallow water and is situated just north of Maui. Both areas are small in comparison to the SMAs and hence the environmental variability is less pronounced. The distribution of water depths is limited to two bathymetry provinces as shown in Table A-38.

Table A-38. Distribution of Bathymetry Provinces in HATS and Potential MK-48 Ranges

Bathymetry	Frequency of Occurrence
100	24.44%
200	75.56%

The South Maui Shallow-water Area and the potential MK-48 area are described in its entirety by the sound speed province 81. Two bottom loss classes, distributed as indicated in Table A-39, are present in these areas.

Table A-39. Distribution of High-Frequency Bottom Loss Classes in South Maui Shallow-water Area and Potential MK-48 Ranges

High-Frequency Bottom Loss Class	Frequency of Occurrence
2	9.55%
8	90.45%

This environmental variability is represented by the four environmental provinces described in Table A-40.

Table A-40. Distribution of Environmental Provinces in HATS and Potential MK-48 Ranges

Environmental Province	Water Depth	SVP Province	HFBL Class	LFBL Province	Sediment Thickness	Frequency of Occurrence
3	100 m	81	8	– 98*	0.2 sec	18.19%
4	200 m	81	2	52	0.2 sec	3.30%
5	200 m	81	8	– 98*	0.23 sec	72.76%
19	100 m	81	2	52	0.2 sec	6.25 %

A.1.3.3.9 Kapu/Quickdraw

Kapu/Quickdraw is a gunnery range located south of Oahu. This range partially overlaps SMA 6 and thus shares some of the same environmental characteristics. The range is strictly deep-water (5,000-m bathymetry province) and described in its entirety by the sound speed province 81. The only material environmental variability is in bottom loss class, as demonstrated in Table A-41.

Table A-41. Distribution of High-Frequency Bottom Loss Classes in Kapu/ Quickdraw Range

High-Frequency Bottom Loss Class	Frequency of Occurrence
4	78.72%
8	21.28%

The bottom-loss distribution, in turn, directly dictates the distribution of environmental provinces as listed in Table A-42.

Table A-42. Distribution of Environmental Provinces in Kapu/Quickdraw Range

Environmental Province	Water Depth	SVP Province	HFBL Class	LFBL Province	Sediment Thickness	Frequency of Occurrence
14	5,000	81	4	13	0.17 sec	78.72%
16	5,000	81	8	52	0.13 sec	21.28%

A.1.3.3.10 Lima Landing

Lima Landing is a limited area near the mouth of Pearl Harbor that is employed as an Explosive Ordnance Demolition (EOD) Range. The limited extent of this range permits the entire range to be characterized by the single environmental province listed in Table A-43.

Table A-43. Distribution of Environmental Provinces in Lima Landing

Environmental Province	Water Depth	SVP Province	HFBL Class	LFBL Province	Sediment Thickness	Frequency of Occurrence
20	10 m	81	2	52	0.2 sec	100 %

A.1.3.3.11 Kingfisher (Old and Proposed)

Two areas in the HRC are designated for Kingfisher training. The "old" range is located just south of Kauai, adjoining the Shallow Water Training Range to the west. The "proposed" area is nearby, just east of Niihau. Both areas are very small in comparison to the resolution of the Navy-standard databases. As such, the only environmental parameter that is apt to vary significantly is water depth. Water depths in the old range are known to vary between 150 to 350 feet (46 to 107 m). Given that the dominant bottom loss class is 2, the best fit for the Kingfisher ranges is provided by environmental province 19, as described in Table A-44.

Table A-44. Distribution of Environmental Provinces in the Kingfisher Ranges

Environmental Province	Water Depth	SVP Province	HFBL Class	LFBL Province	Sediment Thickness	Frequency of Occurrence
19	100 m	81	2	52	0.2 sec	100%

A.1.3.3.12 Puuloa

Puuloa Underwater Training Area is a small area just south of Pearl Harbor. The limited extent of this range permits the entire range to be characterized by the single environmental province listed in Table A-45.

Table A-45. Distribution of Environmental Provinces in Puuloa Range

Environmental Province	Water Depth	SVP Province	HFBL Class	LFBL Province	Sediment Thickness	Frequency of Occurrence
20	10 m	81	2	52	0.2 sec	100 %

A.1.3.3.13 Shallow Water Training Range

The SWTR is located just to the west of Kauai, overlapping a portion of the Barking Sands Ranges and part of SMA 1. The bathymetry distribution emphasizes shallow water as indicated in Table A-46.

Table A-46. Distribution of Bathymetry Provinces in SWTR

Bathymetry	Frequency of Occurrence
50	9.85%
100	9.85%
200	1.79%
500	47.70%
1,000	30.81%

The distribution of sound speed provinces is provided in Table A-47.

Table A-47. Distribution of Sound Speed Provinces in SWTR

Sound Speed Province	Frequency of Occurrence
81	72.46%
88	27.54%

The distribution of bottom loss classes presented in Table A-48 indicates relatively equal portions of low-loss and high-loss bottoms in SWTR.

Table A-48. Distribution of High-Frequency Bottom Loss Classes in SWTR

High-Frequency Bottom Loss Class	Frequency of Occurrence
2	2.72%
3	38.03%
8	59.25%

Without the influence of large, deep-water provinces, the SWTR is more uniformly distributed over the 10 environmental provinces it contains as indicated in Table A-49.

Table A-49. Distribution of Environmental Provinces in SWTR

Environmental Province	Water Depth	SVP Province	HFBL Class	LFBL Province	Sediment Thickness	Frequency of Occurrence
2	50 m	81	8	– 98*	0.2 sec	9.85%
3	100 m	81	8	– 98*	0.2 sec	4.92%
4	200 m	81	2	52	0.2 sec	0.71%
5	200 m	81	8	– 98*	0.23 sec	1.08%
6	500 m	88	8	0	0.11 sec	14.60%
7	500 m	81	8	– 98*	0.23 sec	3.00%
8	1,000 m	81	8	52	0.22 sec	1.79%
9	1,000 m	88	8	52	0.11 sec	29.02%
18	500 m	88	2	– 98*	0.2 sec	30.10%
19	100 m	81	2	52	0.2 sec	4.92%

A.1.4 IMPACT VOLUMES AND IMPACT RANGES

Many 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 harm 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 (or taken according 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 set 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.

With the exception of explosive sources, 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. Harassment measures for explosive sources include energy flux density and pressure-related metrics (peak pressure and positive impulse).

Regardless of the type of source, estimating the number of animals that may be injured or harassed 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). This discussion is presented in two parts: active sonars and explosive sources. 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 Section A.1.5.

A.1.4.1 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.

A.1.4.1.1 Transmission Loss Calculations

TL data are pre-computed for each of two seasons in the five environmental provinces described in the previous subsection using the GRAB propagation loss model (Keenan, 2000). The TL output consists of a parametric description of each significant eigenray (or propagation path) from source to animal. The description of each eigenray includes 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 and source depth TL inputs are specified in Table A-50.

Table A-50. TL Frequency and Source Depth by Sonar Type

Sonar	Frequency	Source Depth
MK-48	20 kHz	27 m
AN/SQS-53C	5 kHz	7 m
AN/AQS-22	4.1 kHz	27 m
AN/ASQ-62	8 kHz	27 m

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-51. Note that some of the low-power sources do not require TL data to large maximum ranges.

Table A-51. TL Depth and Range Sampling Parameters by Sonar Type

Sonar	Range Step	Maximum Range	Animal Depth
MK-48	10 meter (m)	10 kilometer (km)	0 – 1 km in 5-m steps 1 km – Bottom in 10-m steps
AN/SQS-53C	10 m	20 km	0 – 1 km in 5-m steps 1 km – Bottom in 10-m steps
AN/AQS-22	10 m	10 km	0 – 1 km in 5-m steps 1 km – Bottom in 10-m steps
AN/ASQ-62	5 m	5 km	0 – 1 km in 5-m steps 1 km – Bottom in 10-m steps

In a few cases, most notably the AN/SQS-53C for thresholds below approximately 180 dB, TL data may be required by the energy summation algorithm at ranges greater than covered by the pre-computed GRAB data. In these cases, TL is extrapolated to the required range using a simple cylindrical spreading loss law in addition to the appropriate absorption loss. This extrapolation leads to a conservative (or under) estimate of transmission loss at the greater ranges.

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.

The other important feature that storing eigenray data supports is the ability to model the effects of surface-image interference that persist over range. However, this is primarily important at frequencies lower than those associated with the sonars considered in this subsection. A detailed description of the modeling of surface-image interference is presented in the subsection on explosive sources.

A.1.4.1.2 Energy Summation

The summation of energy flux density over multiple pings in a range-independent environment is a trivial 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 are 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.

The source is then moved along one of the axes in the horizontal plane by the specified ping separation distance and the second ping is processed in a similar fashion. 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 omni 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 (R_{MAX}) for a single ping. The impact range in this case is the maximum range at which the effective energy source level reduced by the transmission loss is less 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 CPA range of R_{MAX} at the mid-point of the source track. That total energy flux density is then compared to the prescribed threshold. If it is greater than the threshold (which, for the first R_{MAX}, it must be) then R_{MAX} is increased by 10%, 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 the same essentially the same amount. This geometry is demonstrated in Figure A-3.

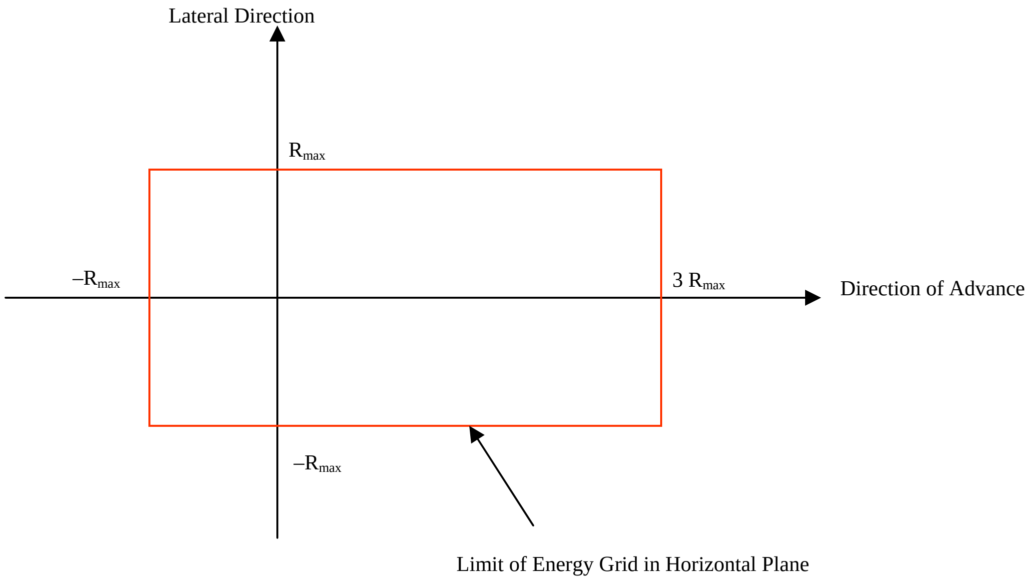

Figure A-3. Horizontal Plane of Volumetric Grid for Omni Directional Source.

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-4.

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 1%). 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 40 m in order to ensure that significant TL variability over depth is captured.

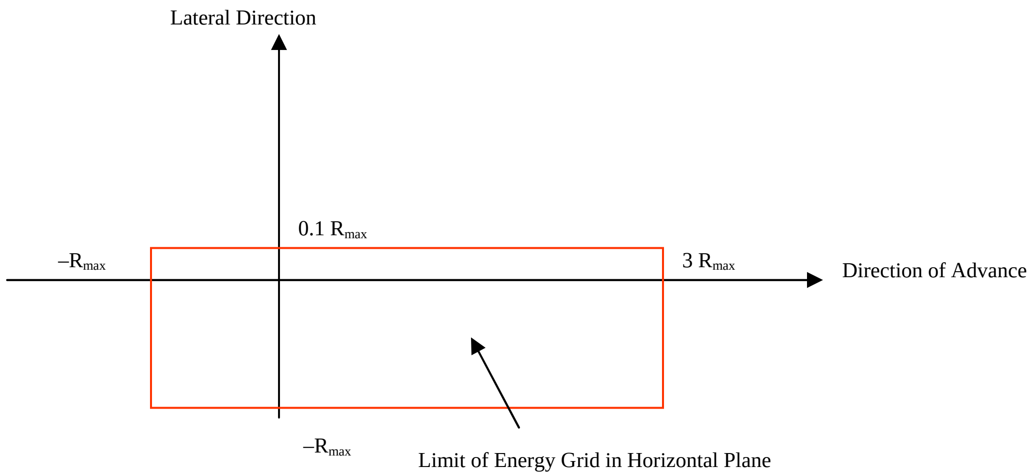

Figure A-4. Horizontal Plane of Volumetric Grid for Starboard Beam Source.

