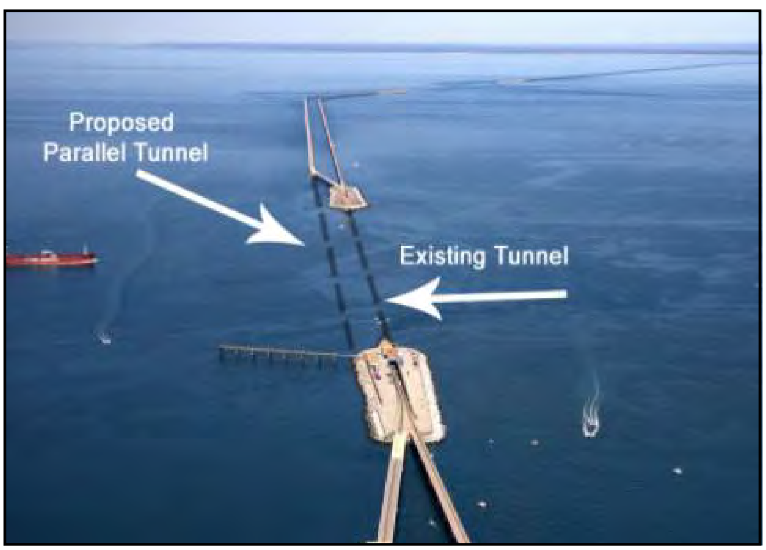
Appendix A: Figures



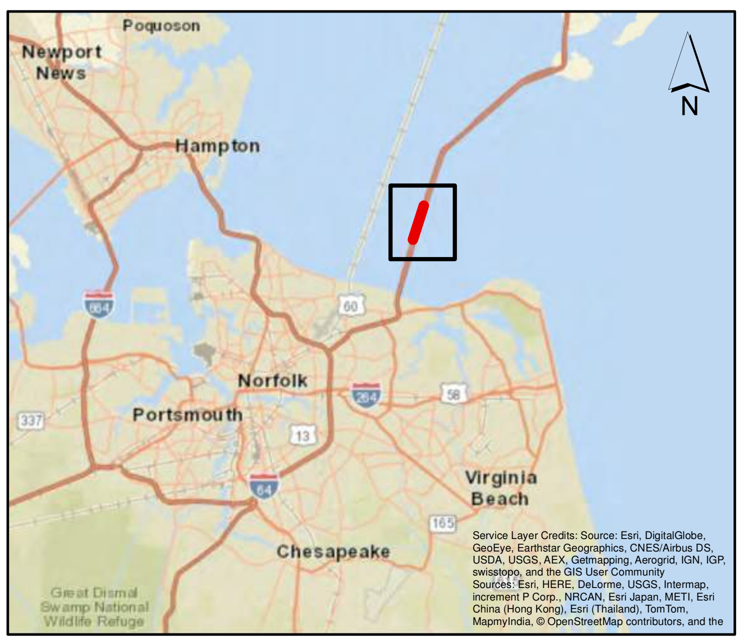


Figure 1. Project Location Map
Chesapeake Bay Bridge and Tunnel District
Thimble Shoal Parallel Tunnel

CHESAPEAKE TUNNEL JV

CHESAPEAKE BAY BRIDGE-TUNNEL

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Figure 2. Permit Level Design Impact Area Plan- Portal Island No. 1

LEGEND – TEMPORARY IMPACTS

- SUBAQUEOUS ROCK STOCKPILE AREA 133,158 SQ. FT. (3.06 ACRES), AREA OUTSIDE BERM FOOTPRINT 24,068 SQ. FT. (0.55 ACRES)
- ROADWAY TRESTLE & TEMPORARY DOCK– MAXIMUM 64, 36" DIA. IN-WATER HOLLOW STEEL PILES, 453 SQ. FT. (0.42 ACRES) SUBAQUEOUS BOTTOM IMPACTS AND A MAXIMUM 47, 36" DIA. HOLLOW STEEL PILE ABOVE MHW (333 SQ. FT.) APPROXIMATELY 34,000 SQ. FT. (0.78 ACRES) FOR DOCKING SUPERSTRUCTURE
- LOCATION TO BE DETERMINED: A MAXIMUM TOTAL OF 12 CONCRETE BLOCK AND/OR DELTA ANCHORS WITH APPROXIMATE 6'X6'X6' DIMENSION (36 SQ. FT. OF BOTTOM IMPACTS) WILL BE PLACED WITHIN ENVIRONMENTAL STUDY LIMIT. 432 SQ. FT. (0.01 ACRES) FOR DOCKING SUPERSTRUCTURE
- TYPICAL SPUD BARGE IMPACTS TO SUBAQUEOUS BOTTOM FOR FISHING PIER REPAIR 203 SQ.FT. (0.005 ACRES)
- TYPICAL SPUD BARGE IMPACTS TO SUBAQUEOUS BOTTOM FOR BRIDGE TRESTLE "A" REPAIR 203 SQ. FT. (0.005 ACRES)
- SETTLEMENT MITIGATION/BERM CONSTRUCTION MAXIMUM 324, 36" DIA. HOLLOW STEEL PILES ABOVE MHW AND MAXIMUM 254, 36" DIA. HOLLOW STEEL PILES BELOW MHW. IMPACT WITHIN BERM FOOTPRINT.
- SETTLEMENT MITIGATION/BERM CONSTRUCTION 152 SHEET PILES (PZC-26) ABOVE MHW (362 L.F.)
- PIEZOMETER (VWP-TBM-PZ#) 3 PIEZOMETER TOTAL OF 3 SQ. FT. BOTTOM IMPACTS
- TYPICAL MOORING CLUSTERS (A.K.A BREASTING DOLPHINS)–EACH CONSISTING OF FIVE 36" DIA HOLLOW STEEL PILES 250 SQ. FT. OF SUBAQUEOUS BOTTOM IMPACT PER CLUSTER (4 CLUSTERS = TOTAL 1,000 SQ. FT. (0.02 ACRES) SUBAQUEOUS BOTTOM IMPACTS)
- MUCK BIN King Pile 1180M-24D (doubles)-11 EA x 111'long IBZ14-770 Sheet Pile West Wall -95 EA x 43'long IBZ14-770 Sheet Pile N/S Wall -11 EA x 43'long IBZ14-770 Sheet Pile East Wall -88 EA x 43'long 17,856 SQ. FT. ABOVE MHW; NO SUBAQUEOUS BOTTOM IMPACT
- TEMPORARY BERM CONSTRUCTION TRESTLE MAXIMUM 80, 36" DIA. IN-WATER HOLLOW STEEL PILES. 566 SQ. FT. (0.01 ACRES) SUBAQUEOUS BOTTOM IMPACTS AND A MAXIMUM 12, 36" DIA. HOLLOW STEEL PILE ABOVE MHW (85 SQ. FT.). APPROXIMATELY 30,580 SQ. FT. (0.70 ACRES) FOR TRESTLE SUPERSTRUCTURE; IMPACT WITHIN BERM FOOTPRINT
- BERM FOUNDATION DREDGING 35,103 SQ. FT.(0.81 ACRES) 6,155 CY.; TEMPORARY IMPACT OUTSIDE BERM FOOTPRINT
- TEMPORARY SPUD BARGE IMPACTS FOR CONSTRUCTION OF TEMPORARY DOCK MAXIMUM 61 SQ. FT. (0.001 ACRES) OF SUBAQUEOUS BOTTOM IMPACT WITHIN A 13,950 SQ. FT. (0.32 ACRES) WORK AREA

LEGEND – PERMANENT IMPACTS

- ENGINEERED BERM ON SUBAQUEOUS BOTTOM (SAND) BELOW MLW 196,456 SQ. FT. (4.51 ACRES)
- ENGINEERED BERM ON SUBAQUEOUS BOTTOM (ROCK) BELOW MLW 64,469 SQ. FT. (1.48 ACRES)
- ENGINEERED BERM ON EXISTING TIDAL NON-VEGETATED WETLANDS (ROCK) MLW TO MHW 1,742 SQ. FT. (0.04 ACRES)
- BRIDGE TRESTLE "A" SUPERSTRUCTURE AND SUBSTRUCTURE MAINTENANCE REPAIR AND/OR REPLACEMENT OF UP TO THIRTY, 54" CONCRETE CYLINDER PILES – 477 SQ. FT. (0.011 ACRES)
- FISHING PIER SUPERSTRUCTURE AND SUBSTRUCTURE MAINTENANCE REPAIR AND/OR REPLACEMENT OF UP TO THIRTY, 54" CONCRETE CYLINDER PILES – 477 SQ. FT. (0.011 ACRES)

NOTES:

- ON WATER WORK AREA FOR BRIDGE TRESTLE "A" REPAIR AND/OR REPLACEMENT – 139,154 SQ. FT. (3.19 ACRES) NO SUBAQUEOUS BOTTOM IMPACTS
- ON WATER WORK AREA FOR FISHING PIER REPAIR AND/OR REPLACEMENT – 59,121 SQ. FT. (1.36 ACRES) NO SUBAQUEOUS BOTTOM IMPACTS
- TOTAL BERM FOUNDATION DREDGING 151,456 SQ. FT.(3.48 ACRES) 48,352 CY.
- ENGINEERED BERM ON EXISTING UPLAND ABOVE MHW 6,970 SQ. FT. (0.16 ACRES); NO SUBAQUEOUS BOTTOM IMPACT

MHW = 2.92' CBBT DATUM
MLW = 0.37' CBBT DATUM
NOTES: MHW/MLW SHOWN AS APPROXIMATE LOCATIONS, ADDITIONAL SURVEY DATA REQUIRED.

120 60 0 120 240
SCALE IN FEET

NO.	DATE	BY	APP.	REVISION

SUBMISSION TYPE:

FILE NAME
JOB NO.

CHESAPEAKE TUNNEL JV
2377 FERRY ROAD
VIRGINIA BEACH, VA 23455

COMMONWEALTH OF VIRGINIA
CHESAPEAKE BAY BRIDGE AND TUNNEL DISTRICT

PARALLEL THIMBLE SHOAL TUNNEL
TO
LUCIUS J. KELLAM, JR. BRIDGE-TUNNEL

CTJV PERMIT UPDATE
PORTAL ISLAND #1

DRAWN BY: MH	DATE: 3/06/19	DWG. NO.
CHECKED BY:	SCALE: AS NOTED	SHEET 1 OF 2

Figure 3. Permit Level Design Impact Area Plan- Portal Island No. 2

LEGEND – TEMPORARY IMPACTS

- LOCATION TO BE DETERMINED — A MAXIMUM TOTAL OF 12 CONCRETE BLOCK AND/OR DELTA ANCHORS WITH APPROXIMATE 6'X6'X6' DIMENSION (36 SQ. FT. OF BOTTOM IMPACTS) WILL BE PLACED WITHIN ENVIRONMENTAL STUDY LIMIT. 432 SQ. FT. (0.01 ACRES) OF SUBAQUEOUS BOTTOM IMPACTS.
- TYPICAL SPUD BARGE IMPACTS TO SUBAQUEOUS BOTTOM FOR BRIDGE TRESTLE "B" REPAIR 189 SQ. FT. (0.004 ACRES)
- TEMPORARY BERM CONSTRUCTION TRESTLE AND TEMPORARY MOORINGS MAXIMUM 80, 36" DIA. IN-WATER HOLLOW STEEL PILES. 566 SQ. FT. (0.01 ACRES) SUBAQUEOUS BOTTOM IMPACTS AND A MAXIMUM 12, 36" DIA. HOLLOW STEEL PILE ABOVE MHW (85 SQ. FT.). APPROXIMATELY 28,432 SQ. FT. (0.65 ACRES) FOR TRESTLE SUPERSTRUCTURE; IMPACT WITHIN BERM FOOTPRINT
- SETTLEMENT MITIGATION/BERM CONSTRUCTION MAXIMUM 324, 36" DIA. HOLLOW STEEL PILES ABOVE MHW AND MAXIMUM 254, 36" DIA. HOLLOW STEEL PILES BELOW MHW. IMPACT WITHIN BERM FOOTPRINT.
- SETTLEMENT MITIGATION/BERM CONSTRUCTION 152 SHEET PILES (PZC-26) ABOVE MHW (362 LF)
- PIEZOMETER (VWP-TBM-PZ#) 3 PIEZOMETERS TOTAL OF 3 SQ. FT. OF SUBAQUEOUS BOTTOM IMPACTS
- TYPICAL MOORING CLUSTERS (A.K.A BREASTING DOLPHINS)– EACH CONSISTING OF FIVE 36" DIA HOLLOW STEEL PILES 250 SQ. FT. OF SUBAQUEOUS BOTTOM IMPACT PER CLUSTER (2 CLUSTERS = TOTAL 500 SQ. FT. (0.01 ACRES) SUBAQUEOUS BOTTOM IMPACTS) EXACT LOCATION TO BE VERIFIED IN THE FIELD

LEGEND – PERMANENT IMPACTS

- ENGINEERED BERM ON SUBAQUEOUS BOTTOM (SAND) BELOW MLW – 183,388 SQ. FT. (4.21 ACRES)
- ENGINEERED BERM ON SUBAQUEOUS BOTTOM (ROCK) BELOW MLW – 58,806 SQ. FT. (1.35 ACRES)
- ENGINEERED BERM ON EXISTING TIDAL NON-VEGATATED WETLANDS (ROCK) MLW TO MHW – 2,614 SQ. FT. (0.06 ACRES)
- BRIDGE TRESTLE "B" SUPERSTRUCTURE AND SUBSTRUCTURE MAINTENANCE REPAIR AND/OR REPLACEMENT OF UP TO TWENTY-EIGHT, 54" CONCRETE CYLINDER PILES – 445 SQ. FT. (0.01 ACRES)

NOTES:

- TEMPORARY ROADWAY TRESTLE MAXIMUM 10, 36" DIA. HOLLOW STEEL PILES ABOVE MHW (71 SQ. FT.). APPROXIMATELY 4,865 SQ. FT. (0.11 ACRES) FOR ROADWAY TRESTLE SUPERSTRUCTURE. NO SUBAQUEOUS BOTTOM IMPACTS
- ON WATER WORK AREA FOR BRIDGE TRESTLE "B" SUPERSTRUCTURE REPAIR AND/OR REPLACEMENT – 77,683 SQ. FT. (1.78 ACRES) NO SUBAQUEOUS BOTTOM IMPACTS
- ENGINEERED BERM ON EXISTING UPLANDS ABOVE MHW 9,583 SQ. FT. (0.22 ACRES); NO SUBAQUEOUS BOTTOM IMPACTS

SUBMISSION TYPE:	NO.	DATE	BY	APP.	REVISION

CHESAPEAKE TUNNEL JV
2377 FERRY ROAD
VIRGINIA BEACH, VA 23455

COMMONWEALTH OF VIRGINIA
CHESAPEAKE BAY BRIDGE AND TUNNEL DISTRICT

PARALLEL THIMBLE SHOAL TUNNEL
TO
LUCIUS J. KELLAM, JR. BRIDGE-TUNNEL

CTJV PERMIT UPDATE
PORTAL ISLAND #2

DRAWN BY: MH	DATE: 03/06/19	DWG. NO.
CHECKED BY:	SCALE:	SHEET 2 OF 2

FILE NAME
JOB NO.

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Figure 4. Optional User Spreadsheet Calculations: IMPULSIVE 4 Piles/Day

E.1: IMPACT PILE DRIVING (STATIONARY SOURCE: Impulsive, Intermittent)

VERSION 2.1: 2020

KEY

(green)	**Action Proponent Provided Information**
(pink)	**NMFS Provided Information (Technical Guidance)**
(blue)	**Resultant Isopleth**

STEP 1: GENERAL PROJECT INFORMATION

PROJECT TITLE	Chesapeake Bay Bridge-Tunnel, Impact Installation
PROJECT/SOURCE INFORMATION	Caltrans 2020, applies to both 36 and 42 inch steel pipe piles. Conservative proxy using highest 36" impact levels, with bubble curtain, assuming 6dB reduction

Please include any assumptions

PROJECT CONTACT	Sarah Falin, 757-334-9318

STEP 2: WEIGHTING FACTOR ADJUSTMENT

		Specify if relying on source-specific WFA, alternative weighting/dB adjustment, or if using default value
Weighting Factor Adjustment (kHz)¥	2	

¥ Broadband: 95% frequency contour percentile (kHz); For appropriate default WFA: See INTRODUCTION tab

† If a user relies on alternative weighting/dB adjustment rather than relying upon the WFA (source-specific or default), they may override the Adjustment (dB) (row 73), and enter the new value directly. However, they must provide additional support and documentation supporting this modification.

STEP 3: SOURCE-SPECIFIC INFORMATION

NOTE: METHOD E.1-1 is PREFERRED method when SEL-based source levels are available (because pulse duration is not required). Only use method E.1-2 if SEL-based source levels are not av

E.1-1: METHOD TO CALCULATE PK AND SEL_{cum} (SINGLE STRIKE EQUIVALENT) **PREFERRED METHOD (pulse duration not needed)**

Unweighted SEL_{cum} (at measured distance) = SEL_{ss} + 10 Log (# strikes)	**213.0**

SEL_{cum}

Single Strike SEL_{ss} ($L_{E,p,\text{single strike}}$) specified at "x" meters (Cell B32)	177
Number of strikes per pile	1000
Number of piles per day	4
Transmission loss coefficient	15
Distance of single strike SEL_{ss} ($L_{E,p,\text{single strike}}$) measurement (meters)	10

PK

$L_{p,0\text{-pk}}$ specified at "x" meters (Cell G29)	203
Distance of $L_{p,0\text{-pk}}$ measurement (meters)*	10
$L_{p,0\text{-pk}}$ Source level	218.0

RESULTANT ISOPLETHS*

*Impulsive sounds have dual metric thresholds (SELcum & PK). Metric producing largest isopleth should be used.

Hearing Group	Low-Frequency Cetaceans	Mid-Frequency Cetaceans	High-Frequency Cetaceans	Phocid Pinnipeds	Otariid Pinnipeds
SEL_{cum} Threshold	183	185	155	185	203
PTS Isopleth to threshold (meters)	**1,001.8**	**35.6**	**1,193.3**	**536.1**	**39.0**
PK Threshold	219	230	202	218	232
PTS PK Isopleth to threshold (meters)	**NA**	**NA**	**11.7**	**NA**	**NA**

"NA": PK source level is < to the threshold for that marine mammal hearing group.

E.1-2: METHOD TO CALCULATE PK AND SEL_{cum} (USING RMS SPL SOURCE LEVEL)

SEL_{cum}

Sound Pressure Level (L_{rms}), specified at "x" meters (Cell B53)	193
Number of piles per day	6
Strike (pulse) Duration^ (seconds)	0.1
Number of strikes per pile	1000
Duration of Sound Production (seconds)	600
10 Log (duration of sound production)	27.78
Transmission loss coefficient	15
Distance of sound pressure level (L_{rms}) measurement (meters)	10

^Window that makes up 90% of total cumulative energy (5%-95%) based on Madsen 2005

PK

$L_{p,0\text{-pk}}$ specified at "x" meters (Cell G47)	210
Distance of $L_{p,0\text{-pk}}$ measurement (meters)*	10
$L_{p,0\text{-pk}}$ Source level	225.0

NOTE: The User Spreadsheet tool provides a means to estimates distances associated with the Technical Guidance's PTS onset thresholds. Mitigation and monitoring requirements associated with a Marine Mammal Protection Act (MMPA) authorization or an Endangered Species Act (ESA) consultation or permit are independent management decisions made in the context of the proposed activity and comprehensive effects analysis, and are beyond the scope of the Technical Guidance and the User Spreadsheet tool.

RESULTANT ISOPLETHS*

*Impulsive sounds have dual metric thresholds (SELcum & PK). Metric producing largest isopleth should be used.

Hearing Group	Low-Frequency Cetaceans	Mid-Frequency Cetaceans	High-Frequency Cetaceans	Phocid Pinnipeds	Otariid Pinnipeds
SEL_{cum} Threshold	183	185	155	185	203
PTS Isopleth to threshold (meters)	**3,297.4**	**117.3**	**3,927.7**	**1,764.6**	**128.5**
PK Threshold	219	230	202	218	232
PTS PK Isopleth to threshold (meters)	**2.5**	**NA**	**34.1**	**2.9**	**NA**

"NA": PK source level is < to the threshold for that marine mammal hearing group.

WEIGHTING FUNCTION CALCULATIONS

Weighting Function Parameters	Low-Frequency Cetaceans	Mid-Frequency Cetaceans	High-Frequency Cetaceans	Phocid Pinnipeds	Otariid Pinnipeds
a	1	1.6	1.8	1	2
b	2	2	2	2	2
f_1	0.2	8.8	12	1.9	0.94
f_2	19	110	140	30	25
C	0.13	1.2	1.36	0.75	0.64
Adjustment (-dB)†	**-0.01**	**-19.74**	**-26.87**	**-2.08**	**-1.15**

NOTE: If user decided to ov they need to make sure to d to ensure the built-in calcul

$$W(f) = C + 10\log_{10}\left\{\frac{(f/f_1)^{2a}}{[1+(f/f_1)^2]^a[1+(f/f_2)^2]^b}\right\}$$

Figure 5. Optional User Spreadsheet Calculations: VIBRATORY 4 Piles/ Day

A.1: Vibratory Pile Driving (STATIONARY SOURCE: Non-Impulsive, Continuous)

VERSION 2.1: 2020

KEY

(green)	**Action Proponent Provided Information**
(pink)	**NMFS Provided Information (Technical Guidance)**
(blue)	**Resultant Isopleth**

STEP 1: GENERAL PROJECT INFORMATION

PROJECT TITLE	Chesapeake Bay Bridge-Tunnel, Vibratory Installation
PROJECT/SOURCE INFORMATION	Caltrans 2020, Applies to 36 and 42" Piles, base level 170 RMS/170SEL, 6dB attenuation from bubble curtains, ambient noise 122.78

Please include any assumptions

PROJECT CONTACT	Sarah Falin, 757-334-9318

STEP 2: WEIGHTING FACTOR ADJUSTMENT

		Specify if relying on source-specific WFA, alternative weighting/dB adjustment, or if using default value
Weighting Factor Adjustment (kHz)[¥]	2.5	

[¥] Broadband: 95% frequency contour percentile (kHz) OR Narrowband: frequency (kHz); For appropriate default WFA: See INTRODUCTION tab

† If a user relies on alternative weighting/dB adjustment rather than relying upon the WFA (source-specific or default), they may override the Adjustment (dB) (row 48), and enter the new value directly. However, they must provide additional support and documentation supporting this modification.

STEP 3: SOURCE-SPECIFIC INFORMATION

Sound Pressure Level (L_{rms}), specified at "x" meters (Cell B30)	164
Number of piles within 24-h period	4
Duration to drive a single pile (minutes)	12
Duration of Sound Production within 24-h period (seconds)	2880
10 Log (duration of sound production)	34.59
Transmission loss coefficient	15
Distance of sound pressure level (L_{rms}) measurement (meters)	10

NOTE: The User Spreadsheet tool provides a means to estimates distances associated with the Technical Guidance's PTS onset thresholds. Mitigation and monitoring requirements associated with a Marine Mammal Protection Act (MMPA) authorization or an Endangered Species Act (ESA) consultation or permit are independent management decisions made in the context of the proposed activity and comprehensive effects analysis, and are beyond the scope of the Technical Guidance and the User Spreadsheet tool.

RESULTANT ISOPLETHS

Hearing Group	Low-Frequency Cetaceans	Mid-Frequency Cetaceans	High-Frequency Cetaceans	Phocid Pinnipeds	Otariid Pinnipeds
SEL_{cum} Threshold	199	198	173	201	219
PTS Isopleth to threshold (meters)	**9.3**	**0.8**	**13.8**	**5.7**	**0.4**

WEIGHTING FUNCTION CALCULATIONS

Weighting Function Parameters	Low-Frequency Cetaceans	Mid-Frequency Cetaceans	High-Frequency Cetaceans	Phocid Pinnipeds	Otariid Pinnipeds
a	1	1.6	1.8	1	2
b	2	2	2	2	2
f_1	0.2	8.8	12	1.9	0.94
f_2	19	110	140	30	25
C	0.13	1.2	1.36	0.75	0.64
Adjustment (-dB)†	**-0.05**	**-16.83**	**-23.50**	**-1.29**	**-0.60**

NOTE: If user decided to override tl
they need to make sure to downloa
to ensure the built-in calculations fu

$$W(f) = C + 10\log_{10}\left\{\frac{(f/f_1)^{2a}}{[1+(f/f_1)^2]^a[1+(f/f_2)^2]^b}\right\}$$

Figure 6. Optional User Spreadsheet Calculations: DTH 3 Piles/ Day

E.2: DTH PILE DRIVING/INSTALLATION (STATIONARY SOURCE: Impulsive, Intermittent)

VERSION 2.2: 2020

KEY

(green)	**Action Proponent Provided Information**
(pink)	**NMFS Provided Information (Technical Guidance)**
(blue)	**Resultant Isopleth**

STEP 1: GENERAL PROJECT INFORMATION

PROJECT TITLE	CTJV , Single DTH Installation
PROJECT/SOURCE INFORMATION	Dense et al 2019, NOAA Draft DTH Guidance

CTJV , Single DTH Installation

Please include any assumptions

PROJECT CONTACT	Sarah Falin

STEP 2: WEIGHTING FACTOR ADJUSTMENT

Specify if relying on source-specific WFA, alternative weighting/dB adjustment, or if using default value

Weighting Factor Adjustment (kHz)[¥]	2	

[¥] Broadband: 95% frequency contour percentile (kHz); For appropriate default WFA: See INTRODUCTION tab

† If a user relies on alternative weighting/dB adjustment rather than relying upon the WFA (source-specific or default), they may override the Adjustment (dB) (row 50), and enter the new value directly However, they must provide additional support and documentation supporting this modificatio

STEP 3: SOURCE-SPECIFIC INFORMATION

Unweighted $SEL_{cum\ (at\ measured\ distance)}$ = SEL_{ss} + 10 Log (# strikes)	**220.3**

SEL_{cum}

Single Strike SEL_{ss} ($L_{E,p,\ single\ strike}$) specified at "x" meters (Cell B30)	170
Strike rate (average strikes per second)	20
Duration to drive pile (minutes)	30
Number of piles per day	3
Transmission loss coefficient	15
Distance of single strike SEL_{ss} ($L_{E,p,\ single\ strike}$) measurement (meters)	10
Total number of strikes in a 24-h period	108000

PK

$L_{p,0\text{-}pk}$ specified at "x" meters (Cell G26)	194
Distance of $L_{p,0\text{-}pk}$ measurement (meters)⁺	10
$L_{p,0\text{-}pk}$ Source level	209.0

RESULTANT ISOPLETHS*

*Impulsive sounds have dual metric thresholds (SELcum & PK). Metric producing largest isopleth should be used.

Hearing Group	Low-Frequency Cetaceans	Mid-Frequency Cetaceans	High-Frequency Cetaceans	Phocid Pinnipeds	Otariid Pinnipeds
SEL_{cum} Threshold	183	185	155	185	203
PTS Isopleth to threshold (meters)	**3,078.6**	**109.5**	**3,667.1**	**1,647.5**	**120.0**
PK Threshold	219	230	202	218	232
PTS PK Isopleth to threshold (meters)	**NA**	**NA**	**2.9**	**NA**	**NA**

"NA": PK source level is ≤ to the threshold for that marine mammal hearing group.

WEIGHTING FUNCTION CALCULATIONS

Weighting Function Parameters	Low-Frequency Cetaceans	Mid-Frequency Cetaceans	High-Frequency Cetaceans	Phocid Pinnipeds	Otariid Pinnipeds
a	1	1.6	1.8	1	2
b	2	2	2	2	2
f_1	0.2	8.8	12	1.9	0.94
f_2	19	110	140	30	25
C	0.13	1.2	1.36	0.75	0.64
Adjustment (-dB)†	**-0.01**	**-19.74**	**-26.87**	**-2.08**	**-1.15**

NOTE: If user decided to override these Adjustment values, they need to make sure to download another copy to ensure the built-in calculations function properly.

$$W(f) = C + 10\log_{10}\left\{\frac{(f/f_1)^{2a}}{[1+(f/f_1)^2]^a[1+(f/f_2)^2]^b}\right\}$$

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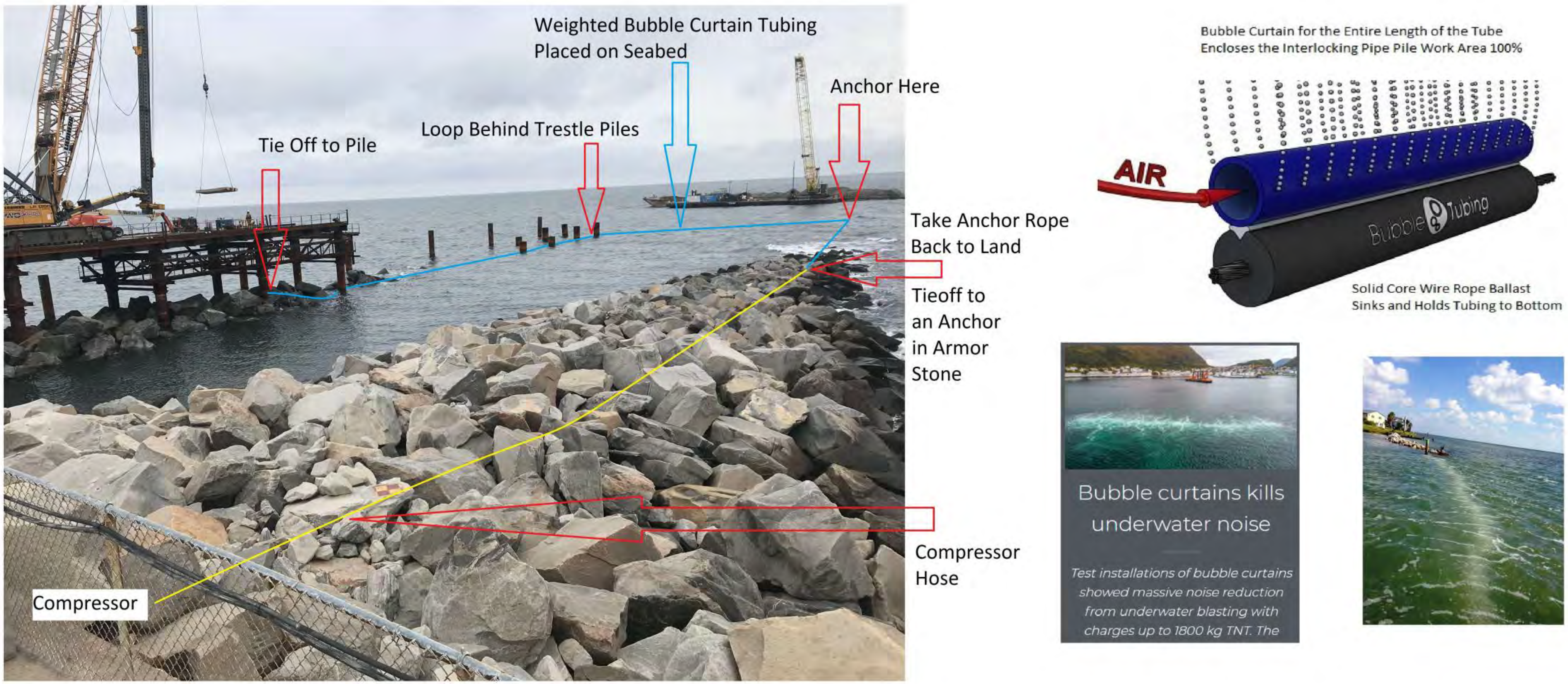
Figure 7 . NOAA Approved Alternative Bubble Curtain for Interlocking Pipe Piles

Bubble Curtain for Interlocking Pipe Pile on North End of Island One



Bubble Curtain Encloses Work Area Where Earth Doesn't, Enclosing the Work Area 100%

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Figure 8. Island No. 1 Level A Harassment: DTH 3 Piles/Day

