National Oceanic and Atmospheric Administration

Draft Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammals

Acoustic Threshold Levels for Onset of Permanent and Temporary Threshold Shifts

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ACRONYMS

dB	Decibel
$\mathrm{dB}_{\mathrm{peak}}$	Peak sound pressure level
$\mathrm{dB}_{\mathrm{p\text{-}p}}$	Peak-to-peak sound pressure level
$\mathrm{dB}_{\mathrm{rms}}$	Root mean square sound pressure level
DOD	Department of Defense
EEH	Equal Energy Hypothesis
EQL	Equal Loudness
ESA	Endangered Species Act
HF	High-frequency
HISA	Highly Influential Scientific Assessment
Hz	Hertz
in	Inch
IQG	Information Quality Guidelines
kHz	Kilohertz
LF	Low-frequency
MF	Mid-frequency
min	Minutes
MMPA	Marine Mammal Protection Act
MSA	Magnuson-Stevens Fishery Conservation and Management Act
msec	Millisecond
NB	Narrowband
NMFS	National Marine Fisheries Service
NMSA	National Marine Sanctuaries Act
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service
NS2	National Standard 2
OMB	Office of Management and Budget
PTS	Permanent Threshold Shift
RL	Received Level
RMS	Root Mean Square
s	Seconds
SEL	Sound Exposure Level
$\mathrm{SEL}_{\mathrm{cum}}$	Cumulative Sound Exposure Level
SPAWAR	The Space and Naval Warfare Systems Command
SPL	Sound Pressure Level
TS	Threshold Shift
TTS	Temporary Threshold Shift
µPa	Micropascal
$\mu\mathrm{Pa}^2$-s	Micropascal squared second
W(f)	Weighting function

EXECUTIVE SUMMARY

This document provides guidance for assessing the effects of anthropogenic sound on marine mammal species under the jurisdiction of the National Marine Fisheries Service (NMFS) and the National Ocean Service (NOS) (hereafter referred to collectively as the National Oceanic and Atmospheric Administration (NOAA)). Specifically, it identifies the received levels, or thresholds, above which individual marine mammals are predicted to experience changes in their hearing sensitivity (either temporary or permanent) for all underwater anthropogenic sound sources. This is the first time NOAA has presented this information in a single, comprehensive document. This guidance is intended to be used by NOAA analysts and managers and other relevant user groups and stakeholders, including other federal agencies, when seeking to determine whether and how their activities are expected to result in particular types of impacts to marine mammals via acoustic exposure. This document outlines NOAA's updated acoustic threshold levels and describes in detail how the thresholds were developed and how they will be updated in the future.

NOAA has compiled, interpreted, and synthesized the best available science to produce updated acoustic threshold levels for the onset of both temporary (TTS) and permanent hearing threshold shifts (PTS). These thresholds replace those currently in use by NOAA. Updates include a protocol for estimating PTS and TTS onset levels for impulsive (e.g., airguns, impact pile drivers) and non-impulsive (e.g., sonar, vibratory pile drivers) sound sources, the formation of marine mammal functional hearing groups (low-, mid-, and high-frequency cetaceans, and otariid and phocid pinnipeds), and the incorporation of marine mammal auditory weighting functions into the calculation of thresholds. These acoustic threshold levels are presented using the dual metrics of cumulative sound exposure level and peak sound pressure level. This document addresses how to combine multiple datasets, as well as how to determine appropriate surrogates when data are not available. While the updated acoustic thresholds are more complex than those previously used by NOAA, they accurately reflect the current state of scientific knowledge regarding the characteristics of sound that have the potential to impact marine mammal hearing sensitivity. Given the specific nature of these updates, it is not possible to directly compare the updated thresholds presented in this document with the thresholds previously used by NOAA.

Although NOAA has updated the acoustic threshold levels from those previously used, and these changes may necessitate new methodologies for calculating impacts, the application of the thresholds in the regulatory context under applicable statutes (Marine Mammal Protection Act, Endangered Species Act, and National Marine Sanctuaries Act) remains consistent with past NOAA practice. It is important to note that these updated acoustic threshold levels do not represent the entirety of an impact assessment, but rather serve as one tool (in addition to behavioral impact thresholds, auditory masking assessments, evaluations to help understand the ultimate effects of any particular type of impact on an individual's fitness, population assessments, etc.), to help evaluate the effects of a proposed action on marine mammals and make findings required by our various statutes.

This acoustic guidance is classified as a Highly Influential Scientific Assessment by the Office of Management and Budget. As such, independent peer review is required prior to broad public dissemination by the Federal Government. Details of the peer review can be found within this document, and at the following website: http://www.nmfs.noaa.gov/pr/acoustics/.

This document is organized so that the most pertinent information can be found easily in the main body. Additional details are provided in the appendices. Section I provides an introduction to the document and a description of how NOAA addressed uncertainty and data limitations in the development of this guidance. NOAA's updated acoustic threshold levels for onset of PTS and TTS for marine mammals exposed to underwater sound are presented in Section II. Section III describes how acoustic threshold levels are interpreted under NOAA's statutes. NOAA's plan for periodically updating acoustic threshold levels is presented in Section IV. More details on the marine mammal auditory weighting functions, the development of acoustic threshold levels, the peer review process, and a glossary of acoustic terms can be found in the appendices.

National Oceanic and Atmospheric Administration
DRAFT Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammals

Acoustic Threshold Levels for Onset of Permanent and Temporary Threshold Shifts

I. INTRODUCTION

This document provides guidance for assessing the effects of anthropogenic sound on marine mammal species under the jurisdiction of the National Marine Fisheries Service (NMFS) and the National Ocean Service (NOS) (hereafter referred to collectively as the National Oceanic and Atmospheric Administration (NOAA)). Specifically, it identifies the received levels, or thresholds, above which individual marine mammals are predicted to experience changes in their hearing sensitivity (either temporary or permanent) for all underwater anthropogenic sound sources. This guidance is intended to be used by NOAA analysts and managers and other relevant user groups and stakeholders, including other federal agencies, when seeking to determine whether and how their activities are expected to result in particular types of impacts to marine mammals via acoustic exposure. This document outlines NOAA's updated acoustic threshold levels and describes in detail how the thresholds were developed and how they will be revised and updated in the future.

The updated acoustic threshold levels presented do not represent the entirety of an impact assessment, but rather serve as one tool (in addition to behavioral impact thresholds, auditory masking assessments, evaluations to help understand the ultimate effects of any particular type of impact on an individual's fitness, population assessments, etc.), to help evaluate the effects of a proposed action on marine mammals and make findings required by our various statutes. This document does not provide acoustic threshold levels for non-auditory injury (i.e., lung injury or gastrointestinal tract injury), or exposure to airborne sounds for pinnipeds, and does not address mitigation measures that may be associated with particular acitivities.

This document had been classified as a Highly Influential Scientific Assessments (HISA)[1] by the Office of Management and Budget (OMB); as such, independent peer review was required before it could be disseminated more broadly by the Federal Government. NOAA also sought informal input from key federal agencies regarding various aspects of this document.

1.1 Addressing Uncertainty and Data Limitations

NOAA acknowledges the inherent data limitations that occur in many instances when assessing acoustic effects on marine mammals. Data limitations, which make it difficult to account for uncertainty and variability, are not unique to assessing the effects of anthropogenic sound on marine mammals and are commonly encountered by resource managers (Ludwig et al. 1993; Francis and Shotton 1997; Harwood and Stokes 2003; Punt and Donovan 2007). Southall et al. (2007) acknowledged the inherent data limitations when assessing acoustic effects on marine mammals (e.g., data available from a limited number of species, a limited number of individuals within a species, and/or limited number of sound sources). They applied certain extrapolation procedures to estimate effects that had not been directly measured but that could be reasonably approximated using existing information and reasoned logic. NOAA acknowledges these

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[1] Its dissemination could have a potential impact of more than $500 million in any one year on either the public or private sector; or that the dissemination is novel, controversial, or precedent-setting; or that it has significant interagency interest (OMB 2005).

limitations, as well as the need for using the best available science to make decisions in cases where data are lacking. Where NOAA has faced such uncertainty and variability in the development of its proposed acoustic threshold levels, we have articulated our extrapolation methodology. As such, the contents of this document include the development of an assessment framework, including data standards and extrapolation procedures, used to date, to address data limitations.

1.2.1 Assessment Framework

NOAA's approach applies a set of assumptions to develop a framework that addresses uncertainty in predicting potential effects of sound on individual marine mammals. One of these assumptions includes the use of "representative" or surrogate individuals/species for establishing TTS and PTS onset acoustic threshold levels for species where little to no data exist. The use of representative individuals/species is done as a matter of practicality (i.e., it is unlikely that adequate data will exist for the 125[2] marine mammal species found worldwide or that we will be able to account for all sources of variability at an individual level), but is also scientifically based (i.e., taxonomy, functional hearing group). As new data become available for more species, this approach will be reevaluated.

These procedures and assumptions (further described in Appendix B), along with our stipulated data standards (see Appendix B, Section III), are intended to ensure that data are assessed and such procedures are subsequently modified in a consistent manner. NOAA recognizes that additional applicable data may become available to allow us to better address many of these issues. As these new data become available, NOAA has an approach for updating our acoustic threshold levels (see Section IV).

1.2.2 Data Standards

In assessing potential acoustic effects on marine mammals, as with any such issue facing the agency, standards for determining applicable data need to be articulated. Specifically, NOAA has Information Quality Guidelines[3] (IQG) for "ensuring and maximizing the quality, objectivity, utility, and integrity of information disseminated by the agency" (with each of these terms defined within the IQG). Furthermore, the IQG stipulate that "To the degree that the agency action is based on science, NOAA will use (a) the best available science and supporting studies (including peer-reviewed science and supporting studies when available), conducted in accordance with sound and objective scientific practices, and (b) data collected by accepted methods or best available methods."

The National Research Council (NRC 2004) provided basic guidelines on National Standard 2 (NS2)[4] under the Magnuson-Stevens Fishery Conservation and Management Act, section 301, which stated "Conservation and management measures shall be based upon the best scientific information available." They recommended that data underlying the decision-making and/or policy-setting process be: 1) relevant, 2) inclusive, 3) objective, 4) transparent and open, 5) timely, 6) verified and validated, and 7) peer reviewed[5]. Although NRC's guidelines (NRC 2004)

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[2] Current number of marine mammal species worldwide recognized by NMFS Office of Protected Resources (see http://www.nmfs.noaa.gov/pr/species/)

[3] http://www.st.nmfs.noaa.gov/science-quality-assurance/national-standards/ns2_revisions

[4] NOAA is currently proposing revisions to NS2 to provide guidance on the use of best scientific information available (NOAA 2013).

[5] NOAA also requires Peer Review Plans for Highly Influential Scientific Assessments (HISA) and Influential Scientific Information (ISI).

were not written specifically for marine mammals and this particular issue, they do provide a means of articulating minimum data standards. NOAA is taking this into account in assessing acoustic effects on marine mammals. Use of the NRC Guidelines does not preclude development of acoustic-specific data standards in the future.

II. NOAA'S ACOUSTIC THRESHOLD LEVELS FOR ONSET OF PERMANENT AND TEMPORARY THRESHOLD SHIFTS IN MARINE MAMMALS

This document advances NOAA's assessment ability based upon the best available science. As described in detail in this section, this includes both quantitative and qualitative approaches based on the best available science. Quantitative assessment consists of two parts: 1) an acoustic threshold level and 2) an associated weighting function (when appropriate) based upon measured and approximated marine mammal equal loudness contours. Additionally, qualitative considerations that illustrate general trends associated with noise-induced hearing loss are provided and may be useful within a larger assessment, even though they cannot be applied quantitatively.

This document provides acoustic threshold levels for the onset of PTS and TTS based on characteristics defined at the source and not the receiver. No direct data on marine mammal PTS exist; PTS onset thresholds have been extrapolated from marine mammal TTS data. PTS and TTS onset acoustic threshold levels, for all sound sources, are divided into two broad categories: 1) impulsive and 2) non-impulsive. Acoustic threshold levels are also presented as dual acoustic threshold levels using cumulative sound exposure level (SEL_{cum}) and peak pressure (dB_{peak}) metrics. As dual metrics, NOAA considers onset of PTS or TTS to have occurred when either one of the two metrics is exceeded. Additionally, to account for the fact that different species groups use and hear sound differently, acoustic threshold levels are sub-divided into five broad functional hearing groups (i.e., low-, mid-, and high-frequency cetaceans and phocid and otariid pinnipeds). Where appropriate, the PTS and TTS onset acoustic threshold levels include marine mammal auditory weighting functions.

2.1 Marine Mammal Functional Hearing Groups

Current data (via direct measurements [behavioral and electrophysiological]) and predictions (based on inner ear morphology, behavior, vocalizations, or taxonomy) indicate that not all marine mammal individuals/species have equal hearing capabilities, in terms of absolute hearing sensitivity and the frequency band of hearing (Richardson et al. 1995; Wartzok and Ketten 1999; Southall et al. 2007; Au and Hastings 2008). Hearing has been directly measured in a multitude of odontocete and pinniped species[6] (see review in Southall et al. 2007). Direct measurements of mysticete hearing are lacking (e.g., there was an unsuccessful attempt to directly measure hearing in a stranded gray whale calf by Ridgway and Carder 2001). Thus, hearing predictions for mysticetes are based on other methods (e.g., anatomical studies: Houser et al. 2001; Parks et al. 2007; vocalizations[7]: see reviews in Richardson et al. 1995; Wartzok and Ketten 1999; Au and Hastings 2008; taxonomy and behavioral responses to sound: Dahlheim and Ljungblad 1990; see review in Reichmuth 2007).

To more accurately reflect marine mammal hearing capabilities, Southall et al. (2007) recommended that marine mammals be divided into functional hearing groups based on

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[6] Both in air and underwater for pinniped species.

[7] Studies in other species indicate that perception of frequencies may be broader than frequencies produced (e.g., Luther and Wiley 2009).

measured or estimated functional hearing ranges. NOAA modified the functional hearing groups proposed by Southall et al. (2007)[8] as follows (Table 1):

- <u>Extension of upper end of low-frequency cetacean hearing range</u>: NOAA extended slightly the estimated upper end of the hearing range for low-frequency cetaceans, from 22 to 30 kHz, based on data from Watkins et al. (1986) for numerous mysticete species (variety of mysticete species responding to sounds up to 28 kHz), Au et al. (2006) for humpback whales (songs having harmonics that extend beyond 24 kHz), Lucifredi and Stein (2007) for gray whales (reported potentially responding to sounds beyond 22 kHz), and an unpublished report (Ketten and Mountain 2009) and data (Tubelli et al. 2012) for minke whales (predicted hearing range of up to 30 kHz based on inner ear anatomy). These new data indicate that some mysticetes can hear above 22 kHz. As more data become available, these estimated hearing ranges may require future modification.

Table 1: Marine mammal functional hearing groups.

Functional Hearing Group	Functional Hearing Range*
Low-frequency (LF) cetaceans+ (baleen whales)	7 Hz to 30 kHz
Mid-frequency (MF) cetaceans (dolphins, toothed whales, beaked whales, bottlenose whales)	150 Hz to 160 kHz
High-frequency (HF) cetaceans (true porpoises, *Kogia*, river dolphins, cephalorhynchid, *Lagenorhynchus cruciger* and *L. australis*)	200 Hz to 180 kHz
Phocid pinnipeds (true seals)	75 Hz to 100 kHz
Otariid pinnipeds (sea lions and fur seals)	100 Hz to 40 kHz

***** Represents frequency band of hearing for entire group as a composite (i.e., all species within the group), where individual species' hearing ranges are typically not as broad.

+ Estimated hearing range for low-frequency cetaceans is based on behavioral studies, recorded vocalizations, and inner ear morphology measurements. No direct measurements of hearing ability have been successfully completed.

- <u>Division of pinnipeds into phocids and otariids</u>: NOAA subdivided pinnipeds into their two families: Phocidae and Otariidae. Based on a review of the literature, phocid species have consistently demonstrated an extended frequency range of hearing compared to otariids, especially in the higher frequency range (Hemilä et al. 2006; Kastelein et al. 2009; Reichmuth et al. 2013). This is believed to be because phocid ears are anatomically distinct from otariid ears in that phocids have larger, more dense middle ear ossicles, inflated auditory bulla, and larger portions of the inner ear (i.e., tympanic membrane, oval window, and round window), which make them more adapted for underwater hearing (Terhune and Ronald 1975; Kastak and Schusterman 1998; Hemilä et al. 2006; Mulsow et al. 2011; Reichmuth et al. 2013).

- <u>Addition of hourglass (*Lagenorhynchus cruciger*) and Peale's (*L. australis*) dolphins to high-frequency functional hearing group</u>: Recent echolocation data (Kyhn et al. 2009; Kyhn et al. 2010; Tougaard et al. 2010) indicate that these two species produce sounds (i.e., higher mean peak frequency) similar to other narrow band high-frequency cetaceans, such as porpoises, *Kogia*, and *Cephalorhynchus*, and are distinctly different from other *Lagenorhynchus* species. Genetic data also suggest these two species are more closely related to other *Cephalorhynchus* species (May-Collado and Agnarsson 2006). Thus, NOAA has decided to move these two species from the mid-frequency

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[8] NOAA considered separating sperm whales from other MF cetaceans, but there are currently not enough data to stipulate exactly how this should be done.

functional hearing group (MF cetaceans) to the high-frequency functional hearing group (HF cetaceans).

2.2 Marine Mammal Auditory Weighting Functions

The ability to hear sounds varies across a species functional hearing range. Most mammal audiograms have a typical "U-shape", with frequencies at the bottom of the "U" being those to which the animal is more sensitive, in terms of hearing (i.e. the animal's best hearing range)[9]. To reflect this higher sensitivity at particular frequencies, sounds are often weighted (e.g., A-weighting for humans where frequencies below 1 kHz and above 6 kHz are deemphasized; e.g., Fletcher and Munson 1933; Suzuki and Takeshima 2004). There are other types of weightings for humans, as well (e.g., B, C, D) that deemphasize different frequencies to different extremes.

Auditory weighting functions have recently been proposed for marine mammals, specifically associated with PTS and TTS acoustic threshold levels expressed in the cumulative sound exposure level metric (SEL_{cum})[10], which take into account what is known about marine mammal hearing (Southall et al. 2007; Finneran and Jenkins 2012). Finneran and Jenkins (2012)[11] developed auditory weighting functions specifically for cetaceans, including extrapolation procedures when no data were available. These auditory weighting functions reflect frequencies within which functional hearing groups are most sensitive to sound in terms of hearing and vulnerability to noise-induced threshold shifts. Compared to human auditory weighting functions, the proposed weighting functions for cetaceans ("M-weighting") are a hybrid of A-weighting functions for frequencies that marine mammals are expected to be more susceptible to threshold shifts from sound exposure (i.e., where we have data: Finneran and Schlundt 2009; Finneran and Schlundt 2010; Finneran and Schlundt 2011; Finneran and Schlundt 2013) and broad C-weighting functions for frequencies where fewer data are available (i.e., more uncertainty: Southall et al. 2007).

2.2.1 Cetacean Auditory Weighting Functions

Cetacean auditory weighting functions merge the marine mammal or "M-weighting" functions proposed in Southall et al. (2007) with a more recently derived Equal Loudness (EQL) weighting function based on bottlenose dolphin (MF cetacean)[12] equal loudness measurements (Finneran and Schlundt 2011) and frequency-specific TTS data (Finneran and Schlundt 2010; Finneran and Schlundt 2009; Finneran and Schlundt 2013) (Figure 1). The modification of the original Southall et al. (2007) auditory weighting functions reflects the incorporation of more recent data on frequencies with a relatively increased susceptibility to noise-induced threshold shifts. This hybrid function was then used to extrapolate similar weighting functions for HF cetaceans, where no data currently exist (Finneran and Jenkins 2012). A similar extrapolation was proposed for LF

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[9] Auditory weighting functions best reflect an animal's ability to hear a sound. It may not necessarily reflect how an animal will perceive that sound and behaviorally react to that sound.

[10] Auditory weighting functions are not to be applied to PTS or TTS onset acoustic threshold levels expressed as the peak pressure metric.

[11] Finneran and Jenkins (2012) specifically addressed Navy sonar and explosive usage with their updated criteria and weighting functions. Other sound sources, like pile driving and seismic relied on NMFS' generic criteria (i.e., 180/190 dB for auditory injury for cetaceans and pinnipeds for impulse and continuous sources) and does not incorporate auditory weighting functions. This guidance document updates the auditory injury acoustic threshold levels for all sounds sources (i.e., replaces the generic 180/190 dB level) and includes the incorporation of auditory weighting functions.

[12] Since data for no other marine mammal species are available, the assumption is that bottlenose dolphins are an appropriate surrogate for the entire MF cetacean group and that a similar trend would be predicted for all other echolocating cetaceans.

cetaceans by Finneran and Jenkins, but NOAA derived LF cetacean auditory weighting function input parameters in a different manner (See Section 2.2.1.2).

To derive the merged cetacean weighting function, both the M-weighting and EQL curves are plotted, with the maximum weighting function amplitude at each frequency taken to define the merged curve. Each of the two component curves can be calculated with the following equation (Southall et al. 2007; Finneran and Jenkins 2012):

$$W(f) = K + 20\log_{10}\left[\frac{b^2 f^2}{(a^2+f^2)(b^2+f^2)}\right]$$

In this equation, *f* is frequency (Hz), *a* and *b* are the parameters that define the appropriate "roll off" frequency limits to each component portion of the curve, and K is a constant used to normalize the equation to a particular frequency (Finneran and Jenkins 2012). For the M-weighting curve, *a* and *b* are related to the lower and upper hearing limits (Hz) of a functional hearing group. For the EQL curve, lower (*a*) and upper frequency (*b*) cut-offs for MF cetaceans were derived from the 90 dB equal loudness contour obtained from a bottlenose dolphin (Finneran and Schlundt 2011), which is assumed to be an appropriate surrogate species for the entire MF cetacean functional hearing group. The parameters for each of these functions, as proposed in Finneran and Jenkins (2012), are listed in Table 2.

This equation produces a weighting function amplitude (in dB) at each frequency for each of the two component functions. The highest weighting function amplitude at each frequency then defines the merged curve, with M-weighting generally determining the lower frequencies, while the EQL curve determines higher frequencies (Figure 1).

