National Marine Fisheries Service: Summary of Endangered Species Act Acoustic Thresholds (Marine Mammals, Fishes, and Sea Turtles)

This document summarizes NMFS acoustic thresholds for marine mammals, protected fishes, and sea turtles. These acoustic thresholds use the best available science at the time which they were developed (see references following each section or threshold table).

Note: NMFS expects to re-evaluate these thresholds in the near future.

SOUND SOURCE CHARACTERIZATION (NMFS 2018)

To determine which threshold is appropriate, NMFS characterizes sound sources as impulsive/non-impulsive (permanent and temporary threshold shifts) and intermittent/continuous (behavioral disturbance):

- 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.

- 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.

MARINE MAMMALS

Marine Mammal Hearing Groups (NMFS 2018)

The application of marine mammal hearing groups (based on hearing sensitivity) 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, *Kogia*, river dolphins, Cephalorhynchid, *Lagenorhynchus cruciger* & *L. australis*)	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).

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

PTS Onset for Impulsive and Non-impulsive Sources (NMFS 2018)

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

* Dual metric acoustic 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 should also be considered.

Note: Peak sound pressure (L_{pk}) has a reference value of 1 µPa, and cumulative sound exposure level (L_E) has a reference value of 1µPa²s. In this Table, thresholds are abbreviated to reflect American National Standards Institute standards (ANSI 2013). However, peak sound pressure is defined by ANSI 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 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.

Onset of Temporary Threshold Shift (TTS) (NMFS 2018)

TTS Onset for Impulsive and Non-impulsive Sources (NMFS 2018)

Hearing Group	TTS Onset Acoustic Thresholds (Received Level) for Impulsive Sources*	TTS Onset Acoustic Thresholds (Received Level) for Non-impulsive Sources*
Low-Frequency (LF) Cetaceans	*Cell 1* $L_{pk,flat}$: 213 dB $L_{E,LF,24h}$: 168 dB	*Cell 2* $L_{E,LF,24h}$: 179 dB
Mid-Frequency (MF) Cetaceans	*Cell 3* $L_{pk,flat}$: 224 dB $L_{E,MF,24h}$: 170 dB	*Cell 4* $L_{E,MF,24h}$: 178 dB
High-Frequency (HF) Cetaceans	*Cell 5* $L_{pk,flat}$: 196 dB $L_{E,HF,24h}$: 140 dB	*Cell 6* $L_{E,HF,24h}$: 153 dB
Phocid Pinnipeds (PW) (Underwater)	*Cell 7* $L_{pk,flat}$: 212 dB $L_{E,PW,24h}$: 170 dB	*Cell 8* $L_{E,PW,24h}$: 181 dB
Otariid Pinnipeds (OW) (Underwater)	*Cell 9* $L_{pk,flat}$: 226 dB $L_{E,OW,24h}$: 188 dB	*Cell 10* $L_{E,OW,24h}$: 199 dB

* Dual metric acoustic thresholds for impulsive sounds: Use whichever results in the largest isopleth for calculating TTS onset. If a non-impulsive sound has the potential of exceeding the peak sound pressure level thresholds associated with impulsive sounds, these thresholds should also be considered.

Note: Peak sound pressure (L_{pk}) has a reference value of 1 µPa, and cumulative sound exposure level (L_E) has a reference value of 1µPa²s. In this Table, thresholds are abbreviated to reflect American National Standards Institute standards (ANSI 2013). However, peak sound pressure is defined by ANSI 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 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.

Onset of Behavioral Disturbance

NMFS acoustic thresholds for the onset of behavioral disturbance (underwater and in-air) are determined by the root-mean-square (RMS) received levels.

Underwater Onset of Behavioral Disturbance Acoustic Thresholds (NMFS 2005)

Source type	Threshold (RMS)
Continuous	120 dB re 1 µPa
Non-explosive impulsive or intermittent	160 dB re 1 µPa

In-Air Onset of Behavioral Disturbance Acoustic Thresholds (Southall et al. 2007; NOAA 2009)

Species/Group	Threshold (RMS)*
Harbor seal	90 dB re 20 µPa
All other pinnipeds	100 dB re 20 µPa

*Recent Navy activities involving airborne sources have relied upon a cumulative sound exposure level threshold of 100 dB re 20 µPa (DoN 2017). NMFS is currently in the process of re-evaluating the Navy's threshold.