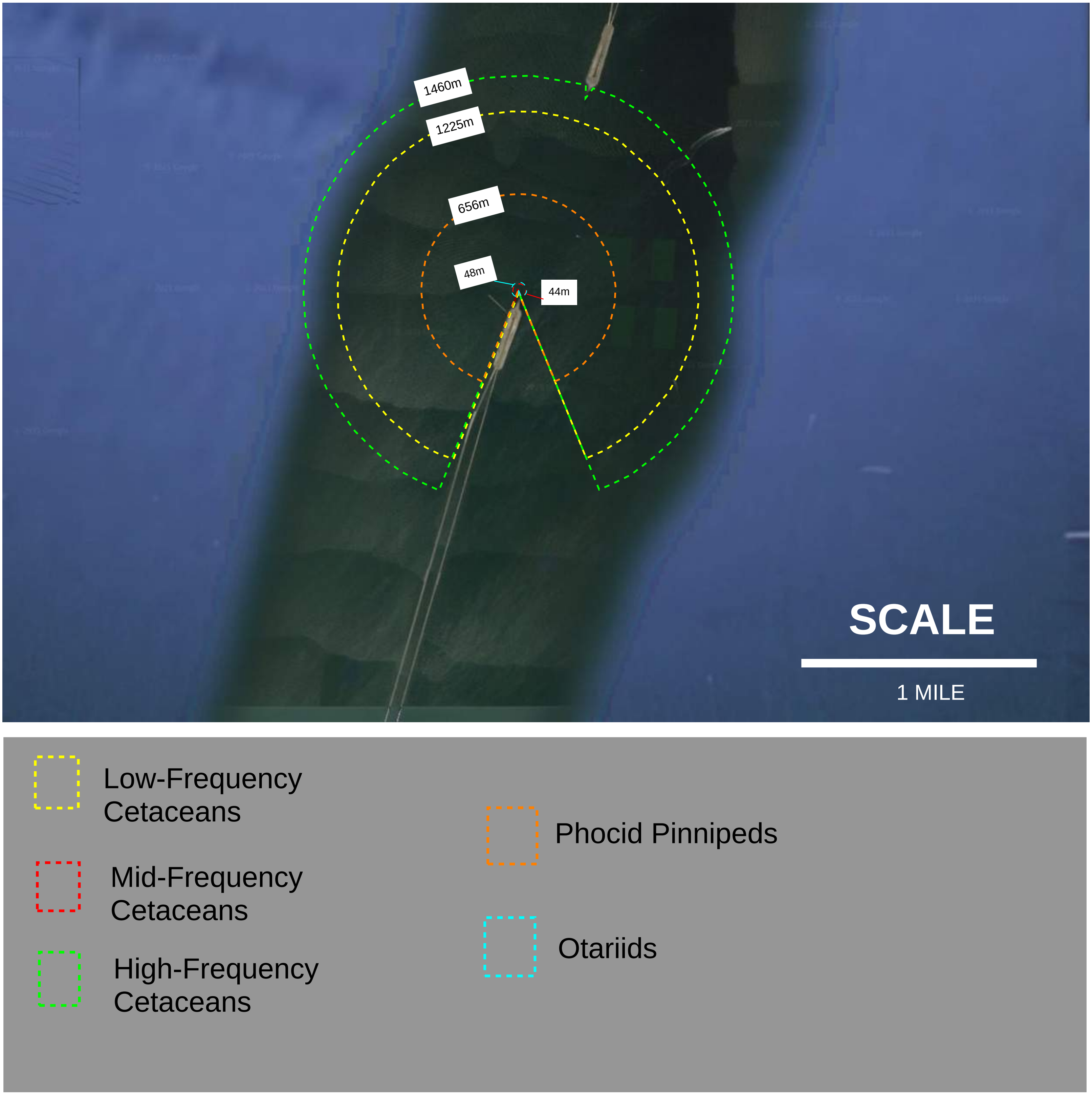


Figure 9. Island No. 1 Level A Harassment Impact: 4 Piles/ Day

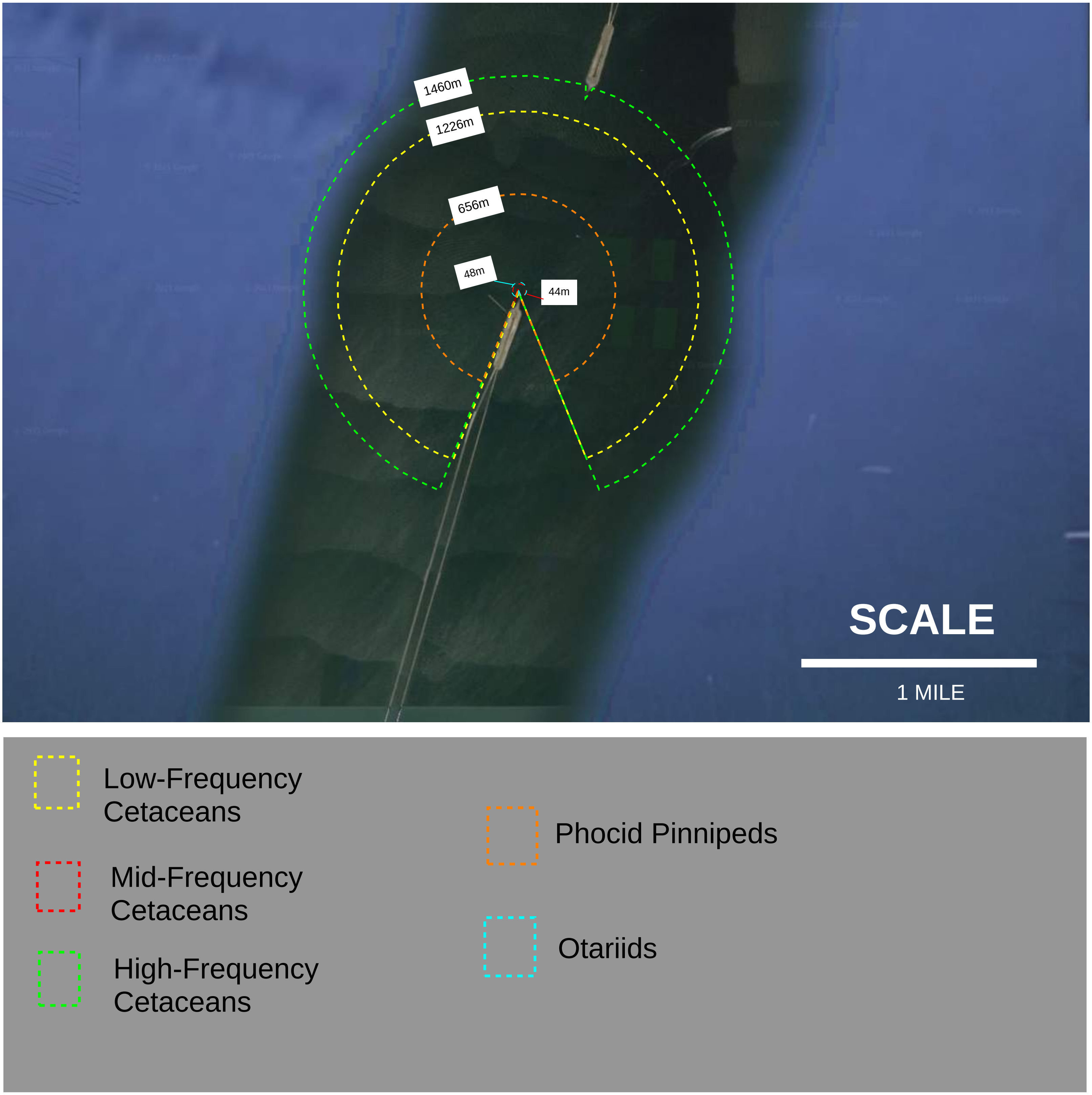


Figure 10. Island No. 1 Level A Harassment Impact: 6 Piles/Day

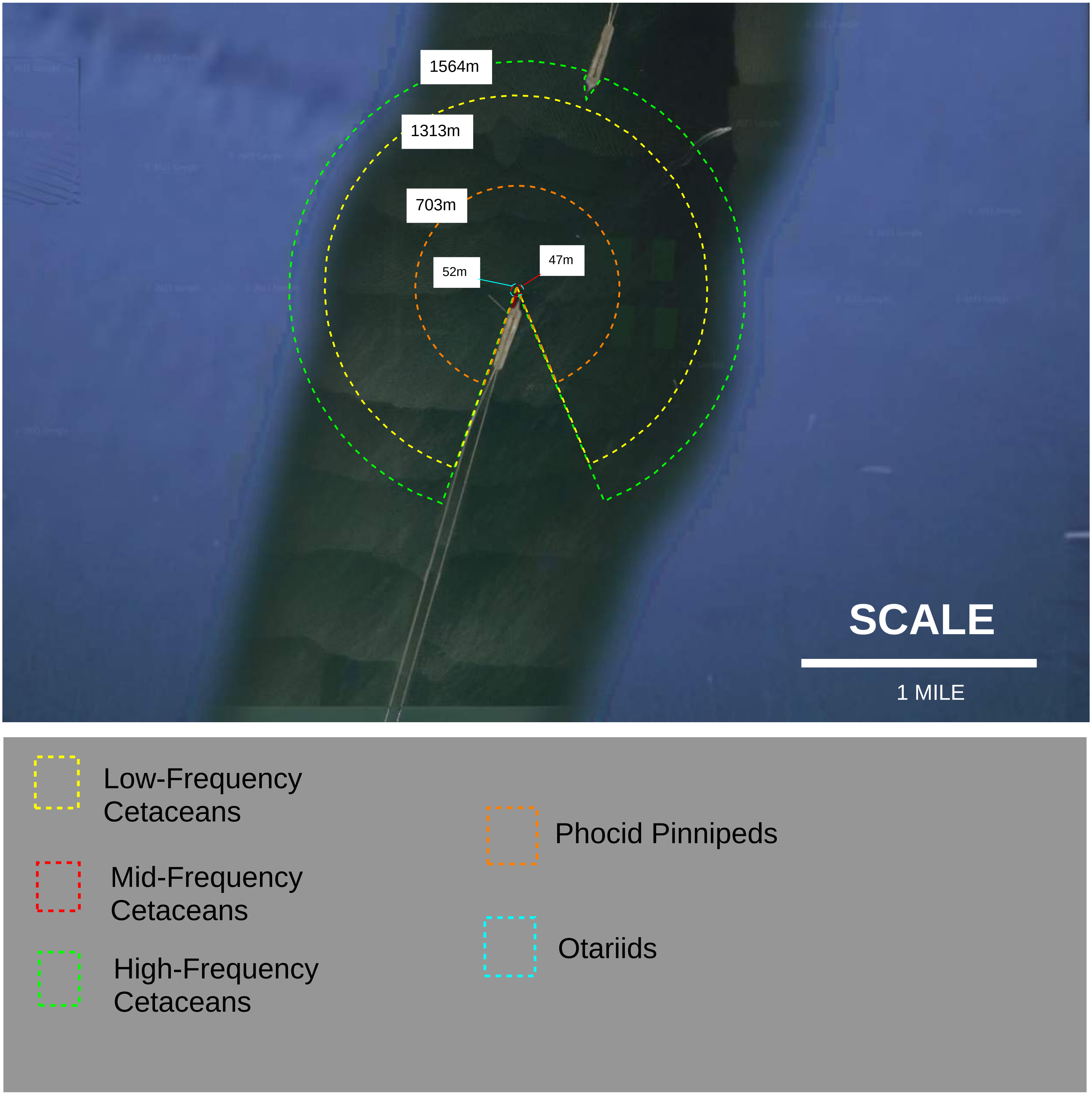


Figure 11. Island No. 2 Level A Harassment: DTH 3 Piles/Day

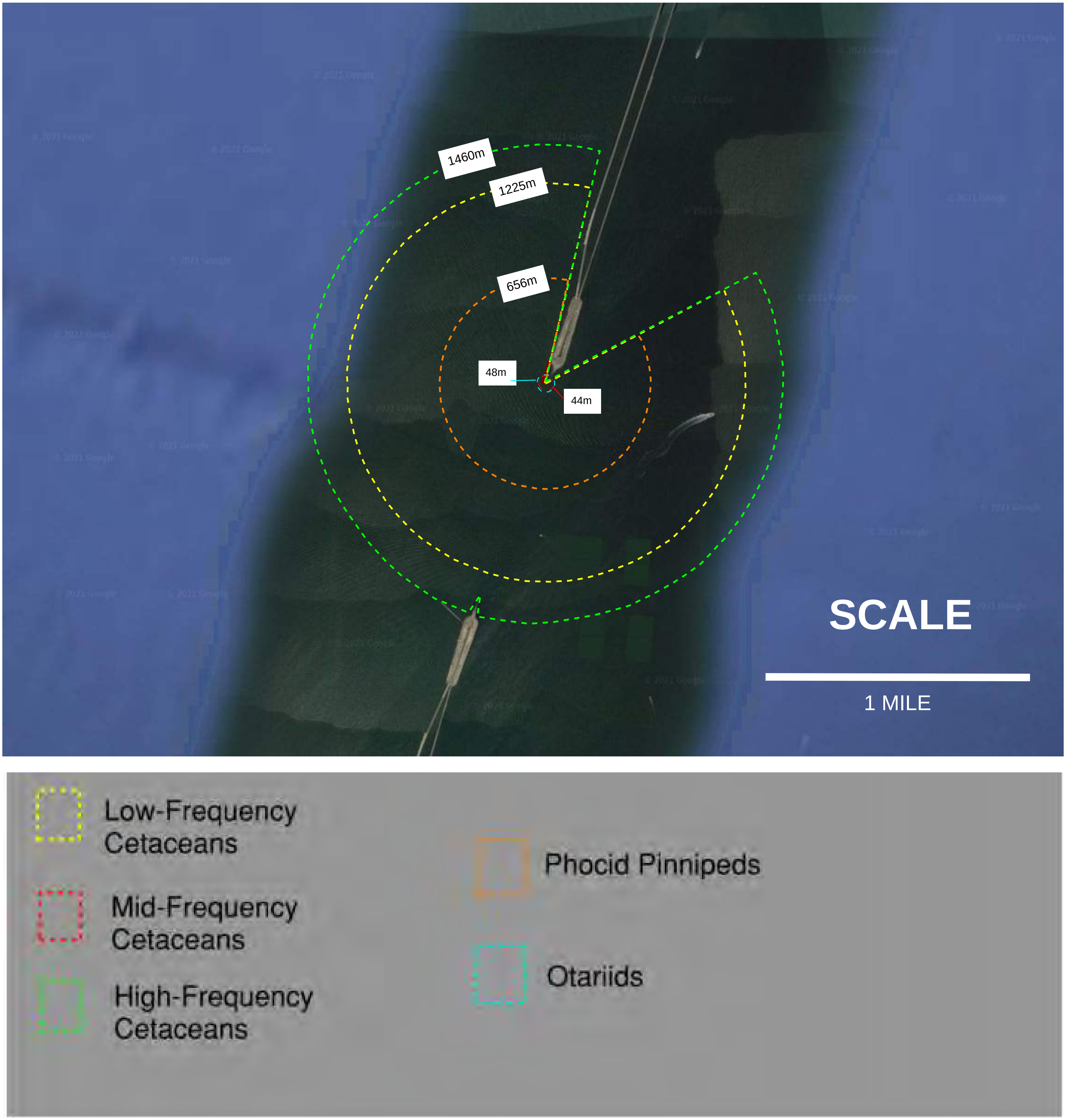


Figure 12. Island No. 2 Level A Harassment Impact 4 Piles/Day

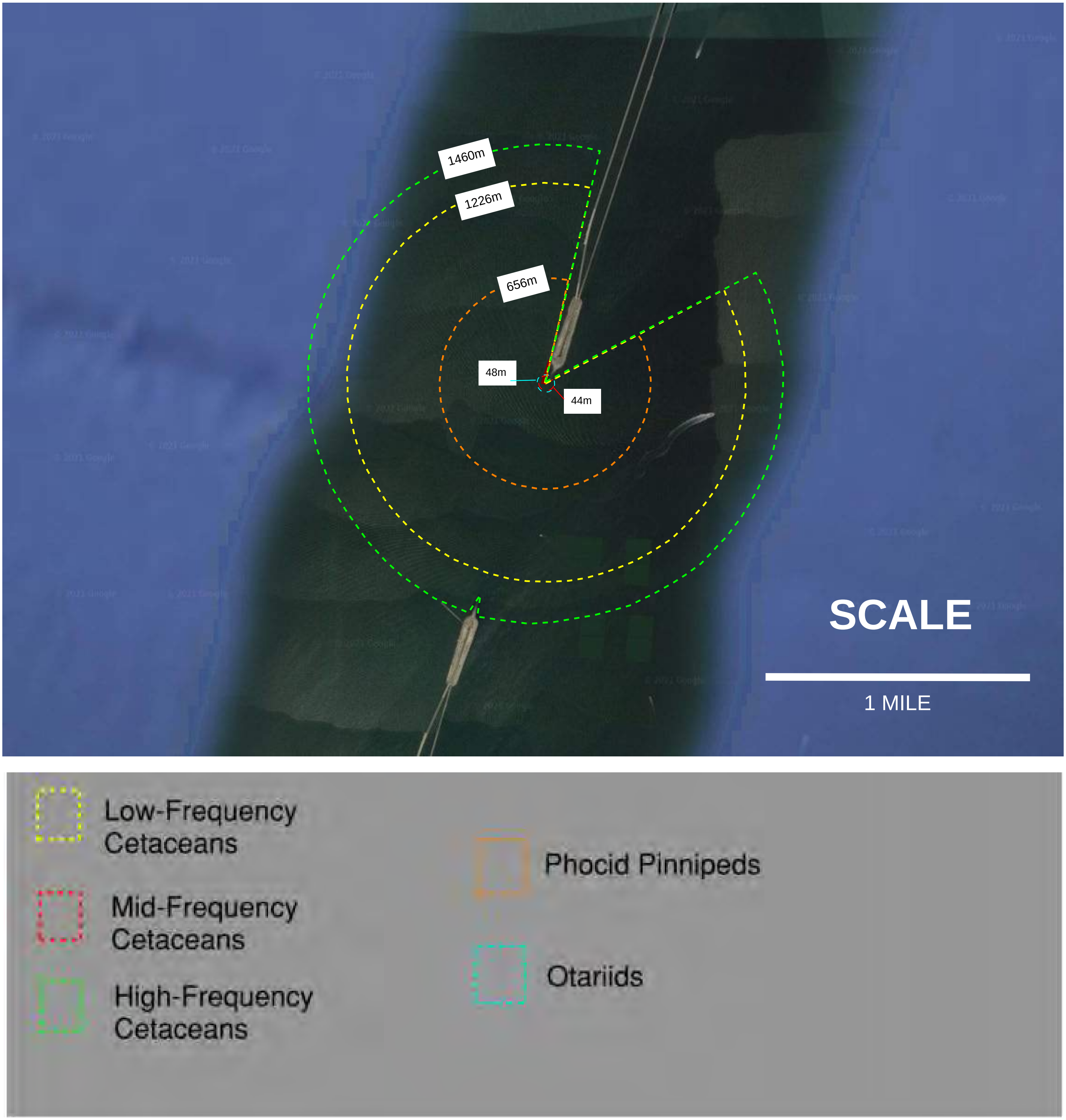


Figure 13. Island No. 2 Level A Harassment Impact: 6 Piles/Day

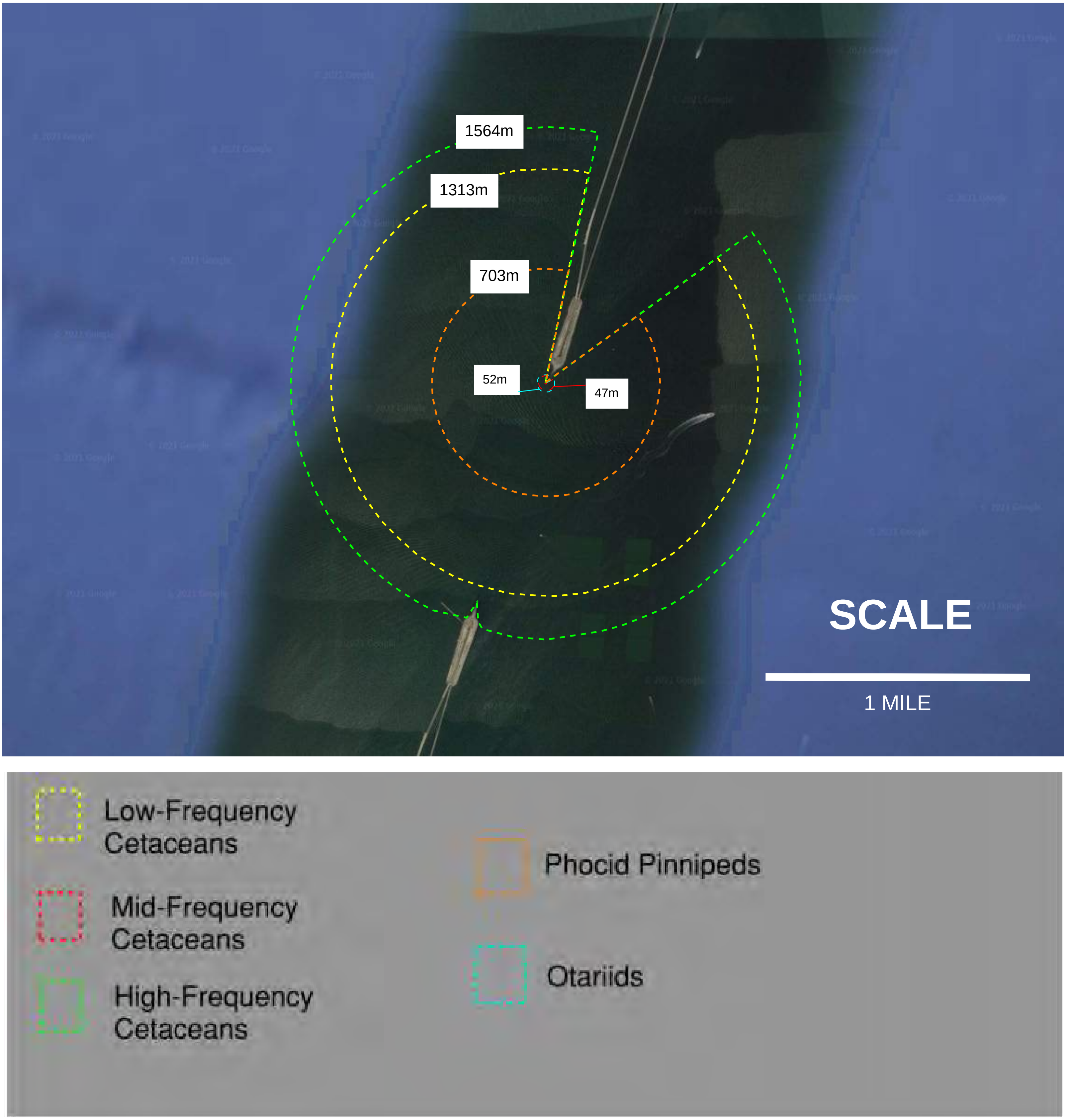


Figure 14. Island No. 1 Level B Harassment Zones

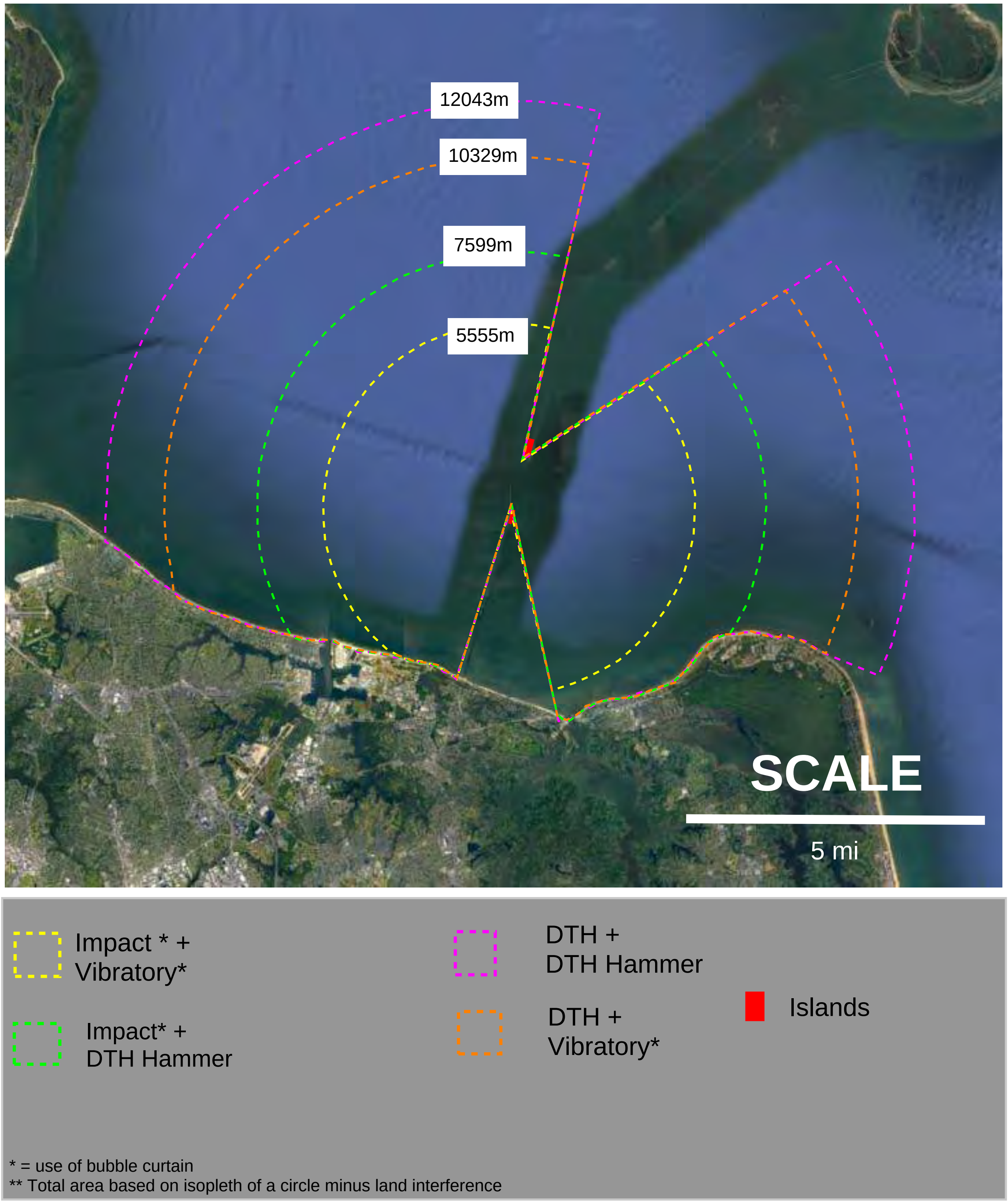


Figure 15. Island 2 Level B Harassment Zones

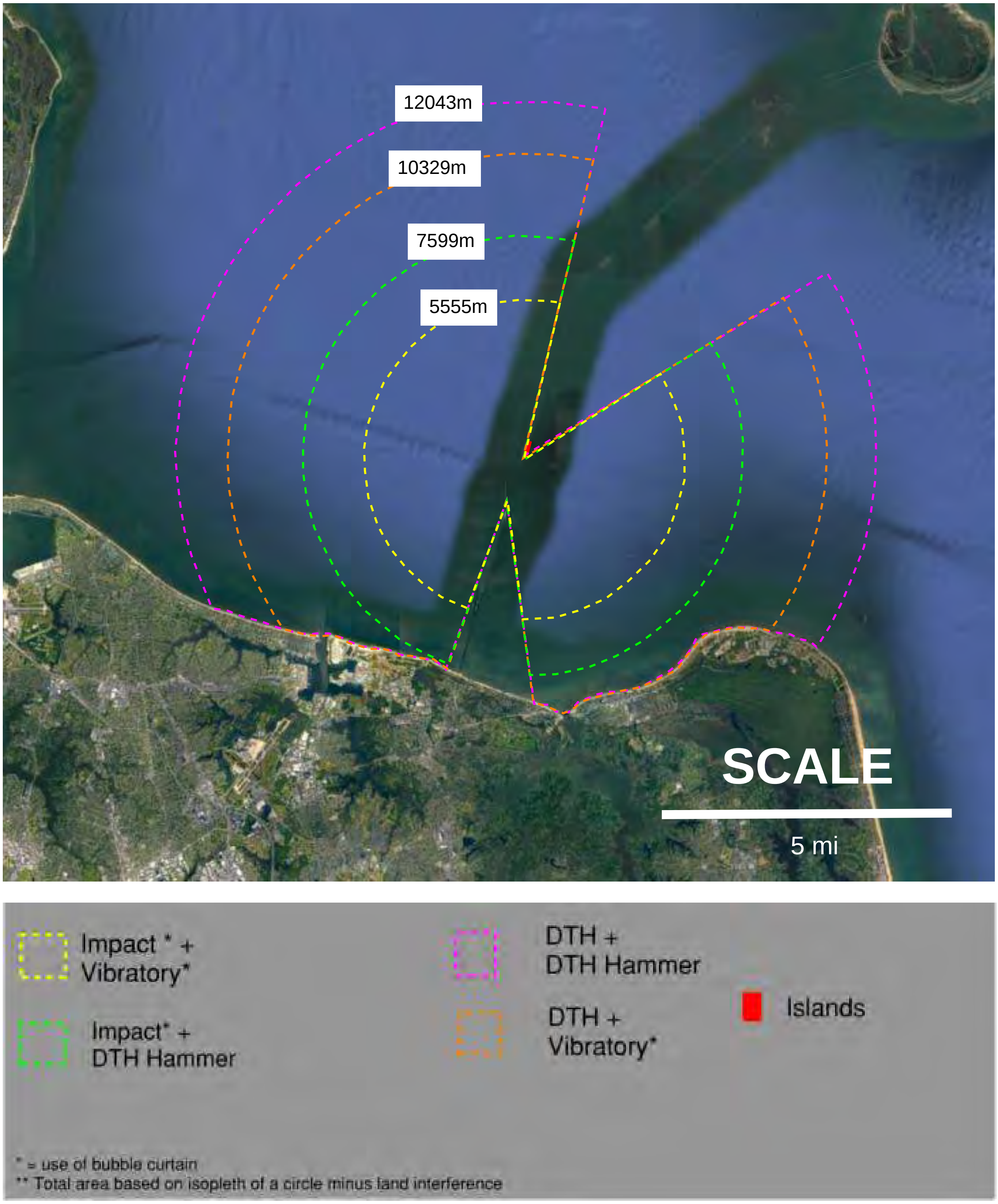
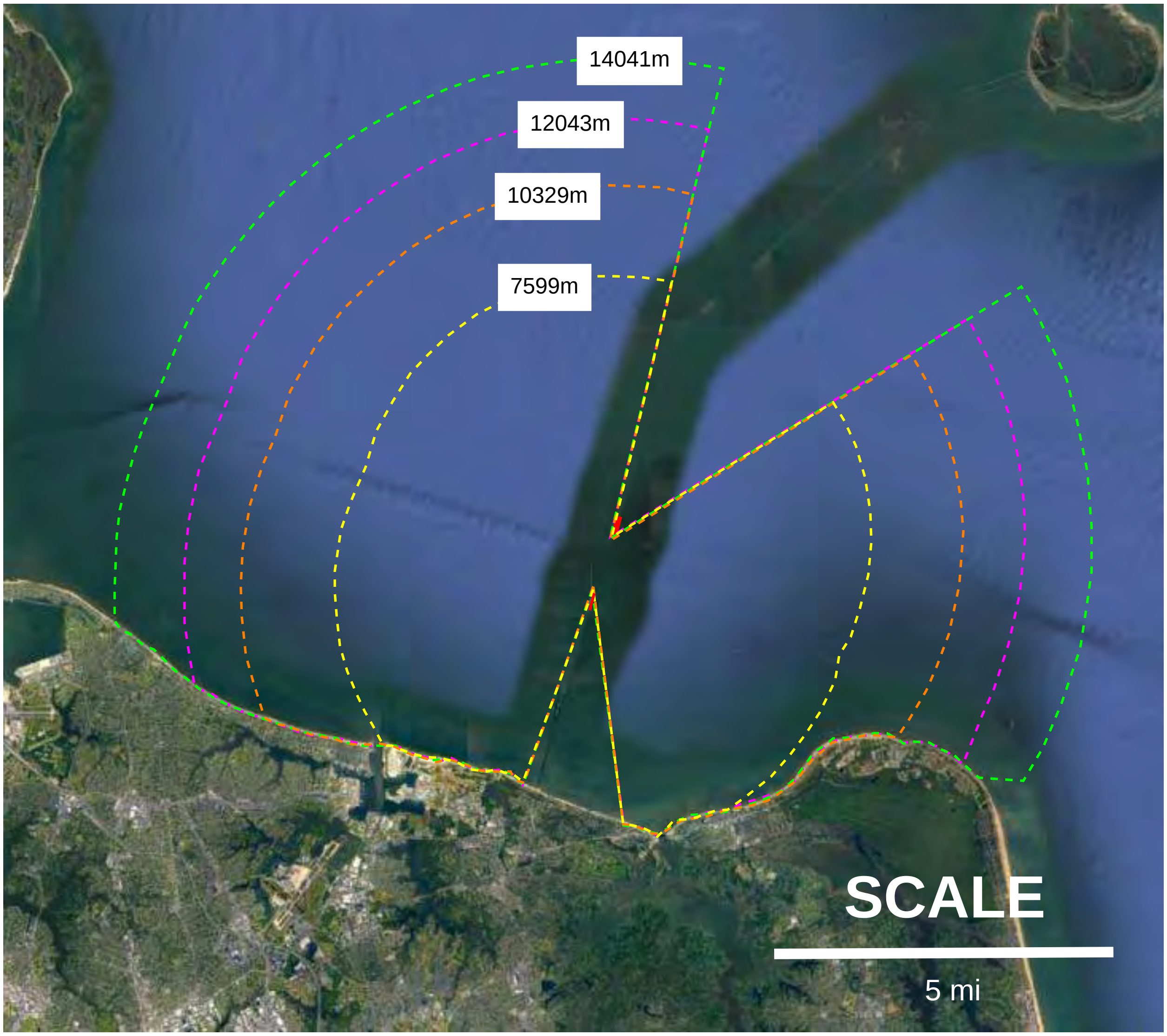


Figure 16. Level B Impact Area for Simultaneous Driving On Both Islands Per Driving Scenario



DTH + Impact* + Impact*

Dual DTH + Impact* Hammer

DTH + Vibratory* + Impact*

Dual DTH + Vibratory

* = Use of bubble curtain
** Total area based on isopleth of a circle minus land interference

Figure 17. Island No. 1 Shutdown Zones

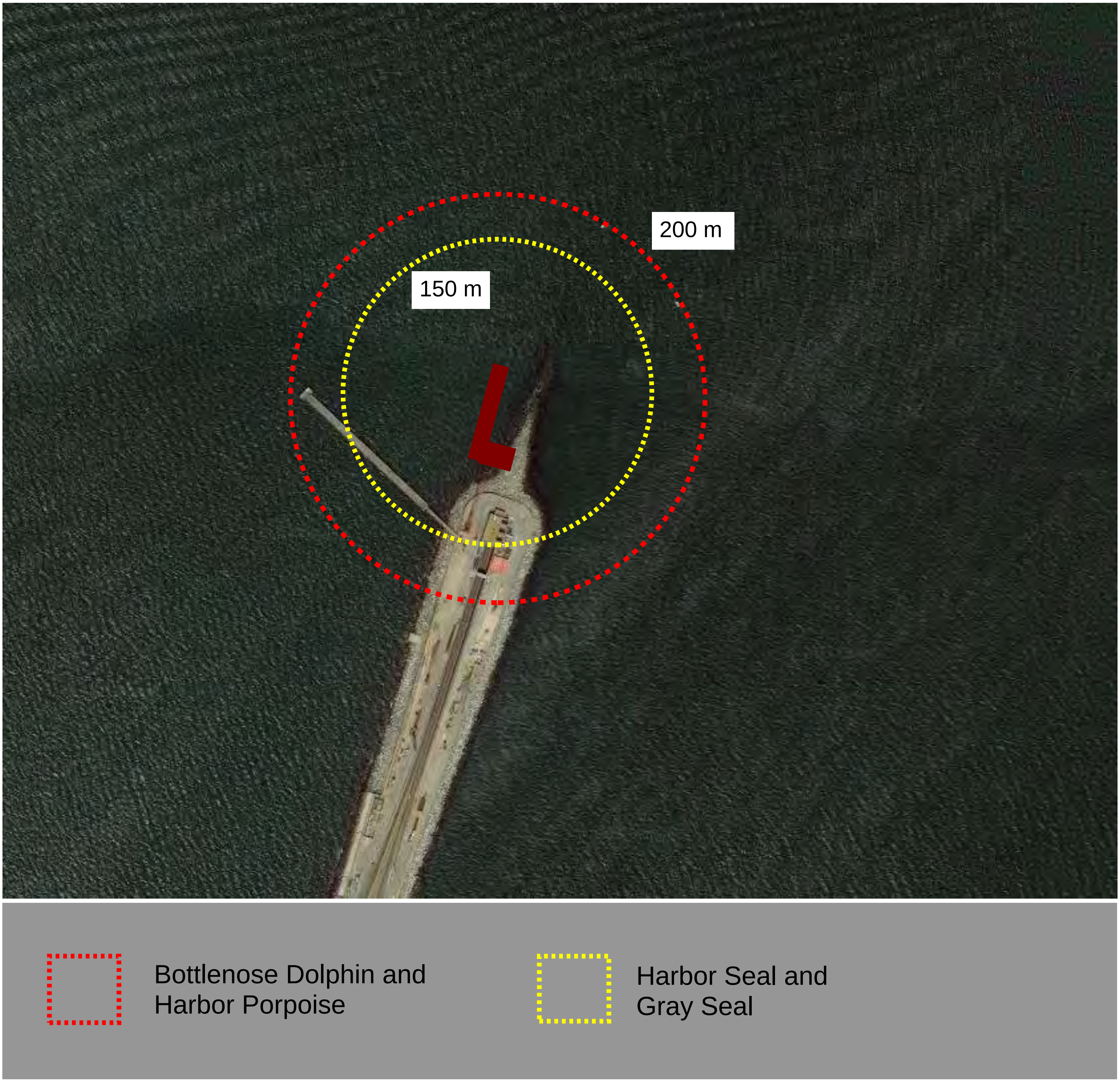


Figure 18. Island No. 2 Shutdown Zones

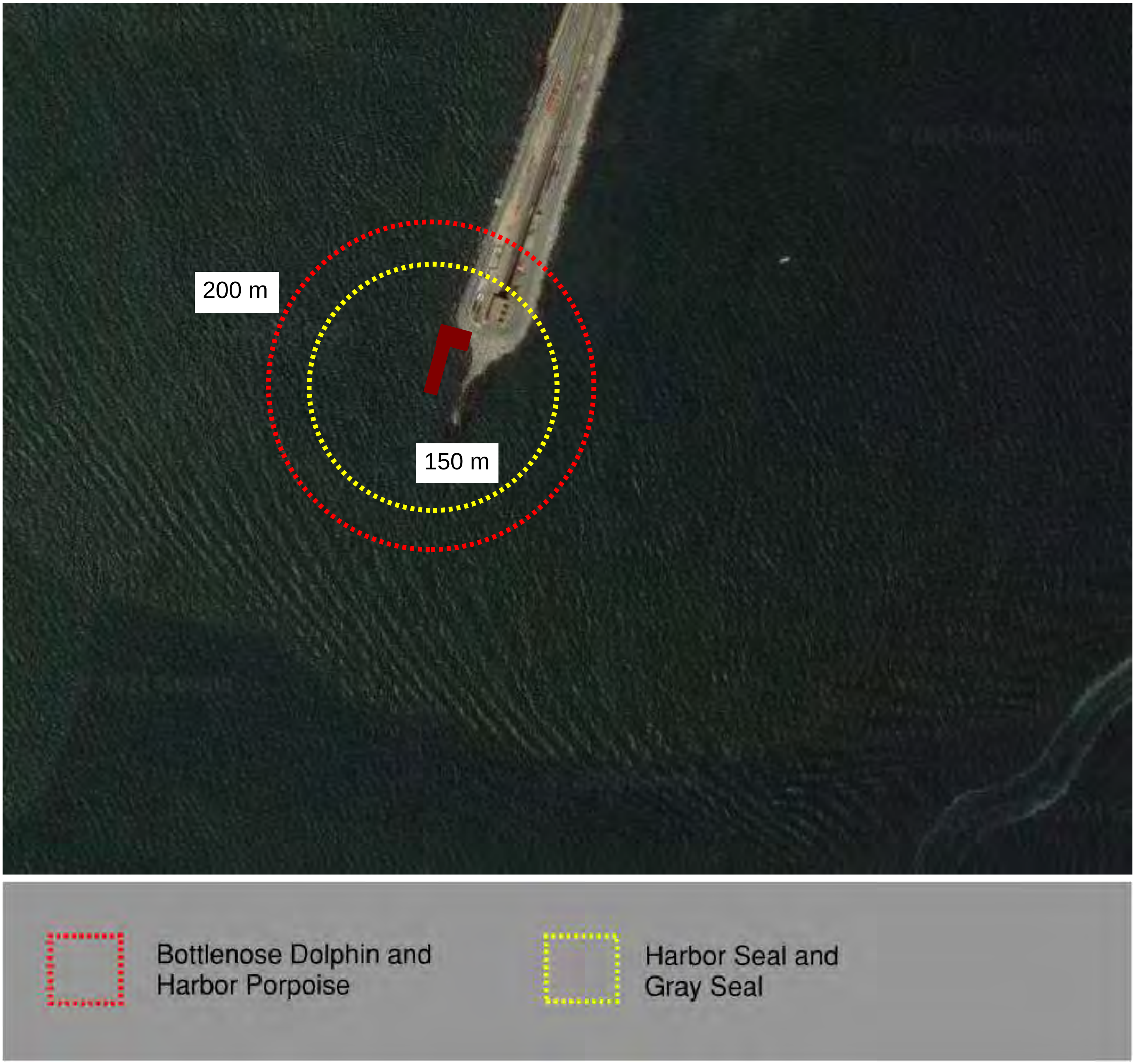


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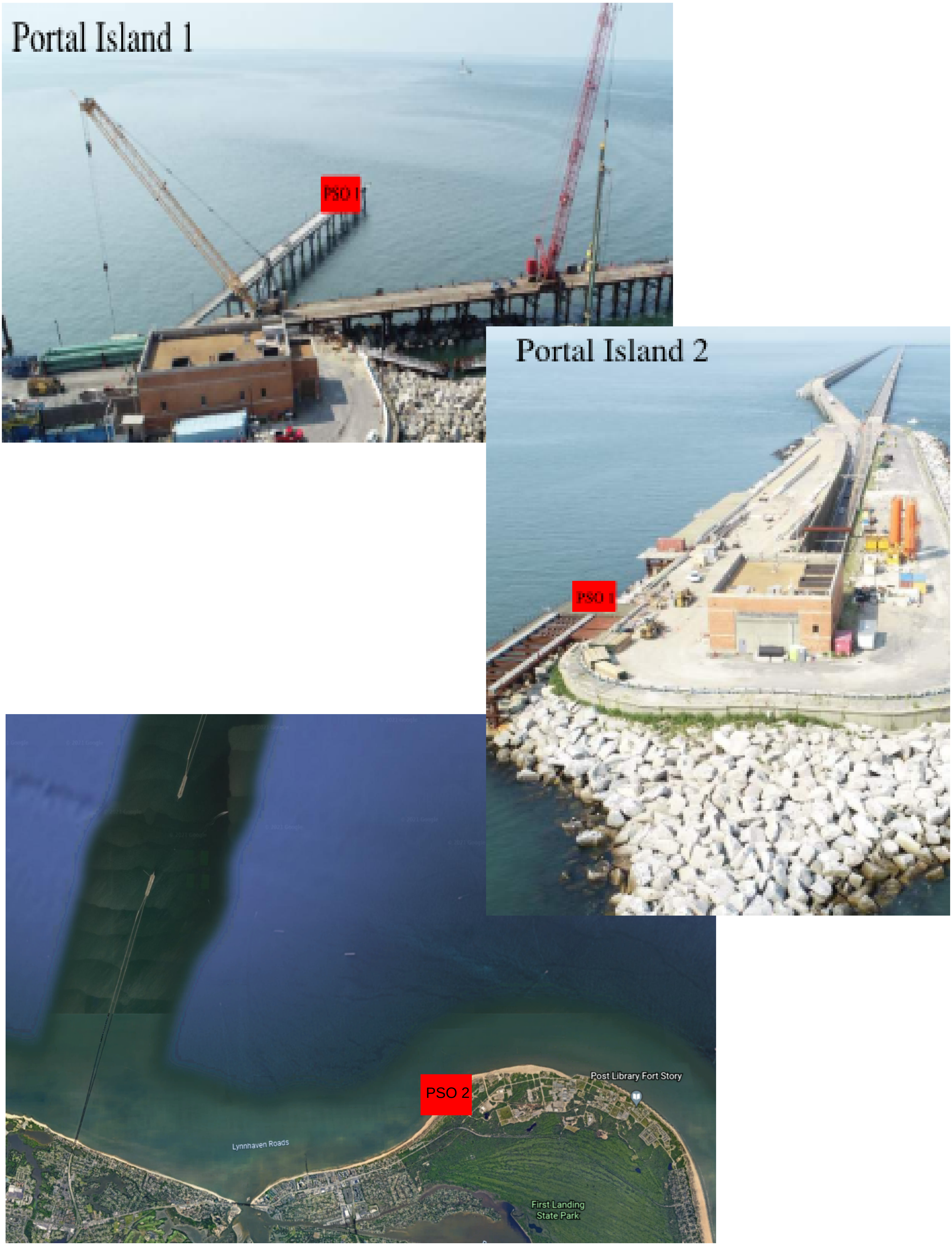
Figure 19. PSO Locations



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Appendix B: Marine Mammal Monitoring Plan

Marine Mammal Monitoring Plan
for the
Parallel Thimble Shoal Tunnel Project

Prepared by:

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September 2021

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ACRONYMS AND ABBREVIATIONS

CTJV	Chesapeake Tunnel Joint Venture
DTH	Down the Hole
ft	feet
GPS	Global Positioning System
IHA	Incidental Harassment Authorization
MHW	Mean High Water
MLW	Mean Low Water
MMMP	Marine Mammal Monitoring Plan
NOAA	National Oceanic and Atmospheric Administration
NOAA Fisheries	National Marine Fisheries Service
PSO	Protected Species Observer
PTS	Permanent Threshold Shift
PTST	Parallel Thimble Shoal Tunnel
SOE	Support of Excavation
TBM	Tunnel Boring Machine
ZOI	Zone Of Impact

1. INTRODUCTION

The Parallel Thimble Shoal Tunnel (PTST) Project consists of the construction of a two-lane parallel tunnel to the west of the existing Thimble Shoal Tunnel, connecting Portal Island Numbers (Nos.) 1 and 2 (Figure 1). Upon completion, the new tunnel will carry two lanes of southbound traffic and the existing tunnel will remain in operation and carry two lanes of northbound traffic. The 6,525 linear feet (ft) of new tunnel will be constructed using a tunnel boring machine (TBM), with 5,356 linear ft located below Mean High Water (MHW).

Pile driving during construction of the PTST Project has the potential to cause sound levels that exceed Level A and Level B acoustic harassment thresholds for marine mammals as defined by the National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service (NOAA Fisheries) Office of Protected Resources (NOAA Fisheries 2016) and updated June 2020 NOAA guidelines for the Down The Hole (DTH) Hammer Sound Modeling.

The following activites are scheduled to occur during the 12-month construction period extending from November 2021 through October 2022 and is illustrated in table 1.

- Berm Construction Mooring piles on Portal Island 1& Island 2:

  - Portal Island No.1: Installation of (28) 36-inch hollow steel pipe piles. Installation will be by vibratory hammer with bubble curtain. It is expected to take a total of 7 days over several months to install the 28 piles (4 piles/day).

  -Portal Island No. 2: Installation of (16) 36-inch hollow steel pipe piles, which shall be installed by vibratory hammer with bubble curtain. The anticipated installation is expected to take a total of 4 days, which shall be completed over several months.

- Construction of two temporary Omega trestles:
  - Portal Island No. 1- Installation of (26) 42” pipe piles diameter steel pipe piles. These will be installed using a vibratory hammer with bubble curtain. In the event a large boulder is encountered during installation then the vibratory hammer will be switched out with an impact hammer. The estimated production rate for the installation of these piles are 2 piles/day. There will be a 2-week span between the driving of a pair of these pipe piles to allow for the installation of the trestle super structure before continuing with the extension. The total number of days of actual driving of these piles should not exceed 13 days.
  - Portal Island No. 2- Installation of (24) 36” piles hollow steel piles for the original design of the trestle will be done with the DTH and impact hammer with bubble curtain. As with on Island 1, the estimated production rate will be 2 piles per day followed by the installation of the superstructure. It will take a total of 12 days spanning over several months in install the (24) 36” piles. The (24) 42” piles for the trestle extension will be installed via vibratory hammer with bubble curtain. Based on the forecasted schedule of activities during the year of this IHA, it is anticipated that only 16 of these 24 piles will be installed. If boulders are encountered during installation the vibratory hammer will be switched out with an

impact hammer with bubble curtain and will follow the same production schedule as the 36” piles, taking a total of 8 days under this IHA, spread over several months.

- Construction of two engineered berms, which as described here in; Portal Island No. 1, is approximately 1,395 ft. in length (in that length, 435 ft. is located above MHW and 960 ft. below MHW). Portal Island No. 2 is approximately 1,354 ft. in length (in that length 446 ft. is located above MHW and 908 ft. below MHW). Both berms will extend channelward from the west side of the existing berm on each portal island. Methods for construction will include: dredging; stone placement (core, bedding, filter, armor 1 & 2 stone); DTH hammer and impact pile driving of 36” interlocked pipe piles; excavation between SOE walls; and placement of engineered and flowable fill. Below are the details of these activities.

  - Portal Island No. 1- Installation of (209) 36” hollow steel interlocking piles on the west wall and (107) on the East wall of the Portal Island 1 Berms. Both will be installed to the West of the existing berm, starting on the northwest corner of Island 1, extending channelward in alignment with the existing tunnel. Pile installation will occur with the use of the DTH hammer to cut through existing armor stone and the impact hammer with bubble curtain to drive the remainder of the pile to the design elevation. On the west wall, 3 piles a day can be installed, while only 2 piles a day can be installed on the east wall. This is due to the significant size and quantity of the boulders encountered on the east wall, which is closer to the existing berm. It will take 70 days to install the west wall and 54 days to install the east wall, although some of these piles will be installed simultaneously.

  -Portal Island No. 2- Installation of (257) 36” hollow steel interlocking piles on the west wall and (166) on the east wall of the Portal Island 2 Berms. Based on the forecasted schedule of activities during the year of this IHA, it is anticipated that only 204 of the 257 piles on the west wall and 134 of the 166 on the east wall will be installed. Both will be installed to the west of the existing berm, starting on the southwest corner of Island 2, extending channelward in alignment with the existing tunnel. Pile installation will occur with the use of the DTH hammer to cut through existing armor stone and the impact hammer with bubble curtain to drive the remainder of the pile. Production rates will be the same as on Island 1 and will take 68 days to install the west wall and 67 days to install the east wall.

Table 1. Anticipated Pile Installation Schedule (November 2021- October 2022)

Pile Location	Pile Function	Pile Type	Installation/ Removal Method	Bubble Curtain Yes/No	Number of Piles Below MHW	Number of Days per Activity (Total)	Number of Days per Activity (Per Hammer Type)	Anticipated Installation Date
Portal Island No. 1	Berm Construction Trestle Mooring Piles & Dolphins	36-inch Diameter Hollow Steel Pipe Pile	Vibratory	Yes	28	7	7 Days (4 Piles/Day)	**November 2021 through June 2022**
Portal Island No. 1	Berm Construction Trestle Extension (Omega Trestle Extension)	42-inch Diameter Hollow Steel Pipe Piles	Vibratory	Yes	26	*13*	13 Days (2 Piles/Day)	**November 2021 through May 2022**
			Impact (If needed)	Yes				
Portal Island No. 1	Berm Support of Excavation Wall - West Side	36-inch Diameter Hollow Steel Interlocked Pipe Piles	DTH	No	209	*140*	70 Days (3 Piles/Day)	**November 2021 through June 2022**
			Impact	Yes			70 Days (3 Piles/Day)	
Portal Island No. 1	Berm Support of Excavation Wall - East Side	36-inch Diameter Hollow Steel Interlocked Pipe Piles	DTH	No	107	*108*	54 Days (2 Piles/Day)	**November 2021 through June 2022**
			Impact	Yes			54 Days (2 Piles/Day)	
Portal Island No. 2	Berm Construction Trestle (Omega Trestle)	36-inch Diameter Hollow Steel Pipe Piles	DTH	No	24	*24*	12 Days (2 Piles/Day)	**January 2022 through June 2022**
			Impact	Yes			12 Days (2 Piles/Day)	
Portal Island No. 2	Berm Construction Trestle (Omega Trestle)	42-inch Diameter Hollow Steel Pipe Piles	Vibratory	Yes	16*	*8*	8 Days (2 Piles/Day)	**July 2022 through October 2022**
			Impact (If needed)	Yes				
Portal Island No. 2	Berm Support of Excavation Wall - West Side	36-inch Diameter Hollow Steel Interlocked Pipe Piles	DTH	No	204*	*136*	68 Days (3 Piles/Day)	**February 2022 through October 2022**
			Impact	Yes			68 Days (3 Piles/Day)	
Portal Island No. 2	Berm Support of Excavation Wall - East Side	36-inch Diameter Hollow Steel Interlocked Pipe Piles	DTH	No	134*	*134*	67 Days (2 Piles/Day)	**February 2022 through October 2022**
			Impact	Yes			67 Days (2 Piles/Day)	
Portal Island No. 2	Berm Construction Trestle Mooring Piles	36-inch Diameter Hollow Steel Pipe Piles	Vibratory	Yes	16	*4*	4 Days (4 Piles/Day)	**1 March 2022 through October 2022**

* Operation won't be completed under this IHA

Although 40 species of marine mammals under NMFS jurisdiction have been documented to occur within the waters of the mid-Atlantic region of the western North Atlantic Ocean; only 8 of those species (six cetacean and two pinniped) have regular (species that occurs as a regular or normal part of the fauna of the area, regardless of how abundant or common it is) or rare (species that only occurs in the area sporadically, not common) occurrences in the Chesapeake Bay (Department of the Navy (DoN) 2008). Any occurrences of other marine mammal species would be considered extralimital (a species that does not normally occur in the area). Based on correspondence between NOAA Fisheries and Federal Highway Administration and use of the U.S. Fish and Wildlife Service's Information for Planning and Conservation Online System, a list of marine mammals that may be present in the Project Area was developed (Table 2).

Table 2 lists all species with expected potential for occurrence near the project area and summarizes information related to the population or stock, including regulatory status under the MMPA and ESA and Potential Biological Removal (PBR), where known. For taxonomy, we follow Committee on Taxonomy (2020). PBR is defined by the MMPA as the maximum number of animals, not including natural mortalities, that may be removed from a marine mammal stock while allowing that stock to reach or maintain its optimum sustainable population (as described in NMFS's SARs). While no mortality is anticipated or authorized here, PBR and annual serious injury and mortality from anthropogenic sources are included here as gross indicators of the status of the species and other threats.

Marine mammal abundance estimates presented in this document represent the total number of individuals that make up a given stock, or the total number estimated within a particular study or survey area. NMFS's stock abundance estimates for most species represent the total estimate of individuals within the geographic area, if known, that comprises that stock. For some species, this geographic area may extend beyond U.S. waters. All managed stocks in this region are assessed in draft United States Atlantic and Gulf of Mexico Marine Mammal Stock Assessments (Hayes *et al.* 2019; 2020) and the North Atlantic Right Whale Consortium 2020 Annual Report Card (Pettis et al. 2020).

Table 2: Marine Mammal Species Known to Occur Within the CTJV Project Area

Species / Stock	**ESA/MMPA Status; Strategic (Y/N)[1]**	**Stock abundance (CV, N_{min}, most recent abundance survey)[2]**	**PBR**	**Annual M/SI[3]**
Order Cetartiodactyla – Cetacea – Superfamily Mysticeti (baleen whales)				
Family Balaenidae				
North Atlantic Right Whale[7] *(Eubalaena glacialis)* Western North Atlantic (WNA)	E, D; Y	368 (95% credible intervals 0, 408, 2018)	0.8	18.6
Family Balaenopteridae (rorquals)				
Humpback Whale[5] *(Megaptera novaeangliae)* Gulf of Maine	-,-; N	1393 (0; 1375; 2016)	22	58
Fin Whale[7] *(Balaenoptera physalus)* WNA	E,D; Y	6,802 (0.24; 5,573; 2016)	11	2.5
Superfamily Odontoceti (toothed whales, dolphins and porpoises)				
Family Delphinidae				
Bottlenose Dolphin *(Tursiops truncatus)* WNA Coastal, Northern Migratory	-,-; Y	6,639 (0.41; 4,759; 2011)	48	12.2-21.5
Bottlenose Dolphin *(Tursiops truncatus)* WNA Coastal, Southern Migratory	-,-; Y	3,751 (0.06; 2,353; 2011)	23	0-148.3
Bottlenose Dolphin *(Tursiops truncatus)* Northern North Carolina Estuarine System	-,-; Y	823 (0.06; 782; 2017)	7.8	7.2-30
Family Phocoenidae (porpoises)				
Harbor porpoise *(Phocoena phocoena)* Gulf of Maine/Bay of Fundy	-, -; N	95,543 (0.31; 74, 034; 2016)	851	217
Order Carnivora – Superfamily Pinnipedia				
Family Phocidae (earless seals)				

Harbor Seal *(Phoca vitulina)* WNA	-; N	75,834 (0.1; 66,884, 2012)	2,006	350
Gray Seal[6] *Halichoerus grypus* WNA	-; N	27,131 (0.19, 23,158, 2016)	1,359	4,729

1 - Endangered Species Act (ESA) status: Endangered (E), Threatened (T)/MMPA status: Depleted (D). A dash (-) indicates that the species is not listed under the ESA or designated as depleted under the MMPA. Under the MMPA, a strategic stock is one for which the level of direct human-caused mortality exceeds PBR, or which is determined to be declining and likely to be listed under the ESA within the foreseeable future. Any species or stock listed under the ESA is automatically designated under the MMPA as depleted and as a strategic stock.
2- NMFS marine mammal stock assessment reports online at*: https://www.fisheries.noaa.gov/national/marine-mammal-protection/marine-mammal-stock-assessment-reports-region*. CV is coefficient of variation; Nmin is the minimum estimate of stock abundance. In some cases, CV is not applicable
3 - These values, found in NMFS's SARs, represent annual levels of human-caused mortality plus serious injury from all sources combined (*e.g.,* commercial fisheries, ship strike). Annual M/SI often cannot be determined precisely and is in some cases presented as a minimum value or range. A CV associated with estimated mortality due to commercial fisheries is presented in some cases.
4 - For the North Atlantic right whale the best available abundance estimate is derived from the North Atlantic Right Whale Consortium 2020 Annual Report Card (Pettis *et al.* 2020).
5 - 2018 U.S. Atlantic SAR for the Gulf of Maine feeding population lists a current abundance estimate of 896 individuals. However, we note that the estimate is defined based on feeding location alone (*i.e.,* Gulf of Maine) and is therefore likely an underestimate.
6 - The NMFS stock abundance estimate applies to U.S. population only; however, the actual stock abundance is approximately 505,000.
7 - Species are not expected to be taken or authorized for take.

Of the marine mammal species that may occur in the Project Area, harbor seals, gray seals, harbor porpoise, bottlenose dolphin, and humpback whales are the most likely to be present. Whales, seals, and porpoises are mobile species and are expected to easily avoid the disturbance and activity associated with construction.

Given the preference of whales for water deeper than is found in the Project Area, their presence near the construction areas is unlikely. Although, whales have been observed in the deeper waters in the vicinity of the PTST Project. Construction activity within open water will be located adjacent to Portal Island Nos. 1 and 2, and the use of the bored method for construction will prevent open water impacts in the areas more likely to be used by whale species. Given the feeding habits of whales, they are unlikely to be attracted to the portal islands and are not expected to venture into shallower construction areas.

Seals and harbor porpoises may be found in shallower areas; however, it is unlikely that harbor porpoises are using the shallowest areas of the Project Area. Both species may be temporarily displaced from the Project Area and within the Level A and B ZOIs. Seals are known to use the shallow portion of the Project Area to reach shoreline haul out areas on the portal islands. Seals would be displaced from these upland areas during construction areas and would likely continue to use Portal Island Nos. 3 and 4. Portal Island No. 3 would be used for storage of monthly materials, which would be consistent with existing routine operations associated with CBBT maintenance. Portal Island No. 4 is not located within the Project footprint. Requested takes are shown below in Table 3.

Table 3. Number of Level A and Level B Takes Requested Per Species

Species	Stock	Level A Takes Requests	Level B Takes Requests
Humpback Whale	Gulf of Maine	-	12
Harbor Porpoise	Gulf of Maine/ Bay of Fundy	5	7
Bottlenose Dolphin	WNA Coastal, Northern Migratory	-	43,228

	WNA Coastal, Southern Migratory	-	43,228
	NNCES	-	200
Harbor Seal	Western North Atlantic	1,154	1,730
Gray Seal	Western North Atlantic	16	24

2. METHODS

2.1 MONITORING AND SHUTDOWN PROCEDURES

The following measures would apply to CTJV's monitoring and shutdown procedures during pile driving activities.

- Establishment of Shutdown Zone— For all pile driving and drilling activities, CTJV would establish a shutdown zone. The purpose of a shutdown zone is generally to define an area within which shutdown of activity would occur upon sighting of a marine mammal (or in anticipation of an animal entering the defined area). These shutdown zones would be used to prevent incidental Level A harassment from pile driving. Shutdown zones for species proposed for authorization are as follows: • 200 meters for harbor porpoise and bottlenose dolphin. • 150 meters for harbor seal and gray seal. • For humpback whale, shutdown distances are shown in Table 3 under low-frequency cetaceans and are dependent on activity type.
- Establishment of Monitoring Zones for Level A and Level B Harassment—CTJV would establish monitoring zones based on calculated Level A harassment isopleths associated with specific pile driving activities and scenarios. These are areas beyond the established shutdown zone in which animals could be exposed to sound levels that could result in Level A harassment in the form of PTS.

- Use of Protected Species Observers (PSO)s during pile pile driving activities. Observers will meet the criteria defined in Section 2.2.

- Monitoring distances, in accordance with the Level A Shutdown Zone and Level B ZOI identified in Section 3, will be determined by using a range finder, scope, hand-held global positioning system (GPS) device or landmarks with known distances from the monitoring positions. Monitoring locations will be based on land at either Portal Island No. 1 or Portal Island No. 2.

- If the entire Level B monitoring zone is not visible, pile driving activities may continue, and the number of individual listed animals within the Level B zone will be estimated and recorded. Estimated numbers of individuals will be extrapolated by dividing the number of observed individuals by the percentage of the monitoring zone that was visible.

- Zones will be monitored for the presence of marine mammals 30 minutes before, during, and 30 minutes after any pile driving activity. Observers will scan the waters within the area of potential sound effects using binoculars (10X42 or similar) or spotting scopes (20-60 zoom or equivalent), and make visual observations.

- Monitoring will be continuous unless the contractor takes a break longer than 2 hours from active pile and sheet pile driving, in which case, monitoring will be required 30 minutes prior to restarting pile installation.

- If marine mammals are observed, their location within the zones, and their reaction (if any) to pile activities will be documented.

- If a marine mammal crosses into the designated ZOIs for that species, additional monitoring or a temporary stop to pile driving activity will occur, in accordance with the procedures outlined in Section 5 of this Monitoring Plan.

- If weather or sea conditions restrict the observer's ability to observe, or become unsafe, pile installation will be suspended until conditions allow for monitoring to resume.

- For in-water pile driving, under conditions of fog or poor visibility that might obscure the presence of a marine mammal within the shutdown zone, the pile in progress will be completed and then pile driving suspended until visibility conditions improve. Visibility will be confirmed and approved by the PSO at the beginning of the shift. Likewise, the certified PSO will determine the number of observers needed to cover the ZOI based on the visibility conditions anticipated for the following shift and their best professional judgement call.

Monitoring will occur year-round, during pile driving operations, because some marine mammal species have the potential to be present at any time of the year.

2.2 OBSERVER QUALIFICATIONS

The CTJV will employ NOAA Fisheries-approved PSOs to monitor Level A Shutdown Zones and Level B ZOI. These individuals must be independent contrators (i.e., not construction personnel) trained biologists. At least one PSOs must be in close proximity to each pile driving rig during active operation of single or multiple, concurrent driving devices. A minimum of one additional PSOs is required at each active driving rig if the Level B harassment zone and shutdown zones cannot reasonably be observed by one PSO.

PSOs shall scan the waters using binoculars, and/or spotting scopes, and shall use a handheld GPS or range-finder device to verify the distance to each sighting from the project site. All PSOs shall be trained in marine mammal identification and behaviors and are required to have no other project-related tasks while conducting monitoring. In addition, monitoring will be conducted by qualified observers, who will be placed at the best vantage point(s) practicable to monitor for marine mammals and implement shutdown/delay procedures when applicable by calling for the shutdown to the hammer operator. CTJV shall adhere to the following PSOs qualifications:

- Visual acuity in both eyes sufficient to see moving objects on the water's surface; ability to estimate object size and distance.
- The ability to make visual field observations and collect data as described in the protocol.
- Experience or training with identifying marine mammals in the field.
- Sufficient training, orientation or experience with the construction operation to provide for personal safety during observations.
- Ability to communicate orally, by radio or in person, with project personnel to provide real-time information on marine mammals observed in the area as necessary.
- Experience and ability to conduct field observations and collect data according to assigned protocols (this may include academic experience).
- The ability to prepare a status report of monitoring activities that describes the species and number of individuals observed, dates and times of construction activities; dates when construction activities were ceased or shutdown to avoid Level A harassment to any species or Level B harassment for any species for that the PTST Project is not authorized to take.

Additional standard observer qualifications include**:**

- Ability to conduct field observations and collect data according to assigned protocols.
- Experience or training in the field identification of marine mammals, including the identification of behaviors.
- Sufficient training, orientation, or experience with the construction operation to provide for personal safety during observations.
- Writing skills sufficient to prepare a report of observations including but not limited to the number and species of marine mammals observed; dates and times when in-water construction activities were conducted; dates and times when in-water construction activities were suspended to avoid potential incidental injury from construction sound of marine mammals observed within a defined shutdown zone; and marine mammal behavior
- Ability to communicate orally, by radio or in person, with project personnel to provide real-time information on marine mammals observed in the area as necessary.

2.3 DATA COLLECTION

Observers will be required to use approved data forms. Among other pieces of information, CTJV shall keep recorded detailed information about any implementation of shutdowns, including the distance and direction of animals to the pile and description of specific actions that ensued and resulting behavior of the animal, if any. PSOs s shall attempt to distinguish between the number of individual animals taken and the number of incidences of take. Required sighting forms shall include the following information be collected:

- Dates and times (begin and end) of all marine mammal monitoring.

- Construction activities occurring during each daily observation period, including: The number and type of piles that were driven and the method (e.g., impact, vibratory, down-the-hole).

- Total duration of driving time for each pile (vibratory driving) and number of strikes for each pile (impact driving); and for down-the-hole drilling, duration of operation for both impulsive and non-pulse components.

- PSO locations during marine mammal monitoring.

- Environmental conditions during monitoring periods (at beginning and end of PSO shift and whenever conditions change significantly), including Beaufort Sea state and any other relevant weather conditions including cloud cover, fog, sun glare, and overall visibility to the horizon, and estimated observable distance.

- Upon observation of a marine mammal, the following information:
- Name of PSO who sighted the animal(s) and PSO location and activity at time of sighting.
- Time of sighting.
- Identification of the animal(s) (e.g., genus/species, lowest possible taxonomic level, or unidentified), PSO confidence in identification, and the composition of the group if there is a mix of species.
- Distance and location of each observed marine mammal relative to the pile being driven for each sighting.
- Estimated number of animals (min/max/best estimate).
- Estimated number of animals by cohort (adults, juveniles, neonates, group composition, etc.).
- Animal's closest point of approach and estimated time spent within the harassment zone.
- Description of any marine mammal behavioral observations (e.g., observed behaviors such as feeding or traveling), including an assessment of behavioral responses thought to have resulted from the activity (e.g., no response or changes in behavioral state such as ceasing feeding, changing direction, flushing, or breaching).
- Number of marine mammals detected within the harassment zones, by species; and

- Detailed information about implementation of any mitigation (e.g., shutdowns and delays), a description of specific actions that ensued, and resulting changes in behavior of the animal(s), if any.

2.4 EQUIPMENT

Marine mammal observers will have the following equipment available during monitoring:

- Binoculars
- Range finder
- Logbook
- Cell phone or other wireless communication
- GPS Unit (for all vessel based observations, if implemented).

3. LEVEL A AND LEVEL B MONITORING ZONES

3.1 NOAA/ NMFS FISHERIES SERVICE ACOUSTIC CRITERIA

To assess potential effects of exposure to underwater anthropogenic sound on the hearing of marine mammals, the CTJV used NMFS published updated Technical Guidance (NMFS 2020a). This Technical Guidance identifies the received levels, or thresholds, above which individual marine mammals are predicted to experience permanent changes (e.g., a permanent threshold shift [PTS]) in their hearing sensitivity from incidental exposure to underwater anthropogenic sound sources (NMFS 2020a). NMFS considers the Technical Guidance to represent the best available scientific information and, on this basis, suggests that these thresholds and weighting functions be used to assess the potential for PTS in marine mammals, which equates to Level A harassment under the MMPA. The models used to derive the acoustic thresholds for onset of PTS incorporate marine mammal auditory weighting functions in recognition of the variability found among marine mammal species in their hearing sensitivity. The auditory weighting functions are defined for four functional hearing groups that are present in the Project area: low-frequency (LF), mid-frequency (MF), and high-frequency (HF) cetaceans, and phocid in water (PW) pinnipeds. Additionally, the models used to derive the PTS onset acoustic thresholds incorporate a time component in the form of a cumulative sound exposure level (SELcum) for both impulsive and non-impulsive sound, and a SPL component by using peak sound level (Lpk) for impulsive sounds (NMFS 2020a).

Level B Harassment for non-explosive sources—Though significantly driven by received level, the onset of behavioral disturbance from anthropogenic noise exposure is also informed to varying degrees by other factors related to the source (e.g., frequency, predictability, duty cycle), the environment (e.g., bathymetry), and the receiving animals (hearing, motivation, experience, demography, behavioral context) and can be difficult to predict (Southall et al., 2007; Ellison et al., 2012). Based on what the available science indicates and the practical need to use a threshold based on a factor that is both predictable and measurable for most activities, NMFS has previously used a generalized acoustic threshold based on received level to estimate the onset of behavioral harassment. It is predicted that marine mammals are likely to be behaviorally harassed in a manner considered Level B harassment when exposed to underwater anthropogenic noise above received levels of 120 dB re 1 μPa (rms) for continuous (e.g., vibratory pile-driving) and above 160 dB re 1 μPa (rms) for non-explosive impulsive (e.g., impact pile driving) or intermittent (e.g., scientific sonar) sources. CTJV's planned activity includes the use of continuous (vibratory and DTH hammer pile driving) and impulsive (impact pile driving) sources, and therefore the 120 and 160 dB re 1 μPa (rms) thresholds are applicable. Following the 2020 NMFS guidance for DTH Pile installation, the DTH hammer pile driving is considered both impulsive and continuous components and indicated that Level A harassment is impulsive, and Level B is a continuous source level of 166 dB re 1 μPa (rms). Given that a bubble curtain will be utilized for all vibratory and impact pile driving, updated 2020 Caltrans guidance allows a 5 dB reduction, however justification for the CTJV using a 6 dB reduction is discussed in section 6.

Level A harassment for non-explosive sources—NMFS' Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2.0) (Technical Guidance, 2020) identifies dual criteria to assess auditory injury (Level A harassment) to five different marine mammal groups (based on hearing sensitivity) as a result of exposure to noise from two different types of sources (impulsive or non-impulsive).

3.2 DISTURBANCE ZOIS FOR IN-WATER NOISE

3.2.1 Level A and B Harassment Zones for Multiple Hammers

The proposed pile installation assumes the use of more than one (up to three) vibratory, impact or down-the-hole hammer drilling to occur within a single day or simultaneously. Down-the-hole hammers have been considered by NMFS to produce impulsive noise near the pile, so decibel addition will not be used for Level A harassment zones. Each hammer scenario will implement Level A harassment zones based on whether or not there is not simultaneous use of hammers.

This measure, although conservative, would also minimize the need for onsite coordination among Project sites and components. When multiple vibratory or down-the-hole hammers are used simultaneously, the Level B harassment zone will depend on the combination of sound sources due to decibel addition of multiple hammers producing continuous noise.

Based on decibel addition for overlapping continuous sound sources, it is possible that sound will ensonify in a portion of the surrounding waters. However, pile installation is an intermittent activity with multiple stops and starts of the hammer for each pile, and decibel addition is applied only when the adjacent continuous sound sources experience overlapping sound fields, which requires proximity. It is anticipated that simultaneous use of more than one hammer making continuous sound with overlapping sound fields will be uncommon and of short duration.The Level A and B harassment areas are reflected below in Table 4.