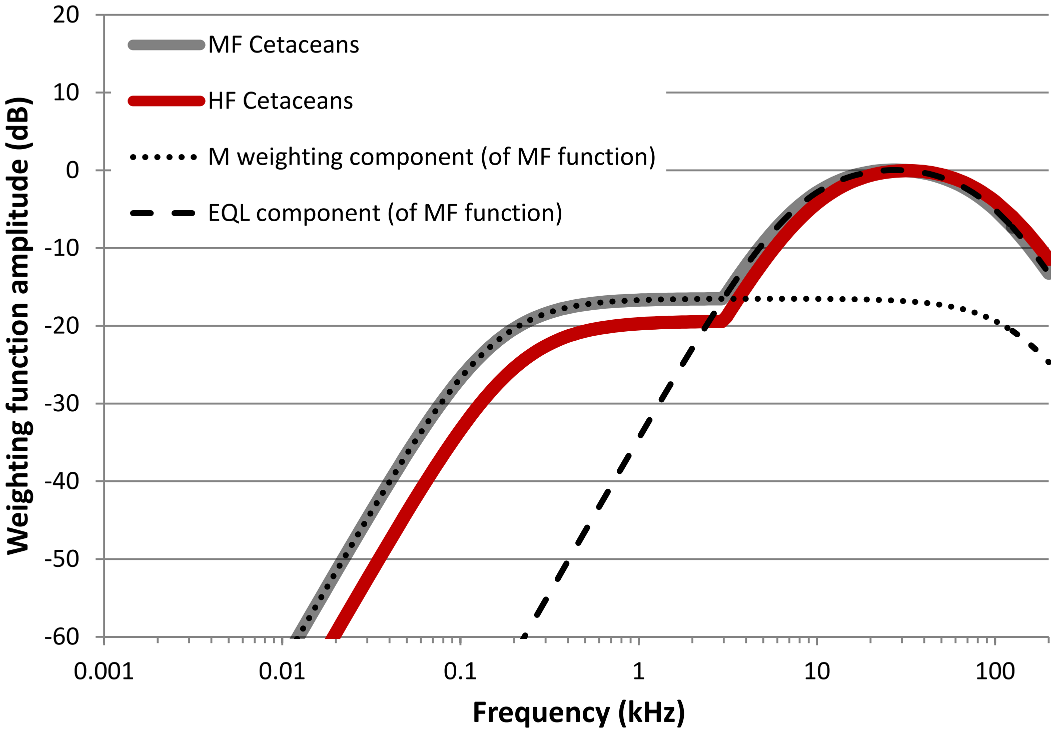

Figure 1: **Mid-frequency (gray line) and high-frequency (red line) cetacean merged auditory weighting functions. Complete EQL (dashed line) and M-weighting (dotted line) components of merged mid-frequency curve are illustrated.**

Table 2: Mid-frequency and high-frequency cetacean auditory weighting function parameters.

	M-Weighting			EQL Weighting		
Functional Hearing Group	K	*a* (Hz)	*b* (Hz)	K	*a* (Hz)	*b* (Hz)
Mid-frequency (MF) cetacean	-16.5	150	160,000	1.4	7829	95,520
High-frequency (HF) cetacean	-19.4	200	180,000	1.4	9480	108,820

2.2.1.1 Extrapolated Auditory Weighting Function for High-Frequency Cetaceans

Because equal loudness data are not available and only limited TTS data exist for most cetacean functional hearing groups, auditory weighting functions were estimated using bottlenose dolphin data (Finneran and Jenkins 2012). NOAA considered this extrapolation appropriate for HF cetaceans, since they use and hear sound in a similar manner to MF cetaceans (e.g., both MF and HF cetaceans echolocate).

Ketten (2000) indicated that cetaceans with Type II cochlea (i.e., typically those classified as MF cetaceans) echolocate with peak frequencies below 80 kHz, while cetaceans with Type I cochlea (i.e., typically those already classified as HF cetaceans) echolocate with peak frequencies above 100 kHz. Thus, based on auditory anatomy and vocalizations, it would seem that HF cetaceans would be more sensitive to higher frequencies compared to MF cetaceans.

However, the auditory weighting functions presented in this document are used specifically in conjunction with proposed PTS and TTS onset acoustic threshold levels and are intended to reflect not only the frequencies that functional hearing groups hear best, but also their susceptibility to noise-induced hearing loss. When new auditory weighting functions were proposed for MF cetaceans incorporating recent bottlenose dolphin data on equal loudness measurements (Finneran and Schlundt 2011) and frequency-specific temporary threshold shifts (Finneran and Schlundt 2009; Finneran and Schlundt 2010; Finneran and Schlundt 2013), HF cetacean TTS studies were examined to see if similar trends existed (there are no data on equal loudness for any HF cetacean). The only TTS study for HF cetaceans available examined hearing loss in higher frequency ranges in Yangtze finless porpoise (Popov et al. 2011a). This study exposed two individuals to half-octave band noise (-1 to +0.5 octaves) relative to 32, 45, 64, and 128 kHz. In this paper, Popov et al. (2011a) also presented baseline hearing data of the two individuals used in the study, which indicated greatest auditory sensitivity between 45 to 139 kHz. However, the general finding from this study was that the lower frequency ranges (where auditory sensitivity was reduced) were more impacted by noise than the higher frequency ranges (where auditory sensitivity was greatest).

Finneran and Schlundt (2013) also indicated that TTS susceptibility might not necessarily directly reflect hearing sensitivity. Their research, along with Popov et al. (2013), found that MF cetaceans (i.e., bottlenose dolphin and belugas) have increased susceptibility to TTS at frequencies from 10 to 30 kHz. Popov et al. 2011a seems to indicate a similar finding, in terms of the TTS susceptibility range, for HF cetaceans (i.e., Yangtze finless porpoise). Thus, based on these data, there does not seem to be justification to modify the HF cetacean weighting function (i.e., EQL weighting parameters) proposed by Finneran and Jenkins (2012).

Upper and lower cut-offs for HF cetaceans were derived for the EQL weighting function by extrapolating from those values calculated for MR cetaceans. The approach used was based on octave spacing (log base 2; ANSI 1994), which reflects what is known about the organization of the ear and perception of frequency (i.e., base-2 logarithmic perception; Yost 2007; Ketten 2000). The resulting extrapolated parameters are presented in Table 2.

2.2.1.2 Generalized Auditory Weighting Function for Low-Frequency Cetaceans

Finneran and Jenkins (2012) also proposed an updated auditory weighting function for LF cetaceans based on similar methodology used to create auditory weighting functions for HF cetaceans. However, their LF auditory weighting function predicted that the EQL portion of the function (which while flatter, is generally reflective of the region of best auditory sensitivity) would indicate highest susceptibility to noise-induced threshold shifts between approximately 700 Hz and 12 kHz. As the EQL curve is generally flatter than an inverse audiogram would be expected to be, this would suggest the region of best hearing sensitivity in LF cetaceans would be in an even narrower range between these two frequencies. Based on what is known about the predominant vocal range of LF cetaceans, as well as hypothesized sensitivity to lower frequency sounds, the Finneran and Jenkins (2012) auditory weighting function was deemed not to reflect what is currently known about LF cetaceans' potential auditory capabilities. Thus, NOAA decided to develop an alternative LF cetacean auditory weighting function (Figure 2).

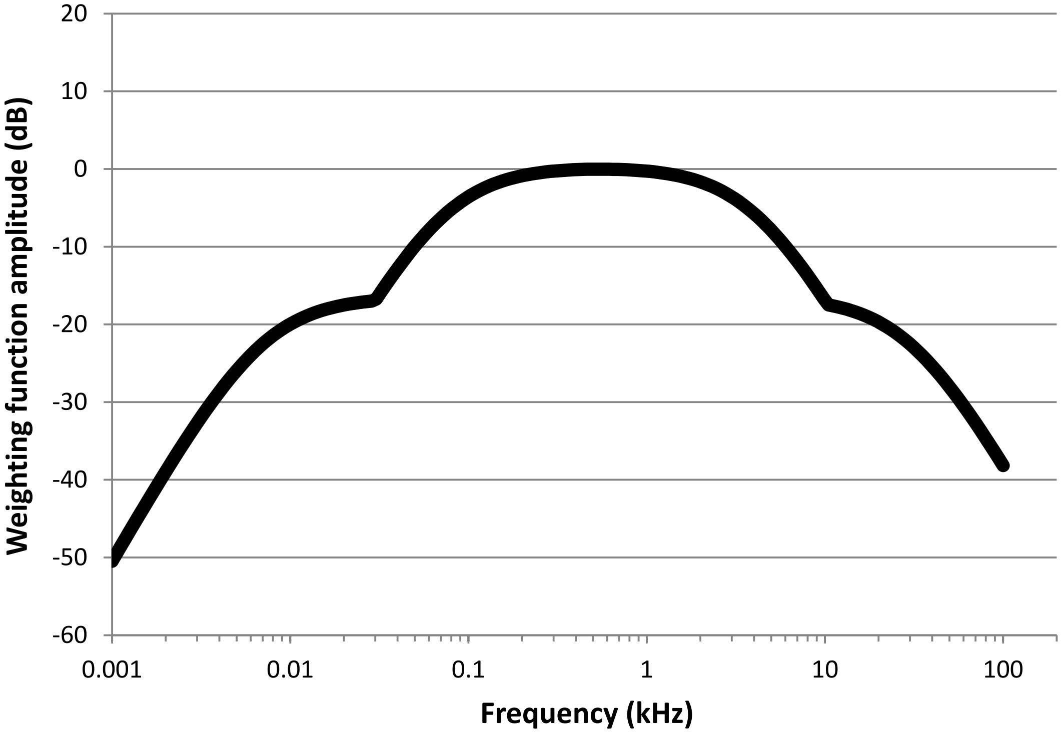

Figure 2: **Low-frequency cetacean auditory weighting function.**

Developing an auditory weighting function for LF cetaceans is difficult because of a general lack of empirical data on what frequencies these marine mammals hear. However, LF cetaceans are predicted to have good sensitivity from 20 Hz to 2 kHz (Ketten 1998), with some species like humpback (Houser et al. 2001) and minke whales (Tubelli et al. 2012) predicted to have an expanded best hearing range (i.e., up to 6 to 7.5 kHz) base upon inner ear anatomy.

Vocalization range was also considered as an appropriate predictor of best sensitivity for LF cetaceans. Ketten (1998) indicated "Most animals have vocalizations that are tightly linked to their peak hearing sensitivities in order to maximize intra-specific communication, but they also have hearing beyond that peak range that is related to the detection of acoustic cues from predators, prey, or other significant environmental cues." For LF cetaceans, vocal frequency with maximum energy typically is below 4 kHz and primarily below 1 kHz for most species (Ketten 1998).

Both MF and HF weighting functions are comprised of two component curves, and EQL and M-weighting curves. These same two component curves were used to develop the LF cetacean weighting function. Auditory weighting function parameters (*a* and *b* frequency limits) were modified in order to better reflect what is reasonably assumed about potential auditory capabilities of LF cetaceans (Table 3). This modification was chosen instead of extrapolating the *a* and *b* parameters of the EQL portion of the curve by assuming the same relationship to the overall functional hearing limits as exists in MF cetaceans (as was done with HF cetaceans, and as proposed by Finneran and Jenkins (2012) for LF cetaceans leading to a likely displaced region of best sensitivity). This included setting the *a* and *b* parameters encompassing the EQL portion of the curve at 75 Hz and 4 kHz respectively[13], as well as extending the upper frequency functional hearing limit from 22 kHz to 30 kHz for the M-weighted portion of the curve.

Table 3: Low-frequency cetacean auditory weighting function parameters.

	M Weighting			**EQL Weighting**		
Functional Hearing Group	**K**	***a* (Hz)**	***b* (Hz)**	**K**	***a* (Hz)**	***b* (Hz)**
Low-frequency (LF) cetaceans	-16.5	7	30,000	0.3	75	4,000

2.2.2 Underwater Pinniped Auditory Weighting Functions

Underwater pinniped auditory weighting functions are derived solely from the M-weighting function (i.e., their weighting functions do not contain the EQL curve component; Figure 3), because EQL measurements have not been obtained for any pinniped species, and data are therefore insufficient to incorporate an analogous region of higher susceptibility to noise induced threshold shifts. While future EQL measurements in pinnipeds may provide the data necessary to generate an EQL portion of the curve, currently, none of the available TTS datasets indicate that pinnipeds are more susceptible to noise-induced threshold shifts within a certain portion of their auditory range[14]. NOAA has therefore adopted the methodology for deriving auditory weighting functions for pinnipeds presented in Southall et al. (2007) and Finneran and Jenkins (2012). Because phocids have consistently demonstrated an extended frequency range of hearing compared to otariids, particularly at higher frequencies. NOAA has modified the upper functional hearing range of phocid pinnipeds by extending it from 75 to 100 kHz based on data presented in Hemilä et al. (2006) and Kastelein et al. (2009).

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[13] Fin and blue whales regularly vocalize in the 20-50Hz range, which may suggest a lowering the *a* parameter. However, the evolution of hearing in typical ambient noise conditions would suggest lower sensitivity at these very low frequencies as the noise floor is increased (Clark and Ellison 2004). While this has not been accounted for in the LF cetacean curve, it suggests that these cetaceans may have evolved and increased hardiness and be less susceptible to hearing effects from these lower, typically louder, frequencies.

[14] NOAA acknowledges that compared to cetaceans, there have been far fewer TTS studies completed on pinnipeds. As more data become available, NOAA will re-evaluate these pinniped auditory weighting functions.

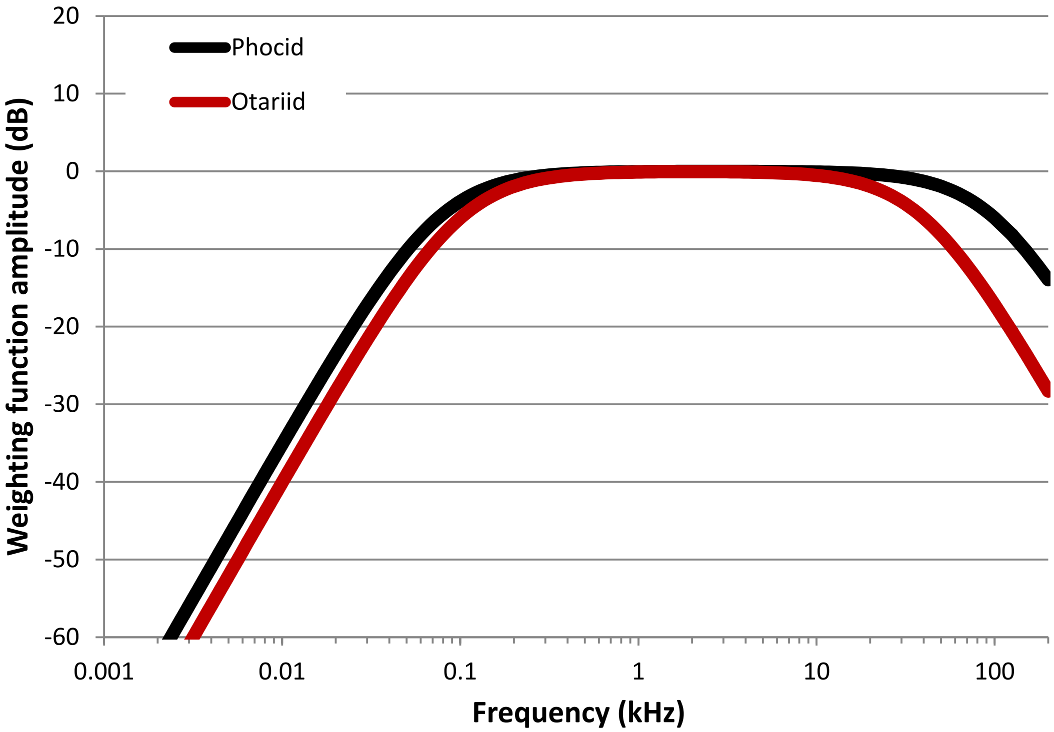

Figure 3: **Underwater pinniped auditory weighting functions.**

The auditory weighting functions for pinnipeds are represented by the same equation as cetaceans (Southall et al. 2007; Finneran and Jenkins 2012). In the case of pinniped auditory weighting functions, the K constant is zero because the weighting function is essentially flat through most of the auditory range (i.e., does not need to be normalized to any frequency).

NOAA has adopted this methodology for deriving auditory weighting functions for pinnipeds, but has modified it to create separate weighting functions for phocid and otariid pinnipeds, based on updated data, using the following parameters (Table 4):

Table 4: **Pinniped auditory weighting function parameters.**

	Weighting		
Functional Hearing Group	**K**	***a* (Hz)**	***b* (Hz)**
Phocid pinnipeds (underwater)	0	75	100,000
Otariid pinnipeds (underwater)	0	100	40,000

2.2.3. Implementation of Marine Mammal Auditory Weighting Functions for PTS and TTS Acoustic Threshold Levels

The implementation of marine mammal auditory weighting functions emphasizes the importance of making measurements and characterizing sound sources in terms of biologically important frequencies (e.g., frequencies used for environmental awareness, communication or the detection of predators or prey), not only the frequencies of interest or concern for the completion of the sound-producing activity (i.e., context of sound source). Marine mammal auditory weighting functions will be used in two aspects of an impact assessment:

1) After considering and evaluating all available data, establishing numerical acoustic threshold levels for PTS and TTS onset (for SEL_{cum} metric threshold only; the peak pressure metric threshold is not weighted), which is NOAA's responsibility; and

2) Determining PTS and TTS onset isopleths (i.e., modeling of the area impacted around a source) associated with an activity, which is typically completed by an applicant/federal agency.

If the frequencies produced by a sound source are outside the range of a functional hearing group's best hearing sensivitiy (where the weighting function amplitude is 0), sounds must be louder in order to produce a similar to noise-induced hearing loss (i.e., TTS or PTS onset). The farther a sound source's frequency is away from the range of best sensitivity, the louder it must be. Because auditory weighting functions take a functional hearing group's differing sensitivity to frequencies into account, the implementation of these functions typically results in smaller isopleths at frequencies where the group is less sensitive. These marine mammal auditory weighting functions should be used in conjunction with corresponding PTS and TTS onset acoustic threshold levels, derived using auditory weighting functions. If the use of auditory weighting functions is not possible, NOAA has provided alternative, non-weighted PTS and TTS onset acoustic threshold levels to be used (Table 7).

2.3 TTS and PTS Onset Acoustic Threshold Levels

This section provides numeric acoustic threshold levels for the onset of TTS and PTS (Tables 6a, weighted and 7, non-weighted). Dual metrics of SEL_{cum} and peak sound pressure level have been recommended as most appropriate for establishing TTS and PTS onset acoustic threshold levels for marine mammals (Southall et al. 2007).

Based on data from cetacean TTS studies (see Southall et al. 2007 for a review), a threshold shift of 6 dB is considered the minimum threshold shift clearly larger than any day-to-day or session-to-session variation in a subject's normal hearing ability (Schlundt et al. 2000; Finneran et al. 2000; Finneran et al. 2002). Available data from humans and other terrestrial mammals indicate that a 40 dB threshold shift approximates PTS onset (see Ward et al. 1958, 1959; Ward 1960; Kryter et al. 1966; Miller 1974; Ahroon et al. 1996; Henderson et al. 2008).

The acoustic threshold levels presented in Table 6a replace previously issued NOAA acoustic threshold levels and are similar to those proposed elsewhere (Finneran and Jenkins 2012). However, the acoustic threshold levels described below also take into account new TTS data available, and follow a protocol developed by NOAA for combining multiple datasets. In addition to providing numeric acoustic threshold levels, NOAA has provided qualitative factors (Table 6b) that can be considered in conjunction with utilizing the numeric acoustic threshold levels. Numeric levels consist of both an acoustic threshold level and weighting function for the SEL_{cum} metric (weighting functions are not appropriate for peak pressure metric; see Section 2.3.2). NOAA recognizes that the implementation of marine mammal weighting functions represents a new and complicating factor for consideration, which may extend beyond the capabilities of some applicants. Thus, NOAA has developed alternative acoustic threshold levels for those who cannot apply weighting functions (Table 7). The use of these alternative acoustic threshold levels will typically result in a higher number of exposures compared to those that incorporate weighting functions.

2.3.1 Cumulative Sound Exposure Level (SEL_{cum}) Metric

The SEL metric takes into account both source level and duration of exposure (ANSI 1994). Often this metric is used to normalize a single sound exposure to a duration of one second. NOAA intends for the SEL metric to account for the *accumulated* exposure (i.e., SEL_{cum} cumulative exposure over the duration of the activity[15]).

One assumption made when using the SEL_{cum} metric is the equal energy hypothesis (EEH), where it is assumed that sounds of equal SEL_{cum} produce the equal risk for hearing loss (i.e., if the SEL_{cum} of two sources are similar, a sound from a lower level source with a longer exposure duration may have similar risks to a shorter duration exposure from a higher level source). As has been shown to be the case with humans and terrestrial mammals (Henderson et al. 1991), the EEH does not always hold true within marine mammals due the inherent complexity of predicting threshold shifts (Kastak et al. 2007; Mooney et al. 2009a; Mooney et al. 2009b; Finneran et al. 2010a; Finneran et al. 2010b; Finneran and Schlundt 2010). Factors like level (e.g., overall level, sensation level, or level above background), duration, repetition rate (intermittent versus continuous exposure; potential recovery between intermittent periods), number of transient components (short duration and high amplitude), and/or frequency (especially in relation to hearing sensitivity) often are also important factors associated with threshold shifts (e.g., Buck et al. 1984; Clark et al. 1987; Ward 1991; Lataye and Campo 1996). This is especially the case for exposure to impulsive sound sources (Danielson et al. 1991; Henderson et al. 1991; Hamernik et al. 2003), which is why acoustic threshold levels are also expressed as a peak pressure metric (see next section). However, in many cases the EEH approach functions reasonably well as a first-order approximation, especially for higher-level, short-duration sound exposures such as those that are most likely to cause TTS in marine mammals[16].

2.3.1.1 Recommended Baseline Accumulation Period

In order to use the cumulative sound exposure level metric, accumulation time must be specified. Generally, it is predicted that most individuals will only be in the closest ranges to a sound source/activity for a minimal amount of time[17]. This is further supported by what is known about behavioral responses to non-lethal human disturbances, with animals typically responding as they would to potential predators (as both have similar costs associated with the perception of risk and/or other fitness consequences; Frid and Dill 2002; Beale and Monaghan 2004; Ford and Reeves 2008; Wirsing et al. 2008; Barber et al. 2010; Wade et al. 2012). Richardson et al. (1995) noted that “avoidance reactions are the most obvious manifestations of disturbance,” and marine mammal literature on behavioral responses to anthropogenic noise support this conclusion (reviewed in Nowacek et al. 2007; Southall et al. 2007). Avoidance of a sound source will ultimately reduce exposure, particularly at the highest sound pressure levels and/or distances closest to the source (Patenaude et al. 2002; DeRuiter et al. 2013). Additionally, mitigation is typically used to reduce the risk of animals receiving levels causing PTS. Thus, individuals closest to the sound source should be detected by marine mammal observers and exposure to the highest sound pressure levels reduced, in turn reducing the likelihood of exposures causing auditory impacts.

Because of the time component in the SEL_{cum} metric, the use of different types of models to predict sound exposure may necessitate different approaches to evaluating likely effects in the context of the PTS/TTS thresholds. All marine mammals and some sources move in space and time, however, not all models are able to simulate relative source and receiver movement.

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[15] The SEL_{cum} metric is being proposed to be applied for discrete activities/sources and not meant to accumulate sound exposure for multiple activities occurring within the same area or over the same time.

[16] It is valuable for applicants, if possible, to indicate under what conditions these acoustic threshold levels will be exceeded.

[17] Gedamke et al. 2011 modeled seismic exposure scenarios and found “cumulative SEL is primarily going to be dictated by the relatively few highest SELs from individual shots that the whale encounters.”

Additionally, some models are able to predict the received level of sound at each modeled animal (often called animats) and accumulate sound at these receivers while incorporating the changing model environment. For applicants/users that have the ability to model moving animals and/or sources and the accumulating sound at each receiver, NOAA proposes that 24-hours or the length of activity, whichever is less, be used as the accumulation time. 24 hours has been used in other noise assessment planning applications (e.g., community noise planning for aircraft, vehicular traffic, and railway noise) and provides a reasonable outer bound in situations where the model will be able reflect realistic changes in relative distance between the source and likely exposed marine mammals over the course of a day.

