Morven North Offshore Wind Array Project

Environmental Impact Assessment Report

Volume 3, Annex 10.2: Underwater Sound Shared Technical Report

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1 Introduction

1.1.1.1 The Morven North Offshore Wind Array Project (hereafter "Morven North") and the Morven South Offshore Wind Array Project (hereafter "Morven South") are both located within the Morven Option Lease Agreement Site (hereafter "Morven Site") in Scottish offshore waters (Figure 1.1). Morven North is located approximately 61km from the Aberdeenshire coast (at its closest point) and Morven South is located approximately 86km from the Aberdeenshire coast (at its closest point). Each project will include wind turbines, Offshore Substation Platforms (OSPs), associated foundations, inter-array and interconnector cables and cable protection. Consent for the offshore export cables of Morven North and Morven South will be sought separately.

1.1.1.2 As shown in Figure 1.1, Morven North is situated northwest of Morven South. The external boundaries of the projects correspond with the boundaries of the Morven Site.

1.1.1.3 This Underwater Sound Shared Technical Report presents results of distances to recognised impact threshold levels for marine mammals and fish relating to underwater sound for both Morven North and Morven South.

1.1.1.4 Consent for Morven North and Morven South will be sought separately, aided by the development of a separate Environmental Impact Assessment (EIA) and Habitats Regulations Appraisal (HRA) for each project. To enable the assessment of cumulative effects, modelling has been undertaken for Morven North and Morven South (as separate projects) but also for the Morven Site (both projects). The modelling outcomes for both Morven North and Morven South are therefore reported in this Underwater Sound Shared Technical Report.

1.1.1.5 The information from this Underwater Sound Shared Technical Report provides results of distances to recognised impact threshold levels relating to underwater sound to inform the assessment of the likely significant effects of Morven North and Morven South on marine mammals and fish. This report accompanies the EIA provided in Volume 2, Chapter 10: Marine Mammals and Volume 2, Chapter 7: Fish and Shellfish Ecology for Morven North or Morven South to support the respective consent applications.

1.1.1.6 The aim of this Underwater Sound Shared Technical Report is to:

- provide predictions of underwater acoustic fields resulting from operations arising from the construction of Morven North and Morven South;
- use predictions of sound fields to produce distances to which sound levels drop below certain acoustic impact thresholds related to deleterious effects.

1.1.1.7 Multiple sound sources were identified as generating sound levels likely to exceed impact thresholds for hearing-sensitive receptors. These include pile driving, underwater explosives, vessels, and geophysical survey systems. Each source was either modelled directly, or sound levels taken from literature. The radiated sound fields were calculated using the sound source information and proprietary sound propagation models.

1.1.1.8 The acoustic sound fields were compared against recommended impact criteria to determine the impact distance of the operations.

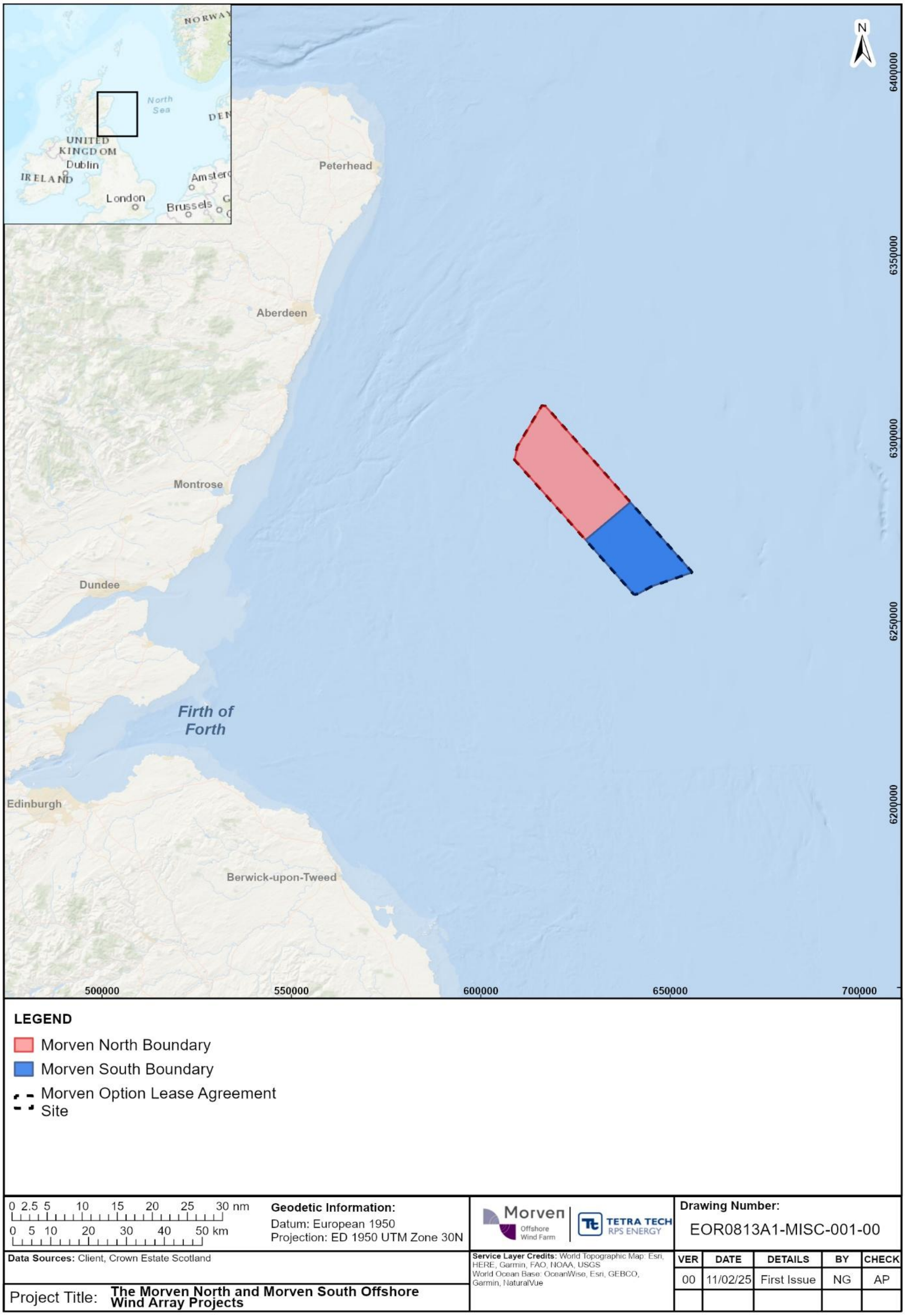

Figure 1.1: The boundaries of Morven North and Morven South within the Morven Site

2 Modelled scenarios

2.1 Overview

2.1.1.1 This work investigates sound fields for three different foundation options: 16.0m diameter monopile installed with a maximum energy of 6,600kJ; 5.3m diameter pin pile installed with a maximum energy of 4,500kJ; and 3.7m diameter pin pile installed with a maximum energy of 4,000kJ.

2.1.1.2 Numerous options across the range of possible installations in the Project Design Envelope (PDE), as outlined within Volume 1, Chapter 3: Project Description, were considered; the three options identified jointly predicted the greatest effect distances following a preliminary modelling study. Modelling inputs, including the hammer details and environment, are based on the latest design specifications of the projects. Modelling includes predictions for piling sequences including an Acoustic Anti-Deterrent (ADD) preceding pile initiation and soft start procedures.

2.1.1.3 In addition to the sound from impact piling, this study also investigates the radiated sound from vessels, geophysical survey sources, and the clearing of Unexploded Ordnance (UXO). An overview list of scenarios studied in this report is presented in Table 2.1.

Table 2.1: Overview of all modelled scenarios studied for each of Morven North and Morven South

Scenario	Description
MP BE [A-D]	Single strike on monopile (16.0m) for best estimate (BE) modelling at four separate depths [A-D] and entire piling operation
MP UB [A-D]	Single strike on monopile (16.0m) for upper-bound (UB) modelling at four separate depths [A-D] and entire piling operation
PPL BE [A-D]	Single strike on pin pile (5.3m dia.) for best estimate (BE) modelling at four separate depths [A-D] and entire piling operation
PPL UB [A-D]	Single strike on pin pile (5.3m dia.) for upper-bound (UB) modelling at four separate depths [A-D] and entire piling operation
PPS BE [A-D]	Single strike on pin pile (3.7m dia.) for best estimate (BE) modelling at four separate depths [A-D] and entire piling operation
PPS UB [A-D]	Single strike on pin pile (3.7m dia.) for upper-bound (UB) modelling at four separate depths [A-D] and entire piling operation
AG [MP/PPL/PPS] [BE/UB] C	Concurrent scenarios considering combined sound fields from two nearby piling operations for single strikes and entire piling operation
AG [MP/PPL/PPS] [BE/UB] F	Concurrent scenarios considering combined sound fields from two distant piling operations for single strikes and entire piling operation
V[1-4]	Underwater radiated sound from vessel for installation operations and other activities
HRG[1-6]	Radiated sound from high-resolution geophysical (HRG) surveys
UXO[1-4]	Clearance of UXO

2.1.1.4 Scenarios are modelled across two distinct environments. The best-estimate scenarios use inputs that are most representative across the site in terms of water depths and geoacoustic properties. The conservative or upper-bound sites are modelled using a combination of water depth and geoacoustic properties that are most likely to result in sound propagating further.

2.1.1.5 This section is organised as follows. A description of the source locations used in modelling is included in Section 2.2. The specifications of the proposed pile foundation designs and devised piling scenarios are outlined in Section 2.3 for single piling operations and Section 2.4 for concurrent piling operations. An outline of the vessel scenarios is shown in Section 2.5 and finally Sections 2.6 and 2.7 provide details of the geophysical survey sources and UXO scenarios.

2.2 Source locations

2.2.1.1 To determine representative and worst-case source locations for the piling, a short preliminary study was carried out that investigated the potential differences between different source locations and geoacoustic parameters (Appendix A).

2.2.1.2 Following the study, it was found that the minimum depth location generated slightly greater propagation ranges for the piling. Conversely, the maximum depth location is presumed to provide the conservative case for the vessel scenarios. A representative location that is typical of the water depths within the Morven North and Morven South boundaries, based on the median of all water depths in the zone, was also established. Details of these source locations are provided in Table 2.2 for Morven North and Table 2.3 for Morven South. All locations are shown in the map in Figure 2.1.

Table 2.2: Modelled source locations for Morven North

Location	Latitude (°)	Longitude (°)	Easting (m)	Northing (m)	Water depth (m)
Representative	56°44.235'N	0°58.534'W	623841	6290108	68.1
Minimum depth	56°42.954'N	0°55.893'W	626605	6287813	64.1
Maximum depth	56°40.691'N	1°02.677'W	619805	6283413	74.9

Spatial reference: ED50 UTM30N.

Table 2.3: Modelled source locations for Morven South

Location	Latitude (°)	Longitude (°)	Easting (m)	Northing (m)	Water depth (m)
Representative	56°32.992'N	0°41.721'W	641681	6269798	69.6
Minimum depth	56°35.044'N	0°43.850'W	639374	6273532	64.7
Maximum depth	56°31.852'N	0°31.942'W	651774	6268032	75.6

Spatial reference: ED50 UTM30N.

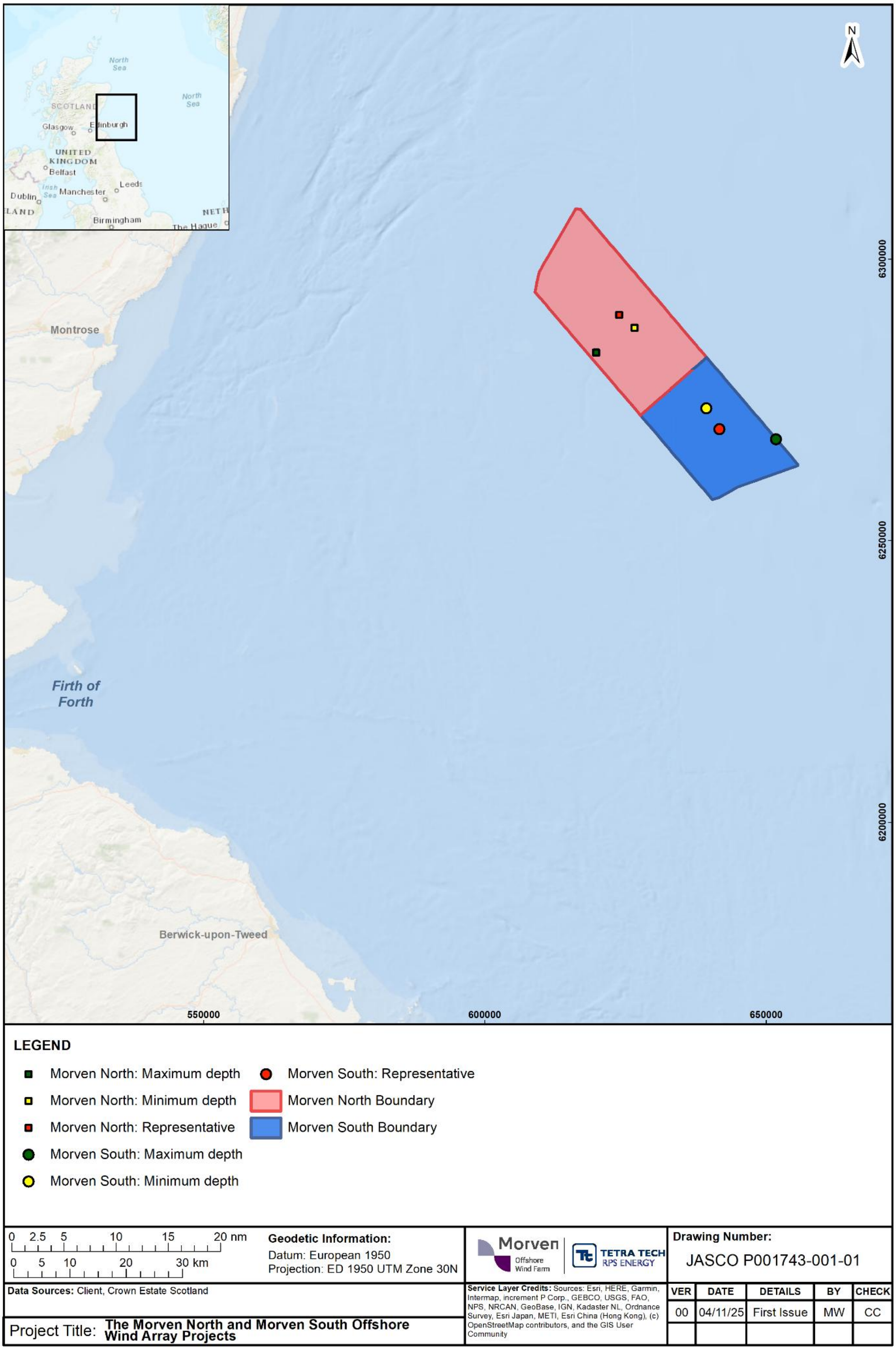

Figure 2.1: Source locations of activities modelled in this report for Morven North and Morven South

2.3 Impact piling scenarios

2.3.1 Pile geometries

2.3.1.1 A monopile foundation used for a wind turbine or an OSP is a single hollow cylinder fabricated from steel that is installed by pile-driving (hammering) it into the seabed. Following consideration of numerous potential pile designs, the selected pile is expected to generate the highest sound levels. The monopile modelled here was a 16m diameter structure (Table 2.4).

2.3.1.2 Piled jacket foundations used for wind turbines consist of a large lattice structure supported/secured by pin piles. The pin piles to secure the jacket structure for Morven North and Morven South are 3.7m and 5.3m diameter straight cylindrical steel piles. The dimensions of the considered piles are presented in Table 2.4.

Table 2.4 Pile dimensions for modelled scenarios

Parameter	16.0m Monopile	5.3m Pin pile	3.7m Pin pile
Top section length (m)	25	-	-
Top section outer diameter (m)	13	-	-
Conical section length (m)	30	-	-
Bottom section length (m)	95	-	-
Bottom section outer diameter (m)	16	5.3	3.7
Total length (m)	150	93	75
Wall thickness (cm)	18	11	11

2.3.2 Impact Hammers

2.3.2.1 Although the precise final details of hammer choice are not yet known, potential hammers have been identified. Due to there being no detailed driveability study for the sequences, the conservative case of maximum hammer energy throughout the sequence has been assumed. Table 2.5 shows the selection of hammers and associated parameters used in the modelling.

Table 2.5 Details of hammer and helmet weights in the modelling

Pile	Hammer model	Helmet weight (kN)	Hammer energy (kJ)
16m monopile	IQIP IQ6	4400	6600
5.3m pin pile	IQIP IQ6	4000	4500
3.7m pin pile	IHC S-4000	2255	4000

2.3.3 Modelled scenarios

2.3.3.1 The scenarios were developed to represent typical and conservative cases, referred to as Best Estimate (BE) and Upper Bound (UB), respectively, based on environmental inputs that influence design choices leading to the most likely and the highest levels of radiated sound. To this end, studies investigating the different source locations and geoacoustic profiles were carried out (Appendix A). Following this work, a representative case, comprising the median geoacoustic profile and median water depth location, and a conservative case, comprising the maximum geoacoustic profile and minimum water depth location, were defined for the study cases.

2.3.3.2 In addition to the environmental inputs, the amount of sound generated during pile driving varies with the energy required to drive piles to a desired depth and depends on the sediment resistance encountered. Sediment types with greater resistance require hammers that deliver higher energy strikes and/or an increased number of strikes relative to installations in softer sediment. For monopiles particularly, maximum sound levels usually occur during the last stage of impact pile driving where the greatest resistance is encountered (Betke 2008) and consequently, the highest hammer energy. Conversely for pin piles, whilst increased hammer energy results in more radiated sound, there is a countering effect as a reduction in the wetted length of the pile has been shown also to reduce sound levels (Lippert *et al.* 2017).

2.3.3.3 Driveability studies for representative monopile and pin pile cases were provided to JASCO by the Applicant (Kent Group PLC (2023)). These provide the anticipated blow count throughout the piling sequence for similar piles based on different hammer properties and soil assumptions.

2.3.3.4 To provide indicative results over the course of the piling sequence, four penetration depths for each pile are studied. The initiation and soft-start sections have been included for the moving receiver results as detailed in Section 4.8. Additionally, analyses have been performed both with and without an ADD 30 minutes prior to piling with details of the ADD provided in Section 4.2.2.

2.3.3.5 A summary of the modelled scenarios is presented in Table 2.6. The different penetration depths are labelled A through D from shallowest to deepest. The environments are denoted as UB or BE for the upper bound and best estimate environments respectively.