A.1.4.1.3 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 Figure A-5.

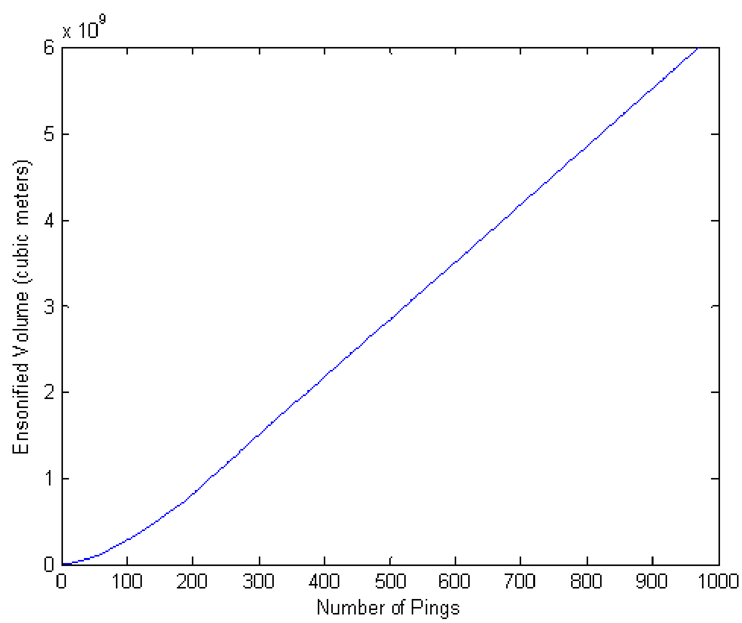

Figure A-5. 53C Impact Volume by Ping

The slope of the impact volume versus number of pings 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-6 provides an example of an hourly impact volume vector for a particular environment.

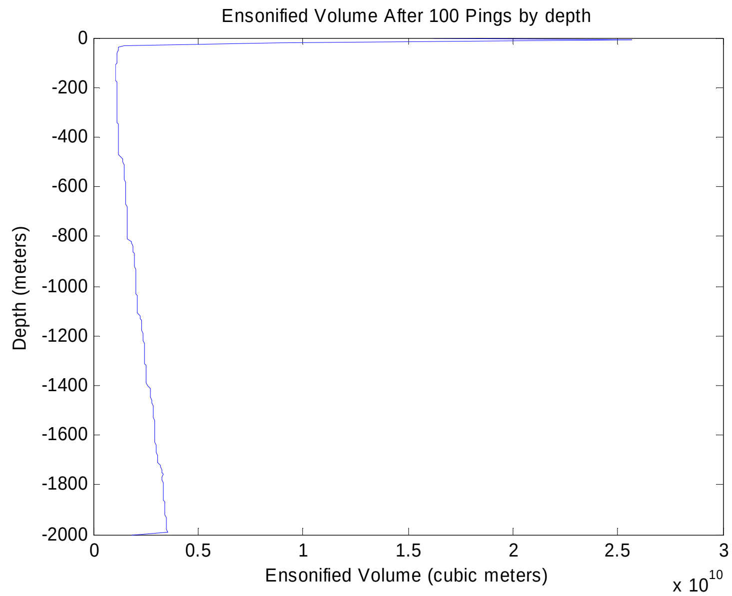

Figure A-6. Example of an Impact Volume Vector

A.1.4.2 Computing Impact Volumes for Explosive Sources

This section provides the details of the modeling of the explosive sources. This energy summation algorithm is similar to that used for sonars, only differing in details such as the sampling rates and source parameters. These differences are summarized in the following subsections. A more significant difference is that the explosive sources require the modeling of additional pressure metrics: (1) peak pressure, and (2) "modified" positive impulse. The modeling of each of these metrics is described in detail in the subsections of A.1.4.2.3.

A.1.4.2.1 Transmission Loss Calculations

Modeling impact volumes for explosive sources span requires the type of same TL data as needed for active sonars. However unlike active sonars, explosive ordnances are very broadband, contributing significant energy from tens of hertz to tens of kilohertz. To accommodate the broadband nature of these sources, TL data are sampled at seven frequencies from 10 Hz to 40 kHz, spaced every two octaves.

An important propagation consideration at low frequencies is the effect of surface-image interference. As either source or target approach the surface, pairs of paths that differ in history by a single surface reflection set up an interference pattern that ultimately causes the two paths to perfectly cancel each other when the source or target is at the surface. A fully coherent summation of the eigenrays produces such a result but also introduces extreme fluctuations at all depths that would have to be highly sampled range and depth, and then smoothed to give meaningful results. An alternative approach is to implement what is sometimes called a semi-coherent summation. A semi-coherent sum attempts to capture significant effects of surface-image interference (namely the reduction of the field as the source or target approach the surface) without having to deal with the more rapid fluctuations associated with a fully coherent sum. The semi-coherent sum is formed by a random phase addition of paths that have already been multiplied by the expression:

$$\sin^2 [4\pi f z_s z_a / (c^2 t)]$$

where f is the frequency, z_s is the source depth, z_a is the animal depth, c is the sound speed and t is the travel time from source to animal along the propagation path. For small arguments of the sine function this expression varies directly as the frequency and the two depths. It is this relationship that causes the propagation field to go to zero as the depths approach the surface or the frequency approaches zero.

A final important consideration is the broadband nature of explosive sources. This is handled by sampling the TL field at a limited number of frequencies. But the image-interference correction given above varies substantially over that frequency spacing. To avoid possible under sampling, the correction is averaged over each frequency interval.

A.1.4.2.2 Source Parameters

Unlike the active sonars, the explosive sources are defined by only two parameters: (1) net explosive weight, and (2) source detonation depth. Values for these source parameters are defined in Section A.1.2.2.

The effective energy source level, which is treated as a de facto input for the other sonars, is instead modeled directly for EER and explosives. For both the energy source level is comparable to the model used for other explosives (Arons [1954], Weston [1960], McGrath [1971], Urick [1983], Christian and Gaspin [1974]). The energy source level over a one-third octave band with a center frequency of f for a source with a net explosive weight of w pounds is

$$10 \log_{10} (0.26 f) + 10 \log_{10} (2 p_{max}^2 / [1/\theta^2 + 4 \pi f^2]) + 197 \text{ dB}$$

where the peak pressure for the shock wave at 1 m is defined as

$$p_{max} = 21600 (w^{1/3} / 3.28)^{1.13} \text{ psi} \qquad \text{(A-1)}$$

and the time constant is defined as:

$$\theta = [(0.058) (w^{1/3}) (3.28 / w^{1/3})^{0.22}] / 1,000 \text{ msec} \qquad \text{(A-2)}$$

A.1.4.2.3 Impact Volumes for Various Metrics

The impact of explosive sources on marine wildlife is measured by four different metrics, each with its own threshold(s). The energy metric, peak one-third octave, is treated in similar fashion as the energy metric used for the active sonars, including the summation of energy if there are multiple source emissions. The other two, peak pressure and positive impulse, are not accumulated but rather the maximum levels are stored.

Peak One-Third Octave Energy Metric

The computation of impact volumes for the energy metric follows closely the approach taken to model the energy metric for the active sonars. The only significant difference is that energy flux density is sampled at several frequencies in one-third-octave bands and only the peak one-third-octave level is accumulated.

Peak Pressure Metric

The peak pressure metric is a simple, straightforward calculation. At each range/animal depth combination, transmission ratio modified by the source level in a one-octave band and beam pattern is averaged across frequency on an eigenray-by-eigenray basis. This averaged transmission ratio (normalized by the broadband source level) is then compared across all eigenrays with the maximum designated as the peak arrival. Peak pressure at that range/animal depth combination is then simply the product of:

- The square root of the averaged transmission ratio of the peak arrival,
- The peak pressure at a range of 1 m (given by equation A-1), and
- The similitude correction (given by $r^{-0.13}$, where r is the slant range along the eigenray estimated as tc with t the travel time along the dominant eigenray and c the nominal speed of sound.

If the peak pressure for a given grid point is greater than the specified threshold, then the incremental volume for the grid point is added to the impact volume for that depth layer.

"Modified" Positive Impulse Metric

The modeling of positive impulse follows the work of Goertner (Goertner, 1982). The Goertner model defines a "partial" impulse as

$$\int_0^{T_{min}} p(t)\, dt$$

where p(t) is the pressure wave from the explosive as a function of time t, defined so that p(t) = 0 for t < 0. This pressure wave is modeled as

$$p(t) = p_{max}\, e^{-t/}$$

where p_{max} is the peak pressure at 1 m (see equation A-1), and θ is the time constant defined as

$$\theta = 0.058\, w^{1/3} (r/w^{1/3})^{0.22} \text{ seconds}$$

with w the net explosive weight (pounds), and r the slant range between source and animal.

The upper limit of the "partial" impulse integral is

$$T_{min} = \min \{T_{cut}, T_{osc}\}$$

where T_{cut} is the time to cutoff and T_{osc} is a function of the animal lung oscillation period. When the upper limit is T_{cut}, the integral is the definition of positive impulse. When the upper limit is defined by T_{osc}, the integral is smaller than the positive impulse and thus is just a "partial" impulse. Switching the integral limit from T_{cut} to T_{osc} accounts for the diminished impact of the positive impulse upon the animals lungs that compress with increasing depth and leads to what is sometimes call a "modified" positive impulse metric.

The time to cutoff is modeled as the difference in travel time between the direct path and the surface-reflected path in an isospeed environment. At a range of r, the time to cutoff for a source depth z_s and an animal depth z_a is

$$T_{cut} = 1/c \{ [r^2 + (z_a + z_s)^2]^{1/2} – [r^2 + (z_a – z_s)^2]^{1/2} \}$$

where c is the speed of sound.

The animal lung oscillation period is a function of animal mass M and depth z_a and is modeled as

$$T_{osc} = 1.17\, M^{1/3} (1 + z_a/33)^{-5/6}$$

where M is the animal mass (in kg) and z_a is the animal depth (in feet).

The modified positive impulse threshold is unique among the various injury and harassment metrics in that it is a function of depth and the animal weight. So instead of the user specifying the threshold, it is computed as $K (M/42)^{1/3} (1 + z_a / 33)^{1/2}$. The coefficient K depends upon the level of exposure. For the onset of slight lung injury, K is 19.7; for the onset of extensive lung hemorrhaging (1% mortality), K is 47.

Although the thresholds are a function of depth and animal weight, sometimes they are summarized as their value at the sea surface for a typical calf dolphin (with an average mass of 12.2 kg). For the onset of slight lung injury, the threshold at the surface is approximately 13 psi-msec; for the onset of extensive lung hemorrhaging (1% mortality), the threshold at the surface is approximately 31 psi-ms.

As with peak pressure, the "modified" positive impulse at each grid point is compared to the derived threshold. If the impulse is greater than that threshold, then the incremental volume for the grid point is added to the impact volume for that depth layer.`

A.1.4.2.4 Impact Volume per Explosive Detonation

The detonations of explosive sources are generally widely spaced in time and/or space. This implies that the impact volume for multiple firings can easily be derived by scaling the impact volume for a single detonation. Thus the typical impact volume vector for an explosive source is presented on a per detonation basis.

The one exception to this rule is SINKEX exercises. Impact volume vectors for the representative SINKEX are provided on a per exercise basis (that is, representing the cumulative impact of all weapons fired during the exercise).

A.1.4.3 Impact Volume by Operating Area

The HRC Operating Area is comprised of 20 environmental provinces. The hourly impact volume vector for operations involving any particular source is a linear combination of the 20 volume impact vectors, $\{v_1, v_2, ..., v_{20}\}$, with the weighting determined by the distribution of those 20 environmental provinces within the source's operation area. Unique hourly impact volume vectors for winter and summer are calculated for each type of source and each metric/threshold combination.

A.1.5 EXPOSURES

This section defines the animal densities and their depth distributions for the Hawaii Range Complex. This is followed by a series of tables providing exposure estimates per unit of operation for each source type (active sonars and explosives) and for a SINKEX exercise.

A.1.5.1 Animal densities

Densities are usually reported by marine biologists as animals per square kilometer, which is an area metric. This gives an estimate of the number of animals below the surface in a certain area, but does not provide any information about their distribution in depth. The impact volume vector (see Subsection A.1.4.1.3) specifies the volume of water ensonified above the specified threshold in each depth interval. A corresponding animal density for each of those depth intervals is required to compute the expected value of the number of exposures. The two-dimensional area densities do not contain this information, so three-dimensional densities must be constructed by using animal depth distributions to extrapolate the density at each depth. The required depth distributions are presented in next subsection.