Table 4. Refined In-Water Area (km2) from Pile Driven to Level A and Level B Harassment Zones for Cetaceans, Pinnipeds and Otariids

Driving Scenerio / Radii/ Island	Level A Harassment Zones															Level B Harassment Zones		
	Low-Frequency Cetaceans			Mid-Frequency Cetaceans			High-Frequency Cetaceans			Phocid Pinnipeds			Otariids					
	Radius (m)	Island 1	Island 2	Radius (m)	Island 1	Island 2	Radius (m)	Island 1	Island 2	Radius (m)	Island 1	Island 2	Radius (m)	Island 1	Island 2	Radius (m)	Island 1	Island 2
DTH (3 piles/day)	1,225	4.201	4.011	44	0.005	0.005	1,460	5.952	5.743	656	1.214	1.122	48	0.008	0.008	7,599	141	163
Impact (4 piles/day)	1,226	4.201	4.011	44	0.005	0.005	1,460	5.952	5.743	656	1.214	1.122	48	0.008	0.008	631	136	136
Impact (6 piles/day)	1,313	4.741	4.715	47	0.007	0.007	1,564	6.719	6.711	703	1.346	1.337	52	0.009	0.009	631	136	136
Vibratory (4 piles/day)	9	0.001	0.001	1	0.0001	0.0001	14	0.001	0.001	6	0.001	0.001	1	0.001	0.001	5,555	98	98
Impact + DTH	Use zones for each source alone															7,599	136	147
DTH + Vibratory	Use DTH zones															10,329	218	250
Impact + Vibratory	Use DTH zones															5,555	80	79
Simultaneous Driving																	**Both Islands**	
Impact+ Dual DTH	Use zones for each source alone															12,043	323	
Dual DTH + Vibratory	Use DTH zones															14,041	402	
DTH + Vibratory + Impact	Use DTH zones															10,329	255	
Impact + Impact+ DTH	Use zones for each source alone															7,599	163	

3.2.2 Calculation of Disturbance ZOIs for Airborne Noise

Literature estimates were used to estimate the amount of in-air sound produced from impact driving a pile above the MHW line (Laughlin 2010 a, b). Hollow steel piles that were 30 inches in diameter were used as a close proxy to the 36 & 42-inch-diameter hollow steel piles that will be driven at the PTST Project. Airborne sound produced from DTH hammer pile driving for 36-inch diameter hollow steel piles was estimated based on a 90dB threshold for simplicity, though gray seals have a 100dB threshold. This does not affect harassments due to the areas being so much smaller than the in-water harassment zones.

Given the maximum source level of 98 dBA for in-air noise during impact pile installation of 42-inch steel piles, the calculated isopleths for in-air noise can be used for all pile sizes and types associated with the Project. Installation of smaller piles is generally assumed to produce lower ound levels than installation of larger piles. Based on this model, in-air noise from impact installation of 42-inch steel piles could extend up to 205 meters from the noise source over open water until it attenuates to a level below the NMFS threshold for harassment of phocid pinnipeds such as harbor and gray seals (Table 5).

Table 5. Radial distance (meters) from pile driven above MHW to PTS sound thresholds for Harbor Seals and Gray Seals

Source	Sound Level	Level A Harassment Zone (m)	Level B Harassment Zone (m)*
			Harbor Seals/ Gray Seals
Impact Hammer 36-inch Pile	97 dBLMAX at 92m[a]	N/A	205
Impact Hammer 42-inch Pile	97 dBLMAX at 92m[a]	N/A	205
Vibratory Hammer 36-inch Pile	98 dB $_{LMAX}$ @15.24m[b]	N/A	40
Vibratory 42-inch Pile	98 dB LMAX @15.24m[b]	N/A	40
Down-the-hole Hammer 42-inch Pile	88 dB$_{L5SEQ}$ at 10m[c]	N/A	7.94

[a]Laughlin 2007
[b] Laughlin 2010
[c] Mincon Group PLC. 2019.
* Using 90dB threshold

3.3 MONITORING AND SHUTDOWN OF DISTURBANCE ZONES

The following measures would apply to CTJV's mitigation requirements: Establishment of Shutdown Zone— For all pile driving and drilling activities, CTJV would establish a shutdown zone. The purpose of a shutdown zone is generally to define an area within which shutdown of activity would occur upon sighting of a marine mammal (or in anticipation of an animal entering the defined area). These shutdown zones would be used to prevent incidental Level A harassment from pile driving. Shutdown zones for species proposed for authorization are as follows: • 200 meters for harbor porpoise and bottlenose dolphin. • 150 meters for harbor seal and gray seal. • For humpback whale, shutdown distances are shown in Table 4 under low-frequency cetaceans and are dependent on activity type. Establishment of Monitoring Zones for Level A and Level B Harassment—CTJV would establish monitoring zones based on calculated Level A harassment isopleths associated with specific pile driving activities and scenarios. These are areas beyond the established shutdown zone in which animals could be exposed to sound levels that could result in Level A harassment in the form of PTS.

The proposed Level A (Shutdown Zone) and Level B ZOI (Table 6) will be monitored during all phases of construction.

Table 6: Required Shutdown Zone Actions During Construction

Common Name	Shutdown Action During Project Activity
Fin whale	Shutdown if observed approaching or within ZOIs A or B
Humpback whale	Shutdown if observed approaching or within Level A ZOI
North Atlantic right whale	Shutdown if observed approaching or within ZOIs A or B
Bottlenose dolphin	Record takes for Level B, Shutdown if observed approaching 200 meters
Harbor porpoise	Record takes for Levels A and B. Shutdown if observed approaching 200 meters
Harbor seal	Shutdown if observed approaching 150 meters
Gray seal	Shutdown if observed approaching 150 meters

4. MARINE MAMMAL OBSERVATION AND PROTECTION

Observations shall be conducted onsite during pile driving activities. Observers will have the authority to shut down pile driving activities if marine mammals are observed entering the designated shutdown harassment zones. Monitoring shall be conducted by NMFS-approved Protected Species Observers (PSO). Trained observers shall be placed from the best vantage point(s) practicable to monitor for marine mammals and implement shutdown or delay procedures when applicable through communication with the equipment operator. For the work covered under this IHA, PSOs will be located on the end of the fishing pier and on land near Fort Story/ First Landing Park to observe all impacted areas for pile driving on Island 1. On Portal Island 2, the PSOs will be located on the trestle and on land near Fort Story/ First Landing Park to observe all impacted areas from pile driving on Island 2. Figure 1 shows expected locations of the PSOs on both Portal Islands.

Observer training must be provided prior to project start, and shall include instruction on species identification (sufficient to distinguish the species in the project area), description and categorization of observed behaviors and interpretation of behaviors that may be construed as being reactions to the specified activity, proper completion of data forms, and other basic components of biological monitoring, including tracking of observed animals or groups of animals such that repeat sound exposures may be attributed to individuals (to the extent possible).

Monitoring shall be conducted 30 minutes before, during, and 30 minutes after pile driving activities. In addition, observers shall record all incidents of marine mammal occurrence, regardless of distance from activity, and shall document any behavioral reactions in concert with distance from piles being driven. Pile driving activities include the time to install a single pile or series of piles, if the time elapsed between uses of the pile driving equipment is no more than 30 minutes.

CTJV shall be required to station PSOs at locations offering the best available views of the monitoring harassment zones. PSOs will be located on the end of the fishing pier and the northeast corner of Portal Island 1, to observe all monitoring zones for pile driving on Island 1. On Portal Island 2, the PSOs will be located on the trestle and the southeast corner to observe all monitoring zones for pile driving on Island 2. When there is driving occurring on both islands, there will be two PSOs located on both islands, in the areas mentioned above.

At least one PSOs must be in close proximity to each pile driving rig during active operation of single or multiple, concurrent driving devices. A minimum of one additional PSOs is required at each active driving rig if the Level B harassment zone and shutdown zones cannot reasonably be observed by one PSO.

PSOs shall scan the waters using binoculars, and/or spotting scopes, and shall use a handheld GPS or range-finder device to verify the distance to each sighting from the project site. All PSOs shall be trained in marine mammal identification and behaviors and are required to have no other project-related tasks while conducting monitoring. In addition, monitoring will be conducted by qualified observers, who will be placed at the best vantage point(s) practicable to monitor for marine mammals and implement shutdown/delay procedures when applicable by calling for the shutdown to the hammer operator. CTJV shall adhere to the following PSOs qualifications:

- Independent observers (*i.e.*, not construction personnel) are required.
- At least one observer must have prior experience working as an observer.
- Other observers may substitute education (degree in biological science or related field) or training for experience.
- Where a team of two or more observers are required, one observer shall be designated as lead observer or monitoring coordinator. The lead observer must have prior experience working as an observer.
- CTJV shall submit observer CVs for approval by NMFS.

Additional standard observer qualifications include**:**

- Ability to conduct field observations and collect data according to assigned protocols.

- Experience or training in the field identification of marine mammals, including the identification of behaviors.
- Sufficient training, orientation, or experience with the construction operation to provide for personal safety during observations.
- Writing skills sufficient to prepare a report of observations including but not limited to the number and species of marine mammals observed; dates and times when in-water construction activities were conducted; dates and times when in-water construction activities were suspended to avoid potential incidental injury from construction sound of marine mammals observed within a defined shutdown zone; and marine mammal behavior; and
- Ability to communicate orally, by radio or in person, with project personnel to provide real-time information on marine mammals observed in the area as necessary.

Observers will be required to use approved data forms. Among other pieces of information, CTJV shall keep recorded detailed information about any implementation of shutdowns, including the distance and direction of animals to the pile and description of specific actions that ensued and resulting behavior of the animal, if any. PSOs s shall attempt to distinguish between the number of individual animals taken and the number of incidences of take. Required sighting forms shall include the following information be collected:

- Dates and times (begin and end) of all marine mammal monitoring.

- Construction activities occurring during each daily observation period, including: The number and type of piles that were driven and the method (e.g., impact, vibratory, down-the-hole).

- Total duration of driving time for each pile (vibratory driving) and number of strikes for each pile (impact driving); and for down-the-hole drilling, duration of operation for both impulsive and non-pulse components.

- PSO locations during marine mammal monitoring.

- Environmental conditions during monitoring periods (at beginning and end of PSO shift and whenever conditions change significantly), including Beaufort Sea state and any other relevant weather conditions including cloud cover, fog, sun glare, and overall visibility to the horizon, and estimated observable distance.

- Upon observation of a marine mammal, the following information:

- Name of PSO who sighted the animal(s) and PSO location and activity at time of sighting.
- Time of sighting.
- Identification of the animal(s) (e.g., genus/species, lowest possible taxonomic level, or unidentified), PSO confidence in identification, and the composition of the group if there is a mix of species.

- Distance and location of each observed marine mammal relative to the pile being driven for each sighting.
- Estimated number of animals (min/max/best estimate).
- Estimated number of animals by cohort (adults, juveniles, neonates, group composition, etc.).
- Animal's closest point of approach and estimated time spent within the harassment zone.
- Description of any marine mammal behavioral observations (e.g., observed behaviors such as feeding or traveling), including an assessment of behavioral responses thought to have resulted from the activity (e.g., no response or changes in behavioral state such as ceasing feeding, changing direction, flushing, or breaching).
- Number of marine mammals detected within the harassment zones, by species; and
- Detailed information about implementation of any mitigation (e.g., shutdowns and delays), a description of specific actions that ensued, and resulting changes in behavior of the animal(s), if any.

5. REPORTING

An annual report will be prepared and distributed to NOAA Fisheries at the end of the year covered under the current Incidental Harassment Authorization. This annual report will include an executive summary, monitoring methodology, tabulation of marine mammal observations (including number, type, and location of observations), dates and times when monitoring occurred, and pile driving was completed, and dates and times when in-water construction was suspended because of marine mammals.

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Figure 1. PSO Locations

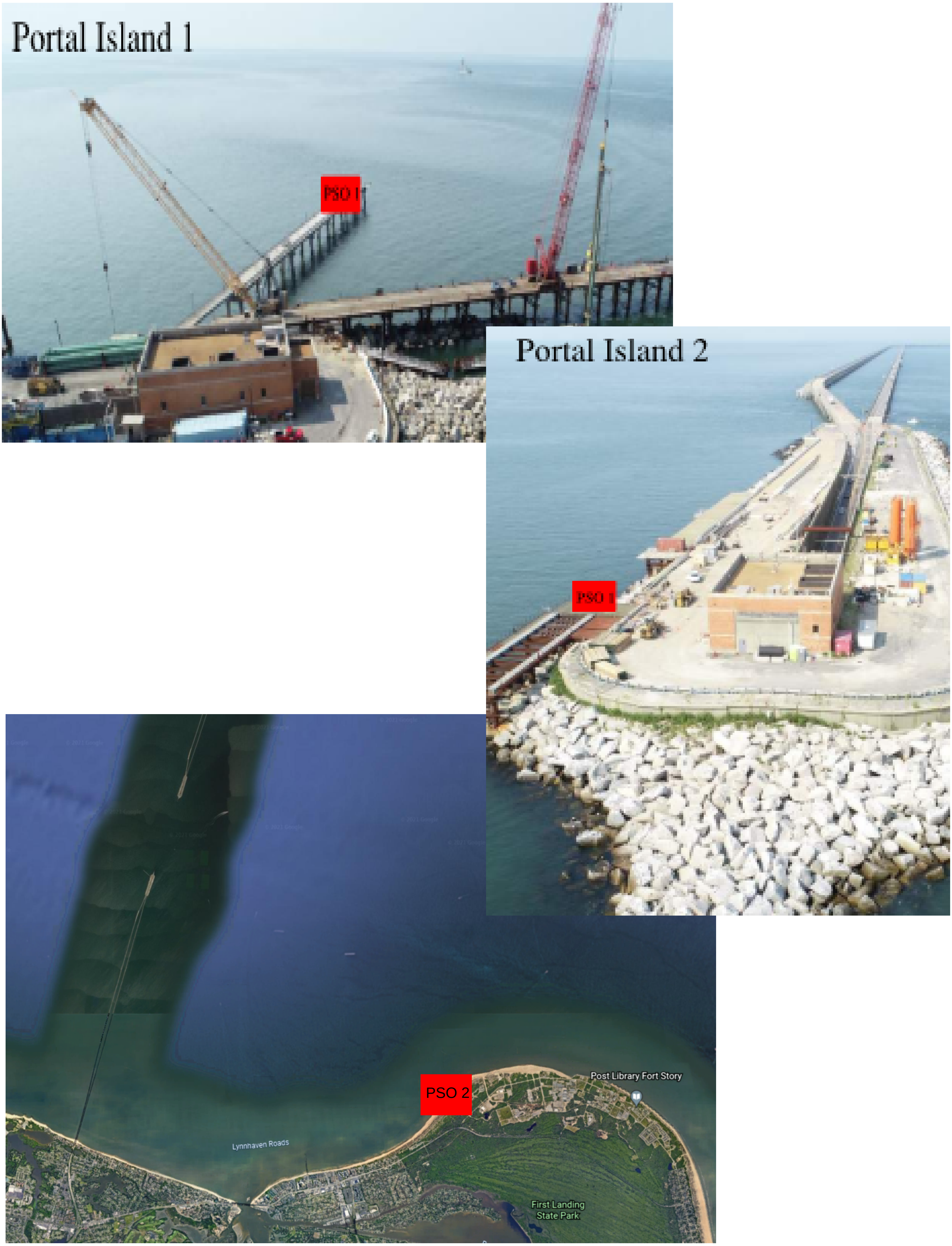


Figure 2. Island No. 1 Level A Harassment: DTH 3 Piles/Day

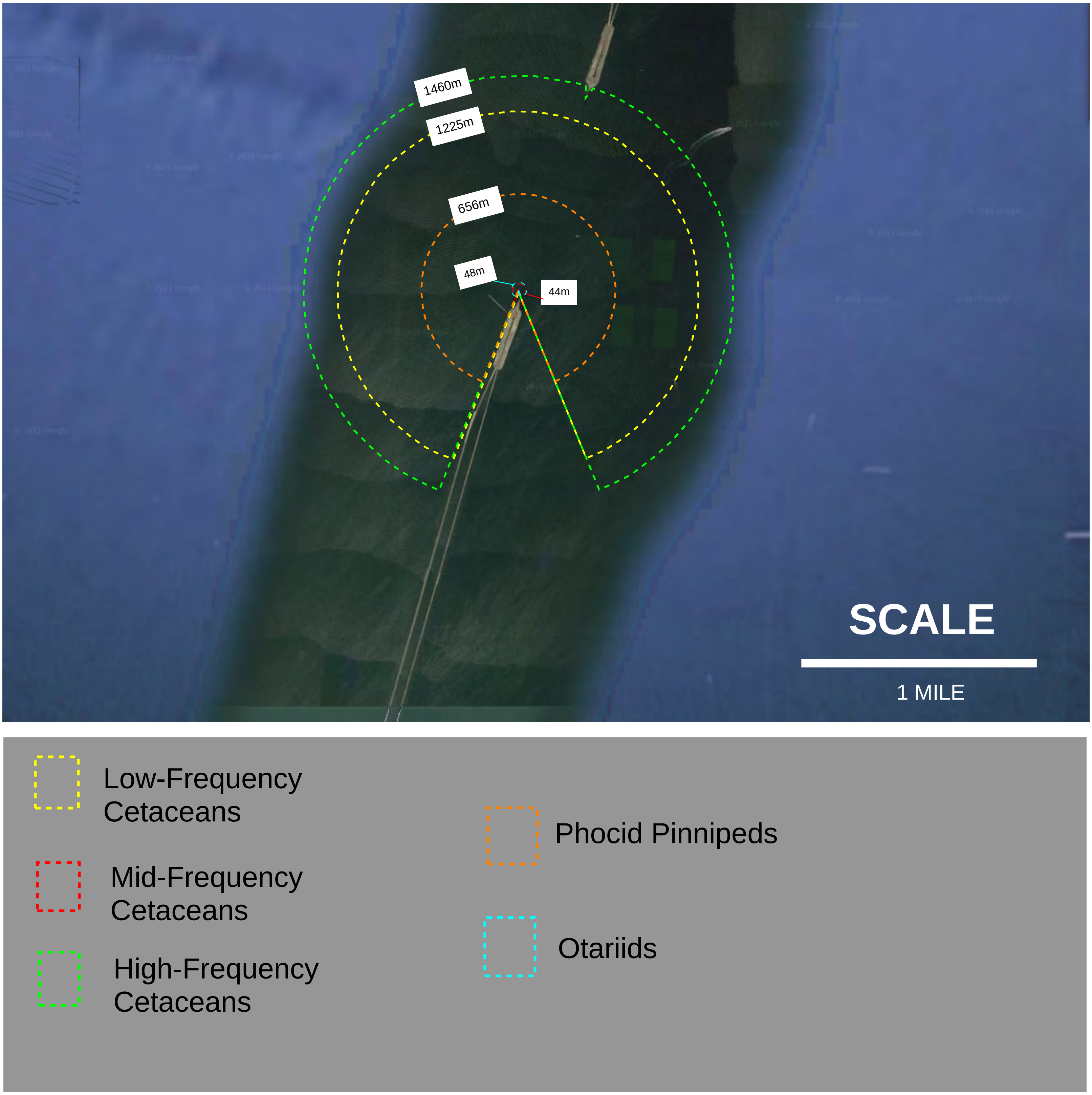


Figure 3. Island No. 1 Level A Harassment Impact: 4 Piles/ Day

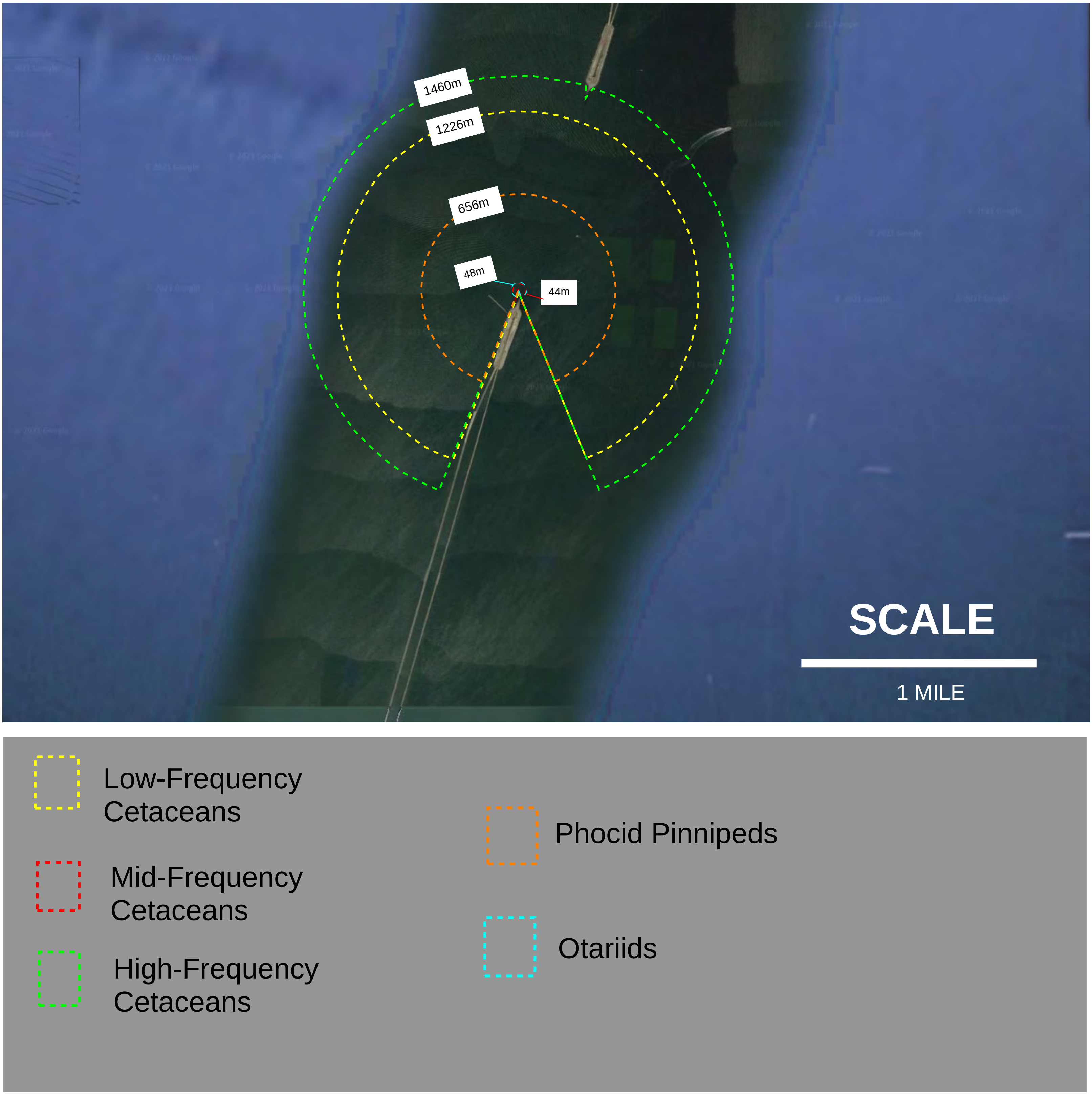


Figure 4. Island No. 1 Level A Harassment Impact: 6 Piles/Day

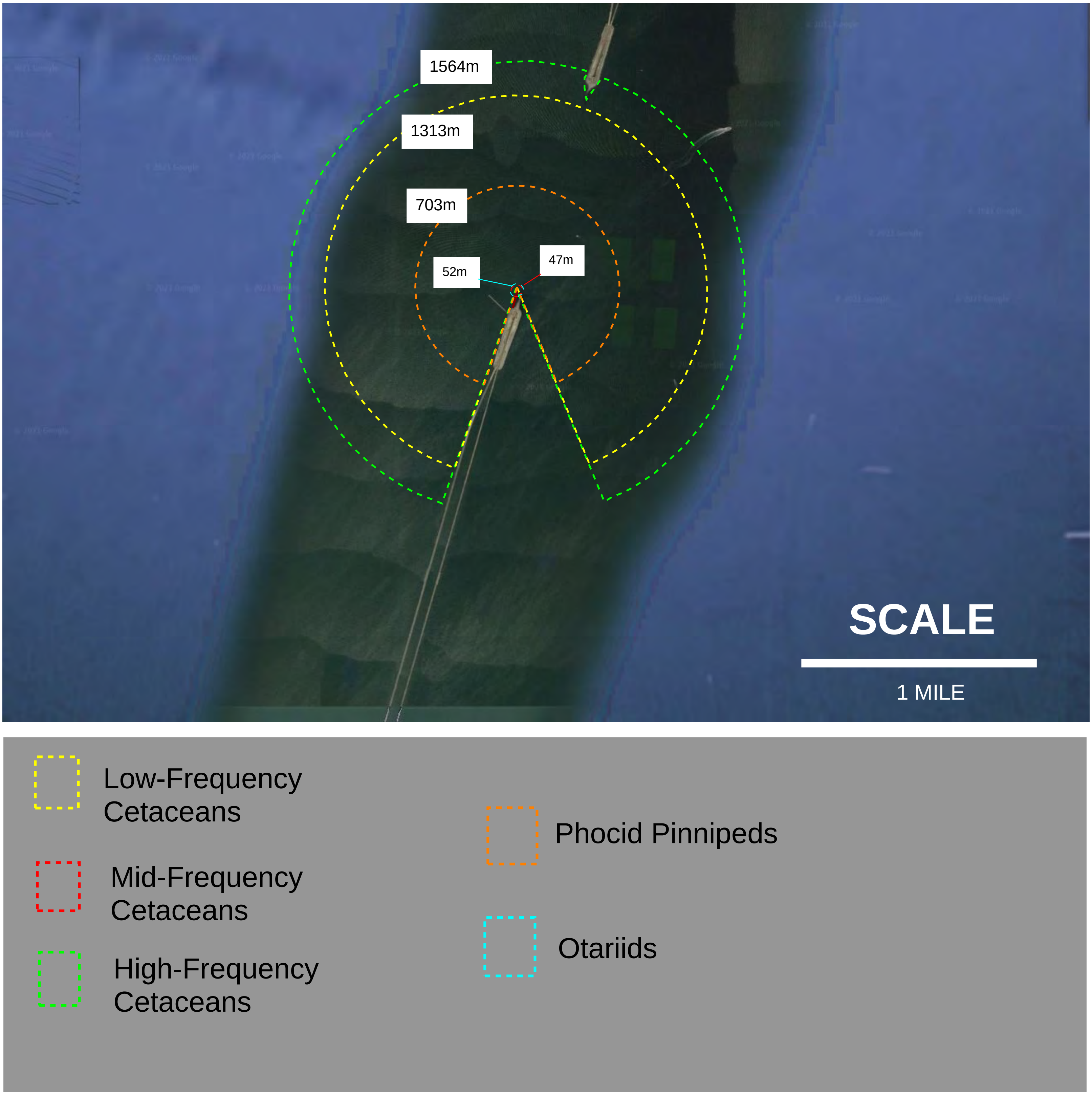


Figure 5: Island No. 2 Level A Harassment: DTH 3 Piles/Day

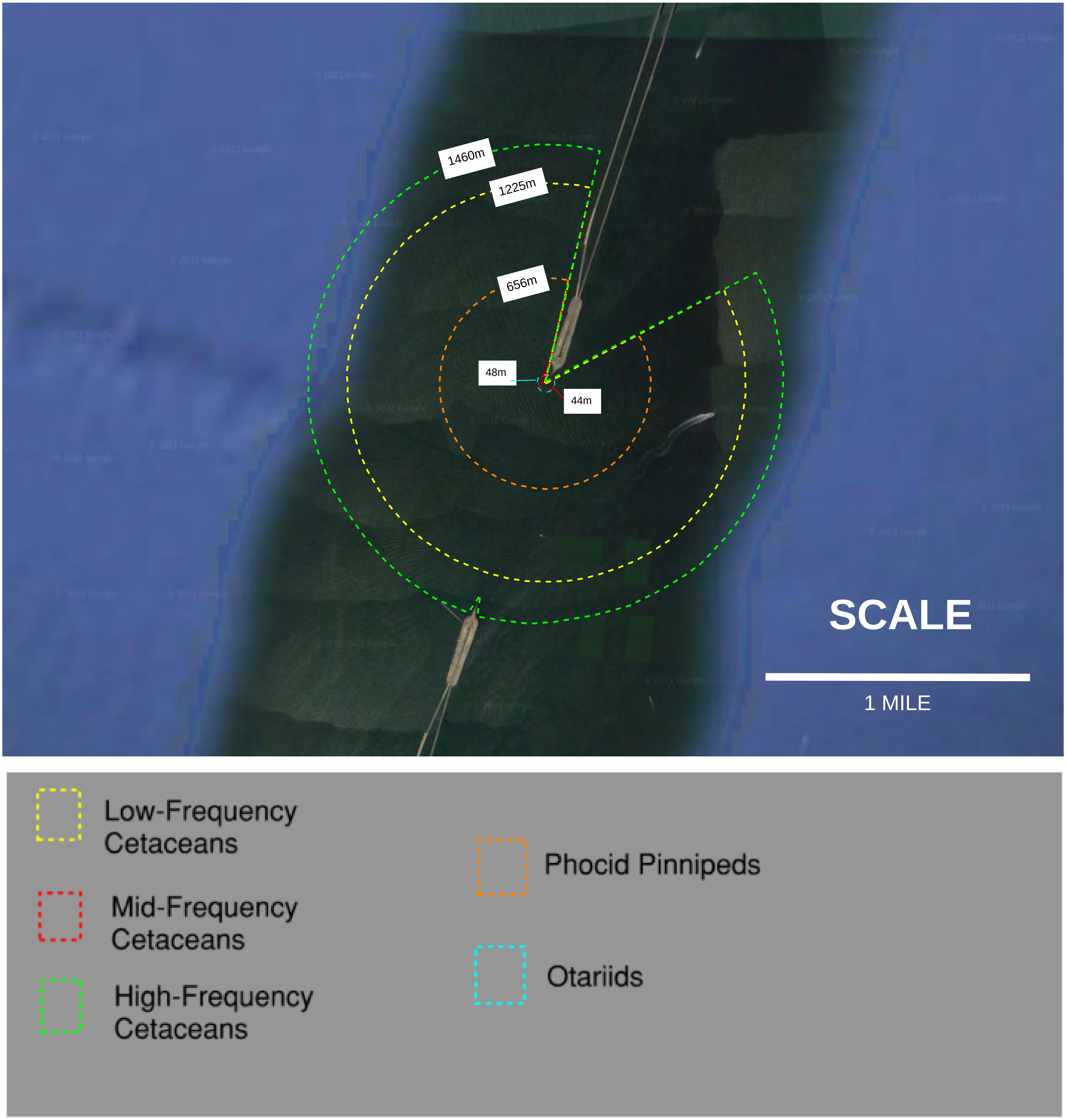


Figure 6: Island No. 2 Level A Harassment Impact 4 Piles/Day

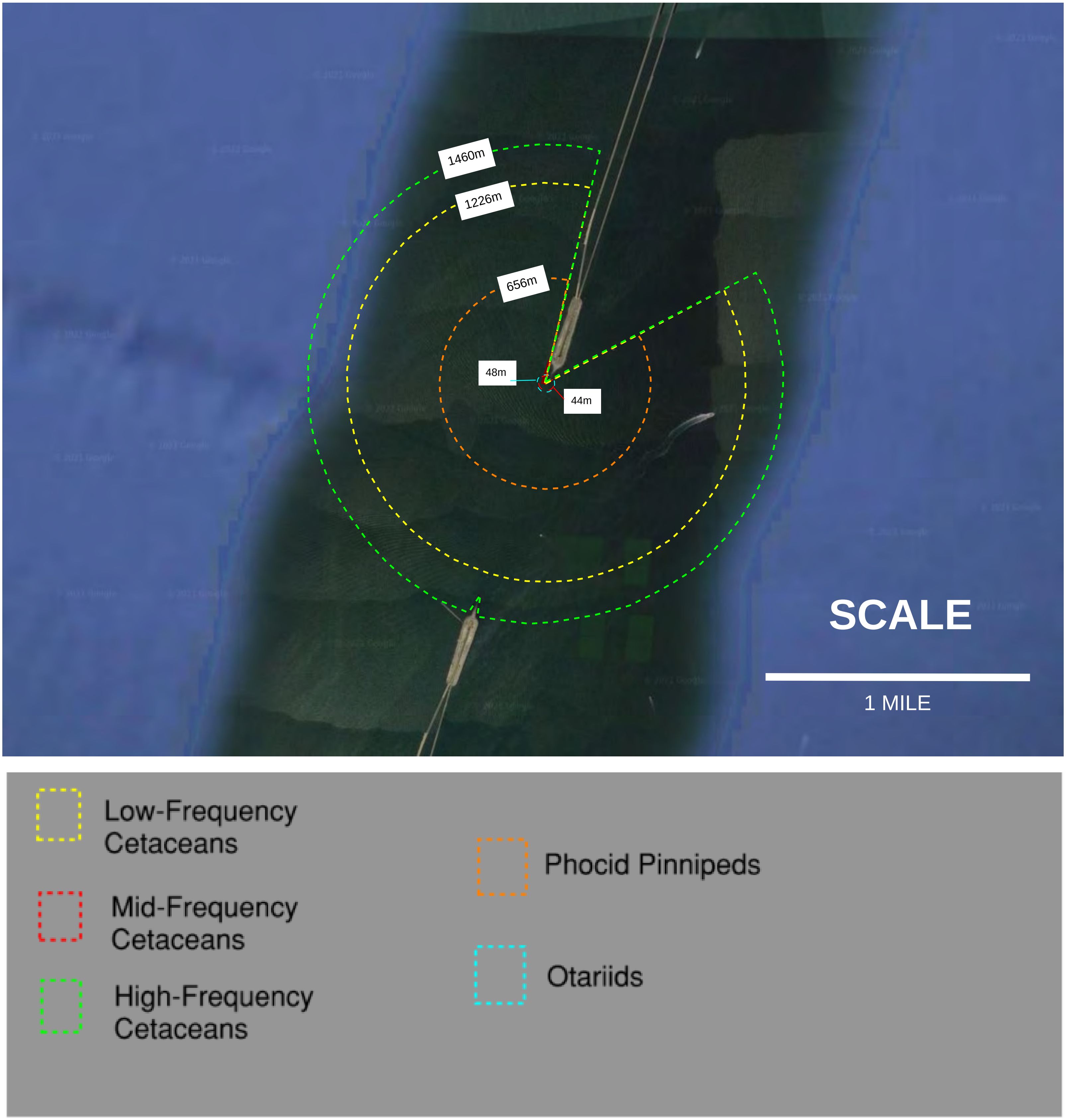


Figure 7. Island No. 2 Level A Harassment Impact: 6 Piles/Day

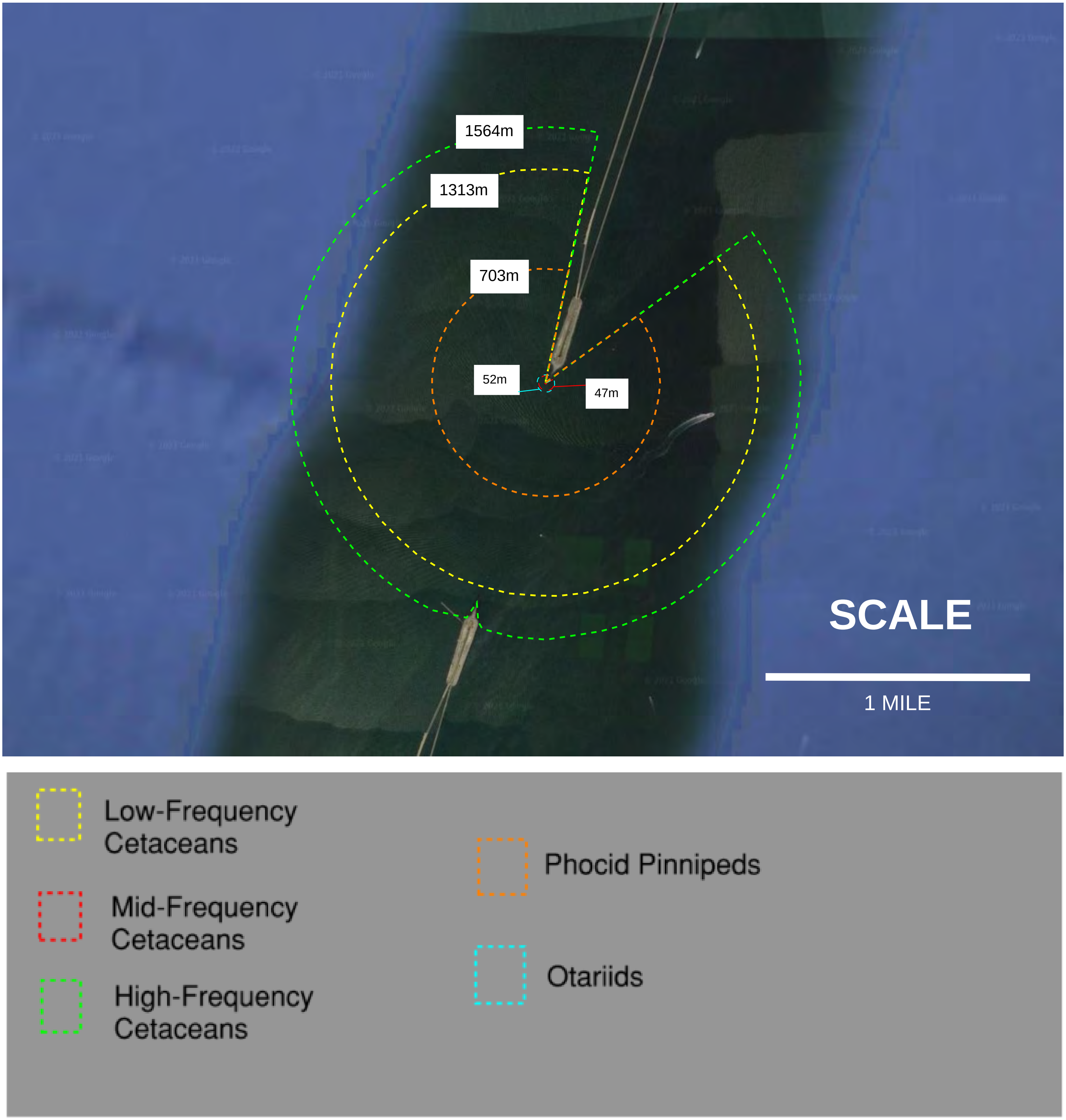


Figure 8. Island No. 1 Level B Harassment Zones

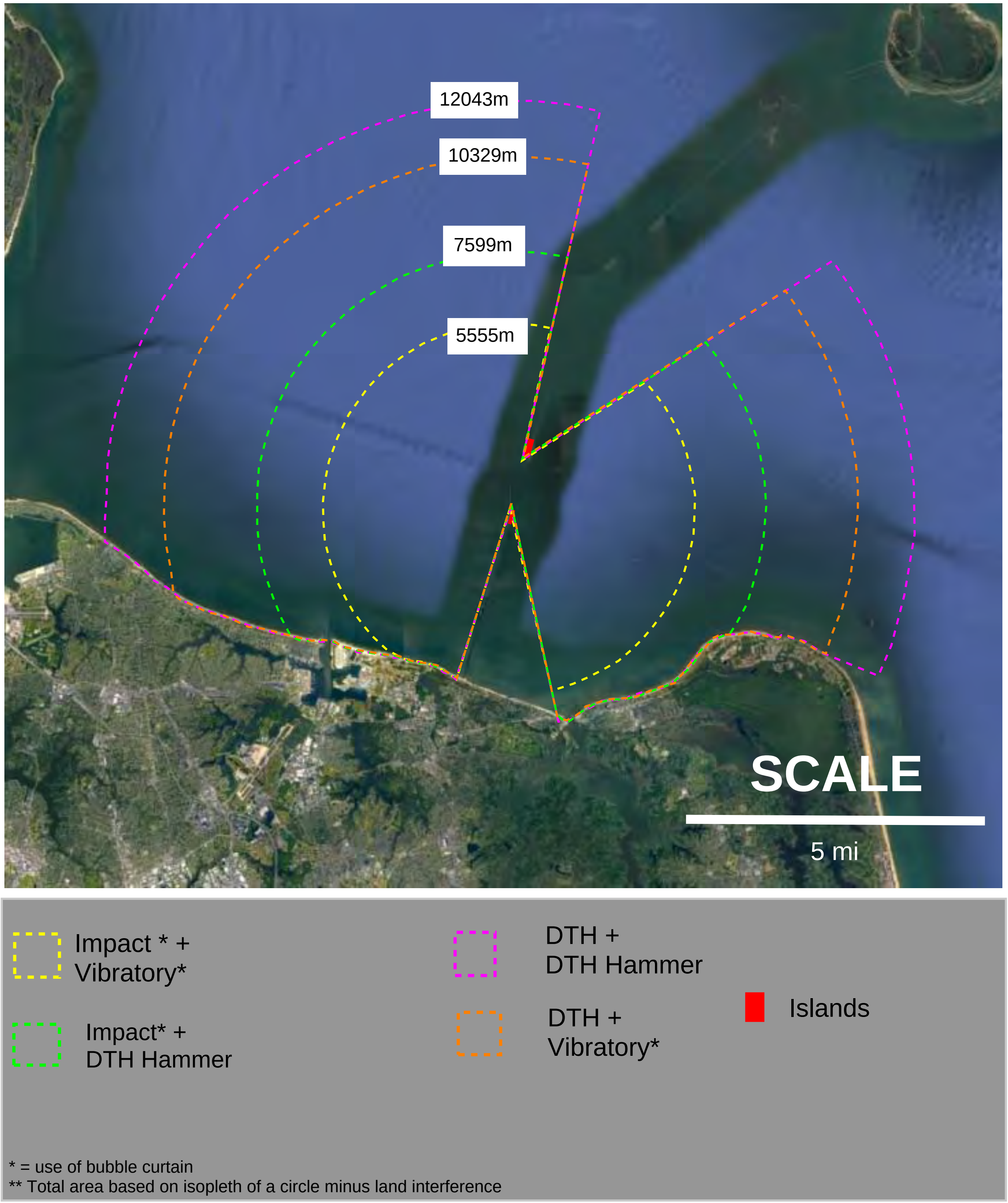


Figure 9. Island 2 Level B Harassment Zones

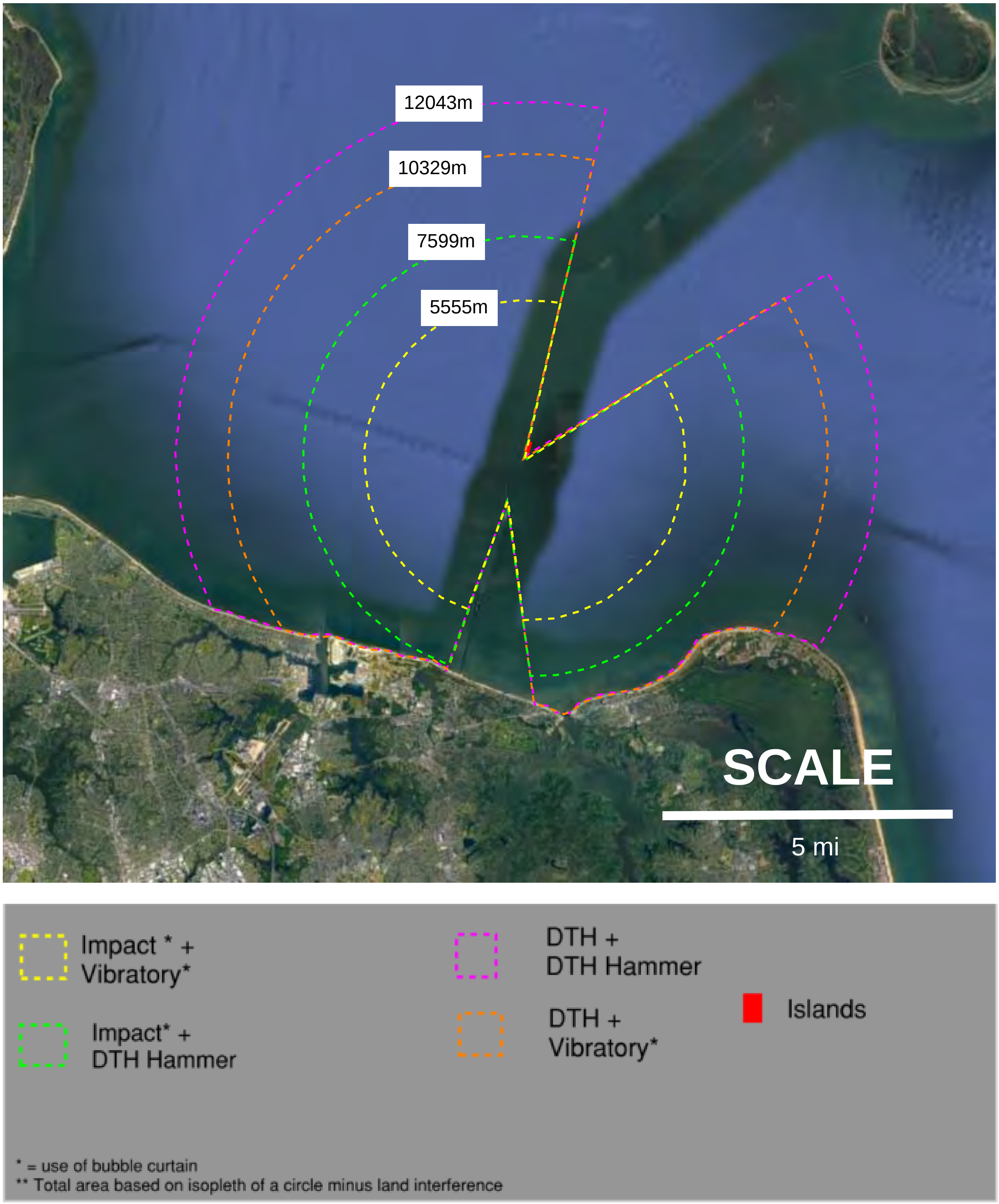
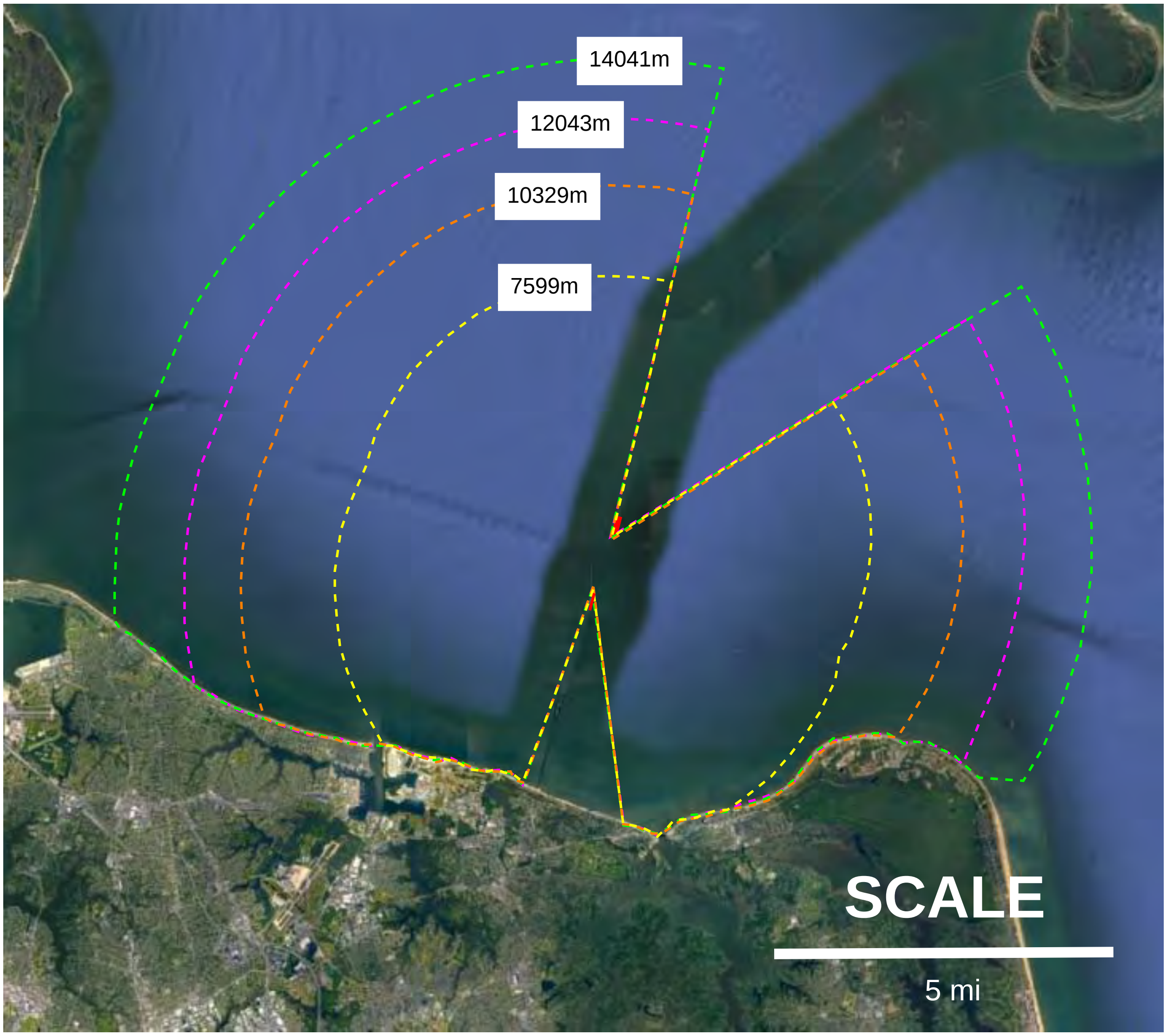


Figure 7. Level B Impact Area for Simultaneous Driving On Both Islands Per Driving Scenario



DTH + Impact* + Impact*

Dual DTH + Impact* Hammer

DTH + Vibratory* + Impact*

Dual DTH + Vibratory

* = Use of bubble curtain
** Total area based on isopleth of a circle minus land interference

Figure 9. Island No. 1 Shutdown Zones

Figure 10. Island No. 2 Shutdown Zones

Appendix C : JASCO Sound Source Characterization of Down-the- Hole Hammering Report

Sound Source Characterization of Down-the-Hole Hammering

Thimble Shoal, Virginia

Submitted to:

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3 October 2019

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Disclaimer:

The results presented herein are relevant within the specific context described in this report. They could be misinterpreted if not considered in the light of all the information contained in this report. Accordingly, if information from this report is used in documents released to the public or to regulatory bodies, such documents must clearly cite the original report, which shall be made readily available to the recipients in integral and unedited form.

Contents

Figures

Tables

1. Introduction

JASCO Applied Sciences (JASCO), an ISO 9001 certified company, was contracted by the Chesapeake Tunnel Joint Venture (CTJV) to perform acoustic measurements at Thimble Shoal along the Chesapeake Bay Bridge Tunnel in Virginia, USA (Figure 1). DTH hammering is a new technology being used to create casings for dock pile installation (pile locations shown in Figure 2 and inset in Figure 1). The aim of the measurements is to determine the underwater sound levels produced during DTH hammering.

Figure 1. location of project. Inset shows pile locations drawn in Figure 2

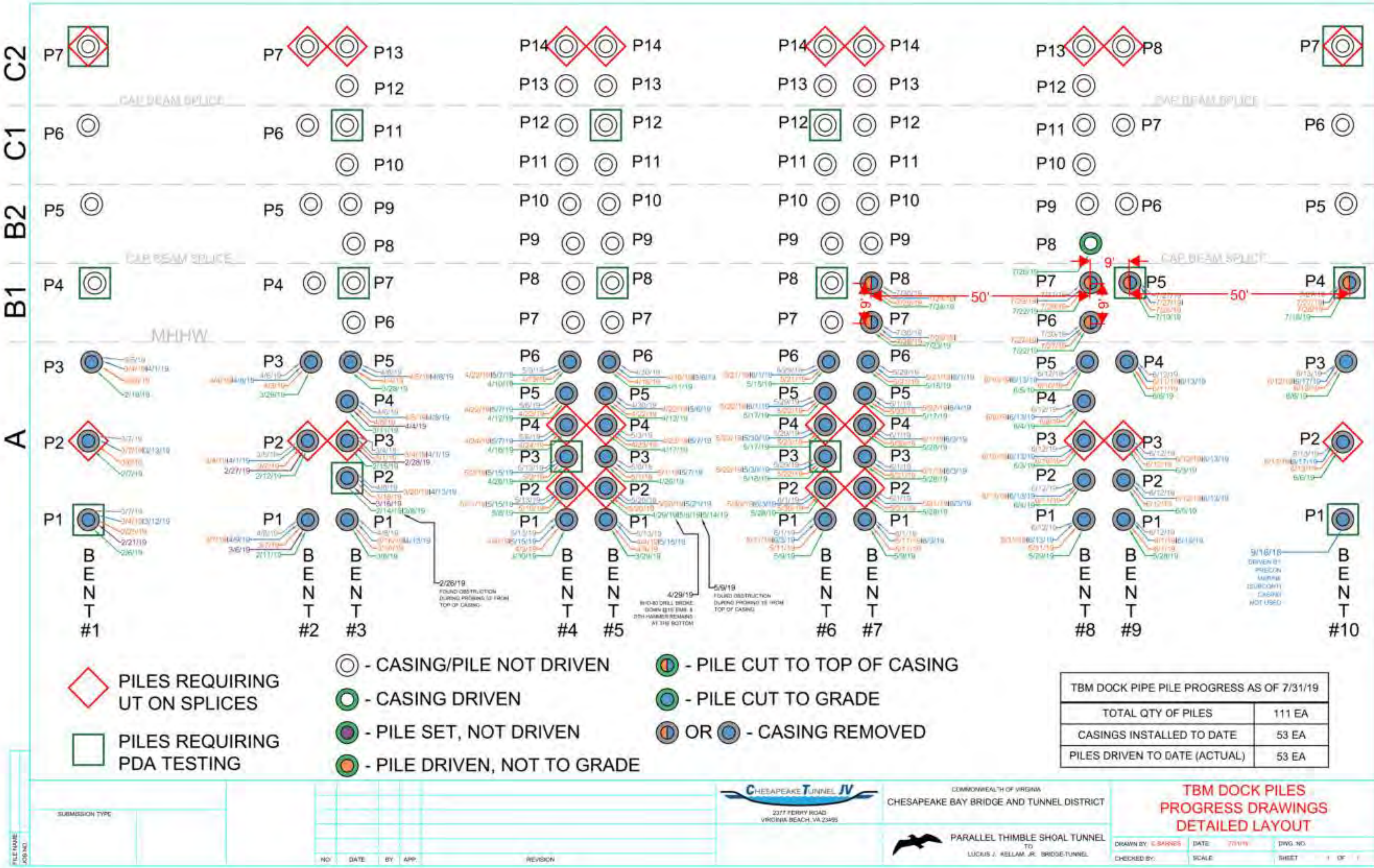

Figure 2. drawing of pile locations

2. Methods

The CTJV submitted an Incidental Harassment Authorization (IHA) application for their proposed Parallel Thimble Shoal Tunnel Project. As part of the IHA approval, an Underwater Noise Monitoring Plan [based on previously published “Noise measurements at bridge drilling site” (Imatra, Finland report (04.05.119)] was included that requires measurements to determine whether the predicted level of 166 dB re 1µPa at 10 m (the median value measured for rock drilling at 10m; Denes et al. 2016) is an acceptable estimate of the sound levels produced by DTH hammering. The current measurement program was designed to determine sound levels produced during DTH hammering through rock at Thimble Shoal, local sound propagation from the DTH hammering, and ambient sound levels (when DTH is not employed).