Table 2.6: Driving schedule for the considered pile designs

Modelled scenario	Pile	Location water depth	Geoacoustic profile	Analysis penetration depth (m)	Representative pen. depth range (m)	Pen. per blow (cm)	Strike count
MP UB A	16.0m monopile	Minimum	Maximum	8	1 to 15	1.30	1077
MP UB B				20	15 to 31	2.00	800
MP UB C				33	31 to 35	0.40	1000
MP UB D				50	35 to 64	0.40	7250
MP BE A		Median	Median	8	1 to 15	1.30	1077
MP BE B				20	15 to 31	2.00	800
MP BE C				33	31 to 35	0.40	1000
MP BE D				50	35 to 64	0.40	7250
PPL UB A	5.3m pin pile	Minimum	Maximum	9	1 to 17	1.80	894
PPL UB B				25	17 to 33	0.84	1905
PPL UB C				45	33 to 58	0.48	5208
PPL UB D				70	58 to 83	0.31	8065
PPL BE A		Median	Median	9	1 to 17	1.80	894
PPL BE B				25	17 to 33	0.84	1905
PPL BE C				45	33 to 58	0.48	5208
PPL BE D				70	58 to 83	0.31	8065
PPS UB A	3.7m pin pile	Minimum	Maximum	9	1 to 17	1.90	847
PPS UB B				25	17 to 33	0.82	1951
PPS UB C				39	33 to 45	0.52	2308
PPS UB D				55	45 to 66	0.36	5556
PPS BE A		Median	Median	9	1 to 17	1.90	847

Modelled scenario	Pile	Location water depth	Geoacoustic profile	Analysis penetration depth (m)	Representative pen. depth range (m)	Pen. per blow (cm)	Strike count
PPS BE B				25	17 to 33	0.82	1951
PPS BE C				39	33 to 45	0.52	2308
PPS BE D				55	45 to 66	0.36	5556

UB: Upper bound; BE Best estimate

2.4 Concurrent scenarios

2.4.1.1 During the construction of Morven North and Morven South, it is possible that there will be concurrent piling activities. Table 2.7 lists details of the scenarios where impact piling sound fields are combined to determine the potential impact of simultaneous operations.

2.4.1.2 The sound fields are combined presuming that the piling is not exactly synchronised such that the instantaneous sound pressure is no different than for a single pile. The total sound energy over the two operations, however, is accumulated.

2.4.1.3 To determine the range of possible impacts, both the largest and smallest separation distances are considered. The largest distances are taken as extremes within the Morven Site. The nearby piling cases consider the operations at the representative location and 1km to the northwest. Runs are performed for all three pile types and for both geoacoustic profiles. Locations for sources in the concurrent scenarios are listed in Table 2.8 for Morven North and Table 2.9 for Morven South.

Table 2.7: Overview of the concurrent piling scenarios assuming two piling operations at the same time

Scenario	Pile	Analysis	Proximity
AG MP BE C	16m monopile	Best estimate	Nearby
AG MP UB C	16m monopile	Upper bound	Nearby
AG MP BE F	16m monopile	Best estimate	Distant
AG MP UB F	16m monopile	Upper bound	Distant
AG PPL BE C	5.3m pin pile	Best estimate	Nearby
AG PPL UB C	5.3m pin pile	Upper bound	Nearby
AG PPL BE F	5.3m pin pile	Best estimate	Distant
AG PPL UB F	5.3m pin pile	Upper bound	Distant
AG PPS BE C	3.7m pin pile	Best estimate	Nearby
AG PPS UB C	3.7m pin pile	Upper bound	Nearby
AG PPS BE F	3.7m pin pile	Best estimate	Distant
AG PPS UB F	3.7m pin pile	Upper bound	Distant

UB: Upper bound; BE Best estimate

Table 2.8: Modelled source locations for the concurrent piling scenarios for Morven North

Scenarios	Source 1 Easting (m)	Source 1 Northing (m)	Source 2 Easting (m)	Source 2 Northing (m)
Nearby piling	626605	6287813	625898	6288520
Distant piling	616159	6308913	627674	6272263

Spatial reference: ED50 UTM30N.

Table 2.9: Modelled source locations for the concurrent piling scenarios for Morven South

Scenarios	Source 1 Easting (m)	Source 1 Northing (m)	Source 2 Easting (m)	Source 2 Northing (m)
Nearby piling	641681	6269798	640974	6270505
Distant piling	627674	6272263	655653	6263330

Spatial reference: ED50 UTM30N.

2.5 Vessel scenarios

2.5.1 Overview of vessel scenarios

2.5.1.1 Numerous vessels are anticipated to be operating throughout the construction phases of Morven North and Morven South. Whilst it is infeasible to model every configuration of vessel traffic over the construction phase, representative scenarios provide indications of the likely radiated sound fields given common situations.

2.5.1.2 Four vessel scenarios are defined (Table 2.10), each with its own combination of vessels and activities. As stated, whilst it may not directly reflect reality, they provide results representative of each of the operations. Further details of the acoustic characteristics of the vessels are provided in Section 4.3. All vessel scenarios are calculated for the conservative case of the high-reflectivity seabed (see Appendix A). Sections 2.5.2 to 0 define the vessel scenarios in more detail.

Table 2.10: Overview of vessel scenarios

Scenario	Description	Sources	Activity
V1	Foundation installation	Pile installation vessel	Dynamic positioning (DP)
		Jacket installation vessel	DP
		4 Tugs	Barge handling
		Guard vessel	Orbiting
V2	Wind turbine installation	Wind turbine installation vessel	DP
		Offshore support vessel	DP
		Guard vessel	Orbiting
V3	Cable laying	Trenching vessel	Trenching
		Cable lay vessel	DP

Scenario	Description	Sources	Activity
		Support vessel	DP
		Guard vessel	Orbiting
V4	Crew transfer	Crew transfer vessel	Transit to/from site

2.5.1.3 For the following scenarios, the locations relate to the maximum depth locations in Table 2.2 for Morven North and Table 2.3 for Morven South. The offsets listed specify the distance of the modelled location of a particular vessel relative to the maximum depth location.

2.5.2 V1: Foundation installation

2.5.2.1 The foundation installation scenario involves the pile installation vessel, the jacket installation vessel, four tugs, and a guard vessel. The installation vessels are close to the pile location and modelled using Dynamic Positioning (DP), the tugs are close to the piling site at low speed (3kts), and the guard vessel is 1km from the site at transiting speeds (10kts). Table 2.11 provides an overview of sources, activities, and locations.

Table 2.11: Overview of the foundation installation scenario

Source	Activity	Easting offset (m)	Northing offset (m)
Pile installation vessel	DP	0	0
Jacket installation vessel	DP	100	0
Tug 1	Barge handling	-100	25
Tug 2	Barge handling	-100	-25
Tug 3	Barge handling	-125	0
Tug 4	Barge handling	-75	0
Guard vessel	Orbiting	0	1000

2.5.3 V2: Wind turbine installation

2.5.3.1 The wind turbine installation scenario involves the wind turbine installation vessel, an offshore support vessel, and a guard vessel. The installation vessel and offshore support vessel are close to the pile location and modelled with DP is in use; the guard vessel is 1km from the site at transiting speeds (10kts). Table 2.12 provides an overview of sources, activities, and locations.

Table 2.12: Overview of the wind turbine installation scenario

Source	Activity	Easting offset (m)	Northing offset (m)
Wind turbine installation vessel	DP	0	0
Offshore support vessel	DP	-100	0
Guard vessel	Orbiting	0	1000

2.5.4 V3: Cable laying

2.5.4.1 The cable laying presumes a worst-case situation of trenching and cable laying being performed by two separate vessels. The sound sources comprise the trenching vessel and associated machinery, the cable laying vessel, and offshore support vessel, and a guard vessel. The cable laying vessel and offshore support vessel are modelled presuming DP is in use, and the guard vessel is 1km from the site at transiting speeds (10kts). The pile location is the representative site. Table 2.13 provides an overview of sources, activities, and locations.

Table 2.13: Overview of the cable laying scenario

Source	Activity	Easting offset (m)	Northing offset (m)
Trenching vessel	Trenching	-100	0
Cable laying vessel	DP	0	0
Offshore support vessel	DP	0	-100
Guard vessel	Orbiting	0	1000

2.5.5 V4: Crew transfer

2.5.5.1 The crew transfer scenario considers a single static vessel at the representative modelled location. Table 2.14 provides the scenario activity and location details.

Table 2.14: Overview of the crew transfer scenario

Source	Activity	Easting offset (m)	Northing offset (m)
Crew transfer vessel	Transiting	0	0

2.6 Geophysical source scenarios

2.6.1.1 A number of possible geophysical and geotechnical site investigations to be carried out at the site were identified by the Applicant along with potential source levels and frequency ranges. To determine cumulative effects of sound, further parameters determining the vessel speed and pulse repetition rate have been presumed. Given the limited propagation of these sources, they are modelled for the general case and not at a specific location. Those identified to have potential acoustic impact are listed in Table 2.15.

Table 2.15: High-resolution geophysical sources considered for modelling

Description	Source level (dB re 1μPa²m²)	Frequency range (kHz)
Multi-Beam Echo-Sounder (MBES)	180 – 240	200 – 500
Side-Scan Sonar (SSS)	216 – 228	200 – 700
Single-Beam Echo-Sounder (SBES)	180 – 240	120 – 400
Sub-Bottom Profiler (SBP): CHIRP	200 – 240	0.20 – 14.0
SBP: Pinger	200 – 235	2.00 – 7.00

Description	Source level (dB re 1μPa²m²)	Frequency range (kHz)
Ultra-High-Resolution Seismic (UHRS)	182	0.05 – 4.00

2.6.1.2 It is noted that the highest source levels listed for each device is not typically achievable across the entire stated frequency range. A review of available literature provided combinations of frequencies and source levels for each device that would result in the greatest radiated sound fields. Based on this review, the inputs were further refined and scenarios defined as shown in Table 2.16. Further details of this process are provided in Section 4.4.2.

Table 2.16: Overview of the high-resolution geophysical source scenarios

Scenario	Description	Source level (rms) (dB re 1μPa²m²)	Analysis frequency (kHz)
HRG1	MBES	240	100.0
HRG2	SSS	228	100.0
HRG3	SBES	230	20.0
HRG4	SBP: CHIRP (2kHz)	210	2.00
HRG5	SBP: CHIRP (3.5kHz)	232	3.50
HRG6	Sparker for UHRS	214	0.50

2.7 Unexploded ordnance clearance scenarios

2.7.1.1 The following scenarios define the identified possible cases of UXO clearance in the region. These comprise the worst-case of estimated largest charge, detonated without mitigation, through to clearing though deflagration. These are shown in Table 2.17.

Table 2.17: Overview of the Unexploded Ordnance clearance scenarios

Scenario	Description	Modelled explosive mass (kg)	Location
UXO1	Allied MK I Mine	554	Representative
UXO2	500lb Allied Anti-submarine bomb	132	Representative
UXO3	Smaller hazard	25	Representative
UXO4	Deflagration	0.25	Representative

3 Acoustic impact criteria

3.1 Overview

3.1.1.1 The underwater sound modelling presented in this report has been developed in accordance with the regulatory expectations of the Marine Directorate, the authority responsible for marine licensing and environmental protection in Scottish waters. The Marine Directorate requires that developers assess the potential impacts of underwater sound on marine species through comprehensive EIAs and HRAs, particularly for impulsive activities such as piling and UXO clearance. The modelling approach used here, including the application of species-specific thresholds for auditory injury and Temporary Threshold Shift (TTS), aligns with methodologies accepted by the Marine Directorate and reflects best practice in the sector. These assessments are essential to ensure that developments do not compromise the conservation objectives of designated sites or protected species.

3.1.1.2 This report also supports compliance with broader UK and devolved guidance, including the draft updated Sectoral Marine Plan for Offshore Wind Energy by the Scottish Government (2025), which outlines a strategic framework for sustainable offshore wind development in Scottish waters. The plan emphasises the importance of minimising environmental impacts whilst supporting Scotland's net zero ambitions. In-line with this, the modelling scenarios presented here are consistent with JNCC guidelines (JNCC, 2025a, 2025b). These documents advocate for the adoption of quieter installation techniques, such as the use of low-order deflagration for UXO clearance and for effective mitigation measures for piling, such as ADDs and soft start procedures, to reduce the spatial extent and severity of acoustic impacts. The inclusion of deflagration for explosives sounds sources such as UXO, and ADDs for impact piling in this report reflects current regulatory expectations and contributes to the evidence base required for licensing and consent in Scottish waters.

3.1.1.3 Underwater sound can affect marine fauna in several ways, and the criteria on which impact assessments are based can be complex. At least three primary severity levels for how sound affects marine fauna should be considered when assessing impacts: chronic and cumulative effects; auditory injury; and disturbance. Chronic and cumulative effects that affect the populations in the longer-term are hard to quantify, however, and evaluating them is complex; hence there is currently limited consensus on how to perform those assessments.

3.1.1.4 There are two categories of auditory threshold shifts or hearing loss:

- Permanent Threshold Shift (PTS): an irreversible loss of hearing sensitivity;
- TTS: a temporary reduction in an animal's hearing sensitivity.

3.1.1.5 Following recent guidelines for marine mammals, the PTS is considered within the wider bracket of Auditory Injury (AUD INJ), to cover trauma that is not directly related to the change in sensitivity thresholds. The impact criteria to be used represent the most recent guidance and best available science. More information on the acoustic metrics is presented in Appendix B. The following sections outline the specific thresholds used in this report for marine mammals and fish.

3.2 Marine mammals

3.2.1 Classification of sound

3.2.1.1 Studies have shown that the response of an animal to different sounds depends not only on the loudness, but also on the character of the sound. NMFS provides descriptors of the following categories:

- Characterisation for AUD INJ and TTS:
  - **Impulsive** sound sources produce sounds that are typically transient, less than one second, broadband, and comprise a high peak pressure with rapid rise and decay;

  - **Non-impulsive** sound sources can be continuous or intermittent, and produce sounds that can be broadband, narrowband, or tonal, and brief or prolonged. They do not have the high peak pressure and rapid decay associated with impulsive sounds.
- Characterisation for behavioural disturbance:
  - **Continuous** sound sources generate sound pressure levels that remain above ambient levels during the entire observation period;
  - **Intermittent** sound sources have interrupted levels of low or no sound or bursts of sound separated by silent periods.

3.2.2 Auditory injury and temporary threshold shift

3.2.2.1 Historical approaches to assessing the impact of sound on marine mammals considered solely root-mean-square (rms) Sound Pressure Level (SPL) without consideration of overall duration of the sound or its frequency content. However, since 2007, several expert groups have developed assessment approaches for evaluating auditory injury considering Sound Exposure Level (SEL) criteria for non-impulsive sounds and dual metric criteria considering both SEL and peak sound pressure level (PK) for impulsive sounds. Key works include Southall *et al.* (2007a), Finneran and Jenkins (2012), United States National Marine Fisheries Service (NMFS 2018) and Southall et al. (2019). The most recent accepted standards are the criteria set out by NMFS (2024a), and are used in this report to help assess the potential for the possible injury and hearing sensitivity changes in marine mammals, considering both TTS and AUD INJ.

3.2.2.2 For the assessment of radiated sound in marine mammals, NMFS (2024a) specifies dual auditory injury criteria considering both PK and cumulative SEL (SEL_{24h}); the subscript 24h indicates the duration of accumulation to be 24 hours. The PK criterion is not frequency-weighted, whereas the SEL criterion is frequency-weighted according to the appropriate marine mammal species hearing group.

3.2.2.3 Whilst there are no limits for non-impulsive explicitly stated, the guidance from NMFS states that if a non-impulsive sound has the potential of exceeding the peak sound pressure level criteria associated with impulsive sounds, the PK criteria are recommended for consideration of non-impulsive sources (NMFS 2024b).

3.2.2.4 Marine mammal hearing groups are defined for cetaceans, pinnipeds, sirenians and other marine carnivores, and further categorised based on the generalised frequency range of hearing. The marine mammal hearing groups defined in NMFS (2024a) under consideration are:

- Low-Frequency (LF) cetaceans; comprising all mysticetes (baleen whales).
- High-Frequency (HF) cetaceans; comprising odontocetes (toothed whales) including most delphinid species, beaked whales, sperm whales (*Physeter macrocephalus*), and killer whales (*Orcinus orca*).
- Very High-Frequency (VHF) cetaceans; comprising true porpoises and other odontocetes specialised at using very high frequencies (primarily 100kHz and above).
- Phocid Carnivores in Water (PCW); comprising all true seals including harbour seal (*Phoca vitulina*) and grey seal (*Halichoreus grypus*).

3.2.2.5 AUD INJ and TTS onset criteria from NMFS (2024a) are presented in Table 3.1 for impulsive and non-impulsive sound. Further information on marine mammal frequency-weighting functions is presented in Appendix C.

Table 3.1: Auditory injury and temporary threshold shift onset criteria for effects of impulsive sound on marine mammals from National Marine Fisheries Service (2024a)

Hearing Group	Impulsive				Non-impulsive	
	AUD INJ		TTS		AUD INJ	TTS
	Weighted SEL_{24h} (dB)	PK (dB)	Weighted SEL_{24h} (dB)	PK (dB)	Weighted SEL_{24h} (dB)	Weighted SEL_{24h} (dB)
Low-frequency (LF) cetaceans	183	222	168	216	197	177
High-frequency (HF) cetaceans	193	230	178	224	201	181
Very high-frequency (VHF) cetaceans	159	202	144	196	181	161
Phocid carnivores in water (PCW)	183	223	168	217	195	175

3.2.3 Disturbance

3.2.3.1 Numerous studies on marine mammal behavioural responses to sound exposure have not resulted in a consensus in the scientific community regarding an appropriate metric and associated levels for assessing behavioural reactions due to the complexity and variability of those reactions. However, it is recognised that the context in which the sound is received affects the nature and extent of responses to a stimulus (Southall *et al.* 2007a, Ellison and Frankel 2012, Southall *et al.* 2016).

3.2.3.2 Various means of assessing marine mammal behavioural responses to sound are being developed and are in use, including step function (all-or-none) thresholds, probabilistic response and dose-response relationships. On an internationally recognised regulatory level, National Oceanic and Atmospheric Administration (NOAA) Fisheries currently uses step function SPL thresholds to assess and regulate level B sound-induced behavioural impacts for marine mammals (NOAA 2019).

3.2.3.3 The recommended SPL thresholds for behavioural disturbances are shown in Table 3.2; as described, these are divided into intermittent sounds and continuous sounds. Whilst the work by Southall *et al.* (2021) provides recommendations and discusses the nuances of assessing behavioural response, the authors do not recommend alternative numerical thresholds for the onset of behavioural responses for marine mammals. The NOAA (2019) criteria for assessing behavioural responses to underwater sound has, therefore, been applied in this study.

