DOCUMENT CONTAINING PROPOSED CHANGES TO:

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION DRAFT GUIDANCE FOR ASSESSING THE EFFECTS OF ANTHROPOGENIC SOUND ON MARINE MAMMAL HEARING

UNDERWATER ACOUSTIC THRESHOLD LEVELS FOR ONSET OF PERMANENT AND TEMPORARY THRESHOLD SHIFTS

INTRODUCTION

This document presents proposed changes to National Oceanic and Atmospheric Administration's (NOAA) 2015 July Draft Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (NOAA 2015a) for consideration by the public during a 14-day comment period.

This is the third public comment period for NOAA's Draft Guidance. The first comment period began in December 2013, and a second comment period was announced in July 2015 following proposed changes to the Draft Guidance. As NOAA worked to address comments it received during the first and second public comment periods and finalize the Guidance, the U.S. Navy's methodology (Appendix A of 2015 July Draft Guidance, NOAA 2015a) was further evaluated internally (within NOAA), as well as by the Navy (SPAWAR Systems Center Pacific). As a result, several recommendations/modifications were suggested. Upon consideration, NOAA has updated portions of the Draft Guidance to reflect these suggested modifications and is soliciting public comment on the proposed changes via a focused[1] 14-day public comment period.

The proposed changes to the Draft Guidance presented in this document are organized into six sections:

- Section 1. Low-Frequency (LF) Cetaceans: Modification of the methodology for predicting a composite audiogram and acoustic threshold levels for LF cetaceans

- Section 2. Mid-Frequency (MF) Cetaceans: Placement of white-beaked dolphins from the MF cetacean to the high-frequency (HF) cetacean functional hearing group

- Section 3. High-Frequency (HF) Cetaceans: Inclusion of an additional audiogram from a harbor porpoise based on recently published data

[1] Concurrent with this third public comment period, NOAA requested that the peer reviewers of the Navy's methodology review the proposed changes to the Draft Guidance and indicate whether the revisions would significantly alter any of the comments made during their original review (NOAA 2015b).

- Section 4. Phocid (PW) Pinniped: Removal of datasets with individuals having hearing loss and/or non-representative hearing from the PW pinniped functional hearing group

- Section 5. Peak Sound Pressure Level (PK) Acoustic Threshold Levels: Removal of PK acoustic threshold levels for non-impulsive sounds for all functional hearing groups and use of dynamic range methodology to derive PK thresholds for functional hearing groups with no direct data

- Section 6. Summary of Proposed Changes: Summarized proposed changes to the 2015 July Draft Guidance (NOAA 2015a) via tables and figures, with specific changes highlighted in green[2])

At the beginning of each section, text in red is provided to indicate the specific proposed change, as well as what would be modified in the 2015 July Draft Guidance (NOAA 2015a).

Note: There is no need to reiterate or resubmit comments made on other portions of the Draft Guidance and/or made during the first or second public comment periods (i.e., all substantive public comments made during all three public comment periods will be addressed as part of the Guidance's finalization process).

1. LOW-FREQUENCY (LF) CETACEANS

NOAA acknowledges that available information to derive an auditory weighting function and acoustic thresholds levels for LF cetaceans is limited compared to other functional hearing groups (i.e., For LF cetaceans, there are only audiograms available from predicted models with no empirical measurements of hearing and no data on effects of noise on hearing).[3] As a result, modifications were made to the July 2015 Draft Guidance's original methodology (NOAA 2015a) for deriving a predicted composite audiogram/auditory weighting function (Section 1.1) and acoustic threshold levels (Section 1.2) to better account for uncertainty associated with this functional hearing group.

1.1 AUDITORY WEIGHTING FUNCTION

PROPOSED CHANGE: Modification of methodology used to predict composite audiogram/auditory weighting function for LF cetaceans (i.e., removal of preliminary data sources)

[2] Note: Other than the modifications proposed in this document, the Navy's methodology (Finneran 2015; Appendix A of NOAA 2015a) remains unchanged. However, as a result of the modifications associated with the proposed changes, weighting function parameters and associated weighting functions for many of the functional hearing groups have changed compared to the July 2015 Draft Guidance (NOAA 2015a).

[3] Note: NOAA is aware that the authors of Southall et al. (2007) are in the process of updating their original publication and recognizes that when this updated publication becomes available, it may suggest alternative means for predicting an auditory weighting function and acoustic threshold levels for this functional hearing group. NOAA may re-evaluate our methodology for LF cetaceans when this updated Southall et al. publication becomes available.

Specifically, this proposed change would modify NOAA 2015a:

1. Main Document
    a. Section 2.2.3, Step 1a: Updated methodology replaces previous method for deriving composite audiogram for LF cetaceans

    b. Section 2.2.3, Step 1d: Updated methodology to predict best-fit parameters for Equation 3

    c. Figure 1: Auditory weighting function for LF cetaceans changed to reflect updated methodology

    d. Figure 4: Predicted composite audiogram for LF cetaceans changed to reflect updated methodology

    e. Table 2: Species used to derive the LF cetacean predicted audiogram are removed to reflect updated methodology

    f. Table 3: Best-fit parameters for composite audiogram changed to reflect updated methodology

    g. Table 4: Composite audiogram frequency of best hearing and low-frequency slope for LF cetaceans changed based on updated methodology

    h. Table 5: Derivation of low-frequency exponent (*a*) for LF cetaceans changes based on update methodology

    i. Table 7 and Table 11: Weighting and exposure function parameters for LF cetaceans changed based on updated methodology (See Section 6: Table PC3 for LF cetacean weighting function parameters)

2. Appendix A
    a. Section 5, Step 1: Updated methodology replaces previous method for deriving composite audiogram for LF cetaceans

    b. Section 5, Step 5: Updated methodology to predict best-fit parameters for Equation 3

    c. Figures E-2, E-3, 17, 21, 22, and 23: Auditory weighting and exposure functions for LF cetaceans changed to reflect updated methodology

    d. Figures 6 and 7: Predicted composite audiogram for LF cetaceans changed to reflect updated methodology

    e. Table E-1 and Table 10: Weighting and exposure function parameters for LF cetaceans updated based on updated methodology

f. Table 2: Species used to derive the LF cetacean predicted audiogram are removed to reflect updated methodology

g. Table 4: Best-fit parameters for composite audiogram changed to reflect updated methodology

h. Table 5: Composite audiogram frequency of best hearing and low-frequency slope for LF cetaceans changed based on updated methodology

1.1.1 Discussion

Upon re-evaluation, the Navy recommended and NOAA concurred that preliminary data relating to predicted audiograms for LF cetaceans should not be included at this time[4] (e.g., Ketten and Mountain 2009; Ketten 2014; Ketten and Mountain 2014). This leaves only two studies available for consideration (i.e., predicted audiogram for a humpback whale from Houser et al. 2001 and fin whale[5] from Cranford and Krysl 2015), which alone is not enough to derive a predicted audiogram for this entire functional hearing group. Thus, an alternative approach must be used to predict a composite audiogram and associated weighting function for LF cetaceans.