However, for models that do not incorporate animal movement, it is not appropriate to make the assumption that animals will remain at a constant distance from the source accumulating acoustic energy for 24 hours. Additionally, if sound accumulation cannot be modeled, an alternative method must be used. For situations where modelling of movement and sound accumulation are not possible, an alternate method that is intended to address the accumulation of sound energy over time, but instead provides a distance from the source ("SEL threshold distance") that is simpler to apply in exposure modeling (i.e., would be used in calculations in the same way distance is used to calculate exposures above previous NOAA sound pressure level thresholds) should be used. Based on what we know about typical animal movement and avoidance, we propose a 1-hour accumulation period be used to calculate the "SEL threshold distance". This "SEL threshold distance" is calculated by determining the distance from the source at which an animal would have to remain for 1 hour in order to accumulate sound to the designated threshold. While, animals may move closer and farther from the source, this distance is considered a reasonable and conservative approximation.

The 24-hour (for models able to account for movement and sound accumulation) and 1-hour (for models not able to account for movement and sound accumulation) accumulation periods are considered a conservative baseline for accumulation time under most situations. The use of models able to account for movement and sound accumulation may also allow for the inclusion of additional details to provide a more realistic results based on the accumulation of sound (e.g. information on residence time of individuals, swim speeds for transient species, or specific times when activity temporarily ceases). Alternatively, there may be case-specific circumstances where the 1-hour accumulation time should be modified to account for situations where animals are expected to be in closer proximity to the source over a notably longer amount of time, based on activity, site, and species-specific information (e.g., where there is a resident population in a small and/or confined area and a long-duration activity with a large sound source, or a continuous stationery activity nearby a pinniped pupping beach).

2.3.2 Peak Pressure Metric

Sound exposure containing transient components (e.g., short duration and high amplitude; impulsive sounds) can create a greater risk of causing direct mechanical fatigue (as opposed to strictly metabolic) to the inner ear compared to sounds that are strictly non-impulsive (Henderson and Hamernik 1986; Levine et al. 1998; Henderson et al. 2008). Often the risk of damage from these transients does not depend on the duration of exposure (e.g., concept of "critical level," where damage switches from being primarily metabolic to more mechanical; short duration of impulse can be less than the ear's integration time, leading to the potential to damage beyond the level the ear can perceive (Akay 1978)). Human noise standards recognize and some provide separate acoustic threshold levels for impulsive sound sources (Occupational Safety and Health Administration (OSHA) 29 CFR 1910.95; Starck et al. 2003). Thus, SEL_{cum} is not an appropriate metric to capture these effects (i.e., often violates EEH; NIOSH 1998), which is why instantaneous peak sound pressure level has also been chosen as part of NOAA's dual acoustic threshold levels. Auditory weighting is not considered appropriate for use with this metric, as direct mechanical damage associated with sounds having high peak pressures typically does not strictly reflect the frequencies an individual species hears best (Ward 1962; Saunders et al. 1985; ANSI 1986; DOD 2004; OSHA 29 CFR 1910.95).

2.3.3 Comparison Among Metrics

NOAA's previous acoustic threshold levels are expressed as root-mean-square (dB_{rms}), which uses a different metric from peak sound pressure levels (dB_{peak}) and SEL_{cum} that are being recommended for our TTS and PTS onset acoustic threshold levels. Thus, we recommend caution when comparing past acoustic threshold levels to the acoustic threshold levels presented in this document as because they are based on different metrics, they are not directly comparable. For example, a 180 dB_{rms} level is not equal to a 180 dB_{peak} level. Furthermore, the SEL_{cum} metric incorporates time and is an energy level with a different reference value (re: 1μPa^2-s), thus it is not directly comparable to other metrics that describe sound pressure levels (re: 1 μPa).

2.3.4 Development of TTS and PTS Onset Acoustic Threshold Levels

NOAA's development of the TTS and PTS onset acoustic threshold levels, consisted of the following steps (for specific details on each of the steps used to derive these acoustic threshold levels, see Appendix B.):

1. Identification of available data on hearing loss associated with acoustic threshold in marine mammals (e.g., Google Scholar, Web of Knowledge, Southall et al. 2007, references in listed in available reports/publications).
2. Evaluation and summary of currently available, published data (26 studies found in Table 5) on hearing loss associated with noise exposure in marine mammals.
   - Because no published data exist on PTS in marine mammals, TTS onset data were evaluated and summarized in order to extrapolate to PTS onset.
   - Studies were summarized by dividing them into the following categories based on characteristics of the sound at the source (i.e., not characteristics at the receiver) and functional hearing group studied:
     - Impulsive[18] sources (transient, brief (less than 1 second), broadband, and typically consist of high peak pressure with rapid rise time and rapid decay (ANSI 1986; NIOSH 1998; ANSI 2005)) vs. Non-impulsive sources (can be broadband, narrowband or tonal, brief or prolonged, continuous or intermittent) and typically do not have a high peak pressure with rapid rise time (typically only small fluctuations in dB level) that impulsive signals do (ANSI 1995; NIOSH 1998).
     - Marine mammal functional hearing groups: LF Cetaceans, MF Cetaceans, HF Cetaceans, Phocid Pinnipeds, and Otariid Pinnipeds.
3. Determination of TTS onset (RLs, both in peak pressure and SEL_{cum} metrics) for each individual where data were available.
4. Implementation of appropriate marine mammal weighting function to data (SEL_{cum} metric acoustic threshold level only).
5. Final determination TTS onset for each sound category and by each marine mammal functional hearing group.

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[18] Note the definition of impulsive in this document relates specifically to noise-induced hearing loss and specifies the physical characteristics of a sound source, which likely gives them a higher potential to cause injury. This definition captures how these sound types may be more likely to affect auditory physiology. These definitions are not meant, however, to reflect how sounds have previously been characterized for behavior under NOAA's 120 and 160 dB MMPA thresholds.

  - Established protocol (Table B7) for combining data from multiple individuals or use of surrogates when no data were available within a certain category.

6. Extrapolation for PTS onset (in both peak pressure and SELcum metrics) based on data from humans and terrestrial mammals.

Table 5: Currently available underwater marine mammal threshold shift peer reviewed studies.

References in Chronologic Order+	Sound Source (Sound Source Category)	Sound-Exposed Species (number of individuals^)
Kastak et al. 1999	Octave-band noise (non-impulsive)	California sea lion (1), northern elephant seal (1), & harbor seal (1)
Finneran et al. 2000	Explosion simulator (impulsive)*	Bottlenose dolphin (2) & beluga (1)
Schlundt et al. 2000	Tones (non-impulsive)	Bottlenose dolphin (5) & beluga (2)
Finneran et al. 2002	Seismic watergun (impulsive)	Bottlenose dolphin (1) & beluga (1)
Finneran et al. 2003	Arc-gap transducer (impulsive)*	California sea lion (2)
Nachtigall et al. 2003	Octave-band noise (non-impulsive)	Bottlenose dolphin (1)
Nachtigall et al. 2004	Octave-band noise (non-impulsive)	Bottlenose dolphin (1)
Finneran et al. 2005	Tones (non-impulsive)	Bottlenose dolphin (2)
Kastak et al. 2005	Octave-band noise (non-impulsive)	California sea lion (1), northern elephant seal (1), & harbor seal (1)
Finneran et al. 2007	Tones (non-impulsive)	Bottlenose dolphin (1)
Lucke et al. 2009	Single airgun (impulsive)	Harbor porpoise (1)
Mooney et al. 2009a	Octave-band noise (non-impulsive)	Bottlenose dolphin (1)
Mooney et al. 2009b	Mid-frequency sonar (non-impulsive)	Bottlenose dolphin (1)
Finneran et al. 2010a	Tones (non-impulsive)	Bottlenose dolphin (2)
Finneran et al. 2010b	Tones (non-impulsive)	Bottlenose dolphin (1)
Finneran and Schlundt 2010	Tones (non-impulsive)	Bottlenose dolphin (1)
Popov et al. 2011a	Half-octave band noise (non-impulsive)	Yangtze finless porpoise (2)
Popov et al. 2011b	Half-octave band noise (non-impulsive)	Beluga (1)
SEAMARCO 2011+	Impact pile driving (impulsive)	Harbor porpoise (1)
Kastelein et al. 2012a	Octave-band noise (non-impulsive)	Harbor seal (2)
Kastelein et al. 2012b	Octave-band noise (non-impulsive)	Harbor porpoise (1)
Finneran and Schlundt 2013	Tones (non-impulsive)	Bottlenose dolphin (2)
Popov et al. 2013	Half-octave band noise (non-impulsive)	Beluga (2)
Kastelein et al. 2013a+	Impact pile driving (impulsive)	Harbor seal (2)
Kastelein et al. 2013b	Octave-band noise (non-impulsive)	Harbor seal (1)
Kastelein et al. 2013c	Tone (non-impulsive)	Harbor porpoise (1)

+ Peer reviewed studies available and evaluated as of 30 November 2013. Note there are two papers expected to publish in the near future and are currently taken into account in this document. However for both these studies, TTS onset could not be induced. Thus, neither study affects the proposed acoustic threshold levels and are instead included for completeness.

^ Note, some individuals have been used in multiple studies.

* No incidents of temporary threshold shift were recorded in study.

Table 6: a. Summary of TTS and PTS onset dual acoustic threshold levels.
b. Other factors for considerations based on frequency and duration of exposure.

a. Numeric Level*⁺

	PTS Onset (Received Level)		TTS Onset (Received Level)	
Hearing Group	**Impulsive**	**Non-impulsive**	**Impulsive**	**Non-impulsive**
Low-Frequency (LF) Cetaceans	*Cell 1* 230 dB$_{peak}$ **&** 187 dB SEL$_{cum}$	*Cell 2* 230 dB$_{peak}$ **&** 198 dB SEL$_{cum}$	*Cell 11* 224 dB$_{peak}$ **&** 172 dB SEL$_{cum}$	*Cell 12* 224 dB$_{peak}$ **&** 178 dB SEL$_{cum}$
Mid-Frequency (MF) Cetaceans	*Cell 3* 230 dB$_{peak}$ **&** 187 dB SEL$_{cum}$	*Cell 4* 230 dB$_{peak}$ **&** 198 dB SEL$_{cum}$	*Cell 13* 224 dB$_{peak}$ **&** 172 dB SEL$_{cum}$	*Cell 14* 224 dB$_{peak}$ **&** 178 dB SEL$_{cum}$
High-Frequency (HF) Cetaceans	*Cell 5* 201 dB$_{peak}$ **&** 161 dB SEL$_{cum}$	*Cell 6* 201 dB$_{peak}$ **&** 180 dB SEL$_{cum}$	*Cell 15* 195 dB$_{peak}$ **&** 146 dB SEL$_{cum}$	*Cell 16* 195 dB$_{peak}$ **&** 160 dB SEL$_{cum}$
Phocid Pinnipeds (Underwater)	*Cell 7* 235 dB$_{peak}$ **&** 192 dB SEL$_{cum}$	*Cell 8* 235 dB$_{peak}$ **&** 197 dB SEL$_{cum}$	*Cell 17* 229 dB$_{peak}$ **&** 177 dB SEL$_{cum}$	*Cell 18* 229 dB$_{peak}$ **&** 183 dB SEL$_{cum}$
Otariid Pinnipeds (Underwater)	*Cell 9* 235 dB$_{peak}$ **&** 215 dB SEL$_{cum}$	*Cell 10* 235 dB$_{peak}$ **&** 220 dB SEL$_{cum}$	*Cell 19* 229 dB$_{peak}$ **&** 200 dB SEL$_{cum}$	*Cell 20* 229 dB$_{peak}$ **&** 206 dB SEL$_{cum}$

* Dual acoustic threshold levels: Use whichever level [dB$_{peak}$ or dB SEL$_{cum}$] exceeded first. All SEL$_{cum}$ acoustic threshold levels (re: 1 µPa^2-s) are weighted. Note that acoustic threshold levels for impulsive or non-impulsive sources are based on characteristics at the source and not the receiver.

\+ The SEL$_{cum}$ could be exceeded in multitude of ways (i.e., varying exposure levels and durations). It is valuable for applicants, if possible, to indicate under what conditions these acoustic threshold levels will be exceeded.

Additional Detail Regarding Data Used to Derive Acoustic Threshold Levels:

Cells 1 through 10: Acoustic threshold level (peak and SEL$_{cum}$) based on an extrapolation, using related data (when available), rather than direct measurements. All PTS onset acoustic threshold levels are extrapolations based on terrestrial and limited marine mammal growth rate data.

Cell 11: Direct measurements of TTS onset do not exist. Mid-frequency cetaceans are used as surrogates for peak and SEL$_{cum}$ acoustic threshold levels.

Cell 12: Direct measurements of TTS onset do not exist. Mid-frequency cetaceans are used as surrogates for peak and SEL$_{cum}$ acoustic threshold levels.

Cell 13: Peak pressure and SEL$_{cum}$ acoustic threshold levels are based on data from a beluga exposed to a seismic watergun (Finneran et al. 2002).

Cell 14: Peak pressure is based on data from a beluga exposed to a seismic watergun (Finneran et al. 2002). The SEL$_{cum}$ level is based on data from bottlenose dolphins (n=6) exposed to either octave-band noise or tones (Schlundt et al. 2000; Mooney et al. 2009a; Finneran et al. 2010a; Finneran and Schlundt 2010). For bottlenose dolphins: median = 178 dB SEL$_{cum}$, 1st quartile = 175.5 dB SEL$_{cum}$, 3rd quartile = 181.6 dB SEL$_{cum}$. Median level also supported by beluga data (Schlundt et al. 2000).

Cell 15: Peak pressure and SEL$_{cum}$ acoustic threshold levels are based on data from a harbor porpoise exposed to airgun shots (Lucke et al. 2009).

Cell 16: Peak pressure level is based on data from a harbor porpoise exposed to airgun shots (Lucke et al. 2009). The SEL$_{cum}$ is based on data from a harbor porpoise exposed to octave-band noise (Kastelein et al. 2012b).

Cell 17: Direct measurements of TTS onset for this type of sound source do not exist. The SEL$_{cum}$ and peak pressure acoustic threshold level are based on an extrapolation from methodology derived from Southall et al. 2007.

Cell 18: Peak pressure level is based on an extrapolation from methodology derived from Southall et al. 2007, since no direct measurements exist. The SEL$_{cum}$ is based on data from a harbor seal (n=1) exposed to octave-band noise (Kastak et al. 2005).

Cell 19: Direct measurements of TTS onset for this type of sound source do not exist. The SEL$_{cum}$ is based on an extrapolation from methodology derived from Southall et al. 2007. Phocid extrapolation is used as a surrogate for the peak pressure level, since extrapolation produces unrealistic results.

Cell 20: The SEL$_{cum}$ is based on data from a California sea lion (n=1) exposed to octave-band noise (Kastak et al. 2005). Phocid extrapolation is used as a surrogate for the peak pressure level, since extrapolation produces unrealistic results.

b. Qualitative Factors for Considerations[+]: Frequency and Duration of Exposure

Frequency[^]:

General Trend Identified:

1) Growth of threshold shift (TS): Growth rates of TS (dB of TTS/dB noise) are higher for frequencies where hearing is more sensitive (Finneran and Schlundt 2010)

Duration:

General Trends Identified:

1) Violation of Equal Energy Hypothesis: Non-impulsive, intermittent exposures require higher SEL_{cum} to induce TS compared to continuous exposures of the same duration (Mooney et al. 2009a; Finneran et al. 2010b)

2) Violation of Equal Energy Hypothesis: Exposures of longer duration and lower levels induce TTS at a lower level than those exposures of higher level (below the critical level) and shorter duration with the same SEL_{cum} (Kastak et al. 2005; Kastak et al. 2007; Mooney et al. 2009b; Finneran et al. 2010a)

3) Recovery from TS: With the same SEL_{cum}, longer exposures require longer durations to recover (Mooney et al. 2009b; Finneran et al. 2010a)

4) Recovery from TS: Intermittent exposures recover faster compared to continuous exposures of the same duration (Finneran et al. 2010b)

[+] Although these descriptions do not provide a direct means for quantifying general trends (i.e., all cited studies are based on a limited number of species and individuals), they may be useful within a larger assessment.

[^] Frequency dependent hearing loss (i.e., PTS) is taken into account, quantitatively, with frequency weighting functions.

Table 7: Alternative PTS and TTS onset dual acoustic threshold levels for applicants unable to incorporate auditory weighting functions* (i.e., all acoustic threshold levels are unweighted).

Numeric^{+} Level				
	PTS Onset **(Received Level)**		**TTS Onset** **(Received Level)**	
Hearing Group	**Impulsive**	**Non-Impulsive**	**Impulsive**	**Non-Impulsive**
Low-Frequency (LF) Cetaceans	**Source: All** 230 dB_{peak} **&** 187 dB SEL_{cum}	**Source: NB ≥ 10 kHz** 230 dB_{peak} **&** 215 dB SEL_{cum}	**Source: All** 224 dB_{peak} **&** 172 dB SEL_{cum}	**Source: NB ≥ 10 kHz** 224 dB_{peak} **&** 195 dB SEL_{cum}
		Source: All others 230 dB_{peak} **&** 198 dB SEL_{cum}		**Source: All others** 224 dB_{peak} **&** 178 dB SEL_{cum}
Mid-Frequency (MF) Cetaceans	**Source: All** 230 dB_{peak} **&** 204 dB SEL_{cum}	**Source: NB ≥ 3 kHz** 230 dB_{peak} **&** 198 dB SEL_{cum}	**Source: All** 224 dB_{peak} **&** 189 dB SEL_{cum}	**Source: : NB ≥ 3 kHz** 224 dB_{peak} **&** 178 dB SEL_{cum}
		Source: All others 230 dB_{peak} **&** 215 dB SEL_{cum}		**Source: All others** 224 dB_{peak} **&** 195 dB SEL_{cum}
High-Frequency (HF) Cetaceans	**Source: All** 201 dB_{peak} **&** 180 dB SEL_{cum}	**Source: NB ≥ 3 kHz** 201 dB_{peak} **&** 180 dB SEL_{cum}	**Source: All** 195 dB_{peak} **&** 165 dB SEL_{cum}	**Source: NB ≥ 3 kHz** 195 dB_{peak} **&** 160 dB SEL_{cum}
		Source: All others 201 dB_{peak} **&** 199 dB SEL_{cum}		**Source: All others** 195 dB_{peak} **&** 179 dB SEL_{cum}
Phocid Pinnipeds (Underwater)	**Source: All** 235 dB_{peak} **&** 192 dB SEL_{cum}	**Source: All** 235 dB_{peak} **&** 197 dB SEL_{cum}	**Source: All** 229 dB_{peak} **&** 177 dB SEL_{cum}	**Source: All** 229 dB_{peak} **&** 183 dB SEL_{cum}
Otariid Pinnipeds (Underwater)	**Source: All** 235 dB_{peak} **&** 215 dB SEL_{cum}	**Source: All** 235 dB_{peak} **&** 220 dB SEL_{cum}	**Source: All** 229 dB_{peak} **&** 200 dB SEL_{cum}	**Source: All** 229 dB_{peak} **&** 206 dB SEL_{cum}

* Dual acoustic threshold levels: Use whichever [dB_{peak} or dB SEL_{cum}] exceeded first. These alternative acoustic threshold levels are based on whether the sound pressure levels from the source are predominantly within the “M-weighting” component of the curve, or the EQL portion of the auditory weighting curve (i.e., below or above 3 kHz for MF and HF cetaceans and 10 kHz for LF cetaceans, respectively). Since pinniped auditory weighting functions are derived solely from the M-weighting function, the same exposure levels are used for all sound sources. They also are based on an assumption that the most common of impulsive sources (i.e., airguns, impact pile drivers, explosives) have the majority of their sound pressure level at low frequencies (i.e., within the M-weighted component of the curve for HF and MF cetaceans: below 3 kHz). If there were an impulsive source with the majority of its energy above 3 kHz, the proposed alternative criteria would need to be modified on a case-by-case basis.

Note that acoustic threshold levels for impulsive or non-impulsive sources are based on characteristics at the source and not the receiver.

+ Other qualitative factors for considerations presented in Table 6b should still be considered in conjunction with these acoustic threshold levels

III. REGULATORY CONTEXT FOR AUDITORY IMPACT ACOUSTIC THRESHOLD LEVELS FOR MARINE MAMMALS

NOAA has compiled, interpreted and synthesized the best available science to produce new thresholds for the onset of both temporary and permanent hearing threshold shift ("TTS" and "PTS", respectively) in marine mammals from underwater sound. In the regulatory context, NOAA uses this information to help quantify "take" and to conduct more comprehensive effects analyses under several statutes.

Marine Mammal Protection Act and Endangered Species Act. NOAA equates the onset of permanent threshold shift (PTS), which is an auditory injury, with "Level A Harassment" as defined in the Marine Mammal Protection Act (MMPA) and with "harm" as defined in Endangered Species Act (ESA) regulations, such that exposing an animal to weighted received sound levels at or above the indicated PTS threshold is considered to result in these two types of "take."

As explained below, NOAA does not consider temporary threshold shift (TTS) to be an auditory injury and thus it does not qualify as Level A harassment or harm. Nevertheless, TTS is an adverse effect that constitutes another kind of "take" under those statutes: "Level B harassment" under the MMPA and "harassment" under the ESA. MMPA Level B harassment and ESA harassment are broad categories that encompass not only TTS but also other effects such as behavioral impacts, which almost always involve a lower onset threshold than that for onset of TTS. In quantifying take by Level B harassment or harassment, NOAA considers *all* effects that fall into those categories of take, not just TTS. NOAA currently is in the process of developing new thresholds for onset of behavioral effects. When that process is completed, TTS will be addressed for purposes of take quantification. In the meantime, the TTS thresholds presented represent the best available science and will be used in the comprehensive effects analyses under the MMPA and the ESA and may inform the development of mitigation and monitoring.

National Marine Sanctuaries Act. The broad definition of "injury" under the National Marine Sanctuaries Act (NMSA) regulations includes both PTS and TTS (as well as other adverse changes in physical or behavioral characteristics that are not addressed in this document).

3.1 Background: Applicable Statutory and Regulatory Standards, Definitions and Processes

3.1.1 Marine Mammal Protection Act

The MMPA prohibits the take of marine mammals, with certain exceptions, one of which is the issuance of incidental take authorizations (ITAs). Sections 101(a)(5)(A) & (D) of the MMPA (16 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 if certain findings are made. Through delegation by the Secretary of Commerce, NMFS is required to authorize the incidental taking of marine mammals if it finds that the total taking will have a negligible impact on the species or stock(s) and will not have an unmitigable adverse impact on the availability of the species or stock(s) for certain subsistence uses. NMFS must also set forth the permissible methods of taking and requirements pertaining to the mitigation, monitoring, and reporting of such takings. (The "small numbers" and "specified geographical region" provisions do not apply to military readiness activities.)

The term "take" means to harass, hunt, capture, or kill, or attempt to harass, hunt, capture or kill any marine mammal. 16 U.S.C. § 1362(13).

Except with respect to certain activities described below, "harassment" means any act of pursuit, torment, or annoyance which:

- has the potential to injure a marine mammal or marine mammal stock in the wild ***[Level A Harassment]***, or
- has the potential to disturb a marine mammal or marine mammal stock in the wild by causing disruption of behavioral patterns, including, but not limited to, migration, breathing, nursing, breeding, feeding or sheltering ***[Level B Harassment]***.

See id. at 1362(18)(A)(i) & (ii) (emphasis added).

Congress amended the definition of "harassment" as it applies to a "military readiness activity" as follows (section 3(18)(B) of the MMPA):

- 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
- 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].***

See id. at 1362(18)(B)(i) & (ii) (emphasis added).

The term "negligible impact" is defined 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. 50 C.F.R. § 216.103.

