

National Marine Fisheries Service: Summary of Marine Mammal Protection Act Acoustic Thresholds

Marine mammals are considered harassed when exposed to elevated sound levels that may lead to mortality, temporary or permanent hearing impairment (threshold shift), non-auditory physical or physiological effects, and behavioral disturbance. Using the best available science, NMFS has developed acoustic thresholds that identify the received level of underwater sound from explosive and non-explosive sources above which exposed marine mammals would be expected to:

- be behaviorally disturbed or incur a temporary threshold shift (TTS), both of which qualify as Level B harassment under the Marine Mammal Protection Act (MMPA), or
- incur a permanent threshold shift (PTS) of some degree or lung or gastrointestinal (g.i.) tract injury, both of which qualify as Level A harassment.

NMFS has also developed thresholds identifying the received level of in-air sound above which exposed pinnipeds would likely be behaviorally disturbed (Level B harassment under the MMPA). This document serves as a summary of NMFS's current marine mammal acoustic thresholds.

Note: NMFS expects to re-evaluate these thresholds in the near future. The PTS thresholds could be updated as early as late 2022.

SOURCE CHARACTERIZATION (NMFS 2018)

To determine which threshold is appropriate, NMFS characterizes sound sources as impulsive/non-impulsive (PTS/TTS) and intermittent/continuous (behavioral harassment):

- Continuous sound sources: emit sound with a sound pressure level that remains above ambient sound during the entire observation period. Examples of continuous sound sources include drilling and vibratory pile driving.
- Intermittent sound sources: have interrupted levels of low or no sound or bursts of sound separated by silent periods. Typically, intermittent sounds have a more regular (predictable) pattern of bursts of sounds and silent periods (i.e., duty cycle). Examples of intermittent sound sources include scientific sonar, high-resolution geophysical survey equipment (i.e., sub-bottom profilers), and impact pile driving.
- Impulsive sound sources: produce sounds that are typically transient, brief (less than one second), broadband, and consist of high peak sound pressure with rapid rise time and rapid decay. Impulsive sounds can occur in repetition (e.g., seismic airguns, impact pile driving) or as a single event (e.g., explosives).
- Non-impulsive sound sources: can be continuous or intermittent, and produce sounds that

can be broadband, narrowband or tonal, and brief or prolonged. Non-impulsive sources do not have the high peak sound pressure with rapid rise time typical of impulsive sounds. Examples of non-impulsive sources include drilling, vibratory pile driving, and certain active sonars.

MARINE MAMMAL HEARING GROUPS

The application of marine mammal hearing groups occurs in two ways. First, thresholds are designated by hearing group to acknowledge that not all marine mammal species have identical hearing or susceptibility to noise-induced hearing loss. Second, marine mammal hearing groups are used to establish marine mammal auditory weighting functions.

Marine Mammal Hearing Groups (NMFS 2018)

Hearing Group	Generalized Hearing Range*
Low-frequency (LF) cetaceans (baleen whales)	7 Hz to 35 kHz
Mid-frequency (MF) cetaceans (dolphins, toothed whales, beaked whales, bottlenose whales)	150 Hz to 160 kHz
High-frequency (HF) cetaceans (true porpoises, <i>Kogia</i> , river dolphins, Cephalorhynchid, <i>Lagenorhynchus cruciger</i> & <i>L. australis</i>)	275 Hz to 160 kHz
Phocid pinnipeds (PW) (underwater) (true seals)	50 Hz to 86 kHz
Otariid pinnipeds (OW) (underwater) (sea lions and fur seals)	60 Hz to 39 kHz

* Represents the generalized hearing range for the entire group as a composite (i.e., all species within the group), where individual species’ hearing ranges are typically not as broad. Generalized hearing range chosen based on ~65 dB threshold from normalized composite audiogram, with the exception for lower limits for LF cetaceans (Southall et al. 2007) and PW pinniped (approximation).

LEVEL A HARASSMENT

NMFS’s 2018 Revised Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (NOAA Technical Memorandum NMFS-OPR-59) identifies criteria to assess auditory injury or PTS (Level A harassment) to five different marine mammal groups (based on hearing sensitivity) as a result of exposure to sound from impulsive and non-impulsive sources.