Barlow presents density results based on an in-depth analysis of line-transect data collected during vessel surveys conducted within the U.S. Exclusive Economic Zone (EEZ) near the Hawaiian Island Archipelago from August-November 2002 (Barlow, 2006). Results from these surveys were initially published in a NMFS Administrative Report (Barlow, 2003), which is cited for density/abundance values in the RIMPAC report (Gilcrest et al., 2006). However, the Barlow (2006) paper (Barlow, 2006) is a peer-reviewed journal article and represents the "best available information" for this region. The study area and densities provided in Barlow (2006) also overlap entirely with older aerial survey data presented by Mobley (Mobley, et al., 2000); therefore the "Inshore" densities included in the RIMPAC document are also not necessary nor is their use advised. Barlow (Barlow, 2006; Table 4) provided abundance for two stratum, the Main Island stratum which covered from the main islands to approximately 75 nautical miles (nm) (140 km) offshore, and the Outer EEZ (OEEZ) stratum which covered the rest of the EEZ (200 nm, 370 km) around the entire Hawaiian island chain. Density and CV were pooled for combined strata only.

Based on the abundance numbers per stratum in Barlow (Barlow, 2006), it would be tempting to apply the pooled densities to only the OEEZ stratum (for those species with 100% occurrence) or divide based on percentage abundance in each strata (e.g., bottlenose dolphins had 14% abundance in Main Island and 86% abundance in OEEZ). However, this is likely not a good idea. Other researchers (Baird et al., 2006; Baird et al., 2005a,b; Baird, 2005) have carried out long-term studies near the main Hawaiian Islands, and have observed many species, not seen by Barlow (Barlow, 2006) in the Main Island stratum, within 75 nm of the main islands. While these other studies do not provide densities, they do indicate that other species occur close to the islands. Therefore, it is most appropriate to apply densities to the overall area (both strata) exactly as provided in Barlow (Barlow, 2006). The only exceptions to this would be Fraser's dolphin, Longman's beaked whale and Bryde's whale; these three species were seen by Barlow (Barlow, 2006) only in the OEEZ stratum and have not been sighted within 75 nm of the main islands by other researchers either. The densities calculated for these three species by Barlow (Barlow, 2006) can be applied to the OEEZ stratum only (greater than 75 nm from the main Hawaiian islands; see figure 1 in Barlow [Barlow, 2006]).

Barlow (2006) reports on densities for the summer/fall time period. Most of the species for which densities were calculated are resident to the archipelago (i.e., not migratory). Therefore, the densities are applicable year-round. Marine mammals that were not seen by Barlow (2006) occur too rarely to be of concern (right, blue, fin, sei, minke), with two notable exceptions. Humpback whales are seasonal migrants, occurring in the Hawaiian Islands generally from December through April (and therefore were not present during the summer 2002 surveys). The most recent NMFS Alaska Stock Assessment Report (Angliss and Outlaw, 2005) provides an abundance estimate of 4005 for wintering humpback whales in Hawaii, but no density. Mobley et al. (2001) conducted aerial surveys from 1993-2000 over shallow near-shore waters as well as deep pelagic regions (survey lines extended approximately 25 nm offshore). Densities were corrected for availability bias, and the corrected density estimate for 2000 was 0.2186 (CV=0.153), with an abundance of 4,491. This number applies only to winter/spring months and only to areas within 25 nm (46 km) of the main Hawaiian Islands.

The RIMPAC report (Gilcrest, Cembrola and Deavenport, 2006) includes only cetaceans "due to the lack of significant presence of pinnipeds". This does not adequately reflect "best available data". Hawaiian monk seals, an endangered species, are resident throughout the Hawaiian Islands. They are found more often in the northwestern Hawaiian Islands where most pupping and foraging occurs (Johanos and Baker, 2005). However, monk seals have been sighted in the Main Hawaiian Islands, particularly Kauai and Niihau (Baker and Johanos, 2004); 52 were counted during aerial surveys in 2001 and they may be recolonizing the main islands. Monk seals forage most frequently in less than 40-m depth but have been recorded foraging to 500-m depth. The most recent population estimate is 1,252 (Carretta et al., 2006), which is applicable to the entire archipelago.

The NUWC RIMPAC report divided the SMA areas into percentage of Operational Area within 25 nm of Land and beyond 25 nm of Land, based on the offshore surveys by Mobley (Mobley, et al, 2000) and the preliminary analysis by Barlow (Barlow, 2003). Those divisions are not applicable for the densities used here, with the exception of humpback whales.

Each SMA should be assessed in the following manner:

1. Humpback whales and Monk seals only – occurrence is limited to offshore areas only. Therefore, the percentage of operational SMAs within 25 nm of land for Humpback and 37 nm for Monk seals (already given in RIMPAC for most areas, see Table 3-2) are the only areas to which density/abundance should be applied.

2. Fraser's dolphin, Bryde's whale, Longman's beaked whale – occurrence appears to be in offshore areas only. Therefore, the percentage of operational SMAs that are beyond 75 nm of the main Hawaiian Islands (see Figure 1 in Barlow [Barlow, 2006]) are the only areas to which density/abundance should be applied.

3. All marine mammal species not specifically noted in #1 and 2 above – occurrence is throughout the Hawaiian Islands including Leeward Islands. Therefore, the percentage of SMAs from 200 nm (370 km) of land (likely 100% for each SMA) are the areas to which density/abundance should be applied.

The animal area densities for the HRC are given in Table A-52.

Table A-52. Hawaiian Islands Animal Densities

Species Name	Scientific Name	Abundance	Area for population (km^2)*	Density (#/km^2)	CV	Area	Season	Reference
Bryde's whale	*B. edeni*	469	N/A	0.0002	0.45	75-200 nm offshore	Year-round	Barlow 2006
Humpback whale	*Megaptera novaeangliae*	4,491	N/A	0.2186	0.15	0-25 nm offshore	Dec-Mar	Mobley et al. 2001
Sperm whale	*Physeter catodon*	6,919	N/A	0.0028	0.81	0-200 nm offshore	Year-round	Barlow 2006
Dwarf sperm whale	*Kogia sima*	17,519	N/A	0.0071	0.74	0-200 nm offshore	Year-round	Barlow 2006
Pygmy sperm whale	*Kogia breviceps*	7,138	N/A	0.0029	1.12	0-200 nm offshore	Year-round	Barlow 2006
Cuvier's beaked whale	*Ziphius cavirostris*	15,242	N/A	0.0062	1.43	0-200 nm offshore	Year-round	Barlow 2006
Longman's beaked whale	*Indopacetus pacificus*	1,007	N/A	0.0004	1.26	75-200 nm offshore	Year-round	Barlow 2006
Blainville's beaked whale	*Mesoplodon densirostris*	2,872	N/A	0.0012	1.25	0-200 nm offshore	Year-round	Barlow 2006
Unidentified beaked whale	*Family Ziphiidae*	371	N/A	0.0002	1.17	0-200 nm offshore	Year-round	Barlow 2006
Bottlenose dolphin	*Tursiops truncatus*	3,215	N/A	0.0013	0.59	0-200 nm offshore	Year-round	Barlow 2006
False killer whale	*Pseudorca crassidens*	236	N/A	0.0001	1.13	0-200 nm offshore	Year-round	Barlow 2006
Killer whale	*Orcinus orca*	349	N/A	0.0001	0.98	0-200 nm offshore	Year-round	Barlow 2006
Pygmy killer whale	*Feresa attenuata*	956	N/A	0.0004	0.83	0-200 nm offshore	Year-round	Barlow 2006
Short-finned pilot whale	*Globicephala macrorhychus*	8,870	N/A	0.0036	0.38	0-200 nm offshore	Year-round	Barlow 2006
Risso's dolphin	*Grampus griseus*	2,372	N/A	0.0010	0.65	0-200 nm offshore	Year-round	Barlow 2006
Melon-headed whale	*Peponocephala electra*	2,950	N/A	0.0012	1.17	0-200 nm offshore	Year-round	Barlow 2006
Rough-toothed dolphin	*Steno bredanensis*	8,709	N/A	0.0036	0.45	0-200 nm offshore	Year-round	Barlow 2006
Fraser's dolphin	*Lagenodelphis hosei*	10,226	N/A	0.0042	1.16	75-200 nm offshore	Year-round	Barlow 2006
Offshore pantropical spotted dolphin	*Stenella attenuata*	8,978	N/A	0.0037	0.48	0-200 nm offshore	Year-round	Barlow 2006
Spinner dolphin	*Stenella longirostris*	3,351	N/A	0.0014	0.74	0-200 nm offshore	Year-round	Barlow 2006
Striped dolphin	*Stenella coeruleoalba*	13,143	N/A	0.0054	0.46	0-200 nm offshore	Year-round	Barlow 2006
Hawaiian monk seal	*Monachus schauinslandi*	1,252	360,000	0.0035	N/A	Offshore HI Island Archipelago	Year-round	Carretta et al. 2006

* Area was derived via ArcMap (obtaining individual areas for all main HI Islands then subtracting those from the overall area of the HI island archipelago).

Density for monk seals derived via dividing the abundance from Carretta et al (2006) with the area obtained via ArcMap.

A.1.5.2 Hawaii Range Complex Marine Mammal Depth Distribution Summary

There is very limited depth distribution data for most marine mammals. This is especially true for cetaceans, as they must be tagged at-sea and using a tag that either must be implanted in the skin/blubber in some manner or that adheres 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/techniques that can be used to determine depth distribution percentages, but by far the most widely used technique at this time is the time-depth recorder. These instruments are designed to be attached to the animal for a fairly short period of time (several hours to a few days) via a suction cup, and are retrieved immediately after detachment. Depth information can also be collected via satellite tags, sonic tags, digital tags, and, for sperm whales, via acoustic tracking of sounds produced by the animal itself.

Barlow (Barlow, 2006) provides density values for 20 species (Table 4). There were several species/species groups seen during the 2002 survey for which no abundance/density was calculated; these species are not included in the depth distribution analysis. Monk seals are present year-round and humpbacks are seasonally present in shallow waters of the Hawaiian Islands, bringing the total number of species requiring depth distribution data to 22. Of these 22, there are somewhat suitable depth distribution data for 10. Sample sizes are extremely small for these 10 species, usually fewer than 10 animals total and often only one or two animals. Depth distribution information often must be interpreted from other dive and or preferred prey characteristics, so confidence in any of these depth distributions is not high. However, these depth distribution data represent the “best available” at this time. Depth distributions for the remaining 12 cetaceans in the Hawaiian Islands area have been extrapolated from similar species to provide the “best available” depth distribution information.

A.1.5.2.1 Depth Distributions for Mysticetes

Bryde’s whale (*B. edeni*)——There are no depth distribution data for this species. They feed on small schooling fish and krill. They are quite a bit smaller than fin whales (13 feet versus 21 feet) but still closer in size to fins than to blue whales. Therefore, in light of the total lack of data for this species, fin whale (*Balaenoptera physalus*) depth distribution data will be extrapolated to Bryde’s whales. Fin whale data from Ligurian Sea are the most complete (Panigada et al., 2003), and showed differences between day and night diving; daytime dives were shallower (within 100 m) and night dives were deeper (>400 m), likely taking advantage of nocturnal prey migrations into shallower depths; this data may be atypical of fin whales elsewhere in areas where they do not feed on vertically-migrating prey. Goldbogen (Goldbogen, et al. 2006) studied fins in southern CA and found that 60% of total time was spent diving, with the other 40% near surface (<50 m); dives were to >225 m and were characterized by rapid gliding ascent, foraging lunges near the bottom of dive, and rapid ascent with flukes. Dives are somewhat V-shaped although the bottom of the V is wide. Therefore, percent of time at depth levels for fin whales could be estimated as 40% at <50 m, 20% at 50 to 225 m (covering the ascent and descent times) and 40% at <225 m.

Humpback whales (*Megaptera novaeangliae*)—In a feeding area (Greenland), 37% of time at <4 m, 25% of time 4-20 m, 7% of time 20-35 m, 4% of time 35-50 m, 6% of time 50-100 m, 7% of time 100-150 m, 8% of time 150-200 m, 6% of time 200-300 m, <1% at >300 m (Dietz et al., 2002). In a non-feeding area (HI), humpbacks spent 40% of time in 0-10 m, 27% in 11-20 m, 12% in 21-30 m, 4% in 31-40 m, 3% in 41-50 m, 2% in 51-60 m, 2% in 61-70 m, 2% in 71-80 m, 2% in 81-90 m, 2% in 91-100 m, 1% in 101-110 m, 1% in 111-120 m, 1% in 121-130 m, 1% in 131-140 m, and <1% in <140 m depth (Baird et al., 2000, Table 3).