Table 3.2: Underwater onset of behavioural disturbance acoustic thresholds

Source type	Behavioural threshold (dB)
Intermittent	160
Continuous	120

3.2.3.4 In addition to the SPL threshold, behavioural responses in harbour porpoises are estimated from the probability of disturbance as a function of sound level as recommended by Heinis et al. (2022). The curve relates the unweighted per-pulse SEL from piling to a probability of response. The dose-response curve is shown in Figure 3.1. Additionally, distances to the unweighted 143dB per-pulse SEL are provided based on the generalised threshold for porpoise reactions to impact piling pulses from Brandt *et al.* (2018).

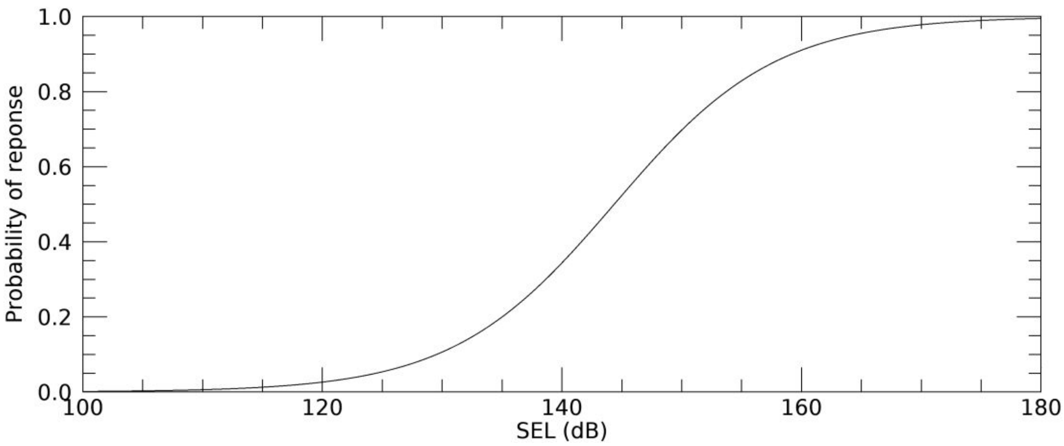

Figure 3.1: Dose-response relationship for the disturbance of harbour porpoises by piling sound. Per-pulse sound elevated levels in dB re 1µPa²s

3.3 Fish (adults, eggs, and larvae)

3.3.1.1 In 2006, the Working Group on the Effects of Sound on Fish and Turtles, sponsored by the Acoustical Society of America, was formed to continue developing sound exposure criteria for fish and sea turtles. The guidelines developed by this working group (Popper et al. 2014) provide received sound levels based on the best available science that are suitable as provisional criteria for assessing onset of injury to fish from various sources.

3.3.1.2 Popper *et al.* (2014) categorise fish into different groups based on their hearing capabilities, which are typically determined by whether a swim bladder is present and, if it is, whether it is directly used in hearing. Thus, different thresholds are proposed for the following categories:

- Group 1: fish without a swim bladder (also appropriate for sharks and applied to whale sharks in the absence of other information).
- Group 2: fish with a swim bladder not used for hearing.
- Groups 3 and 4: fish that use their swim bladders for hearing, where the swim bladder is either close to or mechanically linked to the ear for group 3 and group 4, respectively (Hawkins and Popper 2017).
- Fish eggs and fish larvae.

3.3.1.3 Popper *et al.* (2014) proposed criteria for impact pile driving and explosions which are outlined for the following effects:

- mortality and potential mortal injury;
- recoverable injury (including injuries unlikely to result in mortality, such as hair cell damage and minor haematoma);
- TTS;
- masking;
- behaviour.

3.3.1.4 Where numerical thresholds are not defined, risks of effect are instead assessed qualitatively with relative risk rather than specific sound level thresholds. Risks are assessed subjectively based on the proximity of the receiver to the source as either near (tens of metres), intermediate (hundreds of metres), or far (thousands of metres). Risks are then categorised as high, moderate, or low.

3.3.1.5 A summary of the injury and impairment criteria is presented in Table 3.3 for piling and Table 3.4 for explosions. Effects considered qualitatively by relative risk, including masking and behavioural response, are not considered in this report and those shown in Table 3.3 and Table 3.4 for fish eggs and fish larvae are presented for completeness only.

Table 3.3: Injury and impairment criteria for effects of pile driving sound on fish from Popper *et al.* (2014)

<table>
<tr><th rowspan="3">Fish group</th><th colspan="2" rowspan="2">Mortality and potential mortal injury</th><th colspan="3">Impairment</th></tr>
<tr><th colspan="2">Recoverable injury</th><th>TTS</th></tr>
<tr><th>SEL_{24h} (dB re 1µPa²s)</th><th>PK (dB re 1µPa)</th><th>SEL_{24h} (dB re 1µPa²s)</th><th>PK (dB re 1µPa)</th><th>SEL_{24h} (dB re 1µPa²s)</th></tr>
<tr><td>Group 1</td><td>>219</td><td>>213</td><td>>216</td><td>>213</td><td>≫186</td></tr>
<tr><td>Group 2</td><td>210</td><td>>207</td><td>203</td><td>>207</td><td>>186</td></tr>
<tr><td>Group 3 & 4</td><td>207</td><td>>207</td><td>203</td><td>>207</td><td>186</td></tr>
<tr><td>Fish eggs, and fish larvae</td><td>> 210</td><td>>207</td><td colspan="3">Near: Moderate
Intermediate: Low
Far: Low</td></tr>
</table>

Table 3.4: Injury and impairment criteria for effects of explosive sound on fish from Popper *et al.* (2014)

<table>
<tr><th rowspan="3">Fish group</th><th rowspan="2">Mortality and potential mortal injury</th><th colspan="2">Impairment</th></tr>
<tr><th>Recoverable injury</th><th>TTS</th></tr>
<tr><th>PK (dB re 1µPa)</th><th></th><th></th></tr>
<tr><td>Group 1</td><td>229-234</td><td>Near: High
Intermediate: Low
Far: Low</td><td>Near: High
Intermediate: Moderate
Far: Low</td></tr>
<tr><td>Group 2</td><td>229-234</td><td>Near: High
Intermediate: High
Far: Low</td><td>Near: High
Intermediate: Moderate
Far: Low</td></tr>
<tr><td>Group 3 & 4</td><td>229-234</td><td colspan="2">Near: High
Intermediate: High
Far: Low</td></tr>
<tr><td>Fish eggs, and fish larvae</td><td>>13 mm/s peak velocity</td><td colspan="2">Near: High
Intermediate: Low
Far: Low</td></tr>
</table>

4 Methods

4.1 Environmental parameters

4.1.1 Bathymetry

4.1.1.1 High-resolution bathymetric data within the Morven Site was provided to JASCO. As sound will propagate beyond the region of the Morven Site, this dataset has been supplemented and extended with bathymetry from the EMODnet Digital Terrain Model. The EMODnet DTM provides water depths in gridded form over whole of the European maritime region on a grid of 1/16 × 1/16 arc minutes (ca. 115 metre grid).

4.1.1.2 Bathymetry for a 348 × 352km² area were extracted and re-gridded along with the high-resolution data onto a Universal Transverse Mercator (UTM) Zone 30 coordinate projection (Datum: ED50) with a regular grid spacing of 50m in easting and northing for modelling. The bathymetry used in the modelling is shown in Figure 4.1.

4.1.2 Sound speed profile

4.1.2.1 The water column Sound Speed Profile (SSP) is a function of pressure (depth) and changes in water temperature and salinity over depth, which vary between seasons. A worst-case sound speed profile was chosen to generate the most conservative estimates of acoustic impact ranges. For this modelling study, a winter sound speed profile was chosen. In winter the water column is well mixed and the temperature is broadly the same (isothermal) across the water column, leading to a sound speed profile which is upwardly refracting. This leads to sound propagation over greater distances by reducing the extent of interaction with the seabed and reducing attendant scattering, absorption and refractive losses.

4.1.2.2 The sound speed profile for the modelling study was derived from temperature and salinity profiles from the US Naval Oceanographic Office's Generalized Digital Environmental Model V 3.0 (GDEM; Teague *et al.* 1990, Carnes 2009). GDEM provides an ocean climatology of temperature and salinity for the world's oceans on a latitude-longitude grid with 0.25° resolution, with a temporal resolution of one month, based on global historical observations from the US Navy's Master Oceanographic Observational Data Set (MOODS). The GDEM temperature-salinity profiles were converted to sound speed profiles according to Coppens (1981). A mean sound speed profile for December was derived from the GDEM profiles; the SSP used throughout the project is shown in Figure 4.2.

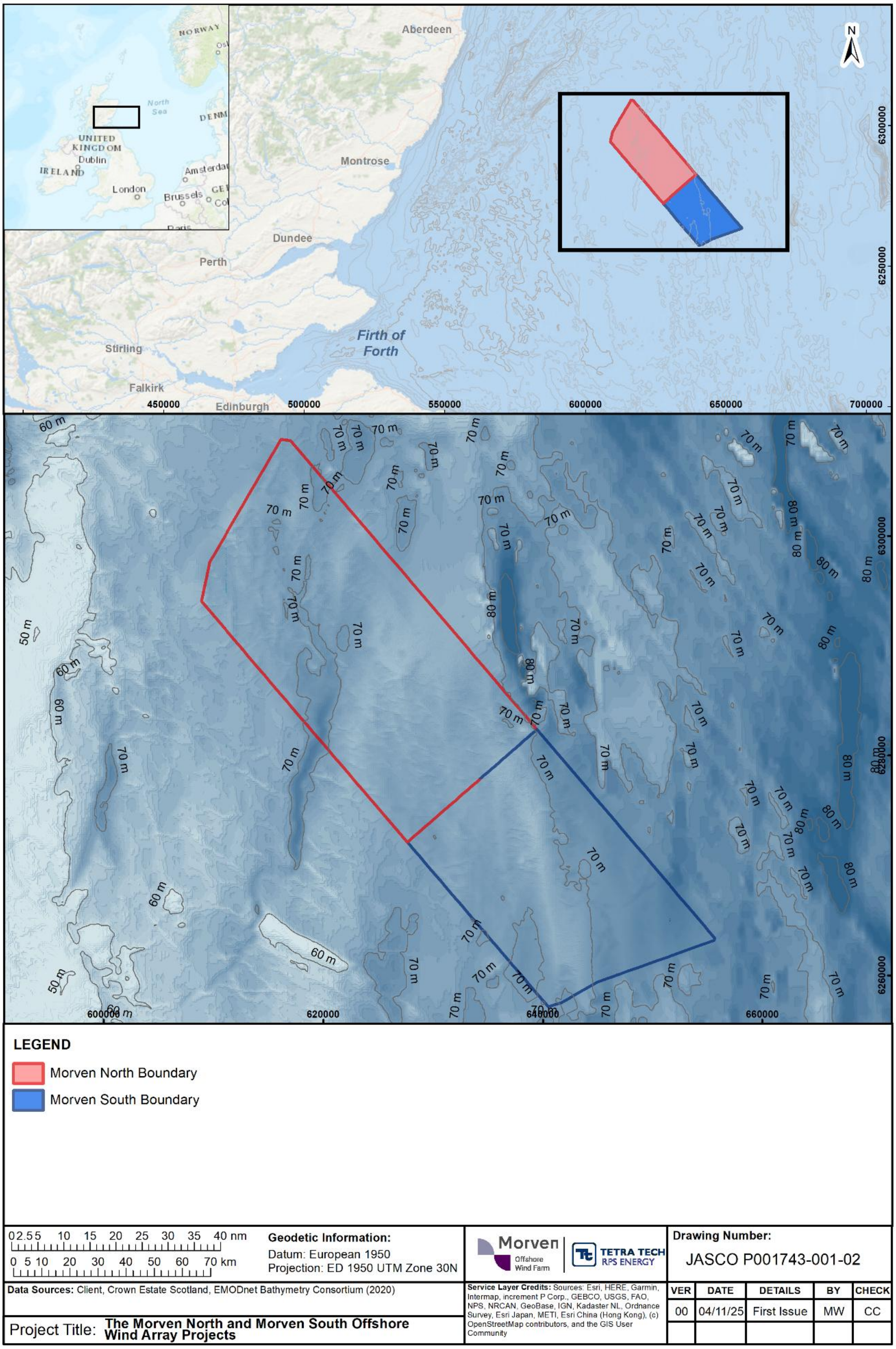

Figure 4.1: Bathymetry of the modelled domain

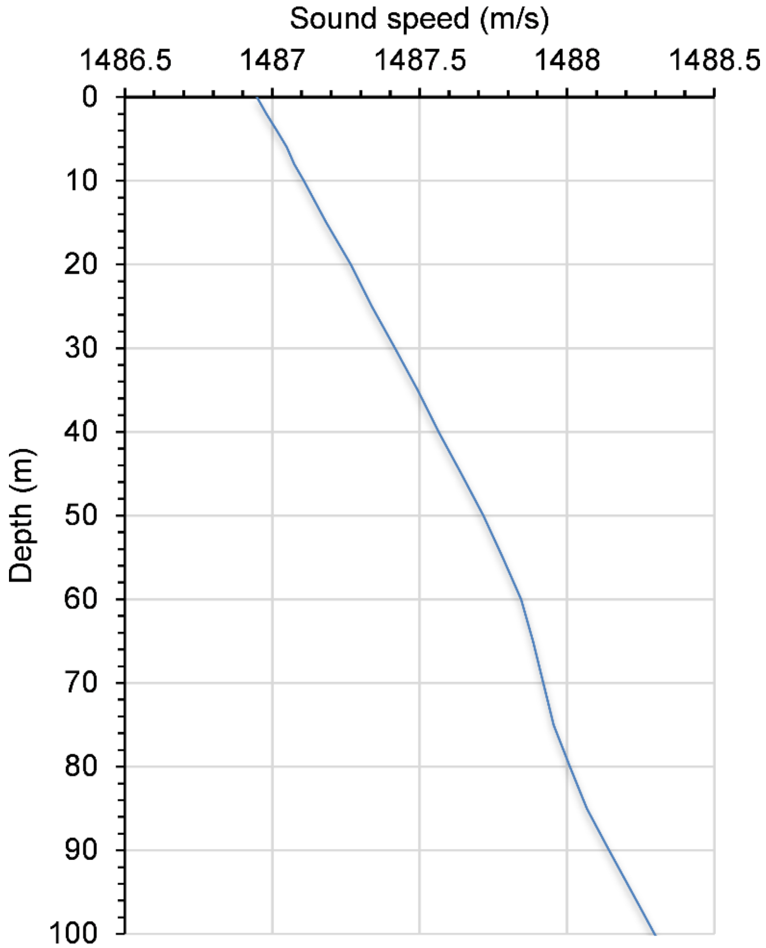

Figure 4.2: Sound speed profile for December used throughout modelling

4.1.3 Geoacoustics

4.1.3.1 The makeup of the seabed dictates both how sound is reflected from it and how sound is transmitted through it. The geoacoustic profile provides details of the density, compressive wave speeds and attenuations, and shear wave speeds and attenuations.

4.1.3.2 Geoacoustic profiles were generated based on data provided to JASCO of 13 boreholes across the Morven Site. The data were digitised, with density and wave speed characteristics determinable directly from the data. Using this data, three profiles were generated: minimum reflectivity, median reflectivity, and maximum reflectivity profiles (Appendix A.3). It is anticipated that, for the general case, the maximum reflectivity geoacoustic profile will result in the greatest sound propagation.

4.1.3.3 The parameters of compressive and shear wave speed attenuation were calculated using equations from Hamilton (1980) to produce sound speed profiles of unconsolidated elements. The profiles were further extended with bedrock of chalk with parameters from Jensen *et al.* (2011). The sound propagation model used considers only shear wave parameters at the seabed, hence the shear wave parameters are constant through all modelled sediment layers.

4.1.3.4 To provide representative and conservative results, modelling has been limited to using the median and maximum reflectivity geoacoustic profiles; these are shown in Table 4.1 (median profile) and Table 4.2 (maximum profile) and in Figure 4.3.

Table 4.1: Median geoacoustic profile for the acoustic modelling. Each parameter varies linearly within the stated range

Depth below seafloor (m)	Density (g/cm^3)	Compressional wave		Shear wave	
		Speed (m/s)	Attenuation (dB/λ)	Speed (m/s)	Attenuation (dB/λ)
0-2	2.01-2.01	1534-1624	0.72-0.77	191	3.65
2-7	2.01-1.99	1624-1673	0.77-0.80		
7-33	1.99-2.10	1673-1805	0.80-0.80		
33-40	2.10-2.10	1805-1967	0.80-0.87		
40-52	2.10-2.09	1967-2027	0.87-0.90		
52-80	2.09-2.20	2027-2261	0.90-0.92		
80+	2.20	2400	0.20		

Table 4.2: Maximum geoacoustic profile for the acoustic modelling. Each parameter varies linearly within the stated range

Depth below seafloor (m)	Density (g/cm^3)	Compressional wave		Shear wave	
		Speed (m/s)	Attenuation (dB/λ)	Speed (m/s)	Attenuation (dB/λ)
0-3	2.14-2.12	1571-1771	0.67-0.77	191	3.65
3-32	2.12-2.37	1771-1978	0.77-0.69		
32-56	2.37-2.23	1978-2894	0.69-1.15		
56-68	2.23-2.29	2894-2479	1.15-0.93		
68-80	2.29-2.38	2479-2558	0.93-0.87		
80+	2.20	2400	0.20		

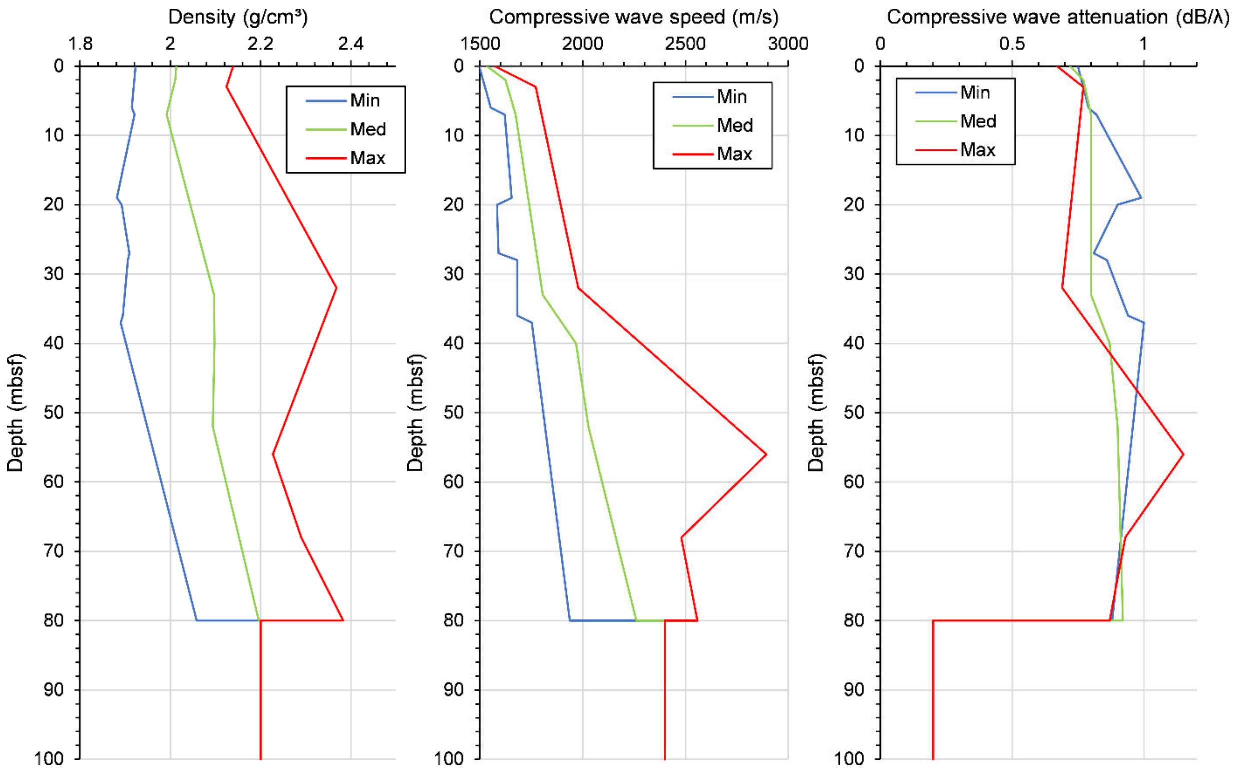

Figure 4.3: Geoacoustic profiles of density (left), compressive wave speed (centre), and compressive wave attenuation (right) derived from borehole data. Note that the minimum profile is not used in the modelling

4.2 Impact pile driving

4.2.1 Pile source modelling

4.2.1.1 Piles deform when driven with impulsive impact hammers, creating a bulge that travels down the pile and radiates sound into the surrounding air, water and seabed. This sound may be received as a direct transmission from the sound source to biological receivers (such as marine mammals and fish) through the water, or as the result of reflected paths from the surface or re-radiated into the water from the seabed. Sound transmission depends on many environmental parameters, such as the sound speeds in water and substrates, sound production parameters of the pile and how it is driven, including the pile material and size (length, diameter, and thickness), and the design and energy of the hammer.