Note: Sound levels underwater (re: 1 µPa) have a different reference pressure compared to in-air sounds (re: 20 µPa). 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 PTS, TTS, behavioral disturbance, 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. 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 Disturbance Onset (Multiple Detonations) for Underwater Explosives (NMFS 2018)

Hearing Group	PTS Impulsive Thresholds	TTS Impulsive Thresholds	Behavioral Threshold (multiple detonations)
Low-Frequency (LF) Cetaceans	*Cell 1* $L_{pk,flat}$: 219 dB $L_{E,LF,24h}$: 183 dB	*Cell 2* $L_{pk,flat}$: 213 dB $L_{E,LF,24h}$: 168 dB	*Cell 3* $L_{E,LF,24h}$: 163 dB
Mid-Frequency (MF) Cetaceans	*Cell 4* $L_{pk,flat}$: 230 dB $L_{E,MF,24h}$: 185 dB	*Cell 5* $L_{pk,flat}$: 224 dB $L_{E,MF,24h}$: 170 dB	*Cell 6* $L_{E,MF,24h}$: 165 dB
High-Frequency (HF) Cetaceans	*Cell 7* $L_{pk,flat}$: 202 dB $L_{E,HF,24h}$: 155 dB	*Cell 8* $L_{pk,flat}$: 196 dB $L_{E,HF,24h}$: 140 dB	*Cell 9* $L_{E,HF,24h}$: 135 dB
Phocid Pinnipeds (PW) (Underwater)	*Cell 10* $L_{pk,flat}$: 218 dB $L_{E,PW,24h}$: 185 dB	*Cell 11* $L_{pk,flat}$: 212 dB $L_{E,PW,24h}$: 170 dB	*Cell 12* $L_{E,PW,24h}$: 165 dB
Otariid Pinnipeds (OW) (Underwater)	*Cell 13* $L_{pk,flat}$: 232 dB $L_{E,OW,24h}$: 203 dB	*Cell 14* $L_{pk,flat}$: 226 dB $L_{E,OW,24h}$: 188 dB	*Cell 15* $L_{E,OW,24h}$: 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 µPa, and cumulative sound exposure level (L_E) has a reference value of 1µPa²s. In this Table, thresholds are abbreviated to reflect American National Standards Institute standards (ANSI 2013). However, peak sound pressure is defined by ANSI 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 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
	Cell 1	*Cell 2*	*Cell 3*
All Marine Mammals	Modified Goertner model; Equation 1	Modified Goertner model; Equation 2	$L_{pk,0\text{-}pk,flat}$: 237 dB

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

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

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

M **= animal (adult and/or juvenile) mass (kg) (Table C.9 in DoN 2017)**

D **= animal depth (meters)**

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

Note: Peak sound pressure (L_{pk}) has a reference value of 1 µPa. 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.

FISHES

Below are the protected fish acoustic thresholds. Note that NMFS' acoustic thresholds for fishes are for all species of fish and do not distinguish between fishes of different groups (e.g., elasmobranchs or teleosts).

Onset of Physical Injury

Because of limited data, the FHWG relied on data from a variety of surrogate impulsive sources (i.e., explosives: Govoni et al. 2003; Govoni et al. 2007; Hastings et al. 2007; Yelverton et al. 1975; seismic airguns: Popper et al. 2005; Song et al. 2008; See Stadler and Woodbury 2009 for more information) to derive dual interim thresholds for impact pile driving that account for vulnerability depending on fish size. These thresholds are appropriate for other non-explosive impulsive sources.

Onset of Physical Injury[1] for Impulsive Sources for Fishes (FHWG 2008)

	Onset of Physical Injury (Received Level)
Fish Size	**Impulsive**
Fishes ≥ 2 g	*Cell 1* $L_{p,0\text{-pk,flat}}$: 206 dB $L_{E,p,12h}$: 187 dB
Fishes < 2 g	*Cell 2* $L_{p,0\text{-pk,flat}}$: 206 dB $L_{E,p,12h}$: 183 dB

Onset of Mortality and Physical Injury for Underwater Explosives for Fishes (FHWG 2008; Popper et al. 2014)

Onset of Mortality (Received Level)	**Onset of Physical Injury (Received Level)**
Cell 1 $L_{p,0\text{-pk,flat}}$: 229 dB	*Cell 2* $L_{p,0\text{-pk,flat}}$: 206 dB $L_{E,p,12h}$: 187 dB (≥ 2 g) $L_{E,p,12h}$: 183 dB (< 2 g)

Onset of Behavioral Disturbance

While this is not a "formal" threshold, it allows us to have a level where one can begin to look at potential responses.