A.1.5.2.2 Depth Distributions for Odontocetes

Sperm whale (*Physeter catodon,* aka *Physeter macrocephalus*)—Unlike other cetaceans, there is a preponderance of dive information for this species, most likely because it is the deepest diver of all species and so generates a lot of interest (and funding). 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. The most consistent dive type recorded 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. Perhaps the best source for depth distribution data comes from Amano and Yoshioka (2003), who attached a tag to a female sperm whale near Japan in an area where water depth was 1,000-1,500 m. Based on values in Table 1 for dives with active bottom periods, the total dive sequence was 45.9 min (mean surface time plus dive duration). Mean surface time divided by total time (8.5/45.9) yields a percent of time at the surface (0-2 m) of 19%. Mean bottom time divided by total time (17.5/45.9) yields a percent of time at the bottom of the dive (in this case >800 m as the mean maximum depth was 840 m) of 38%. Total time in the water column descending or ascending equals duration of dive minus bottom time (37.4-17.5) or ~20 minutes. Assuming a fairly equal descent and ascent rate (as shown in the table) and a fairly consistent descent/ascent rate over depth, we assume 10 minutes each for descent and ascent and equal amounts of time in each depth gradient in either direction. Therefore, 0-200 m = 2.5 minutes one direction (which correlates well with the descent/ascent rates provided) and therefore 5 minutes for both directions. Same for 201-400 m, 401-600 m and 601-800 m. Therefore, the depth distribution for sperm whales based on information in the Amano paper is: 19% in 0-2 m, 10% in 2-200 m, 11% in 201-400 m, 11% in 401-600 m, 11% in 601-800 m and 38% in >800 m. The percentages derived above from data in Amano and Yoshioka (2003) are in fairly close 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.

Dwarf sperm whale(*Kogia sima)*—There are no depth distribution data for this species. Prey preference appears to be cephalopods, crustaceans and fish, and there is some evidence that they feed at the bottom. In lieu of any other information, Blainville's beaked whale depth distribution data will be extrapolated to dwarf sperm whales as the two species appear to have similar prey preferences and Kogia sp. are closer in size to Blainville's than to sperm or Cuvier's beaked whales.

Pygmy sperm whale (*Kogia breviceps*)—There are no depth distribution data for this species. An attempt to record dive information on a rehabbed pygmy sperm whale failed when the TDR package was never recovered (Scott et al., 2001). Prey preference appears to be cephalopods, crustaceans and fish, and there is some evidence that they feed at the bottom. 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 Kogia sp. are closer in size to Blainville's than to sperm or Cuvier's beaked whales.

<u>Cuvier's beaked whale</u> (*Ziphius cavirostris*)—Studies in Hawaii (Baird et al., 2005a; Baird et al., 2006) found that this species undertook three or four different types of dives, including intermediate (to depths of 292-568 m), deep (>1,000 m) and short-interventilation (within 2-3 m of surface). Studies in the Canary Islands indicated that Cuvier's beaked whales dived to >1,000 m and usually started "clicking" (actively searching for prey) around 475 m (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, although maximum dive depths were similar. There was no significant difference between day and night diving indicating that preferred prey likely do not undergo vertical migrations. To determine depth distribution data for this species, the graph representing daytime dives in Figure 5 in Baird et al. (2005a) was used. It would appear that ~15% of total time is spent in 0-100 m depth, ~13% from 101-200 m depth, ~22% from 201-300 m depth, ~13% from 301-600 m depth, ~6% from 601-800 m depth, ~11% from 801-1,000 m depth, and 20% at >1000 m. These data are representative of only one animal so, like all the other depth distribution data, are very limited in scope.

<u>Longman's beaked whale</u> (aka Tropical bottlenose whale) (*Indopacetus pacificus*)—There are no depth distribution data for this species, and preferred prey species are also unknown. There has been one study on northern bottlenose whales, *Hyperoodon ampullatus*, which provides some guidance as to depth distribution (Hooker and Baird, 1999). Most (62-70%, average = 66%) of the time was spent diving (>40 m), and most dives were somewhat V-shaped. Both shallow dives (<400 m) and deep dives (>800 m) were recorded, and whales spent 24-30% (therefore, average of 27%) of dives at 85% maximum depth indicating they feed near the bottom. Using these data points, we estimate 34% of time at 0-40 m, 39% at 41-800 m, 27% at >800 m for H. ampullatus and extrapolate this to I. pacificus.

<u>Blainville's beaked whale</u> (*Mesoplodon densirostris)*—Studies in Hawaii (Baird et al., 2004; 2005a; 2006) found that this species undertook several different types of dives, including shallow (0-50 m with most time at 0-20 m), deep (mean maximum of 890 and 1,408 m) and short-interventilation (within 2-4 m of surface). Studies in the Canary Islands indicated that Blainville's beaked whales dived to >655 m and usually started "clicking" (actively searching for prey) around 200-570 m (Johnson et al., 2004). Clicking continued at depths and ceased once ascent to the surface began, indicating active foraging at depth. To determine depth distribution data for this species, the top two left-side graphs in Figure 6 in Baird et al. (2005a) were used. It would appear that ~48% of total time is spent in 0-50 m depth, ~11% from 51-100 m depth, ~11% from 101-200 m depth, ~9% from 201-500 m depth, ~5% from 501-800 m depth, ~5% from 801-1,000 m depth, and 11% at >1,000 m. This data is representative of only two animals, so like all the other depth distribution data is very limited in scope.

<u>Unidentified beaked whale</u> (Family Ziphiidae)—This encompasses all beaked whales and several genera that might be found offshore Hawaii. Based on the total lack of additional information

about what this species may have been, suggest using the limited dive information available for Cuvier's beaked whale.

<u>Bottlenose dolphin</u> (*Tursiops truncatus)*—There have been a few studies on bottlenose dolphin depth distributions. Corkeron and Martin (2004) reported that two dolphins spent 66% of time in top 5 m of water surface; maximum dive depth was greater than 150 m and there was no apparent diurnal pattern. Based on this study plus information from Hastie et al. (2006), the following depth distribution has been estimated for bottlenose dolphins: 66% of time at 0-10 m, 12% at 11-20 m, 12% at 21-30 m, 5% at 31-40 m, 4% at 41-50 m, and 1% at >50 m.

<u>False killer whale</u> (*Pseudorca crassidens*)—The only study conducted on false killer whales diving in Hawaii has not been published in any detail (Ligon and Baird, 2001), but an abstract provides limited information. False killer whales did not dive deep and instead recorded maximum dives of 22, 52 and 53 m in near-shore Hawaii waters. Based on the nearly total lack of data for this species, suggest using the limited dive information available for killer whales.

<u>Killer whale</u> (*Orcinus orca*)—Diving studies on killer whales have been undertaken mainly on "resident" (fish-eating) killer whales in the Puget Sound and are likely not 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, and males dove more frequently and more often to depths >100 m than females, with fewer deep dives at night. Using best available data from Baird et al. (2003a), it would appear that killer whales spend ~4% of time at depths >30 m and 96% of time at depths <30 m. Dives to deeper depths were often characterized by velocity bursts which may be associated with foraging or social activities.

<u>Pygmy killer whale</u> (*Feresa attenuata*)—There are no depth distribution data for this species, and there is little information on prey preference. In lieu of any other information, killer whale depth distribution data will be extrapolated to pygmy killer whales.

<u>Short-finned pilot whale</u> (*Globicephala macrorhychus*)—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 did indicate that there are significant differences between day and night diving; dives of >100m were far more frequent at night, likely to take advantage of vertically-migrating prey; night dives regularly went to 300-500 m. Deepest dives were during the day, however, perhaps because prey was deeper. A closely-related species, the long-finned pilot whale, also shows marked differences in daytime and nighttime diving in studies in the Ligurian Sea (Baird et al., 2002), but there is no information on % of time at various depth categories. A study following two rehabilitated and released LF pilot whales provides a breakdown of % of time at depth distribution for 2 whales (Nawojchik et al., 2003). Averaging the values for the two whales results in the following depth distribution breakdown: 64% at <15 m, 19% at 16-50 m, 7% at 51-100m, 4% at 101-150 m, 5% at 151-200 m, 1% at 201-250 m and <1% at >250 m. As the same type of detailed dive depth distribution is not available for SF pilot whales, these numbers will have to suffice.

Risso's dolphin (*Grampus griseus*)—There are no depth distribution data for this species. They are primarily squid eaters and feeding is presumed to take place at night. In lieu of any other information, short-finned pilot whale depth distribution data will be extrapolated to Risso's dolphins.

Melon-headed whale (*Peponocephala electra*)—There are no depth distribution data for this species. They are primarily squid and pelagic fish eaters and at least some feeding is presumed to take place at fairly deep depth. In lieu of any other information, short-finned pilot whale depth distribution data will be extrapolated to melon-headed whales.

Rough-toothed dolphin (*Steno bredanensis*)—There are no depth distribution data for this species. They are believed to be deep divers and feeders. In lieu of any other information, spinner dolphin depth distribution data will be extrapolated for rough-toothed dolphins.

Fraser's dolphin (*Lagenodelphis hosei* —Studies on diving by this species have not been undertaken, but studies of stomach contents in the eastern tropical Pacific and Sulu Sea indicate that they eat myctophid fish as well as cephalopods and crustaceans (Dolar et al., 2003). Based on prey species, this species apparently regularly feeds in deeper waters than spinner dolphins as several of its major prey items are regularly found between 600 and 1000 m. It is believed that Fraser's dolphins also feed mainly at night. Based on this very limited information, the following are very rough order estimates of time at depth: daytime: 100% at 0-50 m; nighttime: 100% at 0-700 m.

Offshore pantropical spotted dolphin (*Stenella attenuata)*—One study on this species 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% of time was spent within 0-10 m, most of the rest of the time was 10-50 m, and the deepest dive was to 122 m. At night, only 59% of time was spent from 0-10 m and the deepest dive was to 213 m; dives were especially pronounced at dusk. For activities conducted during daytime-only, the depth distribution would be 89% at 0-10 m and 11% at 11-50 m, with <1% at 51-122 m. For activities conducted over a 24-hour period, the depth distribution needs to be modified to reflect less time at surface and deeper depth dives; 80% at 0-10 m, 8% at 11-20 m, 2% at 21-30 m, 2% at 31-40 m, 2% at 41-50 m, and 6% at 51-213 m.

Spinner dolphin (*Stenella longirostris*)—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 fishes). Mean depth of spinner dolphins was always within 10 m 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) waters. Prey distribution during the day is estimated at 400-700 m. Based on these data, the following are very rough order estimates of time at depth: daytime: 100% at 0-50 m; nighttime: 100% at 0-400 m.

Striped dolphin (*Stenella coeruleoalba*)—Studies are rare on this species. In lieu of any other information, pantropical spotted dolphin depth distribution data will be extrapolated to striped dolphins.

A.1.5.2.3 Depth Distributions of Pinnipeds

Hawaiian monk seal (*Monachus schauinslandi*)—There have been several recent studies on foraging patterns by monk seals near rookeries in the northwestern Hawaiian Islands. Dive depths appear to differ slightly between rookeries as well as between age and sex classes. At Pearl and Hermes Reef, most dives were from 8-40 m with a second much smaller node at 100-120 m (Stewart, 2004). At Kure Atoll, most dives were shallower than 40 m, with males tending to dive deeper than females (Stewart and Yochem, 2004a). At Laysan Island, a similar dive pattern was recorded with most dives shallower than 40 m, but at that location females tended to dive deeper than males (250-350 m) (Stewart and Yochem, 2004b). Parrish et al (2002) noted a tendency towards night diving at French Frigate Shoals, with dives to ~80-90 m. Based on these data, the following are rough order estimates of time at depth: 90% at 0-40 m; 9% at 40-120 m; 1% at >120 m.

A.1.5.3 Exposure Estimates

The following sperm whale example demonstrates the methodology used to create a three-dimensional density by merging the area densities with the depth distributions. The sperm whale surface density is 0.0028 whales per square kilometer. From the depth distribution report, "depth distribution for sperm whales based on information in the Amano paper is: 19% in 0-2 m, 10% in 2-200 m, 11% in 201-400 m, 11% in 401-600 m, 11% in 601-800 m and 38% in >800 m." So the sperm whale density at 0 to 2 m is (0.0028*0.19/0.002 =) 0.266 per cubic km, at 2-200 m is (0.0028*0.10/0.198 =) 0.001414 per cubic km, and so forth.

In general, the impact volume vector samples depth in finer detail than given by the depth distribution data. When this is the case, the densities are apportioned uniformly over the appropriate intervals. For example, suppose the impact volume vector provides volumes for the intervals 0 to 2 m, 2 to 10 m, and 10 to 50 m. Then for the depth-distributed densities discussed in the preceding paragraph,

- 0.266 whales per cubic km is used for 0 to 2 m,
- 0.001414 whales per cubic km is used for the 2 to 10 m, and
- 0.001414 whales per square km is used for the 10 to 50 m.

Once depth-varying, three-dimensional densities are specified for each species type, with the same depth intervals and the ensonified volume vector, the density calculations are finished. The expected number of ensonified animals within each depth interval is the ensonified volume at that interval multiplied by the volume density at that interval and this can be obtained as the dot product of the ensonified volume and animal density vectors.

Since the ensonified volume vector is the ensonified volume per unit operation (i.e., per hour, per sonobuoy, etc), the final exposure count for each animal is the unit operation exposure count multiplied by the number of units (hours, sonobuoys, etc). The tables below are organized by Alternative and threshold level; each table represents the total yearly exposures modeled at different threshold levels for each alternative. For sonar sources, exposures are reported at the appropriate dose function level, 195 dB, and 215 dB.