In support of the analysis that is necessary to make the required statutory determinations, MMPA implementing regulations require ITA applicants to provide NMFS with specific information. The new acoustic thresholds are particularly relevant to the following two of the fourteen required pieces of information:

- The ***type*** of incidental taking authorization that is being requested (i.e., takes by Level B Harassment only; ***Level A Harassment***; or serious injury/mortality) and the method of incidental taking;
- By age, sex, and reproductive condition (if possible), the ***number*** of marine mammals (by species) that may be taken ***by each type*** of taking identified in paragraph (a)(5) of this section, and the number of times such takings by each type of taking are likely to occur.

50 CFR § 216.104 (emphasis added).

3.1.2 Endangered Species Act

Section 9 of the ESA prohibits the take of ESA-listed species, with limited exceptions. Section 7 of the ESA requires that each federal agency, in consultation with NMFS and/or the U.S. Fish and Wildlife Service (USFWS), ensure that any action authorized, funded, or carried out by the agency is not likely to jeopardize the continued existence of any endangered or threatened species or result in the destruction or adverse modification of designated critical habitat. *See* 16 U.S.C. § 1536(a)(2). Provided that NMFS or the USFWS reaches these conclusions through a "formal consultation" process, incidental take of ESA-listed species may be exempted from the Section 9 take prohibition through an "incidental take statement" that must specify the impact, i.e., the amount or extent, of the taking on the species. *See id.* at § 1536(b)(4).Incidental take statements must also include reasonable and prudent measures necessary or appropriate to minimize the impact, and the terms and conditions required to implement those measures.

"Take" means to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct. *See id.* at § 1532(19). "Harm" is defined in NMFS regulations as "an act which actually kills or injures fish or wildlife" (and can include significant habitat modification or degradation). *See* 50 C.F.R. § 222.102.

Under NMFS's and the USFWS's implementing regulations for Section 7 of the ESA, "jeopardize the continued existence of" means to engage in an action that reasonably would be expected, directly or indirectly, to reduce appreciably the likelihood of both the survival and recovery of a listed species in the wild by reducing the reproduction, numbers, or distribution of that species. *See id.* at § 402.02.

In support of the analysis necessary to conduct the consultation, the ESA implementing regulations state that in order to initiate formal consultation, the federal action agency must submit a written request for formal consultation to the Director (of NMFS or the USFWS) that includes, among other things, a description of the manner in which the action may affect any listed species. *See id.* at § 402.14(c).

3.1.3 National Marine Sanctuaries Act

Section 304(d) of the NMSA requires federal agencies whose actions are likely to destroy, cause the loss of, or injure a sanctuary resource to consult with the Office of National Marine Sanctuaries (ONMS) before taking the action. *See* 16 U.S.C. § 1434(d)(1). The NMSA defines sanctuary resource as "any living or nonliving resource of a national marine sanctuary that contributes to the conservation, recreational, ecological, historical, educational, cultural, archeological, scientific, or aesthetic value of the sanctuary." 16 U.S.C. § 1432(8). Through the sanctuary consultation process, ONMS may recommend reasonable and prudent alternatives that will protect sanctuary resources. Recommended alternatives may include alternative locations, timing, and/or methods for conducting the proposed action. *See id.* at § 1434(d)(2). Monitoring may also be recommended to better characterize impacts to sanctuary resources or accompany mitigation. *See id*.

The term "injure" is defined in the ONMS implementing regulations as to "change adversely, either in the short or long term, a chemical, biological or physical attribute of, or the viability of." 15 C.F.R. § 922.3

In support of the analysis necessary to conduct the consultation, the NMSA requires that any federal agency proposing an action that may injure a sanctuary resource provide ONMS with a written statement ("sanctuary resource statement") describing the action and its potential effects on sanctuary resources. *See* 16 U.S.C. § 1434(d)(1)(B).

3.2 Application of Permanent Threshold Shift Acoustic Threshold Levels

The acoustic thresholds for PTS will be used in conjunction with sound source characteristics, environmental factors that influence sound propagation, anticipated marine mammal occurrence and behavior in the vicinity of the activity, as well as other available activity-specific factors, to estimate (acknowledging the gaps in scientific knowledge and the inherent uncertainties in a marine environment) the number of takes of marine mammals (Level A harassment and harm under the MMPA and ESA, respectively) and facilitate compliance with the MMPA, ESA, and NMSA as described above.

NOAA will use the same PTS thresholds in the identification and quantification of MMPA Level A harassment for both military readiness and non-military readiness activities. Because the acoustic thresholds for PTS predict the *onset* of PTS, they are inclusive of the "potential" and "significant potential" language in the two definitions of Level A harassment. The limited data now available do not support the parsing out of a meaningful quantitative difference between the “potential” and “significant potential” for injury and, therefore, the designated PTS thresholds will be treated as Level A harassment for both types of activities.

Estimating the numbers of take by Level A harassment and harm is one piece of the fuller analyses that inform NOAA’s “negligible impact” and “jeopardy” determinations under the MMPA and ESA, respectively, as well as “likely to injure” or “may affect” determinations under the NMSA. Last, the PTS thresholds may be used to inform the development of mitigation and monitoring measures (such as shut-down zones) pursuant to the MMPA, ESA, or NMSA.

When initiating any of the MMPA, ESA, or NMSA processes described above, agencies and other applicants should utilize the PTS thresholds and methods outlined in Section II of this document, in combination with activity-specific information, to predict whether, and if so how many, instances of PTS are expected to occur.

3.2.1 Temporary Threshold Shift Acoustic Threshold Levels

NOAA does not consider TTS an auditory injury based on the work of a number of investigators that have measured TTS before and after exposure to intense sound. For example, Ward (1997) suggested that TTS is within the normal bounds of physiological variability and tolerance and does not represent physical injury. In addition, Southall et al. (2007) indicates that although PTS is a tissue injury, TTS is not because the reduced hearing sensitivity following exposure to intense sound results primarily from fatigue, not loss, of cochlear hair cells and supporting structures, and is reversible. Accordingly, NMFS does not consider TTS as Level A harassment under the MMPA or harm under the ESA. Rather, TTS is considered take by Level B harassment under the MMPA and harassment under the ESA, which will be the subject of future guidance. However, TTS (along with PTS and behavioral impacts) is considered injury under the broad definition of the term “injury” in NMSA regulations.

NOAA is aware of recent studies by Kujawa and Liberman (2009) and Lin et al. (2011), which found that despite completely reversible threshold shifts that leave cochlear sensory cells intact, large (but temporary) threshold shifts could cause synaptic level changes and delayed cochlear nerve degeneration in mice and guinea pigs, respectively. However, these large TTSs that led to the synaptic changes shown in these studies are in the range of the large TTSs used in Southall et al. (2007) and here to calculate PTS thresholds. It is not known whether smaller levels of TTS would lead to similar changes. NOAA acknowledges the complexity of noise exposure on the nervous system, and will re-examine this issue as more data become available.

The occurrence of, and estimated number of, TTS takes is one piece of the larger analysis that informs NOAA’s “negligible impact” and “jeopardy” determinations under the MMPA and ESA, respectively, as well as “likely to injure” or “may affect” determinations under the NMSA. TTS thresholds also may be used to inform the development of mitigation and monitoring measures pursuant to the MMPA, ESA, or NMSA.

Note: This document constitutes a statement of NOAA’s current practice for assessing Level A Harassment and harm pursuant to the MMPA and ESA, respectively, and one kind of injury under the NMSA, from auditory impacts. NOAA recommends that Federal agencies and prospective applicants evaluating these types of impacts for the purposes of engaging in the aforementioned statutory processes also use these thresholds in the manner described here. However, this guidance does not create or confer any rights for or on any person, or operate to bind the public. An alternative approach may be proposed (by Federal agencies or prospective applicants) and used if case-specific information/data indicate that the alternative approach is likely to produce a more accurate estimate of Level A Harassment, harm, or auditory injury for the project being evaluated and if NOAA determines the approach satisfies the requirements of the applicable statutes and regulations.

IV. UPDATE OF ACOUSTIC GUIDANCE AND ACOUSTIC THRESHOLD LEVELS

Research on the effects of anthropogenic sound on marine mammals has increased dramatically since the inception of NOAA's previous acoustic threshold levels, and will likely continue to increase in the future. As such, this document will be reviewed periodically and updated as appropriate to reflect the best available science.

NOAA's initial approach for updating current acoustic threshold levels consisted of providing acoustic thresholds for underwater PTS and TTS onset for marine mammals. As more data become available, acoustic thresholds may be established for additional protected species, such as sea turtles and marine fishes. As with this document, public review and outside peer review will be integral to the development and refinement of acoustic thresholds.

4.1 Procedure and Timeline for Updating Acoustic Thresholds

NOAA will convene staff from our various offices, regions, and science centers, and re-evaluate and update acoustic threshold levels at least every three to five years as new data become available and as deemed appropriate. In addition to evaluating new, relevant scientific studies, NOAA will also periodically re-examine basic concepts and definitions (e.g., functional hearing groups, PTS, TTS, weighting functions), appropriate metrics, data standards, protocols for accounting for uncertainty, temporal and spatial considerations, and other relevant topics. Updates will be posted at http://www.nmfs.noaa.gov/pr/acoustics/

APPENDIX A: MARINE MAMMAL AUDITORY WEIGHTING FUNCTION AMPLITUDES

Marine mammal auditory weighting functions are described in the main body of this document (i.e., Section 2.2). This appendix provides broad weighting function amplitudes (calculated directly from the proposed auditory weighting functions) (Tables A1 to A5).

Table A1: Low-frequency cetacean auditory weighting function amplitudes.*

Frequency (Hz)	Weighting Function Amplitude
7.5	-22 dB
10	-20 dB
20	-17 dB
50	-10 dB
100	-4 dB
250	-1 dB
500	0 dB
1000	0 dB
3000	-3 dB
4000	-6 dB
6000	-10 dB
10000	-17 dB
20000	-20 dB
30000	-23 dB

*Table provides an example of weighting function amplitudes over a broad range of frequencies (i.e., not an exhaustive compilation of all amplitudes at all frequencies)

Table A2: Mid-frequency cetacean auditory weighting function amplitudes.*

Frequency (Hz)	Weighting Function Amplitude
100	-27 dB
500	-17 dB
1000	-17 dB
3000	-17 dB
6000	-7 dB
10000	-3 dB
20000	0 dB
30000	0 dB
40000	0 dB
50000	-1 dB
60000	-2 dB
70000	-2 dB
80000	-3 dB
90000	-4 dB
100000	-5 dB
110000	-6 dB
120000	-7 dB
130000	-8 dB
140000	-9 dB
150000	-9 dB
160000	-10 dB

*Table provides an example of weighting function amplitudes over a broad range of frequencies (i.e., not an exhaustive compilation of all amplitudes at all frequencies)

Table A3: High-frequency cetacean auditory weighting function amplitudes.*

Frequency (Hz)	Weighting Function Amplitude
100	-33 dB
500	-21 dB
1000	-20 dB
3000	-19 dB
4000	-15 dB
6000	-9 dB
10000	-4 dB
20000	-1 dB
30000	0 dB
40000	0 dB
50000	-1 dB
60000	-1 dB
70000	-2 dB
80000	-2 dB
90000	-3 dB
100000	-4 dB
110000	-5 dB
120000	-6 dB
130000	-6 dB
140000	-7 dB
150000	-8 dB
160000	-9 dB
170000	-9 dB
180000	-10 dB

*Table provides an example of weighting function amplitudes over a broad range of frequencies (i.e., not an exhaustive compilation of all amplitudes at all frequencies)

Table A4: Phocid auditory weighting function amplitudes.*

Frequency (Hz)	Weighting function amplitude
50	-10 dB
100	-4 dB
500	-0 dB
1000	-0 dB
3000	-0 dB
60000	-0 dB
10000	-0 dB
20000	-0 dB
30000	-1 dB
40000	-1dB
50000	-2 dB
60000	-3 dB
70000	-3dB
80000	-4dB
90000	-5 dB
100000	-6 dB

*Table provides an example of weighting function amplitudes over a broad range of frequencies (i.e., not an exhaustive compilation of all amplitudes at all frequencies)

Table A5: Otariid auditory weighting function amplitudes.*

Frequency (Hz)	Weighting function amplitude
100	-6 dB
500	-0 dB
1000	-0 dB
3000	-0 dB
6000	-0 dB
10000	-1 dB
20000	-2 dB
30000	-4 dB
40000	-6 dB

*Table provides an example of weighting function amplitudes over a broad range of frequencies (i.e., not an exhaustive compilation of all amplitudes at all frequencies)

APPENDIX B: DEVELOPMENT OF ACOUSTIC THRESHOLD LEVELS FOR ONSET OF PERMANENT AND TEMPORARY THREHSOLD SHIFT

This appendix provides detailed information on the development of NOAA's acoustic threshold levels for onset of permanent and temporary threshold shifts (PTS and TTS), and NOAA's protocols to address data limitations and uncertainty. Along with dual acoustic threshold levels, qualitative factors such as exposure duration and frequency are proposed for consideration.

NOAA's proposed TTS and PTS onset acoustic threshold levels are similar to those recently proposed by Finneran and Jenkins (2012). However, the acoustic threshold levels in Tables 6 and 7 (repeated here in Tables B1 and B2) take into account any new TTS data available and follow a protocol for combining multiple datasets (Table B7).

Table B1: **a. Summary of TTS and PTS onset dual acoustic threshold levels.**
b. Other factors for consideration based on frequency and duration of exposure.

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a. Numeric Level*+				
	PTS Onset (Received Level)		**TTS Onset (Received Level)**	
Hearing Group	**Impulsive**	**Non-impulsive**	**Impulsive**	**Non-impulsive**
Low-Frequency (LF) Cetaceans	*Cell 1* 230 dB_{peak} & 187 dB SEL_{cum}	*Cell 2* 230 dB_{peak} & 198 dB SEL_{cum}	*Cell 11* 224 dB_{peak} & 172 dB SEL_{cum}	*Cell 12* 224 dB_{peak} & 178 dB SEL_{cum}
Mid-Frequency (MF) Cetaceans	*Cell 3* 230 dB_{peak} & 187 dB SEL_{cum}	*Cell 4* 230 dB_{peak} & 198 dB SEL_{cum}	*Cell 13* 224 dB_{peak} & 172 dB SEL_{cum}	*Cell 14* 224 dB_{peak} & 178 dB SEL_{cum}
High-Frequency (HF) Cetaceans	*Cell 5* 201 dB_{peak} & 161 dB SEL_{cum}	*Cell 6* 201 dB_{peak} & 180 dB SEL_{cum}	*Cell 15* 195 dB_{peak} & 146 dB SEL_{cum}	*Cell 16* 195 dB_{peak} & 160 dB SEL_{cum}
Phocid Pinnipeds (Underwater)	*Cell 7* 235 dB_{peak} & 192 dB SEL_{cum}	*Cell 8* 235 dB_{peak} & 197 dB SEL_{cum}	*Cell 17* 229 dB_{peak} & 177 dB SEL_{cum}	*Cell 18* 229 dB_{peak} & 183 dB SEL_{cum}
Otariid Pinnipeds (Underwater)	*Cell 9* 235 dB_{peak} & 215 dB SEL_{cum}	*Cell 10* 235 dB_{peak} & 220 dB SEL_{cum}	*Cell 19* 229 dB_{peak} & 200 dB SEL_{cum}	*Cell 20* 229 dB_{peak} & 206 dB SEL_{cum}

* Dual acoustic threshold levels: Use whichever level [dB_{peak} or dB SEL_{cum}] exceeded first. All SEL_{cum} acoustic threshold levels (re: 1 μPa^2-s) are weighted. Note that acoustic threshold levels for impulsive or non-impulsive sources are based on characteristics at the source and not the receiver.

+The SEL_{cum} could be exceeded in multitude of ways (i.e., varying exposure levels and durations). It is valuable for applicants, if possible, to indicate under what conditions these acoustic threshold levels will be exceeded.

b. Other Factors for Considerations[+]: Duration and Frequency of Exposure

Frequency[▲]:

General Trends Identified:

1) Growth of TTS: Growth rates of threshold shifts (dB of threshold shift/dB noise) are higher for frequencies where hearing is more sensitive (Finneran and Schlundt 2010; Finneran 2011)

Duration:

General Trends Identified:

1) Violation of Equal Energy Hypothesis (EEH): Non-impulsive, intermittent exposures require higher SEL_{cum} to induce threshold shifts compared to continuous exposures of the same duration (Mooney et al. 2009a; Finneran et al. 2010b)
2) Violation of Equal Energy Hypothesis (EEH): Exposures of longer duration and lower levels induce threshold shifts at a lower level than those exposures of higher level* and shorter duration with the same SEL_{cum} (Kastak et al. 2005; Kastak et al. 2007; Mooney et al. 2009b; Finneran et al. 2010a; Kastelein et al. 2012a; Kastelein et al. 2012b)
3) Recovery from threshold shifts: With the same SEL_{cum}, longer exposures require longer durations to recover (Mooney et al. 2009b; Finneran et al. 2010a)
4) Recovery from threshold shifts: Intermittent exposures recover faster compared to continuous exposures of the same duration (Finneran et al. 2010b)

[+] Although these descriptions do not provide a means for quantifying general trends (i.e., all cited studies are based on a limited number of species and individuals), they may be useful within a larger assessment. Additionally, these trends are based specifically on TTS studies.

[▲] The implementation of weighting functions quantitatively allow for frequency-specific consideration of thresholds shifts.

* Below the critical level

Alternative Acoustic Threshold Levels: Without Weighting Functions

TTS and PTS onset acoustic threshold levels consist of both a numerical acoustic threshold level and weighting function. However, NOAA recognizes that the implementation of marine mammal weighting functions represents a new, relatively complex factor for consideration, which may extend beyond the capabilities of some applicants. Thus, NOAA has developed alternative acoustic threshold levels for those who are unable to apply weighting functions (Table B2).

Table B2: Alternative PTS and TTS onset dual acoustic threshold levels (all acoustic threshold levels are unweighted). NB stands for narrowband.

Numeric Level*+				
	PTS Onset **(Received Level)**		**TTS Onset** **(Received Level)**	
Hearing Group	**Impulsive**	**Non-Impulsive**	**Impulsive**	**Non-Impulsive**
Low-Frequency (LF) Cetaceans	**Source: All** 230 dB$_{peak}$ & 187 dB SEL$_{cum}$	**Source: NB ≥ 10 kHz** 230 dB$_{peak}$ & 215 dB SEL$_{cum}$	**Source: All** 224 dB$_{peak}$ & 172 dB SEL$_{cum}$	**Source: NB ≥ 10 kHz** 224 dB$_{peak}$ & 195 dB SEL$_{cum}$
		Source: All others 230 dB$_{peak}$ & 198 dB SEL$_{cum}$		**Source: All others** 224 dB$_{peak}$ & 178 dB SEL$_{cum}$
Mid-Frequency (MF) Cetaceans	**Source: All** 230 dB$_{peak}$ & 204 dB SEL$_{cum}$	**Source: NB ≥ 3 kHz** 230 dB$_{peak}$ & 198 dB SEL$_{cum}$	**Source: All** 224 dB$_{peak}$ & 189 dB SEL$_{cum}$	**Source: : NB ≥ 3 kHz** 224 dB$_{peak}$ & 178 dB SEL$_{cum}$
		Source: All others 230 dB$_{peak}$ & 215 dB SEL$_{cum}$		**Source: All others** 224 dB$_{peak}$ & 195 dB SEL$_{cum}$
High-Frequency (HF) Cetaceans	**Source: All** 201 dB$_{peak}$ & 180 dB SEL$_{cum}$	**Source: NB ≥ 3 kHz** 201 dB$_{peak}$ & 180 dB SEL$_{cum}$	**Source: All** 195 dB$_{peak}$ & 165 dB SEL$_{cum}$	**Source: NB ≥ 3 kHz** 195 dB$_{peak}$ & 160 dB SEL$_{cum}$
		Source: All others 201 dB$_{peak}$ & 199 dB SEL$_{cum}$		**Source: All others** 195 dB$_{peak}$ & 179 dB SEL$_{cum}$
Phocid Pinnipeds (Underwater)	**Source: All** 235 dB$_{peak}$ & 192 dB SEL$_{cum}$	**Source: All** 235 dB$_{peak}$ & 197 dB SEL$_{cum}$	**Source: All** 229 dB$_{peak}$ & 177 dB SEL$_{cum}$	**Source: All** 229 dB$_{peak}$ & 183 dB SEL$_{cum}$
Otariid Pinnipeds (Underwater)	**Source: All** 235 dB$_{peak}$ & 215 dB SEL$_{cum}$	**Source: All** 235 dB$_{peak}$ & 220 dB SEL$_{cum}$	**Source: All** 229 dB$_{peak}$ & 200 dB SEL$_{cum}$	**Source: All** 229 dB$_{peak}$ & 206 dB SEL$_{cum}$

* Dual acoustic threshold levels: Use whichever [dB$_{peak}$ or dB SEL$_{cum}$] exceeded first. These alternative acoustic threshold levels are based on whether the sound pressure levels from the source are predominantly within the “M-weighting” component of the curve, or the EQL portion of the auditory weighting curve (i.e., below or above 3 kHz for MF and HF cetaceans and 10 kHz for LF cetaceans, respectively). Since pinniped auditory weighting functions are derived solely from the M-weighting function, the same exposure levels are used for all sound sources. They also are based on an assumption that the most common of impulsive sources (i.e., airguns, impact pile drivers, explosives) have the majority of their sound pressure level at low frequencies (i.e., within the M-weighted component of the curve for HF and MF cetaceans: below 3 kHz). If there were an impulsive source with the majority of its energy above 3 kHz, the proposed alternative criteria would need to be modified on a case-by-case basis.

Note that acoustic threshold levels for impulsive or non-impulsive sources are based on characteristics at the source and not the receiver.

+ Other factors for considerations presented in Table B1, b should still be considered in conjunction with these acoustic threshold levels

These alternative acoustic threshold levels provided are based on when the sound from the source is predominantly within the “M-weighted” or EQL components of the auditory weighting function for cetaceans (i.e., below or above 3 kHz for MF and HF cetaceans and 10 kHz for LF cetaceans). If a sound is within the EQL portion of the curve, the functional hearing group has enhanced hearing sensitivity and susceptibility to noise-induced hearing loss (i.e., PTS or TTS). Since pinniped auditory weighting functions do not have EQL derived components, the same exposure levels are used for all sound sources. The use of these proposed alternative acoustic threshold levels will typically result in higher estimated exposures compared to those that incorporate weighting functions.

The alternative acoustic threshold levels are based on assumption that the most common impulsive sources (i.e., airguns, impact pile drivers, explosives) and broadband, non-impulsive sounds have the majority of their sound pressure level at low frequencies (i.e., within the M-weighted component for HF and MF cetaceans: ≤3 kHz and LF cetaceans: ≤10 kHz). If there is an impulsive or a non-impulsive, broadband source with the majority of its sound pressure level above 3 kHz (for MF and HF cetaceans) or 10 kHz (for LF cetaceans), then the alternative acoustic threshold levels would need to be modified (case-by-case basis).

I. DATA FOR NUMERIC ACOUSTIC THRESHOLD LEVELS BASED ON RECEIVED LEVEL

Research on the effects of anthropogenic sound on marine mammals has increased dramatically since the inception of NOAA’s previous acoustic threshold levels (e.g., Nowacek et al. 2007; Southall et al. 2007). In particular, scientific threshold recommendations have been made for TTS and PTS onset in the Southall et al. (2007) review, as well as in relevant peer-reviewed studies since the review’s publication in 2007. NOAA has independently reviewed the recommendations made by Southall et al. (2007), as well as available underwater marine mammal threshold shift studies (26 studies as of 30 November 2013) and their provided data (Table B3).
The data in Kastak et al. (2008) did not qualify for inclusion in our analysis, since the data presented in this abstract cannot be validated and verified[19] and/or were not subject to peer review. NOAA is also aware of recent unpublished studies by Kastelein (SEAMARCO 2011; Kastelein et al. 2013a) measuring TTS in a harbor porpoise and two harbor seals exposed to pile driving sounds. NOAA anticipates they will be published in peer-reviewed journals in the near future. As such, these acoustic threshold levels take into account these data.