1.1.1.1 Method for Deriving Predicted Composite Audiogram

Within the Draft Guidance (NOAA 2015a, Appendix A), composite audiograms are defined by the following equation:

$$T(f) = T_0 + A\log_{10}\left(1+\frac{F_1}{f}\right)+\left(\frac{f}{F_2}\right)^B, \qquad \textbf{Equation 1}$$

where $T(f)$ is the threshold at frequency f, and T_0, F_1, F_2, A, and B are constants (i.e., fitting parameters). To understand the physical significance and influence of each parameter, Equation 1 is divided in three individual terms (Equation 2):

$$T(f) = T_0 + L(f) + H(f), \qquad \textbf{Equation 2}$$

Where:

$$L(f) = A\log_{10}\left(1+\frac{F_1}{f}\right) \qquad \textbf{Equation 3}$$

[4] Note: These data currently lack a complete description of methodology used to derive predicted audiograms, with the data in Ketten 2014 and Ketten and Mountain 2014 only available in the format of a slide associated with a presentation.

[5] Note: The Cranford and Krysl 2015 predictive model was based on the skull geometry of a newborn fin whale.

And:

$$H(f) = \left(\frac{f}{F_2}\right)^B \qquad \textbf{Equation 4}$$

The first term, T_0, controls the vertical position of the audiogram (i.e., T_0 shifts the audiogram up or down).

The second term, $L(f)$, controls the low-frequency behavior of the audiogram. At low frequencies, when $f < F_1$, Equation 3 approaches:

$$L(f) = A\log_{10}\left(\frac{F_1}{f}\right), \qquad \textbf{Equation 5}$$

This can also be written as:

$$L(f) = A\log_{10}(F_1) - A\log_{10}(f). \qquad \textbf{Equation 6}$$

Equation 6 has the pattern of $y(x) = b - Ax$, where $x = \log_{10} f$ (i.e., Equation 6 describes a linear function of the logarithm of frequency). This means that, as frequency gets smaller and smaller, Equation 3 (i.e., the low-frequency portion of the audiogram function) approaches a linear function with the logarithm of frequency, and has a slope of A dB/decade. As frequency increases towards F_1, $L(f)$ asymptotically approaches zero.

The third term, $H(f)$, controls the high-frequency behavior of the audiogram. At low frequencies, when $f << F_2$, Equation 4 has a value of zero. As f increases, $H(f)$ exponentially grows. The parameter F_2 defines the frequency at which the thresholds begin to exponentially increase, while the factor B controls the rate at which thresholds increase. Increasing F_2 will move the upper cutoff frequency to higher frequencies, while increasing B will increase the "sharpness" of the high-frequency increase.

Predicting Composite Audiogram Parameters

Within the Draft Guidance (NOAA 2015a, Appendix A), for each functional hearing group, the composite audiogram derived from empirical data are fit to Equation 1. However, for LF cetaceans, where there are no empirical data to directly derive a composite audiogram, Equation 1's fitting parameters (T_0, F_1, F_2, A, and B) need to be predicted. These predictions are informed by published information on LF cetacean hearing. Table PC1 summarizes these predicted parameters, with details on the derivation of each provided below.

Table PC1: Summary of predicted composite audiogram best-fit parameters for LF cetaceans (updates Main Document: Table 3; Appendix A: Table 4 from NOAA 2015a).

Parameter	Predicted Value
T_0	-0.81 dB*
F_1	0.41 kHz
F_2	9.4 kHz
A	20
B	3.2

* Value for normalized composite predicted audiogram (value is 53.19 for non-normalized composite predicted audiogram)

- Parameter A: The constant A is defined by assuming a value for the low-frequency slope of the audiogram, in dB/decade. Most mammals for which thresholds have been measured have low-frequency slopes ranging from ~30 to 40 dB/decade (e.g., Wartzok and Ketten 1999). Recent finite element models associated with fin whale (Cranford and Krysl 2015) and minke whale (Tubelli et al. 2012) hearing suggest lower slopes of ~25 or 20 dB/decade, respectively. Therefore a conservative value of A = 20 dB/decade was used for the predicted value of this parameter.

- Parameter F_1: To predict F_1, the variable T' is defined as the maximum threshold tolerance within the frequency region of best sensitivity (i.e., within the frequency range of best sensitivity, thresholds are within T' dB of the lowest threshold). Further, f' is defined as the lower frequency bound of the region of best sensitivity. When $f = f'$ and $L(f) = T'$, Equation 3 can then be solved for F_1 as a function of f', T', and A:

$$F_1 = f'\left(10^{T'/A} - 1\right)$$ **Equation 7**

Anatomically-based models of LF cetacean hearing have resulted in various estimates for audible frequency ranges and frequencies of best sensitivity. For the North Atlantic right whale, Parks et al. (2007) estimated this species' hearing range to be 10 Hz to 22 kHz. For minke whales, Tubelli et al. (2012) estimated the most sensitive hearing range (defined as the region with thresholds within 40 dB of best sensitivity) to extend from 30 Hz to 7.5 kHz or from 100 Hz up to 25 kHz, depending on the specific model used. Houser et al. (2001) estimated best sensitivity in humpback whales to occur in the range of 2 to 6 kHz (thresholds within 3 dB of best sensitivity from ~1.4 to 7.8 kHz), and Cranford and Krysl

(2015) predicted best sensitivity in fin whales to occur around 1.2 kHz (thresholds within 3 dB of best sensitivity from ~1 to 1.5 kHz). Together, these previously published model of LF cetacean hearing broadly suggest best sensitivity (in terms of parameter T') from ~1 to 8 kHz, with thresholds within ~40 dB of best sensitivity as low as ~30 Hz and up to ~25 kHz.