The following tables, Tables A-53 through A-57, give the number of exposures to mid frequency active sonar at different threshold levels for each type of operational training exercise. Table A-58 presents the Explosives modeling summary for all explosive sources for one year. For the dual TTS criteria modeled at < 182 dB re 1 μPa^2–s or 23 psi, the criteria providing the greatest number of exposures is represented in the table.

Table A-53. Sonar Modeling Summary - Yearly Marine Mammal Exposures from Tracking Exercises

Marine Mammals	Dose Function Behavioral	195 dB TTS	215 dB PTS
Bryde's whale	76	1	0
Fin whale[1, 2]	24	1	0
Sei whale[1, 2]	24	1	0
Humpback whale[1]	7,506	110	0
Sperm whale[1]	346	10	0
Dwarf sperm whale	741	40	0
Pygmy sperm whale	303	16	0
Cuvier's beaked whale	449	6	0
Longman's beaked whale	50	2	0
Blainville's beaked whale	173	7	0
Unidentified beaked whale	14	0	0
Bottlenose dolphin	402	21	0
False killer whale	24	1	0
Killer whale	24	1	0
Pygmy killer whale	97	6	0
Shortfinned pilot whale	917	48	0
Risso's dolphin	255	13	0
Melonheaded whale	306	16	0
Roughtoothed dolphin	389	21	0
Fraser's dolphin	449	24	0
Pantropical spotted dolphin	1,256	60	0
Spinner dolphin	151	8	0
Striped dolphin	1,834	88	0
Monk seal[1]	160	3	0
TOTAL	15,970	504	0

Note: [1] Endangered Species
[2] Due to a lack of density data for fin and sei whales, false killer whale results were used because they have a similar size population within the HRC.
Dose Function Curve
195 dB – TTS 195-215 dB re 1 μPa^2-s
215 dB- PTS >215 dB re 1 μPa^2-s
dB = decibel
TTS = temporary threshold shift
PTS = permanent threshold shift

Table A-54. Sonar Modeling Summary - Yearly Marine Mammal Exposures from Torpedo Exercises

Marine Mammals	Dose Function Behavioral	195 dB TTS	215 dB PTS
Bryde's whale	17	0	0
Fin whale[1, 2]	6	0	0
Sei whale[1, 2]	6	0	0
Humpback whale[1]	2,507	48	0
Sperm whale[1]	90	3	0
Dwarf sperm whale	192	11	0
Pygmy sperm whale	78	4	0
Cuvier's beaked whale	96	2	0
Longman's beaked whale	12	0	0
Blainville's beaked whale	40	2	0
Unidentified beaked whale	3	0	0
Bottlenose dolphin	106	6	0
False killer whale	6	0	0
Killer whale	6	0	0
Pygmy killer whale	26	2	0
Shortfinned pilot whale	248	13	0
Risso's dolphin	69	4	0
Melonheaded whale	83	4	0
Roughtoothed dolphin	101	6	0
Fraser's dolphin	116	6	0
Pantropical spotted dolphin	333	16	0
Spinner dolphin	39	2	0
Striped dolphin	485	24	0
Monk seal[1]	37	1	0
TOTAL	4,702	154	0

Note: [1] Endangered Species
[2] Due to a lack of density data for fin and sei whales, false killer whale results were used because they have a similar size population within the HRC.
Dose Function Curve
173 dB - sub-TTS (NMFS) 173- 195 dB re 1 μPa^2-s
190 dB – sub-TTS (Navy) 190- 195 dB re 1 μPa^2-s
195 dB – TTS 195-215 dB re 1 μPa^2
215 dB- PTS >215 dB re 1 μPa^2
dB = decibel
TTS = temporary threshold shift
PTS = permanent threshold shift

Table A-55. Sonar Modeling Summary - Yearly Marine Mammal Exposures for RIMPAC (Conducted Every Other Year)

Marine Mammals	Dose Function Behavioral	195 dB TTS	215 dB PTS
Bryde's whale	49	1	0
Fin whale[1, 2]	15	1	0
Sei whale[1, 2]	15	1	0
Humpback whale[1]	-	-	-
Sperm whale[1]	230	7	0
Dwarf sperm whale	436	28	0
Pygmy sperm whale	178	12	0
Cuvier's beaked whale	314	4	0
Longman's beaked whale	32	1	0
Blainville's beaked whale	108	5	0
Unidentified beaked whale	10	0	0
Bottlenose dolphin	256	14	0
False killer whale	15	1	0
Killer whale	15	1	0
Pygmy killer whale	59	4	0
Shortfinned pilot whale	578	33	0
Risso's dolphin	160	9	0
Melonheaded whale	193	11	0
Roughtoothed dolphin	229	15	0
Fraser's dolphin	265	17	0
Pantropical spotted dolphin	817	41	0
Spinner dolphin	89	6	0
Striped dolphin	1,193	60	0
Monk seal[1]	98	2	0
TOTAL	5,354	274	0

Note: 1 Endangered Species
[2] Due to a lack of density data for fin and sei whales, false killer whale results were used because they have a similar size population within the HRC.
Dose Function Curve
195 dB – TTS 195-215 dB re 1 μPa^2
215 dB- PTS >215 dB re 1 μPa^2-s
dB = decibel
TTS = temporary threshold shift
PTS = permanent threshold shift

Table A-56. Sonar Modeling Summary - Yearly Marine Mammal Exposures for USWEX (Exposures from Six Exercises Per Year)

Marine Mammals	Dose Function Behavioral	195 dB TTS	215 dB PTS
Bryde's whale	65	1	0
Fin whale[1, 2]	19	1	0
Sei whale[1, 2]	19	1	0
Humpback whale[1]	19,421	261	0
Sperm whale[1]	262	8	0
Dwarf sperm whale	599	31	0
Pygmy sperm whale	244	13	0
Cuvier's beaked whale	378	5	0
Longman's beaked whale	41	1	0
Blainville's beaked whale	145	5	0
Unidentified beaked whale	12	0	0
Bottlenose dolphin	305	15	0
False killer whale	19	1	0
Killer whale	19	1	0
Pygmy killer whale	74	4	0
Shortfinned pilot whale	679	35	0
Risso's dolphin	189	10	0
Melonheaded whale	226	12	0
Roughtoothed dolphin	315	16	0
Fraser's dolphin	363	19	0
Pantropical spotted dolphin	938	44	0
Spinner dolphin	122	6	0
Striped dolphin	1,368	64	0
Monk seal[1]	136	2	0
TOTAL	25,958	556	0

Note: [1] Endangered Species
[2] Due to a lack of density data for fin and sei whales, false killer whale results were used because they have a similar size population within the HRC.
Dose Function Curve
195 dB – TTS 195-215 dB re 1 μPa^2
215 dB- PTS >215 dB re 1 μPa^2
dB = decibel
TTS = temporary threshold shift
PTS = permanent threshold shift

Table A-57. Sonar Modeling Summary—Yearly Marine Mammal Exposures for Three Strike Group Exercise

Marine Mammals	Dose Function Behavioral	195 dB TTS	215 dB PTS
Bryde's whale	66	1	0
Fin whale[1, 2]	18	1	0
Sei whale[1, 2]	18	1	0
Humpback whale[1]	5,364	63	0
Sperm whale[1]	227	6	0
Dwarf sperm whale	597	24	0
Pygmy sperm whale	244	10	0
Cuvier's beaked whale	355	4	0
Longman's beaked whale	41	1	0
Blainville's beaked whale	146	4	0
Unidentified beaked whale	11	0	0
Bottlenose dolphin	280	12	0
False killer whale	18	1	0
Killer whale	18	1	0
Pygmy killer whale	71	4	0
Shortfinned pilot whale	624	28	0
Risso's dolphin	173	8	0
Melonheaded whale	208	9	0
Roughtoothed dolphin	313	13	0
Fraser's dolphin	361	15	0
Pantropical spotted dolphin	840	35	0
Spinner dolphin	122	5	0
Striped dolphin	1,226	51	0
Monk seal[1]	136	1	0
TOTAL	11,480	298	0

Note: [1] Endangered Species
[2] Due to a lack of density data for fin and sei whales, false killer whale results were used because they have a similar size population within the HRC.
Dose Function Curve
195 dB – TTS 195-215 dB re 1 µPa^2-s
215 dB- PTS >215 dB re 1 µPa^2-s
dB = decibel
TTS = temporary threshold shift
PTS = permanent threshold shift

Table A-58. Explosives Modeling Summary - Yearly Marine Mammal Exposures From all Explosive Sources (Mine Neutralization, MISSILEX, BOMBEX, SINKEX, GUNEX, Naval Surface Fire Support)

Marine Mammal Species	TTS Modeled at < 182 dB re 1 μPa^2–s or 23 psi							Total Exposures		
	Mine Neutralization	Air to Surface Missile Exercise	Surface to Surface Missile Exercise	Bombing Exercise	Sink Exercise	Surface to surface Gunnery Exercise	Naval Surface Fire Support	TTS 182 dB, 23 psi	Slight Lung/ TM Injury	Onset Massive Lung Injury
Bryde's whale	0	0	0	0	0	0	0	0	0	0
Fin whale[1, 2]	0	0	0	0	0	0	0	0	0	0
Sei whale	0	0	0	0	0	0	0	0	0	0
Humpback whale[1]	1	0	0	7	0	6	1	15	0	0
Sperm whale[1]	0	0	0	2	3	0	0	5	0	0
Dwarf sperm whale	0	0	0	4	4	1	0	9	0	0
Pygmy sperm whale	0	0	0	2	2	0	0	4	0	0
Cuvier's beaked whale	0	0	0	5	5	0	0	10	0	0
Longman's beaked whale	0	0	0	0	0	0	0	0	0	0
Blainville's beaked whale	0	0	0	1	1	0	0	2	0	0
Unidentified beaked whale	0	0	0	0	0	0	0	0	0	0
Bottlenose dolphin	0	0	0	0	0	0	0	0	0	0
False killer whale	0	0	0	0	0	0	0	0	0	0
Killer whale	0	0	0	0	0	0	0	0	0	0
Pygmy killer whale	0	0	0	0	0	0	0	0	0	0
Shortfinned pilot whale	0	0	0	1	1	0	0	2	0	0
Risso's dolphin	0	0	0	0	0	0	0	0	0	0
Melonheaded whale	0	0	0	0	0	0	0	0	0	0
Roughtoothed dolphin	0	0	0	2	1	0	0	3	0	0
Fraser's dolphin	0	0	0	2	2	0	0	4	0	0
Pantropical spotted dolphin	0	0	0	1	0	1	0	2	0	0
Spinner dolphin	0	0	0	1	1	0	0	2	0	0
Striped dolphin	0	0	0	1	1	1	0	3	0	0
Monk seal[1]	0	0	0	0	0	0	0	0	0	0
Total	1	0	0	29	21	9	1	61	0	0

Note: [1] Endangered Species
2 Due to a lack of density data for fin and sei whales, false killer whale results were used because they have a similar size population within the HRC.
dB = decibel
μPa^2-s = squared micropascal-second
NMFS = National Marine Fisheries Service
PTS = permanent threshold shift
TM = tympanic membrane
TTS = temporary threshold shift

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Appendix B

Dose Function Definitions, Metrics, and Additional References

B.1 DOSE FUNCTION MODELING

B.1.1 DOSE FUNCTION: THEORETICAL AND PRACTICAL IMPLEMENTATION

This section discusses the recent addition of a dose function "threshold" to 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. What these two parts mean, how they affect exposure calculations, and how they are implemented are the objects of discussion.

B.1.1.1 Thresholds and Metrics

The term "thresholds" is broadly used to refer to both thresholds and metrics. The difference, and the distinct roles of each in effects analyses, will be the foundation for understanding the dose function approach, putting it in perspective, and showing that, conceptually, it is similar to past approaches.

Sound is a pressure wave, so at a certain point in space, sound is simply rapidly changing pressure. Pressure at a point is a function of time. Define p(t) as pressure (in micropascals) at a given point at time t (in seconds); this function is called a "time series." Figure B-1 gives the time series of the first "hallelujah" in Handel's Hallelujah Chorus.