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[19] Verification means that the data and procedures used to produce the scientific information are documented in sufficient detail to allow reproduction of the analysis by others with an acceptable degree of precision, while validation refers to the testing of analytical methods to ensure that they perform as intended (NOAA 2013).

Table B3: Currently available underwater marine mammal threshold shift studies.

References in Chronologic Order[+]	Sound Source (Sound Source Category)	Sound-Exposed Species (number of individuals^)
Kastak et al. 1999	Octave-band noise (non-impulsive)	California sea lion (1), northern elephant seal (1), & harbor seal (1)
Finneran et al. 2000	Explosion simulator (impulsive)*	Bottlenose dolphin (2) & beluga (1)
Schlundt et al. 2000	Tones (non-impulsive)	Bottlenose dolphin (5) & beluga (2)
Finneran et al. 2002	Seismic watergun (impulsive)	Bottlenose dolphin (1) & beluga (1)
Finneran et al. 2003	Arc-gap transducer (impulsive)*	California sea lion (2)
Nachtigall et al. 2003	Octave-band noise (non-impulsive)	Bottlenose dolphin (1)
Nachtigall et al. 2004	Octave-band noise (non-impulsive)	Bottlenose dolphin (1)
Finneran et al. 2005	Tones (non-impulsive)	Bottlenose dolphin (2)
Kastak et al. 2005	Octave-band noise (non-impulsive)	California sea lion (1), northern elephant seal (1), & harbor seal (1)
Finneran et al. 2007	Tones (non-impulsive)	Bottlenose dolphin (1)
Lucke et al. 2009	Single airgun (impulsive)	Harbor porpoise (1)
Mooney et al. 2009a	Octave-band noise (non-impulsive)	Bottlenose dolphin (1)
Mooney et al. 2009b	Mid-frequency sonar (non-impulsive)	Bottlenose dolphin (1)
Finneran et al. 2010a	Tones (non-impulsive)	Bottlenose dolphin (2)
Finneran et al. 2010b	Tones (non-impulsive)	Bottlenose dolphin (1)
Finneran and Schlundt 2010	Tones (non-impulsive)	Bottlenose dolphin (1)
Popov et al. 2011a	Half-octave band noise (non-impulsive)	Yangtze finless porpoise (2)
Popov et al. 2011b	Half-octave band noise (non-impulsive)	Beluga (1)
SEAMARCO 2011[+]	Impact pile driving (impulsive)	Harbor porpoise (1)
Kastelein et al. 2012a	Octave-band noise (non-impulsive)	Harbor seal (2)
Kastelein et al. 2012b	Octave-band noise (non-impulsive)	Harbor porpoise (1)
Finneran and Schlundt 2013	Tones (non-impulsive)	Bottlenose dolphin (2)
Popov et al. 2013	Half-octave band noise (non-impulsive)	Beluga (2)
Kastelein et al. 2013a[+]	Impact pile driving (impulsive)	Harbor seal (2)
Kastelein et al. 2013b	Octave-band noise (non-impulsive)	Harbor seal (1)
Kastelein et al. 2013c	Tone (non-impulsive)	Harbor porpoise (1)

[+] Peer reviewed studies available and evaluated as of 30 November 2013. Note there are two Kastelein et al. papers expected to publish in the near future and are currently taken into account. However for both these studies ,TTS onset could not be induced. Thus, neither study affects the proposed acoustic threshold levels and are instead included for completeness.

^ Note, some individuals have been used in multiple studies

* No incidents of temporary threshold shift recorded in study

II. EXPOSURE DURATION AND FREQUENCY

In addition to received level, NOAA recognizes that other factors are also important to consider with the establishment of TTS and PTS onset acoustic threshold levels (i.e., TTS and PTS are complex); namely with regard to exposure duration and exposure frequency. Thus, in addition to numerical acoustic threshold levels based on level, NOAA has provided qualitative factors that it recommends be considered within a broader impact assessment. They are presented as general trends associated with noise-induced hearing loss observed from the limited number marine mammal TTS studies and further supported by human and terrestrial mammal research. Additionally, information on both these factors are summarized in subsequent sections (i.e., Section IV) of this appendix for completeness. Thus, at this point, for marine mammals these factors are for qualitative consideration (i.e., not enough data to establish numerical acoustic threshold levels based on these additional factors).

2.1 Exposure Duration

Exposure duration plays a role in the onset of noise-induced hearing loss, as well as recovery from this loss (Table B4). Recent Mooney et al. (2009a, 2009b) studies and the Finneran et al. (2010a) study in bottlenose dolphins and by Kastak et al. (2005, 2007) in pinnipeds indicated that TTS is more likely to occur for those exposures, having the same energy, with longer durations compared to those with short durations. Finneran et al. (2010a) found that sound pressure level and duration were better predictors of TTS than just SEL_{cum} and using SEL_{cum} could result in an underestimation of TTS onset in situations of long-duration exposures, while in situations of short-duration exposures SEL_{cum} could result in an overestimation of TTS onset[20]. These trends have also been demonstrated in human and terrestrial mammals (e.g., Spieth and Trittipoe 1958; Buck et al. 1984).

NOAA encourages applicants to provide information on the predicted duration of exposure an individual is likely to receive (i.e., are all situations where animals exceed SEL_{cum} acoustic threshold levels associated with a short or extended exposure duration?). Additionally, whether acoustic threshold is intermittent or continuous plays a role in noise-induced hearing loss with animals typically needing to be either closer to the sound source or exposed for a longer duration to induce the same amount of hearing loss compared to those individuals exposed to more continuous sounds (human and terrestrial mammals data: Ward et al. 1958, Clark et al. 1987, Ward 1991; marine mammal data: Mooney et al. 2009b and Finneran et al. 2010b).

When considering exposure durations for animals under realistic exposure conditions, generally[21], it is predicted that most individuals will only be in the closest ranges to a noise source/activity for a minimal amount of time (e.g., animals are capable of moving horizontally and vertically in the water column to reduce exposure, and/or individuals are exposed to mobile sources). Thus, using laboratory data from animals exposed to unusually long, continuous durations of noise (i.e., animals cannot leave exposure scenario) may not best reflect scenarios expected to be encountered by wild individuals. For those reasons, NOAA excluded laboratory noise exposures resulting in TTS onset from further analysis if the exposure duration exceeded one hour of continuous exposure.

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[20] Interestingly, Popov et al. 2011a reported data that are contrary to some of these trends. For example, they reported that acoustic threshold of higher levels and shorter duration were more effective at eliciting higher levels of TTS than those exposures of equal SEL_{cum} but lower levels and longer durations. This highlights the complexity of understanding TTS, especially based on limited data.

[21] An exception would be situations where resident populations are located in confined areas and/or there is the potential for unusually long exposure

Table B4: Effect of exposure duration on TTS.

General Trends	Marine Mammal Studies
Intermittence:	
• Intermittent exposures require higher SEL_{cum} to induce TTS compared to continuous exposures of the duration (i.e., intermittent exposure results in lower levels of TTS); Violation of EEH.	Mooney et al. 2009b; Finneran et al. 2010b
• Intermittent exposures recover faster compared to continuous exposures of the same duration.	Finneran et al. 2010b
• Mean TTS after intermittent exposure was less than mean TTS after continuous exposure of same duration (i.e., cumulative energy approach overestimates growth rate and amount of TTS from intermittent exposures).	Finneran et al. 2010b
Duration:	
• Exposures of longer duration and lower levels induce more TTS (onset at lower level; amount of TTS higher) than those exposures of higher level and shorter duration with the same SEL_{cum}; Violation of EEH.	Kastak et al. 2005; Kastak et al. 2007; Mooney et al. 2009b; Finneran et al. 2010a; Kastelein et al. 2012a; Kastelein et al. 2012b
• Longer exposures require longer durations to recover compared to shorter duration exposures with the same SEL_{cum}.	Mooney et al. 2009a; Finneran et al. 2010a

2.1.1 Recovery

After sound exposure ceases or between successive sound exposures, there is the potential for recovery from hearing loss (i.e., PTS or TTS, with PTS resulting in incomplete recovery and TTS resulting in complete recovery). Predicting recovery from sound exposure can be quite complicated. It can begin rapidly after removal from sound exposure, threshold shifts can continue to grow before recovery begins, or the onset of recovery can be delayed (Hamernik et al. 1988). Hearing loss, because of metabolic mechanisms, typically recovers quicker than losses associated with mechanical mechanisms (Lutz and Hodge 1971; Patuzzi 1998). In general, threshold shifts of less than 40 dB, in humans and terrestrial mammals, demonstrate more rapid recovery than thresholds shifts greater than 40 dB (Ward 1960; Miller 1974; Hamernik et al. 1988). This is another reason NOAA chose 40 dB as PTS onset.

Some recovery rates from anthropogenic sound exposure have been reported or estimated for marine mammals after experiencing TTS (Table B5). Note that many of these studies only induced small amounts of TTS (typically less than 20 dB) and may not be appropriate for determining recovery rates for larger thresholds shifts. Mooney et al. (2009b) also found the duration of exposure contributed to rate of recovery, with longer exposures requiring longer periods to reach full recovery. A recent study by Finneran et al. (2010a) reported that recovery patterns were complex (e.g., multi-phased recovery pattern).

Table B5: Existing marine mammal TTS recovery data.

Study	Source	Species	Recovery Period
Kastak et al. 1999; Kastak et al. 2005	Octave-band noise	California sea lion, harbor seal, & Northern elephant seal	Within 24 hours
Schlundt et al. 2000	Tones	Bottlenose dolphin & Beluga	Within 5 hours or less
Finneran et al. 2002	Seismic watergun	Beluga	Within 4 minutes
Nachtigall et al. 2003	Octave-band noise	Bottlenose dolphin	Within 45 minutes
Nachtigall et al. 2004	Octave-band noise	Bottlenose dolphin	Within 105 minutes
Finneran et al. 2005	Tones	Bottlenose dolphin	Within 24 hours
Finneran et al. 2007	Tones	Bottlenose dolphin	Within 4 days
Lucke et al. 2009	Single airgun	Harbor porpoise	Within 55 hours (estimated)
Mooney et al. 2009a	Octave-band noise	Bottlenose dolphin	Within 40 minutes
Mooney et al. 2009b	MFA sonar	Bottlenose dolphin	Within 80 minutes
Popov et al. 2011	Half octave-band noise	Finless porpoise	Within 20 hours
Finneran and Schlundt 2013	Tones	Bottlenose dolphin	Most exposures within 1000 minutes
Popov et al. 2013	Half octave-band noise	Beluga	Within 24 hours
Kastelein et al. 2013b	Octave-band noise	Harbor seal	Within 4 days
Kastelein et al. 2013c	Tone	Harbor porpoise	Within 96 minutes

Based on current data, most recovery occurs within 24 hours of exposure. There are a few exceptions. For example, the longest, measured recovery time was four days from Finneran et al. (2007) (bottlenose dolphin) associated with 30 dB+ of TTS and from Kastelein et al. (2013b) (harbor seal) associated with 44 dB of TTS. The individuals in these studies were exposed at $\mathrm{SEL}_{\mathrm{cum}}$ at levels above what is being proposed for PTS onset (i.e., even though exposed at level which would exceed our proposed PTS onset acoustic threshold level, the animal still recovered completely).

Currently, recovery in wild marine mammals cannot be accurately quantified. However, Finneran et al. (2010a) and Finneran and Schlundt (2013) propose models that approximates recovery in bottlenose dolphins and whose applicability to other species and other exposure conditions has yet to be determined. In the development of these acoustic threshold levels, NOAA assumes for intermittent, repeated exposure that there is no recovery between subsequent exposures (this is especially important for PTS and TTS onset acoustic threshold levels using energy metrics), although it has been demonstrated in terrestrial mammals (Clark et al. 1987; Ward 1991) and recently in a marine mammal study (Finneran et al. 2010b), that there is a reduction in damage and hearing loss with intermittent exposures.

2.2 Frequency

There are some general trends associated with hearing loss and the frequency associated with exposure (Table B6). The relationship between "best hearing" and the anthropogenic sound exposure becomes important in context of sensation level (sound level referenced to the individual's baseline threshold; Yost 2007), with susceptibility to sound typically increasing in regions where one's hearing is most sensitive (Miller 1974). Finneran et al. (2007) concluded that sensation level played a role in the results they recorded demonstrating higher levels of TTS in dolphins exposed to 20 kHz tones compared to 3 kHz tones (20 kHz tones closer to "best hearing" range compared to 3 kHz tones) but cautioned that other factors may have contributed, as well. Nevertheless, they indicated "a need for data regarding the onset and growth of TTS at higher frequencies where sensitivities are better" (Finneran et al. 2007). Subsequent, data from Finneran and Schlundt (2010) indicate that TTS onset does occur at lower levels and at higher growth rates with exposures of 20 kHz, compared to those at 3 kHz, in bottlenose dolphins, with Finneran and Schlundt (2013) further examining (exposure frequencies ranging from 3 to 80 kHz) the relationship between frequency and growth rates.

Table B6: Effect of exposure frequency on TTS.

General Trends	Marine Mammal Studies
Threshold Shifts Amount*: • Hearing loss is frequency-dependent, with higher levels of TTS (or lower TTS onset) recorded in regions of best hearing sensitivity.	Finneran et al. 2007; Finneran and Schlundt 2010; Finneran and Schlundt 2013
Growth of TTS: • Growth rates of TTS (dB of TTS/dB of noise) are higher for frequencies where hearing is more sensitive.	Finneran and Schlundt 2010; Finneran 2011; Finneran and Schlundt 2013

* The implementation of weighting functions quantitatively allow for frequency-specific consideration of thresholds shifts.

Additionally, for humans, terrestrial mammals, and marine mammals, pure tone or octave-band noise exposure typically results in a maximum thresholds shift one-half to one octave above the upper frequency of sound exposure (often called "half-octave shift," e.g., Hirsch and Bilger 1955; Cody and Johnstone 1981; Cappaert et al. 2000; Yost 2007; Finneran et al. 2007; Popov et al. 2011a; Popov et al. 2011b). Thus, PTS and TTS rarely encompasses an individual's entire auditory range because the anthropogenic sounds themselves are not broad enough to overlap a marine mammal's entire hearing range.

III. MANAGING DATA LIMITATIONS AND UNCERTAINTY

NOAA, like Southall et al. (2007) in their scientific recommendations for TTS and PTS onset acoustic threshold levels, acknowledges the inherent data limitations that occur in many instances when assessing acoustic effects on marine mammals. For example, data are typically only available from a limited number of species and within species, a limited number of individuals. Thus, extrapolations had to be made when there were no data available for a hearing group/sound source. Furthermore, Southall et al. (2007) did not provide explicit guidance on how acoustic threshold levels should be created or revised as more data become available (e.g., when is there enough data from an individual species to establish a separate acoustic threshold level). As a result, NOAA developed certain assumptions to address uncertainty when establishing numerical acoustic threshold levels for TTS onset (Table B7).

Table B7: **NOAA's Protocol for accounting for uncertainty in establishing TTS onset acoustic threshold levels for marine mammals within a sound source category.**

***Step 1*:** Number of Species with Data within Hearing Group	***Step 2*:** Number of Individuals with Data within a Species	***Step 3:*** Hearing Group Representative for Establishing TTS Onset Acoustic threshold Level*	**Example Scenarios (A through F)**
None	—	Surrogates chosen based on the closest related hearing group	**A)** Use mid-frequency cetaceans (as opposed to high-frequency) cetaceans as surrogates for low-frequency cetaceans
One	Few (1- 4 individuals)	Individual with lowest threshold for TTS onset	**B)** Data from 1 beluga: Take the lowest TTS onset acoustic threshold level
	Several (≥ 5 individuals)	Median[+] of individuals' lowest thresholds for TTS onset	**C)** Data from 5 bottlenose dolphins: Take the median of all the individuals' lowest TTS onset acoustic threshold level
Multiple	All species with few (1- 4 individuals)	Most conservative species: Individual with lowest threshold for TTS onset	**D)** Data from bottlenose dolphin and beluga: Take one with the lowest TTS onset acoustic threshold level
	Species with both few (1- 4 individuals) and Several (≥ 5 individuals)	<u>Whichever is the lowest</u>: 1) Few individuals: Individual with lowest threshold for TTS onset *<u>or</u>* 2) Several individuals: Median[+] of individuals' lowest threshold for TTS onset Median of single species' lowest individual thresholds for TTS onset can also represent that particular species	**E)** Data from 1 beluga and 5 bottlenose dolphins: Take whichever is the lowest (either the lowest TTS onset threshold for the beluga or the median of all the bottlenose dolphins' lowest TTS thresholds). Bottlenose dolphins could have their own separate data-based acoustic threshold level (i.e., separate from rest of hearing group).
	All species with several (≥ 5 individuals)	Species with the lowest median[+] of individuals' lowest thresholds for TTS onset. Median of single species' lowest individual thresholds for TTS onset can also represent that particular species	**F)** Data from 5 bottlenose dolphins and 5 belugas: Take whichever is the lowest (either the median of all the bottlenose dolphins' lowest TTS thresholds or the median of all the belugas' lowest TTS thresholds). Bottlenose dolphins or beluga could have their own separate data-based acoustic threshold level (i.e., separate from rest of hearing group.

* TTS onset is lowest acoustic threshold level with at least a 6 dB or greater threshold shift. This table also does not make a distinction for different sound sources *within* a sound source category (impulsive or non-impulsive). Although applying appropriate weighting functions in conjunction with the proposed acoustic threshold levels help to account for some frequency-specific effects.

To best reflect scenarios expected to be encountered by wild individuals, only data points with exposure durations of one hour or less are considered in NOAA's analysis.

[+] When median thresholds are reported, please also report the data range and 1st and 3rd quartiles.

These assumptions help to ensure that NOAA is assessing data in a consistent manner. The protocols for addressing uncertainty should also be useful as more data become available in the future. Currently, these protocols are based on functional hearing groups, but NOAA acknowledges that as more data become available the relatedness of various genus and/or species within a single family may be an important additional consideration (i.e., specific acoustic threshold levels may be able to be derived by family, genus, and/or species). Furthermore, as more data are collected, NOAA will be better able to identify outliers (e.g., one individual has an unusually high or low threshold or testing procedures led to flawed results) and make necessary adjustments (i.e., removal of an outlier datum).

NOAA's PTS onset acoustic threshold levels are informed by data from terrestrial mammals and humans (as are the Southall et al. 2007 thresholds) and have been set at levels below predicted PTS onset for most species. As new data become available, these acoustic threshold levels will be adjusted. At this time, NOAA's determination of where appropriate acoustic threshold levels occur is supported by the existing best available science.

3.1 Representative Species/Individuals

Currently, TTS data only exist for four species of cetaceans (bottlenose dolphins, belugas, harbor porpoises, and Yangtze finless porpoise). For bottlenose dolphins, data are available from multiple individuals, while for belugas data comes from four individuals and for harbor porpoises and Yangtze finless porpoises all data come from just two individuals for each species. For pinnipeds, TTS data exist for three species (Northern elephant seal, harbor seal, and California sea lion), but only for a single individual of Northern elephant seal, lone California sea lion (Finneran et al. 2003 tested exposed two California sea lions but could not induce TTS), and three harbor seals.

Whether these captive individuals are representative (i.e., where this individual's measurements fall within the larger population) of their species, hearing group, and for marine mammals in general (e.g., susceptibility of anthropogenic sound has been shown to vary among terrestrial mammal species; Drescher and Eldredge 1974; Borg and Viberg 1995; Duan et al. 2008; Henderson et al. 2008) is unknown. Nevertheless, these studies contain the only data currently available. NOAA has made assumptions to prevent the interpretation of these data beyond what they truly represent. NOAA recognizes that as more data become available, for a broader array of species and individuals within a species, our acoustic threshold levels will need to be re-examined.

3.2 Representative Sound Sources

For cetaceans, most TTS studies have focused on sound sources (both impulsive and non-impulsive sources) with the majority of their acoustic energy below 10 kHz (Table B8; Finneran et al. 2007). This is often below the best hearing range of the species being tested. For example, non-impulsive sound source TTS studies have primarily focused on exposures with frequencies in the range of tactical mid-frequency active (MFA) sonar (1 to 10 kHz). For pinnipeds underwater, there have been even fewer TTS studies conducted, with even fewer sound sources (Table B8).

Table B8: Sound sources associated with cetacean and underwater pinniped TTS studies.

Sound Source	Predominant Frequency and Exposure Duration	Reference
Cetacean Studies		
Seismic watergun (impulsive)	Frequency: Broadband up to 40 kHz, most energy below 1 kHz Duration: ~6.3 to 73 msec	Finneran et al. 2002
Explosion simulator (impulsive)	Frequency: Broadband up to 40 kHz, most energy between 1-10 kHz Duration: 5.1 to 13 msec	Finneran et al. 2000
Single airgun (impulsive)	Frequency: Broadband up to 20 kHz, most energy below 500 Hz Duration: less than 50 msec	Lucke et al. 2009
Tones (non-impulsive)	Frequency: 0.4, 1.5, 3, 10, 20, or 75 kHz Duration: 1 to 128 s or 60 min	Schlundt et al. 2000; Finneran et al. 2005; Finneran et al. 2007; Finneran et al. 2010a; Finneran et al. 2010b; Finneran and Schlundt 2010; Finneran and Schlundt 2013; Kastelein et al. 2013c
Octave-band noise (non-impulsive)	Frequency: 4 kHz center, from 4 to 8 kHz or 4 to 11 kHz Duration: 1.875 to 54 min, 60 min, or 120 min	Nachtigall et al. 2003; Nachtigall et al. 2004; Mooney et al. 2009a; Kastelein et al. 2012b
Half octave-band noise (non-impulsive)	Frequency: Centered at 22.5 to 128 kHz Duration: 1 to 30 min	Popov et al. 2011a; Popov et al. 2011b; Popov et al. 2013
Impact pile driving (impulsive)	Frequency: peak 630 Hz, most energy between 0.4 to 5 kHz Duration: 120 min	SEAMARCO 2011
MFA sonar (non-impulsive)	Frequency: Main energy at 3 kHz (higher frequency harmonics) Duration: 3 to 15 s	Mooney et al. 2009b
Underwater Pinniped Studies		
Arc-gap transducer (impulsive)	Frequency: Broadband up to 40 kHz, most energy below 1 kHz Duration: 10.5 to 28.3 msec	Finneran et al. 2003
Impact pile driving (impulsive)	Frequency: peak 630 Hz, most energy between 0.4 to 5 kHz Duration: 120 min	Kastelein et al. 2013a
Octave-band noise (non-impulsive)	Frequency: Centered at 0.1, 0.5, 1, 2, 2.5 kHz, or 4 kHz Duration: 7.5 min, 15 min, 20 min, 22 min, 25 min, 30 min 50 min, 60 min, or 120 min	Kastak et al. 1999; Kastak et al. 2005; Kastelein et al. 2012a; Kastelein et al. 2013b

Our current TTS and PTS onset acoustic threshold levels only distinguish between impulsive and non-impulsive sounds and do not take into account the temporal or spectral characteristics of the sound source. NOAA acknowledges that these additional factors still need to be considered, even if only qualitatively at this point.