Based on these studies, it was assumed $T' = 3$ dB and $f' = 1$ kHz. As a result, from Equation 7, $F_1 = 0.41$ kHz. In other words, F_1 is defined so that thresholds are ≤ 3 dB relative to the lowest threshold when the frequency is within the region of best sensitivity (i.e., 1 to 8 kHz).

- Parameters F_2 and B: To predict the high-frequency portion of the audiogram, the values of B and F_2 must be estimated. To estimate B, the median of the B values from the composite audiograms for the other in-water marine mammal functional hearing groups (MF; HF; OW; PW; SI (sirenians)[6]) was used as a surrogate value for LF cetaceans. This results in $B = 3.2$ for the LF cetaceans. Once B is defined, F_2 is adjusted to achieve a threshold value at 30 kHz of 40 dB relative to the lowest threshold. This results in $F_2 = 9.4$ kHz.

- Parameter T_0: The value for T_0 is determined by either adjusting T_0 to place the lowest threshold value to zero (to obtain a normalized audiogram), or to place the lowest expected threshold at a specific SPL (in dB re: 1 μPa). In this case, T_0 was adjusted to set the lowest threshold value to 0 dB, resulting in $T_0 = -0.81$ (i.e., value for normalized audiogram; value of 53.19 for non-normalized audiogram).

Based on these predicted parameters, the resulting predicted composite audiogram for LF cetaceans is shown in Figure PC1. For comparative purposes, predicted audiograms for the fin whale (Cranford and Krysl 2015) and humpback whale (Houser et al. 2001) are included. Although the resulting predicted LF cetacean composite audiogram has lowest threshold (i.e., frequency of best hearing) at 5.6 kHz, it is fairly shallow in the region of best sensitivity (i.e., thresholds are within 1 dB of the lowest threshold from ~1.8 to 11 kHz and within 3 dB of the lowest threshold from ~0.75 to 14 kHz). Additionally, both low-frequency (< ~500 Hz) and high-frequency thresholds from the predicted audiogram are considerably lower than those predicted by Cranford and Krysl (2015).

[6] Note: Acoustic threshold levels for the SI functional hearing groups will not be included in NOAA's Finalized Guidance (i.e., West Indian manatees are under the jurisdiction of the U.S. Fish and Wildlife Service). However, since marine mammal audiogram data are limited, a decision was made to include all available datasets from in-water groups to derive composite audiogram parameters for LF cetaceans (i.e., MF=3.56; HF=17.1; PW=1.41; OW=3.23; SI=1.7).

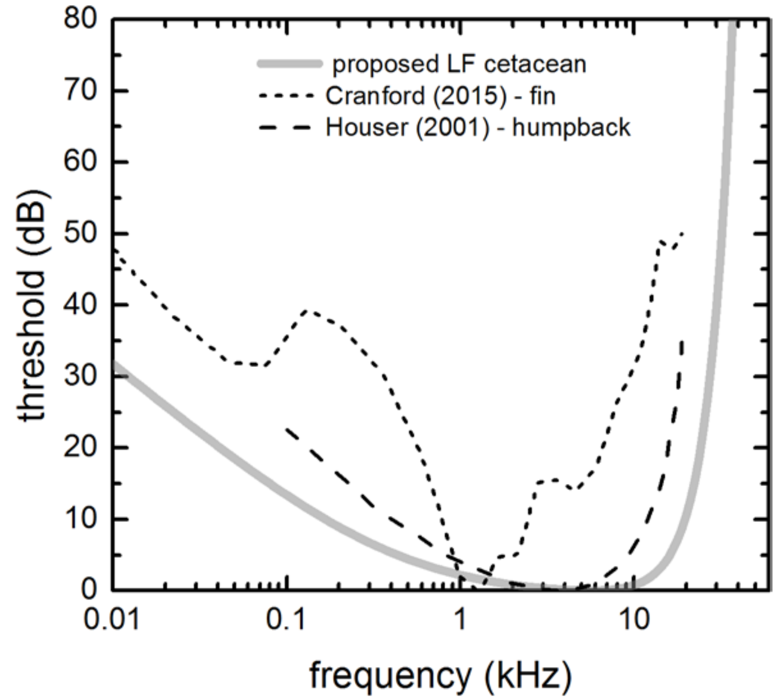

Figure PC1: Updated predicted LF cetacean composite audiogram (updates Main Document: Figure 4; Appendix A: Figure 6 from NOAA 2015a) with comparison to predicted audiograms from anatomical and finite element models.

Additionally, the resulting LF cetacean composite audiogram appears reasonable in a general sense relative the predominant frequencies present in LF cetacean conspecific vocal communication signals. While some species (e.g., blue whales) produce some extremely low (e.g., 10 Hz) frequency call components, the majority of LF cetacean social calls occur in the few tens of Hz to few kHz range, overlapping reasonably well with the predicted auditory sensitivity shown in the composite audiogram (within ~0-30 dB[7] of predicted best sensitivity). A general pattern of some social calls containing energy shifted below the region of best hearing sensitivity is well-documented in other low-frequency species including many phocid seals (see Wartzok and Ketten 1999) and some terrestrial mammals, notably the Indian elephant (Heffner and Heffner 1982).

[7] Note: It is important to remember that the resulting weighting function is wider than the composite audiogram (i.e., this methodology results in an auditory weighting function that is broader than a simple inverse audiogram, which has been recommended to assess impacts; e.g., Hermannsen et al. 2015; Tougaard et al. 2015). For example, the weighting function (See Section 6: Figure PC3) associated with the updated composite audiogram in Figure PC1, has a weighting function amplitude of < -1 dB at 500 Hz and < -7 dB at 100 Hz.

1.1.1.2 Resulting Predicted Weighting Function

By employing the updated methodology for deriving a predicted composite audiogram for LF cetaceans, it is possible to derive a weighting function for LF cetaceans using the original methodology from within the Draft Guidance (NOAA 2015a, Appendix A). See Section 6: Table PC3 for updated weighting function parameters, Figure PC3 for updated weighting function of LF cetaceans, and Figure PC5 for updated exposure function for LF cetaceans.

1.2 ACOUSTIC THRESHOLD LEVELS

PROPOSED CHANGE: Modification to methodology for deriving impulsive and non-impulsive acoustic threshold levels for LF cetaceans (i.e., using data from other in-water functional hearing groups to predict thresholds for LF cetaceans).