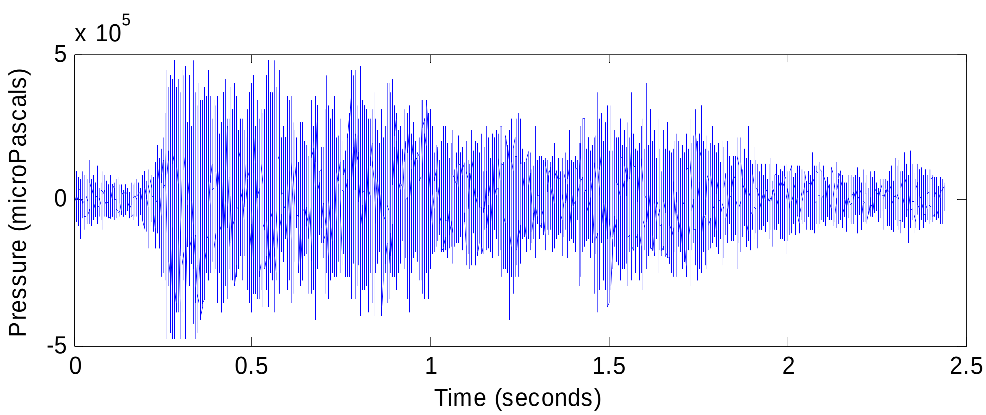

Figure B-1. Time Series

The time-series of a source can be different at different places. Therefore, sound, or pressure, is not only a function of time, but also of location. Let the function p(t), then be expanded to p(t;x,y,z) and denote the time series at point (x,y,z) in space. Thus, the series in Figure B-1 p(t) is for a given point (x,y,z). At a different point in space, it would be different.

Assume that the location of the source is (0,0,0) and this series is recorded at (0,10,-4). The time series above would be p(t;0,10,-4) for 0<t<2.5.

As in Figure B-1, pressure can be positive or negative, but usually the function is squared so it is always positive, this makes integration meaningful. Figure B-2 is $p^2(t;0,10,-4)$.

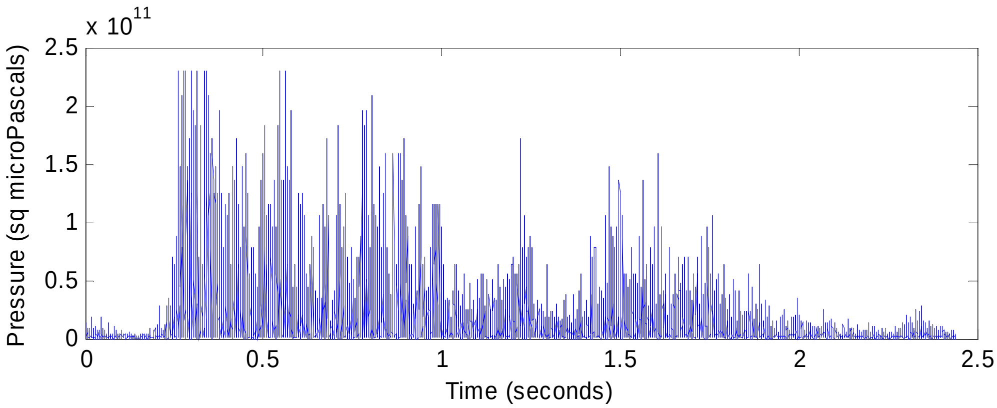

Figure B-2. Time Series Squared

The metric chosen to evaluate the sound field at the end of this first "hallelujah" determines how the time series is summarized from thousands of points, as in Figure B-1, to a single value for each point (x,y,z) in the space. The metric essentially "boils down" the four dimensional p(t,x,y,z) into a three dimensional function m(x,y,z) by dealing with time. There is more than one way to summarize the time component, so there is more than one metric.

Max SPL

One way to summarize $p^2(t;x,y,z)$ to one number over the 2.5 seconds is to only report the maximum value of the function over time or,

$$SPL_{\max} = \max\left\{p^2(t,x,y,z)\right\} \text{ for } 0<t<2.5$$

The $SPL_{\max}$ for this snippet of the Hallelujah Chorus is $2.3\times10^{11}\,\mu Pa^2$ and occurs at 0.2825 seconds, as shown in Figure B-3.

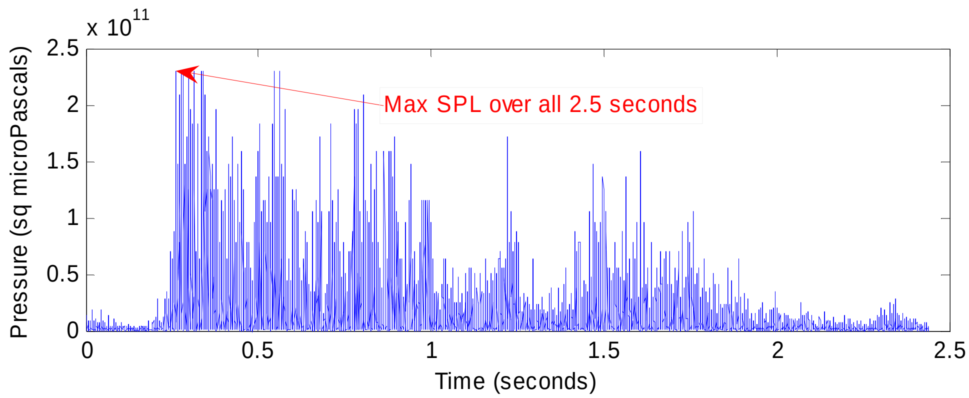

Figure B-3. Max SPL of Time Series Squared

Integration

$SPL_{\max}$ is not necessarily influenced by the duration of the sound (2.5 seconds in this case). Integrating the function over time does take this duration into account. A simple integration of $p^2(t;x,y,z)$ over t is common and usually called "energy."

$$Energy = \int_0^T p^2(t,x,y,z)dt$$ where T is the maximum time of interest, in this case 2.5

The energy for this snippet of the Hallelujah Chorus is $1.24 \times 10^{11}\ \mu Pa \cdot s$.

Energy is sometimes called "equal energy" because if p(t) is a constant function and the duration is doubled, the effect is the same as doubling the signal amplitude (y value). Thus, the duration and the signal have an "equal" influence on the energy metric.

Mathematically,

$$\int_0^{2T} p(t)^2\,dt = 2\int_0^T p(t)^2\,dt = \int_0^T 2p(t)^2\,dt$$

or a doubling in duration equals a doubling in energy equals a doubling in signal.

Sometimes, the integration metrics are referred to as having a "3 dB exchange rate" because if the duration is doubled, this integral increases by a factor of two, or 10log10(2)=3.01 dB. Thus, equal energy has "a 3 dB exchange rate."

After p(t) is determined (i.e., when the stimulus is over), propagation models can be used to determine p(t;x,y,z) for every point in the vicinity and for a given metric. Define

$m_a(x,y,z,T) =$ value of metric "a" at point (x,y,z) after time T

So,

$$m_{energy}(x,y,z;T) = \int_0^T p(t)^2\,dt$$

$$m_{\max SPL}(x, y, z; T) = \max(p(t)) \; over \; [0, T]$$

Since modeling is concerned with the effects of an entire event, T is usually implicitly defined: a number that captures the duration of the event. This means that $m_a(x, y, z)$ is assumed to be measured over the duration of the received signal.

Three Dimensions vs Two Dimensions

To further reduce the calculation burden, it is possible to reduce the domain of $m_a(x, y, z)$ to two dimensions by defining $m_a(x, y) = \max\{m_a(x, y, z)\}$ over all z.
This reduction is not used for this analysis, which is exclusively three-dimensional.

Threshold

For a given metric, a threshold is a function that gives the probability of exposure at every value of m_a. This threshold function will be defined as

$$D(m_a(x, y, z)) = \Pr(effect \; at \; m_a(x, y, z))$$

The domain of D is the range of $m_a(x, y, z)$, and its range is the number of thresholds.

An example of threshold functions is the Heavyside (or unit step) function, currently used to determine permanent and temporary threshold shift (PTS and TTS) in cetaceans. For PTS, the metric is $m_{energy}(x, y, z)$, defined above, and the threshold function is a Heavyside function with a discontinuity at 215 dB, shown in Figure B-4.

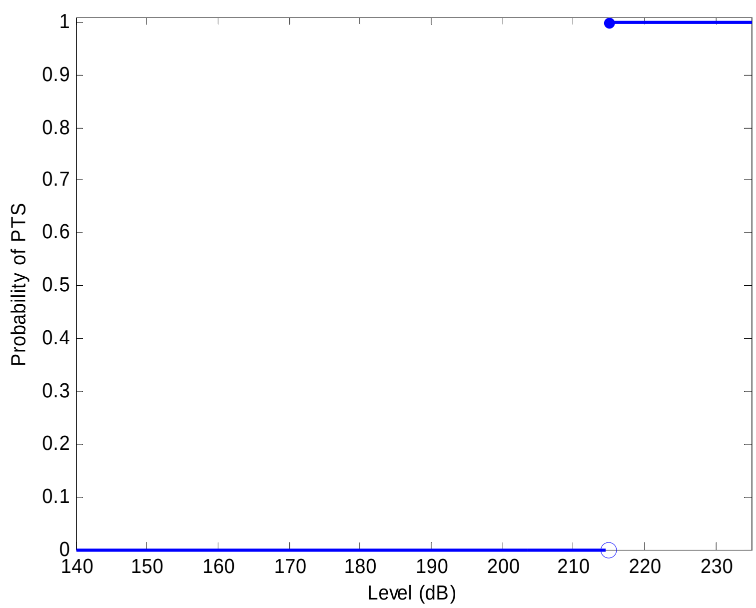

Figure B-4. PTS Heavyside Threshold Function

Mathematically, this D is defined as:

$$D(m_{energy}) = \begin{cases} 0 \ \ for \ m_{energy} < 215 \\ 1 \ \ for \ m_{energy} \geq 215 \end{cases}$$

Any function can be used for D, as long as its range is in [0,1]. The dose function use normal cumulative distribution functions (ncdfs) instead of heavyside functions, and use the max SPL metric instead of the energy metric. While a Heavyside function is specified by a single parameter, the discontinuity, a normal cumulative distribution function requires two parameters: the mean and the standard deviation. This particular approach defines a third parameter, "cutoff," to limit the support (domain of definition) of D. Mathematically, these "dose" functions are defined as

$$D(m_{\max SPL}) = \begin{cases} ncdf(\mu, \sigma, m_{\max SPL}) \ for \ m_a \geq a \\ 0 \ \ for \ m_{\max SPL} < a \end{cases}$$

where a=cutoff, μ=mean, and σ=standard deviation. For these dose functions, cutoff (a) is always a function of μ and σ, a relationship in the form of a= μ-k σ, where k is an integer. The mid-frequency dose function used for small odontocetes is $ncdf(189,12, m_{\max SPL})$, with cutoff= μ-3 σ=153 dB.

Multiple Metrics and Thresholds

It is possible to have more than one metric, and more than one threshold in a given metric. For example, in this document, humpback whales have two metrics (energy and max SPL), and three thresholds (two for energy, one for max SPL). The energy thresholds are heavyside functions, as described above, with discontinuities at 215 and 195 for PTS and TTS respectively. The max SPL threshold is a dose function with μ=175, σ=10, and cutoff = μ-3 σ =145 for disturbance.

B.1.1.2 Calculation of Expected Exposures

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

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

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

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

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

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

Numeric Implementation

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 non-negative 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:

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 section presents a brief outline of 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, so a balance between accuracy and time is determined in the decision of step size. For this analysis, z is sampled in 5-m steps to 1,000 m in depth and 10-m steps to 2,000 m, which is the limit of animal depth in this analysis. The step size for x is 5 m, and y is sampled with an interval that increases as the distance from the source increases. Mathematically,

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

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

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

$$\sum_{i \in Y}\sum_{j \in X} D(m_{\max SPL}(x,y,z_0))\left[\left(x_{j+\frac{j}{|j|}} - x_j\right)\left(y_{i+\frac{i}{|i|}} - y_i\right)\right]$$

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,

$\int_{-\infty}^{0} \rho(z) f(z)dz$ 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 x 200 km--40,000 sq km, 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.

Saving the entire $m_{\max SPL}(x,y,z)$ for each z is unrealistic, requiring great amounts of time and disk space. Instead, the different levels in the range of $m_{\max SPL}(x,y,z)$ are sorted into 0.5 dB wide bins; the volume of water at each bin level is taken from $m_{\max SPL}(x,y,z)$, and associated with its bin. Saving this, just 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

$m_{\max SPL}(x, y, z)$ 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 function V(L,z), where L=.5a for every $a \in R_1$. 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 (dose function curves) are purely a function of level, not location, so this information is sufficient to calculate f(z).

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

$$\sum_{L \in R_1} D(L)V(L, z_0) \approx \int_{-\infty}^{\infty} \rho(z) \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} D(m_{\max SPL}(x, y, z))dxdydz$$

So, once the histograms are saved, neither $m_{\max SPL}(x, y, z)$ nor f(z) must be recalculated to generate $\int_{-\infty}^{\infty} \rho(z) \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} D(m_{\max SPL}(x, y, z))dxdydz$ for a new threshold function.

For the interested reader, the following section includes an in-depth discussion of the method, software, and other details of the f(z) calculation.

B.1.1.3 Software Detail

The dose 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 transmission loss (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, that 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 B-5 shows a volume histogram for a low power sonar.