Onset of Permanent Threshold Shift (PTS) (NMFS 2018)

Hearing Group	PTS Onset Thresholds*	
	Impulsive	Non-impulsive
Low-Frequency (LF) Cetaceans	<i>Cell 1</i> $L_{p,0-pk,flat}$: 219 dB $L_{E,p,LF,24h}$: 183 dB	<i>Cell 2</i> $L_{E,p,LF,24h}$: 199 dB
Mid-Frequency (MF) Cetaceans	<i>Cell 3</i> $L_{p,0-pk,flat}$: 230 dB $L_{E,p,MF,24h}$: 185 dB	<i>Cell 4</i> $L_{E,p,MF,24h}$: 198 dB
High-Frequency (HF) Cetaceans	<i>Cell 5</i> $L_{p,0-pk,flat}$: 202 dB $L_{E,p,HF,24h}$: 155 dB	<i>Cell 6</i> $L_{E,p,HF,24h}$: 173 dB
Phocid Pinnipeds (PW) (Underwater)	<i>Cell 7</i> $L_{p,0-pk,flat}$: 218 dB $L_{E,p,PW,24h}$: 185 dB	<i>Cell 8</i> $L_{E,p,PW,24h}$: 201 dB
Otariid Pinnipeds (OW) (Underwater)	<i>Cell 9</i> $L_{p,0-pk,flat}$: 232 dB $L_{E,p,OW,24h}$: 203 dB	<i>Cell 10</i> $L_{E,p,OW,24h}$: 199 dB

* Dual metric thresholds for impulsive sounds: Use whichever results in the largest isopleth for calculating PTS onset. If a non-impulsive sound has the potential of exceeding the peak sound pressure level thresholds associated with impulsive sounds, these thresholds are recommended for consideration.

Note: Peak sound pressure level ($L_{p,0-pk}$) has a reference value of 1 μPa , and weighted cumulative sound exposure level ($L_{E,p}$) has a reference value of 1 $\mu\text{Pa}^2\text{s}$. In this Table, thresholds are abbreviated to be more reflective of International Organization for Standardization standards (ISO 2017). The subscript “flat” is being included to indicate peak sound pressure are flat weighted or unweighted within the generalized hearing range of marine mammals (i.e., 7 Hz to 160 kHz). The subscript associated with cumulative sound exposure level thresholds indicates the designated marine mammal auditory weighting function (LF, MF, and HF cetaceans, and PW and OW pinnipeds) and that the recommended accumulation period is 24 hours. The weighted cumulative sound exposure level thresholds could be exceeded in a multitude of ways (i.e., varying exposure levels and durations, duty cycle). When possible, it is valuable for action proponents to indicate the conditions under which these thresholds will be exceeded.

LEVEL B HARASSMENT

NMFS predicts that marine mammals are likely to be behaviorally harassed in a manner that qualifies as Level B harassment when exposed to underwater noise *above* root-mean-square (RMS) received levels of 120 dB re 1 μPa for continuous (e.g., vibratory pile driving, drilling) and 160 dB re 1 μPa for non-explosive, impulsive (e.g., seismic airguns, impact pile driving) or intermittent (e.g., scientific, non-tactical sonar) sources.

Underwater Level B Harassment Acoustic Thresholds (NOAA 2005)

Source type	Threshold
Continuous	$L_{p,RMS,flat}$: 120 dB re 1 μ Pa
Non-explosive impulsive or intermittent	$L_{p,RMS,flat}$: 160 dB re 1 μ Pa

For in-air sounds, NMFS predicts that harbor seals exposed to RMS received levels ≥ 90 dB re 20 μ Pa will be behaviorally harassed, and other pinnipeds will be harassed when exposed to RMS received levels ≥ 100 dB re 20 μ Pa.

In-Air Level B Harassment Acoustic Thresholds (Southall et al. 2007; NOAA 2009)

Species/Group	Threshold*
Harbor seal	$L_{p,RMS,flat}$: 90 dB re 20 μ Pa
All other pinnipeds	$L_{p,RMS,flat}$: 100 dB re 20 μ Pa

* A cumulative sound exposure level threshold of 100 dB re 20 μ Pa (DoN 2017) has been used for Navy military readiness activities. NMFS is currently in the process of re-evaluating the Navy's threshold.

Note: Sound levels underwater (re: 1 μ Pa) have a different reference pressure compared to in-air sounds (re: 20 μ Pa). Thus, it is not appropriate to compare sound levels in-air to those underwater.

UNDERWATER EXPLOSIVES

NMFS uses the acoustic and pressure thresholds below to predict the onset of behavioral harassment and TTS as well as PTS, tissue damage (i.e., lung and g.i. tract), and mortality from the use of underwater explosives.

Note: For a single detonation (within a 24-h period), NMFS relies on the TTS onset threshold to assess Level B harassment. For multiple detonations (within a 24-h period), NMFS relies on a behavioral thresholds that is -5 dB from TTS onset (see Table below).