Specifically, this proposed change would modify NOAA 2015a:

1. Main Document
    a. Section 2.2.3, Step 5: Updates methodology and uses data from other in-water functional hearing groups as surrogate data for LF cetaceans

    b. Tables ES1, Table 8, and Table 11: All LF cetacean SEL_{cum} acoustic threshold levels replaced based on updated methodology

    c. Table 6: Procedure for estimating SEL_{cum} TTS onset threshold for LF cetaceans replaced by updated methodology

    d. Table 7: *K* weighting function parameter changed based on updated methodology

2. Appendix A
    a. Section 9.3: Updates methodology and uses data from other in-water functional hearing groups as surrogate data for LF cetaceans

    b. Figures E-2, E-3, 17, 22, and 23: All LF cetacean SEL_{cum} acoustic threshold levels replaced based on updated methodology

    c. Tables E-1, 8, 9, and 10: All LF cetacean SEL_{cum} acoustic threshold levels replaced based on updated methodology

    d. Table 7: *K* weighting function parameter changed based on updated methodology

1.2.1 Discussion

Upon evaluation, the Navy and NOAA recommended that the July 2015 Draft Guidance's (NOAA 2015a) acoustic threshold levels for LF cetaceans be adjusted. This recommendation was based on a re-evaluation of the appropriateness of using a 65 dB threshold at the frequency of best hearing based on data associated with ambient noise levels from Clark and Ellison (2004).

Clark and Ellison (2004) provided a predicted hearing threshold (i.e., 60 to 70 dB) for LF cetaceans based on ambient noise levels between 200 and 400 Hz. However, the July 2015 Draft Guidance's predicted audiogram for LF cetaceans indicates this functional hearing group has best hearing sensitivity at higher frequencies (i.e., NOAA 2015a: 3.5 kHz; updated to 5.6 kHz in Section 1.1.1.1 of this document) rather than the 200-400 Hz range where Clark and Ellison (2004) provided an expected threshold. Accordingly, it is not appropriate to use the Clark and Ellison (2004) threshold recommendation with the best hearing range from the predicted audiogram in the Draft Guidance.

To avoid a mismatch of data, it was decided that until more data can be obtained, the median threshold at best hearing frequency for the other in-water marine mammal functional hearing groups (MF, HF, OW, PW, SI[8]; Table PC2) will be used as surrogates to predict a value for LF cetaceans. This results in a threshold of 54 dB at best hearing frequency (f_0 = 5.6 kHz) for LF cetaceans. Using this updated best hearing threshold for LF cetaceans and following the methodology presented in 2015 July Draft Guidance (NOAA 2015a; Appendix A; using median difference) results in an estimated SEL_{cum} TTS onset acoustic threshold level at f_0 for non-impulsive sources for LF cetaceans of 180 dB (Table PC2; See Section 6: Table PC4 for all updated LF cetacean acoustic threshold levels).

[8] Note: SI acoustic threshold levels will not be included in NOAA's Finalized Guidance (i.e., West Indian manatees are under the jurisdiction of the U.S. Fish and Wildlife Service). However, since marine mammal audiogram data are limited, a decision was made to include all available datasets from in-water groups to derive the threshold of best hearing for LF cetaceans.

Table PC2: Procedure used to estimate TTS onset values for LF cetaceans at f_0 (updates[*] Main Document: Table 6; Appendix A: Table 7 from NOAA 2015a).

Functional Hearing Group	f_0 (kHz)	Auditory threshold at f_0	TTS onset at f_0[†] (SEL_{cum})	Difference (TTS onset minus auditory threshold at f_0)
Low-frequency (LF) cetaceans	5.6	54 dB (estimated)	180 dB (estimated)	126 (estimated)
Mid-frequency (MF) cetaceans	55	54 dB	179 dB	125
High-frequency (HF) cetaceans	105	48 dB	156 dB	108
Phocid pinnipeds (underwater)	8.6	53 dB	181 dB	133
Otariid pinnipeds (underwater)	12	67 dB	200 dB	128
Sirenians (SI)	16	61 dB	No Data	NA

[*] Note: Values in this Table differ from those provided in the July 2015 Draft Guidance (2015a), as result of updates described in this document. West Indian manatees (SI) are under the jurisdiction of the U.S. Fish and Wildlife Service.

[†] Note: The value reflected represents TTS onset at the frequency of best hearing (f_0) associated with the composite audiogram, which are slightly higher than the values in Tables PC3 and PC4, which reflect the weighted TTS threshold level (SEL_{cum}) associated with the weighting function.

2. MID-FREQUENCY (MF) CETACEANS

PROPOSED CHANGE: Placement of white-beaked dolphins from the MF cetacean to the HF cetacean functional hearing group

Specifically, this proposed change would modify NOAA 2015a:

1. Main Document
   a. Table 1: Movement of the white-beaked dolphins from MF to HF cetaceans

2. Appendix A
   a. Table 1: Movement of the white-beaked dolphins from MF to HF cetaceans

2.1 Discussion

Upon re-evaluation, the Navy recommended that white-beaked dolphins (*Lagenorhynchus albirostris*) be moved from the MF cetacean functional hearing group to the HF cetacean functional hearing group. Based on the examination of data obtained via auditory evoked potential methodology (AEP), it was determined that the white-beaked dolphin's audiogram was more similar to other HF cetaceans (i.e., high-frequency sensitivity similar to harbor porpoise; Nachtigall et al. 2008) than to MF cetaceans.

At this time, there is no behavioral audiogram available for the white-beaked dolphin to incorporate into the MF cetacean composite audiogram. Thus, moving this species to the HF cetacean functional hearing group does not result in any changes to the composite audiograms or weighting functions for either MF cetaceans or HF cetaceans.

3. HIGH-FREQUENCY (HF) CETACEANS

PROPOSED CHANGE: Inclusion of an additional audiogram for harbor porpoises

Specifically, this proposed change would modify NOAA 2015a:

1. Main Document
    a. Figures 1 and 4: Updated composite audiogram and weighting function for HF cetaceans reflecting an additional harbor porpoise audiogram

    b. Table 2: Inclusion of additional audiogram for harbor porpoises

2. Appendix A
    a. Figures E-1, E-2, E-3, 5, 6, 7, 17, 19, 21, 22, and 23: Updated composite audiogram and weighting function for HF cetaceans reflecting an additional harbor porpoise audiogram

    b. Table 2: Inclusion of additional audiogram for harbor porpoises

3.1 DISCUSSION

In addition to the moving white-beaked dolphins from the MF cetacean to the HF cetacean functional hearing group, an additional audiogram for harbor porpoises (Kastelein et al. 2015) became available after the release of July 2015 Draft Guidance.