Level bins are 0.5 dB in width and the depth is 50 m in an environment with water depth of 100 m. 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 dose function probability function at that level. Total expected impact volume for a given depth is the sum of these "expected" volumes. Figure B-6 is an example of the impact volume as a function of depth at a water depth of 100 m.

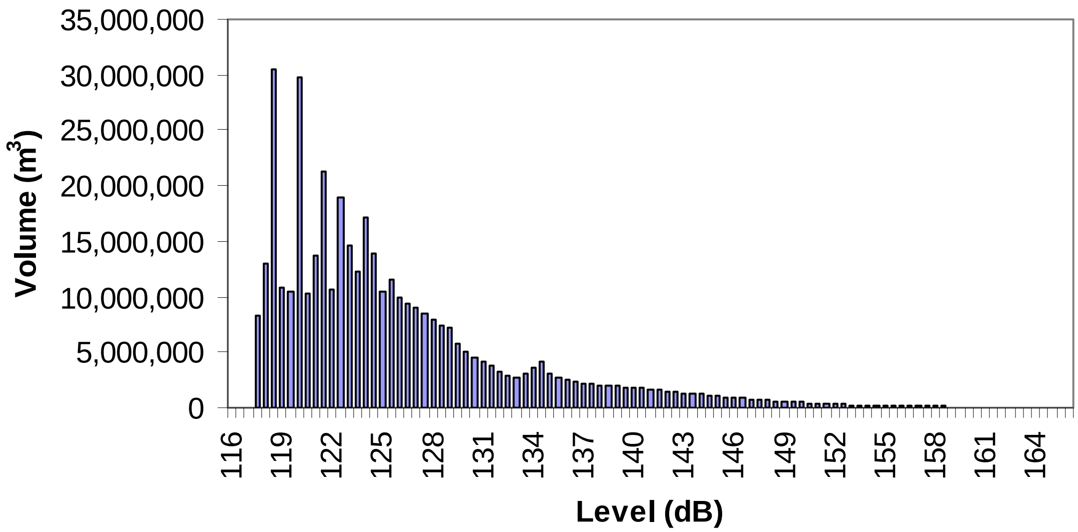

Figure B-5. Example of a Volume Histogram

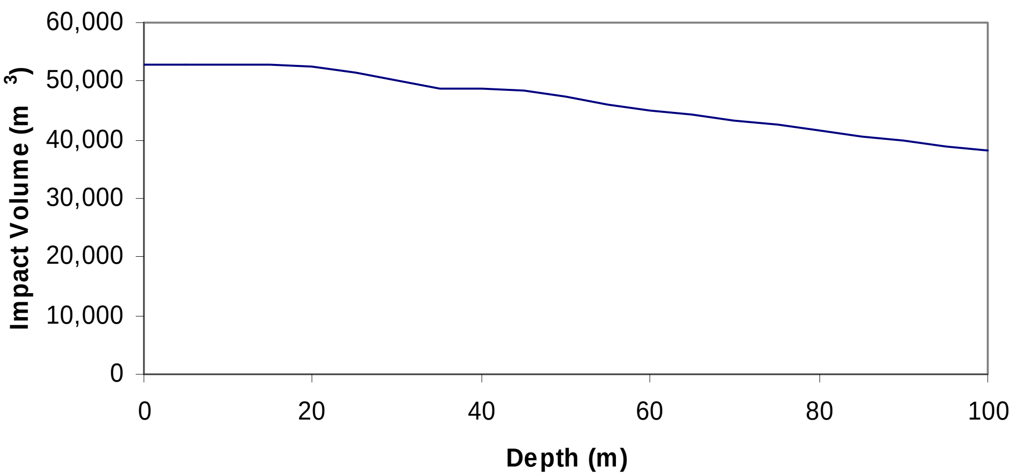

Figure B-6. Example of the Dependence of Impact Volume on Depth

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 in the x-coordinate and a slowly expanding spacing in the y-coordinate that starts with 5 m 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 and a growth factor of 0.005, the 100^{th} grid increment is 8.19 m. 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 –Rmax to +Rmax, where Rmax is the maximum range used in the TL calculations. The z direction uses a uniform spacing of 5 m down to 1,000 m and 10 m from 1,000 to 2,000 m. 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, on the assumption that animals of interest are not found below this depth.

The next three figures indicate how the accuracy of the calculation of impact volume depends on the parameters used to generate the mesh in the horizontal plane. Figure B-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 5m and the y-axis growth factor is 0, i.e., uniform spacing. The impact volume for a 5 m grid size is the reference. For grid sizes between 2.5 and 7.5 m, the change is less than 0.1%. A grid size of 5 m for the x-axis is used in the calculations. Figure B-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 and the y-axis growth factor is 0. The impact volume for a 5 m 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, the change is less than 0.1%. A grid size of 5 m is used for the y-axis in our calculations. Figure B-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. 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%. A growth factor of 0.005 is used in the calculations.

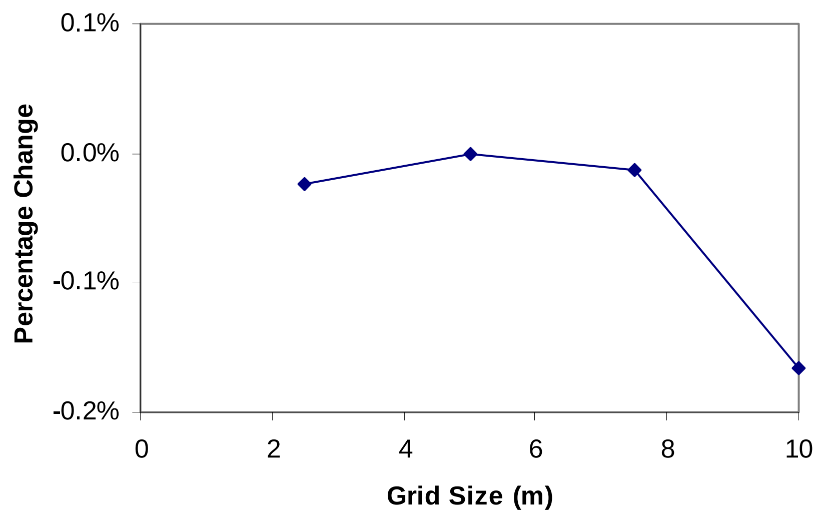

Figure B-7. Change of Impact Volume as a Function of X-axis Grid Size

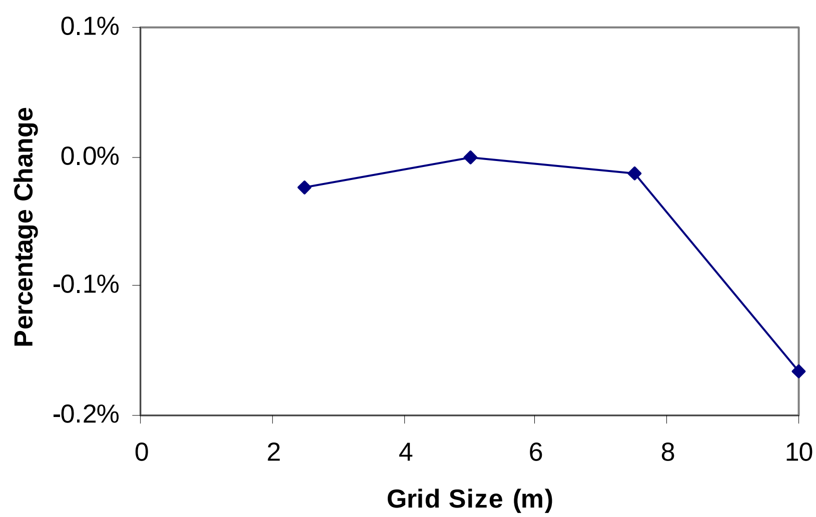

Figure B-8. Change of Impact Volume as a Function of Y-axis Grid Size

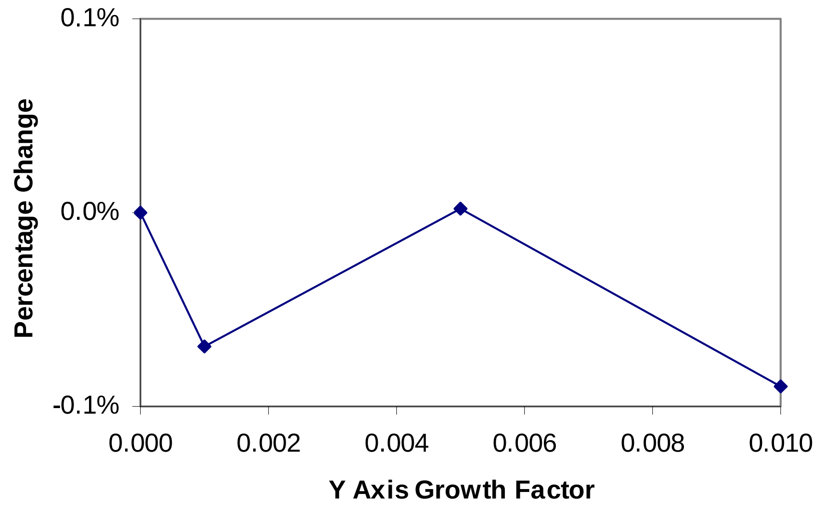

Figure B-9. Change of Impact Volume as a Function of Y-axis Growth Factor

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 B-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 the initial y-axis grid size is 5 m, 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%. A bin width of 0.5 is used in our calculations.

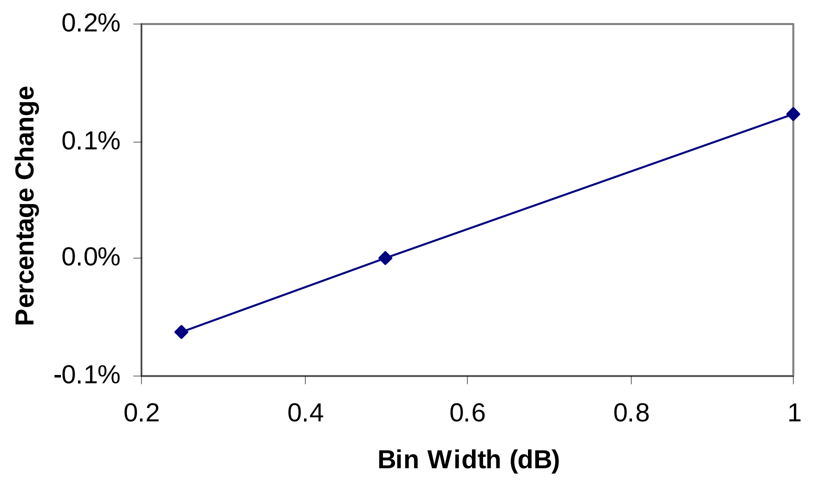

Figure B-10. Change of Impact Volume as a Function of Bin Width

Two other issues for discussion are the maximum range (Rmax) and the spacing in range and depth used for calculating TL. The TL generated for the energy accumulation metric is used for dose 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 Rmax needs some discussion since it is not clear that the same value can be used for both metrics. Rmax was set so that the TL at Rmax is more than needed to reach the energy accumulation threshold of 173 dB for 1000 pings. Since energy is accumulated, the same TL can be used for one ping with the source level increased by 30 dB (10 $\log_{10}$(1000)). 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 1000 pings will also support calculation of impact volumes for the dose 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 has 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 beamformed eigenrays on the range mesh used for the TL calculation, the vertically beamformed 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 dose 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 B-5. Multiplying by the dose function 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 B-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 dose function metric is essentially linear with the number of pings. Figure B-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 B-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.