PTS Onset, TTS Onset, and Behavioral Thresholds (Multiple Detonations) for Underwater Explosives (NMFS 2018)

Hearing Group	PTS Impulsive Thresholds	TTS Impulsive Thresholds	Behavioral Threshold (multiple detonations)
Low-Frequency (LF) Cetaceans	<i>Cell 1</i> $L_{p,0-pk,flat}$: 219 dB $L_{E,LF,24h}$: 183 dB	<i>Cell 2</i> $L_{p,0-pk,flat}$: 213 dB $L_{E,LF,24h}$: 168 dB	<i>Cell 3</i> $L_{E,LF,24h}$: 163 dB
Mid-Frequency (MF) Cetaceans	<i>Cell 4</i> $L_{p,0-pk,flat}$: 230 dB $L_{E,MF,24h}$: 185 dB	<i>Cell 5</i> $L_{p,0-pk,flat}$: 224 dB $L_{E,MF,24h}$: 170 dB	<i>Cell 6</i> $L_{E,MF,24h}$: 165 dB
High-Frequency (HF) Cetaceans	<i>Cell 7</i> $L_{p,0-pk,flat}$: 202 dB $L_{E,HF,24h}$: 155 dB	<i>Cell 8</i> $L_{p,0-pk,flat}$: 196 dB $L_{E,HF,24h}$: 140 dB	<i>Cell 9</i> $L_{E,HF,24h}$: 135 dB
Phocid Pinnipeds (PW) (Underwater)	<i>Cell 10</i> $L_{p,0-pk,flat}$: 218 dB $L_{E,PW,24h}$: 185 dB	<i>Cell 11</i> $L_{p,0-pk,flat}$: 212 dB $L_{E,PW,24h}$: 170 dB	<i>Cell 12</i> $L_{E,PW,24h}$: 165 dB
Otariid Pinnipeds (OW) (Underwater)	<i>Cell 13</i> $L_{p,0-pk,flat}$: 232 dB $L_{E,OW,24h}$: 203 dB	<i>Cell 14</i> $L_{p,0-pk,flat}$: 226 dB $L_{E,OW,24h}$: 188 dB	<i>Cell 15</i> $L_{E,OW,24h}$: 183 dB

* Dual metric acoustic thresholds for impulsive sounds: Use whichever results in the largest isopleth for calculating PTS/TTS onset.

Note: Peak sound pressure (L_{pk}) has a reference value of 1 μ Pa, and cumulative sound exposure level (L_E) has a reference value of 1 μ Pa²s. In this Table, thresholds are abbreviated to reflect American National Standards Institute standards (ANSI 2013). However, ANSI defines peak sound pressure as incorporating frequency weighting, which is not the intent for this Technical Guidance. Hence, the subscript “flat” is being included to indicate peak sound pressure should be flat weighted or unweighted within the overall marine mammal generalized hearing range. The subscript associated with cumulative sound exposure level thresholds indicates the designated marine mammal auditory weighting function (LF, MF, and HF cetaceans, and PW and OW pinnipeds) and that the recommended accumulation period is 24 hours. The cumulative sound exposure level thresholds could be exceeded in a multitude of ways (i.e., varying exposure levels and durations, duty cycle). When possible, it is valuable for action proponents to indicate the conditions under which these acoustic thresholds will be exceeded.

Lung and G.I. Tract Injury Thresholds (DoN 2017)

Hearing Group	Mortality (Severe lung injury)*	Slight Lung Injury*	G.I. Tract Injury
All Marine Mammals	Cell 1 Modified Goertner model; Equation 1	Cell 2 Modified Goertner model; Equation 2	Cell 3 $L_{p,0-pk,flat}$: 237 dB

* Lung injury (severe and slight) thresholds are dependent on animal mass (Recommendation: Table C.9 from DON 2017 based on adult and/or calf/pup mass by species).

Note: Peak sound pressure (L_{pk}) has a reference value of 1 μ Pa. In this Table, thresholds are abbreviated to reflect American National Standards Institute standards (ANSI 2013). However, ANSI defines peak sound pressure as incorporating frequency weighting, which is not the intent for this Technical Guidance. Hence, the subscript “flat” is being included to indicate peak sound pressure should be flat weighted or unweighted within the overall marine mammal generalized hearing range.

Modified Goertner Equations for severe and slight lung injury (pascal-second)

$$\text{Equation 1: } 103M^{1/3}(1 + D/10.1)^{1/6} \text{ Pa-s}$$

$$\text{Equation 2: } 47.5M^{1/3}(1 + D/10.1)^{1/6} \text{ Pa-s}$$

M animal (adult and/or calf/pup) mass (kg) (Table C.9 in DoN 2017)

D animal depth (meters)

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