Note: NOAA recognizes that new data may become available at any time after the finalization of the Guidance. NOAA may not update the Guidance's composite audiograms and associated weighting functions each time new data become available (i.e., Guidance has an established a schedule to re-evaluate all new data every 3 to 5 years). However, in this particular instance, since other adjustments were being made, NOAA decided to incorporate this new dataset now.

Thus, the data from Kastelein et al. 2015 (ID 04) was used in deriving the composite updated audiogram for HF cetaceans (See Section 6: Figure PC2 and PC3 for updated HF composite audiogram and associated weighting function).

4. PHOCID (PW) PINNIPEDS

PROPOSED CHANGE: Removal of PW pinniped datasets containing individuals with hearing loss and/or hearing not representative of their functional hearing group

Specifically, this proposed change would modify NOAA 2015a:

1. Main Document
    a. Figures 2 and 4: Updated composite audiogram and weighting function for PW pinnipeds reflecting removal of non-representative datasets

    b. Table 2: Removal of non-representative datasets from PW pinnipeds

2. Appendix A
    a. Figures E-1, E-2, E-3, 5, 6, 7, 17, 20, 21, 22, and 23: Updated composite audiogram and weighting function for PW pinnipeds reflecting removal of non-representative datasets

    b. Table 2: Removal of non-representative datasets from PW pinnipeds

4.1 Discussion

The Navy recommended that some datasets be excluded from consideration in the development of the PW pinniped composite audiogram (i.e., individuals that likely had some sort of hearing loss and/or not representative of their functional hearing group), and NOAA agrees with this assessment removing the following datasets:

- Møhl 1968 (harbor seal): Removed due to high thresholds likely being masked

- Terhune and Ronald 1972 (harp seal): Removed due to high thresholds likely being masked

- Terhune and Ronald 1975 (ringed seal): Removed due to high thresholds likely being masked

- Babushina 1997 (Caspian seal): Removed due to high thresholds likely being masked

- Sills et al. 2015 (ringed seal): Removed data for one individual (Natchek) due to high-frequency hearing loss

By excluding these datasets, this resulted in an updated PW pinniped composite audiogram (See Section 6: Figure PC2 and PC4 for updated PW pinniped composite audiogram and associated weighting function).

5. PEAK SOUND PRESSURE LEVEL (PK) ACOUSTIC THRESHOLD LEVELS

5.1 REMOVAL OF PEAK SOUND PRESSURE LEVEL ACOUSTIC THRESHOLD LEVELS FOR NON-IMPULSIVE SOUNDS

PROPOSED CHANGE: Removal of PK acoustic threshold levels for non-impulsive sounds for all functional hearing groups

Specifically, this proposed change would modify NOAA 2015a:

1. Main Document
    a. Tables ES1 and 8: Removal of PK acoustic threshold levels for non-impulsive sounds for all functional hearing groups

2. Appendix A
    a. Note: The Navy previously never included PK acoustic threshold levels for non-impulsive sound for all functional hearing groups (i.e., no change is needed)

5.1.1 Discussion

The Draft Guidance divides sounds into impulsive and non-impulsive categories based on physical characteristics at the source, with impulsive sounds having physical characteristics making them potentially more injurious to the auditory system (e.g., high peak sound pressures and rapid rise times) than non-impulsive sounds (terrestrial mammal data: Buck et al. 1984; Dunn et al. 1991; Hamernik et al. 1993; Clifford and Rogers 2009; marine mammal data: reviewed in Southall et al. 2007 and Finneran 2015). For this reason and to reflect human noise standards (Occupational Safety and Health Administration (OSHA) 29 CFR 1910.95; Starck et al. 2003), peak sound pressure level (PK) acoustic threshold levels were derived to account for the increased risk of impulsive sounds to cause mechanical fatigue to the inner ear (Henderson and Hamernik 1986; Levine et al. 1998; Henderson et al. 2008), in additional to thresholds using the cumulative sound exposure level (SEL_{cum}) metric (dual metrics).

Upon evaluation, NOAA determined that for non-impulsive sounds, the SEL_{cum} metric is likely to result in the largest isopleth/greater number of marine mammal exposures. Thus, for the majority of non-impulsive sounds, the consideration of the PK acoustic threshold level is unnecessary (i.e., will result in smaller isopleths/fewer marine mammal exposures compared to the SEL_{cum} acoustic threshold level). As a result, the PK acoustic threshold levels are removed for non-impulsive sounds[9] (See Section 6: Table PC4 for removal of PK acoustic threshold levels for non-impulse sounds for all functional hearing groups). However, if there are instances that a non-impulsive sound has the potential of exceeding the PK acoustic threshold level associated with impulsive sounds, these thresholds should still be considered (i.e., dual metrics).

[9] This modification matches a recommendation made by the Marine Mammal Commission during the second public comment period, as well as makes the Guidance consist with the Navy's methodology (Appendix A), which did not provide PK acoustic threshold levels for non-impulsive sounds.

5.2 Dynamic Range To Estimate Peak Sound Pressure Level Acoustic Threshold Levels For Functional Hearing Groups with No Direct Data

PROPOSED CHANGE: Change in methodology for deriving PK acoustic threshold levels for LF, PW, and OW functional hearing groups

Specifically, this proposed change would modify NOAA 2015a:

1. Main Document
    a. Section 2.2.4, Step 4: Impulsive sounds: Changed methodology (use of dynamic range) replaces that described by Equation 5 for deriving PK acoustic threshold levels for LF, PW, and OW functional hearing groups

    b. Tables ES1 and Table 8: Updated PK acoustic threshold levels for LF, PW, and OW functional hearing groups

2. Appendix A
    a. Section 11: Changed methodology (i.e., use of dynamic range) replaces that described by Equation 5 for deriving PK acoustic threshold levels for LF, PW, and OW functional hearing groups.

    b. Tables E-1 and 10: Updated PK acoustic threshold levels for LF, PW, and OW functional hearing groups.