As more data become available for a broader array of sound sources, especially with sound pressure levels in various species' most sensitive hearing range, NOAA will consider whether to adjust its acoustic threshold levels. It may be necessary to refine the acoustic threshold levels based on particular sound sources (e.g., separate acoustic threshold levels for impulsive pile driving strikes versus seismic airgun shots), duration of exposure (e.g., continuous vs. intermittent), or frequency ranges of exposure (e.g., low-, mid-, or high-frequency) rather than by broad sound source categories.

IV. DEVELOPMENT OF TTS AND PTS ONSET ACOUSTIC THRESHOLD LEVELS

For acoustic threshold levels without associated frequency weighting, see Table B2.

4.1 Temporary Threshold Shifts: Non-Impulsive Sources

4.1.1 Mid-Frequency Cetaceans

Numeric Acoustic threshold Level (Table B9; Cell 14 Table B1a)

Table B9: TTS onset dual acoustic threshold levels for mid-frequency cetaceans exposed to underwater non-impulsive sound sources.

Effect	Exposure Level (Received Level)	Reference
TTS onset (Dual acoustic threshold levels: use whichever [dB_{peak} or dB SEL_{cum}] exceeded first)	224 dB_{peak}	Finneran et al. 2002
	178 dB SEL_{cum}	Schlundt et al. 2000; Mooney et al. 2009a; Finneran & Schlundt 2010; Finneran et al. 2010a

For bottlenose dolphins and belugas, numerous TTS studies have been conducted using non-impulsive sound sources (more so than for any other sound source). For bottlenose dolphins, at least nine different individuals have been exposed to anthropogenic sound, with TTS being induced in seven[22] individuals (Table B10). Thus, bottlenose dolphin data provide an opportunity to examine how TTS onset varies among a group of individuals. The lowest TTS threshold (assumed to represent onset) for each individual recorded (regardless of sound source; e.g., individual may have been exposed to tones at various frequencies) was chosen. The median of these weighted data is 178 dB SEL_{cum} (1st Quartile: 175.5 dB SELc_{um}; 3rd Quartile: 181.6 dB SEL_{cum}; Table B6, Scenario E).

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[22] It was not possible to distinguish individual TTS data for dolphin NAY from that of dolphin BEN in the Finneran et al. 2005 study. Thus, data for NAY are not presented.

Table B10: TTS onset in bottlenose dolphins exposed to underwater non-impulsive sound sources.

Individual	Study	Sound Source/Exposure Duration(s)	TTS Onset^{+} (unweighted)
Boris	Mooney et al. 2009a	Octave band noise (4-8 kHz)/7.5, 15, & 30 min	182.5 dB SEL$_{cum}$▲ (189.5 dB SEL$_{cum}$)
TOD	Schlundt et al. 2000	75 kHz tone/1 s	179 dB SEL$_{cum}$ (182 dB SEL$_{cum}$)
NEM	Schlundt et al. 2000	3 kHz tone/1 s	177 dB SEL$_{cum}$ (194 dB SEL$_{cum}$)
BEN	Schlundt et al. 2000	10 kHz tone/1 s	189 dB SEL$_{cum}$ (192 dB SEL$_{cum}$)
TYH	Finneran et al. 2010a	3 kHz tone/either 16, 32, or 64 s^	175 dB SEL$_{cum}$ (192 dB SEL$_{cum}$^)
BLU	Finneran and Schlundt 2010	3 kHz tone/16 s	174 dB SEL$_{cum}$ (191 dB SEL$_{cum}$*)

Descriptive Statistics (n=6: Boris, TOD, NEM, BEN, TYH, BLU)
Median: 178 dB SEL$_{cum}$; 1st Quartile: 175.5 dB SEL$_{cum}$; 3rd Quartile: 181.6 dB SEL$_{cum}$
Mean: 179.4 dB SEL$_{cum}$; Maximum: 189 dB SEL$_{cum}$; Minimum 174 dB SEL$_{cum}$

▲ Weighting was based on center frequency of octave-band noise.

^ TTS onset estimated from Figure 3a in Finneran et al. 2010. Since onset is estimated, the exact duration of exposure is unknown, but is either 16, 32, or 64 s.

* TTS onset determined from best-fit curve (created from experimental data) rather than a direct measurement at this particular SEL$_{cum}$.

For the two individual belugas exposed to non-impulsive sound sources, the lowest TTS onset occurred at a weighted level of 178 dB SEL$_{cum}$ (Schlundt et al. 2000; Table B11), which is identical to the median of the bottlenose dolphin data. Thus, NOAA is using bottlenose dolphin data as a surrogate for all species within this hearing group.

Table B11: TTS onset in belugas exposed to underwater non-impulsive sound sources.

Individual	Study	Sound Source/Exposure Duration(s)	TTS Onset (unweighted)
MUK	Schlundt et al. 2000	10 kHz tone/1s	189 dB SEL$_{cum}$ (192 dB SEL$_{cum}$)
NOC	Schlundt et al. 2000	3 kHz tone/1 s	178 dB SEL$_{cum}$ (195 dB SEL$_{cum}$)

An additional TTS study was also completed by Popov et al. (2011b) on a single male beluga exposed half-octave band noise (32 kHz center frequency) for durations of 1, 3, 10, and 30 minutes using a new methodology for a more quick determination of hearing thresholds after acoustic threshold. They reported thresholds shifts of 20 dB or greater at RLs starting at ~178 dB SEL$_{cum}$ (i.e., TTS onset was not determined). In addition to TTS, recovery was also measured. Popov et al. (2011b) found that recovery occurred in two phases, with fast recovery resulting in rapid and drastic decreases in threshold within the first minutes after acoustic threshold and slow recovery occurring longer afterwards (i.e., 10 to 30 minutes).

Popov et al. (2013) completed another study using both a male and female beluga whale exposed to half-octave band noise (11.2, 22.5, 45, and 90 kHz center frequencies) for durations of 1, 3, 10, and 30 minutes using similar methodology as was used in Popov et al. 2011b. Again, the goal of this study was to examine a variety of factors that contribute to TTS but not necessarily determine TTS onset. Thus, in the majority of trials, TTS was measured at levels much greater than 6 dB (Table B12).

Table B12: Amount of TTS recorded in Popov et al. 2013 for belugas.

Exposure Duration (SEL_{cum})	TTS at 11.2 kHz*	TTS at 22.5 kHz*	TTS at 45 kHz*	TTS at 90 kHz*
Male beluga				
1 min. (183 dB)	15 dB	27.5 dB	12.5 dB	7.5 dB
3 min. (188 dB)	22.5 dB	45 dB	15 dB	8.8 dB
10 min. (193 dB)	37.5 dB	47.5 dB	25 dB	10 dB
30 min. (198 dB)	47.5 dB	55 dB	42.5 dB	23.8 dB
Female beluga				
1 min. (183 dB)	25 dB	37.5 dB	8.8 dB	21.3 dB
3 min. (188 dB)	27.5 dB	57.5 dB	28.8 dB	21.3 dB
10 min. (193 dB)	50 dB	62.5 dB	43.8 dB	31.3 dB
30 min. (198 dB)	---	----	51.3 dB	31.3 dB

* test frequency = +0.5 octaves

Comparing the TTS measured by Popov et al. 2011b and Popov et al. 2013 with the onset reported in Schlundt et al. 2000 (after applying appropriate weighting functions), NOAA considered whether 178 dB SEL_{cum} was an appropriate acoustic threshold levels for TTS onset. There are some methodological differences between the Schlundt et al. 2000 and two Popov studies that should be considered. Specifically, the Schlundt et al. 2000 study behaviorally measured TTS thresholds, and this typically occurred 1 to 3 minutes after exposure to the fatiguing stimuli. Looking at Figure 2(a) in Popov et al. 2011b, one can see the rapid recovery occurring within the first few minutes after noise exposure (~10 dB within first 5 minutes after noise exposure). Additionally, they exposed this animal at 140 dB for durations up to 30 minutes (~172.5 dB SEL_{cum}) and reported thresholds shifts that were “insufficient and hardly detectable.” Thus, taking these factors into consideration, threshold shifts reported in Popov et al. 2011b are more in-line with the results from Schlundt et al. 2000. Nevertheless, this highlights how differing methodologies can make direct comparisons among studies difficult and must be carefully considered.

Validity of the Equal Energy Hypothesis (EEH)

Two recent Mooney et al. (2009a, 2009b) studies and the Finneran et al. (2010a) study indicated that the EEH is not always valid, especially when considering exposure duration. In other words, despite the 189 dB SEL_{cum} threshold, TTS is more likely to occur for those exposures, having the same energy, with longer durations compared to those with short durations (e.g., more likely to have a TTS onset with an exposure 174 dB_{rms} for 63 seconds than of an exposure of 192 dB_{rms} for 1 second). All exposures from Mooney et al. (2009a) that recorded TTS onset were at least 1.875 minutes or longer, with longer exposures inducing TTS more frequently (i.e., 5 out of 7 exposures of 7.5 minutes led to TTS; 6 out of 7 exposures of 15 minutes led to TTS; and 4 out of 5 exposures of 30 minutes led to TTS). Finneran et al. (2010a) found that sound pressure level and duration were better predictors of TTS than just SEL_{cum}. They found that using SEL_{cum} could result in an underestimation of TTS in situations of long-duration exposures, while in situations of short-duration exposures SEL_{cum} could result in an overestimation of TTS.

Based on these studies, NOAA recommends using the SEL_{cum} thresholds contained herein. However, NOAA recommends caution especially when applying these thresholds to activities where there is the potential for long-duration exposures (i.e., minutes or hours compared to seconds). NOAA encourages applicants to report, in addition to the number of exposures exceeding the SEL_{cum} threshold, the expected exposure histories (i.e., number and duration of exposures). This allows for a more complete assessment and means of addressing EEH concerns (e.g., one can exceed a SEL_{cum} threshold in numerous ways with numerous numbers of exposures or exposure durations), as well as assessing the potential for recovery.

Exposure Frequency and Duration (Table B13)

Of the recent marine mammal TTS studies, most have focused on non-impulsive sources. Exposures have consisted of a broad range of frequencies (0.4 to 80 kHz) and durations (1 s to 30 min) (Table B13). The peak pressure acoustic threshold level derived for impulsive sources for MF cetaceans will also be used for non-impulsive sources (see more detailed description below).

Table B13: Relevant studies provided in the context of exposure frequency and duration.

Species (number of individuals)	Sound source	Predominant Frequency and Exposure Duration	Reference
Bottlenose dolphin (5); Beluga (2)	Tones	Frequency: 0.4, 3, 10, 20, or 75 kHz Duration: 1 s	Schlundt et al. 2000
Bottlenose dolphin (1)	Octave-band noise	Frequency: 4 to 11 kHz Duration: 41 to 54 min	Nachtigall et al. 2003
Bottlenose dolphin (1)	Octave-band noise	Frequency: 4 to 11 kHz Duration: 30 min	Nachtigall et al. 2004
Bottlenose dolphin (2)	Tones	Frequency: 3 kHz Duration: 1 to 8 s	Finneran et al. 2005
Bottlenose dolphin (1)	Tones	Frequency: 20 kHz Duration: 48* to 64 s	Finneran et al. 2007
Bottlenose dolphin (1)	Octave-band noise	Frequency: 4 to 8 kHz Duration: 1.875 to 30 min	Mooney et al. 2009a
Bottlenose dolphin (1)	MFA sonar	Frequency: Main energy at 3 kHz (higher frequency harmonics) Duration: 3 to 15 s*	Mooney et al. 2009b
Bottlenose dolphin (2)	Tones	Frequency: 3 kHz Duration: 4 to 128 s	Finneran et al. 2010a
Bottlenose dolphin (1)	Tones	Frequency: 3 kHz Duration: 64 s*	Finneran et al. 2010b
Bottlenose dolphin (1)	Tones	Frequency: 3 or 20 kHz Duration: 16 s	Finneran and Schlundt 2010
Beluga (1)	Half-octave band noise	Frequency: 32 kHz+ (center frequency) Duration: 1 to 30 min	Popov et al. 2011b
Bottlenose dolphin (2)	Tones	Frequency: 3 to 80 kHz Duration: 16 s	Finneran and Schlundt 2013
Beluga (2)	Half-octave band noise	Frequency: 11.2, 22.5, 45, and 90 kHz (center frequency) Duration: 1 to 30 min	Popov et al. 2013

* Experiment consisted of intermittent exposures (i.e., three 16 s exposures, separated by 11 and 13 minutes)
\+ Exposures at various half-octave exposures, but only data for 32 kHz is directly presented in Popov et al. 2011b

4.1.2 Low-Frequency Cetaceans

Numeric Exposure Level (Table B14, Cell 12 Table B1a)

Table B14: TTS onset dual acoustic threshold levels for low-frequency cetaceans exposed to underwater non-impulsive sound sources.

Effect	Exposure Level (Received Level)	Reference
TTS onset (Dual acoustic threshold levels: use whichever [dB_{peak} or dB SEL_{cum}] exceeded first)	224 dB_{peak}	Surrogate data (Mid-frequency cetaceans)
	178 dB SEL_{cum}	Surrogate data (Mid-frequency cetaceans)

Direct measurements of hearing for LF cetaceans do not exist, let alone measurements of noise-induced threshold shifts for any of these species. Thus, NOAA has decided to use MF cetaceans as surrogates for LF cetaceans, in terms of establishing TTS onset thresholds (i.e., same TTS onset threshold; Table B6, Scenario A). Mysticetes are believed to have poorer overall sensitivity than other cetacean species due to high background noise levels (especially below 1 kHz) in the frequency range where these species are predicted to hear best (Malme et al. 1989; Ketten 1998; Wartzok and Ketten 1999; Clark and Ellison 2004). NOAA acknowledges that this extrapolation may be conservative, but believes is the appropriate alternative based on currently available data.

This extrapolation is used for all LF cetacean TTS onset thresholds (as well as PTS onset thresholds) and thus, justification is not repeated later within this Appendix. It is important to remember that despite having identical acoustic threshold levels to MF cetaceans, LF cetaceans have a different auditory weighting function.

Exposure Frequency and Duration

There are no data on exposure frequency and duration for LF cetaceans exposed to non-impulsive sound sources. Nevertheless, a LF auditory weighting function has been extrapolated using data for potential auditory capabilities based on vocalization ranges (Ketten 1998) and background sound levels (Clark and Ellison 2004).

4.1.3 High-Frequency Cetaceans

Numeric Exposure Level (Table B15, Cell 16 Table B1a)

Table B15: TTS onset dual acoustic threshold levels for high-frequency cetaceans exposed to underwater non-impulsive sound sources.

Effect	Exposure Level (Received Level)	Reference
TTS onset (Dual acoustic threshold levels: use whichever [dB_{peak} or dB SEL_{cum}] exceeded first)	195 dB_{peak}	Lucke et al. 2009
	160 dB SEL_{cum}	Kastelein et al. 2012b

There have been three published TTS studies (Popov et al. 2011a; Kastelein et al. 2012b; Kastelein et al. 2013c) on HF cetaceans exposed to non-impulsive sounds. The Popov et al. (2011a) study exposed two Yangtze finless porpoise to half-octave band noise, while the

Kastelein et al. (2012b) study exposed a single harbor porpoise to octave-band noise. Kastelein et al. (2013c) exposed a single harbor porpoise to a 1.5 kHz tone.

From Kastelein et al. (2012b), TTS onset[23] occurred at 172 dB SEL_{cum} (unweighted) for exposure to octave-band noise centered at 4 kHz. After applying the appropriate weighting function, this value becomes ~159.7 dB SEL_{cum} (rounded up to 160 dB SEL_{cum}). Thus based on this study, HF cetaceans are thought to have a lower TTS onset compared to MF cetaceans (Table B16).

In Kastelein et al. (2012b), 6 dB of TTS also occurred with exposure to 163 dB SEL_{cum} (unweighted; after weighting ~151 dB SEL_{cum}) based on a 120-minute exposure duration. This exposure duration exceeds our protocol for data analysis (Table B7) because exposure was greater than one hour and is considered unlikely encountered by wild individuals. Thus, this particular data point was not considered within our analysis.

Table B16: TTS onset in high-frequency cetaceans exposed to underwater non-impulsive sound sources.

Individual (species)	Study	Sound Source/Exposure Duration(s)	TTS Onset (unweighted)
ID no. 02 (harbor porpoise)	Kastelein et al. 2012b	Octave-band noise/60 min	160 dB SEL_{cum} (172 dB SEL_{cum})
ID no. 02 (harbor porpoise)	Kastelein et al. 2013c	Tone/60 min	170 dB SEL_{cum} (190 dB SEL_{cum})

Kastelein et al. (2013c) exposed the same harbor porpoise as Kastelein et al. (2012b) to a 1.5 kHz tone for 60 minutes. TTS occurred at 190 dB SEL_{cum} (unweighted). After applying the appropriate weighting function, it becomes 170 dB SEL_{cum}. Thus, this level of TTS is higher than what was derived in Kastelein et al. 2012b (Table B16). However, it should be noted that Kastelein et al. (2013c) reported TTS of 11 and 14 dB (i.e., not onset).

The Popov et al. (2011a) study did not derive TTS onset (for either individual). The lowest level (unweighted) of exposure was 162.5 dB SEL during one trial, with several other trials having exposures at 168 dB SEL (Table B17). As with their TTS study on a beluga, Popov et al. 2011a used a rapid threshold-determination procedure, which may make it difficult to directly compare results to other studies (i.e., Popov et al. 2011a "If the threshold measurement procedure were slower, the early phase of the highest TTS would likely have been missed…."). Nevertheless, the weighted threshold from the Kastelein et al. 2012b data is lower than any of the Popov et al. 2011a trials and is deemed the most appropriate and representative of TTS onset threshold (SEL_{cum} metric) for all HF cetaceans at this time.

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[23] In this document, TTS onset is defined as a threshold shift of 6 dB above baseline. In their study, Kastelein et al. (2012b) defined "significant TTS" as a >2.5 dB threshold shift above baseline. Thus, NOAA is relying on the 6 dB definition to define TTS onset and not the definition used by Kastelein et al. (2012b).

Table B17: **Amount of TTS recorded by Popov et al. 2011a for exposures at unweighted 168 dB SEL and below.***

Individual	Noise Band	Exposure Time	Test Frequency	SEL$_{cum}$ (unweighted)	Amount of TTS
A Bao (♂)	0.5 octave above	1 minute	32 kHz	168 dB SEL$_{cum}$	~8 dB▲
A Bao (♂)	On frequency	1 minute	32 kHz	168 dB SEL$_{cum}$	~5 dB▲
Ying Ying (♀)	On frequency	1 minute	64 kHz	168 dB SEL$_{cum}$	~7.5 dB▲
Ying Ying (♀)	On frequency	1 minute	128 kHz	168 dB SEL$_{cum}$	~10 dB▲
A Bao (♂)	0.5 octave below	1 minute	32 kHz	168 dB SEL$_{cum}$	~27.5 dB▲
Ying Ying (♀)	0.5 octave below	1 minute	64 kHz	168 dB SEL$_{cum}$	~22.5 dB▲
Ying Ying (♀)	0.5 octave below	1 minute	128 kHz	168 dB SEL$_{cum}$	~17.5 dB▲
A Bao (♂)	0.5 octave below	1 minute	45 kHz	163 dB SEL$_{cum}$	~25 dB■
Ying Ying (♀)	1 octave below	1 minute	64 kHz	168 dB SEL$_{cum}$	~12 dB▲
Ying Ying (♀)	1 octave below	1 minute	128 kHz	168 dB SEL$_{cum}$	~7.5 dB▲

* Of the 42 combinations of exposures within Popov et al. 2011a, there are 12 combinations where exposures were at 168 dB SEL and below. Within their publication, Popov et al. 2011a did not provide amounts of TTS recorded for all of these trials.

▲Estimated from Figure 7 in Popov et al. 2011a

■ Estimated from Figure 10 in Popov et al. 2011a

The peak pressure acoustic threshold level derived for impulsive sources for all cetacean functional hearing groups will also be used for non-impulsive sources due to limited available data (see more detailed description below).

Exposure Frequency and Duration

The two studies on HF cetaceans examined effects of frequency and duration of exposure on TTS (Table B18).

Table B18: **Relevant studies and provided in the context of exposure frequency and duration.**

Species (number of individuals)	Sound source	Predominant Frequency and Exposure Duration	Reference
Yangtze finless porpoise (2)	Half-octave band noise	Frequency: 22.5 to 128 kHz (center frequency) Duration: 1 to 30 min	Popov et al. 2011a
Harbor porpoise (1)	Octave-band noise	Frequency: centered at 4 kHz Duration: 7.5, 15, 30, 60, or 120 min	Kastelein et al. 2012b
Harbor porpoise (1)	Tone	Frequency: 1.5 kHz Duration: 60 min	Kastelein et al. 2013c

Kastelein et al. 2012b reported that increasing exposure duration was more effective in elevating the amount of TTS compared to increasing the level, once again showing the EEH does not always hold true.

Kastelein et al. 2013c found that hearing thresholds in the range that this species echolocates (i.e., 125 kHz) was not affected by 1.5 kHz tones. Thus, exposure to lower frequency sounds are highly unlikely to affect this species ability to forage efficiently. However, they caution that there is nothing known about the ecological significance of sounds below 120 kHz for harbor porpoise (e.g., lower frequencies could be used to avoid vessels or predators).

Popov et al. 2011a found that, in general, the lower the frequency range of exposure (i.e., 32 kHz), the larger the amount of TTS. This result was reported as unexpected since this species is more sensitive to higher frequencies (i.e., 45 to 139 kHz). It also took longer for these animals to recover that these lower frequencies. They also reported exposures of higher level and shorter duration resulted in higher levels of TTS compared to exposures of lower level and longer duration, which is contrary to what has been found in other studies (e.g., Kastak et al. 2005; Kastak et al. 2007; Mooney et al. 2009b; Finneran et al. 2010a; Kastelein et al. 2012a; Kastelein et al. 2012b). As more information becomes available, this trend can be further examined.

4.1.4 Phocid Pinnipeds (Underwater)

Numeric Exposure Level (Table B19, Cell 18 Table B1a)

Table B19: TTS onset dual acoustic threshold levels for underwater phocid pinnipeds exposed to non-impulsive sound sources.

Effect	Exposure Level (Received Level)	Reference
TTS onset (Dual acoustic threshold levels: use whichever [dB$_{peak}$ or dB SEL$_{cum}$] exceeded first)	229 dB$_{peak}$	Extrapolation based on protocol from Southall et al. 2007
	183 dB SEL$_{cum}$	Kastak et al. 2005

Data are only available from two species (harbor seal, northern elephant seal) from the Kastak et al. (2005) and one species (harbor seal) from the Kastelein et al. (2012a) and Kastak et al. (2005) studies (Table B20). From Kastak et al. (2005), TTS onset was determined directly using these data, as well as fitting the data to an equation by Maslen (1981). For the harbor seal, TTS onset was determined to be 183 dB SEL$_{cum}$ and for the Northern elephant seal, it was approximated at 204 dB SEL$_{cum}$. From the Kastelein et al. 2012a study, TTS onset[24] was at ~184 SEL$_{cum}$.

Table B20: TTS onset in phocid pinnipeds exposed to underwater non-impulsive sound sources.