4.2.1.2 It has been shown that the pile as a sound source cannot be treated as a single point source, but sound radiated down the length of the pile and the distinctive directivity of the source must be reproduced for accurate results (Wood *et al.* 2023). JASCO's physical model of pile vibration and near-field sound radiation (MacGillivray 2014) was used in conjunction with the GRLWEAP 2010 wave equation model (GRLWEAP; Pile Dynamics 2010) to predict source levels associated with impact pile driving activities that reproduce the piling-specific sound field. The sound radiating from the pile itself was simulated using a vertical array of discrete point sources. These models account for several parameters that describe the pile design (type, material, size and length), the pile driving equipment and approximate pile penetration depth.

4.2.1.3 Forcing functions were computed for the monopile and piled jacket foundation scenarios using GRLWEAP (Pile Dynamics 2010). The forcing functions serve as the inputs to JASCO's Pile Driving Source Model (PDSM) used to estimate equivalent acoustic source characteristics; the model is detailed in Appendix D. Decidecade spectral levels close to the pile for each pile are presented in Sections 5.2.2 and 6.2.2 for Morven North and Morven South respectively.

4.2.2 Acoustic Deterrent Device modelling

4.2.2.1 ADD are routinely deployed prior to underwater piling operations in the North Sea, particularly in the context of offshore wind farm construction. Their primary function is to reduce the risk of auditory injury to marine mammals by encouraging them to vacate the vicinity of the piling site before piling commences. The devices emit a series of pulsed sounds at frequencies and amplitudes designed to be aversive to species such as harbour porpoises and seals. Deployment protocols typically require ADD activation for a specified duration (often 15 to 30 minutes) prior to the commencement of piling, in accordance with marine licensing conditions and mitigation guidelines issued by regulatory bodies such as the Marine Directorate.

4.2.2.2 The cumulative piling scenarios in this report are considered for the cases of not using an ADD before piling and for using an ADD for 30 minutes prior to piling. For the purpose of modelling, the model selected as a representative ADD was the OTAQ Sealfence. The device features different modes of operation; calculations were performed presuming the device to be in normal mode.

4.2.2.3 The signal of the Sealfence in normal mode comprises rapid trains of tonal bursts, where each pulse train is separated by a randomly determined duration of between 3 and 9 seconds. For modelling, this duration was fixed at 6 seconds between pulse trains. The principal frequency is 10kHz with a broadband energy source level of 162.7dB re 1μPa²m²s per pulse within the train; each train in Normal mode comprises 67 pulses giving an energy source level over the pulse train of 181.0dB re 1μPa²m²s. Figure 4.4 shows the source SEL in decidecade bands for Normal and Patrol modes.

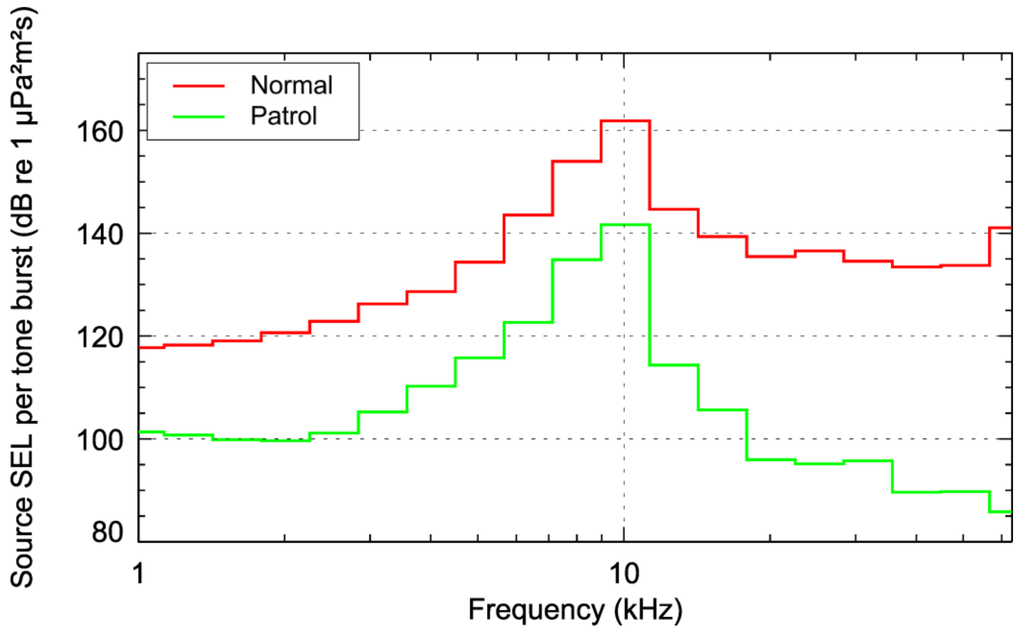

Figure 4.4: Energy source levels of a single tone burst from the Sealfence Acoustic Deterrent Device in Normal and Patrol modes

4.2.2.4 The source position of the ADD was at the respective pile location at a source depth of 15m; in the concurrent pile scenarios, each pile has its own ADD.

4.3 Vessel scenarios

4.3.1 Vessels using dynamic positioning

4.3.1.1 Sound source levels for vessels using DP are based on recorded sound levels of the Siem Sapphire (91m long, 22m wide) also operating under DP. These levels are used for the support vessel anticipated to be operating similarly under DP.

4.3.1.2 It is noted that the pile installation vessels required are likely to be substantially larger than the proxy vessel. To account for the increase in power required, and consequently radiated sound, the acoustic source levels are adjusted based on a suitable proxy vessel, the Bokalift 2 at 231m long, 49m wide.

4.3.1.3 The surrogate spectra were corrected by the power ratings of the target and reference vessels using:

$$S(f,P) = S_0(f) + 10log_{10}\left(\frac{P}{P_0}\right)$$

where S_0 is the reference spectrum and P_0 is the reference power rating.

4.3.1.4 The onboard power of the Siem Sapphire is 18,560kW compared to 34,560kW for the Bokalift 2. This provided a scaling factor of 2.7dB to convert Siem Sapphire source levels to those the larger vessel. The resulting source spectra of the support vessel and the installation vessel are shown in Figure 4.5.

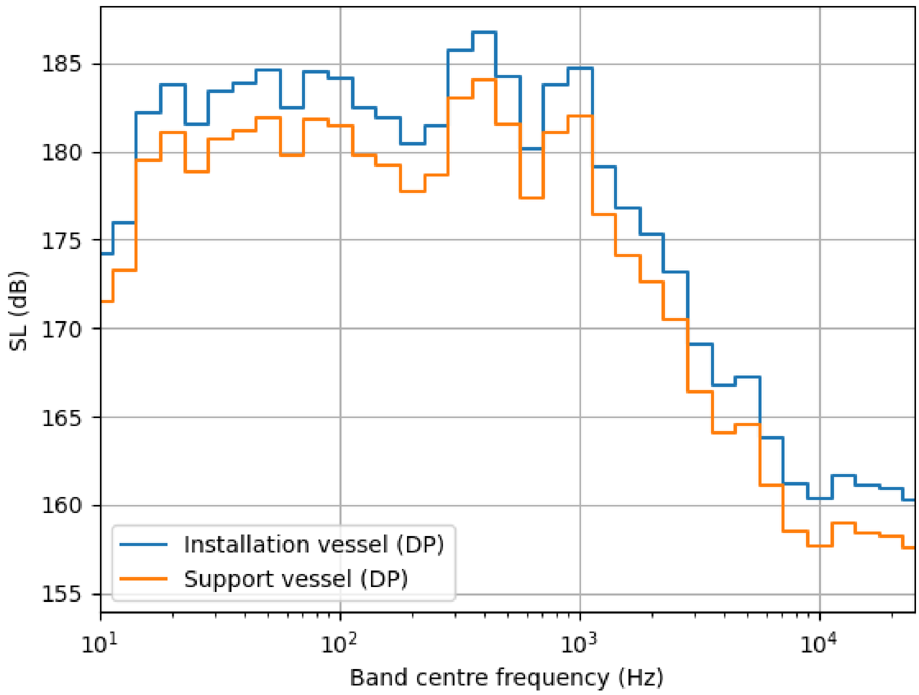

Figure 4.5 Source levels in dB re 1µPa²m² of the vessels on Dynamic Positioning

4.3.2 Vessels under normal propulsion

4.3.2.1 The source levels for vessels under standard propulsion were generated using the JOMOPANS-ECHO source level model (MacGillivray and de Jong 2021). The JOMOPANS-ECHO source level model provides a reference spectrum model that retains the power-law dependence on speed and length but incorporates class-specific reference speeds and new spectrum coefficients. The model calculates the ship source level spectrum, in decidecade bands, as a function of frequency, speed, length, and AIS ship type. The statistical uncertainty in the predicted source level spectra using the JOMOPANS-ECHO model reported in the text is estimated to be 6dB.

4.3.2.2 Table 4.3 shows the inputs used for the model for each vessel. The resulting source spectra for these vessels are shown in Figure 4.6.

Table 4.3: Vessel parameters used to generate source levels using the JOMOPANS-ECHO source level model

Vessel	Category	Length (m)	Draught (m)	Speed (kts)	Broadband SL (dB)
Tug	Tug	32	5	3	153.2
Guard vessel	Other	30	4	3	137.6
Crew transfer vessel	Other	24	4	10	167.0

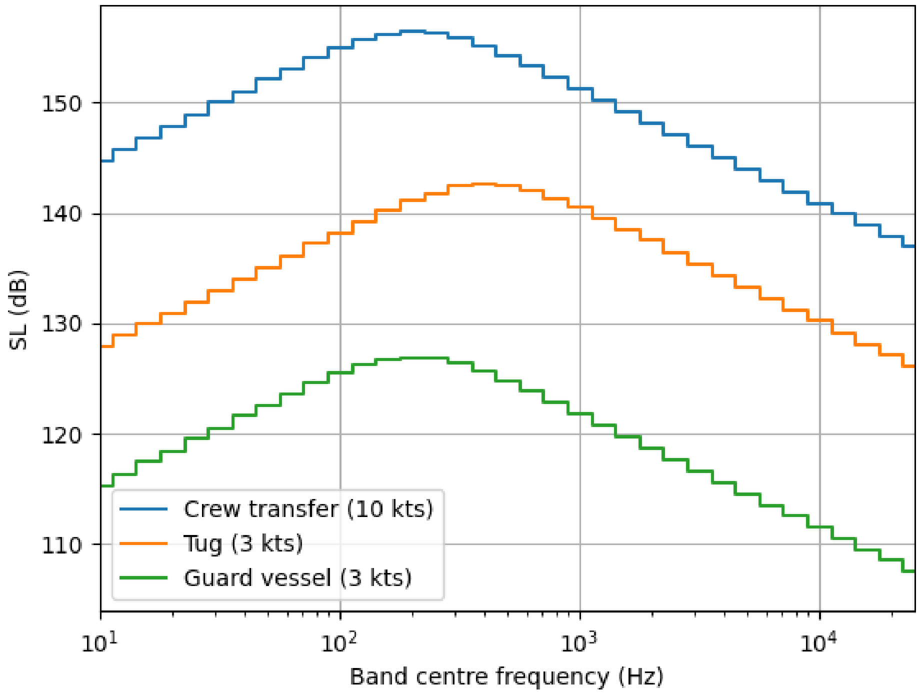

Figure 4.6 Modelled source levels of vessels operating under normal propulsion

4.3.3 Trenching

4.3.3.1 Source levels for the trenching vessel are based on cutter suction dredgers to provide conservative estimates where the ground cannot be presumed to be globally comprising soft sediments.

4.3.3.2 Several acoustic measurements of hydraulic dredgers have been published. The spectrum used for the cable laying scenario represents that of a cutter suction dredger without a propulsion system. It is based on 13 spectra published by Robinson *et al.* (2011), by JASCO (Hannay *et al.* 2004), and by Malme *et al.* (1989).

4.3.3.3 Source levels below 1000Hz in the spectrum are based on smaller hydraulic dredgers and dredgers that were not using their propulsion system during measurements, to minimise the acoustic component associated with the vessel. Source levels above 1000Hz in the final spectrum, i.e., the sound component associated with sediment disintegration and manipulation, are based on the maximum values of all spectra studied.

4.3.3.4 Figure 4.7 shows the source spectrum for the trenching vessel in the modelling.

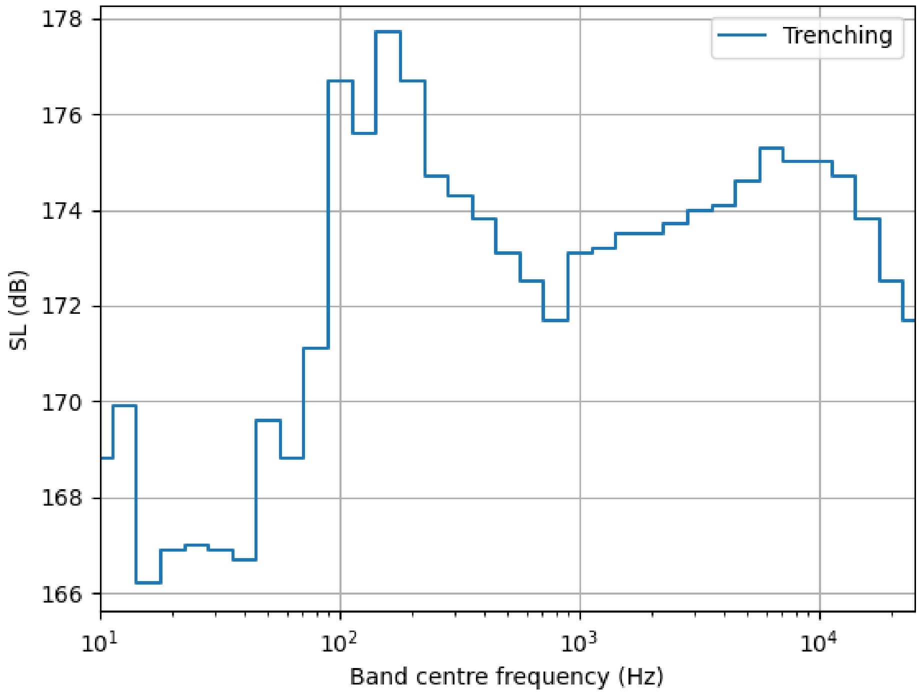

Figure 4.7: Source level spectrum for the trenching vessel

4.4 Geophysical source modelling

4.4.1 Propagation calculations

4.4.1.1 In this analysis, we compute horizontal impact ranges for High-Resolution Geophysical (HRG) sound sources. We consider both the contribution from the main lobe (in-beam) energy of the source, which is directed toward the seafloor, as well as side lobe (out-of-beam) energy that propagates horizontally (see Figure 4.8). The larger of these two is the distance reported.

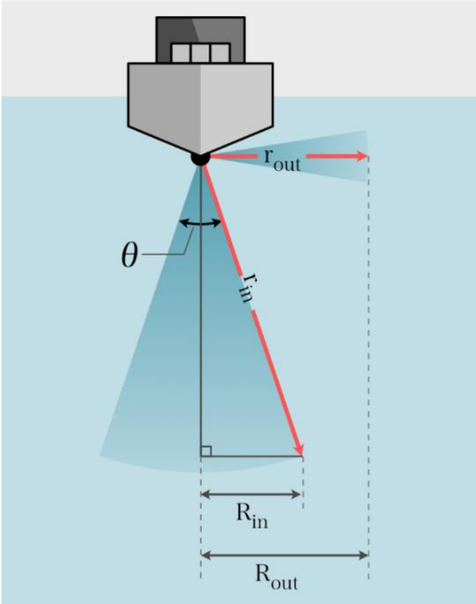

Figure 4.8: Geometry used in computing horizontal impact ranges based on in-beam and out-of-beam energy

4.4.1.2 Our methodology for computing the horizontal component of the main lobe follows the approach described by NMFS (2019) and Guan (2020). For computing the horizontal extent of side lobe energy, we start with a lower source level and assume that the sound energy propagates horizontally. Propagation loss in both cases is estimated using a modified spreading equation.

4.4.1.3 Side lobe energy is generally lower than the main lobe energy. An estimate of the reduction relative to the main lobe energy was generated as a function of the main lobe beam width. Separate approaches were taken for narrow-beam sources (up to 36° beam width), intermediate-beam sources (36° to 90° beam width), and broad-beam sources. Broad-beam sources were treated as omni-directional and had no out-of-beam reduction. The out-of-beam reduction for narrow-beam sources was approximated using a theoretical beam pattern. The out-of-beam reduction for intermediate-beam sources was interpolated between the other two approximations.