5.2.1 Discussion

Data to derive PK acoustic thresholds are only available for MF and HF cetaceans. Thus, for the other functional hearing groups, an alternative method must be used to approximate PK acoustic threshold levels. The 2015 July Draft Guidance (NOAA 2015a) relied on MF cetaceans as a surrogate for LF, PW, and OW functional hearing groups.

Upon further consideration, the auditory system's dynamic range, defined as the threshold of pain minus the threshold of audibility (Yost 2007), was determined a more appropriate methodology for estimating PK sound pressure acoustic threshold levels than the method used in the 2015 July Draft Guidance (NOAA 2015a).[10] To use the dynamic range methodology, it is assumed that the PK TTS onset acoustic threshold level for MF and HF cetaceans defines the upper end of those functional hearing groups' dynamic range (i.e., PK threshold: 224 dB for MF cetaceans and PK threshold: 196 dB for HF cetaceans), with the threshold of audibility derived from the frequency of best hearing (f_0) from the composite audiogram (i.e., 54 dB for MF cetaceans and 48 dB for HF cetaceans)

[10] Dynamic range is used in human noise standards to define the PK acoustic threshold level for impulsive sounds (e.g., 140 dB from OSHA 29 CFR 1910.95). The use of dynamic range was recommended by the Marine Mammal Commission during the second public comment period, as well as during the peer review of the Navy's technical document (NOAA 2015b).

defining the lower end of the groups' dynamic range. This results in a dynamic range of 170 dB for MF cetaceans and 148 dB for HF cetaceans. The median/mean dynamic range from these two functional hearing groups (i.e., 159 dB) is used as the surrogate dynamic range for LF cetaceans (best hearing at f_0= 54 dB; Resulting in a PK TTS threshold of 213 dB and PK PTS threshold of 219 dB); PW pinnipeds (best hearing at f_0=53 dB; Resulting in a PK TTS threshold of 212 dB and PK PTS threshold of 218 dB); and OW pinnipeds (best hearing at f_0=67 dB; Resulting in a PK TTS threshold of 226 dB and a PK PTS threshold of 232 dB) (See Section 6: Table PC4 for updated, LF, PW and OW PK acoustic threshold levels).

6. SUMMARY OF PROPOSED CHANGES

The following Tables (PC3 and PC4) and Figures (PC2, PC3, PC4, and PC5) provide a summary of how these proposed changes impact the Guidance's weighting function parameters, acoustic threshold levels, composite audiograms, and weighting/exposure functions, with specific revisions indicated by green highlighting.

Note: Other than the modifications proposed in this document, the Navy's methodology (Finneran 2015) remains unchanged. However, as a result of the modifications associated with the proposed changes, weighting function parameters and associated weighting functions for many of the functional hearing groups have changed compared to the July 2015 Draft Guidance (NOAA 2015a).

Table PC3: Summary of updated weighting function parameters (updates Main Document: Table 7; Appendix A: Table 8 from NOAA 2015a).

Functional Hearing Group	*a*	*b*	f_1 (kHz)	f_2 (kHz)	*C* (dB)	*K* (dB)	Weighted TTS onset threshold* (SEL_{cum})
Low-frequency (LF) cetaceans	1.0	2	0.2	19	0.13	179	179 dB
Mid-frequency (MF) cetaceans	1.6	2	8.8	110	1.20	177	178 dB
High-frequency (HF) cetaceans	1.8	2	12	140	1.36	152	153 dB
Phocid pinnipeds (PW) (underwater)	1.0	2	1.9	30	0.75	180	181 dB
Otariid pinnipeds (OW) (underwater)	2.0	2	0.94	25	0.64	198	199 dB

* Determined from minimum value of exposure function and the weighting function at its peak (i.e., mathematically equivalent to $K + C$).

Table PC4: Updated acoustic threshold levels[11] (updates Main Document: Tables ES1 and 8; Appendix A: Tables E-1 and 10 from NOAA 2015a).

	PTS Onset Threshold Levels* (Received Level)	
Hearing Group	**Impulsive**	**Non-impulsive**
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 threshold levels for impulsive sounds: Use whichever results in the largest effect distance (isopleth). 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 Guidance. Hence, the subscript "flat" is being included to indicate peak sound pressure should be flat weighted or unweighted within the functional 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 multitude of ways (i.e., varying exposure levels and durations, duty cycle). It is valuable for action proponents, if possible, to indicate under what conditions these acoustic threshold levels will be exceeded.

[11] Note: Based upon a recommendation made during the second public comment period, NOAA modified the Guidance to be more reflective of American National Standards Institute (ANSI) symbols and abbreviations.