2.1. Measured Sound Sources

Underwater sound levels were measured during DTH hammering at five pile locations – 3 without bubble curtain attenuation and 2 with bubble curtain attenuation. The locations of the piles are listed in Table 1.

Table 1. Locations of measured piles.

Attenuation	Pile	Latitude	Longitude
No bubble curtain	C10P4	36.96597207	-76.11329579
	C9P5	36.96584035	-76.11334419
	C8P6	36.96580965	-76.11332336
With bubble curtain	C8P7	36.96581664	-76.11335290
	C8P8	36.96582363	-76.11338245

2.2. Data Collection

2.2.1. Acoustic recorders

Underwater sound was recorded on three, fixed-location, Autonomous Multichannel Acoustic Recorders (AMARs, JASCO; Figure 3 Bottom). Each AMAR was fitted with two M8 omnidirectional hydrophones (GeoSpectrum Technologies Inc.), one hydrophone was low-sensitivity (-195 ± 3 dB re 1 V/µPa) to record high-level sounds during DTH near the source and one was higher sensitivity (-165 ± 3 dB re 1 V/µPa) to record lower levels sounds, including ambient levels. The AMARs recorded continuously at 64 000 samples per second for a recording bandwidth of 10 Hz to 32 kHz. The recording channels had 24-bit resolution with a spectral noise floor of ~20 dB re 1 µPa^2/Hz, and a nominal ceiling level of 201 dB re 1 µPa and 171 dB re 1 µPa, for the low and high sensitivity hydrophones respectively. Acoustic data were stored on 1TB of internal solid-state flash memory. As configured, the recorders were capable of continuously recording for >4 weeks.

The recording systems were calibrated using NIST-traceable GRAS 42AC pistonphone calibrators to verify the sensitivity of the recording system as a whole (i.e., the hydrophone, pre-amplifier, and AMAR). Calibration is performed in JASCO’s warehouse lab prior to shipment and upon receipt after project completion. Calibration measurements are also performed before and after each usage in the field. The sensitivity of the system is measured independently of the software that performs the data analysis, which allows an independent calibration of the analysis software. Field calibration measurements are referenced to the established calibration measurements performed in the warehouse. Post-retrieval calibration measurements are used to verification that no loss of sensitivity occurred during the course of deployment and measurement.

2.2.2. Moorings

Due to high currents near Thimble Shoal, a low-profile, high-flow mooring system was used (Figure 3). These hydrodynamically-shaped instrument moorings reduce flow-induced noise and are ideal for measurements in tidal zones. The moorings are constructed of ¼ inch steel plate with ¼ inch neoprene rubber cover. The moorings are 55.6 × 32.2 × 15.8 in (L x W x H), weigh 472 lbs in air with an AMAR recorder and battery pack (388 lbs in water).

Figure 3. Photos of mooring for proposed sound level measurements of DTH hammering. Top: high-flow mooring. Bottom: high-flow mooring with cover removed to show two AMAR recorders within the mooring.

2.2.3. Deployment locations

AMARs were deployed at three locations (Table 2 and Figure 4) on 26 June 2019 and retrieved on 29 July 2019. Locations were chosen to provide a near field recording at ~10 m from DTH hammering (Station 1), and far field measurements at ~35 m (Station 2) and ~100 m (Station 3).

Table 2. Location and depth of the AMARs deployed for DTH hammering monitoring.

Station	AMAR #	Lat	Long
1	289	36.96591667	-76.11336667
2	294	36.96596667	-76.11361667
3	286	36.96605000	-76.11406667

Figure 4. Photo of recorder locations

2.2.4. Sound level compared to range

To estimate the distance to thresholds, the 90% SPL, SEL, and PK levels as a function of range were fit with the following empirical propagation loss equation:

$$90\% \text{ rms SPL} = \text{ESL} - A \log_{10} R \tag{1}$$

where R is the slant range from the source to the acoustic recorder (m), ESL is the effective source level (dB re 1 μPa or dB re 1 $\mu Pa^2 \cdot s$), and A is the geometric spreading loss coefficient (dB).

3. Results

3.1. Ambient Sound Levels

Broadband (10 Hz – 31.5 kHz) and decidecade band levels were analyzed in 30-minute intervals from 28 June through 15 July for recordings from Station 3. Sound levels include anthropogenic sources (e.g., vessel noise and possible noise from automotive traffic on the bridge), as well as natural (e.g., wind and rain) and biological noise (e.g., animal vocalization) during the period of analysis. The median SPL for this period was 122.78 dB re 1 µPa, with a maximum level of 155.43 dB. 90% of the time, the SPL was below 130.32 dB (Table 3; Figure 5). Band levels below 31.5 Hz were the largest contributors to the SPL (Figure 6).

Table 3. Broadband ambient sound pressure levels from 28 June through 15 July.

	Minimum	10%	25%	Median	75%	90%	Maximum
SPL (dB re 1 µPa)	113.29	117.90	120.04	122.78	127.13	130.32	155.43

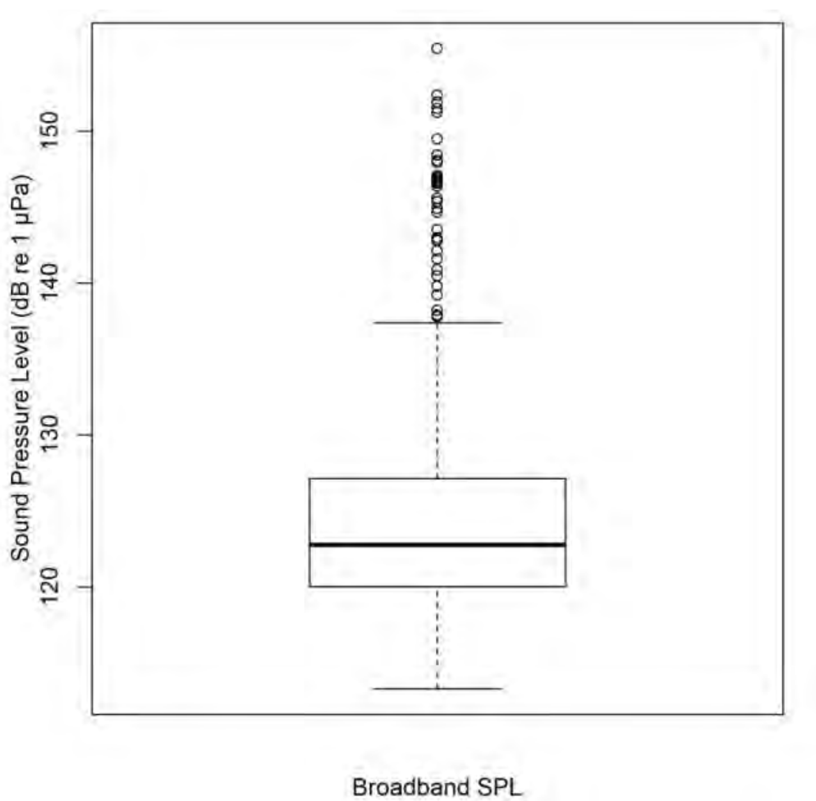

Figure 5. Distribution of ambient broadband SPL (dB re 1 µPa).

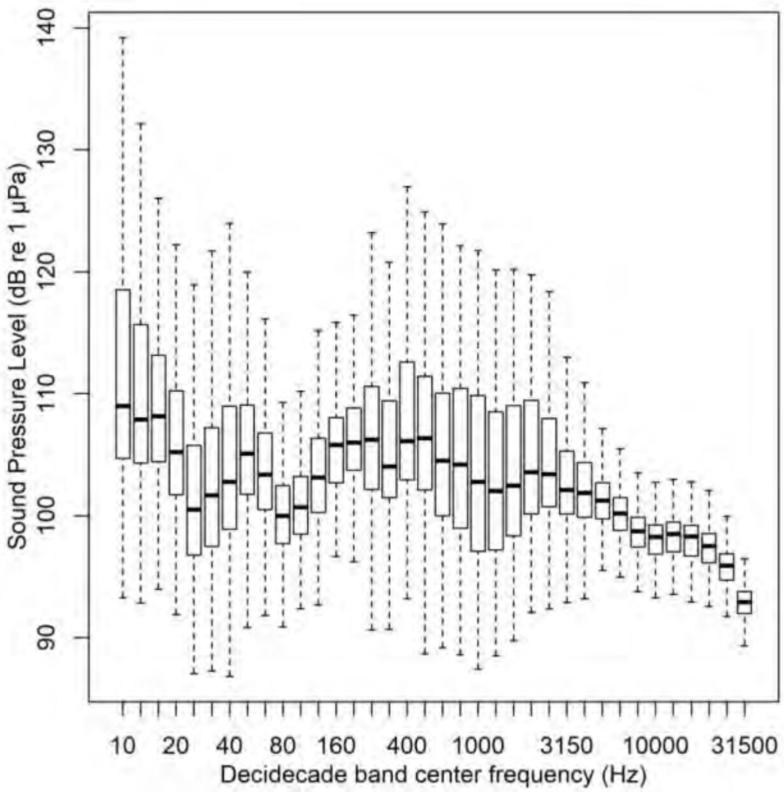

Figure 6. Distribution of ambient decidecade band levels from 10 Hz to 31.5 kHz.

3.2. Source Type and Duration

For regulatory purposes, sound sources are classified as either producing impulsive sounds or non-impulsive sounds. Impulsive sounds, such as impact pile driving, is characterized by short-duration pulses separated by a quiescent interval. Non-impulsive (sometimes referred to as continuous) sounds, such as vibratory pile driving, are longer duration and lack the pulsatile structure of impulsive sounds. The SPL of non-impulsive sounds are relatively consistent throughout the signal whereas SPL of impulsive sounds are markedly greater during the pulse. Southall et al. (2007) suggested that impulsive sounds can be distinguished from non-impulsive sounds by comparing the SPL of a 0.035 s window that includes the pulse and with a 1 s window that may include multiple pulses. If the SPL of the 0.035 s window is 3 dB or more greater than the 1 s window, then the signal is impulsive. Figure 7 shows a representative 1 s sample of DTH hammering and a highlighted (in red) 0.035 s pulse. The SPL of the 0.035 s pulse is 5 dB higher than the SPL of the 1 s sample, so the DTH source can be classified as impulsive.

The average duration of the 90% energy of each pulse at Station 1 (the closest recording location) for each DTH location is shown in Table 4. The mean duration of pulses for DTH locations without bubble curtains was 0.020 s.

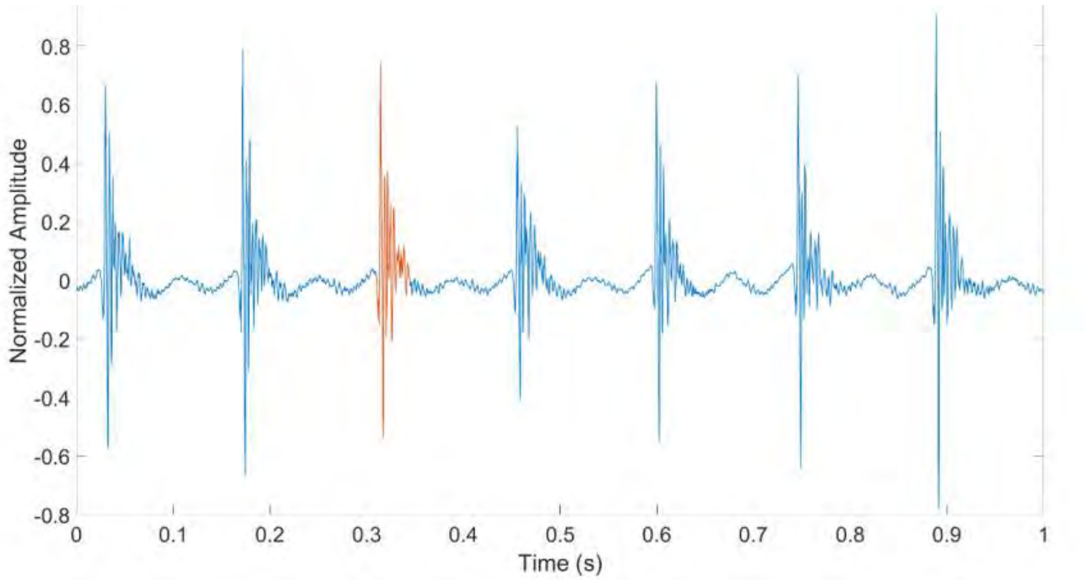

Figure 7. Time-domain waveform of a 1 s sample of DTH hammering. Highlighted in red is a 0.035 s window of a DTH pulse.

Table 4. DTH duration of 90% energy, in seconds, of the pulses at the closest recording station.

DTH location	Station 1
C10P4	0.011294
C9P5	0.025604
C8P8	0.02221
C8P6*	0.022978
C8P7*	0.022956

* with bubble curtain

3.3. Levels over time

Impulses were detected and measured during DTH hammering at the three recording stations. Figures 8 - 22 show the SEL, PK, and SPL of the recorded pulse and the accumulated SEL for DTH hammering at each location. The levels are relatively consistent over time in that first pulses are of similar level as the latter pulses. Appendix B shows the sound levels grouped by location as a function of recording time.

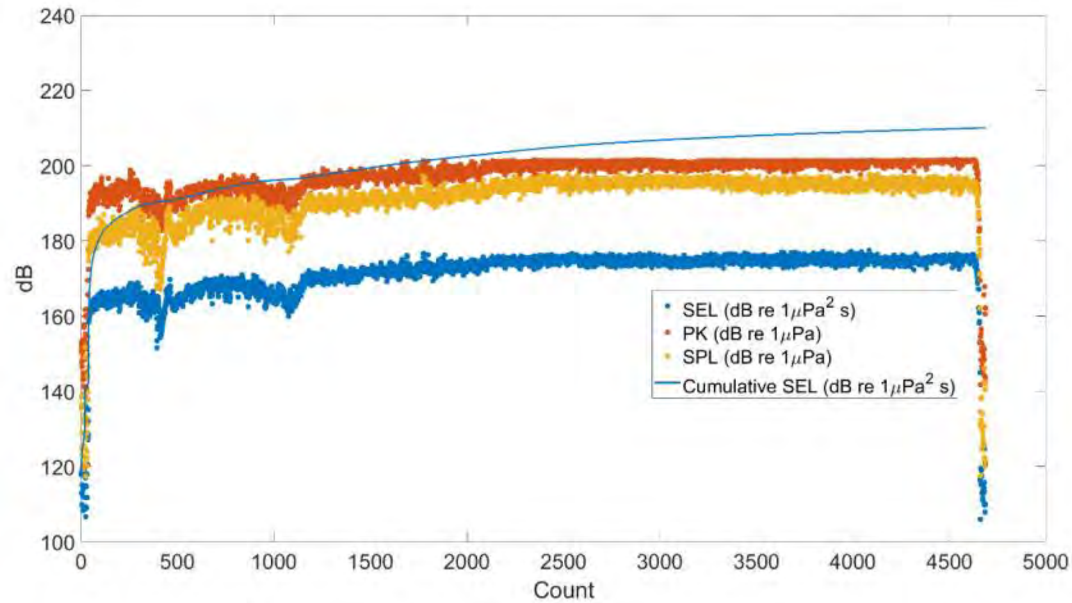

Figure 8. Unweighted single pulse SEL, Unweighted cumulative SEL, PK, and SPL at Station 1 over time for DTH hammering at location C10P4.

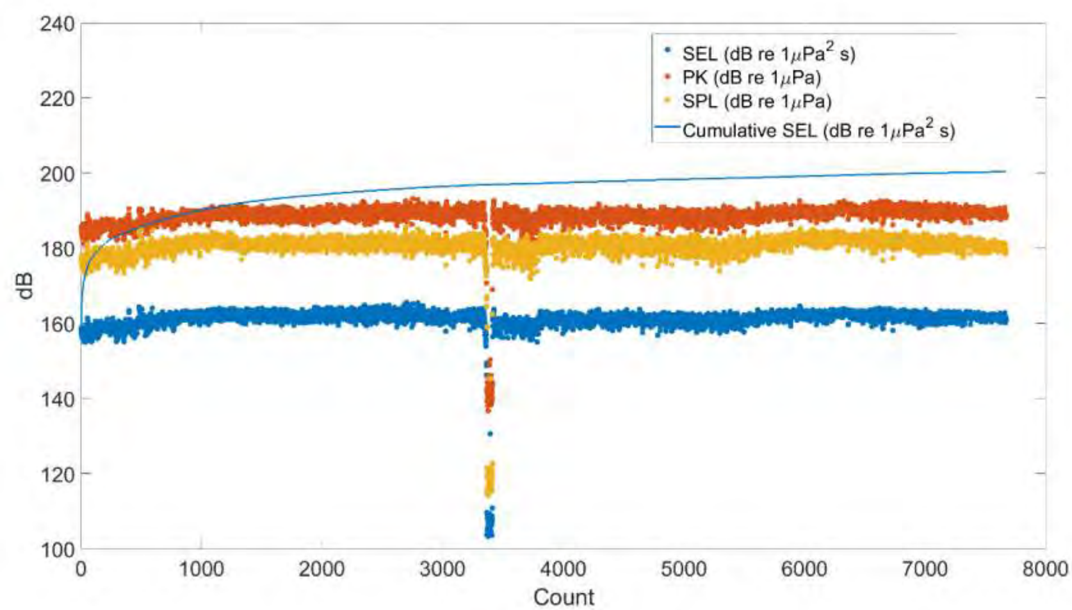

Figure 9. Unweighted single pulse SEL, Unweighted cumulative SEL, PK, and SPL at Station 2 over time for DTH hammering at location C10P4.

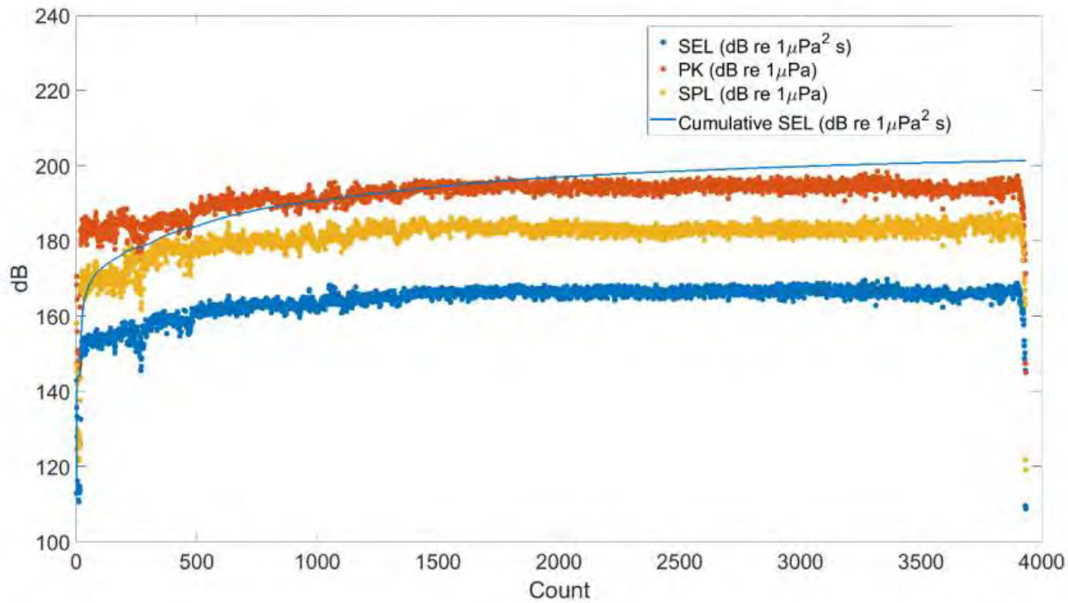

Figure 10. Unweighted single pulse SEL, Unweighted cumulative SEL, PK, and SPL at Station 3 over time for DTH hammering at location C10P4.

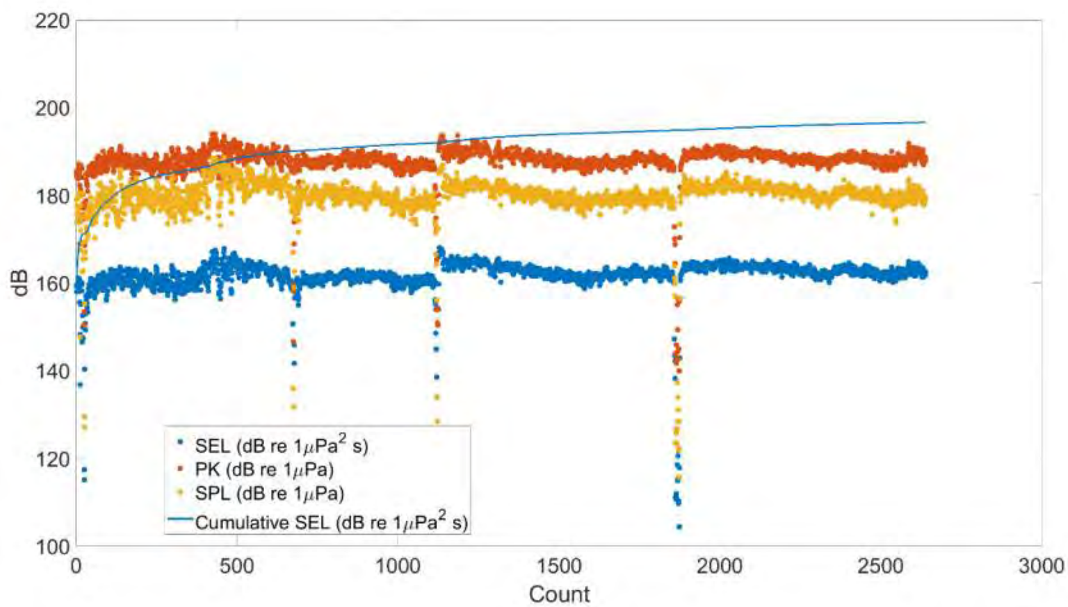

Figure 11. Unweighted single pulse SEL, Unweighted cumulative SEL, PK, and SPL at Station 1 over time for DTH hammering at location C9P5.

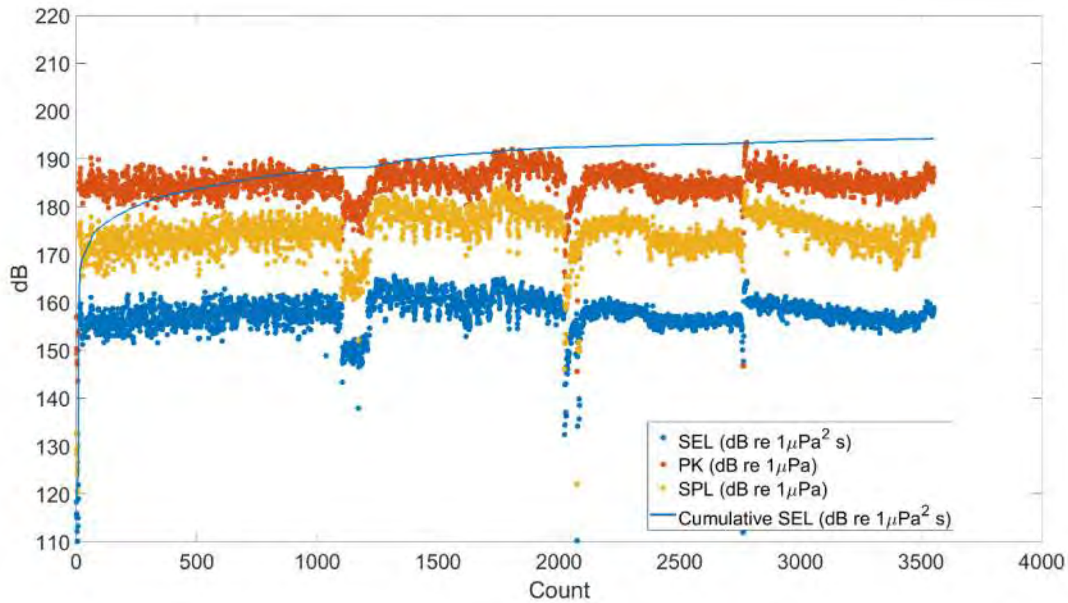

Figure 12. Unweighted single pulse SEL, Unweighted cumulative SEL, PK, and SPL at Station 2 over time for DTH hammering at location C9P5.

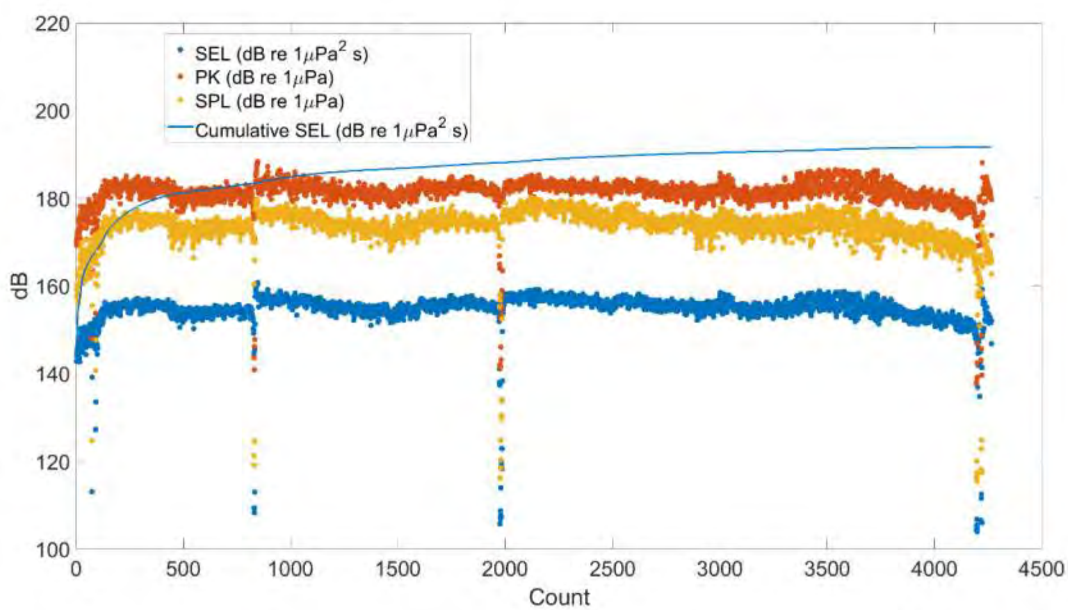

Figure 13. Unweighted single pulse SEL, Unweighted cumulative SEL, PK, and SPL at Station 3 over time for DTH hammering at location C9P5.

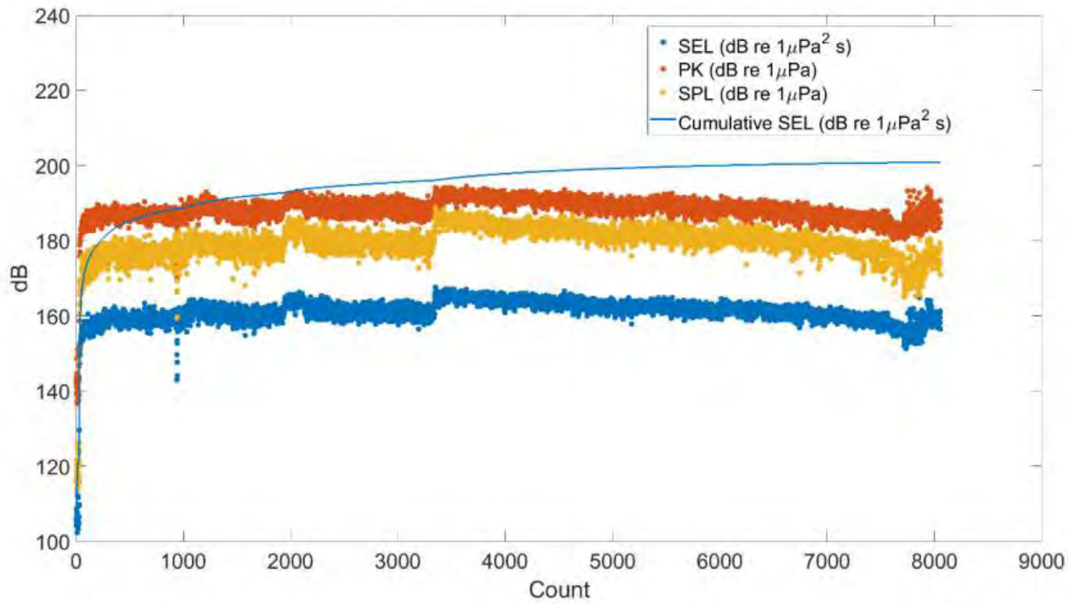

Figure 14. Unweighted single pulse SEL, Unweighted cumulative SEL, PK, and SPL at Station 1 over time for DTH hammering at location C8P8.

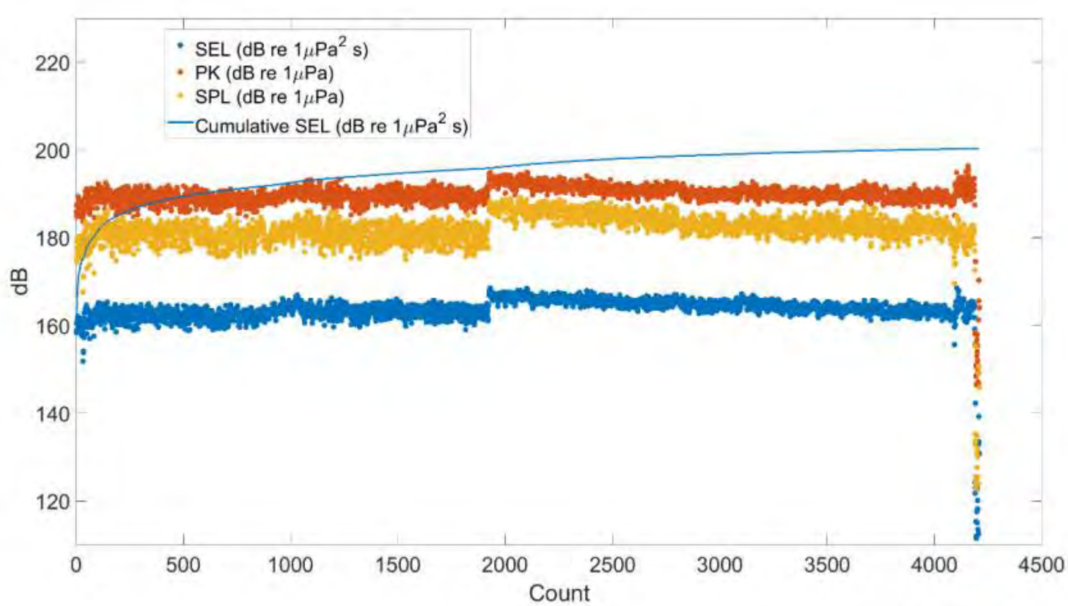

Figure 15. Unweighted single pulse SEL, Unweighted cumulative SEL, PK, and SPL at Station 2 over time for DTH hammering at location C8P8.

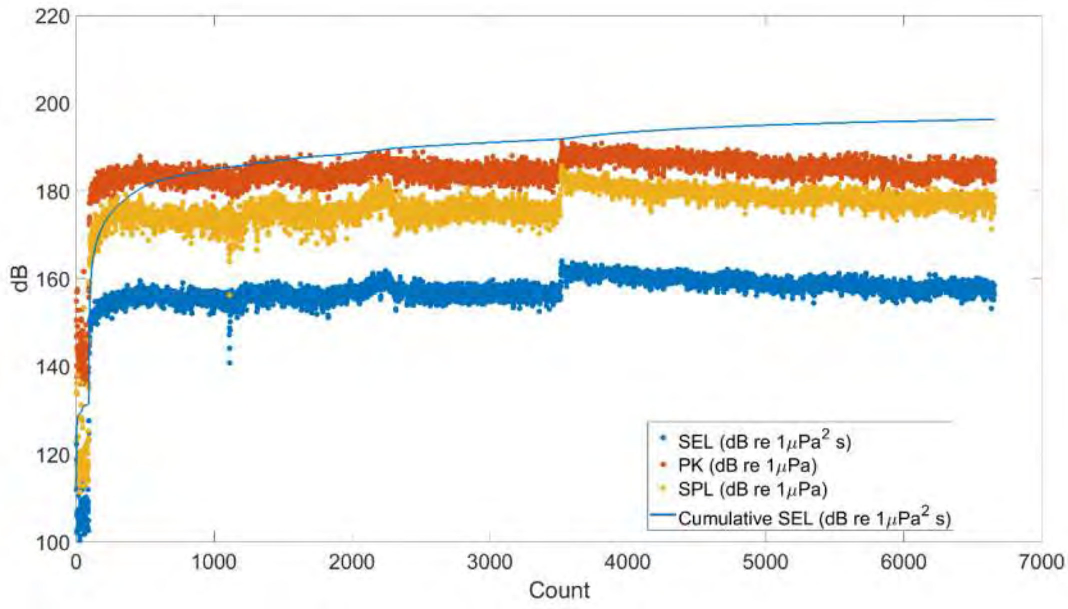

Figure 16. Unweighted single pulse SEL, Unweighted cumulative SEL, PK, and SPL at Station 3 over time for DTH hammering at location C8P8.

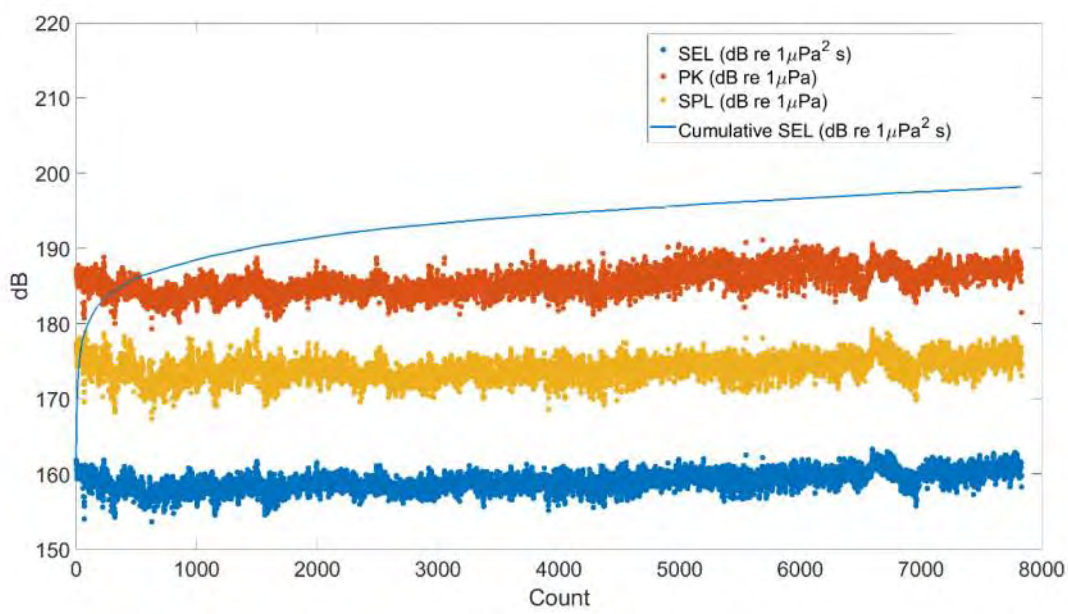

Figure 17. Unweighted single pulse SEL, Unweighted cumulative SEL, PK, and SPL at Station 1 over time for DTH hammering at location C8P6.

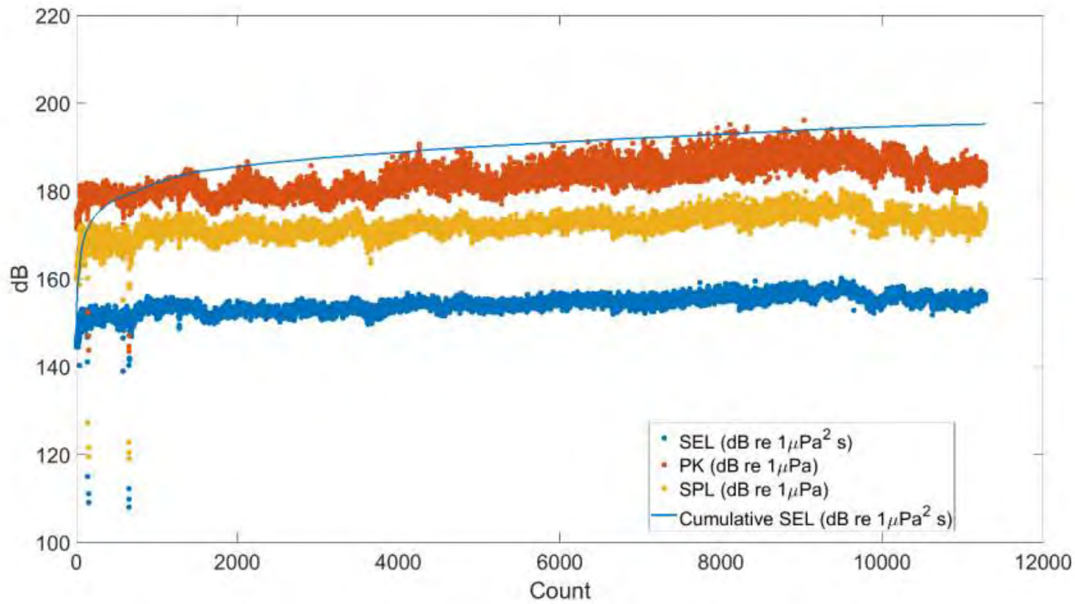

Figure 18. Unweighted single pulse SEL, Unweighted cumulative SEL, PK, and SPL at Station 2 over time for DTH hammering at location C8P6.

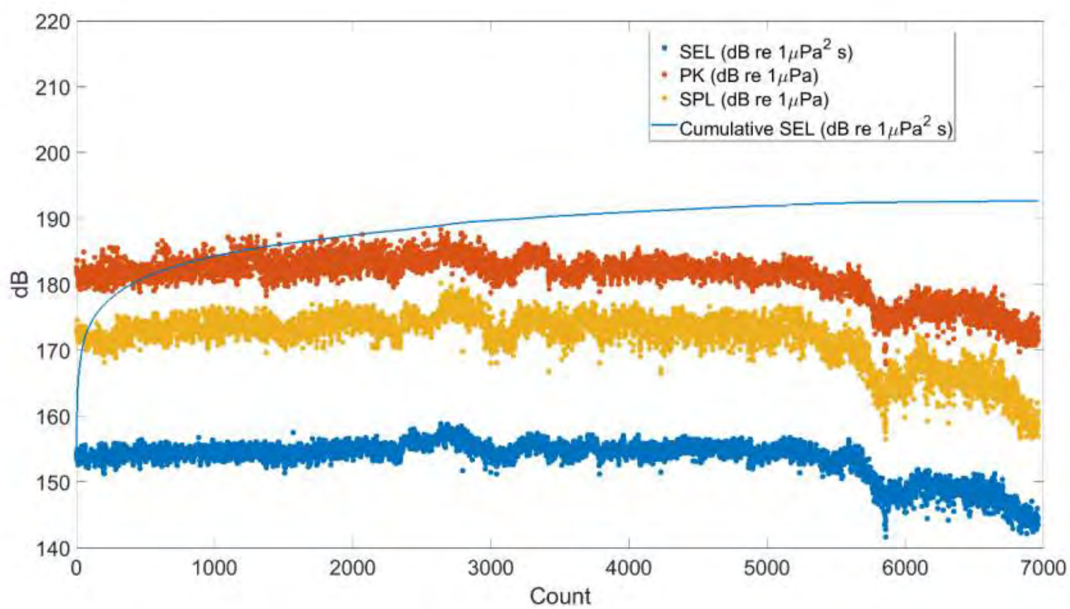

Figure 19. Unweighted single pulse SEL, Unweighted cumulative SEL, PK, and SPL at Station 3 over time for DTH hammering at location C8P6.

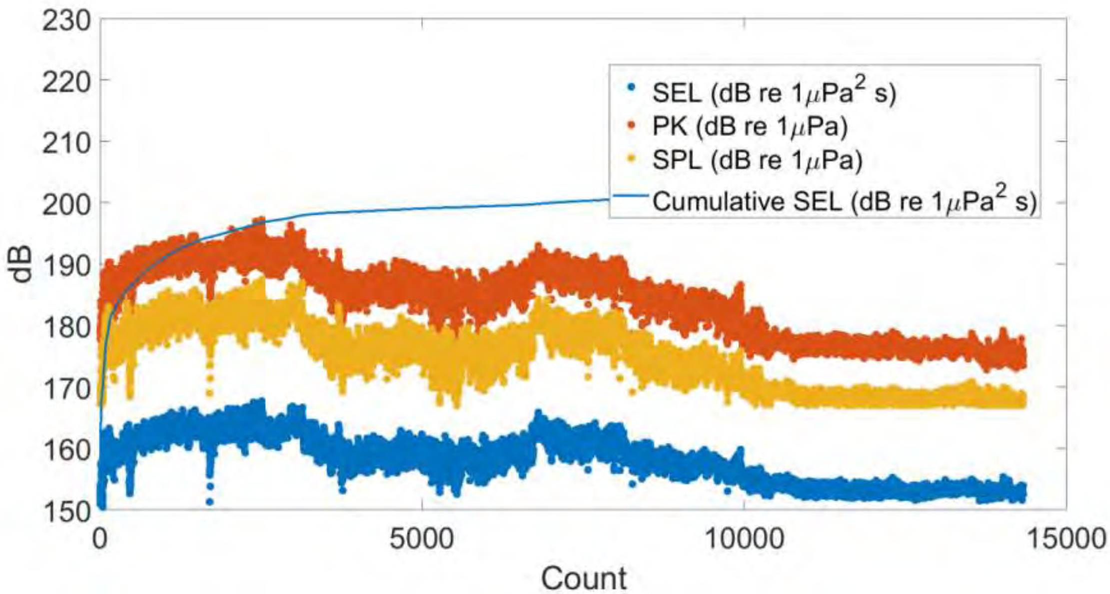

Figure 20. Unweighted single pulse SEL, Unweighted cumulative SEL, PK, and SPL at Station 1 over time for DTH hammering at location C8P7.

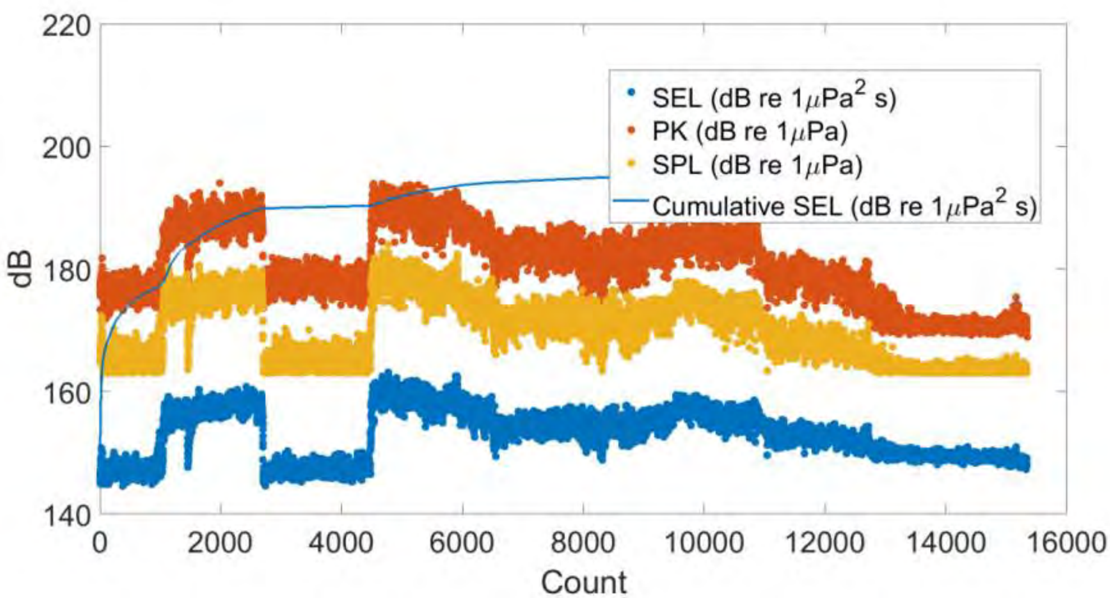

Figure 21. Unweighted single pulse SEL, Unweighted cumulative SEL, PK, and SPL at Station 2 over time for DTH hammering at location C8P7.

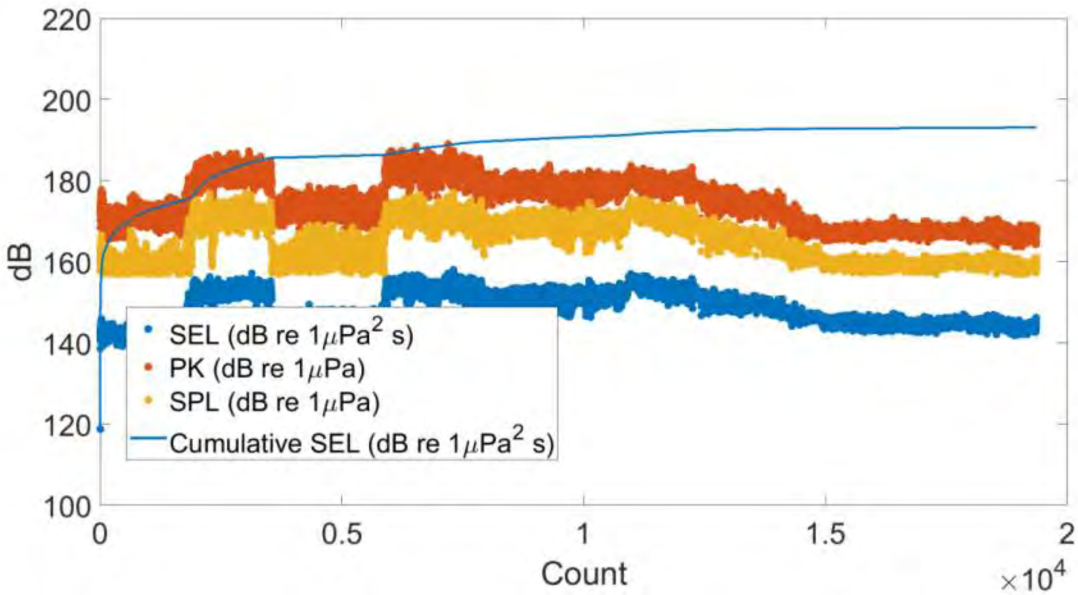

Figure 22. Unweighted single pulse SEL, Unweighted cumulative SEL, PK, and SPL at Station 3 over time for DTH hammering at location C8P7.

3.4. Sound levels as a function distance

The mean sound levels and standard deviations are plotted for SPL (Figure 23), SEL (Figure 24), and PK (Figure 25) for each location without (C10P4, C9P5, and C8P8) and with (C8P7, C8P6) a bubble curtain. While sound levels are highest for C10P4 and C8P8 without a bubble curtain, the levels are similar at C9P5, C8P7, and C8P6 even though C8P7 and C8P6 use a bubble curtain and C9P5 does not. Note that sound levels of C10P4 were loud enough to saturate the recording system at the closest location so those values were not included in range analysis. Sound levels as a function of distance, including weighting SEL for the functional hearing groups are shown in Appendix D.

Table 5 shows the predicted sound level for a single SEL pulse, PK, and SPL for the 90% energy at the DTH hammering locations. For all DTH locations, with and without bubble curtains, the SPL at 10 m exceeded the predicted 166 dB re 1μPa. The average SPL value at 10 m for the DTH location without a bubble curtain was 180 dB re 1μPa, while the average SEL and PK levels were 164 dB re 1μPa^{2}·s and 190 dB re 1μPa, respectively.

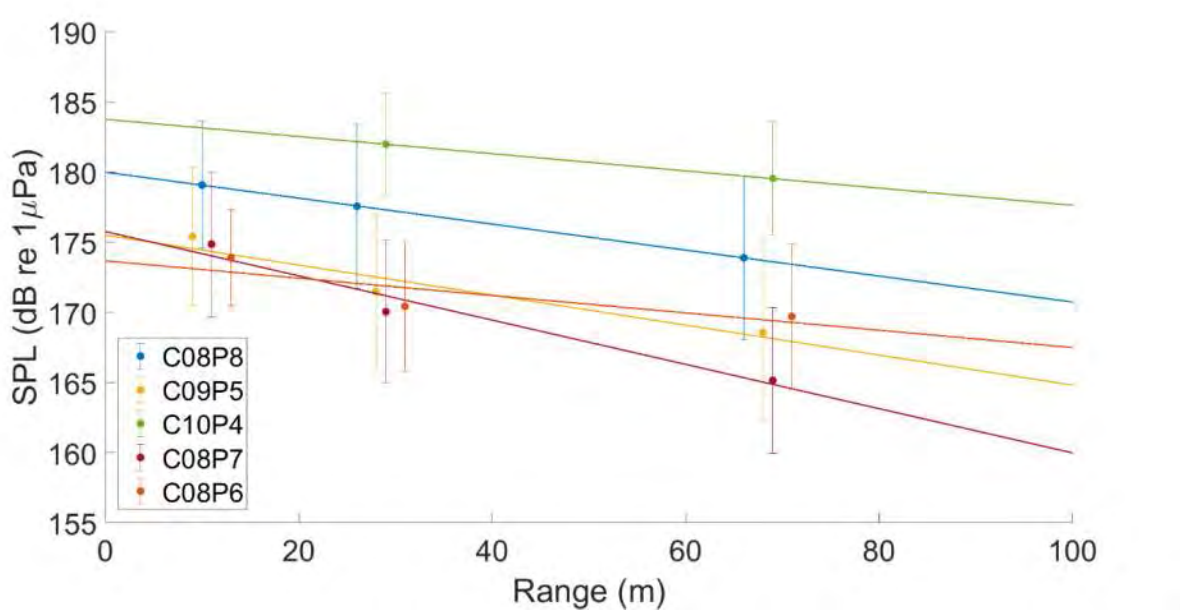

Figure 23. Sound Pressure Level (SPL) of Down-the-hole hammering without (C10P4, C09P5, and C08P8) and with bubble curtain (C08P7, C08P6). Error bars are standard deviation.

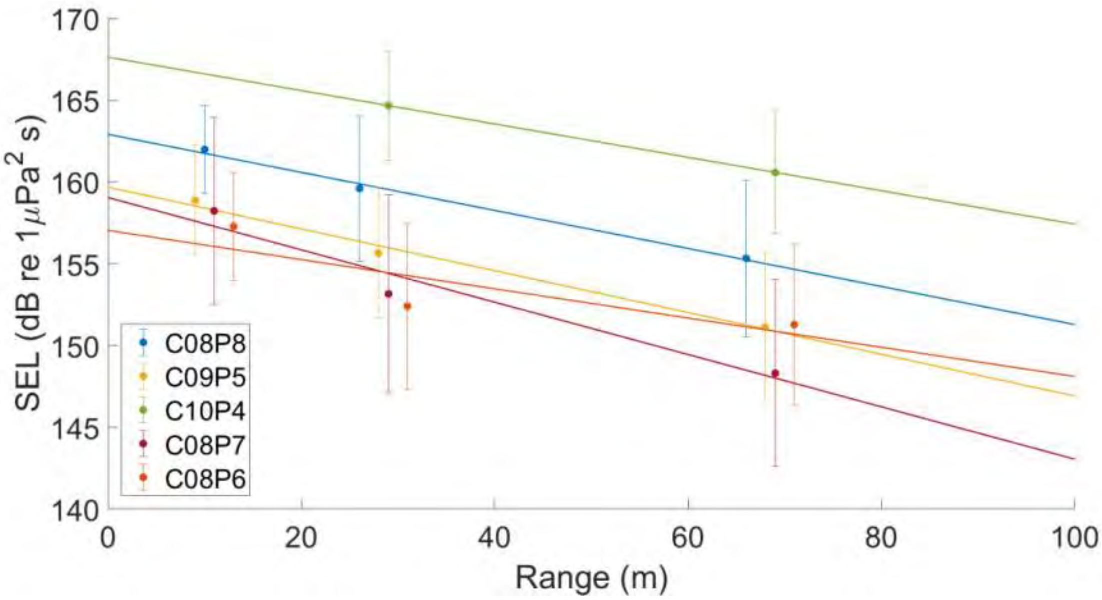

Figure 24. Sound Exposure Level (SEL) of Down-the-hole hammering without (C10P4, C09P5, and C08P8) and with bubble curtain (C08P7, C08P6). Error bars are standard deviation.