4.4.1.4 Full details of the methods used to model these sources is provided in Appendix D.2. Appendices D.2.4 and D.2.5 describe how the distances to AUD INJ thresholds and unweighted behavioural thresholds are determined. It should be noted that all studied HRG sources are categorised as intermittent sources (as opposed to continuous); consequently, the sound level threshold to behavioural response is 160dB re 1μPa^2 (Section 3.2.3).

4.4.1.5 For the cumulative assessment of HRG sources, we consider the total radiated sound over the course of a single track. This takes into account the device pulse length and ping rate, as well as the vessel speed. Cumulative sound levels are frequency-weighted accordingly and the total received SEL calculated at distances from the survey line.

4.4.2 Input parameters

4.4.2.1 A number of geophysical and geotechnical site investigations involving acoustic sources to be carried out at the site was identified as listed in Table 2.15. To determine the worst-case impacts of devices likely to be used in operations whilst not generating unrealistic sets of parameters, a review of available devices and operating conditions was carried out. It is important to note that, for a given sound source level, it requires more energy to drive a transducer at lower frequencies than higher frequencies. Consequently, the higher source levels are always associated with those transducer generating signals into the 10s of kHz. An example of a review of these types of sources is shown in Figure 4.9.

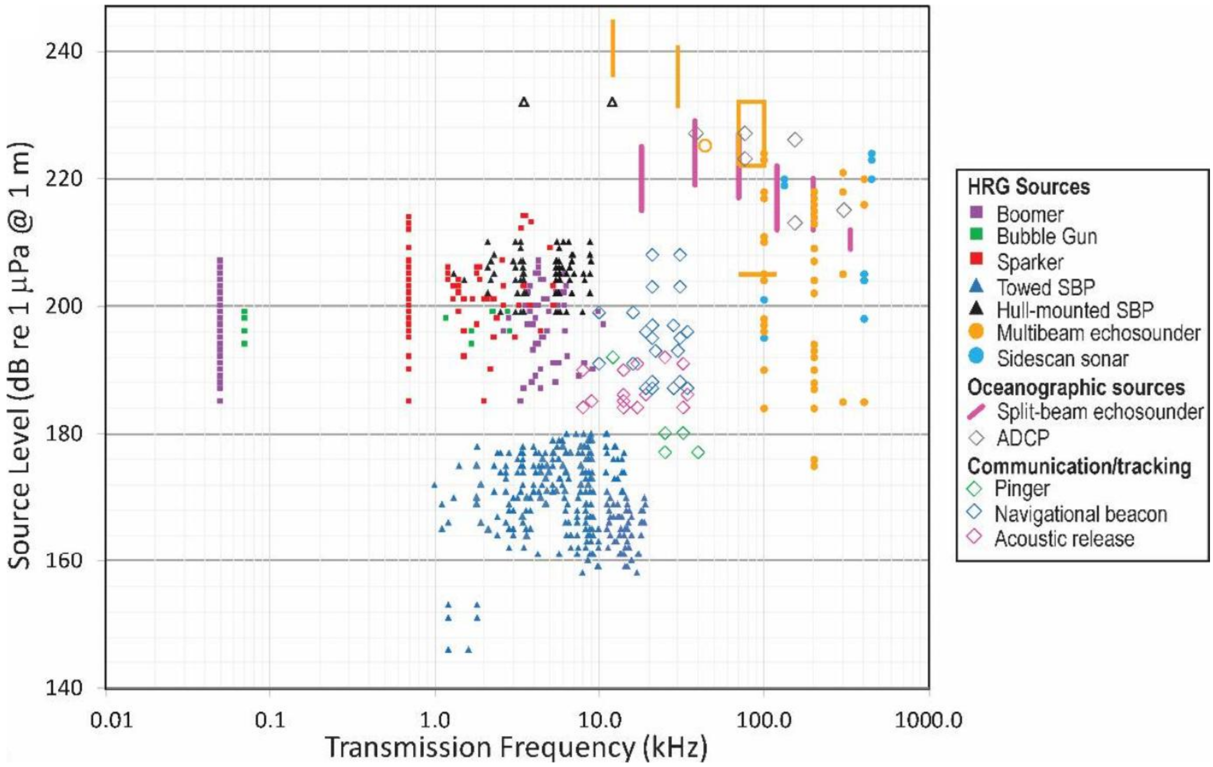

Figure 4.9: Plot of source level against operating frequency for geophysical acoustic sources reproduced from Ruppel *et al.* (2022)

4.4.2.2 Based on existing studies into different geophysical sources, we considered the set of parameters shown in Table 4.4. The lower bound of the frequency range is used for assessment due to the lower rates of absorption. Source levels, beam widths, pulse durations, and ping rates are selected as being appropriate for the source and frequency. For the calculation of cumulative metrics, the survey vessel is presumed to be travelling at 3.5kts.

Table 4.4: High-resolution geophysical sources

Device	SL rms (dB)	SL Peak (dB)	Operating frequency (kHz)	Beam width	Pulse duration (ms)	Ping rate (Hz)	Signal type
MBES	240	246	100.0	150°	100	0.2	Intermittent, non-impulsive
SSS	228	234	100.0	50°	1.0	80	Intermittent, non-impulsive
SBES	230	236	20.0	10°	8	1	Intermittent, non-impulsive
SBP CHIRP	210	216	2.00	Omni.	64	1	Intermittent, non-impulsive
SBP CHIRP	232	238	3.50	90°	64	1	Intermittent, non-impulsive
Sparker for UHRS	214	221	0.50	Omni.	3	4	Intermittent, impulsive

4.5 Explosives source modelling

4.5.1 Modelling methods

4.5.1.1 When explosives are detonated underwater, the explosive material converts rapidly from solid to gaseous form. Because the initial volume of gas occupies the same volume as the solid, it is under extreme pressure. This pressure is transmitted to the water as a pressure wave that initially propagates outward as a shock wave but transitions to a regular acoustic wave within some tens of metres from the source position for small charges. The high-pressure gas bubble begins to expand and eventually overshoots the volume corresponding with ambient pressure. At this point, the pressure becomes negative relative to ambient. The bubble expansion slows, eventually reversing. The collapsing bubble again crosses equilibrium pressure and eventually reaches a second minimum volume that corresponds with a pressure maximum referred to as the first bubble pulse. This oscillatory behaviour continues, with successively lower pressure pulses as energy is lost to heat transfer to the water, viscous drag, and acoustic emissions. In very shallow water detonations, the bubble may break the surface whilst it is still oscillating losing some of its energy to the atmosphere.

4.5.1.2 In this modelling assessment, the blast signature included the empirical exponentially decaying model for an underwater blast (Gaspin 1983, Richardson *et al.,* 1995), as well as contributions from subsequent bubble expansion-contraction cycles. The process to generate the source function is described in Appendix D.3.

4.5.2 Input parameters

4.5.2.1 Scenarios UXO1 to UXO4 describe the generated sound fields due to detonating unexploded ordnance. Scenarios UXO1 to UXO3 describe the detonations of the explosives themselves of equivalent TNT weights of 554kg, 132kg, and 25kg respectively. Scenario UXO4 describes the sound field from deflagration of the UXO using a much smaller doner charge of 0.25kg.

4.5.2.2 For the UXO scenarios describing the sound fields from the explosions themselves, the charge weight is used directly as the input to the source model described in Appendix D.3.For the deflagration case, it has been shown that the radiated sound agrees with that of the doner charge weight rather than the explosive itself.

4.5.2.3 Figure 4.10 shows the sound source signature for the four scenarios respectively as used in the modelling. The signature is the equivalent source signature required to generate the equivalent beyond the shock wave distance.

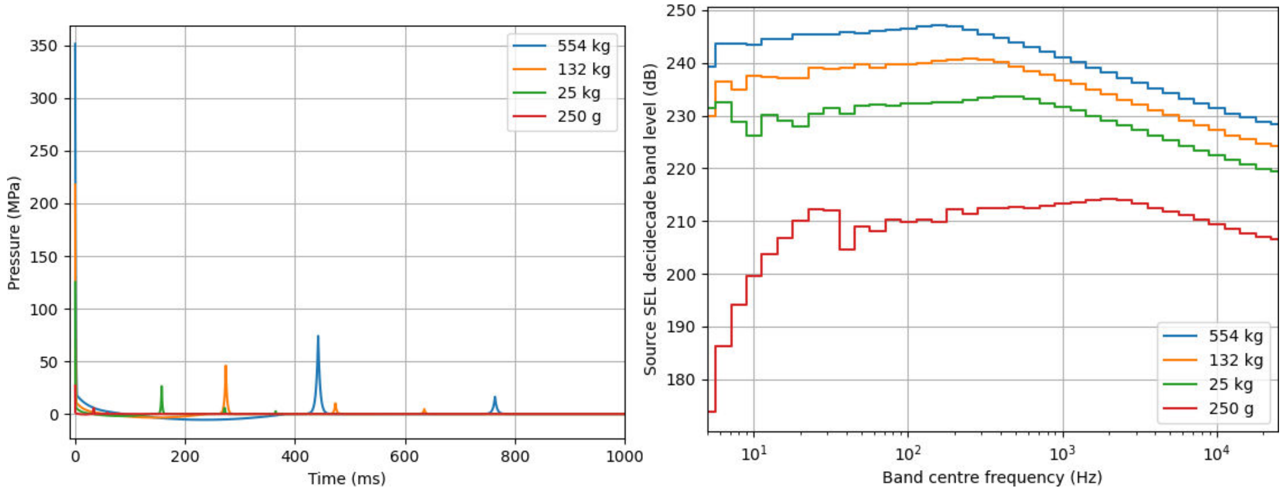

Figure 4.10: Source signatures of the unexploded ordnance scenarios in time domain (left) and in decidecade bands (right)

4.5.2.4 The peak source level, the energy source level, and the transition point from shock wave to linear acoustic wave of each source are shown in Table 4.5.

Table 4.5: Peak sound pressures and maximum shock wave distances for Unexploded Ordnance scenarios

Scenario	Equivalent TNT weight (kg)	Shock wave limit (m)	Equivalent source peak sound pressure (MPa)
UXO1	554	39.1	351.2
UXO2	132	24.2	217.9
UXO3	25	13.9	125.1
UXO4	0.25	3.0	26.9

4.6 Sound propagation modelling

4.6.1 Overview

4.6.1.1 For all sources, the calculation of radiated sound from a single source comprises two main components: a source level or function, and the propagation loss.

4.6.1.2 The sources can vary in terms of whether they represent continuous sound levels, such as those for vessels, and for more impulsive sound, such as the impact piling or explosives. Those that are continuous can be modelled without detailed analysis of the actual signal in the time domain and are often modelled as energy in a limited number of frequency bands, typically in decidecade bands. Where impulsive metrics are required, detailed analysis of the time domain signal is needed, where propagation is calculated in finely spaced frequency bands, typically of 1Hz for a 1 second time window.

4.6.1.3 Additionally, most sound sources underwater can be modelled as if the sound emanates from a single point (point source assumption). As mentioned in Section 4.2.1, however, sound from impact piling does not adhere to the same principles, and that the sound propagation is markedly different.

4.6.1.4 Different sound propagation models are used depending on the nature of the radiated sound. These are described here.

4.6.2 Impulsive sound propagation modelling

4.6.2.1 Where time-dependent metrics were required, the acoustic field in two dimensional planes was modelled using JASCO's Full Waveform Range-dependent Acoustic Model (FWRAM) over the frequency range 4Hz to 1123Hz to capture energy in all decidecade bands between 5Hz and 1kHz. Details of the model are provided in Table 4.5 and Figure 4.10.

4.6.2.2 Above this frequency range, results were extrapolated to match the typical decay rate observed during measurements of impact pile driving and explosives accordingly. FWRAM was used to model synthetic pile driving pressure waveforms to directly calculate PK, SPL and single strike SEL (SEL_{SS}) in the water column.

4.6.2.3 The SEL_{SS} is an energy-like metric related to the dose of sound received over the entire duration of a single pile driving strike. The SPL on the other hand, is related to average sound pressure over a specified time interval. Pulses typically lengthen in duration as they propagate away from their source, due to seafloor and surface reflections, and other waveguide dispersion effects. The changes in pulse length, and therefore the time window considered, affect the numeric relationship between SPL and SEL. This study has applied a fixed window of 0.125s duration to calculate SPL, as implemented in Martin *et al.* (2017).

4.6.3 Continuous sound propagation modelling

4.6.3.1 For sound sources that do not require time domain specific consideration, sound propagation was modelled using JASCO's Marine Operations Noise Model (MONM). MONM computes the propagation loss for a point source at a specified depth.

4.6.3.2 MONM was used to calculate the propagation loss for frequency bands from 10Hz to 1kHz. Above this frequency range, sound propagation was modelled using BELLHOP Gaussian beam model.

4.6.3.3 Both models consider the local geoacoustic and sound speed profile inputs as well as domain-wide bathymetry. BELLHOP also considers the water temperature and salinity for the accurate calculation of sound absorption. Further details of the model are presented in Appendix E.2.

4.7 Concurrent sound fields

4.7.1.1 As noted, multiple piling operations may occur simultaneously at points during the construction of Morven North and Morven South. Additionally, most the vessels scenarios feature more than one operational sound source. To determine the total acoustic contribution from concurrent piling operations or multiple vessels, the sound fields are summed in accordance with the considered sound level metric.

4.7.1.2 In the case of determining the SEL over 24 hours, the sound energy is accumulated from all audible sources. Consequently, in this case, results are generated as the sum of all sound energy fields from contributing sources.

4.7.1.3 For the consideration of PK metrics from impact piling, these are based on instantaneous or near-instantaneous sound levels. Given the impulsive nature of the sound from piling, and the differing arrival times of the sound pulses depending on the location, the PK sound field is taken as the maximum value across the contributing sources.

4.7.1.4 The SPL is treated differently between impulsive (i.e. piling) and continuous (i.e. vessel) sound sources. In the case of continuous sound sources, the sound field at any point in time comprises contributions from all radiating sources. Consequently, the resulting SPL field is the based on the total sum of the mean-squared sound pressures from contributing sources, similarly to the SEL metric.

4.7.1.5 For the impulsive sound from impact piling, the reported SPL is based on the mean-square pressure in a 125ms window, based on mammalian hearing integration times. It is presumed that points where the pulses overlap both temporally and spatially can be neglected, and that the SPL field, for impulsive sources, be represented by the maximum value similarly to the PK metric.

4.8 Accumulated sound for moving marine mammals

4.8.1 Overview

4.8.1.1 Many of the scenarios presented here can have durations of substantial length such that the sound field experienced by a receptor at the start of the operation will differ from that at the end presuming that the receiver has moved.

4.8.1.2 To take into account the total sound energy over time for a moving receiver, we consider the accumulated sound at different points in the sound field over time, considering the time between acoustic events, the swim speed, and the sound fields involved.

4.8.1.3 The results for mobile receivers have been generated for the four studied marine mammal hearing groups. The swim speeds used in the modelling and representative species are shown in Table 4.6.

Table 4.6: The swim speeds and representative species of the studied hearing groups

Hearing group	Representative species	Swim speed (m/s)	Reference
Low-frequency cetaceans	Minke whale	2.3	Boisseau *et al.* (2021)
High-frequency cetaceans	Bottlenose dolphin Short-beaked common dolphin Risso's dolphin	1.52	Bailey and Thompson (2010)
Very high-frequency cetaceans	Harbour porpoise	1.5	Otani *et al.* (2000)
Phocid pinnipeds	Harbour seal Grey seal	1.8	Thompson (2015)

4.8.1.4 In the modelling, a grid of simulated receivers is set up with 100m spacing representative of the receiver start positions. Between each new acoustic event, receivers move directly away from the source according to the swim speed of the animal in interest and the time between events. Where there are two sources of interest, receivers move either perpendicularly to the line between the two sources if it falls between the two, or directly away from the closest source.

4.8.1.5 It should be noted that a degree of conservatism is built into the method in that the assessment presumes receivers swim solely at the depth of the maximum sound level. This discounts the effect of animals coming up to the surface to breathe, where sound levels are demonstrably much lower. Additionally, no allowances are made for animals that reach the coastline; this, however, does not affect the results due to the sound level contours of interest being sufficiently far enough away from land.

4.8.2 Cumulative sound from piling for moving receivers

4.8.2.1 Each cumulative piling scenario comprises modelled per-pulse sound fields encompassing the pile initiation, the soft start, and the main driving sequence represented by calculated fields for four penetration depths. For a moving receiver, the initial strikes are critical as the cumulative sound field is typically dominated by the loudest strikes which are typically those closest to the pile.

4.8.2.2 In addition to the pile-only sequence, calculations of cumulative sound following use of an ADD have been modelled. Where used, the ADD lasts 30 minutes, after which the initial pile strikes preceding the main sequence commence. These initial strikes feature a period of hammer initialisation followed by a soft start, the details of which are provided in Table 4.7.

Table 4.7: Details of hammer initiation and soft start for piling operations

Phase	Hammer energy (kJ)			Time between pulse trains/ impacts (s)	Total no. pulse trains/ impacts	Total duration (minutes)
	16m monopile	5.3m pin pile	3.7m pin pile			
ADD (where used)	–	–	–	6.0	300	30
Hammer initiation	275	275	400	60.0	10	10
Soft start	990	675	600	3.0	400	20

4.8.2.3 Specific modelling of sound fields was not performed for the single strikes involved in the soft start and hammer initiation periods. To provide a suitable proxy for the radiated sound at these stages sound levels for the hammer initiation and soft start phases are scaled from the full energy impact for the shallowest analysis depth. The scaling is calculated according to von Pein *et al.* (2022), where the difference in SEL is provided by:

$$\Delta \mathrm{SEL} = 10\log_{10}\left(\frac{E_i}{E_0}\right)$$

where E_i and E_0 are the target and reference hammer energies respectively.

4.8.2.4 Following the soft start, piling is presumed to continue at the maximum driving rate considered of 50 strikes per minute (i.e. time between impacts of 1.2s), with the total number of impacts as listed in Table 2.6.

4.8.3 Cumulative sound from continuous vessel sources

4.8.3.1 To determine the total cumulative sound for moving receivers from the continuous (vessel) sources, sound fields of the SEL over 10s are used. Snapshots of accumulated sound in 10s intervals at increasing distances from the source are summed over 24h to calculate the total received sound level. Again, this considers animals swimming at the depth providing the highest sound levels and does not consider surfacing for breathing.