Individual (species)	Study	Sound Source/Exposure Duration(s)	TTS Onset (unweighted)
Burnyce (Northern elephant seal)	Kastak et al. 2005	Octave-band noise/22, 25, & 50 min	204 dB SEL$_{cum}$
Sprouts (harbor seal)	Kastak et al. 2005	Octave-band noise/22, 25, & 50 min	183 dB SEL$_{cum}$
ID no. 01 (harbor seal)	Kastelein et al. 2012a	Octave band noise/60 min	~184 dB SEL$_{cum}$

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[24] In this document, TTS onset is defined as a threshold shift of 6 dB above baseline. In their study, Kastelein et al. (2012b) defined "significant TTS" as a >2.5 dB threshold shift above baseline (where TTS onset occurs at ~170 dB SEL$_{cum}$). NOAA is choosing the 6 dB definition to define TTS onset and not the definition used by Kastelein et al. (2012a).

Based on our protocol (Table B7), the species (harbor seal) with the lowest TTS onset threshold is used to represent TTS onset in all phocid pinniped species exposed to underwater non-impulsive sound sources. Thus, 183 dB SEL_{cum} is the TTS onset for the entire phocid group.

The peak pressure acoustic threshold level derived for impulsive sources for pinnipeds is being used for non-impulsive sources due to limited available data (see more detailed description below).

In Kastelein et al. (2012a), 8.1 dB of TTS occurred with exposure at ~175 dB SEL_{cum} and 8 dB of TTS occurred with exposure at ~178 dB SEL_{cum}. The exposure durations associated with both these threshold shifts were longer than one hour (i.e., 120 and 240 minutes). They are considered exposure durations unlikely encountered by wild individuals, and thus, the data points are excluded from further analysis.

Kastelein et al. 2013b unintentionally exposed a harbor seal to 60 minutes of octave-band noise (centered at 4 kHz) at mean levels of 163 dB (SEL_{cum} of ~199 dB). This exposure resulted in TTS of 44 dB, which took four days for complete recovery. From this study, Kastelein et al. (2013b) suggested a critical level (i.e., above which TTS increased rapidly with increasing SPLs) between 186 to 196 dB $SEL_{cum.}$ NOAA did not directly apply these critical levels in its updated PTS onset acoustic threshold level, but it should be noted that our PTS onset level is lower than Kastelein et al. 2013b, which resulted in complete recovery.

Exposure Duration and Frequency (Table B21)

The four available studies consisted of vary similar exposure frequencies and durations. However, longer duration exposures (i.e., 50 min) from Kastak et al. (2005) resulted in TTS onset compared to shorter duration exposures (i.e., 22 to 25 min), with the same trend seen in Kastelein et al. (2012a) and Kastelein et al. (2013b). However, these longer duration exposures also resulted in a higher SEL_{cum}. Thus, effects of duration cannot be determined. Kastelein et al. (2012a) found that duration played a greater factor in the amount of TTS induced compared to level, which is a similar trend reported in other studies (e.g., Mooney et al. 2009a).

Table B21: Relevant studies and provided in the context of exposure frequency and duration.

Species (number of individuals)	Sound source	Predominant Frequency and Exposure Duration	Reference
Harbor seal (1); Northern elephant seal (1)	Octave-band noise	Frequency: Centered at 0.1, 0.5, 1, or 2 kHz Duration: 20 to 22 min	Kastak et al. 1999
Harbor seal (1); Northern elephant seal (1)	Octave-band noise	Frequency: Centered at 2.5 kHz Duration: 22, 25, or 50 min	Kastak et al. 2005
Harbor seal (2)	Octave-band noise	Frequency: centered at 4 kHz Duration: 7.5, 15, 30, 60, 120, or 240 min	Kastelein et al. 2012a; Kastelein et al. 2013b

4.1.5 Otariid Pinnipeds (Underwater)

Numeric Exposure Level (Table B22, Cell 20 Table B1a)

Table B22: TTS onset dual acoustic threshold levels for underwater otariid pinnipeds exposed to non-impulsive sound sources.

Effect	Exposure Level (Received Level)	Reference
TTS onset (Dual acoustic threshold levels: use whichever [dB_{peak} or dB SEL_{cum}] exceeded first)	229 dB_{peak}	Extrapolation from phocid pinnipeds as surrogate
	206 dB SEL_{cum}	Kastak et al. 2005

Data are only available from one individual of one species (i.e., California sea lion) from the Kastak et al. (2005) study. For the California sea lion onset of TTS (206 dB SEL_{cum}) was determined directly using these data, as well as fitting the data to an equation by Maslen (1981). NOAA recommends using 206 dB SEL_{cum} for all otariid pinnipeds.

The peak pressure acoustic threshold level derived for impulsive sources for pinnipeds will also be used for non-impulsive sources due to limited available data (see more detailed description below).

Exposure Duration and Frequency (Table B23)

The Kastak et al. (1999) and Kastak et al. (2005) studies consisted of vary similar exposure frequencies and durations. However, longer duration exposures (i.e., 50 min) from Kastak et al. (2005) resulted in more TTS compared to shorter duration exposures (i.e., 22 to 25 min). From these limited data, the effects of duration cannot be determined.

Table B23: Relevant studies and provided in the context of exposure frequency and duration.

Species (number of individuals)	Sound source	Predominant Frequency and Exposure Duration	Reference
California sea lion (1)	Octave-band noise	Frequency: Centered at 0.1, 0.5, 1, or 2 kHz Duration: 20 to 22 min	Kastak et al. 1999
California sea lion (1)	Octave-band noise	Frequency: Centered at 2.5 kHz Duration: 22 to 50 min	Kastak et al. 2005

4.2 Temporary Threshold Shifts: Impulsive Sources

4.2.1 Mid-Frequency and Low-Frequency Cetaceans

Numeric Exposure Level (Table B24, Cells 11 & 13 Table B1a)

Table B24: **TTS onset dual acoustic threshold levels for mid-frequency and low-frequency cetaceans exposed to underwater impulsive sound sources.**

Effect	Exposure Level (Received Level)	Reference
TTS onset (Dual acoustic threshold levels: use whichever [dB_{peak} or dB SEL_{cum}] exceeded first)	224 dB_{peak}	Finneran et al. 2002
	172 dB SEL_{cum}	Finneran et al. 2002

Between the two studies on MF cetaceans exposed to an impulsive sound source (Finneran et al. 2000; Finneran et al. 2002), there was only one incidence where TTS above 6 dB was recorded (Finneran et al. 2002). This was for an individual beluga exposed to a single pulse of a seismic watergun at the unweighted level of 186 dB SEL_{cum} and 23.2 dB pounds per square inch (psi; approximately 224 dB_{peak}). When the weighting function for MF cetaceans is applied, the SEL_{cum} acoustic threshold level becomes 172 dB SEL_{cum}.

Since these are the only data that exist for MF cetaceans, NOAA adopts these thresholds as our dual acoustic threshold levels for TTS onset for both LF (since no data exist) and MF cetaceans. Consequently, since the 224 dB_{peak} is the only data point available for the peak pressure metric, it will be used for all cetacean species, except HF cetaceans (see below), and for all sound sources (i.e. impulsive and non-impulsive sounds).

NOAA is aware that studies are currently underway to understand TTS associated with exposure to multiple airgun shots in bottlenose dolphins (SPAWAR study[25]). These data will be critical in informing future acoustic threshold levels for impulsive sources, once they become available.

Exposure Frequency and Duration (Table B25)

Based upon the two studies available for consideration by NOAA, the band of exposure frequencies was fairly similar, and despite differences in exposure duration, only one incidence resulted in TTS above 6 dB. This was for a beluga exposed to a 6.3 msec seismic watergun pulse.

Table B25: **Relevant studies and provided in the context of exposure frequency and duration.**

Species (number of individuals)	Sound source	Predominant Frequency and Exposure Duration	Reference
Bottlenose dolphin (2); Beluga (1)	Explosion simulator	Frequency: Broadband up to 40 kHz (most energy between 1-10 kHz) Duration: 5.1 to 13 msec	Finneran et al. 2000
Bottlenose dolphin (1); Beluga (1)	Seismic watergun	Frequency: Broadband up to 40 kHz (most energy below between 1 kHz) Duration: ~6.3 to 73 msec	Finneran et al. 2002

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[25] http://www.soundandmarinelife.org/

4.2.2 High-Frequency Cetaceans

Numeric Exposure Level (Table B26, Cell 15 Table B1a)

Table B26: TTS onset dual acoustic threshold levels for high-frequency cetaceans exposed to underwater impulsive sound sources.

Effect	Exposure Level (Received Level)	Reference
TTS onset (Dual acoustic threshold levels: use whichever [dB_{peak} or dB SEL_{cum}] exceeded first)	195 dB_{peak}	Lucke et al. 2009
	146 dB SEL_{cum}	Lucke et al. 2009

Lucke et al. (2009) provided the first TTS study for a HF cetacean (i.e., a single harbor porpoise exposed to single airgun pulses). This study approximates TTS onset to occur at 164.3 dB SEL_{cum} flat-weighted and 199.7 $dB_{peak\text{-}peak}$ ($dB_{p\text{-}p}$), which is ~195 dB_{peak} (personal communication Lucke 2009[26]). Applying HF cetacean weighting functions to these data result in a TTS onset of 146 dB SEL_{cum}. SEAMARCO 2011 presented preliminary data for a harbor porpoise exposed to playbacks of impact pile driving[27], but at an unweighted level of 158 dB SEL_{cum} (highest level that could be produced without distortion), no TTS was measured.

Given these limited data, NOAA has decided to recommend 146 dB SEL_{cum} and 195 dB_{peak} as our dual acoustic threshold levels for TTS onset for all members of the HF cetacean hearing group. The 195 dB_{peak} acoustic threshold level is also used as the peak pressure acoustic threshold level for HF cetaceans exposed to non-impulsive sounds.

Exposure Frequency and Duration (Table B27)

Data are limited for one species from two separate studies. Thus, the effects of exposure frequency and duration on TTS cannot not be determined.

Table B27: Relevant studies and provided in the context of exposure frequency and duration.

Species (number of individuals)	Sound source	Predominant Frequency and Exposure Duration	Reference
Harbor porpoise (1)	Single airgun	Frequency: Broadband up to 20 kHz (most energy below 500 Hz) Duration: Less than 50 msec	Lucke et al. 2009
Harbor porpoise (1)	Impact piled driving	Frequency: peak 630 Hz, most energy between 0.4 to 5 kHz Duration: 120 min	SEAMARCO 2011

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[26] Klaus Lucke, directly, provided the dB_{peak} equivalent for the $dB_{peak\text{-}peak}$ threshold, which was not included in Lucke et al. 2009.

[27] Playbacks not entirely representative of actual pile strikes.

4.2.3 Phocid Pinnipeds (Underwater)

Numeric Exposure Level (Table B28; Cell 17 Table B1a)

Table B28: TTS onset dual acoustic threshold levels for underwater phocid pinnipeds exposed to impulsive sound sources.

Effect	Exposure Level (Received Level)	Reference
TTS onset (Dual acoustic threshold levels: use whichever [dB_{peak} or dB SEL_{cum}] exceeded first)	229 dB_{peak}	Extrapolation based on protocol from Southall et al. 2007
	177 dB SEL_{cum}	Extrapolation based on protocol from Southall et al. 2007

Few studies examining pinniped TTS after exposure to impulsive sources have been conducted. Preliminary data from Kastelein et al. (2013a) indicate that exposing two harbor seals to impact pile driving recordings[28] up to 183 dB SEL_{cum} (unweighted) did not cause measurable TTS. Thus, there are no datasets available to use to derive TTS onset acoustic threshold levels for phocid pinnipeds exposed to impulsive sound sources. When Southall et al. (2007) developed scientific recommendations for marine mammal acoustic threshold levels, they encountered the same situation and derived a means for estimating an exposure level from available datasets.

Southall et la. 2007's approach assumes the known pinniped-to cetacean difference in TTS-onset upon exposure to non-impulsive sounds would also apply (in a relative sense) to impulsive sounds. Specifically, with non-impulsive sounds, harbor seals experience TTS-onset at approximately 5 dB higher received levels than do bottlenose dolphins (i.e., 183 dB SEL_{cum} versus 178 dB SEL_{cum}). Assuming that this difference for non-impulsive sounds exists for pulses as well, TTS-onset in phocids exposed to single underwater pulses is estimated to occur at a peak pressure of 229 dB_{peak} and/or 177 dB SEL_{cum}. Each of these metrics is 5 dB more than the comparable value for MF cetaceans. The dB SEL_{cum} acoustic threshold level is probably a bit lower than the actual onset because Kastelein et al. (2013a) did not record any incidents of TTS at RL of 183 dB SEL_{cum}. As more data become available, this acoustic threshold level may be modified (i.e., based on actual data versus using a protocol to derive acoustic threshold levels).

Exposure Frequency and Duration (Table B29)

As mentioned above, there has only been one study exposing phocid pinnipeds to an impulsive source and TTS was not induced. Nevertheless, information on the duration and frequencies associated with these exposures is presented below.

Table B29: Relevant studies and provided in the context of exposure frequency and duration.

Species (number of individuals)	Sound source	Predominant Frequency and Exposure Duration	Reference
Harbor seal (2)	Impact pile driving	Frequency: 630 Hz peak (most energy between 0.4 to 5 kHz) Duration: 120 min	Kastelein et al. 2013a

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[28] Playbacks are not completely representative of actual pile strikes.

4.2.4 Otariid Pinnipeds (Underwater)

Numeric Acoustic threshold Level (Table B30; Cell 19 Table B1a)

Table B30: TTS onset dual acoustic threshold levels for underwater otariid pinnipeds exposed to impulsive sound sources.

Effect	Exposure Level (Received Level)	Reference
TTS onset (Dual acoustic threshold levels: use whichever [dB_{peak} or dB SEL_{cum}] exceeded first)	229 dB_{peak}	Extrapolation from phocid pinnipeds as surrogate
	200 dB SEL_{cum}	Extrapolation based on protocol from Southall et al. 2007

Finneran et al. (2003) exposed two California sea lions to an arc-gap transducer, and despite exposures with SEL_{cum} as high 163 dB SEL_{cum} (unweighted), TTS was not induced.

Similar to phocid pinnipeds, there are not enough data to derive directly TTS onset acoustic threshold levels for impulsive sources for otariid pinnipeds. Thus, the same protocol (Southall et al. 2007) was used to derive phocid acoustic threshold levels. This protocol results in a 200 dB SEL_{cum} TTS onset acoustic threshold level for otariid pinnipeds (i.e., 28 dB difference between California sea lion and bottlenose dolphin TTS onset acoustic threshold levels for non-impulsive sound sources).

If this same protocol were applied to derive the peak pressure acoustic threshold levels, this would result in an unrealistically high onset level (i.e., 252 dB_{peak}). Thus, instead of using the acoustic threshold level derived from the protocol in Southall et al. 2007, NOAA recommends using the peak pressure acoustic threshold level derived for phocid pinnipeds (i.e., 229 dB_{peak}) until more data become available.

Exposure Frequency and Duration (Table B31)

As mentioned above, there has only been one study exposing otariid pinnipeds to an impulsive source, and TTS was not induced. Nevertheless, information on the duration and frequencies associated with these exposures is presented below.

Table B31: Relevant studies and provided in the context of exposure frequency and duration.

Species (number of individuals)	Sound source	Predominant Frequency and Exposure Duration	Reference
California sea lion (2)	Arc-gap transducer	Frequency: 0.1 to 40 kHz (most energy below 1 kHz) Duration: 10.5 to 28.3 msec	Finneran et al. 2003

4.3 Permanent Threshold Shifts: Non-Impulsive Sources

PTS has only been induced (unintentionally) experimentally in a single marine mammal once (7-10 dB shift over 12 months). However, these data are currently not peer reviewed (i.e., abstract, (Kastak et al. 2008; memorandum to NMFS, Reichmuth 2008) and cannot be used because they cannot be validated and verified. There are no plans for future PTS studies on marine mammals for ethical reasons. Thus, determining PTS onset in marine mammals can only be produced via extrapolations based on hearing loss growth rates (i.e., rate of how quickly threshold shifts grow in relation to increases in decibel level; expressed in dB of TTS/dB of noise) from limited marine mammal TTS studies and more numerous terrestrial mammal TTS/PTS experiments. Typically, the magnitude of a threshold shift increases with increasing duration or level of exposure, until it becomes asymptotic (growth rate begins to level or the upper limit of TTS; Mills et al. 1979; Clark et al. 1987; Laroche et al. 1989; Yost 2007).

NOAA acknowledges this is a simplistic approach for estimating PTS onset. However, it should be noted that for many of the proposed PTS onset levels, marine mammals have experimentally been exposed to these levels and yet recovered, often within 24 h or less (e.g., Kastak et al. 2005; Nachtigall et al. 2003; Nachtigall et al. 2004; Finneran et al. 2010a ; Popov et al. 2011; the exception is Finneran et al. 2007 that saw recovery within four days after exposure).

4.3.1 All Cetaceans

Numeric Acoustic threshold Level (Table B32, Cells 2, 4, & 6 Table B1a)

Table B32: PTS onset dual acoustic threshold levels for cetaceans exposed to underwater non-impulsive sound sources.

Effect	Exposure Level (Received Level)	Reference
PTS onset (Dual acoustic threshold levels: use whichever [dB_{peak} or dB SEL_{cum}] exceeded first)	**Mid-frequency and Low-frequency Cetaceans**	
	230 dB_{peak}	6 dB addition to TTS level
	198 dB SEL_{cum}	20 dB addition to TTS level
	High-frequency Cetaceans	
	201 dB_{peak}	6 dB addition to TTS level
	180 dB SEL_{cum}	20 dB addition to TTS level

For cetaceans, there are limited data on noise-induced hearing loss growth rates. Data only exist for the bottlenose dolphin, specifically three individuals exposed to non-impulsive sound sources (Finneran et al. 2005a; Schlundt et al. 2006 cited in Southall et al. 2007; Finneran and Schlundt 2010; Finneran and Schlundt 2013), and for the Yangtze finless porpoise, specifically two individuals exposed to half-octave band noise (Popov et al. 2011a). Growth rates for the bottlenose dolphin varied from 0.4 to 1.0 dB of TTS/dB of noise, while Yangtze finless porpoise had reported growth rates ranging from 0.38 to 0.95 dB of TTS/dB of noise. These limited data are primarily from marine mammal experiments designed to produce only small amounts of TTS. Thus, they are not necessarily appropriate for determining rates for larger thresholds shifts, like those associated with PTS. Finneran et al. (2005) explained that “It was likely that the observed growth rate would increase if larger SEL_{cum} (and thus larger amounts of TTS were employed). Experiments producing larger amounts of TTS are necessary to estimate the growth rate of TTS beyond the range of the TTS amounts experimentally observed.”

Recent studies have provided more data on hearing loss growth rates in bottlenose dolphins and factors that influence growth rates in Yangtze finless porpoise. First, Finneran et al. (2010a) reported a growth rate of 0.7 dB/dB of noise for data from four individuals, one individual experiencing as much as 23 dB of TTS. A second study by Finneran and Schlundt (2010) reported that growth rates were frequency dependent (i.e., for 3 kHz exposures rates varied from 0.21 to 0.27 dB of TTS/dB of noise and for 20 kHz exposures the rate was 1.2 dB of TTS/dB of noise). Finneran and Schlundt's most recent study (2013), examined growth rates associated with different frequencies of exposure, with most ranging from 0.2 to 0.5 dB of TTS/dB noise, except at three frequencies with higher growth rates (i.e., 14.1 kHz, 20 kHz with rates ~1 dB of TTS/dB noise and 28.3 kHz with a rate of ~4.5 dB TTS/dB noise). Finally, Popov et al. (2011a) recently reported that growth rates for Yangtze finless porpoise varied depending on duration (0.38-0.58 dB of TTS/dB of noise) and overall exposure level (0.92-0.95 dB of TTS/dB of noise). NOAA recommends current cetacean growth rates be considered with caution and have thus relied on better established growth rates from terrestrial mammals for estimating PTS onset levels.

TTS growth rates data for terrestrial mammals exposed to non-impulsive sound sources are more extensive and include data on larger amounts of TTS. It is assumed that the general mechanisms of the mammalian cochlea should be conserved (i.e., mammalian cochlea is similar) between marine and terrestrial mammals (Wartzok and Ketten, 1999; Ketten 2000). Thus, using terrestrial mammals as surrogates for marine mammals is appropriate. Mills et al. (1979) summarize many of the terrestrial mammal non-impulsive growth rates, which typically vary from 1.4 to 2.0 dB of TTS/dB of noise. Although, consistently, a growth rate between 1.6 and 1.7 dB of TTS/dB of noise has been documented in humans (e.g., Ward et al. 1958; Ward et al. 1959; Melnick 1977; Mills et al. 1979; Mills et al. 1981; Quaranta et al. 1998), chinchillas (e.g., Carder and Miller 1972; Clark 1991), and monkeys (summarized in Mills et al. 1979).

NOAA has decided to use the well-documented 1.7 dB of TTS/dB of noise growth rate for all cetacean species, in terms of the SEL_{cum} metric, until more marine mammal data become available (same growth rate recommended by Southall et al. 2007). This results in a 20 dB difference between TTS and PTS onset for non-impulsive sources (Table 1A).

40 dB TS [PTS onset] – 6 dB TS [TTS onset] / [1.7 dB of TTS/dB of noise exposure] = 20 dB

NOAA's chosen terrestrial mammal hearing loss growth rates are generally more conservative (i.e., results in PTS onset occurring at a lower SEL_{cum}) than those previously measured in bottlenose dolphins (e.g., marine mammal data would result in a 28 dB+ difference between TTS and PTS, pushing PTS onset to unrealistically high levels). The only marine mammal data that contradicts the terrestrial mammal growth rate data is from Finneran and Schlundt (2013) who recorded a growth rate of ~4.5 dB of TTS/dB noise for a single bottlenose dolphin exposed to a 28.3 kHz tone (all other growth rates in this study were 1 dB of TTS/dB of noise or less). Recovery for the animal exposed to this tone was also delayed compared to other frequencies tested. Finneran and Schlundt (2013) attribute these result to exposures possibly exceeding the critical level (i.e., where damage switches from being primarily metabolic to more mechanical) at this frequency. Having data from another individual at this exposure frequency would inform the trend observed in this particular individual. Until that time, NOAA will use the more supported terrestrial mammal growth rate.

The rationale for establishing growth rates for thresholds expressed in the peak pressure metric are described later and are identical between non-impulsive and impulsive sound sources.

4.3.2 Underwater Pinnipeds

Numeric Exposure Level (Table B33; Cells 8 & 10 Table B1a)

Table B33: PTS onset dual acoustic threshold levels for underwater pinnipeds exposed to non-impulsive sound sources.

Effect	Exposure Level (Received Level)	Reference
PTS onset (Dual acoustic threshold levels: use whichever [dB_{peak} or dB SEL_{cum}] exceeded first)	**Phocid Pinnipeds**	
	235 dB_{peak}	6 dB addition to TTS level
	197 dB SEL_{cum}	14 dB addition to TTS level
	Otariid Pinnipeds	
	235 dB_{peak}	Extrapolation from phocid pinnipeds as surrogate
	220 dB SEL_{cum}	14 dB addition to TTS level

The current pinniped noise-induced hearing loss growth rate data are limited to a single California sea lion exposed to a non-impulsive aerial anthropogenic sound source. Kastak et al. (2007) reported a growth rate of 2.5 dB of TTS/dB of noise (maximum mean TTS of 23.5 dB) and indicated, “Because of more efficient testing procedures in air, we believe that aerial data can be used as an alternative for predicting the effects of underwater exposure.”