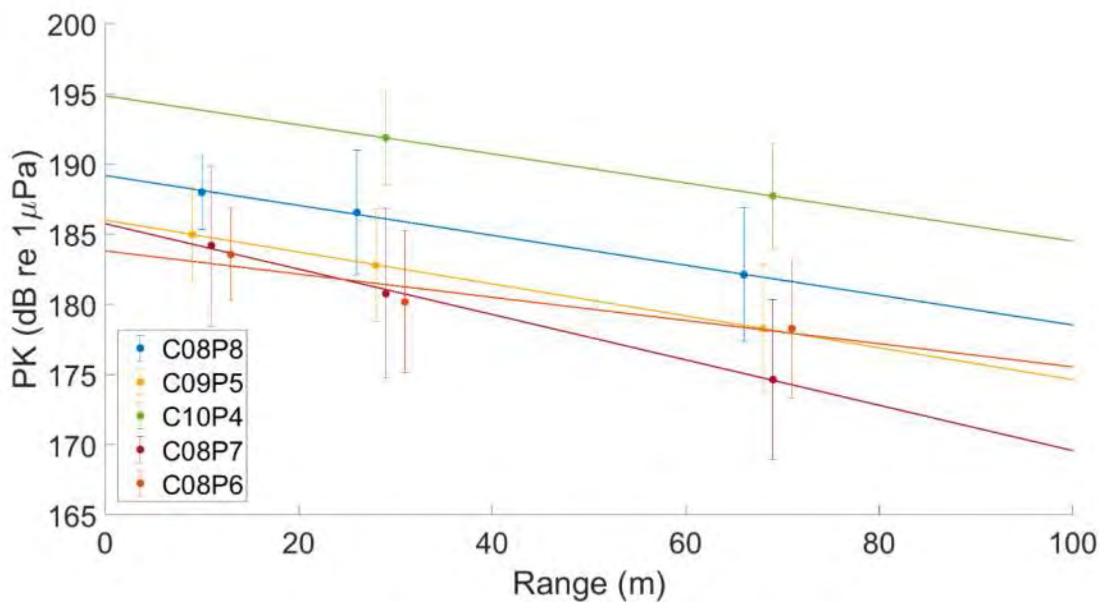

Figure 25. Peak Sound pressure (PK) of Down-the-hole hammering without (C10P4, C09P5, and C08P8) and with bubble curtain (C08P7, C08P6). Error bars are standard deviation.

Table 5. Sound levels of 90% energy 10 m from DTH hammering for SEL (single strike), PK, and SPL.

DTH location	SEL	PK	SPL
C10P4	170.2	197.0	185.5
C9P5	162.6	188.0	179.5
C8P8	159.1	184.6	175.1
C8P6*	158.1	184.2	174.1
C8P7*	158.7	185.3	175.1

* with bubble curtain

3.5. Signal Spectral Content

The spectral band level of the sounds produced by DTH hammering were calculated in decidecade bands. Figures 26 - 30 show that the primary sound energy is between 100 and 1000 Hz, with an additional peak around 1200 Hz. The spectra of the DTH hammering performed with a bubble curtain, C8P7 (Figure 29) and C8P6 (Figure 30) appear to be flatter indicating that the bubble curtain may be attenuating some of the peak energy, though there are not enough examples to produce a convincing trend.

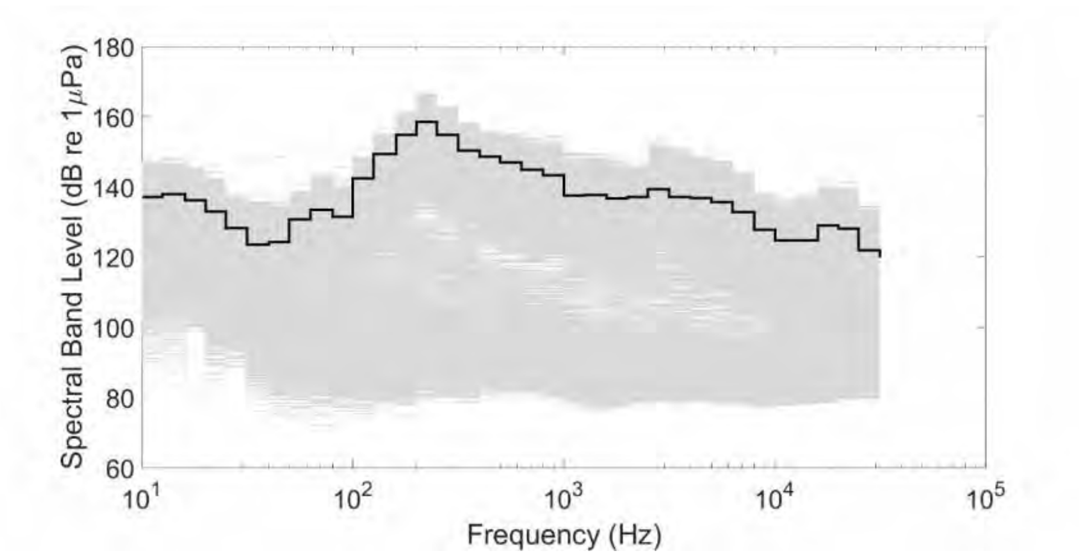

Figure 26. Decidecade spectral band level of sound pressure during Down-the-hole hammering of C10P4

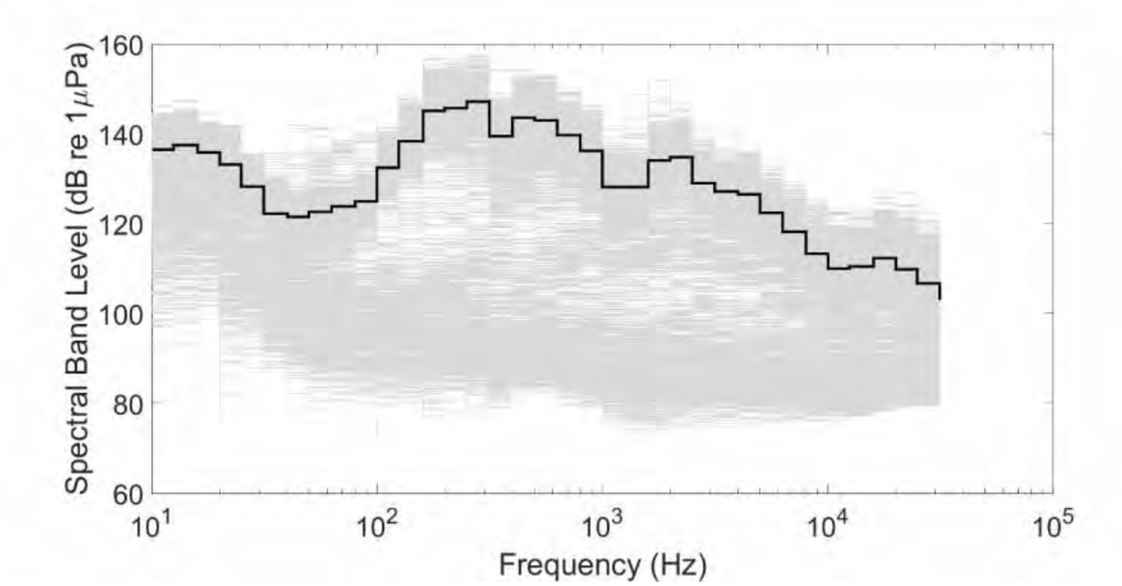

Figure 27. Decidecade spectral band level of sound pressure during Down-the-hole hammering of C09P5

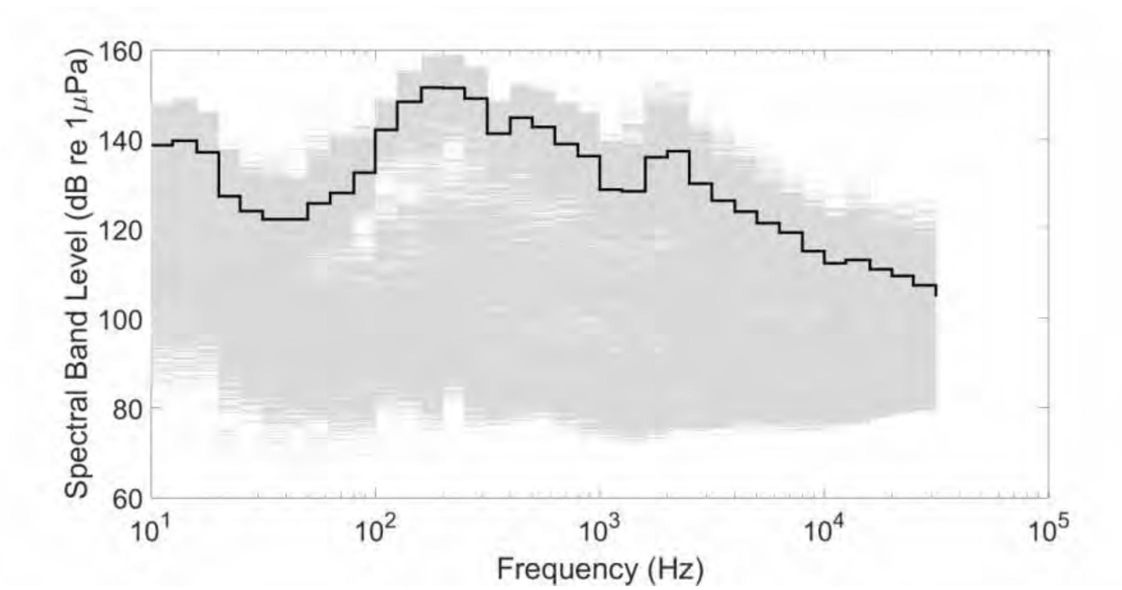

Figure 28. Decidecade spectral band level of sound pressure during Down-the-hole hammering of C08P8

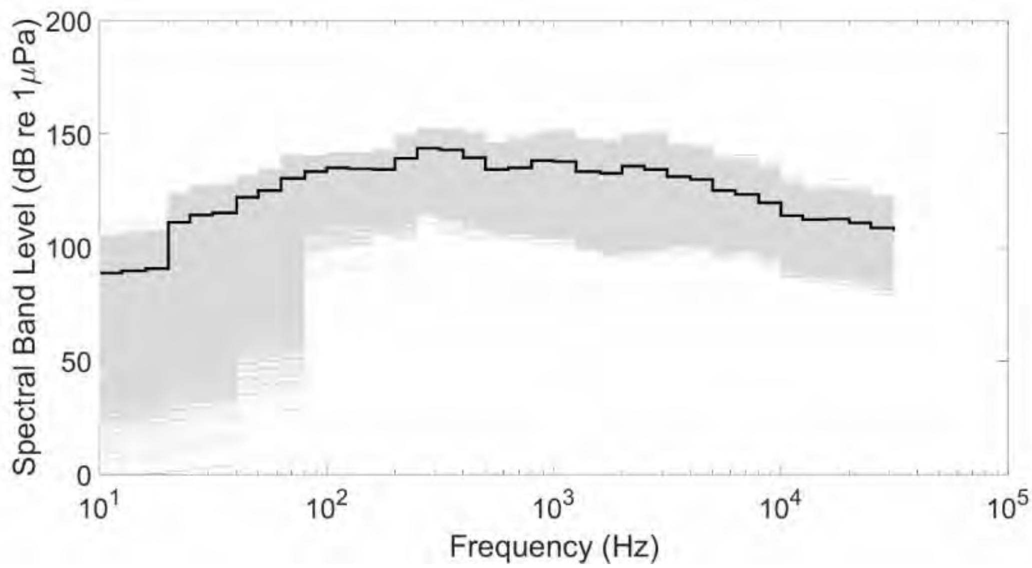

Figure 29. Decidecade spectral band level of sound pressure during Down-the-hole hammering of C08P7

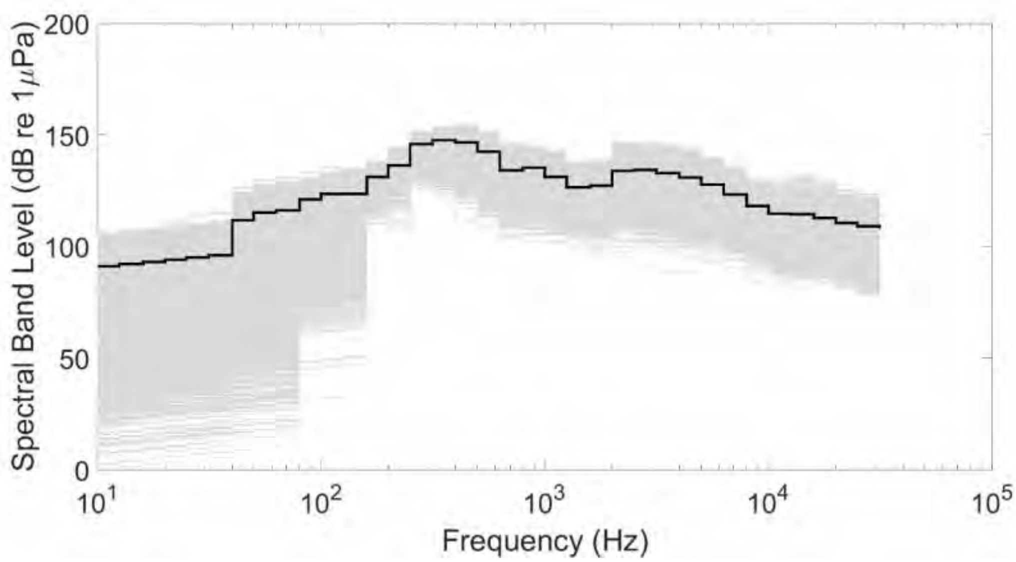

Figure 30. Decidecade spectral band level of sound pressure during Down-the-hole hammering of C08P6 at Station 1

4. Discussion and Conclusion

Underwater sounds were recorded using bottom-mounted flow-shielded moorings at three locations near Thimble Shoal Island of the Chesapeake Bay Bridge Tunnel in Virginia. Ambient sound levels, measured 28 June through 15 July (at Station 3) before DTH construction activities, indicate relatively high background noise levels with a median SPL of 122.78 dB re 1 μPa. The location is near an active shipping and boating channel, and the sound levels may include other construction noise as well as contributions from automotive traffic on the bridge.

Sound from DTH hammering was found to be impulsive based on a >3 dB difference (Southall et al. 2007) in sound pressure level measured over a short (0.035 s) window compared to a longer (1 s) window. Sound levels were determined by detecting and measuring individual pulses of DTH hammering. While initial levels were somewhat lower than later levels, no clear trend in amplitude with penetration depth was evident. All DTH hammering locations exceeded the predicted SPL of 166 dB re 1 μPa at 10 m, with an average SPL among locations of 180 dB re 1 μPa at 10 m (without the use of a bubble curtain). The loudest locations, C10P4 and C8P8, did not use a bubble. DTH hammering at one location, C9P5, without a bubble curtain was approximately the same level as the two locations, C8P7 and C8P6, with a bubble curtain, so an effect of the bubble curtain could not be determined from the measured levels. The spectral band levels of the signals were calculated and it was found that the primary sound energy is between 100 and 1000 Hz. Although a trend could not be established, use of a the bubble curtain did seem to flatten the spectra suggesting the bubble curtain could be attenuating sound levels.

Different metrics are used to determine the potential for injury and behavioral disruption of marine mammals. Potential for injury is assessed using SEL and PK levels (NMFS 2018) while the potential for behavioral disruption is assessed using SPL (NOAA 2005). The SEL levels for DTH hammering of a caisson were well below injury threshold for all hearing groups (Appendix D). With the exception of high-frequency species, the PK levels were also well below the threshold for potential injury (Section 3.4 and Appendix D). As a general statement of DTH, there is some potential for injury to high-frequency cetacea (such as *Kogia* species and harbor porpoise) as the PK levels can exceed 202 dB re 1 μPa within 10 m of DTH hammering for the loudest pulses, but no high frequency species are expected near the project area so no injury is expected. An SPL threshold of 160 dB re 1 μPa is used to assess behavioral disruption of marine mammals exposed to impulsive sound sources. Based on the measured SPL as a function of range (Section 3.4 and Appendix D) the distance to 160 dB re 1 μPa could be several kilometers. These measurements in shallow water near the source and a simple geometric propagation model, however, mean that long distance propagation is difficult to predict. Also, the SPL 160 dB re 1 μPa threshold (NOAA 2005) does not consider the hearing range of the species (unlike injury, no frequency weighting is used). DTH hammering was found to be a low-frequency source (most of the acoustic energy is between 100-1000 Hz), so it is not within the best hearing range of mid-frequency species such as dolphins.

In summary, behavioral responses may be expected, possibly to several kilometers, but no injury could occur.

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Nedwell, J.R. and A.W. Turnpenny. 1998. The use of a generic frequency weighting scale in estimating environmental effect. *Workshop on Seismics and Marine Mammals*. 23–25 Jun 1998, London, UK.

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Southall, B.L., A.E. Bowles, W.T. Ellison, J.J. Finneran, R.L. Gentry, C.R. Greene, Jr., D. Kastak, D.R. Ketten, J.H. Miller, et al. 2007. Marine Mammal Noise Exposure Criteria: Initial Scientific Recommendations. *Aquatic Mammals* 33(4): 411-521. https://doi.org/10.1080/09524622.2008.9753846.

Appendix A. Underwater Acoustics

This section provides a detailed description of the acoustic metrics relevant to the modeling study and the modeling methodology.

A.1. Acoustic Metrics

Underwater sound pressure amplitude is measured in decibels (dB) relative to a fixed reference pressure of p_0 = 1 μPa in water and p_0 = 20 μPa in air. Because the perceived loudness of sound, especially impulsive noise such as from seismic airguns, pile driving, and sonar, is not generally proportional to the instantaneous acoustic pressure, several sound level metrics are commonly used to evaluate noise and its effects on marine life. Here we provide specific definitions of relevant metrics used in the accompanying report. Where possible, we follow the ANSI and ISO standard definitions and symbols for sound metrics, but these standards are not always consistent.

The zero-to-peak sound pressure, or peak sound pressure (L_{pk}; dB re 1 μPa), is the decibel level of the maximum instantaneous acoustic pressure in a stated frequency band attained by an acoustic pressure signal, $p(t)$:

$$L_{p,pk} = 20 \log_{10}\left[\frac{\max\left(\left|p(t)\right|\right)}{p_0}\right] . \tag{A-1}$$

L_{pk} is often included as a criterion for assessing whether a sound is potentially injurious; however, because it does not account for the duration of a noise event, it is generally a poor indicator of perceived loudness.

The peak-to-peak sound pressure ($L_{pk\text{-}pk}$; dB re 1 μPa) is the difference between the maximum and minimum instantaneous sound pressure, possibly filtered in a stated frequency band, attained by an impulsive sound, $p(t)$:

$$L_{p,pk-pk} = 10 \log_{10}\left\{\frac{\left[\max\left(p(t)\right) - \min\left(p(t)\right)\right]^2}{p_0^2}\right\} . \tag{A-2}$$

The sound pressure level (L_p; dB re 1 μPa) is the root-mean-square (rms) pressure level in a stated frequency band over a specified time window (T; s). It is important to note that L_p always refers to an rms pressure level and therefore not instantaneous pressure:

$$L_p = 10 \log_{10}\left(\frac{1}{T}\int_T g(t)\, p^2(t)\, dt \Big/ p_0^2\right) , \tag{A-3}$$

where $g(t)$ is an optional time weighting function. In many cases, the start time of the integration is marched forward in small time steps to produce a time-varying L_p function. For short acoustic events, such as sonar pulses and marine mammal vocalizations, it is important to choose an appropriate time window that matches the duration of the signal. For in-air studies, when evaluating the perceived loudness of sounds with rapid amplitude variations in time, the time weighting function $g(t)$ is often set to a decaying exponential function that emphasizes more recent pressure signals. This function mimics the leaky integration nature of mammalian hearing. For example, human-based fast time-weighted L_p ($L_{p,fast}$) applies an exponential function with time constant 125 ms. A related simpler approach used in underwater acoustics sets $g(t)$ to a boxcar (unity amplitude) function of width 125 ms; the results can be referred to as $L_{p,\text{boxcar 125ms}}$. Another approach, historically used to evaluate L_p of impulsive signals underwater, defines $g(t)$ as a boxcar function with edges set to the times corresponding to 5% and 95% of the cumulative square pressure function encompassing the duration of an impulsive acoustic event. This calculation is applied individually to each impulse signal, and the results have been referred to as 90% SPL ($L_{p,90\%}$).

The sound exposure level (L_E; dB re 1 µPa²·s) is the time-integral of the squared acoustic pressure over a duration (T):

$$L_E = 10 \log_{10}\left(\int_T p^2(t)dt \Big/ T_0 p_0^2 \right), \tag{A-4}$$

where T_0 is a reference time interval of 1 s. L_E continues to increase with time when non-zero pressure signals are present. It is a dose-type measurement, so the integration time applied must be carefully considered in terms of relevance for impact to the exposed recipients.

SEL can be calculated over a fixed duration, such as the time of a single event or a period with multiple acoustic events. When applied to impulsive sounds, L_E can be calculated by summing the L_E of the N individual pulses. For a fixed duration, the square pressure is integrated over the duration of interest. For multiple events, the L_E can be computed by summing (in linear units) the L_E of the N individual events:

$$L_{E,N} = 10 \log_{10}\left(\sum_{i=1}^{N} 10^{\frac{L_{E,i}}{10}} \right). \tag{A-5}$$

If applied, the frequency weighting of an acoustic event should be specified, as in the case of M-weighted SEL (e.g., $L_{E,LF,24h}$). The use of fast, slow, or impulse exponential-time-averaging or other time-related characteristics should also be specified.

Sound particle acceleration is a time-dependent spatial vector quantity. In cylindrical coordinates the acceleration vector $\boldsymbol{a}(t) = \boldsymbol{a}_r(t) + \boldsymbol{a}_z(t)$, where r and z indicate the radial (horizontal) and vertical directions, respectively. The zero-to-peak sound particle acceleration is the largest magnitude of the particle acceleration:

$$a_{pk} = \max\left(|\boldsymbol{a}(t)|\right). \tag{A-6}$$

The radial or vertical peak particle acceleration is the peak acceleration for each dimension, i.e., $a_{r,pk} = \max(|\boldsymbol{a}_r(t)|)$ and $a_{z,pk} = \max(|\boldsymbol{a}_z(t)|)$. The peak acceleration level is

$$L_{a,pk} = 20\mathrm{Log}_{10}\frac{a_{pk}}{a_0}, \tag{A-7}$$

where a_0 is the reference acceleration of 1 µm/s². Peak acceleration levels in the horizontal or vertical directions are calculated using the peak acceleration in the horizontal or vertical directions, respectively.

The rms acceleration level is the level of the square root of the mean-square acceleration,

$$L_{a,rms} = 10\mathrm{Log}_{10}\frac{\frac{1}{T}\int_T |\boldsymbol{a}(t)|^2 dt}{a_0^2}. \tag*{A-8}$$

The rms acceleration level can be calculated in the horizontal or vertical directions using the corresponding components of the acceleration vector.

A.1.1. Decidecade band analysis

The distribution of a sound's power with frequency is described by the sound's spectrum. The sound spectrum can be split into a series of adjacent frequency bands. Splitting a spectrum into 1 Hz wide bands, called passbands, yields the power spectral density of the sound. This splitting of the spectrum into passbands of a constant width of 1 Hz, however, does not represent how animals perceive sound.

Because animals perceive exponential increases in frequency rather than linear increases, analyzing a sound spectrum with passbands that increase exponentially in size better approximates real-world scenarios. In underwater acoustics, a spectrum is commonly split into decidecade bands, which are approximately one-third of an octave (base 2) wide and often referred to as 1/3-octave-bands. Each octave represents a doubling in sound frequency. The center frequency of the ith band, $f_c(i)$, is defined as:

$$f_c(i) = 10^{\frac{i}{10}} \tag{A-9}$$

and the low (f_{lo}) and high (f_{hi}) frequency limits of the ith band are defined as:

$$f_{\mathrm{lo},i} = 10^{\frac{-1}{20}} f_c(i) \quad \text{and} \quad f_{\mathrm{hi},i} = 10^{\frac{1}{20}} f_c(i) \tag{A-10}$$

The decidecade bands become wider with increasing frequency, and on a logarithmic scale the bands appear equally spaced (Figure A-1). In this report, the acoustic modeling spans from band −24 ($f_c(-24) = 0.004$ kHz) to band 14 ($f_c(14) = 25$ kHz).

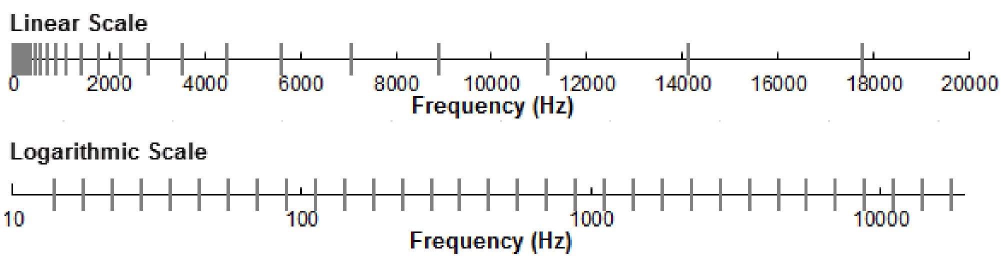

Figure A-1. Decidecade frequency bands (vertical lines) shown on a linear frequency scale and a logarithmic scale.

The sound pressure level in the ith band ($L_{p,i}$) is computed from the spectrum $S(f)$ between $f_{lo,i}$ and $f_{hi,i}$:

$$L_{\mathrm{p},i} = 10 \log_{10} \int_{f_{\mathrm{lo},i}}^{f_{\mathrm{hi},i}} S(f)\, df \tag{A-11}$$

Summing the sound pressure level of all the bands yields the broadband sound pressure level:

$$\text{Broadband SPL} = 10 \log_{10} \sum_i 10^{\frac{L_{p,i}}{10}} \tag{A-12}$$

Figure A-2 shows an example of how the decidecade band sound pressure levels compare to the sound pressure spectral density levels of an ambient noise signal. Because the decidecade bands are wider with increasing frequency, the decidecade band SPL is higher than the spectral levels, especially at higher frequencies. Acoustic modeling of decidecade bands requires less computation time than 1 Hz bands and still resolves the frequency-dependence of the sound source and the propagation environment.

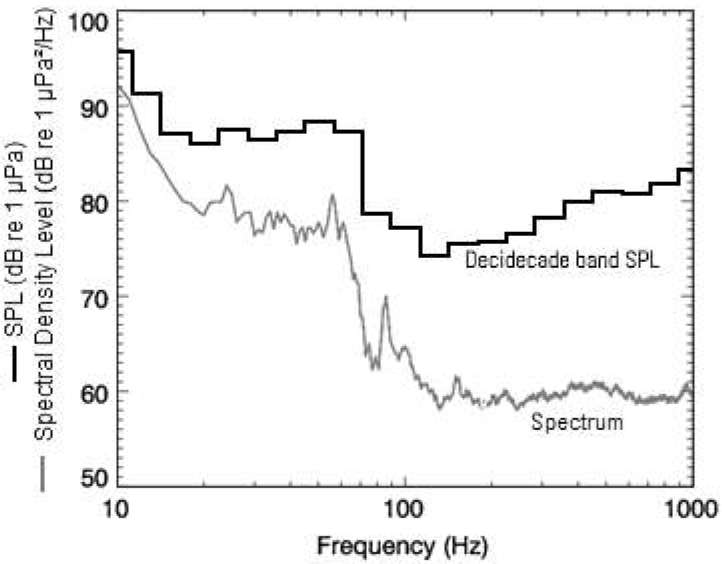

Figure A-2. Sound pressure spectral density levels and the corresponding decidecade band sound pressure levels of example ambient noise shown on a logarithmic frequency scale.

Appendix B. Auditory (Frequency) Weighting Functions

Weighting functions are applied to the sound spectra under consideration to weight the importance of received sound levels at particular frequencies in a manner reflective of an animal's sensitivity to those frequencies (Nedwell and Turnpenny 1998, Nedwell et al. 2007). In this study, multiple weighting functions were used. Southall et al. (2007) were first to suggest weighting functions and functional hearing groups for marine mammals. The weighting functions from Southall et al. (2007) were referred to as m-weighting. For this report the Technical Guidance issued by NOAA (NMFS 2016/2018) included weighting functions and associated thresholds and was used here for determining the ranges for potential injury to marine mammals.

B.1.1. NMFS (2018) frequency weighting functions

In 2015, a U.S. Navy technical report by Finneran (2015) recommended new auditory weighting functions. The auditory weighting functions for marine mammals are applied in a similar way as A-weighting for noise level assessments for humans. The new frequency-weighting functions are expressed as:

$$G(f) = K + 10\log_{10}\left\{\frac{(f/f_1)^{2a}}{[1+(f/f_1)^2]^a[1+(f/f_2)^2]^b}\right\} \qquad \text{(B-1)}$$

Finneran (2015) proposed five functional hearing groups for marine mammals in water: low-, mid- and high-frequency cetaceans (LF, MF, and HF cetaceans, respectively), phocid pinnipeds, and otariid pinnipeds. The parameters for these frequency-weighting functions were further modified the following year (Finneran 2016) and were adopted in NOAA's technical guidance that assesses acoustic impacts on marine mammals (NMFS 2018). The updates did not affect the content related to either the definitions of M-weighting functions or the threshold values. Table B-1 lists the frequency-weighting parameters for each hearing group. Figure B-1 shows the resulting frequency-weighting curves.

Table B-1. Parameters for the auditory weighting functions recommended by NMFS (2018).

Functional hearing group	***a***	***b***	***f_1*** (Hz)	***f_2*** (Hz)	***K*** (dB)
Low-frequency cetaceans	1.0	2	200	19,000	0.13
Mid-frequency cetaceans	1.6	2	8,800	110,000	1.20
High-frequency cetaceans	1.8	2	12,000	140,000	1.36
Phocid pinnipeds in water	1.0	2	1,900	30,000	0.75
Otariid pinnipeds in water	2.0	2	940	25,000	0.64

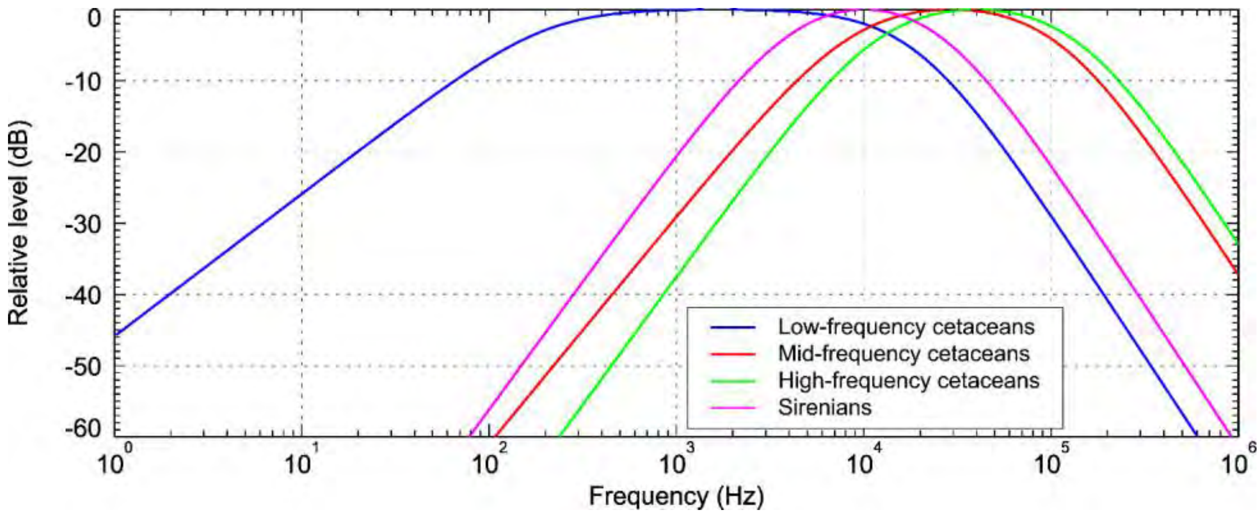

Figure B-1. Auditory weighting functions for the low-, mid-, and high-frequency cetacean and sirenian hearing groups as recommended by NMFS (2018). Sirenian weighting function is from Blackstock et al. (2017).

B.1.2. Source levels

Source levels were determined for DTH-hammering to quantify its inherent loudness. A source level is a measure of the sound emission level of a source at a reference distance of 1 m. For point sources, such as a small transducer, the source levels can be measured directly with a hydrophone 1 m away. For larger sources, such as piles, the source levels are determined indirectly by measuring the sound levels received farther away and back-propagating the levels to the 1 m reference distance. For example, vessels radiate sound from their hulls and propellers, so their source levels must be measured from a distance where the transmission loss from the various sound sources is similar.

Appendix C. Recorded Levels over Time

C.1. C10P4

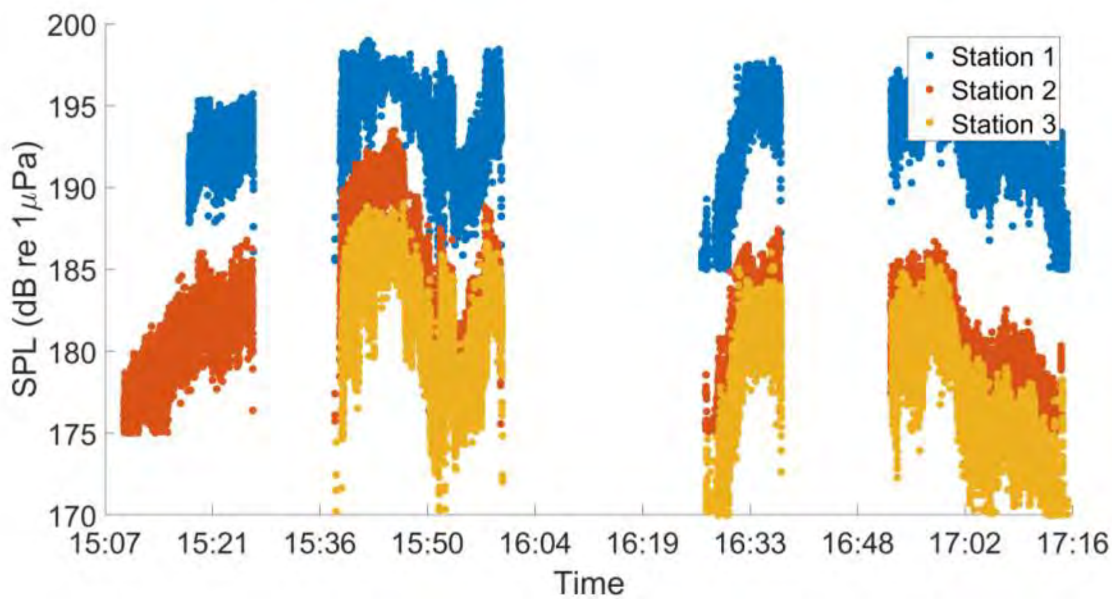

Figure 31. C10P4 recorded Sound Pressure Level (SPL) over time for DTH hammering at the closest (Station 1), mid-range (Station 2), and farthest (Station 3) recording sites.

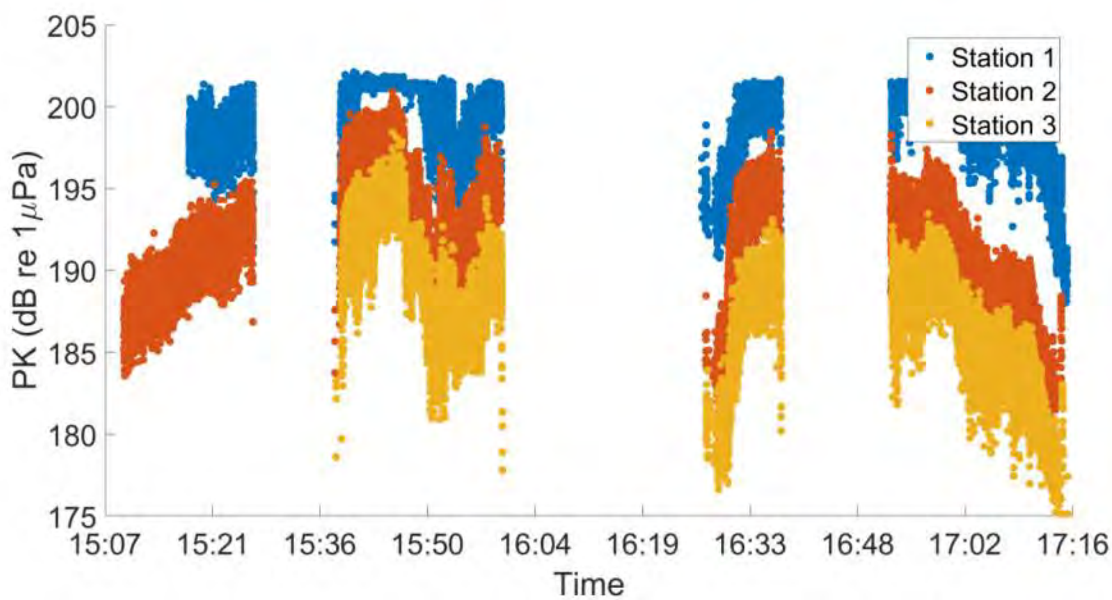

Figure 32. C10P4 recorded Peak Sound Pressure (PK) over time for DTH hammering at the closest (Station 1), mid-range (Station 2), and farthest (Station 3) recording sites.

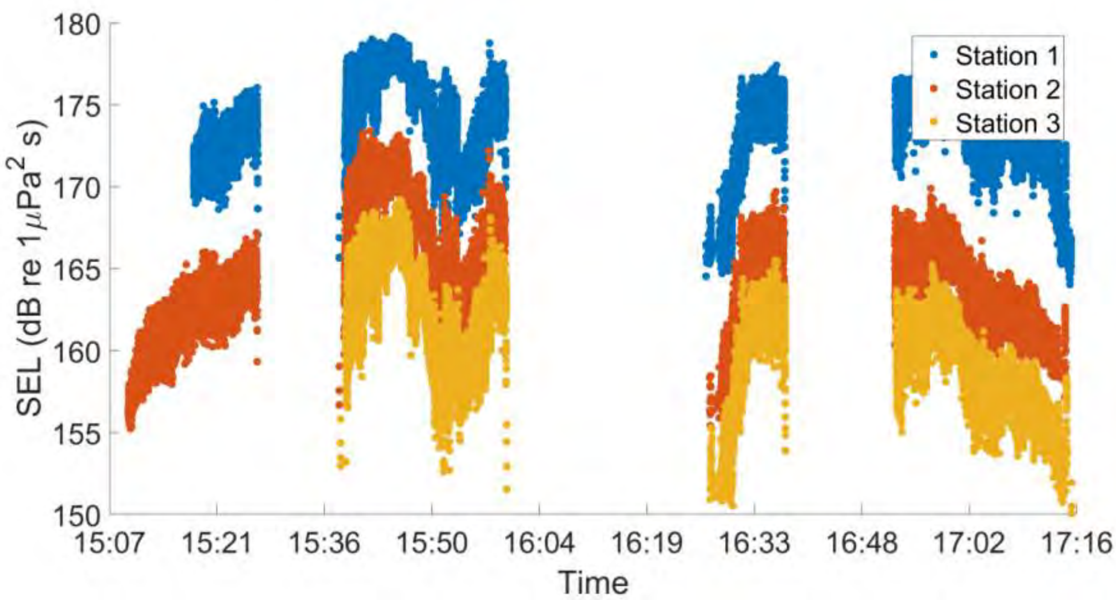

Figure 33. C10P4 recorded Sound Exposure Level (SEL) for single pulses over time for DTH hammering at the closest (Station 1), mid-range (Station 2), and farthest (Station 3) recording sites.

C.2. C8P8

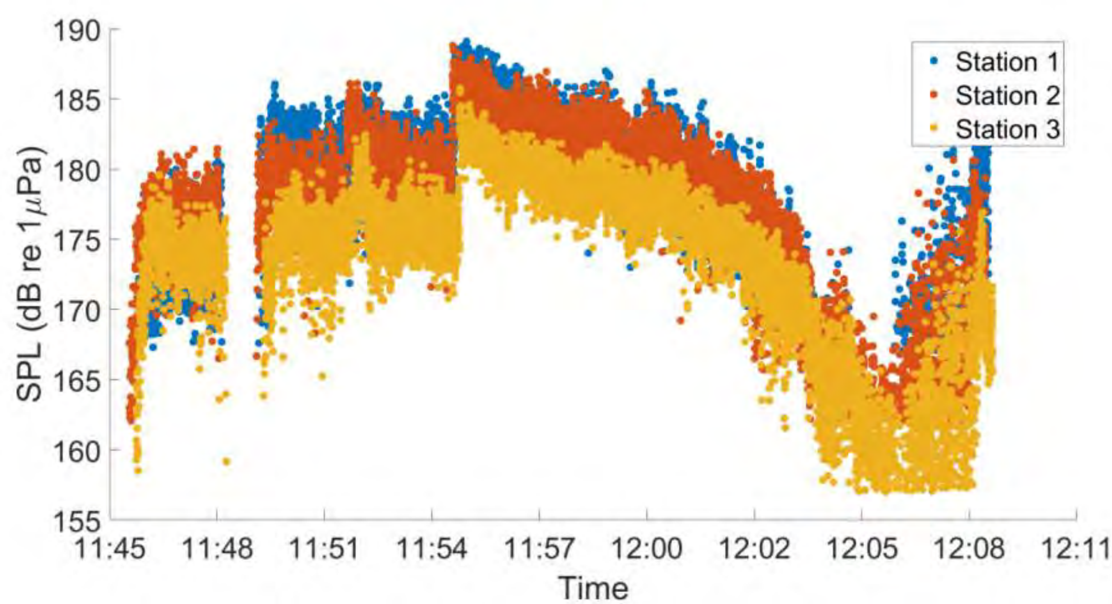

Figure 34. C8P8 recorded Sound Pressure Level (SPL) over time for DTH hammering at the closest (Station 1), mid-range (Station 2), and farthest (Station 3) recording sites.

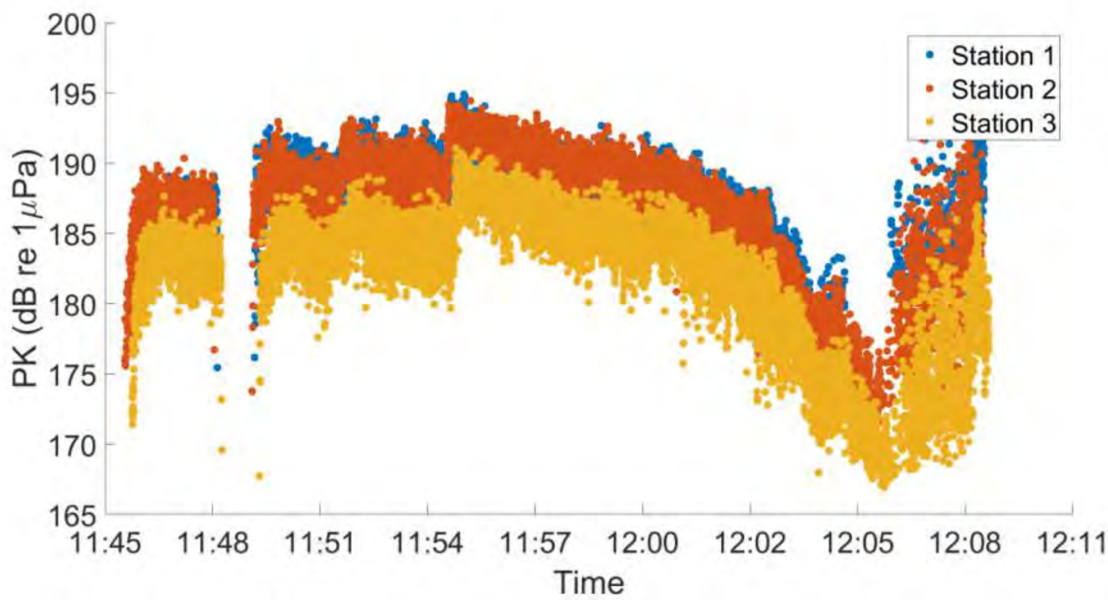

Figure 35. C8P8 recorded Peak Sound Pressure (PK) over time for DTH hammering at the closest (Station 1), mid-range (Station 2), and farthest (Station 3) recording sites.

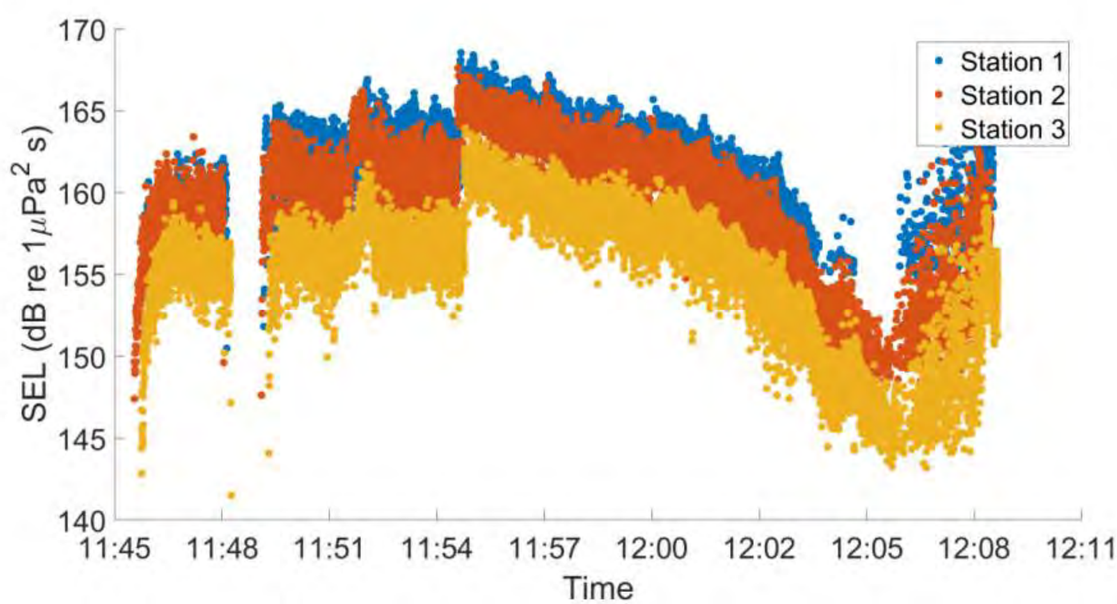

Figure 36. C8P8 recorded Sound Exposure Level (SEL) for single pulses over time for DTH hammering at the closest (Station 1), mid-range (Station 2), and farthest (Station 3) recording sites.

C.3. C8P7

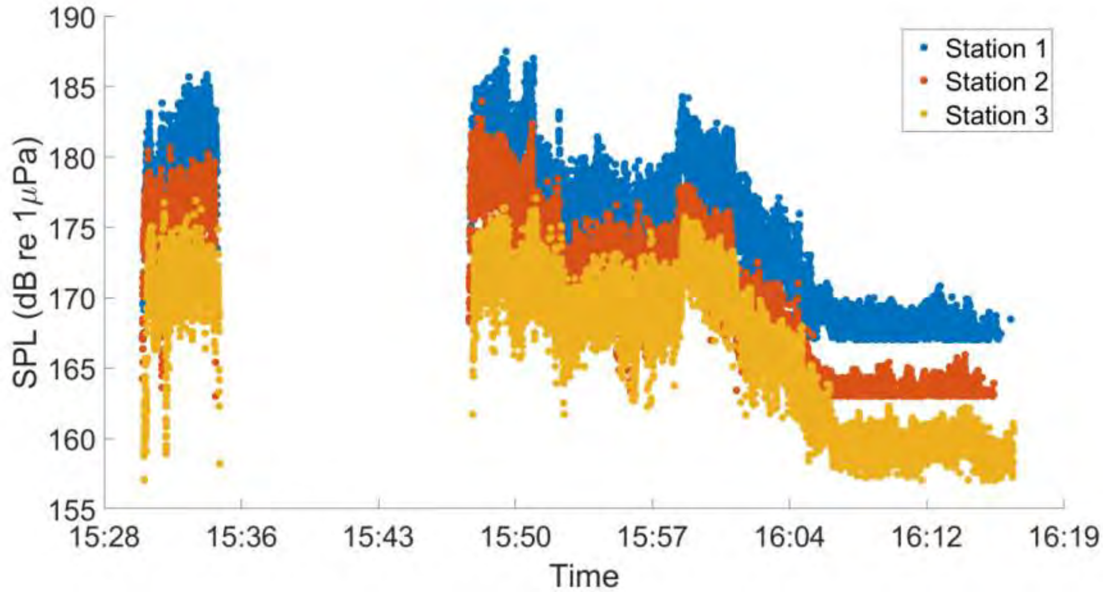

Figure 37. C8P7 recorded Sound Pressure Level (SPL) over time for DTH hammering at the closest (Station 1), mid-range (Station 2), and farthest (Station 3) recording sites.

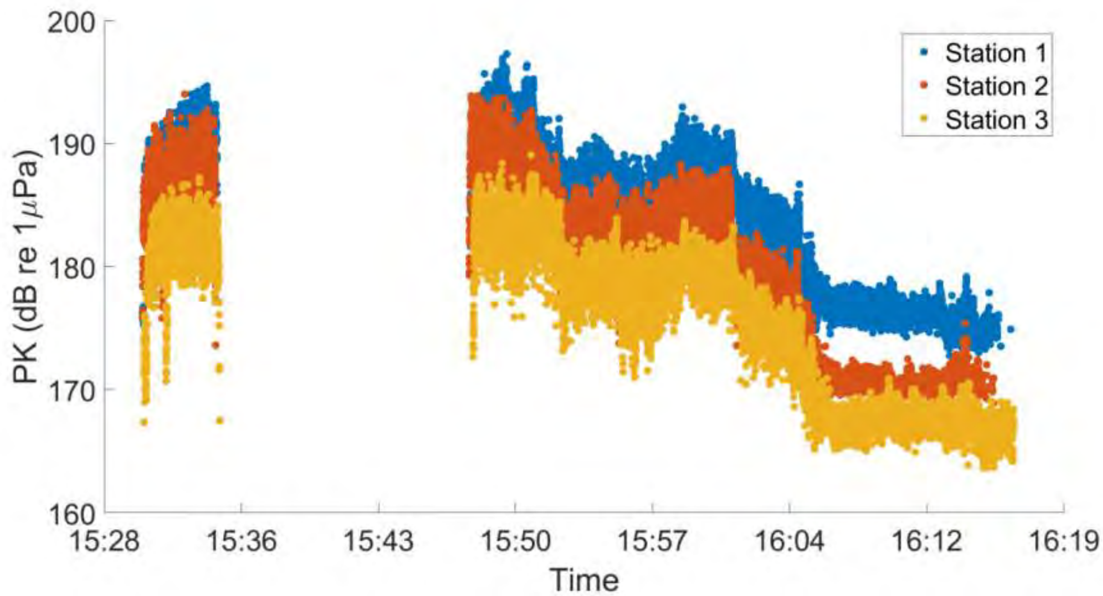

Figure 38. C8P7 recorded Peak Sound Pressure (PK) over time for DTH hammering at the closest (Station 1), mid-range (Station 2), and farthest (Station 3) recording sites.

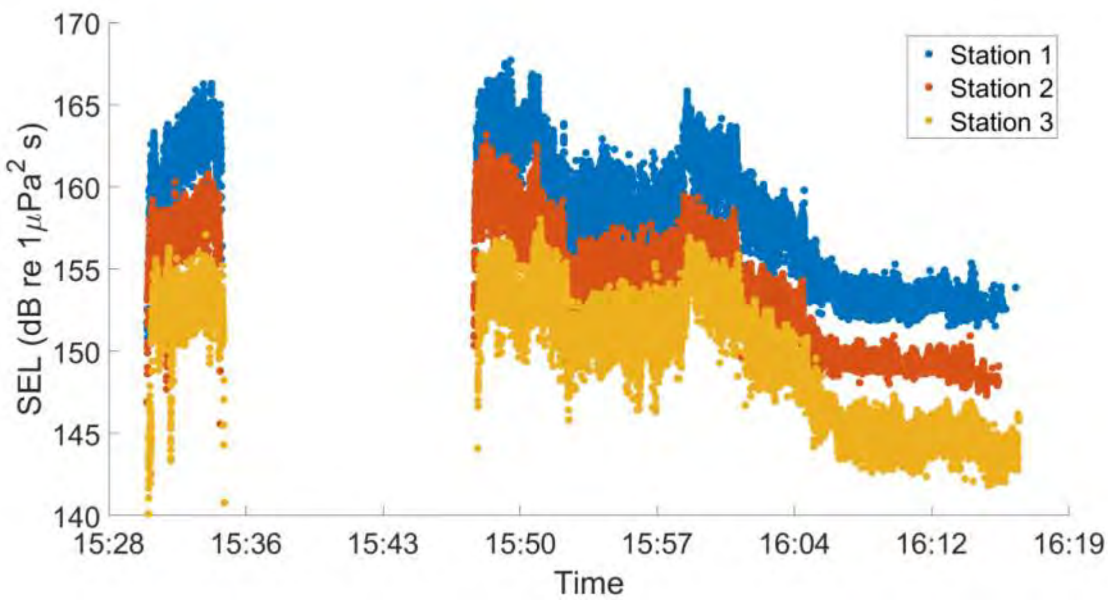

Figure 39. C8P7 recorded Sound Exposure Level (SEL) for single pulses over time for DTH hammering at the closest (Station 1), mid-range (Station 2), and farthest (Station 3) recording sites.