5 Results – Morven North

5.1 Overview

5.1.1.1 This section provides results of the sound field modelling for each of the sources, for all considered metrics for the Morven North Boundary. Where appropriate, these are compared against impact thresholds in scientific literature. Distances are provided in terms of the R_{max}, the maximum distance to the identified sound level, and the $R_{95\%}$, the maximum distance to the threshold after removing the most distant 5% of the ensonified area. Further details of these are provided in Appendix F.

5.2 Impact pile driving – Forcing functions and near-field results

5.2.1 Pile forcing functions

5.2.1.1 The three different piles considered each have a specific hammer and anvil setup. The key parameters are shown in Table 2.4 and Table 2.5. As described, the force at the top of the pile is calculated using GRLWEAP, which takes the specific hammer, anvils, hammer energy, and pile geometry into account in the calculation. The forcing functions are shown in Figure 5.1 in the time domain and in decidecade bands.

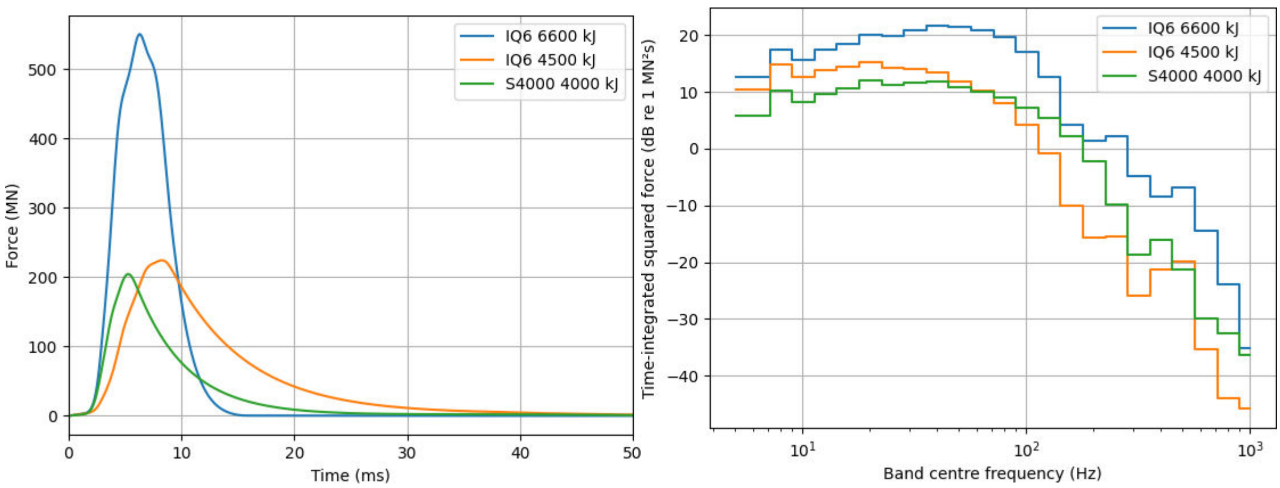

Figure 5.1: Morven North: Forcing functions at the top of the piles in the time domain (left) and in decidecade bands (right)

5.2.2 Sound levels close to the pile

5.2.2.1 It is not physically meaningful to provide a point source level for a driven pile. As described in the previous section, the source function comprises many individual monopile sources that, when combined, recreate the wavefront generated by the impacted pile. To provide a meaningful illustration of "source levels", the following sections show sound levels 10m from the centre of each pile.

5.2.2.2 As described, source functions for the piling scenarios were generated for the three pile designs, each at four different piling penetrations, for the median and maximum reflectivity environments. Figure 5.2, Figure 5.3, and Figure 5.4 show the maximum-over-depth received per-pulse SEL in decidecade bands 10m from the centre of the pile for the 16.0m monopile, 5.3m diameter pin pile, and 3.7m diameter pin pile respectively. Each figure shows the considered combinations of analysed penetration depths and environments.

5.2.2.3 The spectrum is extended to higher frequencies (up to 25kHz) by applying a decay rate of 20dB per decade to match measurements of impact pile driving (Matuschek and Betke 2009, Bellmann *et al.* 2020). Levels presented are the maximum over the water column for each scenario.

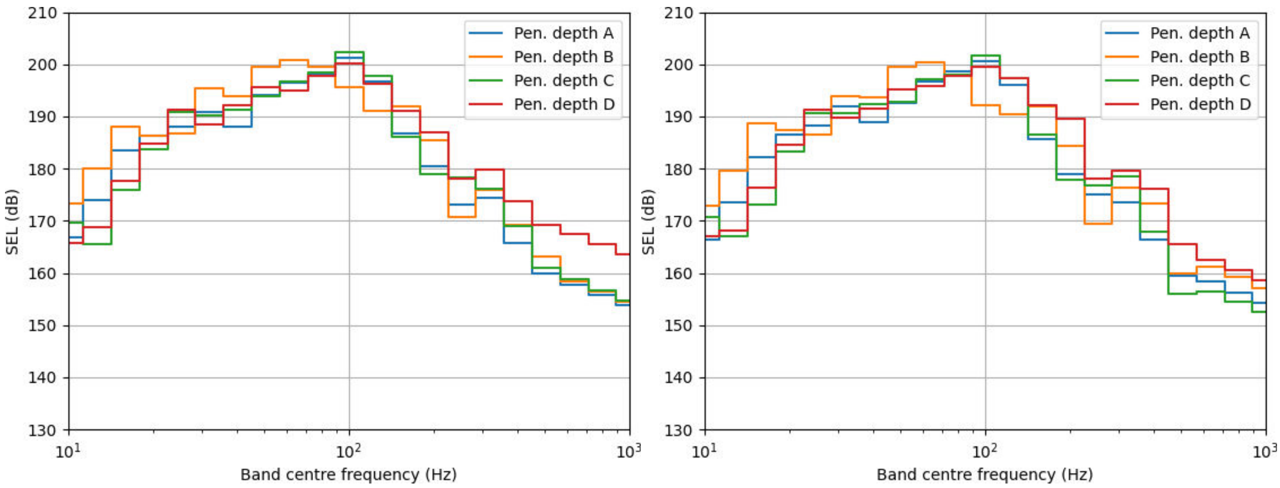

Figure 5.2: Morven North: Maximum-over-depth per-pulse sound exposure levels in decidecade bands, 10m from the pile centre for the 16m monopile in median reflectivity environment (left) and maximum reflectivity environment (right)

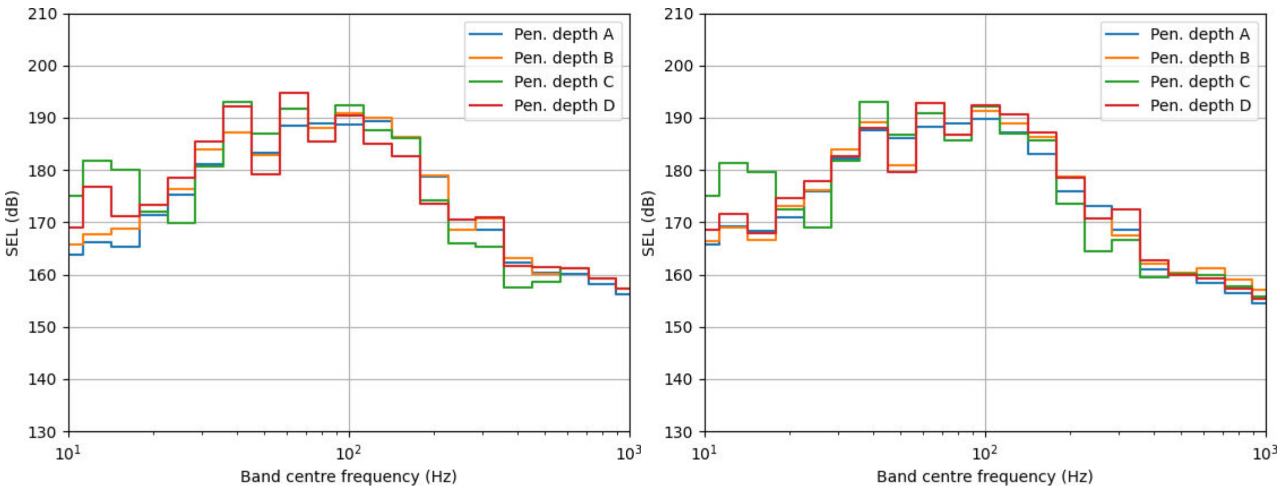

Figure 5.3: Morven North: Maximum-over-depth per-pulse sound elevated levels in decidecade bands, 10m from the pile centre for the 5.3m pin pile in median reflectivity environment (left) and maximum reflectivity environment (right)

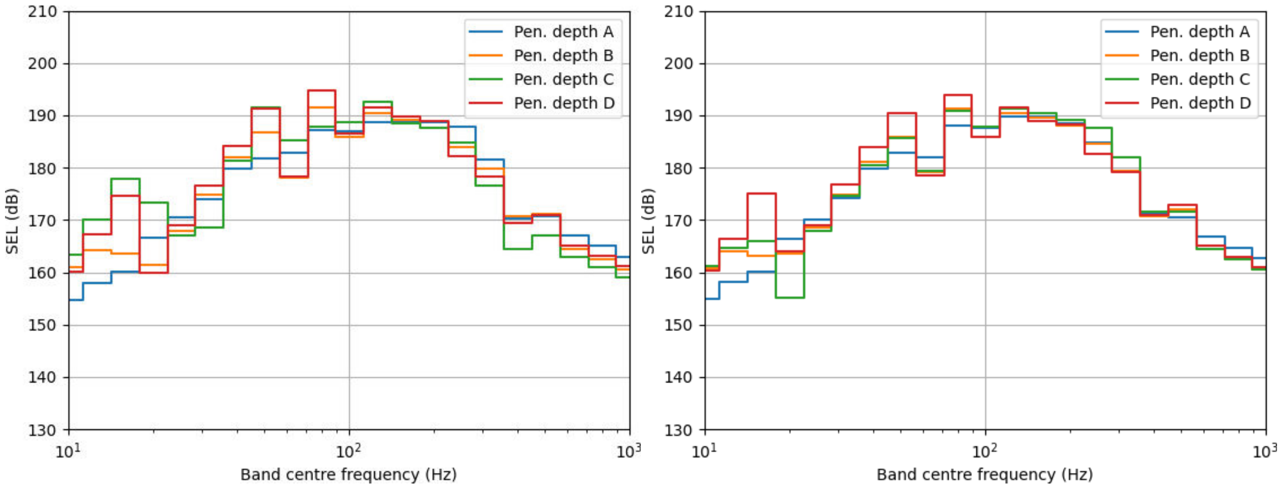

Figure 5.4: Morven North: Maximum-over-depth per-pulse sound exposure levels in decidecade bands, 10m from the pile centre for the 3.7m pin pile in median reflectivity environment (left) and maximum reflectivity environment (right)

5.3 Single pile – Single strikes

5.3.1.1 This section provides results of the impact pile driving when considering single impacts. Results are presented for each of the three considered piles at each of the four penetration depths.

5.3.1.2 Table 5.1 and Table 5.2 show the maximum distances to specified SPL values from the 16m monopile at each analysed penetration depth for representative and conservative cases respectively. Similarly, Table 5.3 and Table 5.4 contain SPL results for the 5.3m pin pile, and Table 5.5 and Table 5.6 show results for the 3.7m pin pile.

5.3.1.3 Table 5.7 and Table 5.8 show the maximum distances to specified unweighted per-pulse SEL values from the 16m monopile at each analysed penetration depth for representative and conservative cases respectively. Similarly, Table 5.9 and Table 5.10 contain unweighted per-pulse SEL results for the 5.3m pin pile, and Table 5.11 and Table 5.12 show results for the 3.7m pin pile.

5.3.1.4 Table 5.13 and Table 5.14 show the maximum distances to identified AUD INJ and TTS PK impact thresholds for marine mammals from NMFS (2024a) and fish from Popper *et al.* (2014) from the 16m monopile at each analysed penetration depth for representative and conservative cases respectively. Similarly, Table 5.15 and Table 5.16 contain equivalent results for the 5.3m pin pile, and Table 5.17 and Table 5.18 show results for the 3.7m pin pile.

Table 5.1: Morven North: Maximum horizontal distances in kilometres from the representative 16m monopile to maximum-over-depth Sound Pressure Level values for each analysed penetration depth

SPL (dB re 1µPa^2)	Maximum horizontal distance to level (km)							
	A		B		C		D	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
120	85.0	71.0	92.8	78.4	88.9	73.1	99.3	85.8
125	66.9	57.0	78.1	65.2	72.9	60.7	81.8	68.8
130	53.8	47.6	64.7	55.1	58.9	51.0	65.5	56.2
135	44.0	40.6	51.9	45.8	46.5	42.5	52.2	46.6
140	37.2	34.8	40.6	37.8	37.9	35.7	41.8	38.7
145	32.0	29.9	33.1	31.0	31.9	29.9	34.0	31.9
150	27.1	25.1	27.1	25.2	26.7	24.9	27.7	25.8
155	22.0	20.7	21.7	20.4	21.8	20.4	22.2	20.8
160	17.0	15.6	16.7	15.3	16.2	15.0	17.1	15.7
165	9.86	9.37	9.78	9.32	9.60	9.14	9.88	9.39
170	7.56	7.08	7.33	6.91	7.00	6.54	7.45	7.01
175	5.19	4.86	5.17	4.88	4.94	4.64	5.29	4.96
180	3.44	3.25	3.63	3.43	3.40	3.21	3.64	3.43
185	2.10	2.01	2.30	2.21	2.15	2.06	2.29	2.19
190	0.95	0.92	1.01	0.97	0.97	0.94	1.12	1.06
195	0.54	0.52	0.55	0.54	0.54	0.52	0.58	0.56
200	0.20	0.20	0.21	0.21	0.22	0.21	0.23	0.22
205	0.12	0.11	0.12	0.12	0.13	0.13	0.14	0.14
210	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 5.2: Morven North: Maximum horizontal distances in kilometres from the conservative 16m monopile to maximum-over-depth Sound Pressure Level values for each analysed penetration depth

SPL (dB re 1μPa²)	Maximum horizontal distance to level (km)							
	A		B		C		D	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
120	138	117	>150	>141	149	130	>150	>142
125	111	93.8	132	116	119	105	132	109
130	88.4	76.5	108	95.0	98.1	86.0	103	87.9
135	72.8	62.7	88.8	76.6	81.1	69.3	83.2	71.3
140	57.5	51.4	71.0	61.0	61.8	55.1	66.4	58.0
145	45.7	41.3	52.2	48.0	46.8	43.2	50.3	46.3
150	36.0	33.3	39.3	36.5	36.5	34.3	38.9	36.3
155	28.3	26.7	28.7	27.5	27.9	26.8	29.1	27.7
160	21.5	20.6	21.6	20.5	21.4	20.5	21.7	20.8
165	14.8	13.8	14.4	13.4	14.1	13.4	15.5	14.6
170	9.26	8.85	8.98	8.53	8.66	8.30	9.41	9.04
175	6.32	6.04	6.12	5.86	5.90	5.66	6.41	6.14
180	3.98	3.85	4.14	4.00	3.96	3.82	4.28	4.12
185	2.39	2.31	2.63	2.54	2.43	2.34	2.60	2.52
190	1.11	1.07	1.36	1.30	1.15	1.10	1.32	1.26
195	0.55	0.53	0.56	0.54	0.54	0.53	0.60	0.58
200	0.17	0.17	0.21	0.21	0.21	0.21	0.22	0.22
205	0.12	0.12	0.12	0.12	0.12	0.12	0.13	0.13
210	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

A dash (-) indicates that the level was not reached within the resolution of the model.
The maximum modelled distance was 150km; an entry of ">150" is used where sound levels exceeding the threshold exist outside the modelled domain.

Table 5.3: Morven North: Maximum horizontal distances in kilometres from the representative 5.3m diameter pin pile to maximum-over-depth Sound Pressure Level values for each analysed penetration depth

SPL (dB re 1μPa²)	Maximum horizontal distance to level (km)							
	A		B		C		D	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
120	73.1	62.5	71.2	62.0	118	101	134	117
125	54.5	48.9	53.2	48.0	90.0	75.4	107	91.1
130	43.2	40.1	41.5	38.4	67.7	57.5	85.4	71.3
135	35.8	33.8	35.1	32.8	47.7	43.9	66.0	56.5
140	29.8	27.9	30.3	28.2	37.6	35.2	48.2	44.0
145	24.2	22.6	25.7	23.8	30.5	28.4	36.4	34.1
150	18.9	17.6	20.9	19.6	24.7	23.0	28.1	26.1
155	11.2	10.2	14.9	13.6	19.8	18.6	20.4	19.1
160	7.97	7.48	9.22	8.68	12.8	11.8	11.7	10.6
165	5.66	5.28	6.52	6.12	8.39	7.92	7.38	6.90
170	3.97	3.72	4.65	4.39	5.31	5.03	4.06	3.88
175	2.68	2.56	3.16	3.00	3.10	2.99	2.19	2.11
180	1.60	1.53	1.97	1.89	1.85	1.79	0.99	0.96
185	0.77	0.75	0.93	0.90	0.78	0.75	0.51	0.49
190	0.33	0.32	0.40	0.39	0.33	0.32	0.22	0.21
195	0.17	0.16	0.20	0.20	0.15	0.15	0.09	0.09
200	0.09	0.09	0.10	0.10	0.07	0.07	0.04	0.04
205	-	-	-	-	0.02	0.02	0.02	0.02
210	-	-	-	-	-	-	-	-

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 5.4: Morven North: Maximum horizontal distances in kilometres from the conservative 5.3m pin pile to maximum-over-depth Sound Pressure Level values for each analysed penetration depth

SPL (dB re 1μPa^2)	Maximum horizontal distance to level (km)							
	A		B		C		D	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
120	113	98.6	118	102	>150	>143	>150	>145
125	86.4	73.9	87.3	74.5	129	113	>150	>143
130	70.7	60.6	67.0	57.7	93.4	80.1	135	119
135	54.7	49.6	52.0	46.9	71.7	60.7	100	86.7
140	42.5	39.5	41.1	38.1	53.9	48.4	77.0	65.4
145	32.4	30.7	32.8	30.9	40.4	37.9	52.5	48.0
150	24.2	23.1	26.2	24.9	30.5	29.0	37.0	34.5
155	17.6	16.7	20.2	19.3	23.7	22.6	25.6	24.5
160	9.80	9.45	12.4	11.5	18.0	17.1	16.3	15.4
165	6.96	6.66	7.98	7.61	9.88	9.53	8.63	8.26
170	4.70	4.54	5.59	5.37	6.49	6.25	4.67	4.50
175	3.10	2.98	3.74	3.60	3.77	3.64	2.44	2.35
180	1.90	1.83	2.26	2.18	2.11	2.04	1.10	1.06
185	0.84	0.81	0.99	0.96	0.98	0.95	0.53	0.51
190	0.36	0.35	0.53	0.51	0.46	0.45	0.23	0.22
195	0.15	0.15	0.20	0.19	0.14	0.14	0.09	0.09
200	0.09	0.09	0.11	0.11	0.09	0.09	0.04	0.04
205	-	-	0.01	0.01	0.01	0.01	0.01	0.01
210	-	-	-	-	-	-	-	-

A dash (-) indicates that the level was not reached within the resolution of the model.
The maximum modelled distance was 150km; an entry of ">150" is used where sound levels exceeding the threshold exist outside the modelled domain.