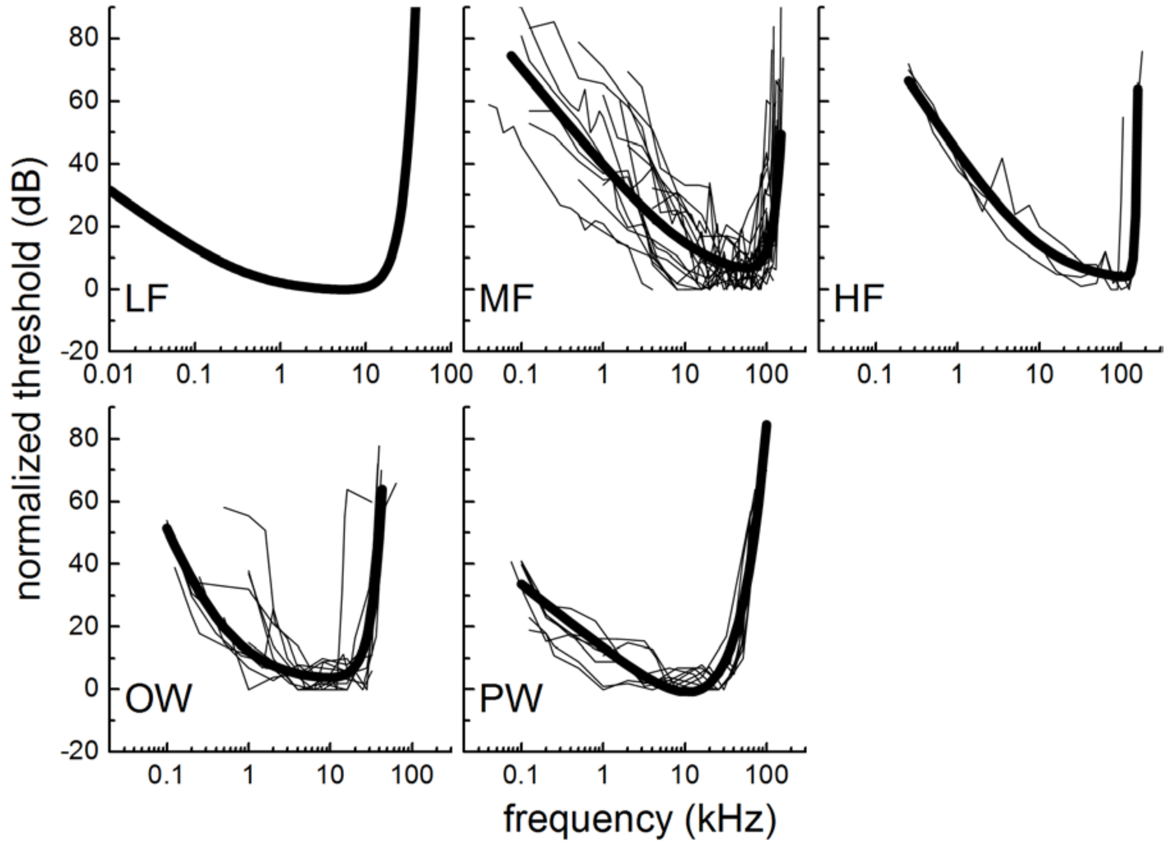

Figure PC2: **Updated normalized composite audiogram for all five functional hearing groups. Thin lines represent threshold data from individual animals, with thick line representing best fit composite audiogram to experimental data or the predicted audiogram for LF cetaceans (updates Appendix A: Figure 6 for LF and HF cetaceans and PW pinnipeds from NOAA 2015a).**

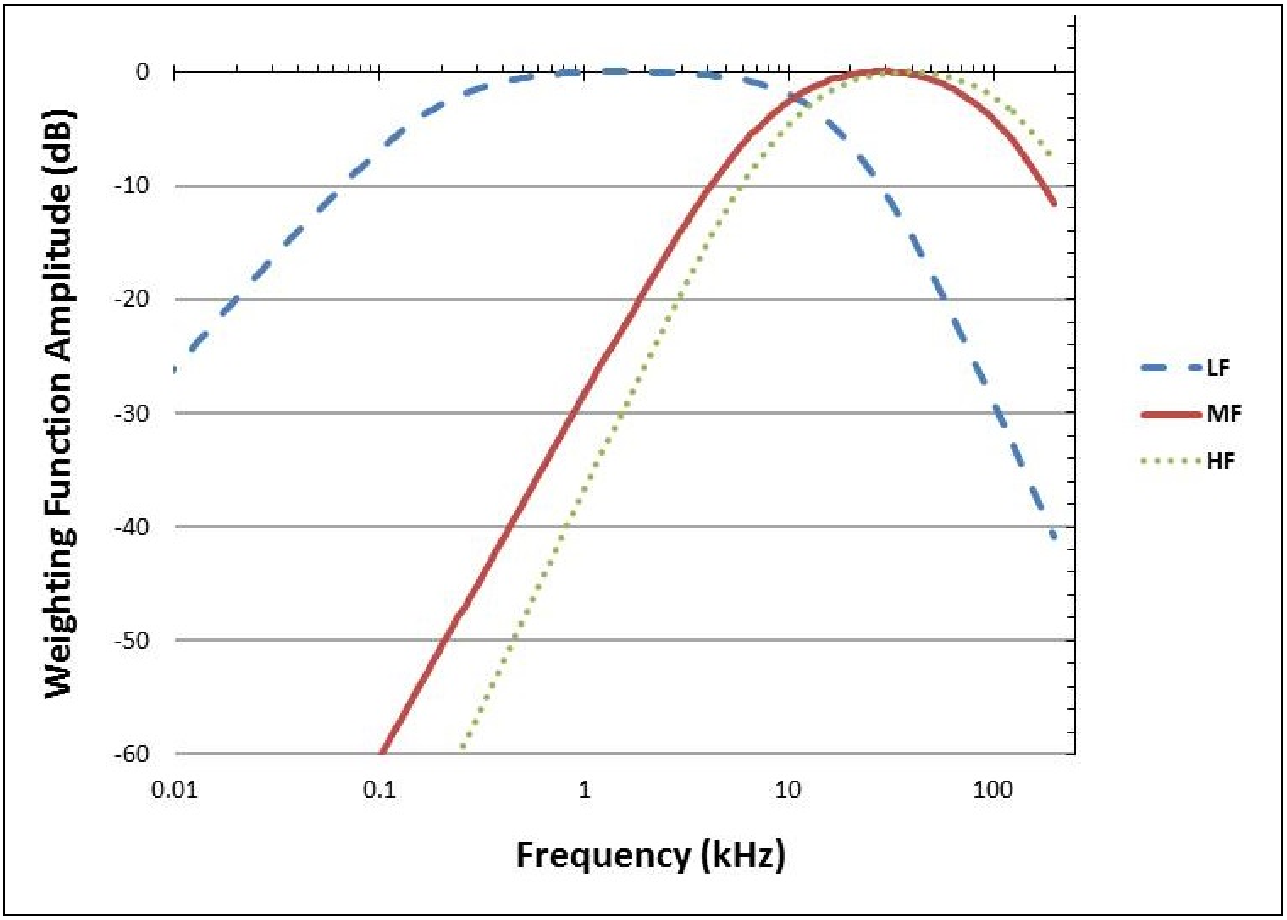

Figure PC3: **Updated auditory weighting functions for low-frequency (LF), mid-frequency (MF), and high-frequency (HF) cetaceans (updates Main Document: Figure 1; Appendix A: Figures E-1 and 21 from NOAA 2015a).**