Appendix D. Levels as a function of range

D.1. C10P4

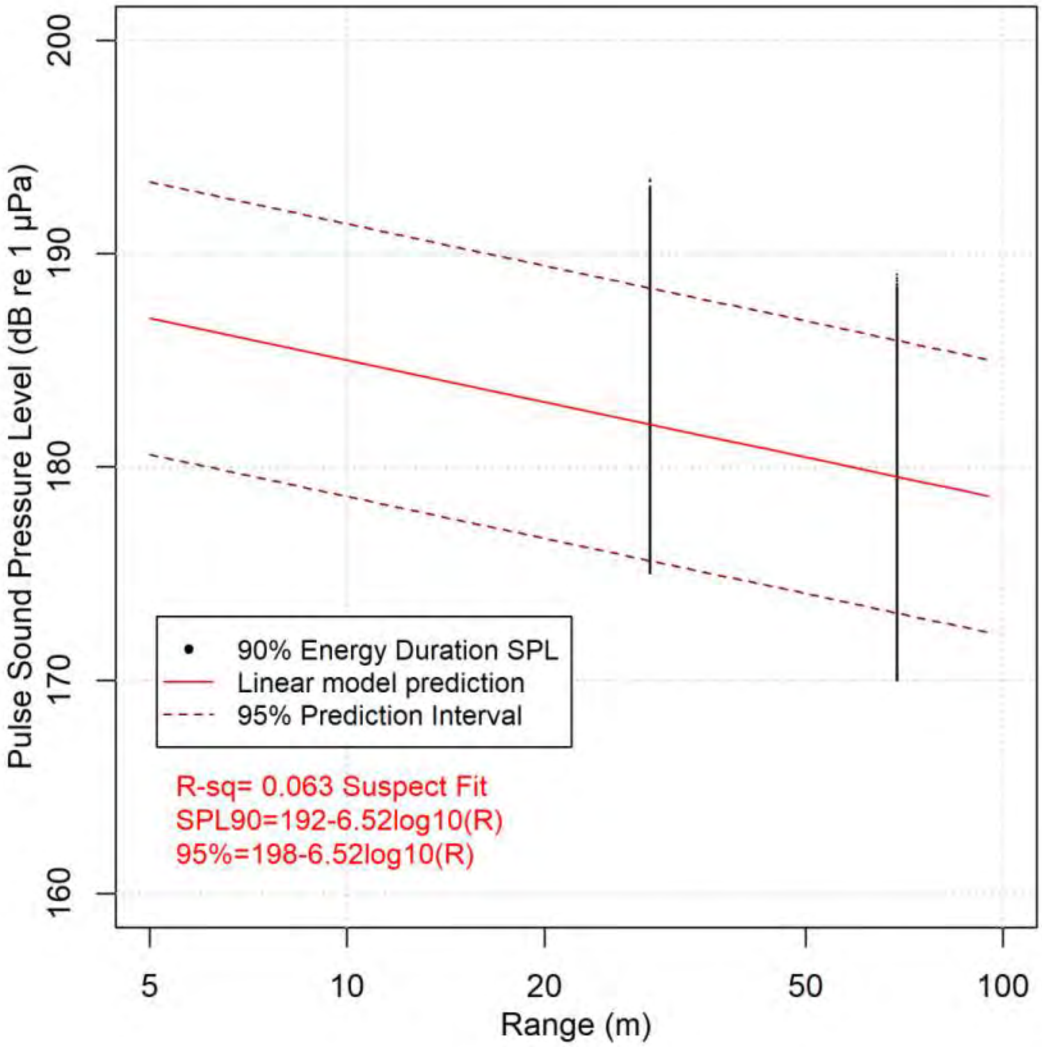

Figure D-1. Sound Pressure Level (SPL) of DTH hammering as a function of range (Stations 2, and 3). Points indicate levels of individual pulses and the red line is the least-squares fit to the individual pulses, with the dashed red lines showing the ±95% confidence interval. Fitting parameters are shown in text. Note that Station 1 is not included in this plot because the recorder saturated at the closest recorder because of high sound levels.

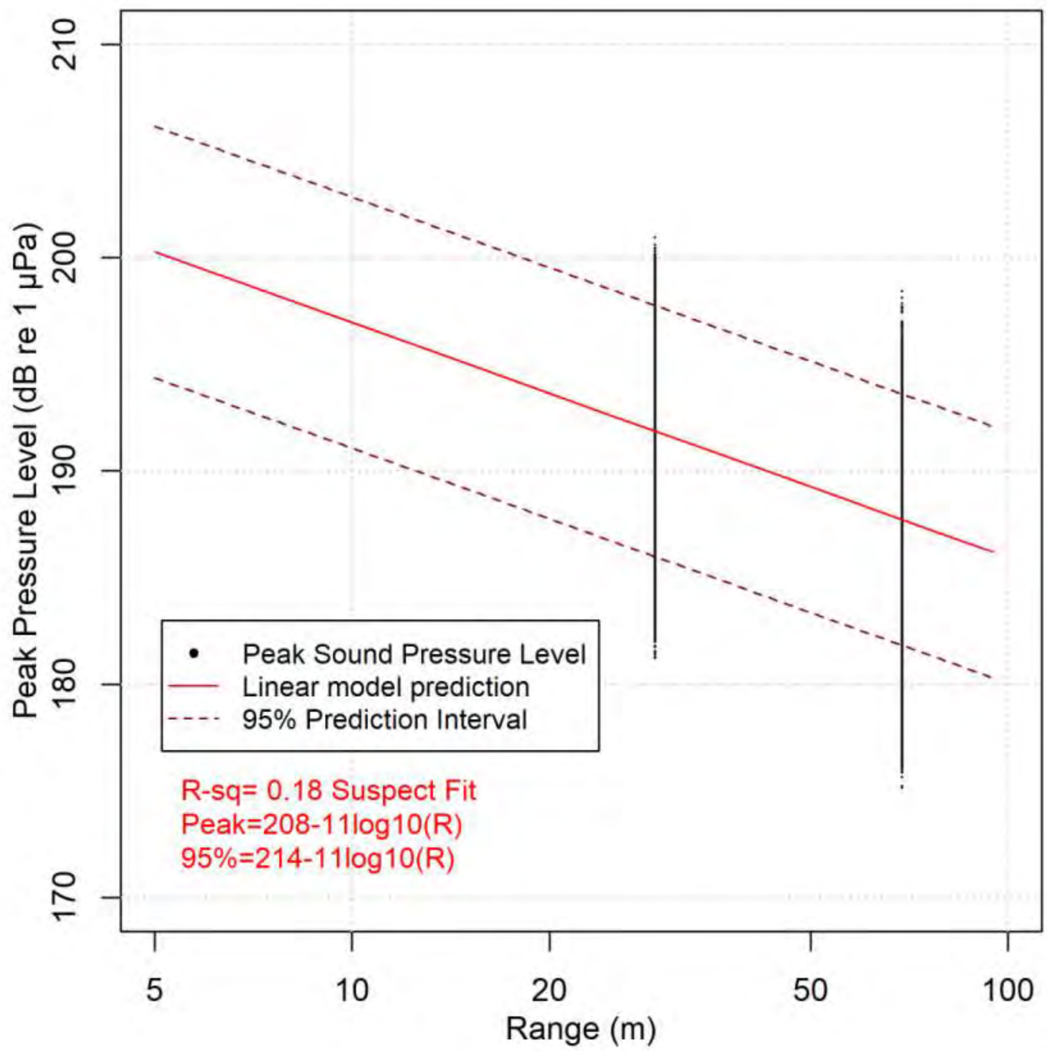

Figure D-2. Peak Sound Pressure (SEL) of DTH hammering as a function of range (Stations 2 and 3). Points indicate levels of individual pulses and the red line is the least-squares fit to the individual pulses, with the dashed red lines showing the ±95% confidence interval. Fitting parameters are shown in text. Note that Station 1 is not included in this plot because the recorder saturated at the closest recorder because of high sound levels.

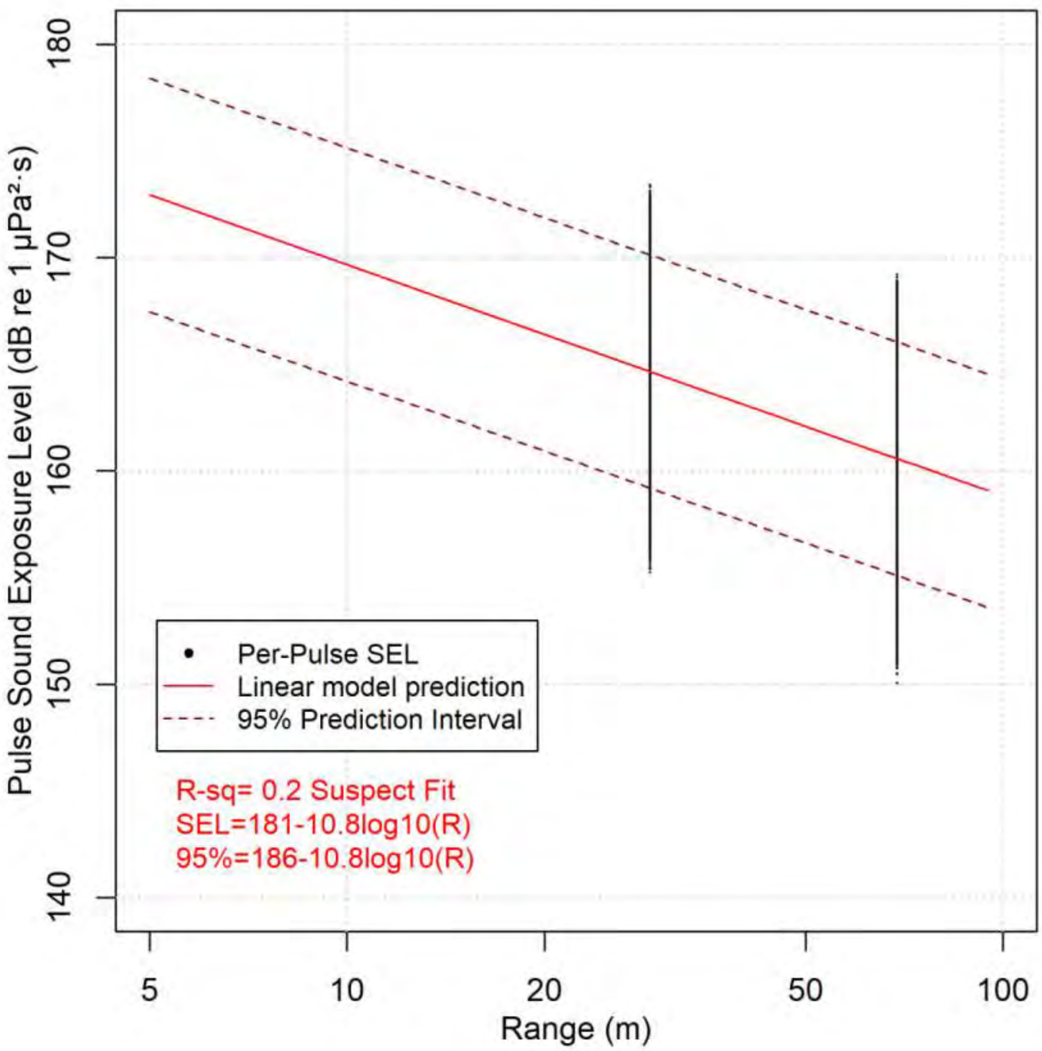

Figure D-3. Per-pulse Sound Exposure Level (SEL) of DTH hammering as a function of range (Stations 2 and 3). Points indicate levels of individual pulses and the red line is the least-squares fit to the individual pulses, with the dashed red lines showing the ±95% confidence interval. Fitting parameters are shown in text. Note that Station 1 is not included in this plot because the recorder saturated at the closest recorder because of high sound levels

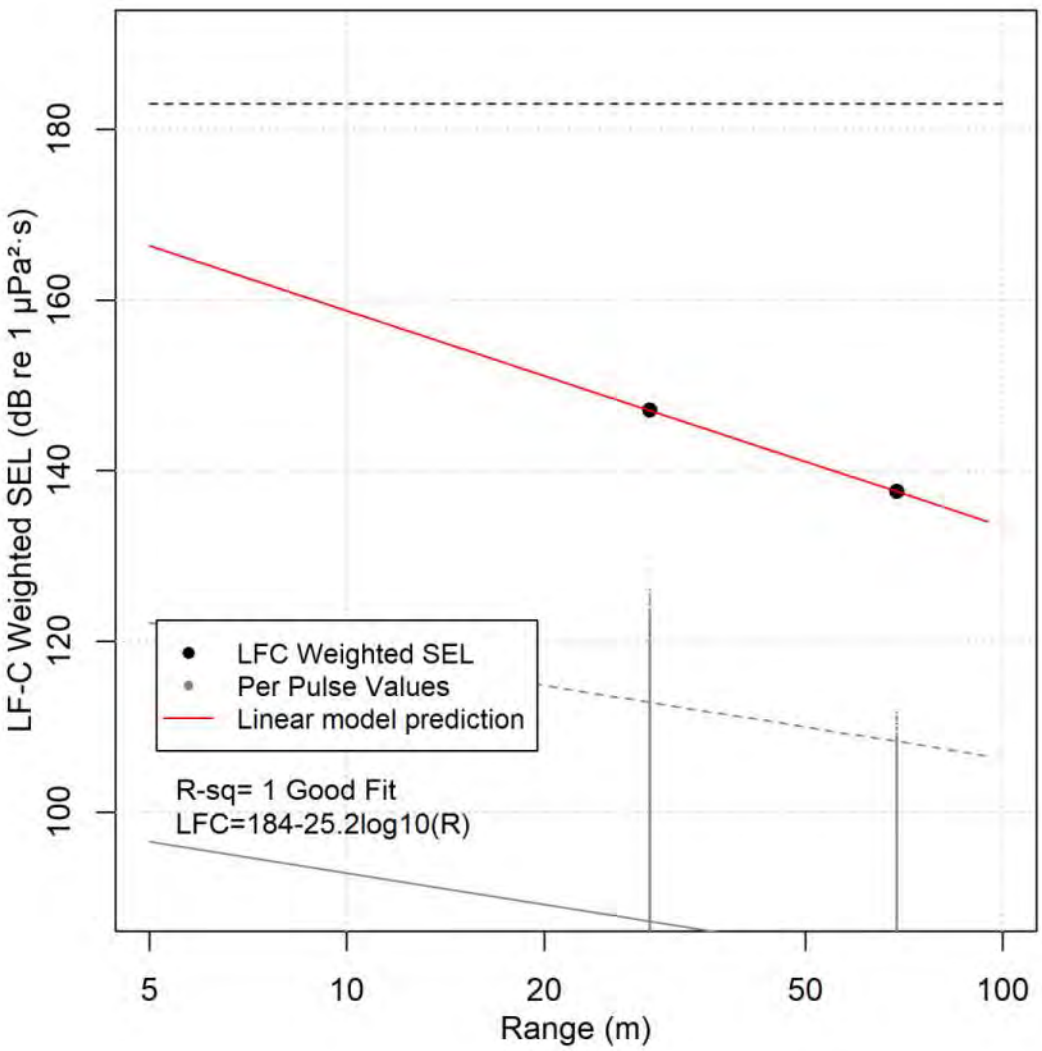

Figure D-4. Low-frequency cetacean (LFC) weighted per-pulse Sound Exposure Level (SEL) and LFC-weighted accumulated SEL for DTH hammering of a caisson as a function of range (Stations 2 and 3). Gray points indicate levels of individual pulses and the gray line is the least-squares fit to the individual pulses, with the dashed gray lines showing the ±95% confidence interval. Black points show the accumulated SEL for the duration of DTH hammering and the red line is the least-squares fit of the accumulated SEL. Fitting parameters are shown in text. Black dashed line is the threshold for injury at 183 dB re 1μPa^2·s (NMFS 2018). The threshold for injury Note that Station 1 is not included in this plot because the recorder saturated at the closest recorder because of high sound levels

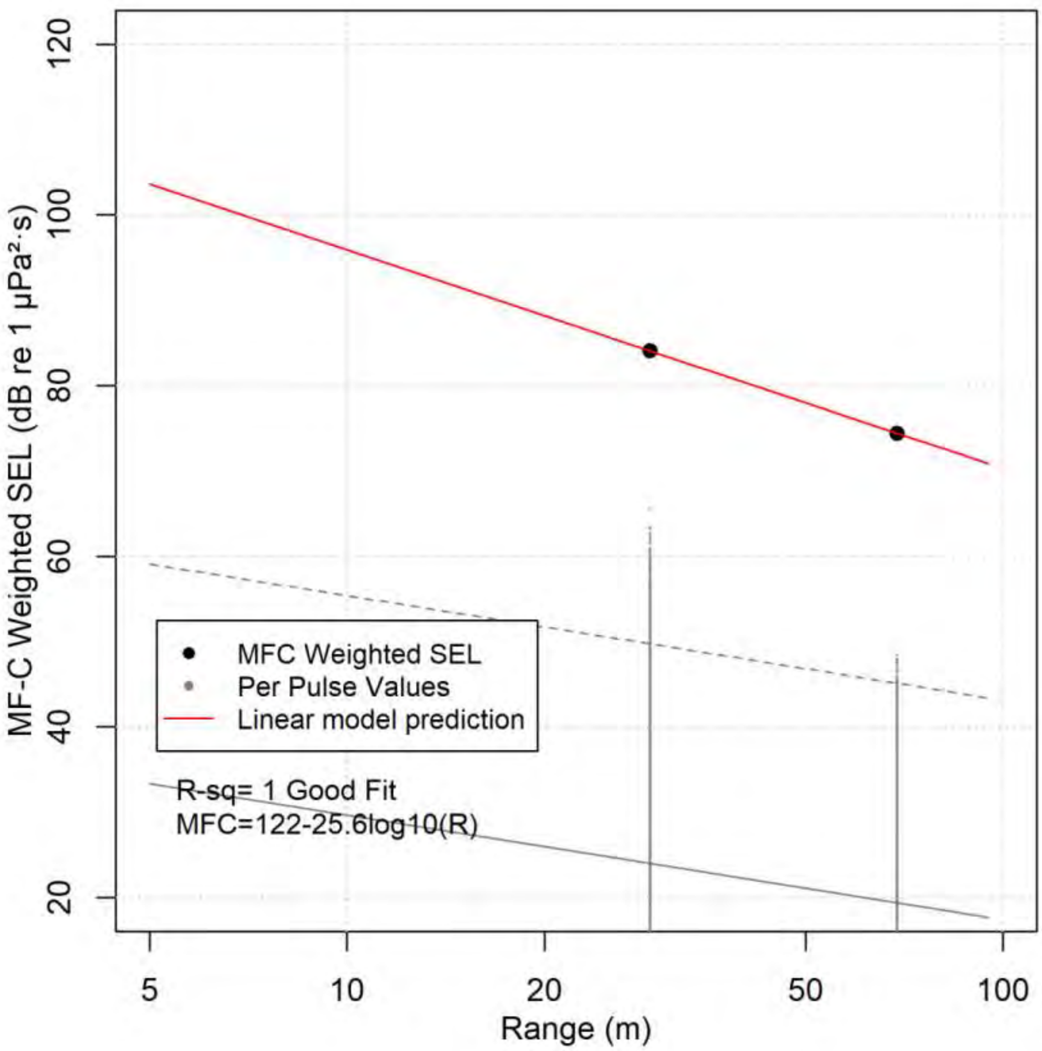

Figure D-5. Mid-frequency cetacean (MFC) weighted per-pulse Sound Exposure Level (SEL) and MFC-weighted accumulated SEL for DTH hammering of a caisson as a function of range (Stations 2 and 3). Gray points indicate levels of individual pulses and the gray line is the least-squares fit to the individual pulses, with the dashed gray lines showing the ±95% confidence interval. Black points show the accumulated SEL for the duration of DTH hammering and the red line is the least-squares fit of the accumulated SEL. Fitting parameters are shown in text. Not shown: the threshold for injury is 185 dB re 1µPa^2·s (NMFS 2018). Note that Station 1 is not included in this plot because the recorder saturated at the closest recorder because of high sound levels

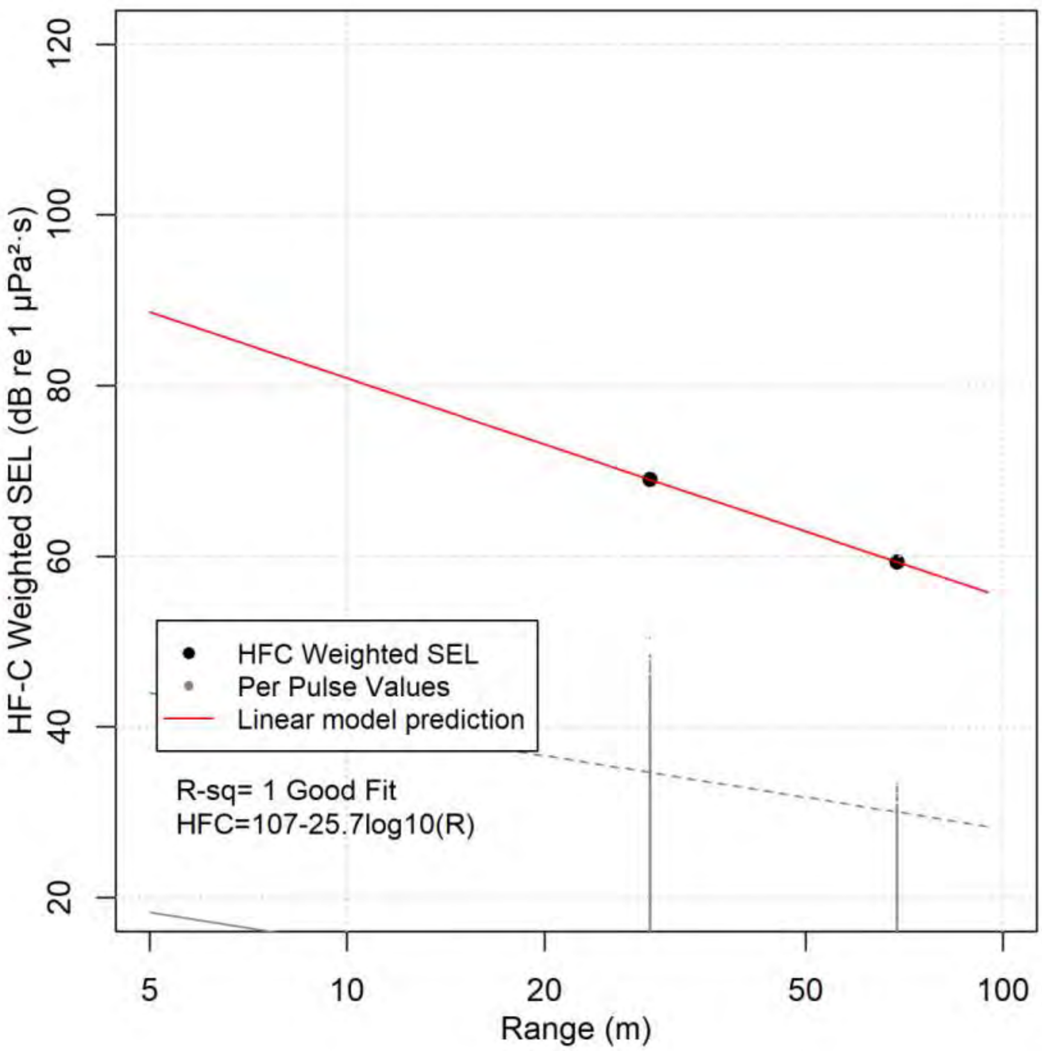

Figure D-6. High-frequency cetacean (HFC) weighted per-pulse Sound Exposure Level (SEL) and HFC-weighted accumulated SEL for DTH hammering of a caisson as a function of range (Stations 2 and 3). Gray points indicate levels of individual pulses and the gray line is the least-squares fit to the individual pulses, with the dashed gray lines showing the ±95% confidence interval. Black points show the accumulated SEL for the duration of DTH hammering and the red line is the least-squares fit of the accumulated SEL. Fitting parameters are shown in text. Not shown: the threshold for injury is 155 dB re 1μPa^2·s (NMFS 2018). Note that Station 1 is not included in this plot because the recorder saturated at the closest recorder because of high sound levels

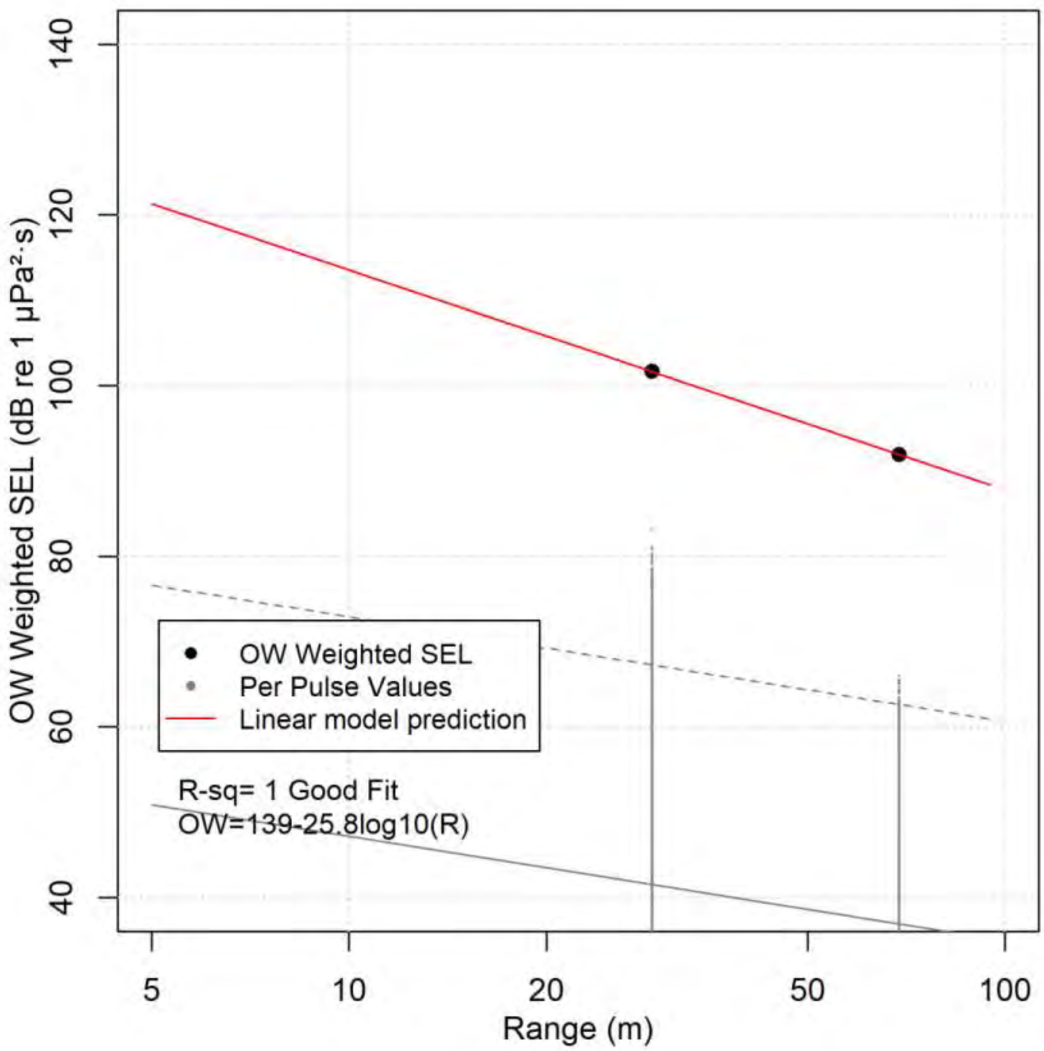

Figure D-7. Otariid underwater (OW) weighted per-pulse Sound Exposure Level (SEL) and OW-weighted accumulated SEL for DTH hammering of a caisson as a function of range (Stations 2 and 3). Gray points indicate levels of individual pulses and the gray line is the least-squares fit to the individual pulses, with the dashed gray lines showing the ±95% confidence interval. Black points show the accumulated SEL for the duration of DTH hammering and the red line is the least-squares fit of the accumulated SEL. Fitting parameters are shown in text. Not shown: the threshold for injury is 203 dB re 1μPa^2·s (NMFS 2018). Note that Station 1 is not included in this plot because the recorder saturated at the closest recorder because of high sound levels

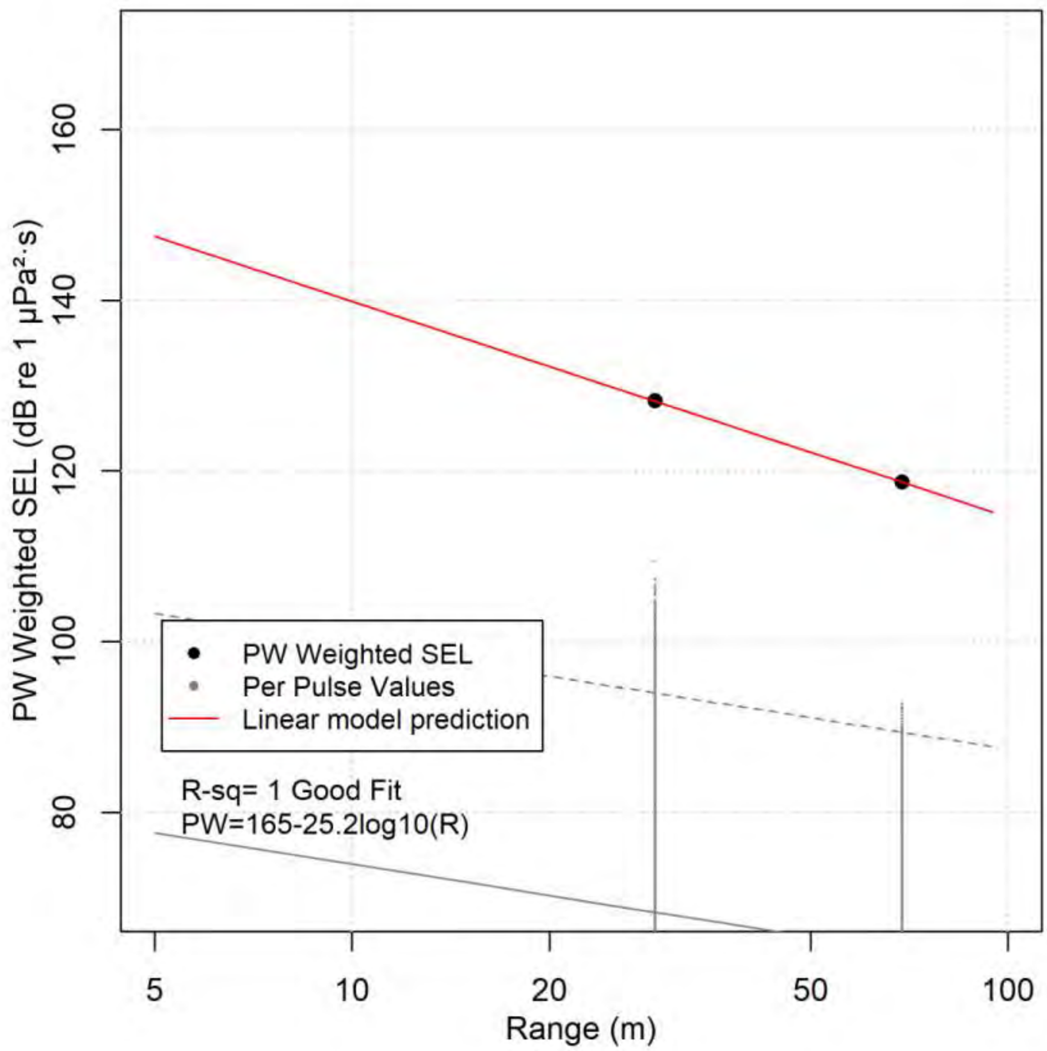

Figure D-8. Phocid underwater (PW) weighted per-pulse Sound Exposure Level (SEL) and PW-weighted accumulated SEL for DTH hammering of a caisson as a function of range (Stations 2 and 3). Gray points indicate levels of individual pulses and the gray line is the least-squares fit to the individual pulses, with the dashed gray lines showing the ±95% confidence interval. Black points show the accumulated SEL for the duration of DTH hammering and the red line is the least-squares fit of the accumulated SEL. Fitting parameters are shown in text. Not shown: the threshold for injury is 185 dB re 1µPa^2·s (NMFS 2018). Note that Station 1 is not included in this plot because the recorder saturated at the closest recorder because of high sound levels

D.2. C8P8

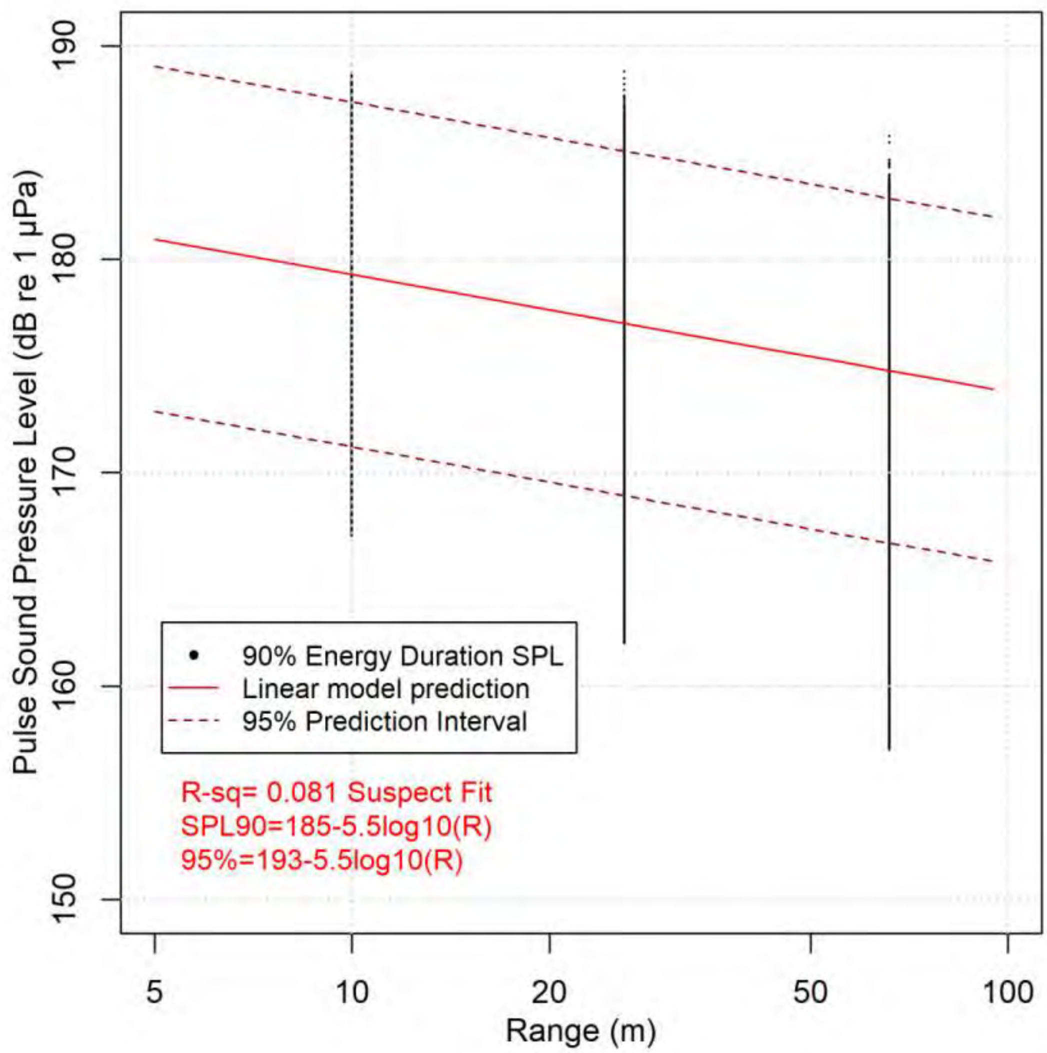

Figure D-9. Sound Pressure Level (SPL) of DTH hammering as a function of range (Stations 1, 2, and 3). Points indicate levels of individual pulses and the red line is the least-squares fit to the individual pulses, with the dashed red lines showing the ±95% confidence interval. Fitting parameters are shown in text.

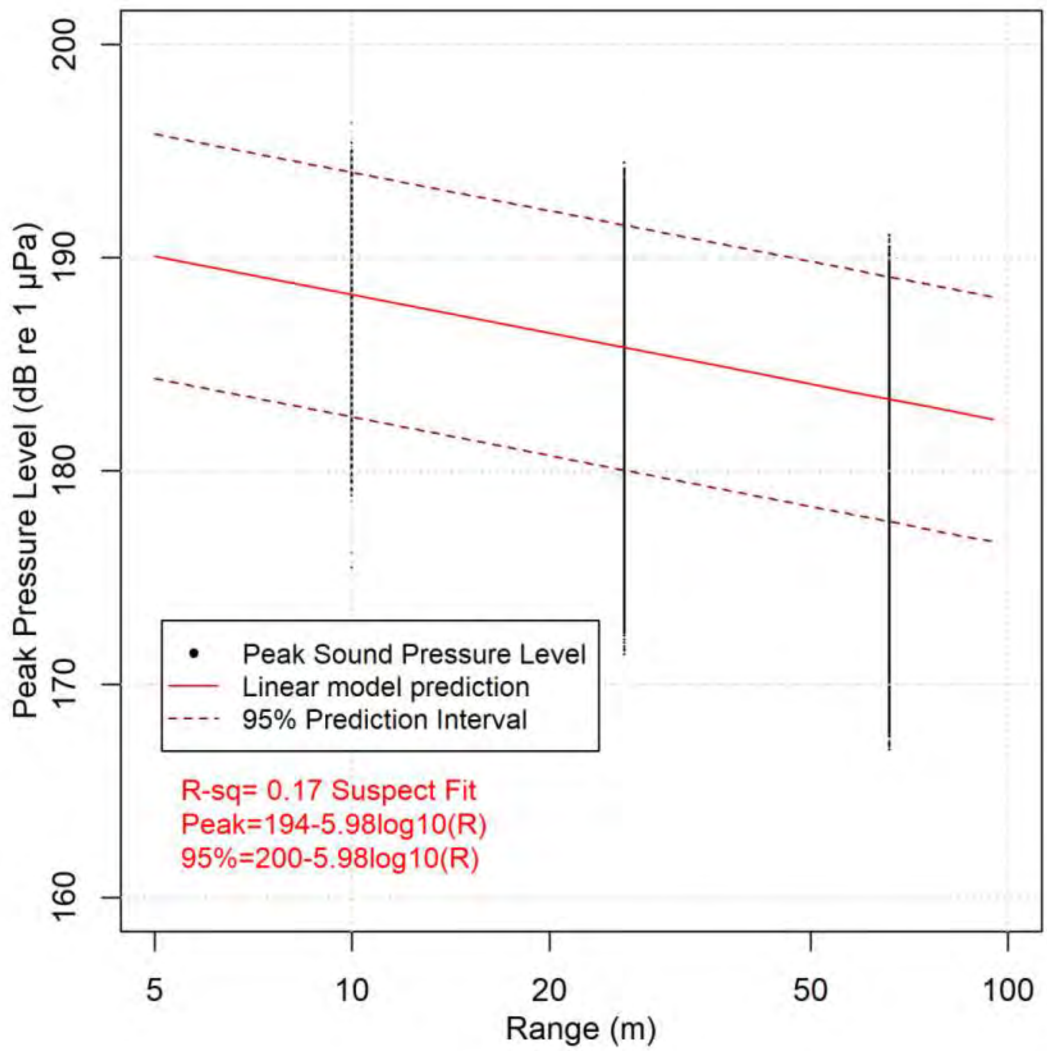

Figure D-10. Peak Sound Pressure (SEL) of DTH hammering as a function of range (Stations 1, 2 and 3). Points indicate levels of individual pulses and the red line is the least-squares fit to the individual pulses, with the dashed red lines showing the ±95% confidence interval. Fitting parameters are shown in text.

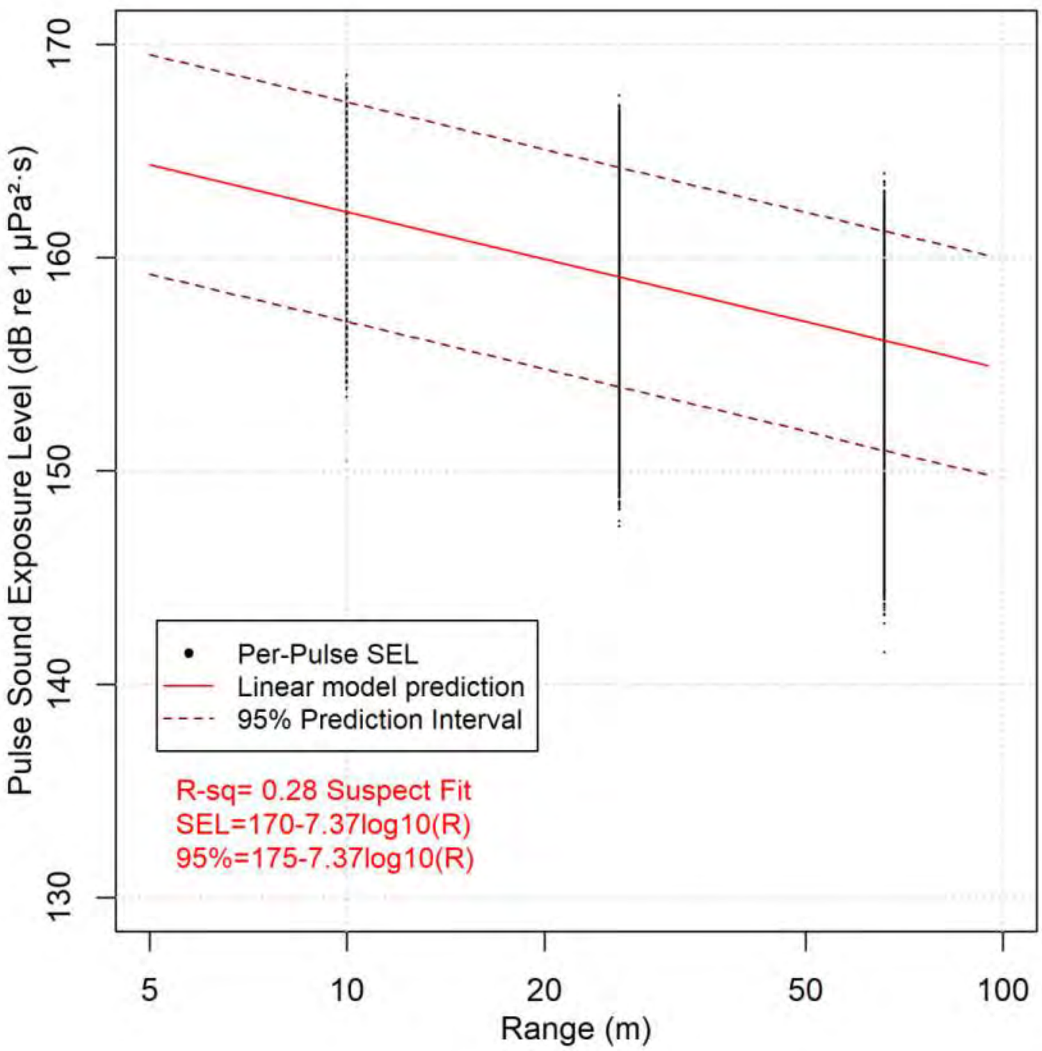

Figure D-11. Per-pulse Sound Exposure Level (SEL) of DTH hammering as a function of range (Stations 1, 2 and 3). Points indicate levels of individual pulses and the red line is the least-squares fit to the individual pulses, with the dashed red lines showing the ±95% confidence interval. Fitting parameters are shown in text.

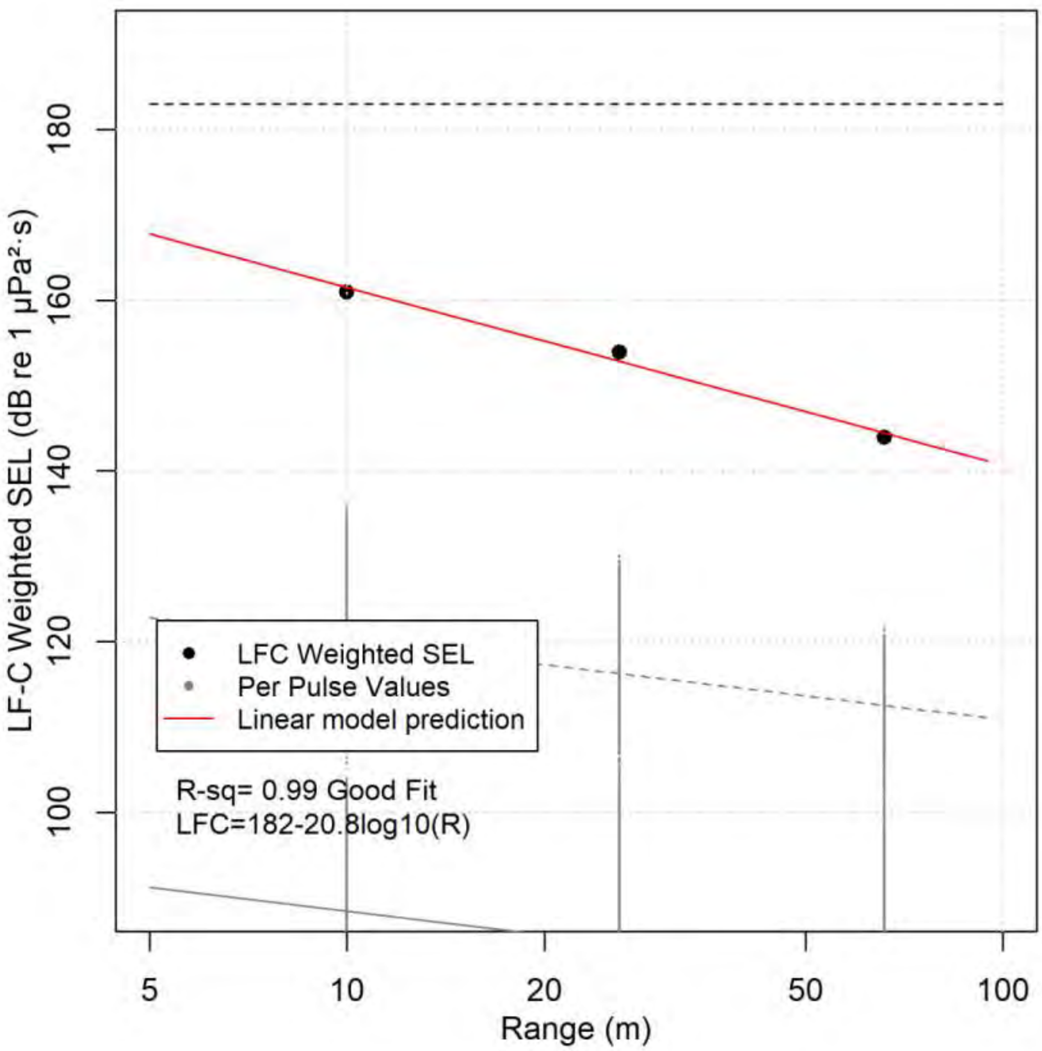

Figure D-12. Low-frequency cetacean (LFC) weighted per-pulse Sound Exposure Level (SEL) and LFC-weighted accumulated SEL for DTH hammering of a caisson as a function of range (Stations 1, 2 and 3). Gray points indicate levels of individual pulses and the gray line is the least-squares fit to the individual pulses, with the dashed gray lines showing the ±95% confidence interval. Black points show the accumulated SEL for the duration of DTH hammering and the red line is the least-squares fit of the accumulated SEL. Fitting parameters are shown in text. Black dashed line is the threshold for injury at 183 dB re 1µPa^2·s (NMFS 2018).

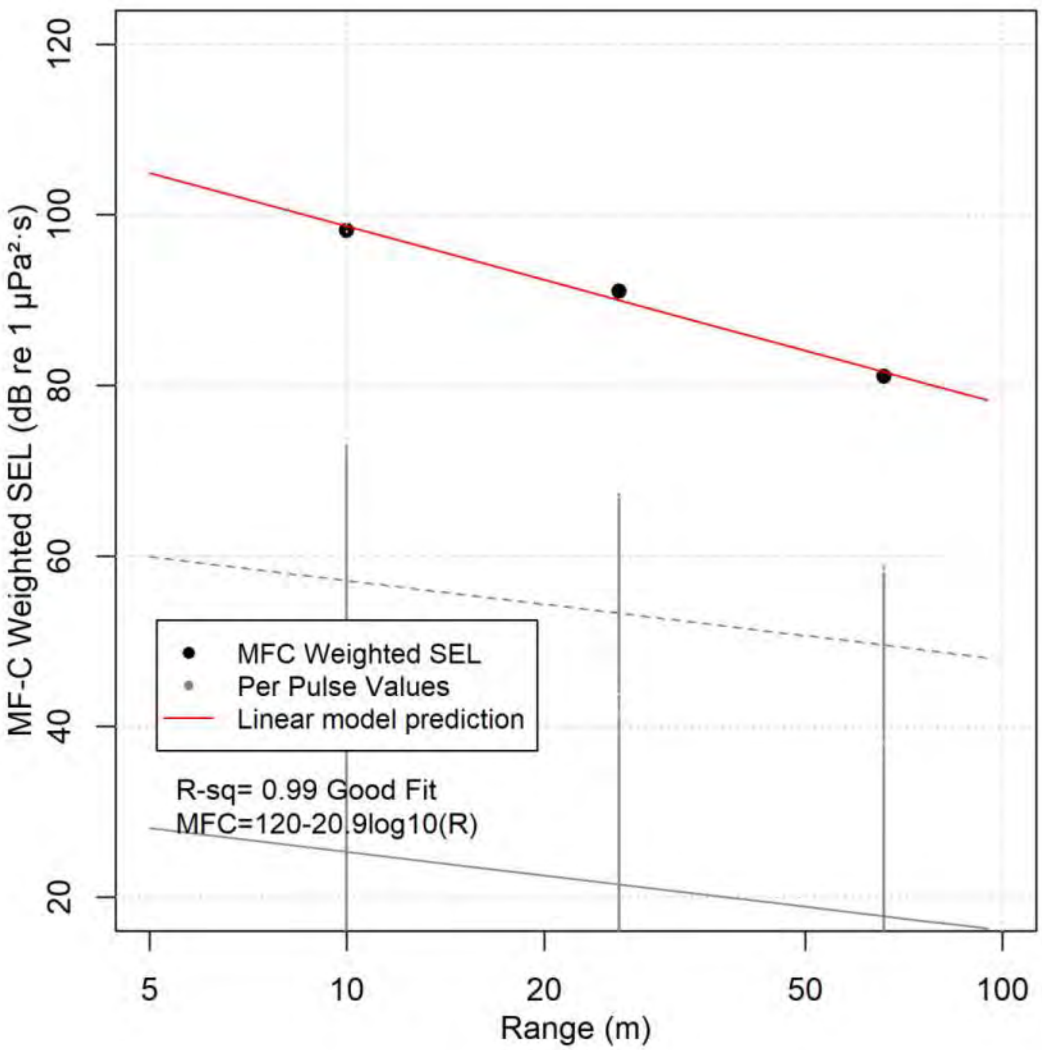

Figure D-13. Mid-frequency cetacean (MFC) weighted per-pulse Sound Exposure Level (SEL) and MFC-weighted accumulated SEL for DTH hammering of a caisson as a function of range (Stations 1, 2 and 3). Gray points indicate levels of individual pulses and the gray line is the least-squares fit to the individual pulses, with the dashed gray lines showing the ±95% confidence interval. Black points show the accumulated SEL for the duration of DTH hammering and the red line is the least-squares fit of the accumulated SEL. Fitting parameters are shown in text. Not shown: the threshold for injury is 185 dB re 1µPa²·s (NMFS 2018).