Table 5.5: Morven North: Maximum horizontal distances in kilometres from the representative 3.7m diameter pin pile to maximum-over-depth Sound Pressure Level values for each analysed penetration depth

SPL (dB re 1μPa^2)	Maximum horizontal distance to level (km)							
	A		B		C		D	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
120	90.9	78.2	>150	>144	>150	>145	>150	>144
125	65.2	57.4	138	122	>150	>142	147	131
130	45.0	41.4	96.4	82.0	116	98.8	108	91.6
135	33.6	31.8	64.8	56.6	80.6	67.6	79.1	66.7
140	26.7	25.1	42.3	39.2	52.0	47.2	55.1	49.3
145	20.9	19.8	29.7	27.5	37.1	34.7	38.7	36.4
150	14.6	13.4	21.8	20.5	27.3	25.4	28.4	26.5
155	9.32	8.74	14.7	13.7	19.9	18.6	19.7	18.5
160	7.07	6.56	9.00	8.45	10.9	9.99	9.98	9.52
165	5.34	4.96	6.08	5.70	7.03	6.62	6.21	5.89
170	3.84	3.64	4.08	3.83	4.19	3.97	3.57	3.42
175	2.63	2.49	2.65	2.52	2.48	2.38	2.05	1.98
180	1.61	1.51	1.58	1.48	1.34	1.29	0.98	0.95
185	0.72	0.70	0.71	0.68	0.69	0.66	0.48	0.45
190	0.32	0.32	0.31	0.30	0.28	0.27	0.20	0.20
195	0.17	0.16	0.14	0.14	0.12	0.11	0.09	0.09
200	0.07	0.07	0.09	0.09	0.07	0.07	0.04	0.04
205	-	-	-	-	0.02	0.02	0.02	0.02
210	-	-	-	-	-	-	-	-

A dash (-) indicates that the level was not reached within the resolution of the model.
The maximum modelled distance was 150km; an entry of ">150" is used where sound levels exceeding the threshold exist outside the modelled domain.

Table 5.6: Morven North: Maximum horizontal distances in kilometres from the conservative 3.7m pin pile to maximum-over-depth Sound Pressure Level values for each analysed penetration depth

SPL (dB re 1µPa^2)	Maximum horizontal distance to level (km)							
	A		B		C		D	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
120	138	119	>150	>145	>150	>145	>150	>145
125	96.7	84.2	>150	>144	>150	>145	>150	>145
130	63.5	57.2	132	115	>150	>142	>150	>142
135	46.3	42.6	89.5	75.7	112	96.7	116	100
140	35.5	33.2	54.6	48.8	76.2	64.5	86.3	72.1
145	27.0	25.6	35.2	33.2	48.5	44.4	54.6	49.8
150	20.3	19.3	25.8	24.5	34.5	32.5	37.1	34.9
155	13.9	12.6	19.3	18.3	23.7	22.7	24.1	23.0
160	9.28	8.77	11.0	10.1	15.6	14.7	13.6	12.9
165	6.91	6.53	7.73	7.41	8.64	8.24	7.45	7.10
170	4.90	4.66	5.09	4.87	4.96	4.76	4.17	4.03
175	3.31	3.14	3.33	3.15	3.02	2.87	2.33	2.25
180	1.97	1.86	1.97	1.85	1.79	1.66	1.16	1.04
185	0.93	0.77	0.93	0.82	0.72	0.68	0.56	0.51
190	0.36	0.35	0.32	0.31	0.30	0.30	0.20	0.20
195	0.15	0.15	0.14	0.13	0.12	0.12	0.09	0.09
200	0.09	0.09	0.09	0.09	0.07	0.07	0.05	0.05
205	-	-	-	-	0.01	0.01	0.01	0.01
210	-	-	-	-	-	-	-	-

A dash (-) indicates that the level was not reached within the resolution of the model.
The maximum modelled distance was 150km; an entry of ">150" is used where sound levels exceeding the threshold exist outside the modelled domain.

Table 5.7: Morven North: Maximum horizontal distances in kilometres from the representative 16m monopile to maximum-over-depth sound exposure level per-pulse values for each analysed penetration depth

SEL per-pulse (dB re 1μPa^{2}s)	Maximum horizontal distance to level (km)							
	A		B		C		D	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
120	69.0	58.3	74.4	62.1	71.6	60.0	76.2	64.2
125	54.1	48.0	58.8	51.1	55.9	49.2	59.8	52.4
130	43.3	39.9	45.7	41.9	43.9	40.5	46.9	42.7
135	35.6	33.4	36.8	34.6	35.7	33.6	37.2	35.0
140	29.9	27.9	30.5	28.6	29.6	27.7	30.6	28.7
143	*26.7*	*24.8*	*27.2*	*25.4*	*26.4*	*24.4*	*27.2*	*25.2*
145	24.6	22.9	25.1	23.4	24.1	22.4	24.9	23.1
150	19.8	18.5	20.1	18.9	19.2	17.8	19.8	18.5
155	13.3	12.1	13.7	12.6	12.2	10.9	13.2	12.0
160	8.86	8.30	9.07	8.48	8.48	7.94	8.86	8.31
165	6.18	5.80	6.37	6.01	5.96	5.59	6.24	5.88
170	4.09	3.86	4.31	4.08	4.02	3.78	4.22	3.98
175	2.47	2.37	2.73	2.60	2.50	2.38	2.65	2.53
180	1.20	1.15	1.37	1.31	1.23	1.16	1.42	1.36
185	0.62	0.61	0.62	0.60	0.62	0.60	0.66	0.64
190	0.23	0.22	0.24	0.23	0.24	0.23	0.25	0.24
195	0.14	0.13	0.14	0.14	0.15	0.14	0.16	0.15
200	0.02	0.02	0.04	0.04	0.02	0.02	0.02	0.02
205	-	-	-	-	-	-	-	-
210	-	-	-	-	-	-	-	-

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 5.8: Morven North: Maximum horizontal distances in kilometres from the conservative 16m monopile to maximum-over-depth sound exposure level per-pulse values for each analysed penetration depth

SEL per-pulse (dB re 1µPa²s)	Maximum horizontal distance to level (km)							
	A		B		C		D	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
120	114	97.3	123	109	117	103	129	109
125	89.4	77.5	99.3	87.1	93.4	82.3	99.1	86.7
130	72.4	62.0	80.4	68.6	76.1	64.9	80.3	68.0
135	55.6	49.8	60.4	54.2	57.1	51.6	60.5	53.8
140	43.4	39.6	45.6	42.2	43.6	40.3	45.6	41.8
143	*37.2*	*34.4*	*38.8*	*36.3*	*37.0*	*34.8*	*38.7*	*35.9*
145	33.5	31.3	34.8	32.8	33.2	31.4	34.5	32.4
150	25.9	24.5	26.4	25.2	25.3	24.2	26.3	24.9
155	20.0	19.0	20.2	19.3	19.4	18.5	20.2	19.3
160	12.6	11.7	13.1	12.2	11.9	11.0	13.1	12.2
165	8.20	7.84	8.49	8.10	8.01	7.66	8.43	8.06
170	5.19	5.00	5.48	5.29	5.13	4.95	5.41	5.21
175	3.02	2.91	3.28	3.17	3.04	2.93	3.20	3.09
180	1.51	1.46	1.78	1.71	1.57	1.50	1.69	1.62
185	0.62	0.61	0.74	0.72	0.69	0.66	0.70	0.68
190	0.22	0.21	0.24	0.24	0.23	0.22	0.24	0.24
195	0.14	0.13	0.14	0.13	0.14	0.13	0.15	0.15
200	0.04	0.04	0.04	0.04	0.04	0.04	0.01	0.01
205	-	-	-	-	-	-	-	-
210	-	-	-	-	-	-	-	-

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 5.9: Morven North: Maximum horizontal distances in kilometres from the representative 5.3m diameter pin pile to maximum-over-depth sound exposure level per-pulse values for each analysed penetration depth

SEL per-pulse (dB re 1μPa²s)	Maximum horizontal distance to level (km)							
	A		B		C		D	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
120	50.0	45.6	49.5	45.0	76.7	64.5	93.5	79.3
125	39.8	37.3	40.5	37.6	57.7	51.0	74.2	62.3
130	32.6	30.6	33.7	31.6	44.2	40.7	55.2	48.7
135	26.6	24.8	28.3	26.3	35.3	33.0	40.5	37.7
140	20.9	19.7	23.1	21.5	28.7	26.7	31.1	29.0
143	*17.7*	*16.4*	*20.2*	*18.9*	*25.0*	*23.3*	*26.3*	*24.4*
145	14.7	13.6	18.0	16.7	22.6	21.2	23.1	21.6
150	9.31	8.76	10.4	9.61	16.6	15.4	15.4	14.1
155	6.74	6.31	7.90	7.44	9.56	9.13	8.82	8.20
160	4.70	4.41	5.57	5.23	6.36	6.02	5.03	4.78
165	3.06	2.91	3.71	3.50	3.76	3.61	2.74	2.64
170	1.87	1.79	2.27	2.18	2.17	2.09	1.46	1.41
175	0.87	0.84	1.00	0.97	0.96	0.94	0.59	0.57
180	0.39	0.38	0.55	0.51	0.52	0.51	0.29	0.29
185	0.18	0.17	0.23	0.22	0.17	0.16	0.10	0.10
190	0.11	0.11	0.12	0.12	0.09	0.09	0.05	0.05
195	-	-	0.02	0.02	0.02	0.02	0.02	0.02
200	-	-	-	-	-	-	-	-
205	-	-	-	-	-	-	-	-
210	-	-	-	-	-	-	-	-

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 5.10: Morven North: Maximum horizontal distances in kilometres from the conservative 5.3m pin pile to maximum-over-depth sound exposure level per-pulse values for each analysed penetration depth

SEL per-pulse (dB re 1μPa²s)	Maximum horizontal distance to level (km)							
	A		B		C		D	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
120	85.2	72.7	86.2	72.9	115	101	>150	>139
125	65.4	57.5	67.3	58.0	90.6	76.9	118	103
130	48.8	45.1	50.9	46.4	70.2	59.5	90.2	76.9
135	37.2	34.9	39.7	36.9	50.8	46.4	64.0	56.4
140	28.1	26.8	30.9	29.2	38.3	36.1	44.4	40.8
143	*23.7*	*22.7*	*26.5*	*25.1*	*32.4*	*30.9*	*35.6*	*33.3*
145	21.3	20.4	23.7	22.6	29.0	27.8	30.4	28.9
150	15.1	14.1	18.2	17.2	21.7	20.8	20.4	19.5
155	9.28	8.87	10.1	9.65	14.0	13.1	9.95	9.64
160	6.35	6.02	7.49	7.12	8.24	7.89	6.16	5.89
165	3.97	3.80	4.78	4.59	4.84	4.67	3.24	3.13
170	2.26	2.17	2.79	2.68	2.67	2.58	1.59	1.53
175	0.96	0.94	1.35	1.29	1.29	1.23	0.75	0.73
180	0.40	0.39	0.62	0.60	0.53	0.52	0.29	0.28
185	0.17	0.17	0.22	0.22	0.20	0.19	0.12	0.12
190	0.11	0.11	0.12	0.12	0.11	0.11	0.05	0.05
195	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
200	-	-	-	-	-	-	-	-
205	-	-	-	-	-	-	-	-
210	-	-	-	-	-	-	-	-

A dash (-) indicates that the level was not reached within the resolution of the model.
The maximum modelled distance was 150km; an entry of ">150" is used where sound levels exceeding the threshold exist outside the modelled domain.

Table 5.11: Morven North: Maximum horizontal distances in kilometres from the representative 3.7m diameter pin pile to maximum-over-depth sound exposure level per-pulse values for each analysed penetration depth

SEL per-pulse (dB re 1μPa^{2}s)	Maximum horizontal distance to level (km)							
	A		B		C		D	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
120	50.8	46.6	103	87.0	121	104	116	100
125	38.3	35.9	70.9	60.8	87.4	73.3	87.2	73.3
130	29.8	28.1	46.8	43.0	59.9	52.8	62.3	54.4
135	23.5	22.0	33.8	31.3	41.5	38.6	43.1	40.1
140	18.1	16.8	24.9	23.1	30.8	28.7	31.4	29.3
143	*14.1*	*12.8*	*20.5*	*19.4*	*25.7*	*23.8*	*25.7*	*23.9*
145	10.9	9.75	17.9	16.7	22.5	21.0	22.1	20.7
150	8.32	7.78	9.82	9.40	14.4	13.3	13.0	11.9
155	6.21	5.75	6.99	6.56	8.40	7.88	7.46	7.02
160	4.33	4.10	4.71	4.42	5.04	4.75	4.35	4.15
165	2.90	2.76	2.99	2.86	2.88	2.77	2.38	2.30
170	1.82	1.72	1.82	1.72	1.62	1.56	1.27	1.19
175	0.78	0.75	0.82	0.76	0.77	0.74	0.58	0.54
180	0.40	0.38	0.35	0.34	0.33	0.32	0.26	0.26
185	0.17	0.17	0.15	0.15	0.13	0.12	0.10	0.10
190	0.11	0.11	0.10	0.10	0.07	0.07	0.05	0.05
195	-	-	0.02	0.02	0.02	0.02	0.02	0.02
200	-	-	-	-	-	-	-	-
205	-	-	-	-	-	-	-	-
210	-	-	-	-	-	-	-	-

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 5.12: Morven North: Maximum horizontal distances in kilometres from the conservative 3.7m pin pile to maximum-over-depth sound exposure level per-pulse values for each analysed penetration depth

SEL per-pulse (dB re 1µPa^{2}s)	Maximum horizontal distance to level (km)							
	A		B		C		D	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
120	84.4	71.7	145	129	>150	>144	>150	>144
125	59.2	53.7	100	86.2	131	114	139	122
130	43.6	40.2	67.6	58.7	92.0	78.9	97.1	84.6
135	32.2	30.4	45.3	41.6	62.3	55.3	68.2	58.9
140	24.5	23.3	32.0	30.2	42.5	39.3	43.6	40.5
143	*21.2*	*20.3*	*26.4*	*25.1*	*33.9*	*32.0*	*33.8*	*32.0*
145	19.5	18.5	23.2	22.2	29.0	27.8	28.4	27.0
150	13.0	11.9	16.6	15.5	20.0	19.1	17.9	17.1
155	8.75	8.29	9.47	9.10	10.2	9.68	9.31	8.96
160	6.04	5.73	6.42	6.11	6.51	6.25	5.34	5.13
165	3.90	3.70	4.02	3.81	3.78	3.59	2.93	2.83
170	2.26	2.15	2.31	2.19	2.13	2.01	1.50	1.37
175	1.00	0.93	1.03	0.96	0.96	0.86	0.62	0.60
180	0.51	0.39	0.48	0.43	0.34	0.33	0.28	0.27
185	0.17	0.17	0.14	0.14	0.19	0.19	0.10	0.10
190	0.11	0.11	0.10	0.10	0.08	0.08	0.05	0.05
195	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
200	-	-	-	-	-	-	-	-
205	-	-	-	-	-	-	-	-
210	-	-	-	-	-	-	-	-

A dash (-) indicates that the level was not reached within the resolution of the model.
The maximum modelled distance was 150km; an entry of ">150" is used where sound levels exceeding the threshold exist outside the modelled domain.

Table 5.13: Morven North: Maximum horizontal distances in kilometres from the representative 16m monopile to maximum-over-depth peak (PK) impact thresholds for marine mammals from National Marine Fisheries Service (2024a) and fish from Popper *et al.* (2014)

Hearing group	Effect	PK (dB)	Maximum horizontal distance to threshold (km)							
			A		B		C		D	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
LF cetaceans	AUD INJ	222	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
	TTS	216	0.12	0.11	0.13	0.12	0.15	0.14	0.17	0.16
HF cetaceans	AUD INJ	230	-	-	-	-	-	-	-	-
	TTS	224	-	-	0.02	0.02	-	-	0.02	0.02
VHF cetaceans	AUD INJ	202	0.84	0.82	0.95	0.92	0.80	0.77	0.83	0.81
	TTS	196	1.70	1.64	1.90	1.82	1.69	1.59	1.81	1.71
PCW	AUD INJ	223	-	-	0.02	0.02	-	-	0.02	0.02
	TTS	217	0.09	0.09	0.10	0.10	0.13	0.13	0.16	0.15
Fish Group 1	Injury	213	0.16	0.15	0.17	0.17	0.20	0.19	0.22	0.22
Fish Group 2, 3, 4, Fish eggs, and fish larvae	Injury	207	0.55	0.54	0.58	0.56	0.56	0.54	0.60	0.58

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 5.14: Morven North: Maximum horizontal distances in kilometres from the conservative 16m monopile to maximum-over-depth peak (PK) impact thresholds for marine mammals from National Marine Fisheries Service (2024a) and fish from Popper *et al.* (2014)

Hearing group	Effect	PK (dB)	Maximum horizontal distance to threshold (km)							
			A		B		C		D	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
LF cetaceans	AUD INJ	222	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	TTS	216	0.12	0.11	0.13	0.13	0.14	0.13	0.15	0.15
HF cetaceans	AUD INJ	230	-	-	-	-	-	-	-	-
	TTS	224	-	-	0.01	0.01	-	-	0.01	0.01
VHF cetaceans	AUD INJ	202	0.80	0.77	0.90	0.85	0.79	0.77	0.90	0.87
	TTS	196	1.94	1.88	1.97	1.89	1.83	1.76	2.09	2.01
PCW	AUD INJ	223	-	-	0.01	0.01	-	-	0.01	0.01
	TTS	217	0.09	0.09	0.11	0.11	0.13	0.13	0.14	0.14
Fish Group 1	Injury	213	0.15	0.15	0.17	0.16	0.17	0.17	0.21	0.21
Fish Group 2, 3, 4, Fish eggs, and fish larvae	Injury	207	0.52	0.51	0.54	0.53	0.51	0.50	0.56	0.54

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 5.15: Morven North: Maximum horizontal distances in kilometres from the representative 5.3m pin pile to maximum-over-depth peak (PK) impact thresholds for marine mammals from National Marine Fisheries Service (2024a) and fish from Popper *et al.* (2014)