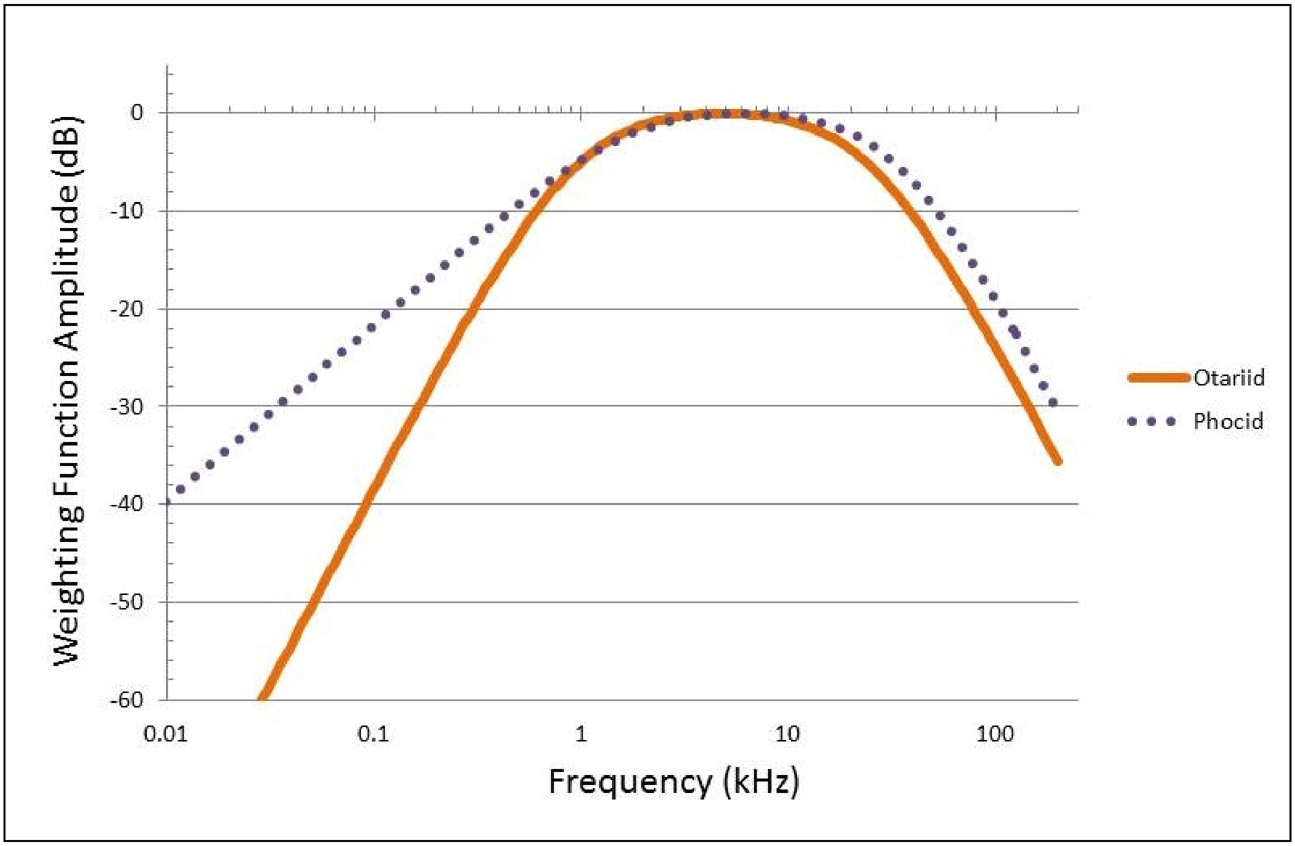

Figure PC4: **Updated underwater auditory weighting functions for otariid (OW) and phocid (PW) pinnipeds (updates Main Document: Figure 2; Appendix A: Figures E-1 and 21 from NOAA 2015a).**

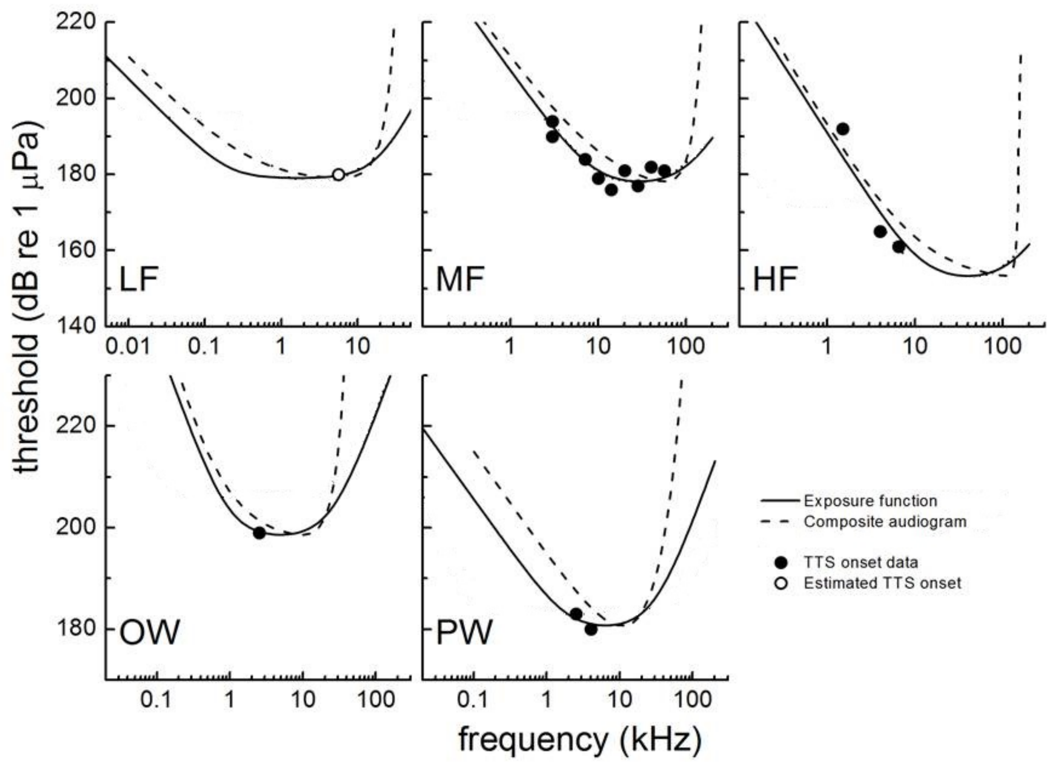

Figure PC5: **Updated underwater exposure functions for all five functional hearing groups based on parameters specified in Table PC3, including normalized composite audiograms from Figure PC2 (updates Appendix A: Figures 17 from NOAA 2015a).**

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