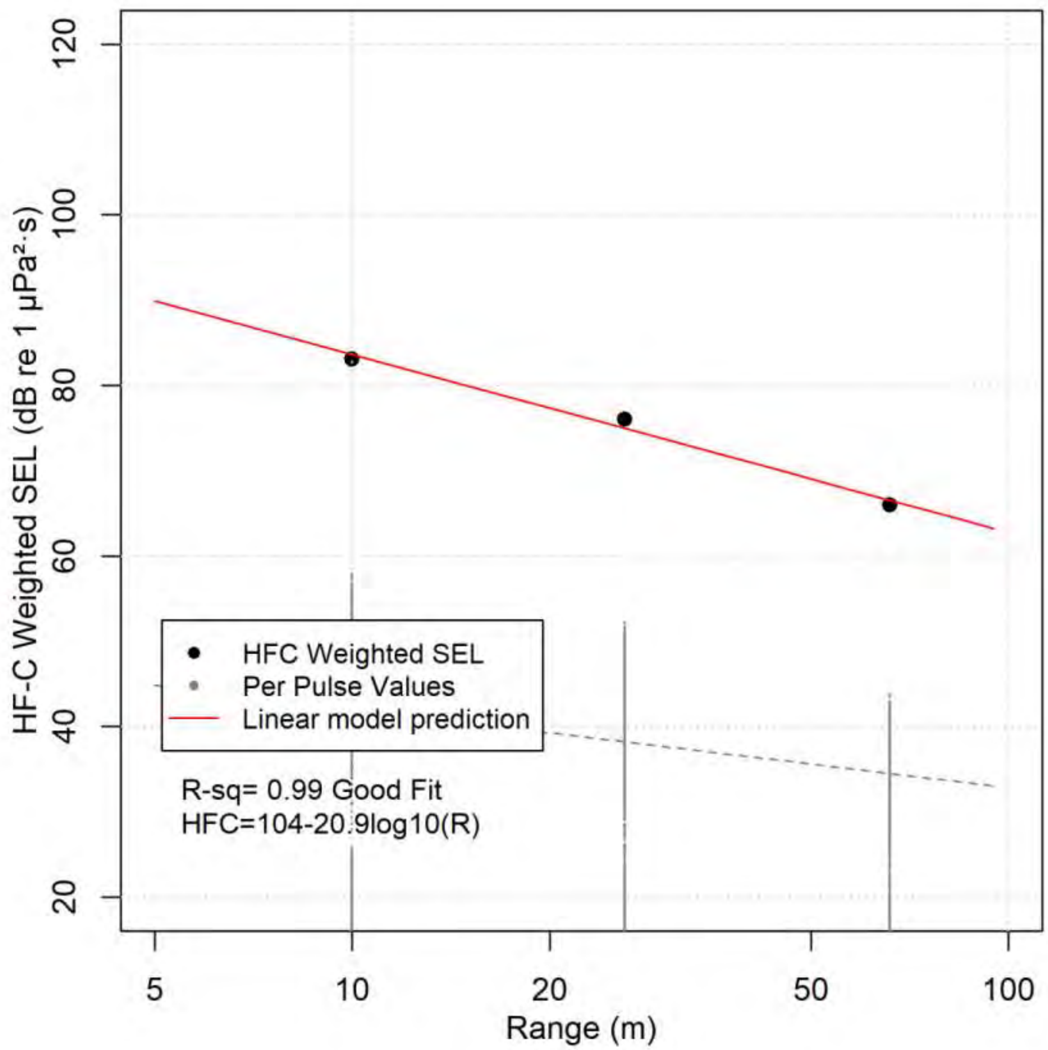

Figure D-14. High-frequency cetacean (HFC) weighted per-pulse Sound Exposure Level (SEL) and HFC-weighted accumulated SEL for DTH hammering of a caisson as a function of range (Stations 1, 2 and 3). Gray points indicate levels of individual pulses and the gray line is the least-squares fit to the individual pulses, with the dashed gray lines showing the ±95% confidence interval. Black points show the accumulated SEL for the duration of DTH hammering and the red line is the least-squares fit of the accumulated SEL. Fitting parameters are shown in text. Not shown: the threshold for injury is 155 dB re 1μPa^2·s (NMFS 2018).

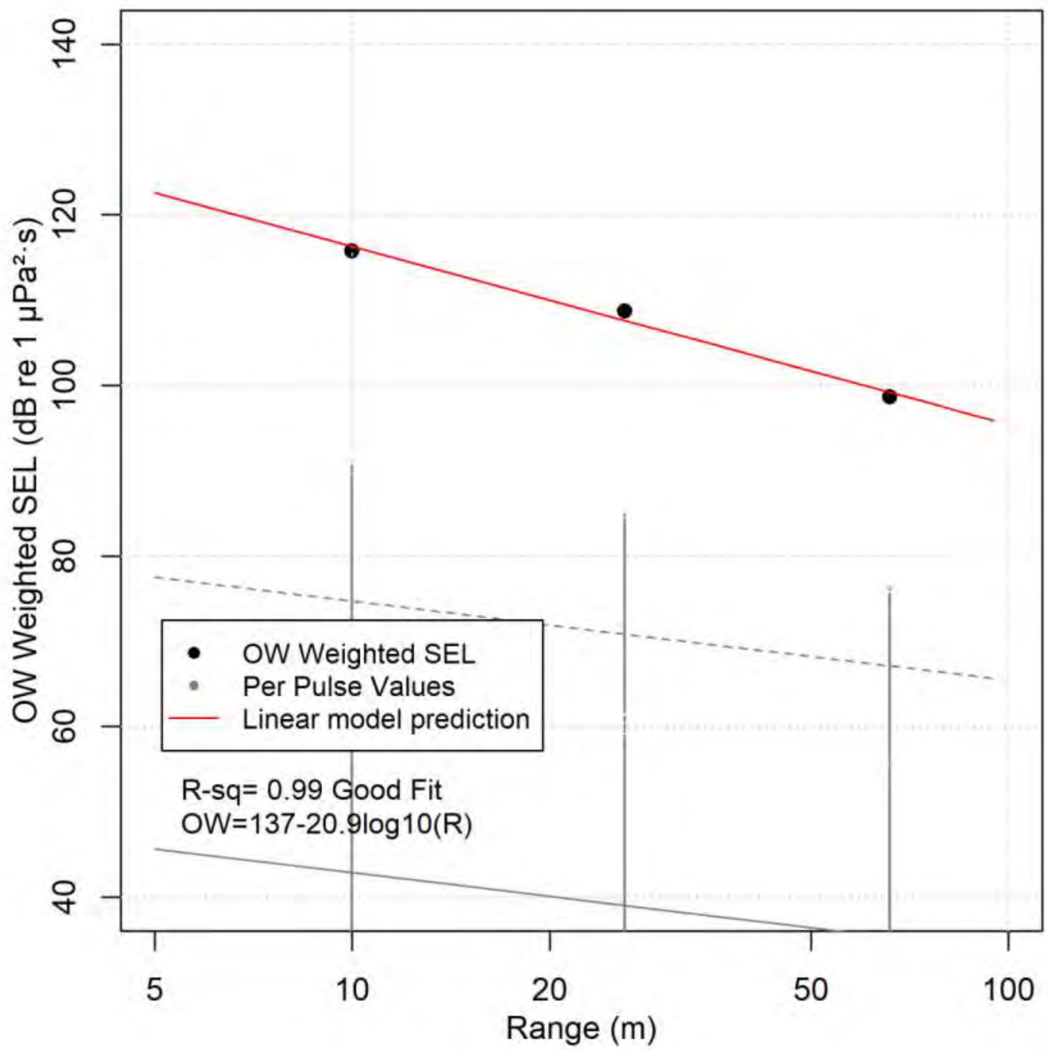

Figure D-15. Otariid underwater (OW) weighted per-pulse Sound Exposure Level (SEL) and OW-weighted accumulated SEL for DTH hammering of a caisson as a function of range (Stations 1, 2 and 3). Gray points indicate levels of individual pulses and the gray line is the least-squares fit to the individual pulses, with the dashed gray lines showing the ±95% confidence interval. Black points show the accumulated SEL for the duration of DTH hammering and the red line is the least-squares fit of the accumulated SEL. Fitting parameters are shown in text. Not shown: the threshold for injury is 203 dB re 1µPa^2·s (NMFS 2018).

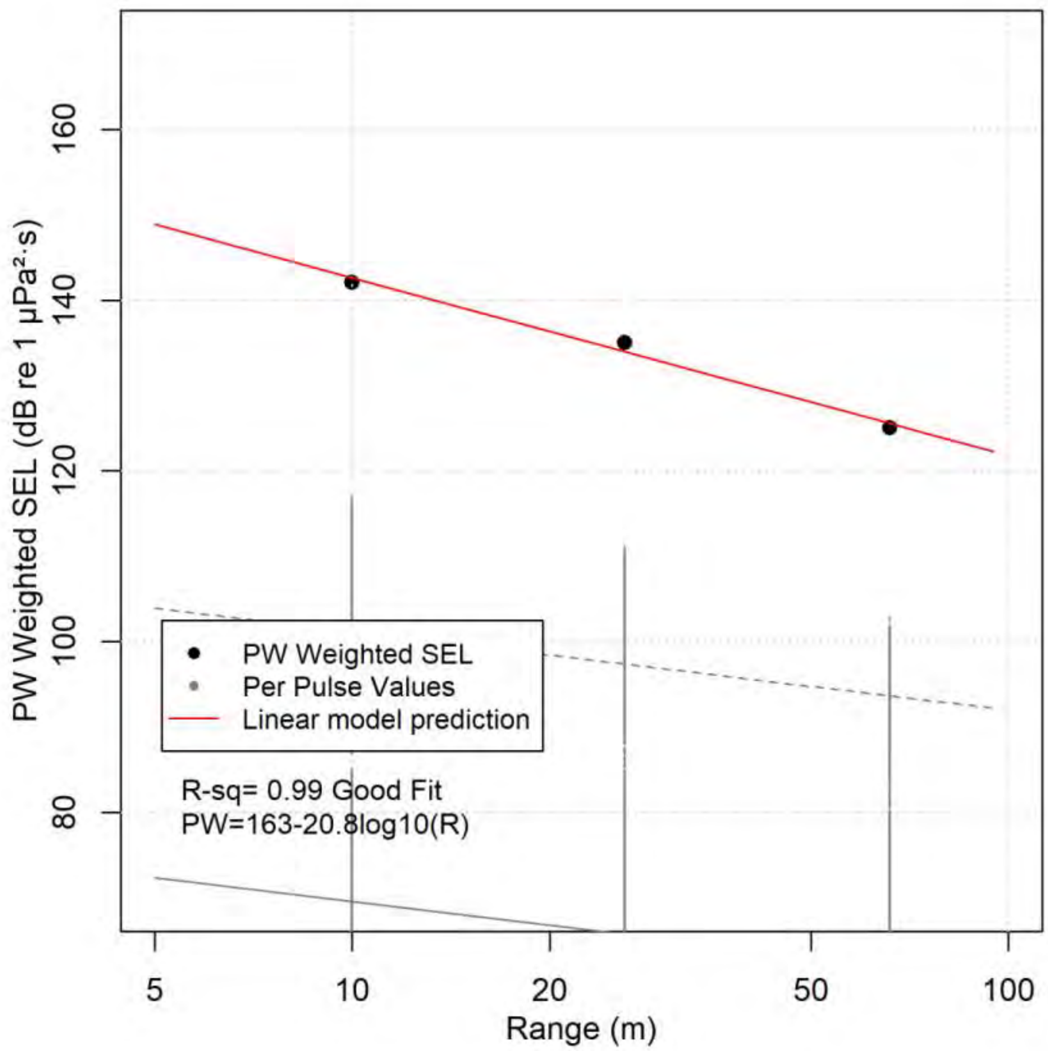

Figure D-16. Phocid underwater (PW) weighted per-pulse Sound Exposure Level (SEL) and PW-weighted accumulated SEL for DTH hammering of a caisson as a function of range (Stations 1, 2 and 3). Gray points indicate levels of individual pulses and the gray line is the least-squares fit to the individual pulses, with the dashed gray lines showing the ±95% confidence interval. Black points show the accumulated SEL for the duration of DTH hammering and the red line is the least-squares fit of the accumulated SEL. Fitting parameters are shown in text. Not shown: the threshold for injury is 185 dB re 1µPa^2·s (NMFS 2018).

D.3. C9P5

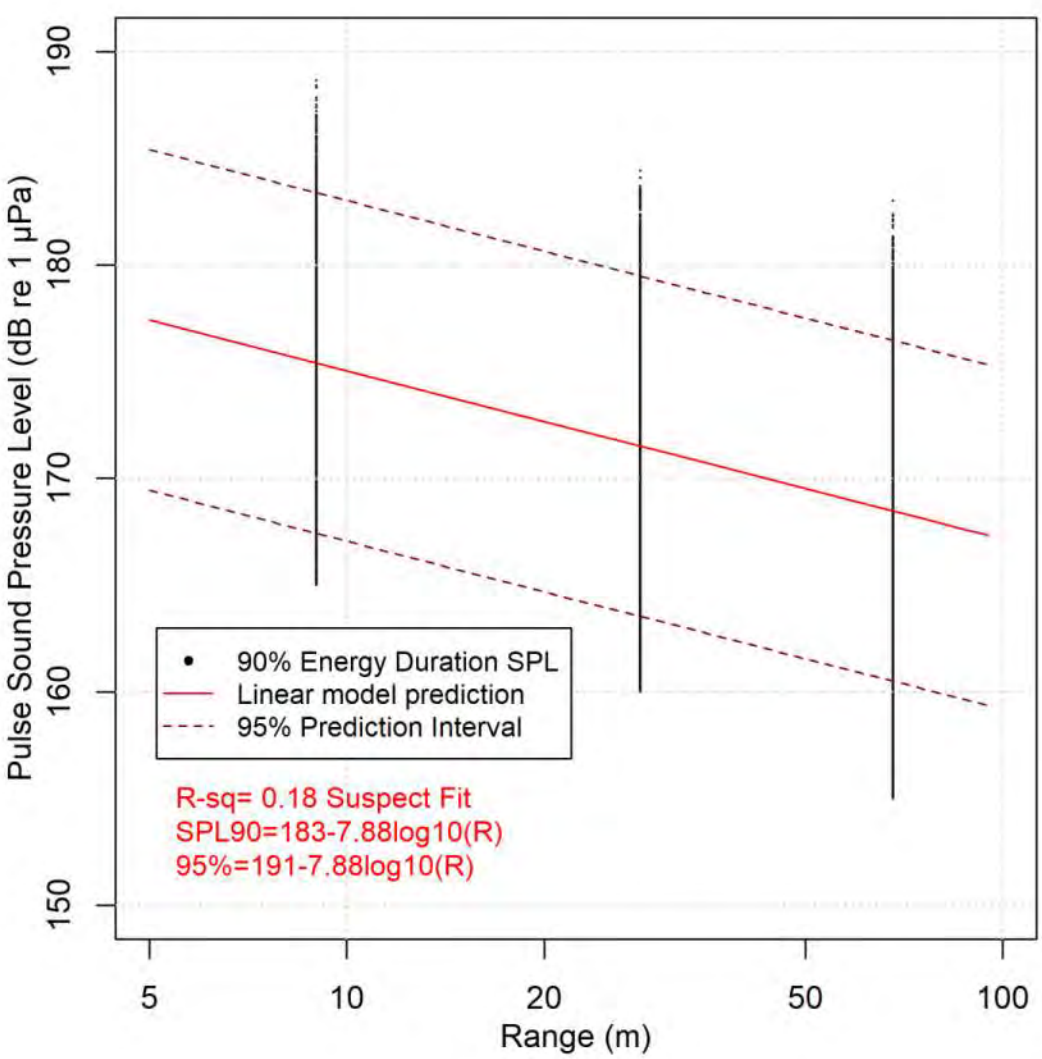

Figure D-17. Sound Pressure Level (SPL) of DTH hammering as a function of range (Stations 1, 2, and 3). Points indicate levels of individual pulses and the red line is the least-squares fit to the individual pulses, with the dashed red lines showing the ±95% confidence interval. Fitting parameters are shown in text.

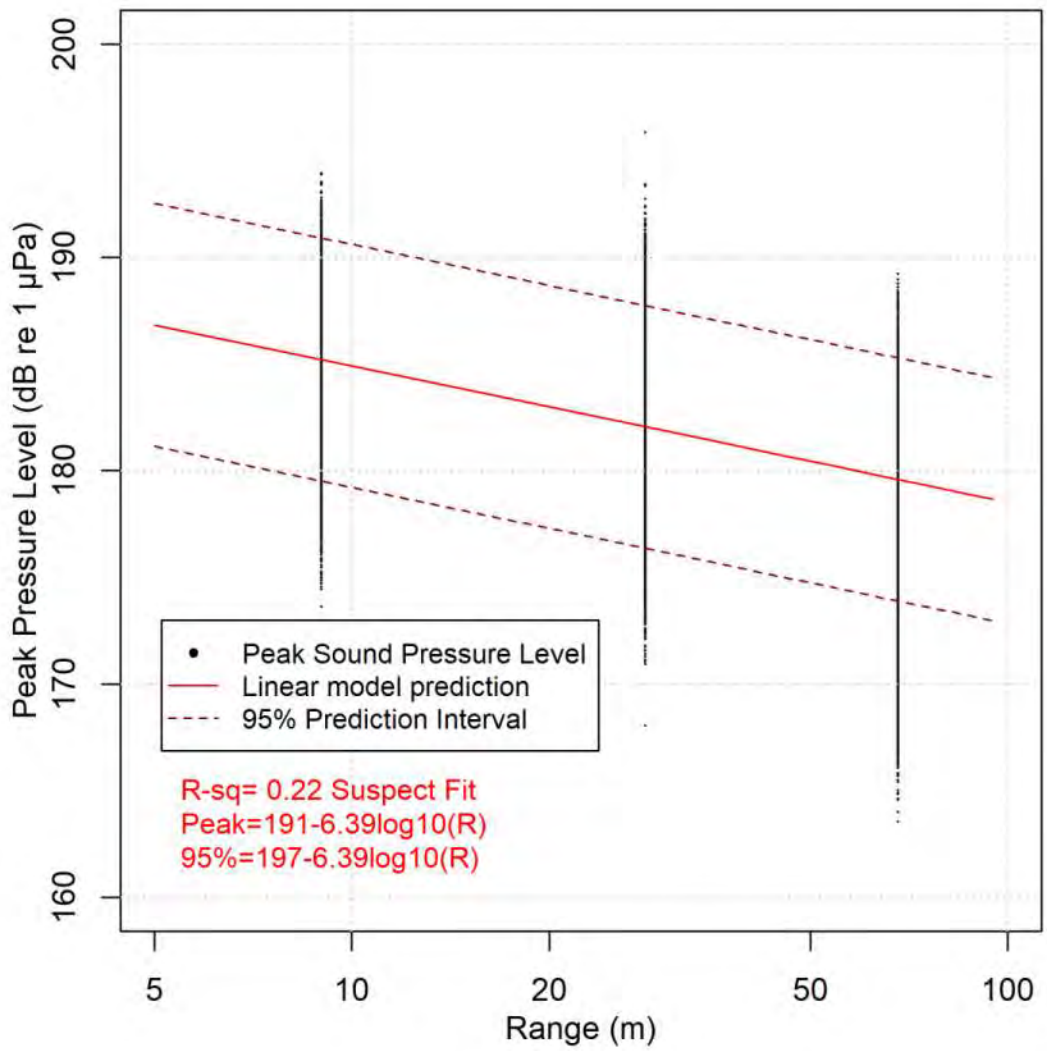

Figure D-18. Peak Sound Pressure (SEL) of DTH hammering as a function of range (Stations 1, 2 and 3). Points indicate levels of individual pulses and the red line is the least-squares fit to the individual pulses, with the dashed red lines showing the ±95% confidence interval. Fitting parameters are shown in text.

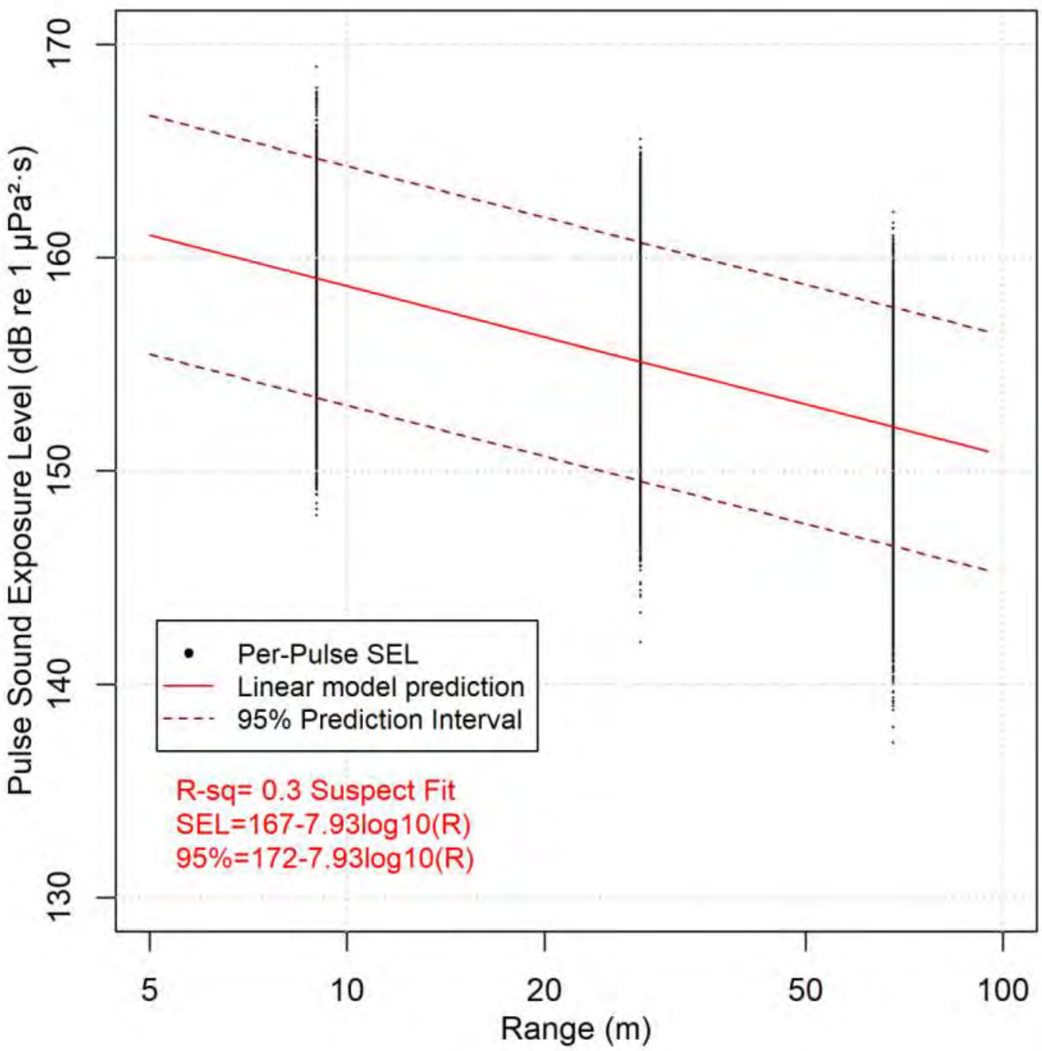

Figure D-19. Per-pulse Sound Exposure Level (SEL) of DTH hammering as a function of range (Stations 1, 2 and 3). Points indicate levels of individual pulses and the red line is the least-squares fit to the individual pulses, with the dashed red lines showing the ±95% confidence interval. Fitting parameters are shown in text.

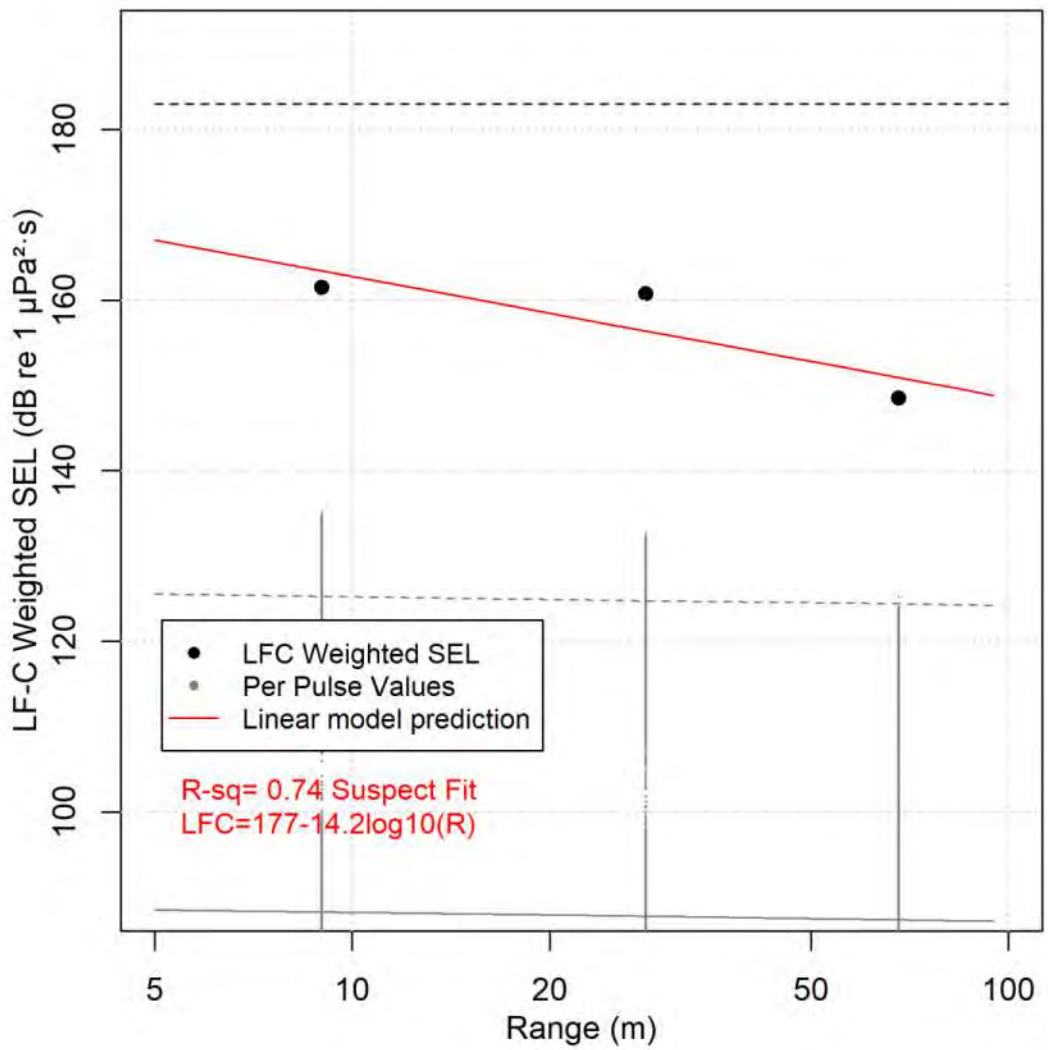

Figure D-20. Low-frequency cetacean (LFC) weighted per-pulse Sound Exposure Level (SEL) and LFC-weighted accumulated SEL for DTH hammering of a caisson as a function of range (Stations 1, 2 and 3). Gray points indicate levels of individual pulses and the gray line is the least-squares fit to the individual pulses, with the dashed gray lines showing the ±95% confidence interval. Black points show the accumulated SEL for the duration of DTH hammering and the red line is the least-squares fit of the accumulated SEL. Fitting parameters are shown in text. Black dashed line is the threshold for injury at 183 dB re 1µPa^2·s (NMFS 2018).

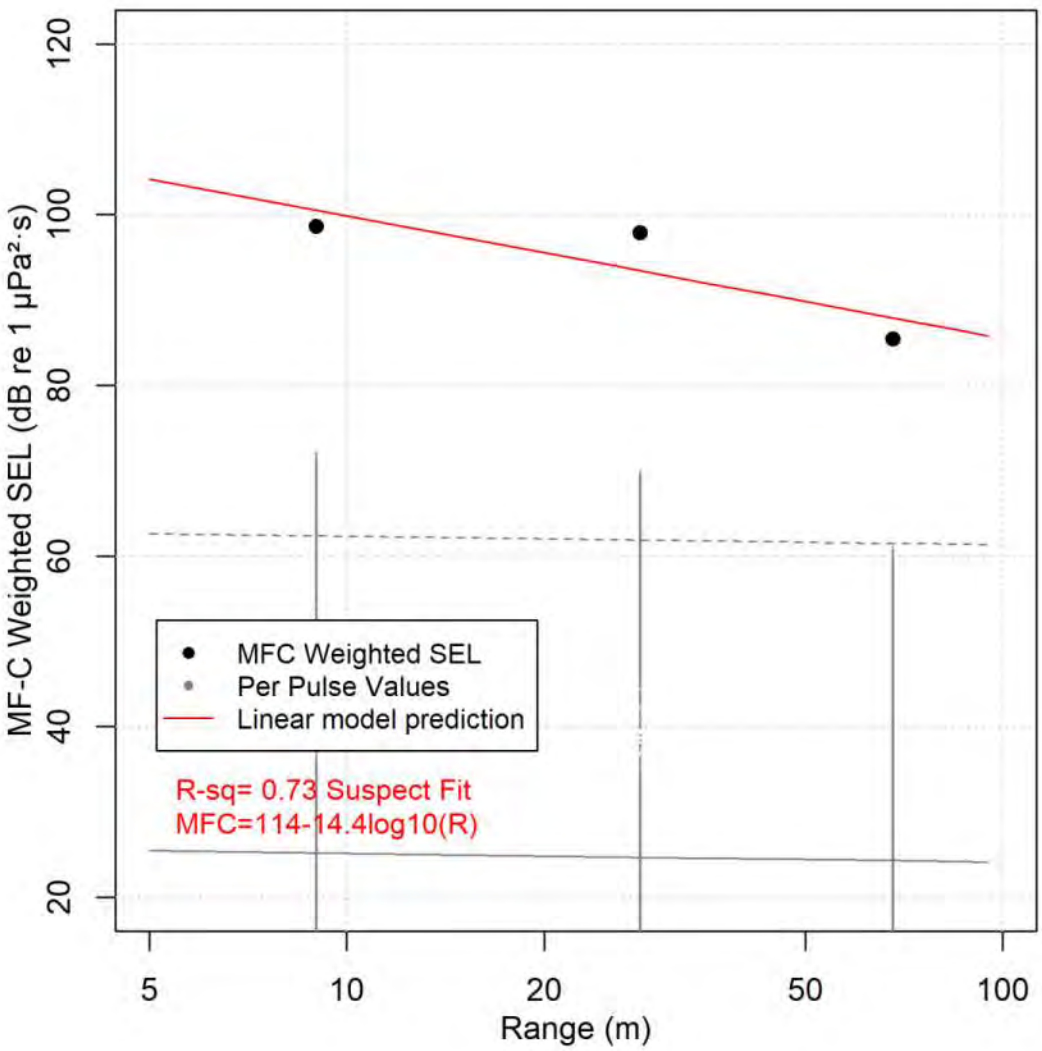

Figure D-21. Mid-frequency cetacean (MFC) weighted per-pulse Sound Exposure Level (SEL) and MFC-weighted accumulated SEL for DTH hammering of a caisson as a function of range (Stations 1, 2 and 3). Gray points indicate levels of individual pulses and the gray line is the least-squares fit to the individual pulses, with the dashed gray lines showing the ±95% confidence interval. Black points show the accumulated SEL for the duration of DTH hammering and the red line is the least-squares fit of the accumulated SEL. Fitting parameters are shown in text. Not shown: the threshold for injury is 185 dB re 1µPa^2·s (NMFS 2018).

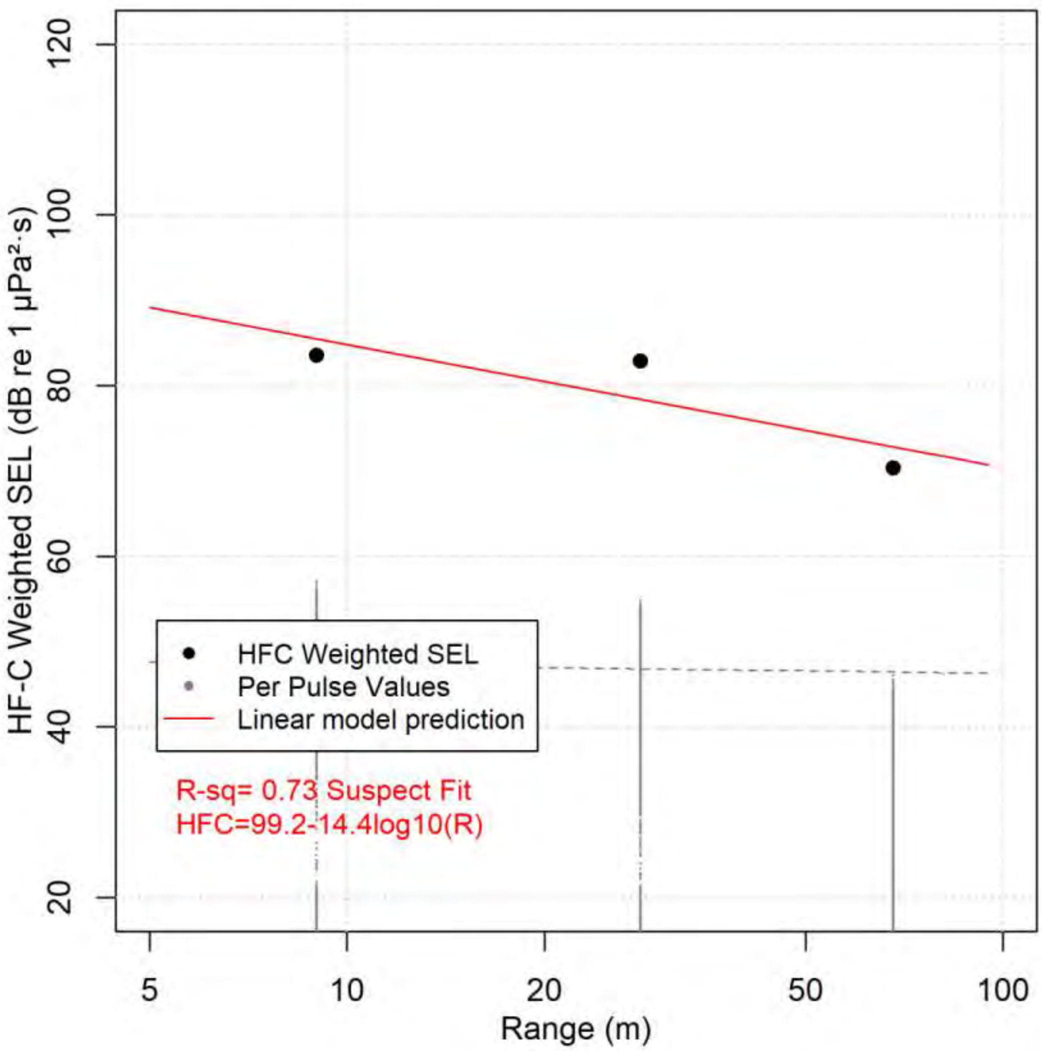

Figure D-22. High-frequency cetacean (HFC) weighted per-pulse Sound Exposure Level (SEL) and HFC-weighted accumulated SEL for DTH hammering of a caisson as a function of range (Stations 1, 2 and 3). Gray points indicate levels of individual pulses and the gray line is the least-squares fit to the individual pulses, with the dashed gray lines showing the ±95% confidence interval. Black points show the accumulated SEL for the duration of DTH hammering and the red line is the least-squares fit of the accumulated SEL. Fitting parameters are shown in text. Not shown: the threshold for injury is 155 dB re 1µPa^2·s (NMFS 2018).

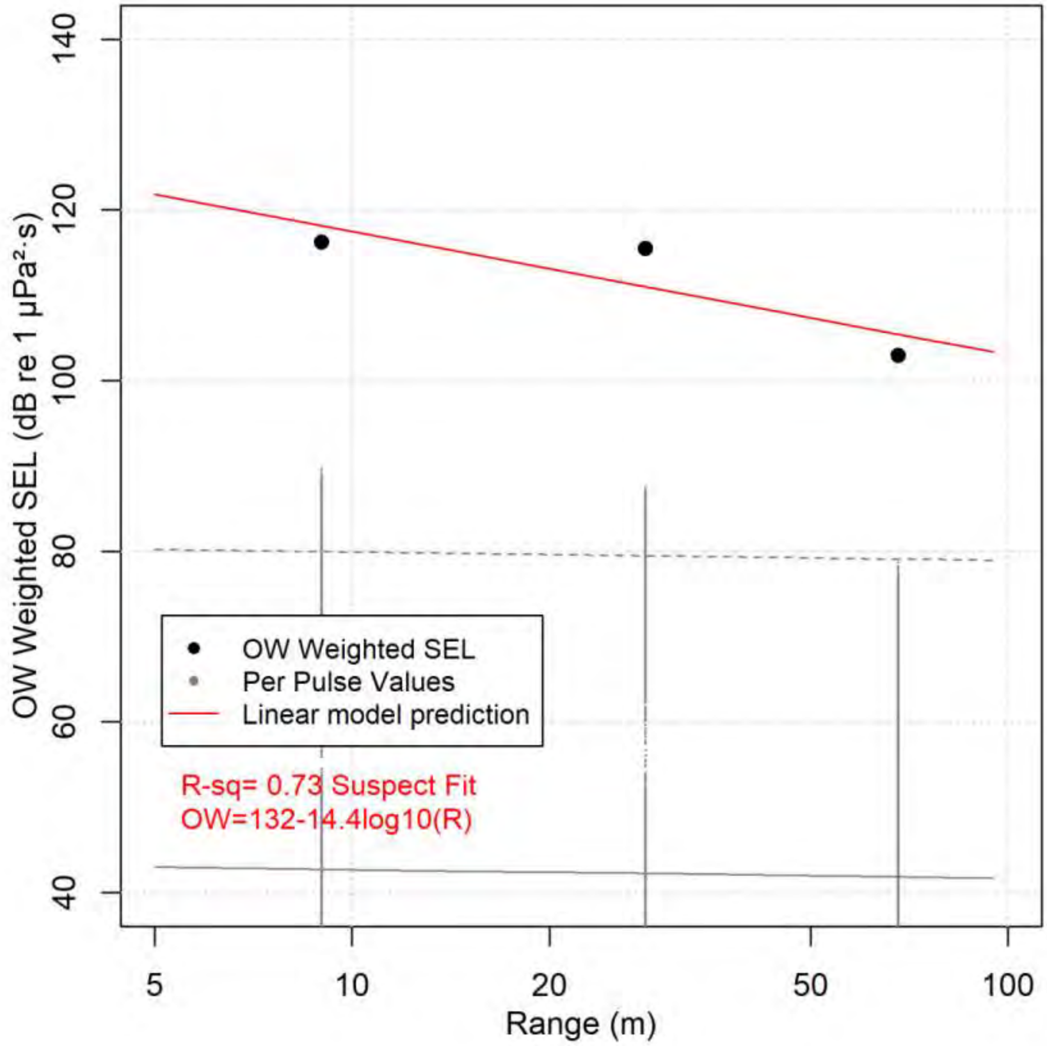

Figure D-23. Otariid underwater (OW) weighted per-pulse Sound Exposure Level (SEL) and OW-weighted accumulated SEL for DTH hammering of a caisson as a function of range (Stations 1, 2 and 3). Gray points indicate levels of individual pulses and the gray line is the least-squares fit to the individual pulses, with the dashed gray lines showing the ±95% confidence interval. Black points show the accumulated SEL for the duration of DTH hammering and the red line is the least-squares fit of the accumulated SEL. Fitting parameters are shown in text. Not shown: the threshold for injury is 203 dB re 1μPa^2·s (NMFS 2018).

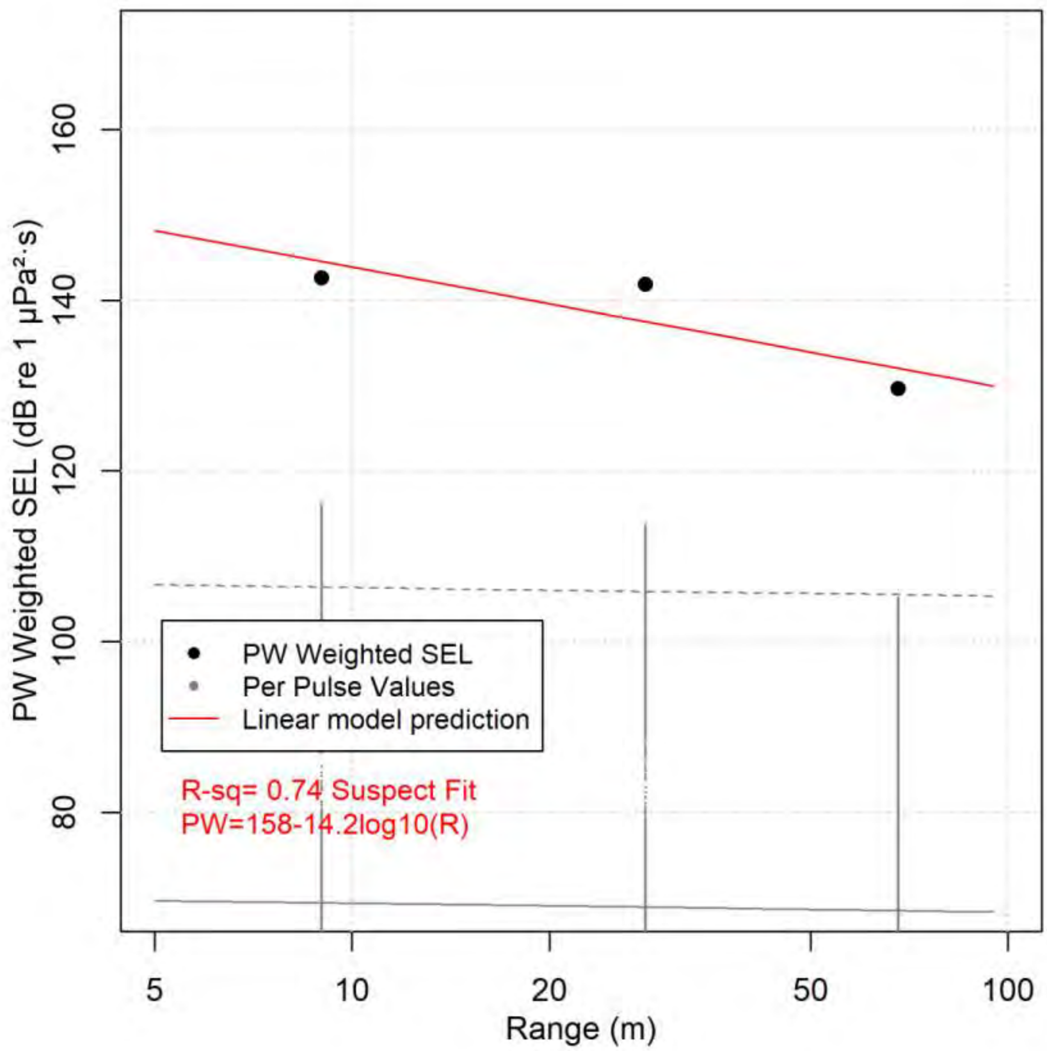

Figure D-24. Phocid underwater (PW) weighted per-pulse Sound Exposure Level (SEL) and PW-weighted accumulated SEL for DTH hammering of a caisson as a function of range (Stations 1, 2 and 3). Gray points indicate levels of individual pulses and the gray line is the least-squares fit to the individual pulses, with the dashed gray lines showing the ±95% confidence interval. Black points show the accumulated SEL for the duration of DTH hammering and the red line is the least-squares fit of the accumulated SEL. Fitting parameters are shown in text.

D.4. C8P6 (with bubble curtain)

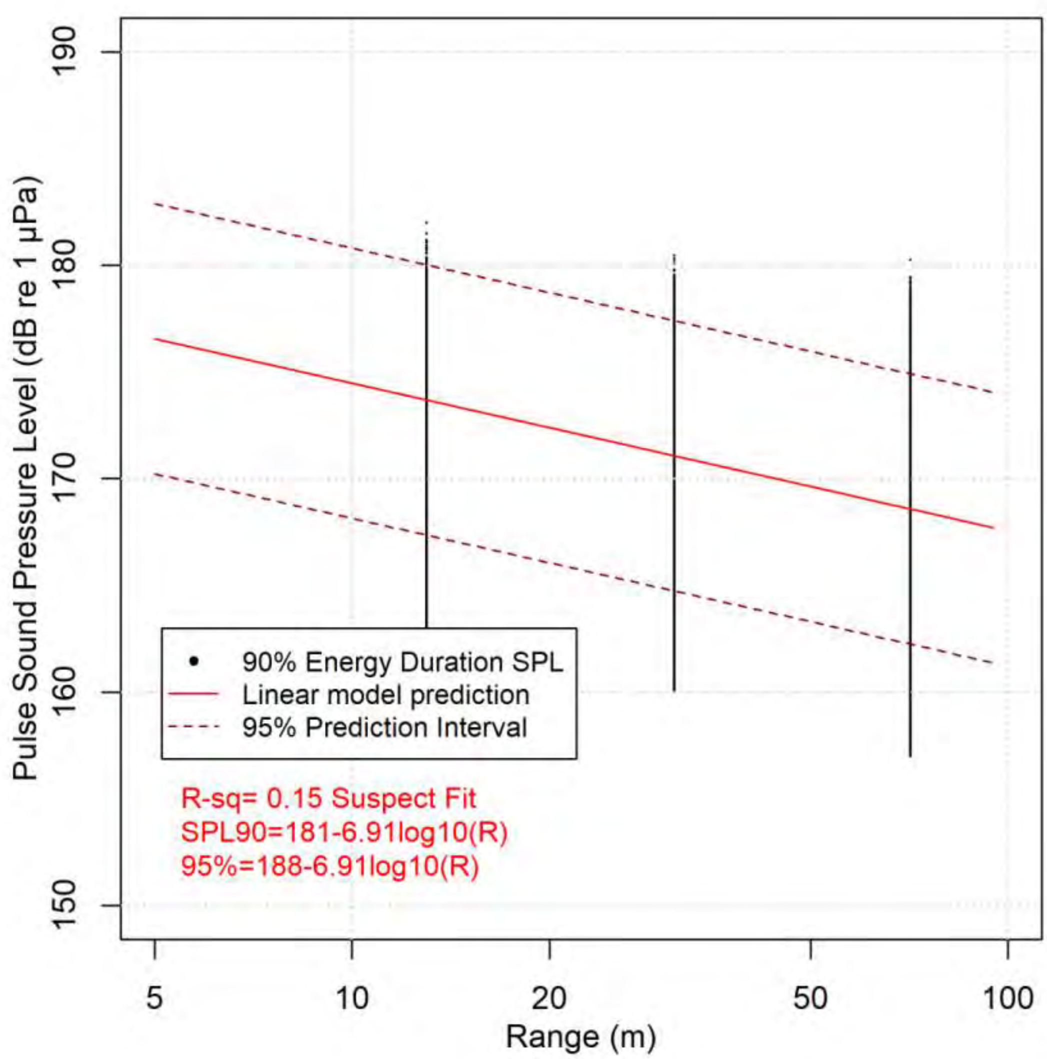

Figure D-25. Sound Pressure Level (SPL) of DTH hammering as a function of range (Stations 1, 2, and 3). Points indicate levels of individual pulses and the red line is the least-squares fit to the individual pulses, with the dashed red lines showing the ±95% confidence interval. Fitting parameters are shown in text.

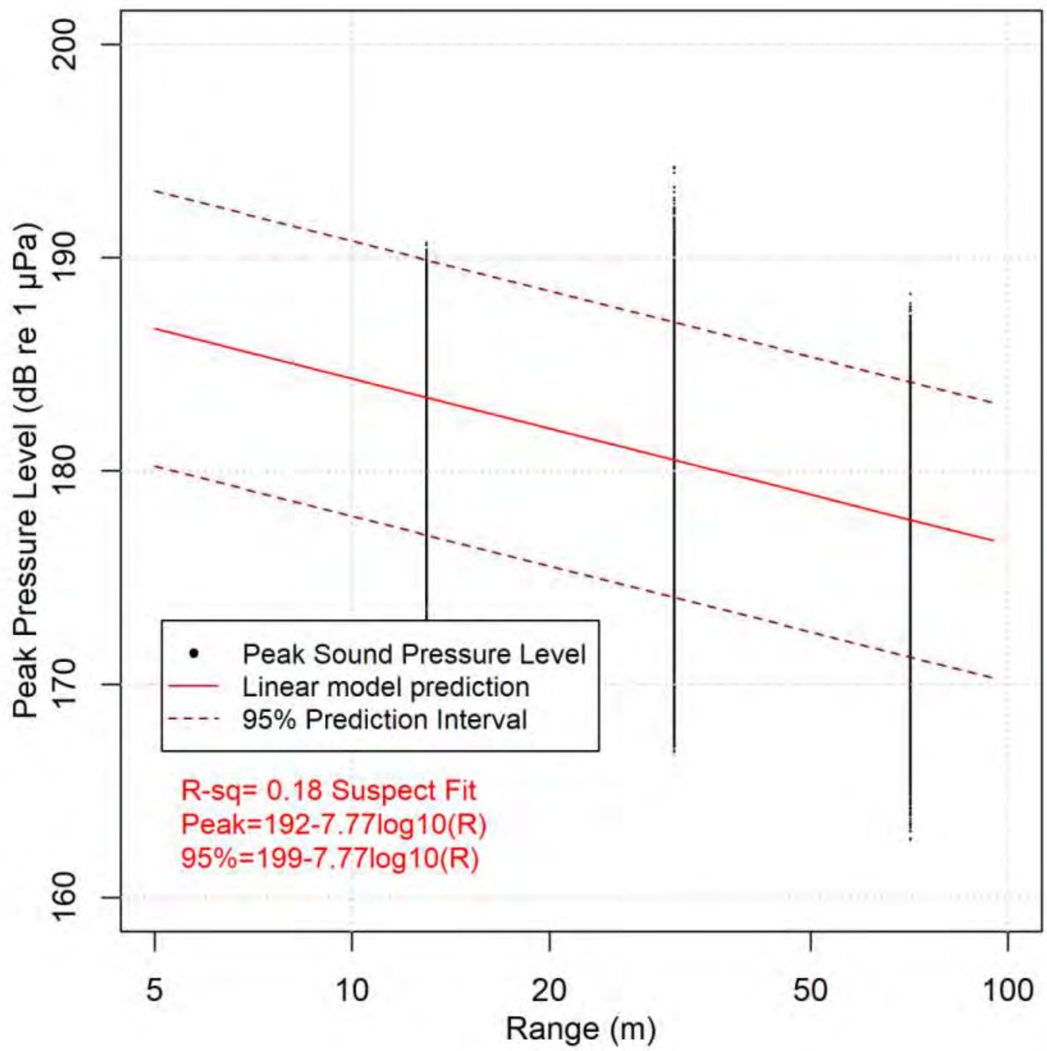

Figure D-26. Peak Sound Pressure (SEL) of DTH hammering as a function of range (Stations 1, 2 and 3). Points indicate levels of individual pulses and the red line is the least-squares fit to the individual pulses, with the dashed red lines showing the ±95% confidence interval. Fitting parameters are shown in text.

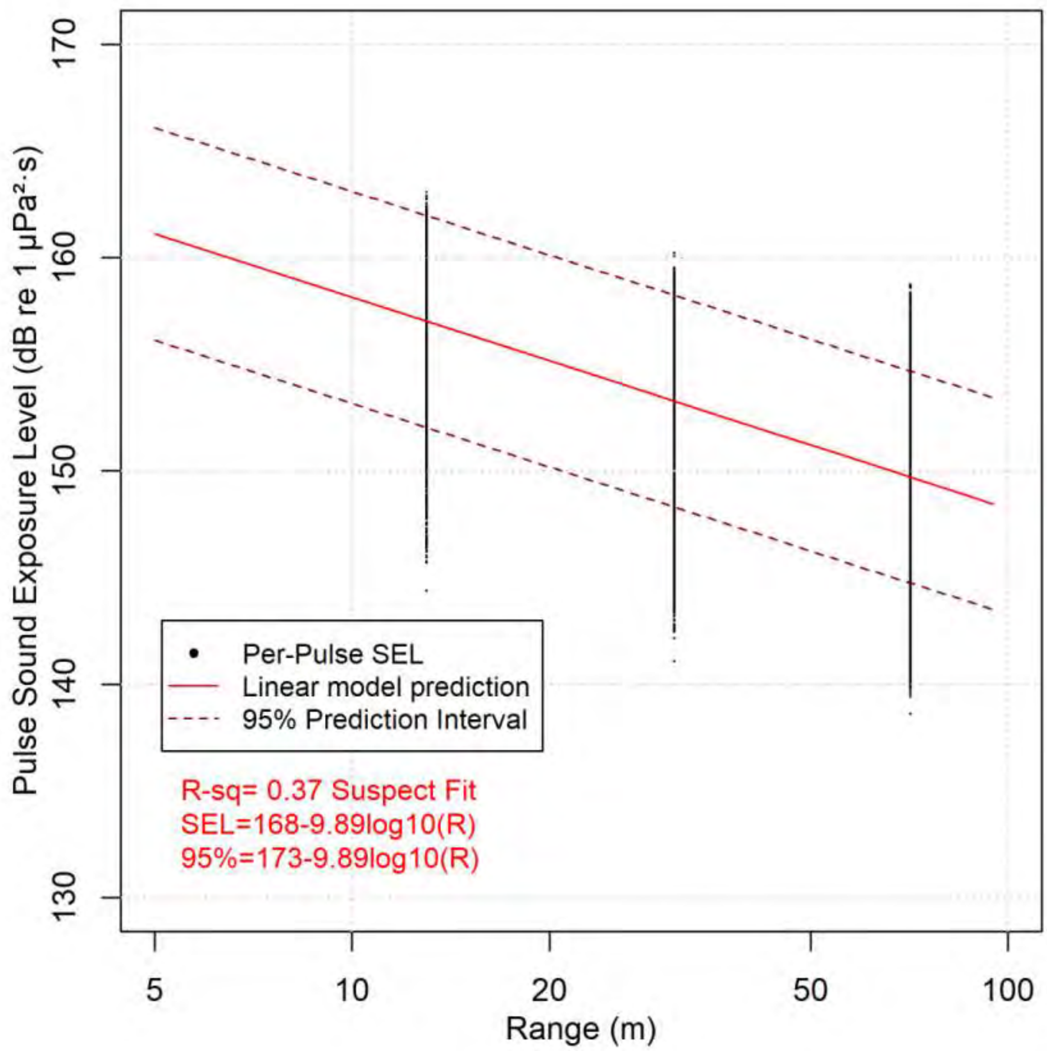

Figure D-27. Per-pulse Sound Exposure Level (SEL) of DTH hammering as a function of range (Stations 1, 2 and 3). Points indicate levels of individual pulses and the red line is the least-squares fit to the individual pulses, with the dashed red lines showing the ±95% confidence interval. Fitting parameters are shown in text.