[1] For fishes, generally, the accumulation period can be reset to zero after a 12-h period of no pile driving, especially in a river or tidally-influenced waterway when the fish should be moving. Note: The accumulation period for marine mammals and sea turtles is 24-h. Furthermore, NMFS does not have physical injury thresholds for non-impulsive sources, except tactical sonar.

For fishes, the SELcum metric also incorporated effective quiet, which means if the received SEL from an individual pile strike is below a certain level (150 dB SELss), then the accumulated energy from multiple strikes would not contribute to injury, regardless of how many pile strikes occur. Effective quiet establishes a limit on the maximum distance from the pile where injury is expected. Beyond this distance no physical injury is expected, regardless of the number of pile strikes. There is currently not enough data to support an effective quiet level for other taxa.

Behavioral Disturbance Acoustic Thresholds for Fishes[2]

Source Type	Threshold
All Sources	L_{RMS} 150 dB

SEA TURTLES

Onset of Permanent Threshold Shift (PTS)

Onset of Permanent Threshold Shift (PTS) for Sea Turtles (DoN 2017)

Hearing Group	PTS Onset Thresholds (Received Level) for Impulsive Sources*	PTS Onset Thresholds (Received Level) for Non-impulsive Sources*
Sea Turtles	*Cell 1* $L_{p,0\text{-pk,flat}}$: 232 dB $L_{E,p,\text{TU,24h}}$: 204 dB	*Cell 2* $L_{E,p,\text{TU,24h}}$: 220 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 ($L_{p,0\text{-pk}}$) has a reference value of 1 µPa, and weighted cumulative sound exposure level ($L_{E,p}$) has a reference value of 1µPa²s. 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 sea turtles (i.e., below 2 kHz). The subscript associated with cumulative sound exposure level thresholds indicates the designated sea turtle weighting function 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.

Onset of Temporary Threshold Shift (TTS)

Onset of Temporary Threshold Shift (TTS) for Sea Turtles (DoN 2017)

Hearing Group	TTS Onset Thresholds (Received Level) for Impulsive Sources*	TTS Onset Thresholds (Received Level) for Non-impulsive Sources*
Sea Turtles	*Cell 1* $L_{p,0\text{-pk,flat}}$: 226 dB $L_{E,p,\text{TU,24h}}$: 189 dB	*Cell 2* $L_{E,p,\text{TU,24h}}$: 200 dB

[2] Note: The derivation and origin of the informal 150 dB threshold is not as well-defined as other thresholds. However, various recent publications do not refute that behavioral disturbance can occur around this level. As one example study, Hawkins et al. 2014 present their data in peak-to-peak sound pressure level and single strike SEL. However, in general, RMS levels for impact pile driving are approximately 10 dB higher than single strike SEL levels. Based on this conversion, the 50% RMS response level, from this study, for sprat and mackerel, range from 145 to 152 dB.

Note: Popper et al. 2019 advocate that the peak-to-peak metric is more appropriate for impulsive sounds compared to the RMS metric. However, pile driving data are not typically reported in this metric.

* 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 ($L_{p,0\text{-pk}}$) has a reference value of 1 µPa, and weighted cumulative sound exposure level ($L_{E,p}$) has a reference value of 1µPa²s. 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 sea turtles (i.e., below 2 kHz). The subscript associated with cumulative sound exposure level thresholds indicates the designated sea turtle weighting function 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.

Onset of Behavioral Disturbance

Data on behavioral reactions of sea turtles to sound sources is limited. However, in general, behavioral disturbance occurs around RMS 175 dB (O'Hara and Wilcox 1990; Moein et al. 1994; Lenhardt 2002; McCauley et al. 2002).

Onset of Behavioral Disturbance Acoustic Thresholds for Sea Turtles (DoN 2017)

Source Type	Threshold
All Sources*	L_{RMS} 175 dB

***** Currently, there are not enough data to derive separate thresholds for different source types.

Note: This threshold is also used for multiple detonations.

Underwater Explosives

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

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

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

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

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

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

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

D = animal depth (meters)

* 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 µPa. 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.

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