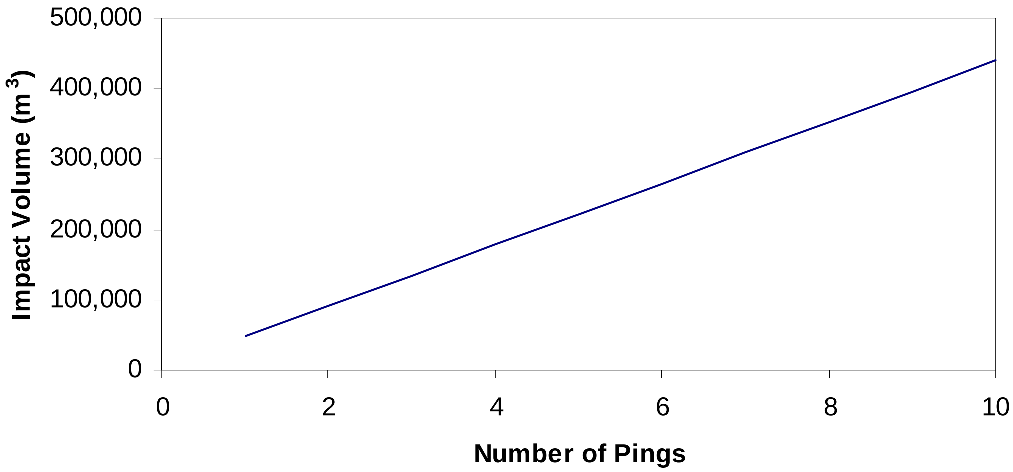

Figure B-11. Dependence of Impact Volume on the Number of Pings

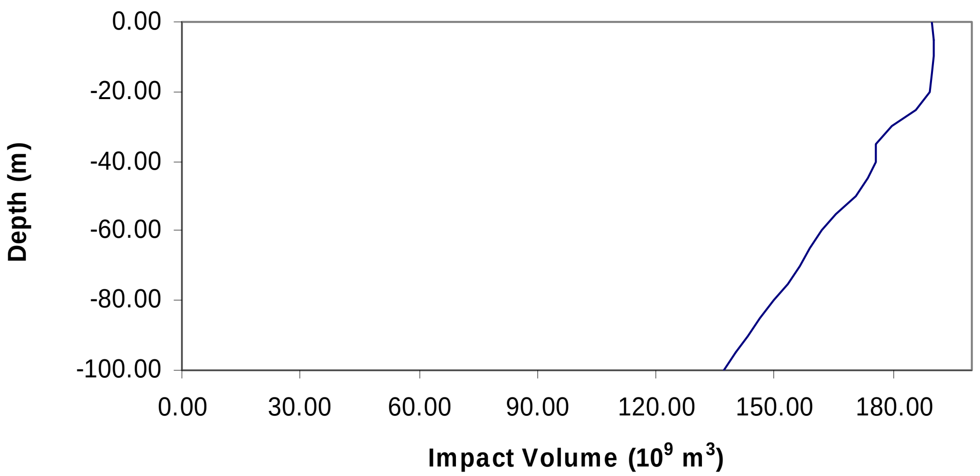

Figure B-12. Example of an Hourly Impact Volume Vector

B.2 DOSE FUNCTION METRICS AND ADDITIONAL REFERENCES

This appendix provides background for the dose-function approach.

B.2.1 DEFINITIONS AND METRICS FOR SOUND AND PROBABILITY/STATISTICS

B.2.1.1 Some Fundamental Definitions of Acoustics

Static Pressure (Acoustics)

At a point in a fluid (gas or liquid), the *static pressure* is the pressure that would exist if there were no sound waves present (paraphrase from 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 (although a pressure wave may have a direction of propagation). *Pressure* has units of force/area. The SI derived unit of pressure is the pascal (Pa) defined as one N/m^2. Alternative units are many (lbs/ft^2, bars, inches of mercury, etc); some are listed at the end of this section.

Acoustic Pressure

Without limiting the discussion to small amplitude or linear waves, define *acoustic pressure* 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 (after Beranek, 1986).

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 p is pressure and T is on the order of several periods of the lowest frequency component of the time series starting at time τ. T can be greater, but should be specified as part of the metric.

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 acoustic 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)

EFD is 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. Units are J/m^2.

B.2.1.2 Definitions Related To Sound Sources, Signals, and Effects

Source Intensity

Define *source intensity*, $I(\theta,\phi)$, as 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 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 (Also, Continuous Wave, CW, Monochromatic Wave, Unmodulated Signal)

Each term means a single-frequency wave or signal. The actual bandwidth of the signal will depend on context, but could be interpreted as “single-frequency as far as can be determined.”

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% 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)

B.2.1.3 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. 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.

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:

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

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

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

$= 40$ dB re 1 μPa

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.

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

$$(1\ \mu Pa^2\ s)/(1.5\ 10^{12}\ \mu Pa(s/m)) = 6.66\ 10^{-13}\ \mu Pa\text{-}m = 6.66\ 10^{-19}\ J/m^2$$

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:

$$190\ dB\ (re\ 1\ \mu Pa^2\ s) = 10^{19} \times 6.66\ 10^{-19}\ J/m^2 = 6.7\ J/m^2$$

$$200\ dB\ (re\ 1\ \mu Pa^2\ s) = 66.7\ J/m^2$$

$$215 \text{ dB (re } 1\ \mu\text{Pa}^2\text{ s)} = 2106.1 \text{ J/m}^2$$

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 0.0006 kW-hr.

B.2.1.4 Some Constants and Conversion Formulas

Length

1 nm = 1.85325 km

1 m = 3.2808 ft

Speed

1 knot = 0.514791 m/s = 1.85325 km/hr

1 mph= 0.447 m/s= 1.6093 km/hr

1 m/s = 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 bar

1 μPa = 10^{-5} dyn/cm^2 = $1.4504 \cdot 10^{-10}$ psi

1 atm = 1.014 bar = 14.7097 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/s) = 10^6 μPa (m/s)

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/s)

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

B.2.1.5 Additional Definitions for Metrics Used in Air

Weighted Sound Levels

For sound pressure measurements in air related to hearing, it is common practice to weight the spectrum to reduce the influence of the high and low frequencies so that the response is similar that of the human ear to noise. *A-weighting* is the most common filter, with the weight resembling the ear's responses. Other popular weightings are B and C. The table below gives a sampling of the filter values for selected frequencies.

Frequency (Hz)	A-Weighting (dB)	B-Weighting (dB)	C-Weighting (dB)
10	-70	-38	-14
20	-50	-24	-6
40	-35	-14	-2
80	-23	-7	-1
160	-13	-3	0
320	-7	-1	0
640	-2	0	0
2,000	+1	0	0
5,000	+1	-1	-1
10,000	-3	-4	-4
12,000	-4	-6	-6
20,000	-9	-11	-11

Decibel levels based on these weighted are usually labeled: dBA or dB(A) for A weighting, etc.

Sound Exposure Level (SEL)

For a time-varying sound pressure p(t), *sound exposure level* is computed as

$$SEL = 10 \log \left[\frac{1}{t_0} \int_0^T p^2(t)dt \Big/ p_0^2 \right],$$

where t_0 is 1 second, T is the total duration of the signal (in the same units as those of t_0, namely seconds) and p_0 is the reference pressure (usually 20 µPa).

SEL is thus a function of p(t), T, and the reference pressure. When the impedance of the medium of interest is approximately constant, then SEL can be viewed as the total energy level for the time interval from 0 to T. It has explicit reference units of p_0 for pressure with implicit units of seconds for time.

SEL is almost never used in underwater sound, primarily because it does not account for changes in impedance (as, for example, in sound propagation through sediments). Instead, energy flux density level is the standard.

When p(t) is A-weighted, then the measure is called the *A-weighted SEL* or *ASEL*. Likewise for other weightings.

Equivalent Sound Level (L_{eq})

The *equivalent sound level (L_{eq})* is defined as the A-weighted sound pressure level (SPL) averaged over a specified time period T. It is useful for noise that fluctuates in level with time. L_{eq} is also sometimes called the *average sound level (L_{AT})*, so that $L_{eq} = L_{AT}$. (see, e.g., Crocker, 1997)

If $p_A(t)$ is the instantaneous A-weighted sound pressure and p_{ref} the reference pressure (usually 20 µPa), then

$$L_{eq} = 10 \log \left\{ \left(\frac{1}{T} \int_0^T p_A{}^2(t)dt \right) \Big/ p_{ref}^2 \right\}.$$

It is thus equivalent to an average A-weighted intensity or power level.

Note that since the averaging time can be specified to be anything from seconds to hours, L_{eq} has become popular as a measure of environmental noise. For community noise, T may be assigned a value as high as 24 hours or more.

L_{dn} (or DNL)

Following Magrab (1975), L_{dn} was introduced by the EPA in 1974 to provide a single-number measure of community noise exposure over a specified period. It was designed to improve L_{eq} by adding a correction of 10 dB for nighttime levels to account for increased annoyance to the population.

L_{dn} is calculated as the level resulting from a weighted averaging of intensities:

$$10^{L_{dn}/10} = (0.625)10^{L_d/10} + (0.375)10^{(L_n+10)/10}$$

It is thus a long-term-average, weighted function of SPL.

B.2.1.6 Definitions for Probability and Statistics (from various public internet sources)

Random Variables

The outcome of an experiment need not be a number, for example, the outcome when a coin is tossed can be 'heads' or 'tails'. However, we often want to represent outcomes as numbers. A random variable is a function that associates a unique numerical value with every outcome of an experiment. The value of the random variable will vary from trial to trial as the experiment is repeated.

A random variable has either an associated probability distribution (discrete random variable) or probability density function (continuous random variable).

Examples

1. A coin is tossed 10 times. The random variable X is the number of tails that are noted. X can only take the values 0, 1, ..., 10, so X is a discrete random variable.

2. A light bulb is burned until it burns out. The random variable Y is its lifetime in hours. Y can take any positive real value, so Y is a continuous random variable.

Expected Value (Mean Value)

The expected value (or population mean) of a random variable indicates its average or central value. It is a useful summary value (a number) of the variable's distribution.

Stating the expected value gives a general impression of the behaviour of some random variable without giving full details of its probability distribution (if it is discrete) or its probability density function (if it is continuous).

Two random variables with the same expected value can have very different distributions. There are other useful descriptive measures which affect the shape of the distribution, for example variance.

The expected value of a random variable X is symbolized by E(X) or μ.

If X is a discrete random variable with possible values x1, x2, x3, ..., xn, and p(xi) denotes P(X = xi), then the expected value of X is defined by:

sum of xi.p(xi)

where the elements are summed over all values of the random variable X.

If X is a continuous random variable with probability density function f(x), then the expected value of X is defined by:

integral of xf(x)dx

Example

Discrete case : When a die is thrown, each of the possible faces 1, 2, 3, 4, 5, 6 (the xi's) has a probability of 1/6 (the p(xi)'s) of showing. The expected value of the face showing is therefore:

$\mu = E(X) = (1 \times 1/6) + (2 \times 1/6) + (3 \times 1/6) + (4 \times 1/6) + (5 \times 1/6) + (6 \times 1/6) = 3.5$

Notice that, in this case, E(X) is 3.5, which is not a possible value of X.

Variance (Square of the Standard Deviation)

The (population) variance of a random variable is a non-negative number which gives an idea of how widely spread the values of the random variable are likely to be; the larger the variance, the more scattered the observations on average.

Stating the variance gives an impression of how closely concentrated round the expected value the distribution is; it is a measure of the 'spread' of a distribution about its average value.

Variance is symbolized by V(X) or Var(X) or sigma^2

The variance of the random variable X is defined to be:

V(X)=E(X^2)-E(X)^2

where E(X) is the expected value of the random variable X.

Notes

1. the larger the variance, the further that individual values of the random variable (observations) tend to be from the mean, on average;

2. the smaller the variance, the closer that individual values of the random variable (observations) tend to be to the mean, on average;

3. taking the square root of the variance gives the standard deviation, i.e.:

sqrt(V(X))=sigma

4. the variance and standard deviation of a random variable are always non-negative.

Probability Distribution

The probability distribution of a discrete random variable is a list of probabilities associated with each of its possible values. It is also sometimes called the probability function or the probability mass function.

More formally, the probability distribution of a discrete random variable X is a function which gives the probability p(xi) that the random variable equals xi, for each value xi:

p(xi) = P(X=xi)

It satisfies the following conditions:

1. 0 <= p(xi) <= 1

2. sum of all p(xi) is 1

Cumulative Distribution Function

All random variables (discrete and continuous) have a cumulative distribution function. It is a function giving the probability that the random variable X is less than or equal to x, for every value x.

Formally, the cumulative distribution function F(x) is defined to be:

F(x) = P(X<=x)

for

-infinity < x < infinity

For a discrete random variable, the cumulative distribution function is found by summing up the probabilities as in the example below.

For a continuous random variable, the cumulative distribution function is the integral of its probability density function.

<u>Probability Density Function</u>

The probability density function of a continuous random variable is a function which can be integrated to obtain the probability that the random variable takes a value in a given interval.

More formally, the probability density function, f(x), of a continuous random variable X is the derivative of the cumulative distribution function F(x):

f(x) = d/dx F(x)

Since F(x) = P(X<=x) it follows that:

integral of f(x)dx = F(b)-F(a) = P(a<X<b)

If f(x) is a probability density function then it must obey two conditions:

1. that the total probability for all possible values of the continuous random variable X is 1:

integral of f(x)dx = 1

2. that the probability density function can never be negative: f(x) > 0 for all x.

Normal (gaussian) Density Function

The normal distribution (the "bell-shaped curve" which is symmetrical about the mean) is a theoretical function commonly used in inferential statistics as an approximation to sampling distributions (see also Elementary Concepts). In general, the normal distribution provides a good model for a random variable, when:

1. There is a strong tendency for the variable to take a central value;
2. Positive and negative deviations from this central value are equally likely;
3. The frequency of deviations falls off rapidly as the deviations become larger.

As an underlying mechanism that produces the normal distribution, one may think of an infinite number of independent random (binomial) events that bring about the values of a particular variable. For example, there are probably a nearly infinite number of factors that determine a person's height (thousands of genes, nutrition, diseases, etc.). Thus, height can be expected to be normally distributed in the population.

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