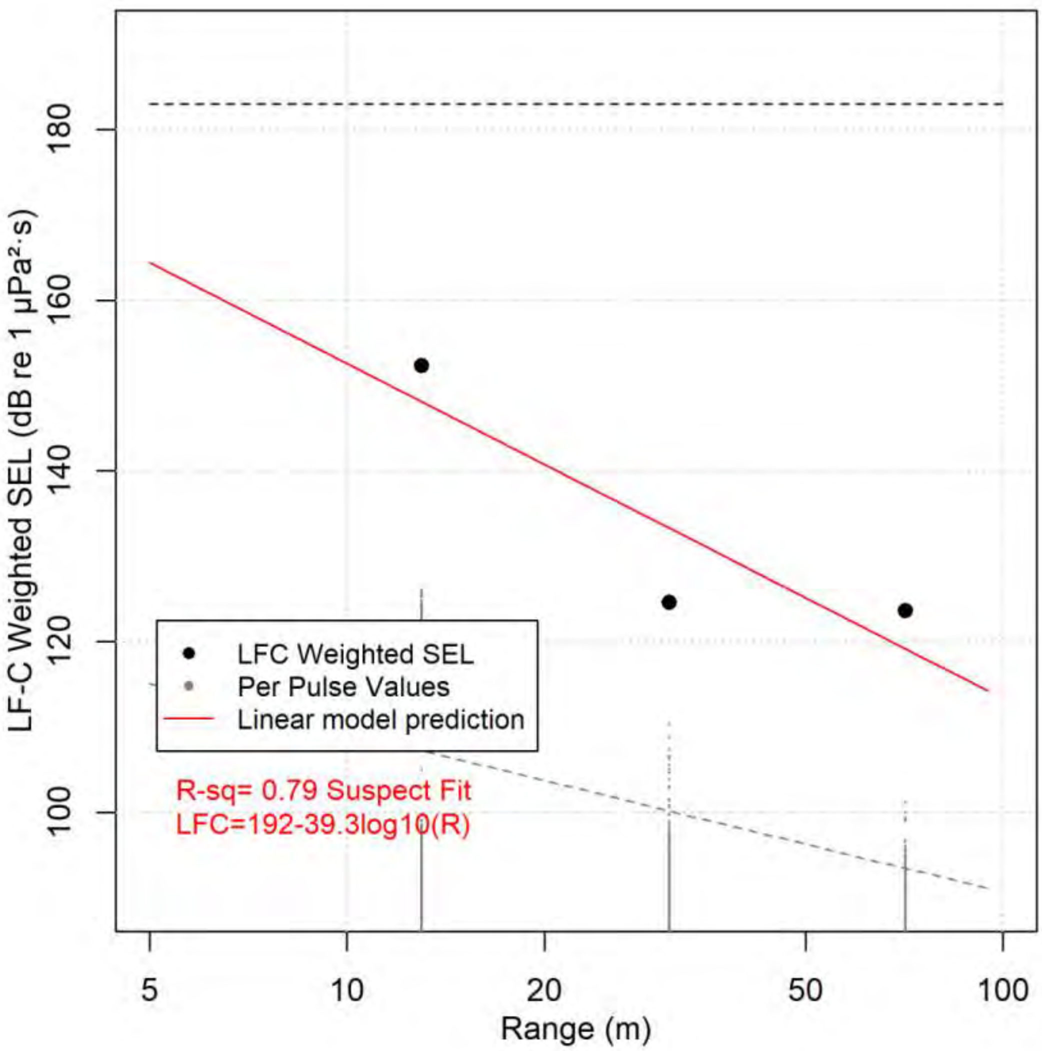

Figure D-28. Low-frequency cetacean (LFC) weighted per-pulse Sound Exposure Level (SEL) and LFC-weighted accumulated SEL for DTH hammering of a caisson as a function of range (Stations 1, 2 and 3). Gray points indicate levels of individual pulses and the gray line is the least-squares fit to the individual pulses, with the dashed gray lines showing the ±95% confidence interval. Black points show the accumulated SEL for the duration of DTH hammering and the red line is the least-squares fit of the accumulated SEL. Fitting parameters are shown in text. Black dashed line is the threshold for injury at 183 dB re 1µPa^2·s (NMFS 2018).

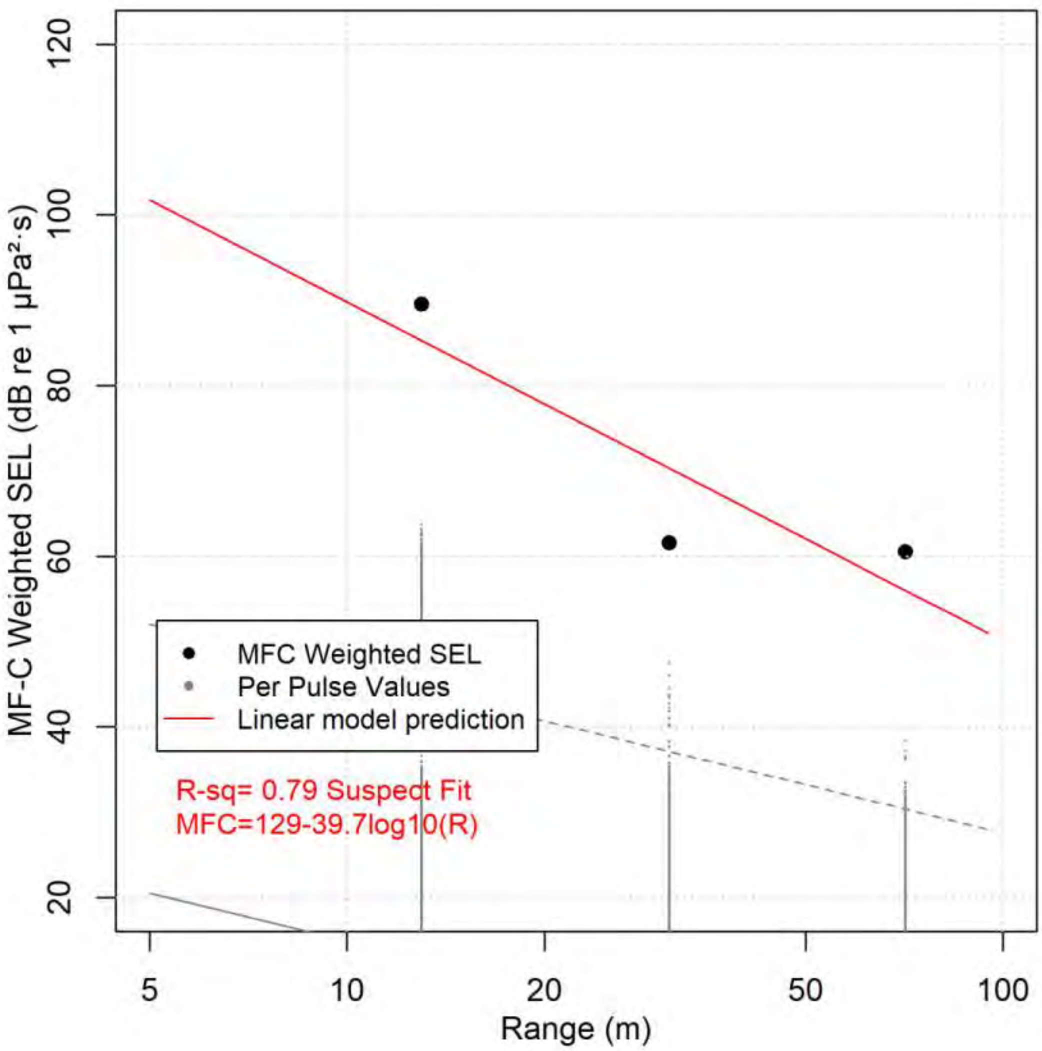

Figure D-29. Mid-frequency cetacean (MFC) weighted per-pulse Sound Exposure Level (SEL) and MFC-weighted accumulated SEL for DTH hammering of a caisson as a function of range (Stations 1, 2 and 3). Gray points indicate levels of individual pulses and the gray line is the least-squares fit to the individual pulses, with the dashed gray lines showing the ±95% confidence interval. Black points show the accumulated SEL for the duration of DTH hammering and the red line is the least-squares fit of the accumulated SEL. Fitting parameters are shown in text. Not shown: the threshold for injury is 185 dB re 1µPa^2·s (NMFS 2018).

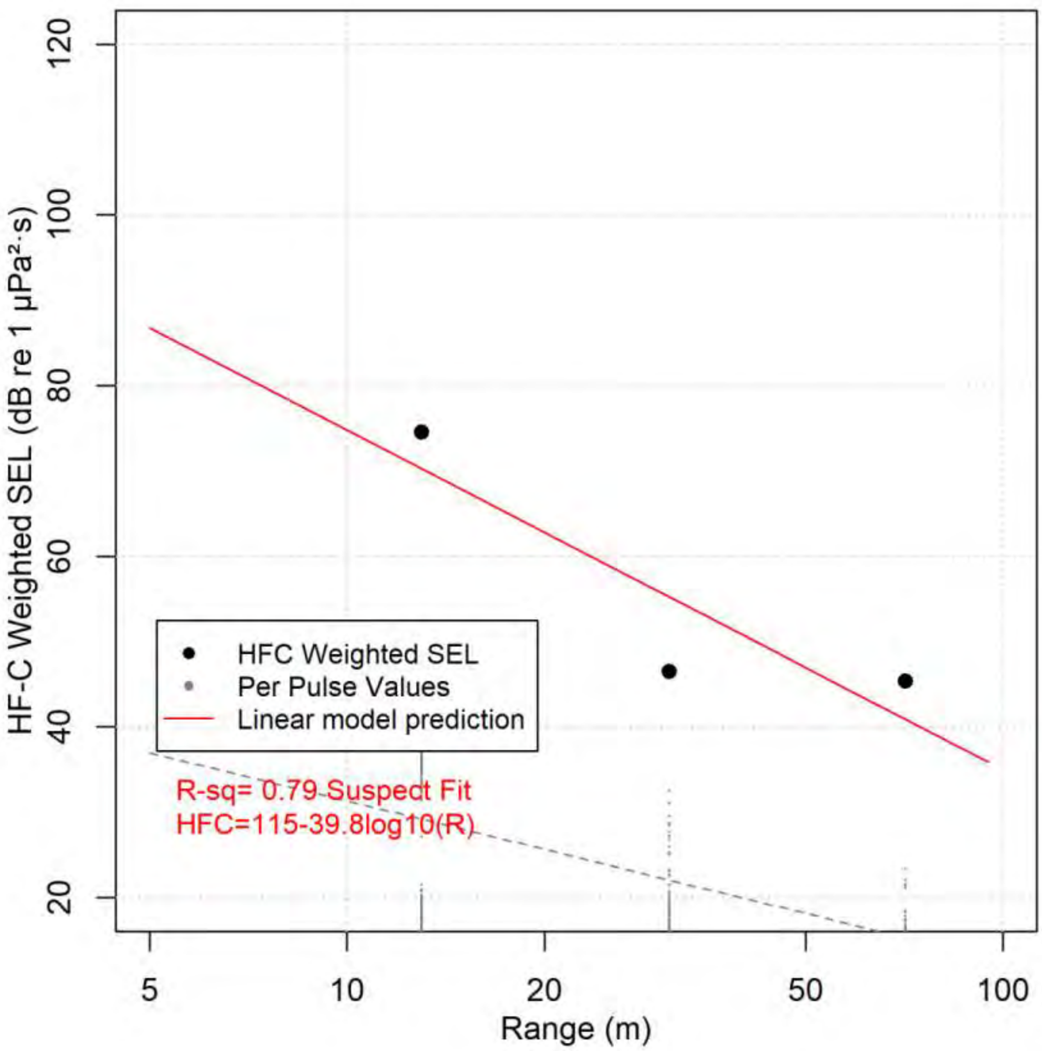

Figure D-30. High-frequency cetacean (HFC) weighted per-pulse Sound Exposure Level (SEL) and HFC-weighted accumulated SEL for DTH hammering of a caisson as a function of range (Stations 1, 2 and 3). Gray points indicate levels of individual pulses and the gray line is the least-squares fit to the individual pulses, with the dashed gray lines showing the ±95% confidence interval. Black points show the accumulated SEL for the duration of DTH hammering and the red line is the least-squares fit of the accumulated SEL. Fitting parameters are shown in text. Not shown: the threshold for injury is 155 dB re 1μPa^2·s (NMFS 2018).

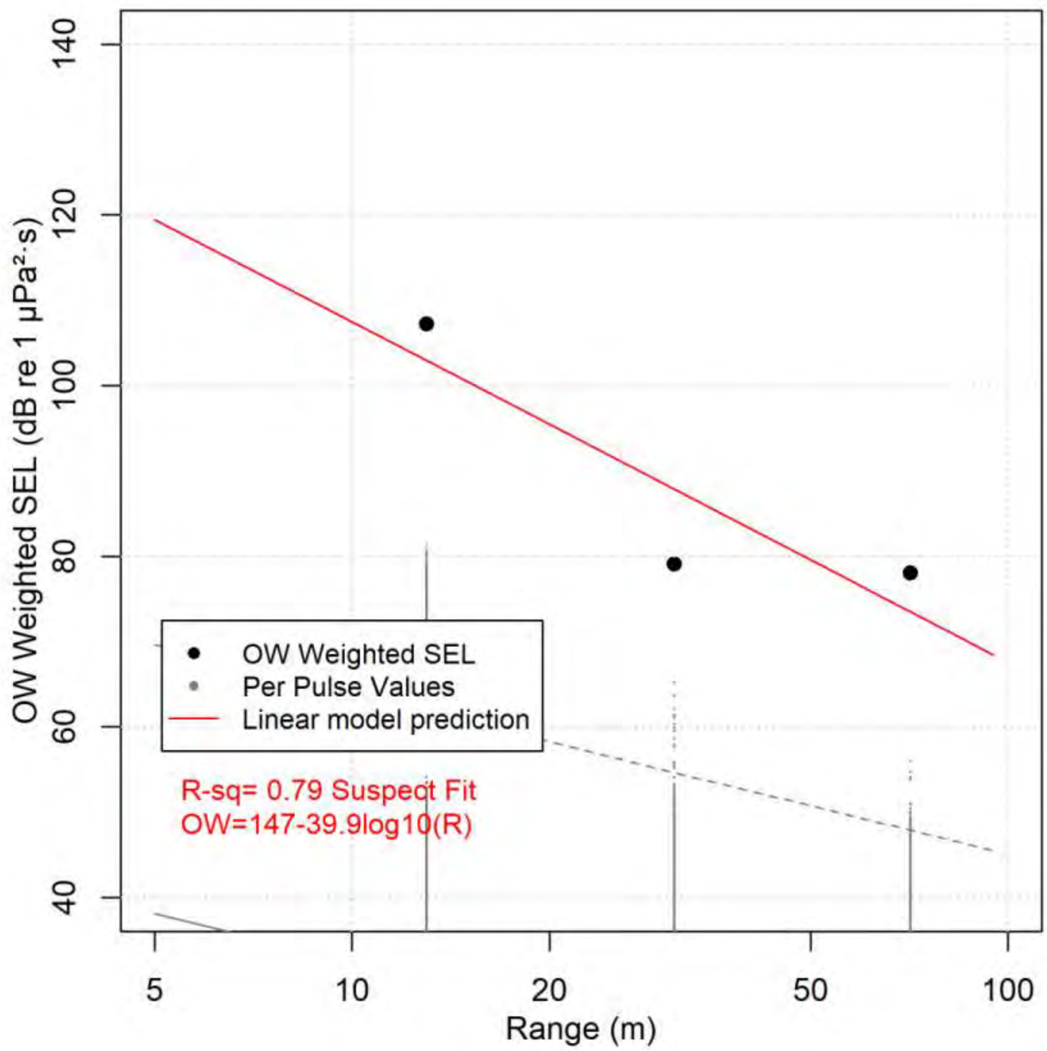

Figure D-31. Otariid underwater (OW) weighted per-pulse Sound Exposure Level (SEL) and OW-weighted accumulated SEL for DTH hammering of a caisson as a function of range (Stations 1, 2 and 3). Gray points indicate levels of individual pulses and the gray line is the least-squares fit to the individual pulses, with the dashed gray lines showing the ±95% confidence interval. Black points show the accumulated SEL for the duration of DTH hammering and the red line is the least-squares fit of the accumulated SEL. Fitting parameters are shown in text. Not shown: the threshold for injury is 203 dB re 1µPa^2·s (NMFS 2018).

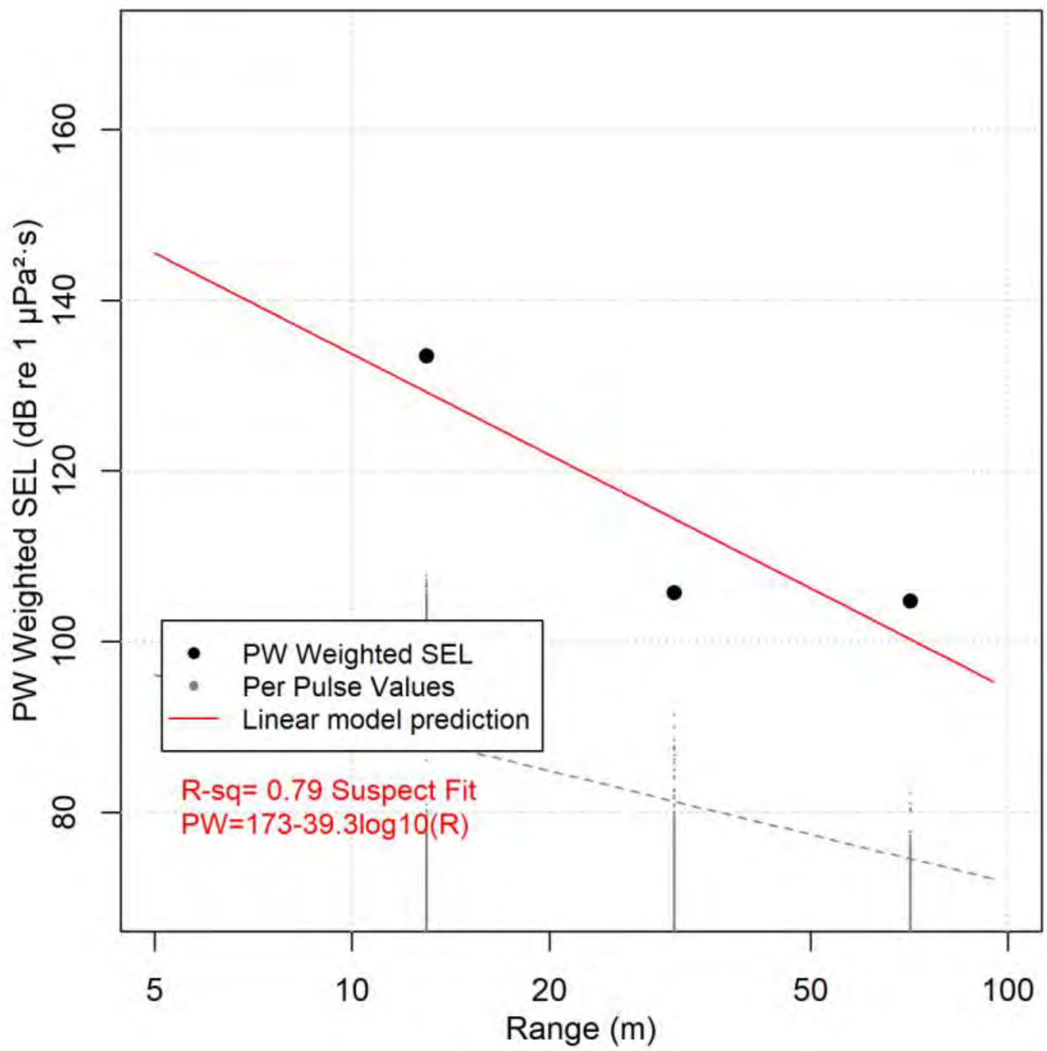

Figure D-32. Phocid underwater (PW) weighted per-pulse Sound Exposure Level (SEL) and PW-weighted accumulated SEL for DTH hammering of a caisson as a function of range (Stations 1, 2 and 3). Gray points indicate levels of individual pulses and the gray line is the least-squares fit to the individual pulses, with the dashed gray lines showing the ±95% confidence interval. Black points show the accumulated SEL for the duration of DTH hammering and the red line is the least-squares fit of the accumulated SEL. Fitting parameters are shown in text. Not shown: the threshold for injury is 185 dB re 1μPa^2·s (NMFS 2018).

D.5. C8P7 (with bubble curtain)

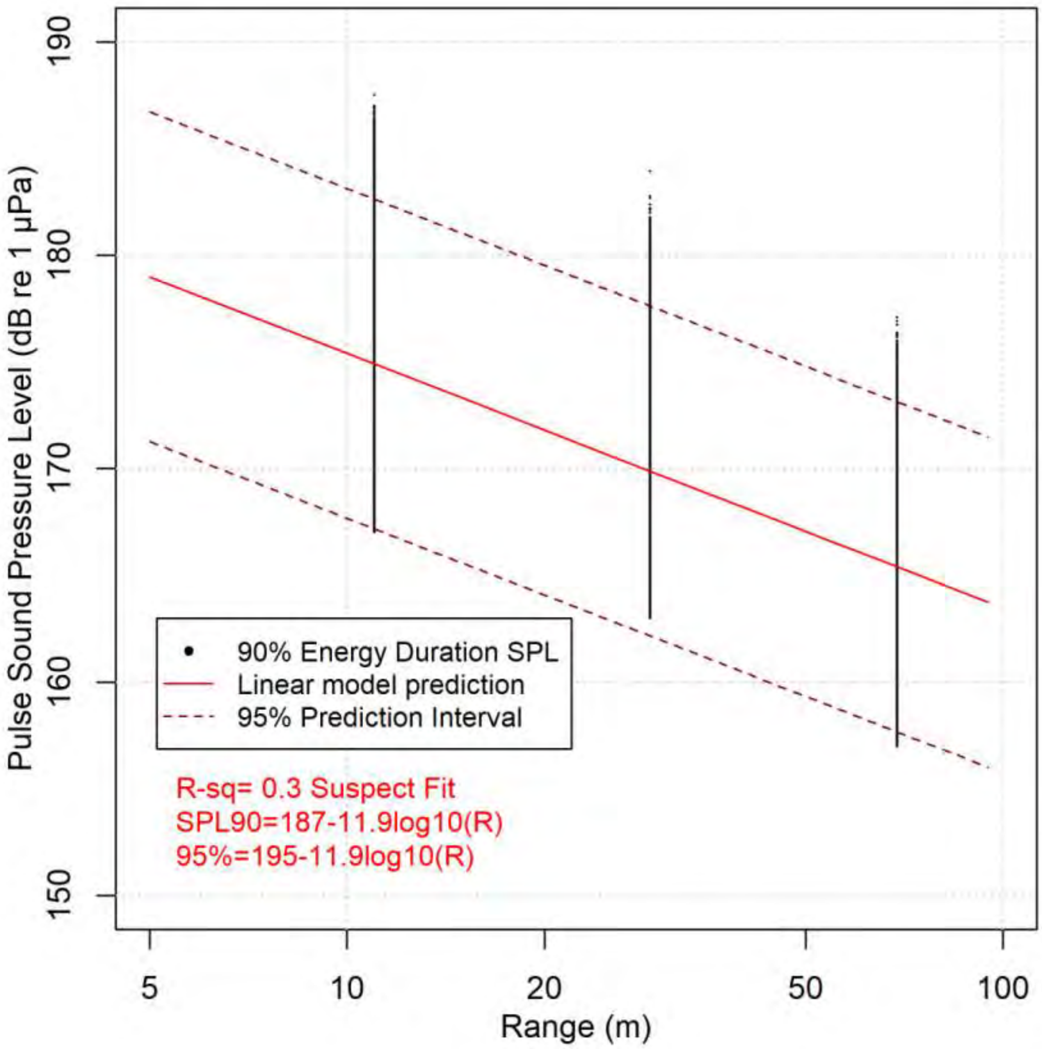

Figure D-33. Sound Pressure Level (SPL) of DTH hammering as a function of range (Stations 1, 2, and 3). Points indicate levels of individual pulses and the red line is the least-squares fit to the individual pulses, with the dashed red lines showing the ±95% confidence interval. Fitting parameters are shown in text.

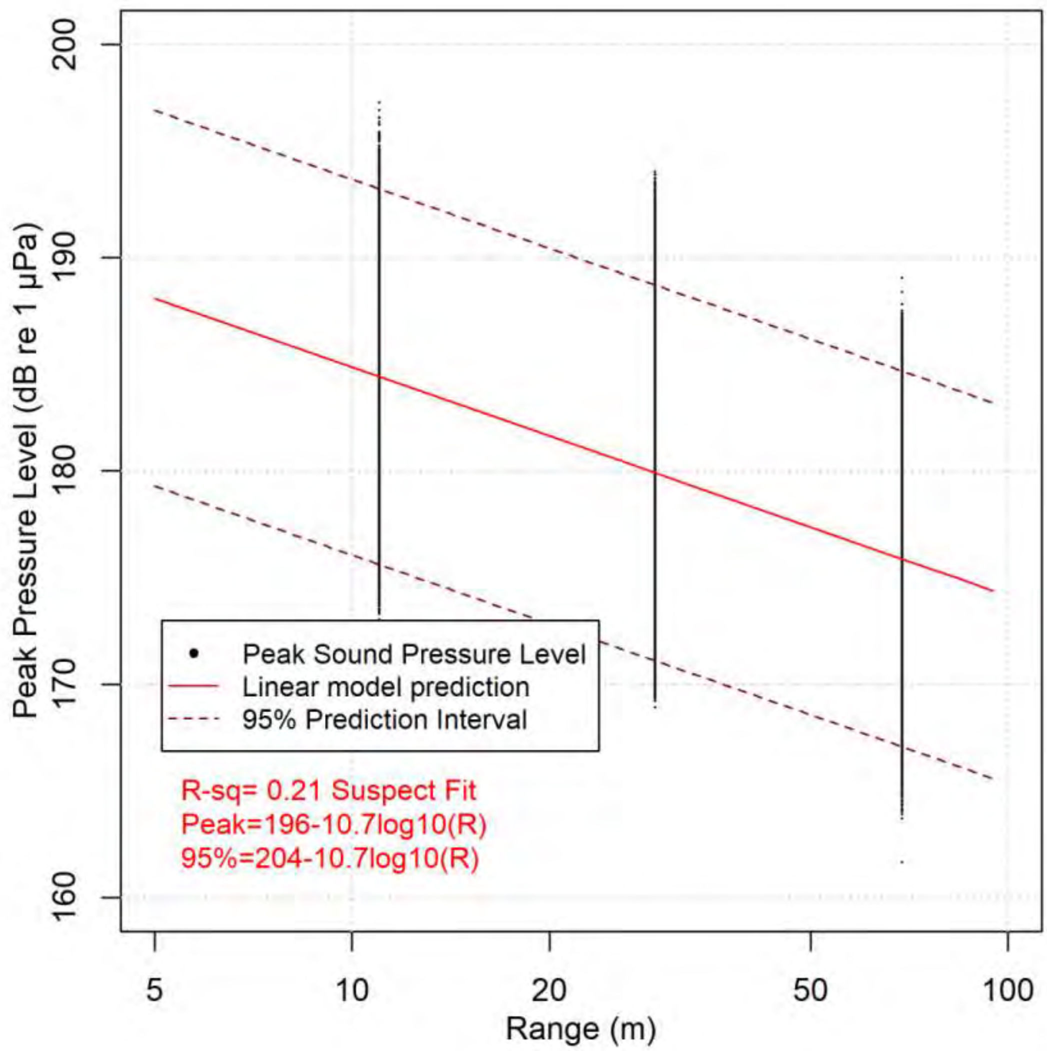

Figure D-34. Peak Sound Pressure (SEL) of DTH hammering as a function of range (Stations 1, 2 and 3). Points indicate levels of individual pulses and the red line is the least-squares fit to the individual pulses, with the dashed red lines showing the ±95% confidence interval. Fitting parameters are shown in text.

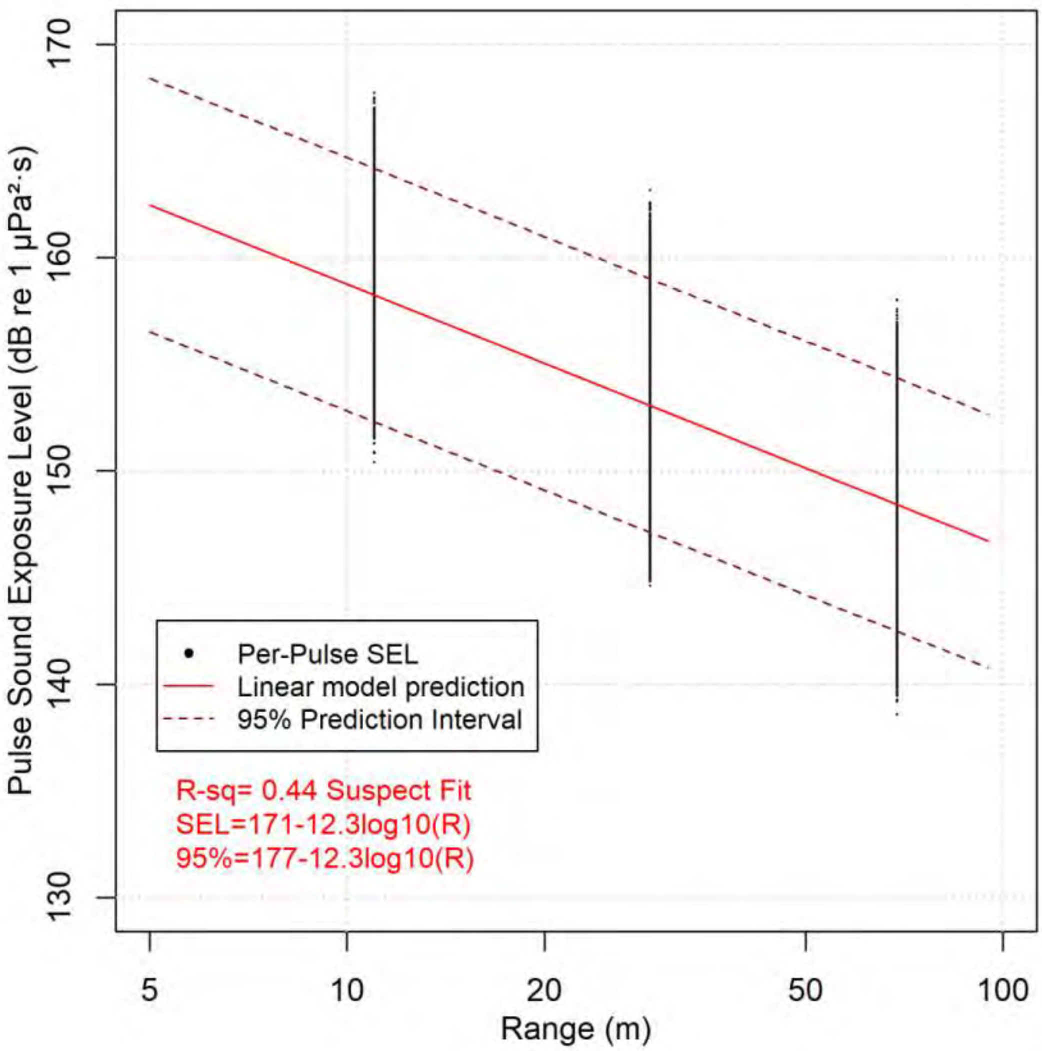

Figure D-35. Per-pulse Sound Exposure Level (SEL) of DTH hammering as a function of range (Stations 1, 2 and 3). Points indicate levels of individual pulses and the red line is the least-squares fit to the individual pulses, with the dashed red lines showing the ±95% confidence interval. Fitting parameters are shown in text.

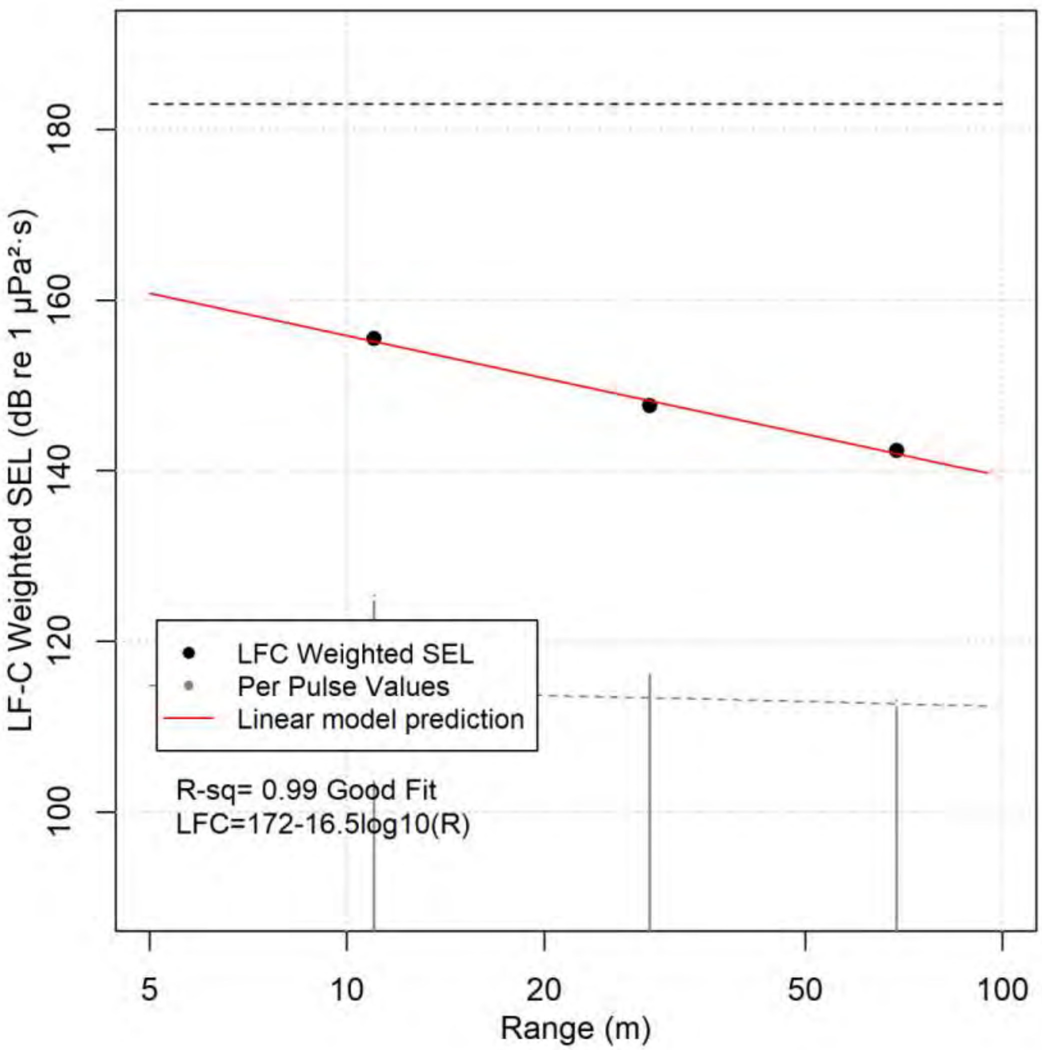

Figure D-36. Low-frequency cetacean (LFC) weighted per-pulse Sound Exposure Level (SEL) and LFC-weighted accumulated SEL for DTH hammering of a caisson as a function of range (Stations 1, 2 and 3). Gray points indicate levels of individual pulses and the gray line is the least-squares fit to the individual pulses, with the dashed gray lines showing the ±95% confidence interval. Black points show the accumulated SEL for the duration of DTH hammering and the red line is the least-squares fit of the accumulated SEL. Fitting parameters are shown in text. Black dashed line is the threshold for injury at 183 dB re 1µPa^2·s (NMFS 2018).

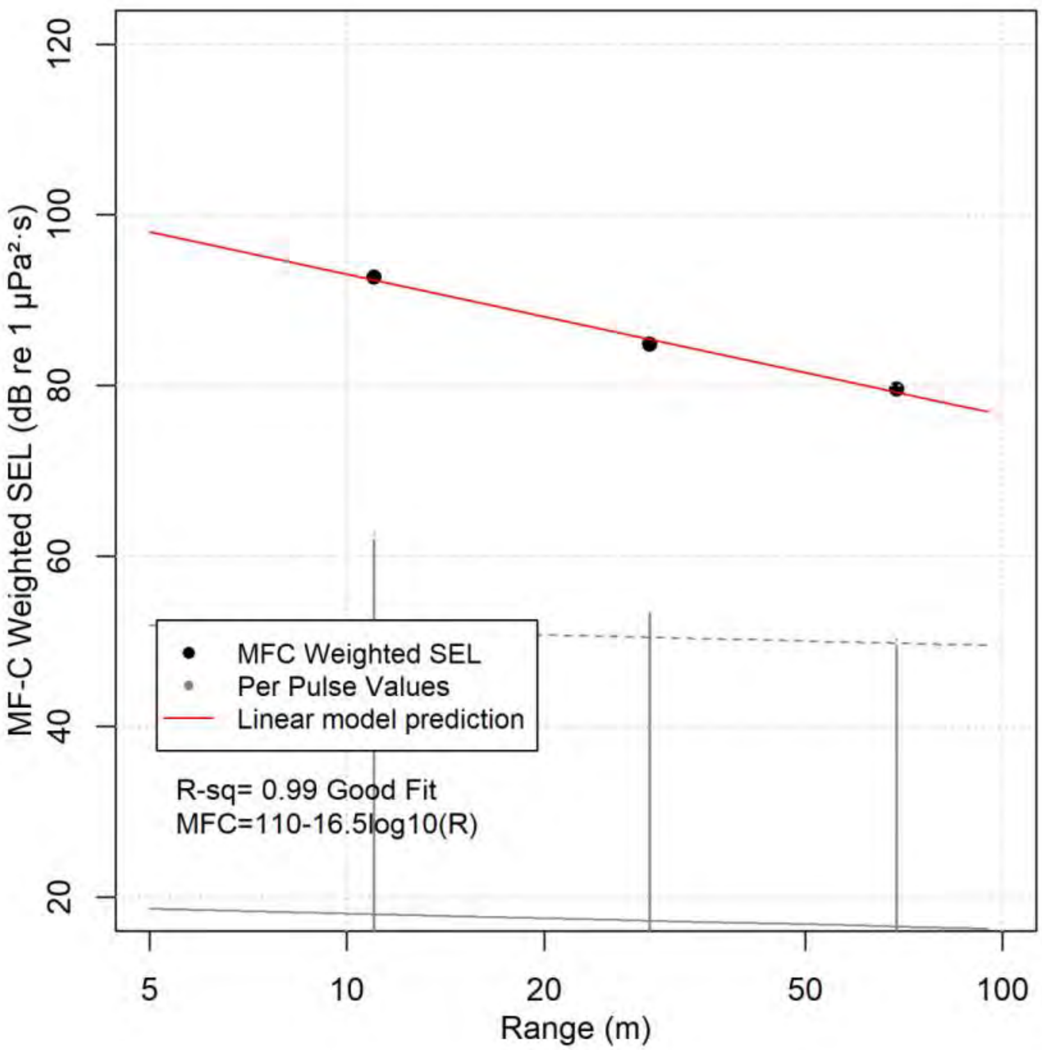

Figure D-37. Mid-frequency cetacean (MFC) weighted per-pulse Sound Exposure Level (SEL) and MFC-weighted accumulated SEL for DTH hammering of a caisson as a function of range (Stations 1, 2 and 3). Gray points indicate levels of individual pulses and the gray line is the least-squares fit to the individual pulses, with the dashed gray lines showing the ±95% confidence interval. Black points show the accumulated SEL for the duration of DTH hammering and the red line is the least-squares fit of the accumulated SEL. Fitting parameters are shown in text. Not shown: the threshold for injury is 185 dB re 1µPa²·s (NMFS 2018).

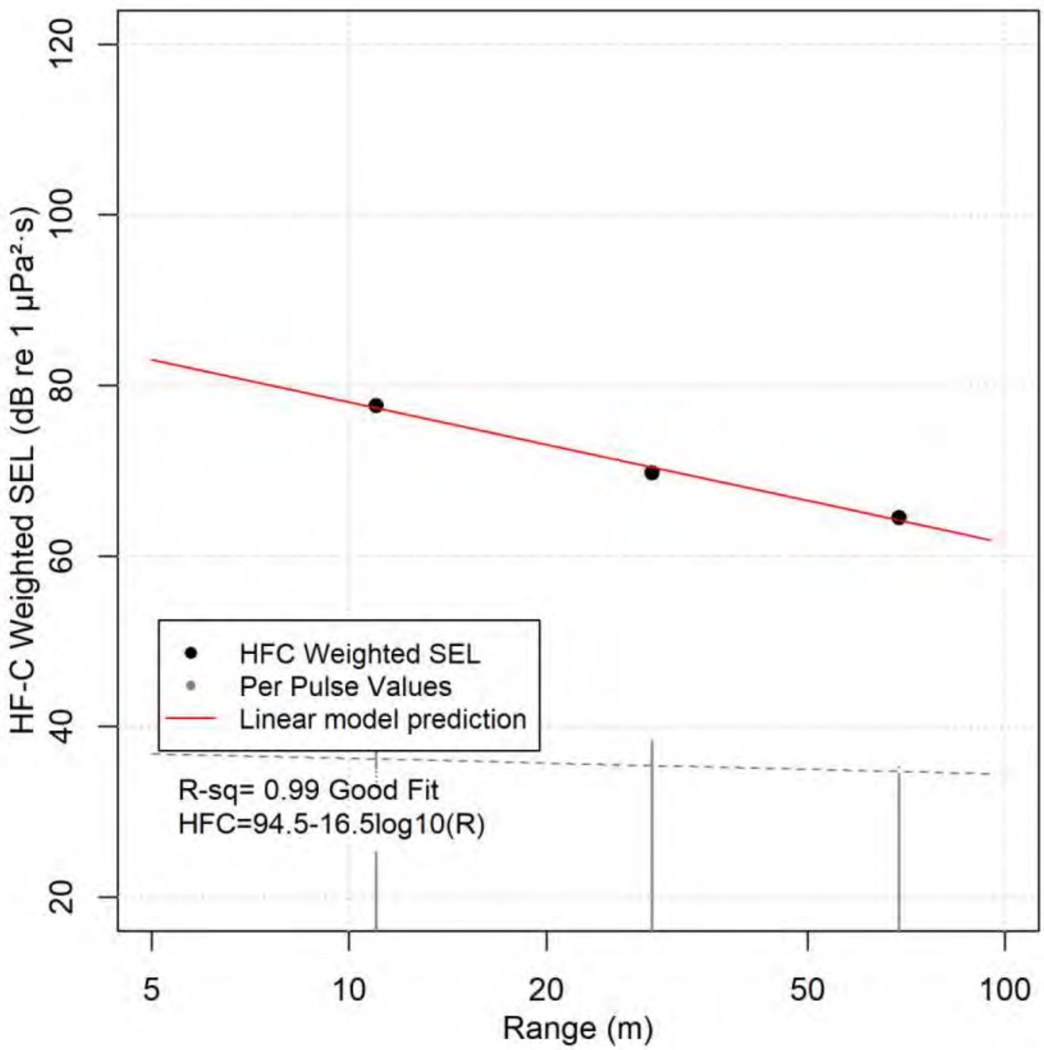

Figure D-38. High-frequency cetacean (HFC) weighted per-pulse Sound Exposure Level (SEL) and HFC-weighted accumulated SEL for DTH hammering of a caisson as a function of range (Stations 1, 2 and 3). Gray points indicate levels of individual pulses and the gray line is the least-squares fit to the individual pulses, with the dashed gray lines showing the ±95% confidence interval. Black points show the accumulated SEL for the duration of DTH hammering and the red line is the least-squares fit of the accumulated SEL. Fitting parameters are shown in text. Not shown: the threshold for injury is 155 dB re 1μPa^2·s (NMFS 2018).

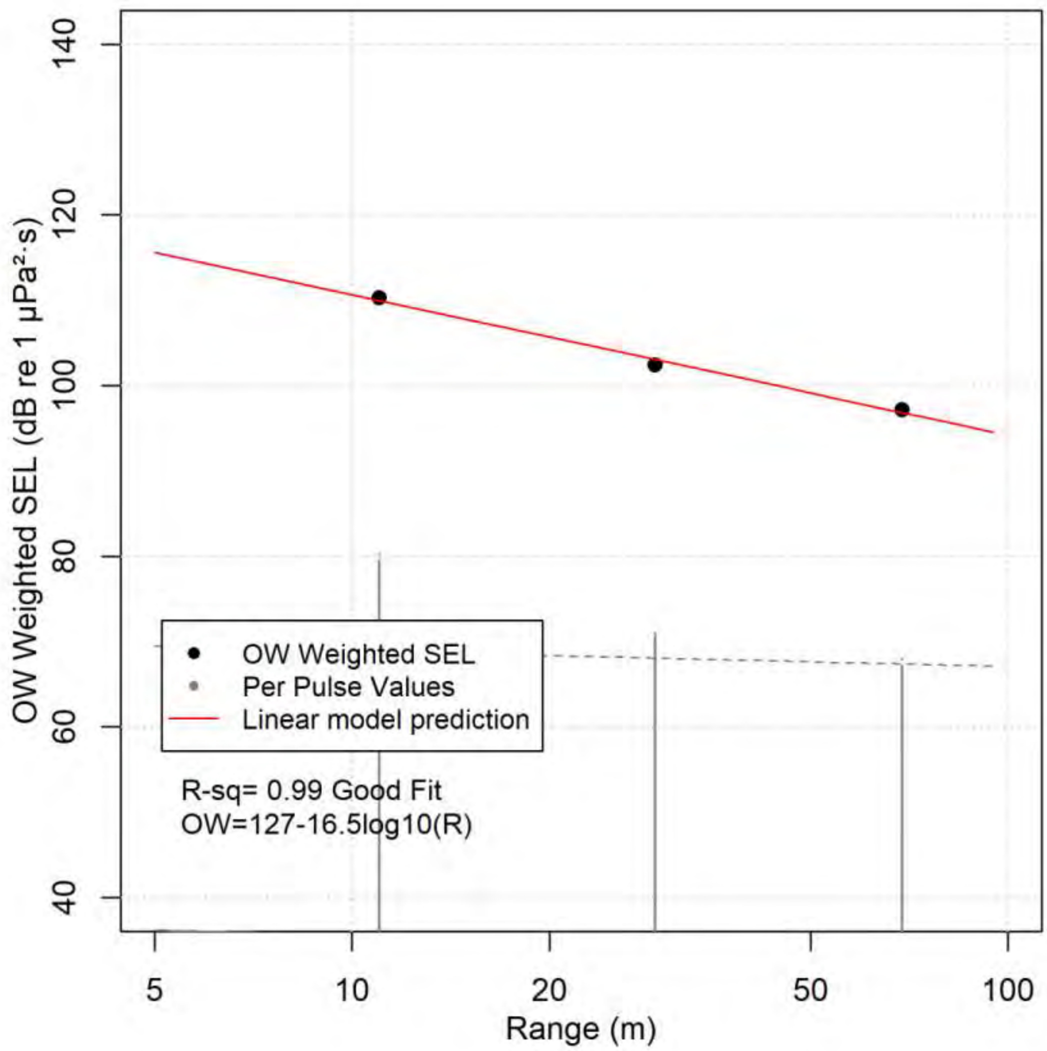

Figure D-39. Otariid underwater (OW) weighted per-pulse Sound Exposure Level (SEL) and OW-weighted accumulated SEL for DTH hammering of a caisson as a function of range (Stations 1, 2 and 3). Gray points indicate levels of individual pulses and the gray line is the least-squares fit to the individual pulses, with the dashed gray lines showing the ±95% confidence interval. Black points show the accumulated SEL for the duration of DTH hammering and the red line is the least-squares fit of the accumulated SEL. Fitting parameters are shown in text. Not shown: the threshold for injury is 203 dB re 1μPa^2·s (NMFS 2018).

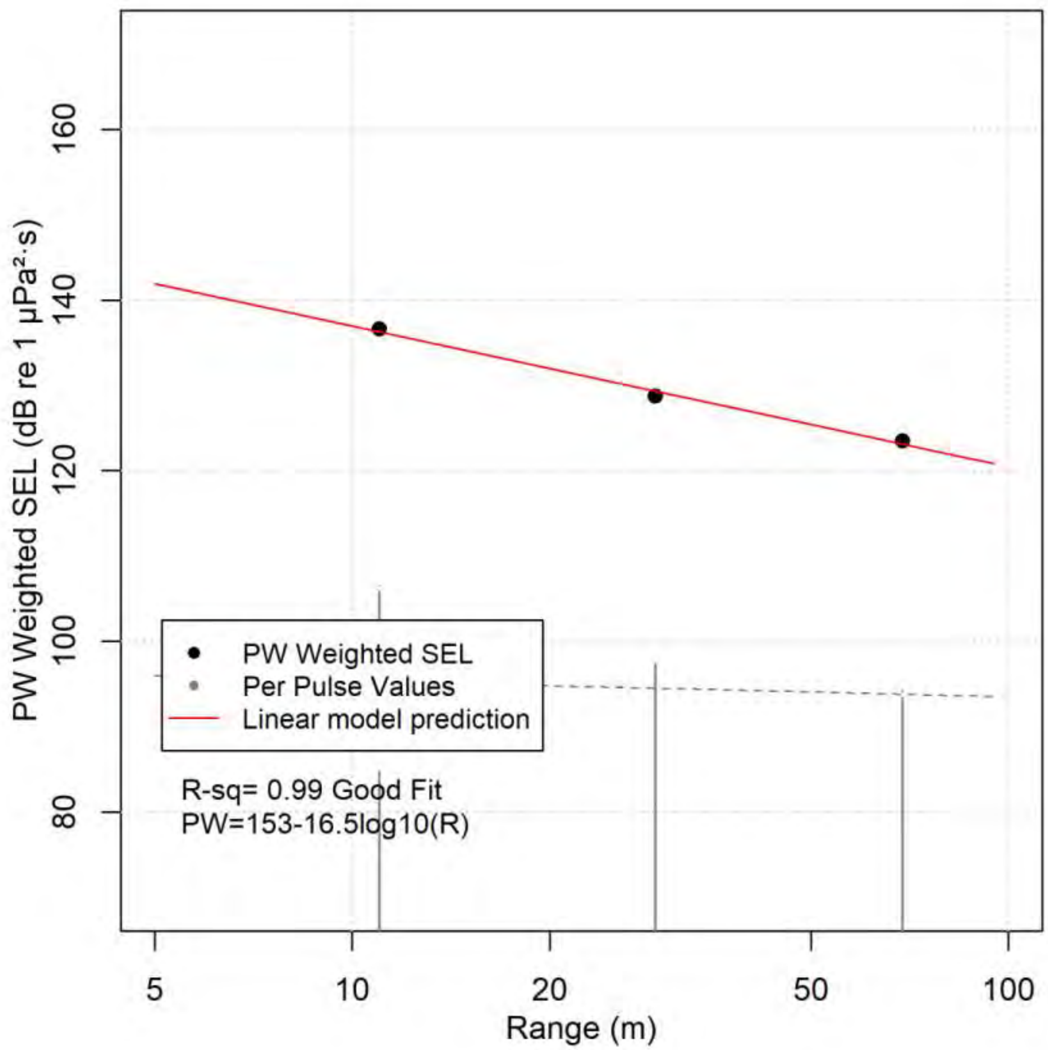

Figure D-40. Phocid underwater (PW) weighted per-pulse Sound Exposure Level (SEL) and PW-weighted accumulated SEL for DTH hammering of a caisson as a function of range (Stations 1, 2 and 3). Gray points indicate levels of individual pulses and the gray line is the least-squares fit to the individual pulses, with the dashed gray lines showing the ±95% confidence interval. Black points show the accumulated SEL for the duration of DTH hammering and the red line is the least-squares fit of the accumulated SEL. Fitting parameters are shown in text. Not shown: the threshold for injury is 185 dB re 1µPa^2·s (NMFS 2018).

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