NOAA has decided to adopt this more conservative hearing loss growth rate (results in 6 dB lower TTS onset acoustic threshold level) for all pinnipeds underwater, as opposed to relying on the well-established terrestrial mammal growth rate used for cetacean growth rates (see previous section). Using the pinniped growth rate results in a 13.6 dB (round it up to 14 dB) difference between TTS and PTS onset (Table 1a):

40 dB TS [PTS onset] – 6 dB TS [TTS onset] / [2.5 dB of TTS/dB of noise exposure] = 13.6 dB

The rationale for establishing hearing loss growth rates for acoustic threshold levels expressed in the peak pressure metric are described later and are identical between non-impulsive and impulsive sound sources.

4.4 Permanent Threshold Shifts: Impulsive Sources

4.4.1 All Cetaceans and Underwater Pinnipeds

Numeric Exposure Level (Table B34; Cells 1, 3, 5, 7, & 9 Table B1a)

Table B34: PTS onset dual acoustic threshold levels for cetaceans and pinnipeds exposed to underwater impulsive sound sources.

Effect	Exposure Level (Received Level)	Reference
PTS onset (Dual acoustic threshold levels: use whichever [dB_{peak} or dB SEL_{cum}] exceeded first)	**Mid-frequency and Low-frequency Cetaceans**	
	230 dB_{peak}	6 dB addition to TTS level
	187 dB SEL_{cum}	15 dB addition to TTS level
	High-frequency Cetaceans	
	201 dB_{peak}	6 dB addition to TTS level
	161 dB SEL_{cum}	15 dB addition to TTS level
	Phocid Pinnipeds	
	235 dB_{peak}	6 dB addition to TTS level
	192 dB SEL_{cum}	15 dB addition to TTS level
	Otariid Pinnipeds	
	235 dB_{peak}	Extrapolation from phocid pinnipeds as surrogate
	215 dB SEL_{cum}	15 dB addition to TTS level

Data indicate noise-induced hearing loss growth rates associated with impulsive sources are more variable than for non-impulsive sources and can often depend on whether exposure is above or below a “critical level.” From terrestrial mammal studies, there seems to be a critical level where hearing losses shift from a strictly metabolic to a more mechanical mechanism (Henderson et al. 1994; Henderson et al. 2008). Below the critical level, risk of hearing loss is generally more related to total energy of exposure (i.e., EEH), while above the critical level, risk seems more associated with peak pressure (Clark 1991; Henderson et al. 1990; Humes et al. 2005). Critical level is not a fixed quantity and can vary by species, along with sound source characteristics and exposure parameters (Price 1981; Roberto et al. 1985; Henderson et al. 1994; Harding and Bohne 2004; Henderson et al. 2008). It also is not limited to just impulsive sounds (i.e., extremely high levels of exposure from either impulsive or non-impulsive sounds can create mechanical fatigue), which has recently been demonstrated in Finneran and Schlundt (2013) that found an unusually high growth rate for exposure to a tone at 28.3 kHz. Nevertheless, it demonstrates that predicting hearing loss is complicated.

For impulsive sources, Southall et al. (2007) recommended a growth rate of 2.3 dB of TTS/dB of noise. This rate was somewhere in between previously recorded rates below (range from 0.7 to 1.9 dB of TTS/dB of noise) and above (range from 2.6 to 7 dB of TTS/dB of noise) the critical levels for terrestrial mammals (Henderson and Hamernik 1982; Henderson and Hamernik 1986; Price and Wansack 1989; Levine et al. 1998; Henderson et al. 2008). Southall et al.’s (2007) recommendation resulted in a more conservative acoustic threshold level for PTS onset than choosing a growth rate below the critical level based on terrestrial data. Thus, NOAA accepts the recommendation made by Southall et al. (2007) as guidance for determining PTS onset for impulsive signals for all cetacean and underwater pinniped species, resulting in an approximate 15 dB difference between TTS and PTS onset (Table 1a):

40 dB TS [PTS onset] – 6 dB TS [TTS onset] / [2.3 dB of TTS/dB of noise exposure] = 15 dB

For the peak pressure acoustic threshold level, Southall et al. (2007) recommended a 6 dB of TTS/dB of noise growth rate. This recommendation was based on several factors, including ensuring that the peak pressure acoustic threshold level did not unrealistically exceed the cavitation of water. Using the rationale of Southall et al. (2007), as well as data for hearing loss growth rates above the critical level for terrestrial mammals, NOAA adopts this hearing loss growth rate for determining PTS onset for all cetaceans and underwater pinnipeds and for all sound sources, including non-impulsive sources that could periodically contain a transient component. This growth rate results in a 6 dB difference between TTS and PTS onset (Table 1a):

40 dB TS [PTS onset] – 6 dB TS [TTS onset] / [6 dB of TTS/dB of noise exposure] = 6 dB

APPENDIX C: PEER REVIEW PROCESS

I. PEER REVIEW PROCESS

The Office Management and Budget (OMB 2005) states “Peer review is one of the important procedures used to ensure that the quality of published information meets the standards of the scientific and technical community. It is a form of deliberation involving an exchange of judgments about the appropriateness of methods and the strength of the author’s inferences. Peer review involves the review of a draft product for quality by specialists in the field who were not involved in producing the draft.”

The peer review of this document was conducted in accordance with NOAA’s Information Quality Guidelines[29] (IQG), which were designed for “ensuring and maximizing the quality, objectivity, utility, and integrity of information disseminated by the agency” (with each of these terms defined within the IQG). Furthermore, the IQG stipulate that “To the degree that the agency action is based on science, NOAA will use (a) the best available science and supporting studies (including peer-reviewed science and supporting studies when available), conducted in accordance with sound and objective scientific practices, and (b) data collected by accepted methods or best available methods.” Under the IQG and in consistent with OMB's Final Information Quality Bulletin for Peer Review (OMB Peer Review Bulletin (OMB 2005), our document was considered a Highly Influential Scientific Assessments (HISA)[30], and peer review was required before it could be disseminated by the Federal Government.

OMB (2005) notes “Peer review should not be confused with public comment and other stakeholder processes. The selection of participants in a peer review is based on expertise, with due consideration of independence and conflict of interest.” For the peer review of this document, potential qualified peer reviewers were nominated by a steering committee put together by the Marine Mammal Commission (MMC). The steering committee consisted of MMC Commissioners and members of the Committee of Scientific Advisors (Dr. Daryl Boness, Dr. Douglas Wartzok, and Dr. Sue Moore).

Nominated peer reviewers were those with expertise marine mammalogy, acoustics/bioacoustics, and/or acoustics in the marine environment. Of the ten nominated reviewers, four were selected as peer reviewers to complete an individual review of the document based on area of expertise and availability (Table D1). The focus of the peer review was on the scientific and technical studies that have been applied and the manner that they have been applied in this document.

Table C1: Peer review panel.

Name	Affiliation
Dr. Paul Nachtigall	University of Hawaii
Dr. Doug Nowacek	Duke University
Dr. Klaus Lucke	Wageningen University and Research (The Netherlands)
Dr. Aaron Thode	Scripps Institution of Oceanography

The following website contains updated information on the peer review process including: the charge to peer reviewers, peer reviewers’ names, peer reviewers’ individual reports, and NOAA’s response to peer reviewer reports http://www.nmfs.noaa.gov/pr/acoustics/guidelines.htm

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[29] http://www.cio.noaa.gov/services_programs/IQ_Guidelines_011812.html

[30] “its dissemination could have a potential impact of more than $500 million in any one year on either the public or private sector; or that the dissemination is novel, controversial, or precedent-setting; or that it has significant interagency interest” (OMB 2005).

APPENDIX D: GLOSSARY

Accumulation period: The amount of time a sound accumulates for the SEL_{cum} metric.

Acoustic threshold level : An acoustic threshold in this document identifies the level of sound after which exceeded NOAA anticipates (after evaluating and interpreting all available science) a change in auditory sensitivity (temporary or permanent threshold shift).

Ambient noise: All-encompassing sound at a given place, usually a composite of sound from many sources near and far (ANSI 1994).

Anthropogenic: Originating (caused or produced by) from human activity.

Audible: Heard or capable of being heard.

Audiogram: A graph depicting hearing threshold level as a function of frequency (ANSI 1995; Yost 2007) (Figure D1).

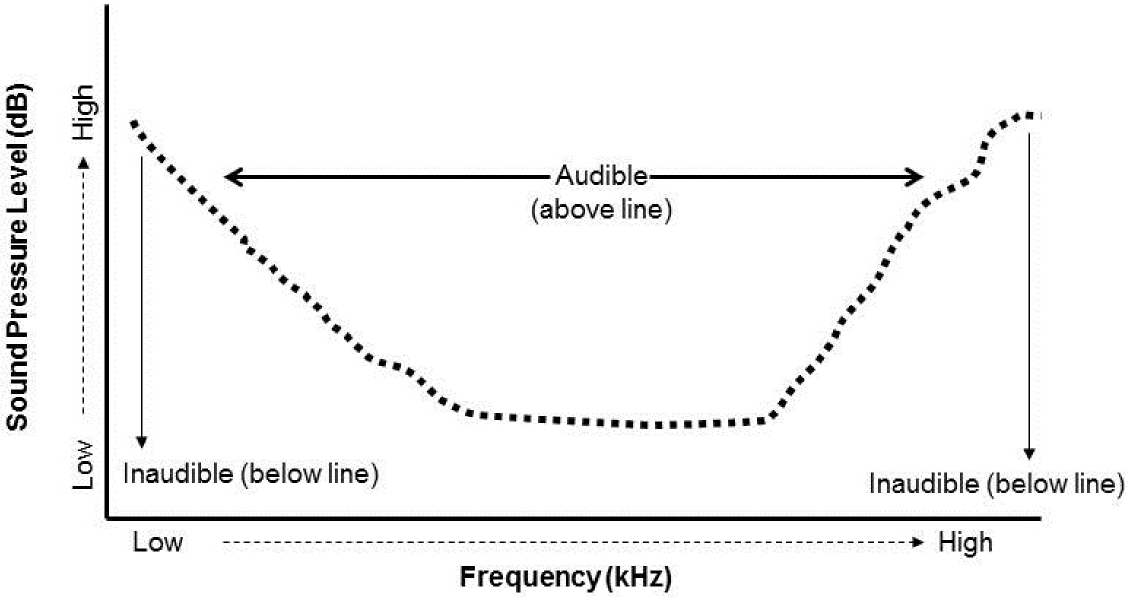

Figure D1. Audiogram.

Auditory bulla: The ear bone in odontocetes that houses the middle ear structure (Perrin et al. 2009).

Auditory weighting function (frequency-weighting function): Auditory weighting functions take into account what is known about marine mammal hearing sensitivity and can be applied to a sound-level measurement to account for frequency-dependent hearing (i.e,. an expression of relative loudness as perceived by the ear) (Southall et al. 2007; Finneran and Jenkins 2012) (see Figures 1-3).

Background noise: Total of all sources of interference in a system used for the production, detection, measurement, or recording of a signal, independent of the presence of the signal (ANSI 1994).

Bandwidth: Bandwidth (Hz or kHz) is the range of frequencies over which a sound occurs (ANSI 2005). Broadband refers to a source that produces sound over a broad range of frequencies (for example, seismic airguns), while narrowband or tonal sources produce sounds over a narrow frequency range (for example, sonar) (ANSI 2005).

Broadband: See “bandwidth”.

Cetacean: Any number of the order Cetacea of aquatic, mostly marine mammals that includes whales, dolphins, porpoises, and related forms; among other attributes they have a long tail that ends in two transverse flukes (Perrin et al. 2009).

Cochlea: Spirally coiled, tapered cavity within the temporal bone, which contains the receptor organs essential to hearing (ANSI 1995). For cetaceans, based on cochlear measurements two cochlea types have been described for echolocating odontocetes (type I and II) and one cochlea type for mysticetes (type M). Cochlea type I is found in species like the harbor porpoise and Amazon river dolphin, which produce high-frequency echolocation signals. Cochlea type II is found in species producing lower frequency echocolation signals (Ketten 1992).

Cognition: Cognition is all stages of information processing from reception by sensory organs to decisions executed by the brain (Dukas 2004).

Continuous sound: A sound whose sound pressure level remains above ambient sound during the observation period (ANSI 2005).

Critical level: The level at which damage switches from being primarily metabolic to more mechanical; e.g., short duration of impulse can be less than the ear’s integration time, leading for the potential to damage beyond level the ear can perceive (Akay 1978).

Cumulative sound exposure level (SEL_{cum}): Level of acoustic energy accumulated over a given period of time or event (EPA 1982) or specifically, ten times the logarithm to the base ten of the ratio of a given time integral of squared instantaneous frequency-weighted sound pressure over a stated time interval or event to the squared reference pressure (ANSI 1994, 1995).

Deafness: A condition caused by a hearing loss that results in the inability to use auditory information effectively for communication or other daily activities (ANSI 1995).

Decibel (dB): One-tenth of a bel. Unit of level when the base of the logarithm is the tenth root of ten, and the quantities concerned are proportional to power (ANSI 1994).

Endangered Species Act (ESA): The Endangered Species Act of 1973 (ESA) (16. U.S.C 1531 et. seq.) provides for the conservation of species that are endangered or threatened throughout all or a significant portion of their range, and the conservation of the ecosystems on which they depend.
NOAA's National Marine Fisheries Service and the U.S. Fish and Wildlife Service (USFWS) share responsibility for implementing the ESA.

Equal Energy Hypothesis (EEH): Assumption that sounds of equal energy produce the equal risk for hearing loss (i.e., if the cumulative energy of two sources are similar, a sound from a lower level source with a longer exposure duration may have similar risks to a shorter duration exposure from a higher level source) (Henderson et al. 1991).

Equal-loudness contour: A curve or curves that show, as a function of frequency, the sound pressure level required to cause a given loudness for a listener having normal hearing, listening to a specified kind of sound in a specified manner (ANSI 1994).

Frequency: The number of periods occurring over a unit of time (unless otherwise stated, cycles per second or Hertz) (Yost 2007).

Functional hearing range: "Functional" refers to the range of frequencies a group hears without incorporating nonacoustic mechanisms (e.g., bone conduction; Wartzok and Ketten 1999). Southall et al. 2007 defined upper and lower limits of the functional hearing range as ~80 dB above most sensitive range. The guidance separates marine mammals under NMFS jurisdiction into five functional hearing groups: low-frequency cetacean, mid-frequency cetacean, high-frequency cetacean, and phocid and otariid pinnipeds.

Harmonic: A sinusoidal quantity that has a frequency which is and integral multiple of the frequency of the periodic quantity to which it is related (ANSI 1994).

Hearing loss growth rates: The rate of threshold shift increase (or growth) as decibel level or exposure duration increase (expressed in dB of temporary threshold shift/dB of noise). Growth rates of threshold shifts are higher for frequencies where hearing is more sensitive (Finneran and Schlundt 2010; Finneran 2011). Typically, the magnitude of a threshold shift increases with increasing duration or level of exposure, until it becomes asymptotic (growth rate begins to level or the upper limit of TTS; Mills et al. 1979; Clark et al. 1987; Laroche et al. 1989; Yost 2007).

Hertz (Hz): Unit of frequency corresponding to the number of cycles per second. One Hertz corresponds to one cycle per second.

High-frequency cetacean: See "functional hearing group".

Impulsive sound: Sound sources that are typically transient, brief (less than 1 second), broadband, and consist of high peak pressure with rapid rise time and rapid decay (ANSI 1986; NIOSH 1998; ANSI 2005). They can occur in repetition or as a single event.

Information Quality Guidelines (IQG): Section 515 of the Treasury and General Government Appropriations Act for Fiscal Year 2001 (Public Law 106-554), directs the Office of Management and Budget (OMB) to issue government-wide guidelines (OMB Guidelines) that "provide policy and procedural guidance to federal agencies for ensuring and maximizing the quality, objectivity, utility, and integrity of information (including statistical information) disseminated by federal agencies." OMB issued guidelines directing each federal agency to issue its own guidelines. NOAA's Information Quality Guidelines can be viewed at: http://www.cio.noaa.gov/services_programs/IQ_Guidelines_011812.html

Integration time (of the ear): In order for a signal to be detected by the ear it must have some critical amount of energy. The process of summing the power to generate the required energy is completed over a particular integration time. If the duration of a signal is less than the integration time required for detection, the power of the signal must be increased in order for it to be detected by the ear (Yost 2007).

Intermittent sound: Interrupted levels of low or no sound (NIOSH 1998) or bursts of sounds separated by silent periods (Richardson and Malme 1993). Typically, intermittent sounds have a more regular (predictable) pattern of bursts of sounds and silent periods (i.e., duty cycle).

Low-frequency cetacean: See "functional hearing group".

Marine Mammal Protection Act (MMPA): The Marine Mammal Protection Act (MMPA) (16. U.S.C. 1361 et. seq.) was enacted on October 21, 1972 and 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. NOAA's National Marine Fisheries Service and the U.S. Fish and Wildlife Service (USFWS) share responsibility for implementing the MMPA.

Masking: Obscuring of sounds of interest by interfering sounds, generally of the similar frequencies (Richardson et al. 1995).

Mid-frequency cetacean: See “functional hearing group”.

Mysticete: The toothless or baleen (whalebone) whales, including the rorquals, gray whale, and right whale; the suborder of whales that includes those that bulk feed and cannot echolocate (Perrin et al. 2009).

Narrowband (NB): See “bandwidth”.

National Marine Sanctuaries Act (NMSA): The National Marine Sanctuaries Act (16 U.S.C. 1431 et. seq.) authorizes the Secretary of Commerce to designate and protect areas of the marine environment with special national significance due to their conservation, recreational, ecological, historical, scientific, cultural, archeological, educational, or esthetic qualities as national marine sanctuaries. Day-to-day management of national marine sanctuaries has been delegated by the Secretary of Commerce to NOAA’s Office of National Marine Sanctuaries.

National Standard 2 (NS2): The Magnuson-Stevens Fishery Conservation and Management Act (MSA) (16 U.S.C. 1801 et. seq.) is the principal law governing marine fisheries in the U.S. and includes ten National Standards to guide fishery conservation and management. One of these standards, referred to as National Standard 2 (NS2), guides scientific integrity and states that “(fishery) conservation and management measures shall be based upon the best scientific information available.”

Non-impulsive sound: Sound sources that are broadband, narrowband or tonal, brief or prolonged, continuous or intermittent, and typically do not have a high peak pressure with rapid rise time (typically only small fluctuations in decibel level) that impulsive signals do (ANSI 1995; NIOSH 1998). Examples of non-impulsive sound sources include: marine vessels, aircraft, machinery operations/construction, certain active sonar (e.g. tactical), and vibratory pile driving.

Octave: The interval between two sounds having a basic frequency ratio of two (Yost 2007). For example, one octave above 400 Hz is 800 Hz. One octave below 400 Hz is 200 Hz.

Odontocete: The toothed whales, including sperm and killer whales, belugas, narwhals, dolphins and porpoises; the suborder of whales including those able to echolocate (Perrin et al. 2009).

Otariid: The eared seals (sea lions and fur seals), which use their foreflippers for propulsion (Perrin et al. 2009).

Peak-to-peak sound pressure level (dB$_{p\text{-}p}$; re: 1 μPa): The absolute difference between the maximum and minimum values of the instantaneous sound pressure (ANSI 1994).

Peak pressure sound pressure level (dB$_{peak}$; re: 1 μPa): The greatest absolute instantaneous sound pressure within a specified time interval (ANSI 1986; ANSI 1994).

Perception: Perception is the translation of environmental signals to neuronal representations (Dukas 2004).

Permanent threshold shift (PTS): A permanent, irreversible increase in the threshold of audibility at a specified frequency or portion of an individual’s hearing range above a previously established reference level. The amount of permanent threshold shift is customarily expressed in decibels (ANSI 1995; Yost 2007). Available data from humans and other terrestrial mammals indicate that a 40 dB threshold shift approximates PTS onset (see Ward et al. 1958, 1959; Ward 1960; Kryter et al. 1966; Miller 1974; Ahroon et al. 1996; Henderson et al. 2008).

Phocid: A family group within the pinnipeds that includes all of the “true” seals (i.e. the “earless” species). Generally used to refer to all recent pinnipeds that are more closely related to *Phoca* than to otariids or the walrus (Perrin et al. 2009).

Pinniped: Seals, sea lions and fur seals (Perrin et al. 2009).

Received Level (RL): The level of sound measured at the receiver.

Reference pressure: See sound pressure level.

Rise time: The time interval a signal takes to rise from 10% to 90% of its highest peak (ANSI 1986; ANSI 1994).

Root-mean-square sound pressure level (dB_{rms}; re: 1 µPa): The square root of the average of the square of the pressure of the sound signal over a given duration (ANSI 1986; ANSI 1994).

Sensation level (dB): The pressure level of a sound above the hearing threshold for an individual or group of individuals (ANSI 1995; Yost 2007).

Sound Exposure Level (SEL): A measure of sound level that takes into account the duration of the signal. Ten times the logarithm to the base 10 of the ration of a given time integral of squared instantaneous frequency-weighted sound pressure over a stated time interval or event to the product of the squared reference sound pressure (1 µPa in water) and reference duration of one second (ANSI 1994)

Sound Pressure Level (SPL): A measure of sound level that represents only the pressure component of sound. Ten times the logarithm to the base 10 of the ratio of time-mean-square pressure of a sound in a stated frequency band to the square of the reference pressure (1 µPa in water). Note that a sound pressure level with reference to a pressure of 1 µPa in water in numerically ≈ 26 decibels greater than the sound pressure level for the same sound pressure with a reference to 20 µPa (reference pressure in gasses) (ANSI 1994).

Source Level (SL): The level of a sound measured at a standard reference distance (1 meter) away from the source (Richardson et al. 1995).

Spatial: Of or relating to space or area.

Spectral/spectrum: Of or relating to frequency component(s) of sound. The spectrum of a function of time is a description of its resolution into components (frequency, amplitude, etc.). The spectrum level of a signal at a particular frequency is the level of that part of the signal contained within a band of unit width and centered at a particular frequency (Yost 2007).

Temporal: Of or relating to time.

Temporary threshold shift (TTS): A temporary, reversible increase in the threshold of audibility at a specified frequency or portion of an individual’s hearing range above a previously established reference level. The amount of temporary threshold shift is customarily expressed in decibels (ANSI 1995, Yost 2007). Based on data from cetacean TTS studies (see Southall et al. 2007 for a review), a TTS of 6 dB is considered the minimum threshold shift clearly larger than any day-to-day or session-to-session variation in a subject’s normal hearing ability (Schlundt et al. 2000; Finneran et al. 2000; Finneran et al. 2002).

Threshold (of audibility): The threshold of audibility (auditory threshold) for a specified signal is the minimum effective sound pressure level of the signal that is capable of evoking an auditory sensation in a specified fraction of trials (either physiological or behavioral) (Yost 2007).

Threshold shift: A change, usually an increase, in the threshold of audibility at a specified frequency or portion of an individual's hearing range above a previously established reference level. The amount of threshold shift is customarily expressed in decibels (ANSI 1995, Yost 2007).

Tone: A sound wave capable of exciting an auditory sensation having pitch. A pure tone is a sound sensation characterized by a single pitch (one frequency). A complex tone is a sound sensation characterized by more than one pitch (more than one frequency) (ANSI 1994).

Transmission (or propagation) loss: Reduction in magnitude of some characteristic of a signal between two stated points in a transmission system (for example the reduction in the magnitude of a signal between a source and a receiver) (ANSI 1994).

Uncertainty: Lack of knowledge about a parameter's true value (Bogen and Spears 1987; Cohen et al. 1996).

Variability: Differences between members of the populations that affects the magnitude of risk to an individual (Bogen and Spears 1987; Cohen et al. 1996; Gedamke et al. 2011).

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