Hearing group	Effect	PK (dB)	Maximum horizontal distance to threshold (km)							
			A		B		C		D	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
LF cetaceans	AUD INJ	222	-	-	-	-	-	-	-	-
	TTS	216	0.04	0.04	0.02	0.02	0.05	0.05	0.02	0.02
HF cetaceans	AUD INJ	230	-	-	-	-	-	-	-	-
	TTS	224	-	-	-	-	-	-	-	-
VHF cetaceans	AUD INJ	202	0.57	0.55	0.57	0.54	0.47	0.42	0.20	0.19
	TTS	196	0.91	0.87	0.94	0.90	0.80	0.77	0.52	0.49
PCW	AUD INJ	223	-	-	-	-	-	-	-	-
	TTS	217	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Fish Group 1	Injury	213	0.14	0.13	0.13	0.13	0.10	0.09	0.04	0.04
Fish Group 2, 3, 4, Fish eggs, and fish larvae	Injury	207	0.24	0.23	0.24	0.23	0.17	0.17	0.09	0.09

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 5.16: Morven North: Maximum horizontal distances in kilometres from the conservative 5.3m pin pile to maximum-over-depth peak (PK) impact thresholds for marine mammals from National Marine Fisheries Service (2024a) and fish from Popper *et al.* (2014)

Hearing group	Effect	PK (dB)	Maximum horizontal distance to threshold (km)							
			A		B		C		D	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
LF cetaceans	AUD INJ	222	-	-	-	-	-	-	-	-
	TTS	216	0.08	0.08	0.08	0.08	0.06	0.06	0.01	0.01
HF cetaceans	AUD INJ	230	-	-	-	-	-	-	-	-
	TTS	224	-	-	-	-	-	-	-	-
VHF cetaceans	AUD INJ	202	0.53	0.51	0.54	0.52	0.43	0.35	0.20	0.19
	TTS	196	0.99	0.96	0.99	0.96	0.96	0.93	0.53	0.46
PCW	AUD INJ	223	-	-	-	-	-	-	-	-
	TTS	217	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Fish Group 1	Injury	213	0.14	0.13	0.13	0.13	0.11	0.11	0.04	0.04
Fish Group 2, 3, 4, Fish eggs, and fish larvae	Injury	207	0.23	0.22	0.22	0.22	0.17	0.16	0.12	0.12

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 5.17: Morven North: Maximum horizontal distances in kilometres from the representative 3.7m pin pile to maximum-over-depth peak (PK) impact thresholds for marine mammals from National Marine Fisheries Service (2024a) and fish from Popper *et al.* (2014)

Hearing group	Effect	PK (dB)	Maximum horizontal distance to threshold (km)							
			A		B		C		D	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
LF cetaceans	AUD INJ	222	-	-	-	-	-	-	-	-
	TTS	216	0.12	0.12	0.10	0.10	0.07	0.07	0.04	0.04
HF cetaceans	AUD INJ	230	-	-	-	-	-	-	-	-
	TTS	224	-	-	-	-	-	-	-	-
VHF cetaceans	AUD INJ	202	0.66	0.64	0.60	0.57	0.53	0.50	0.28	0.27
	TTS	196	1.44	1.32	1.02	0.94	0.89	0.82	0.65	0.61
PCW	AUD INJ	223	-	-	-	-	-	-	-	-
	TTS	217	0.10	0.10	0.09	0.09	0.07	0.07	0.02	0.02
Fish Group 1	Injury	213	0.16	0.16	0.13	0.13	0.10	0.10	0.07	0.07
Fish Group 2, 3, 4, Fish eggs, and fish larvae	Injury	207	0.26	0.25	0.22	0.22	0.19	0.18	0.12	0.12

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 5.18: Morven North: Maximum horizontal distances in kilometres from the conservative 3.7m pin pile to maximum-over-depth peak (PK) impact thresholds for marine mammals from National Marine Fisheries Service (2024a) and fish from Popper *et al.* (2014)

Hearing group	Effect	PK (dB)	Maximum horizontal distance to threshold (km)							
			A		B		C		D	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
LF cetaceans	AUD INJ	222	-	-	-	-	-	-	-	-
	TTS	216	0.11	0.11	0.10	0.10	0.09	0.09	0.05	0.05
HF cetaceans	AUD INJ	230	-	-	-	-	-	-	-	-
	TTS	224	-	-	-	-	-	-	-	-
VHF cetaceans	AUD INJ	202	0.76	0.74	0.59	0.55	0.53	0.48	0.29	0.28
	TTS	196	1.73	1.59	1.35	1.21	0.99	0.94	0.67	0.62
PCW	AUD INJ	223	-	-	-	-	-	-	-	-
	TTS	217	0.10	0.10	0.08	0.08	0.07	0.07	0.04	0.04
Fish Group 1	Injury	213	0.15	0.15	0.13	0.13	0.11	0.11	0.07	0.07
Fish Group 2, 3, 4, Fish eggs, and fish larvae	Injury	207	0.34	0.33	0.27	0.26	0.21	0.21	0.19	0.15

A dash (-) indicates that the level was not reached within the resolution of the model.

5.4 Single pile – Multiple strikes

5.4.1.1 This section provides modelled results of the total radiated sound from single pile operations as defined in Table 2.6, taking into account the multiple penetration depths and number of strikes at each analysed depth.

5.4.1.2 Table 5.19 provides results of the distances from the 16m monopile driving operation to frequency-weighted SEL impact thresholds levels as defined by NMFS (2024a) for marine mammals for the cases of without and with an ADD; the animals are modelled as moving away from the pile as described in Section 4.8.

5.4.1.3 Table 5.20 shows distances to from the 16m monopile to unweighted SEL impact thresholds as defined by Popper *et al.* (2014) for fish for the representative and conservative environments; fish have been modelled as static receivers.

Table 5.19: Morven North: Maximum horizontal distances in kilometres from the modelled 16m monopile to maximum-over-depth sound exposure level impact thresholds for marine mammals from National Marine Fisheries Service (2024a). Sound levels are frequency-weighted for cetaceans according to the hearing group

Hearing group	Effect	SEL (dB)	Maximum horizontal distance to threshold (km)							
			Representative				Conservative			
			No ADD		ADD		No ADD		ADD	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
LF cetaceans	AUD INJ	183	4.73	4.37	0.54	0.53	10.6	9.98	6.49	5.98
	TTS	168	21.2	19.7	17.0	15.7	40.0	34.9	35.9	31.0
HF cetaceans	AUD INJ	193	-	-	-	-	-	-	-	-
	TTS	178	-	-	-	-	-	-	-	-
VHF cetaceans	AUD INJ	159	-	-	-	-	-	-	0.01	0.01
	TTS	144	-	-	0.79	0.77	-	-	0.84	0.82
PCW	AUD INJ	183	-	-	-	-	-	-	-	-
	TTS	168	4.05	3.74	0.76	0.74	8.59	7.95	5.36	4.84

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 5.20: Morven North: Maximum horizontal distances in kilometres from the modelled 16m monopile to maximum-over-depth sound exposure level impact thresholds for fish from Popper *et al.* (2014)

Hearing group	Effect	SEL (dB)	Maximum horizontal distance to threshold (km)			
			Representative		Conservative	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
Fish Group 1	Mortality	219	1.65	1.58	1.96	1.89
	Injury	216	2.36	2.27	2.85	2.74
Fish Group 2	Mortality	210	4.21	3.98	5.40	5.20
	Injury	203	7.19	6.77	9.55	9.18
Fish Group 3 and, 4	Mortality	207	5.39	5.06	7.09	6.80
	Injury	203	7.19	6.77	9.55	9.18
All fish groups	TTS	186	23.8	22.1	32.5	30.7
Fish eggs, and fish larvae	Mortality	210	4.21	3.98	5.40	5.20

5.4.1.4 Table 5.21 provides results of the distances from the 5.3m pin pile driving operation to frequency-weighted SEL impact thresholds levels as defined by NMFS (2024a) for marine mammals for the cases of without and with an ADD; the animals are modelled as moving away from the pile as described in Section 4.8.

5.4.1.5 Table 5.22 shows distances to from the 5.3m pin pile to unweighted SEL impact thresholds as defined by Popper *et al.* (2014) for fish for the representative and conservative environments; fish have been modelled as static receivers.

Table 5.21: Morven North: Maximum horizontal distances in kilometres from the 5.3m pin pile to maximum-over-depth sound exposure level impact thresholds for marine mammals from National Marine Fisheries Service (2024a). Sound levels are frequency-weighted for cetaceans according to the hearing group

Hearing group	Effect	SEL (dB)	Maximum horizontal distance to threshold (km)							
			Representative				Conservative			
			No ADD		ADD		No ADD		ADD	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
LF cetaceans	AUD INJ	183	1.44	1.34	-	-	4.25	3.92	0.01	0.01
	TTS	168	17.1	15.8	13.0	11.8	38.8	32.3	34.7	28.5
HF cetaceans	AUD INJ	193	-	-	-	-	-	-	-	-
	TTS	178	-	-	-	-	-	-	-	-
VHF cetaceans	AUD INJ	159	-	-	-	-	-	-	0.01	0.01
	TTS	144	-	-	0.76	0.74	0.01	0.01	0.83	0.81
PCW	AUD INJ	183	-	-	-	-	-	-	-	-
	TTS	168	1.27	1.18	-	-	3.54	3.28	0.31	0.31

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 5.22: Morven North: Maximum horizontal distances in kilometres from the 5.3m pin pile to maximum-over-depth sound exposure level impact thresholds for fish from Popper *et al.* (2014)

Hearing group	Effect	SEL (dB)	Maximum horizontal distance to threshold (km)			
			Representative		Conservative	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
Fish Group 1	Mortality	219	0.62	0.60	0.69	0.67
	Injury	216	0.96	0.93	1.13	1.07
Fish Group 2	Mortality	210	2.36	2.27	2.90	2.80
	Injury	203	5.06	4.80	6.46	6.21
Fish Group 3 and, 4	Mortality	207	3.34	3.18	4.15	4.01
	Injury	203	5.06	4.80	6.46	6.21
All fish groups	TTS	186	23.6	22.0	30.8	29.3
Fish eggs, and fish larvae	Mortality	210	2.36	2.27	2.90	2.80

5.4.1.6 Table 5.23 provides results of the distances from the 3.7m pin pile driving operation to frequency-weighted SEL impact thresholds levels as defined by NMFS (2024a) for marine mammals for the cases of without and with an ADD; the animals are modelled as moving away from the pile as described in Section 4.8.

5.4.1.7 Table 5.24 shows distances to from the 3.7m pin pile to unweighted SEL impact thresholds as defined by Popper *et al.* (2014) for fish for the representative and conservative environments; fish have been modelled as static receivers.

Table 5.23: Morven North: Maximum horizontal distances in kilometres from the 3.7m pin pile to maximum-over-depth sound exposure level impact thresholds for marine mammals from National Marine Fisheries Service (2024a). Sound levels are frequency-weighted for cetaceans according to the hearing group

Hearing group	Effect	SEL (dB)	Maximum horizontal distance to threshold (km)							
			Representative				Conservative			
			No ADD		ADD		No ADD		ADD	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
LF cetaceans	AUD INJ	183	2.17	2.03	-	-	5.59	5.21	1.44	1.29
	TTS	168	29.6	26.8	25.5	22.9	56.6	46.6	52.5	42.7
HF cetaceans	AUD INJ	193	-	-	-	-	-	-	-	-
	TTS	178	-	-	-	-	-	-	-	-
VHF cetaceans	AUD INJ	159	-	-	-	-	-	-	0.01	0.01
	TTS	144	0.04	0.04	0.77	0.75	0.32	0.29	0.87	0.84
PCW	AUD INJ	183	-	-	-	-	-	-	-	-
	TTS	168	2.34	2.14	-	-	5.33	4.98	2.06	1.87

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 5.24: Morven North: Maximum horizontal distances in kilometres from the 3.7m pin pile to maximum-over-depth sound exposure level impact thresholds for fish from Popper *et al.* (2014)

Hearing group	Effect	SEL (dB)	Maximum horizontal distance to threshold (km)			
			Representative		Conservative	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
Fish Group 1	Mortality	219	0.36	0.35	0.41	0.38
	Injury	216	0.65	0.62	0.69	0.66
Fish Group 2	Mortality	210	1.58	1.51	1.98	1.86
	Injury	203	3.42	3.27	4.44	4.26
Fish Group 3 and, 4	Mortality	207	2.23	2.14	2.85	2.71
	Injury	203	3.42	3.27	4.44	4.26
All fish groups	TTS	186	20.0	18.7	25.3	24.2
Fish eggs, and fish larvae	Mortality	210	1.58	1.51	1.98	1.86

5.5 Concurrent piles – Single strikes

5.5.1.1 This section provides tabulated results of the concurrent piling scenarios, where the total sound field from single strikes from concurrent piling operations is considered. The scenarios are as listed in Table 2.7. In all cases, values shown are the maximum distances to sound levels from the nearer source.

5.5.1.2 As detailed in Section 4.7, the SPL and PK sound fields are taken as the maximum over the two fields. Because of this, the maximum distance to any threshold remains the same as the maximum from the single pile case. In these cases, it is the ensonified area to a threshold sound level that is presented instead of the maximum distance.

5.5.1.3 Table 5.25 and Table 5.26 show the total ensonified areas (km²) to SPL values due to the single pile, two nearby piles, and two distant piles for the 16m monopile for the representative and conservative cases respectively. Similarly, Table 5.27 and Table 5.28 show total ensonified areas (km²) to PK threshold values from NMFS (2024a) and Popper *et al.* (2014) due to the single pile, two nearby piles, and two distant piles for the 16m monopile for the representative and conservative cases respectively.

Table 5.25: Morven North: Ensonified areas (km²) from the representative 16m monopile and near and far concurrent piling scenarios to maximum-over-depth sound pressure levels values for each analysed penetration depth

SPL (dB re 1µPa²)	Ensonified area to level (km²)											
	A			B			C			D		
	Sgl	Near	Far	Sgl	Near	Far	Sgl	Near	Far	Sgl	Near	Far
140	4010	4082	6609	4679	4757	7498	4190	4263	6845	4908	4987	7808
145	2951	3012	5137	3180	3243	5449	2955	3016	5138	3368	3433	5715
150	2087	2138	3865	2104	2155	3885	2043	2093	3796	2194	2247	4023
155	1412	1454	2778	1376	1418	2714	1381	1423	2723	1436	1479	2817
160	789	820	1577	757	789	1514	726	757	1452	804	836	1609
165	290	309	581	287	306	574	276	295	553	291	311	583
170	165	180	330	158	172	316	141	154	282	162	176	324
175	77.9	87.6	156	78.7	88.5	157	71.1	80.5	142	81.3	91.3	163
180	35.0	41.5	69.9	39.0	45.9	78.0	34.0	40.5	68.1	38.9	45.8	77.8
185	13.4	17.4	26.8	16.1	20.5	32.3	14.1	18.2	28.1	15.9	20.3	31.7
190	2.82	4.61	5.65	3.14	5.02	6.27	2.93	4.76	5.86	3.71	5.77	7.42
195	0.73	1.44	1.46	0.96	1.89	1.93	0.91	1.80	1.82	1.05	2.04	2.11
200	0.12	0.24	0.24	0.14	0.28	0.28	0.15	0.29	0.29	0.17	0.34	0.34
205	0.05	0.09	0.09	0.05	0.10	0.10	0.05	0.11	0.11	0.06	0.12	0.12
210	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 5.26: Morven North: Ensonified areas (km²) from the conservative 16m monopile and near and far concurrent piling scenarios to maximum-over-depth sound pressure levels values for each analysed penetration depth

SPL (dB re 1μPa²)	Ensonified area to level (km²)											
	A			B			C			D		
	Sgl	Near	Far	Sgl	Near	Far	Sgl	Near	Far	Sgl	Near	Far
140	8247	8354	12062	11198	11324	15605	9351	9466	13389	10225	10344	14466
145	5567	5652	8677	7320	7419	10884	6082	6171	9330	6855	6950	10324
150	3668	3736	6145	4387	4461	7102	3884	3954	6431	4335	4409	7046
155	2359	2414	4281	2499	2555	4481	2369	2424	4293	2533	2589	4535
160	1408	1450	2768	1389	1430	2735	1394	1436	2744	1431	1473	2807
165	632	660	1263	594	621	1187	594	621	1187	699	728	1397
170	259	277	518	241	258	481	228	245	456	270	288	540
175	121	133	241	114	125	227	106	117	212	125	137	250
180	49.0	56.8	97.9	52.9	61.0	106	48.4	56.2	96.7	56.1	64.5	112
185	17.6	22.3	35.3	21.4	26.6	42.8	18.1	22.9	36.3	20.9	26.0	41.9
190	3.77	5.88	7.55	5.57	8.15	11.1	4.00	6.18	8.01	5.29	7.81	10.6
195	0.93	1.83	1.86	0.95	1.86	1.91	0.91	1.79	1.82	1.12	2.14	2.23
200	0.10	0.20	0.20	0.13	0.26	0.26	0.12	0.24	0.24	0.16	0.33	0.33
205	0.05	0.10	0.10	0.05	0.10	0.10	0.05	0.10	0.10	0.06	0.11	0.11
210	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 5.27: Morven North: Ensonified areas (km²) from the representative 16m monopile and near and far concurrent piling scenarios to maximum-over-depth peak (PK) impact thresholds for marine mammals from National Marine Fisheries Service (2024a) and fish from Popper *et al.* (2014)

Hearing group	Eff.	PK (dB)	Ensonified area to level (km²)											
			A			B			C			D		
			Sgl	Nr	Far	Sgl	Nr	Far	Sgl	Nr	Far	Sgl	Nr	Far
LF cetaceans	INJ	222	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	TTS	216	0.05	0.09	0.09	0.05	0.11	0.11	0.07	0.15	0.15	0.10	0.19	0.19
HF cetaceans	INJ	230	-	-	-	-	-	-	-	-	-	-	-	-
	TTS	224	-	-	-	<0.01	<0.01	<0.01	-	-	-	<0.01	<0.01	<0.01
VHF cetaceans	INJ	202	2.24	3.80	4.48	2.81	4.58	5.62	1.95	3.40	3.91	2.16	3.71	4.33
	TTS	196	8.88	12.1	17.8	11.0	14.6	21.9	8.32	11.5	16.6	9.71	13.1	19.4
Phocid pinnipeds	INJ	223	-	-	-	<0.01	<0.01	<0.01	-	-	-	<0.01	<0.01	<0.01
	TTS	217	0.03	0.05	0.05	0.04	0.07	0.07	0.05	0.11	0.11	0.08	0.15	0.15
Fish Group 1	Inj.	213	0.08	0.16	0.16	0.10	0.20	0.20	0.12	0.24	0.24	0.16	0.32	0.32
Fish Group 2, 3, 4, Fish eggs, and fish larvae	Inj.	207	0.88	1.73	1.76	1.02	1.98	2.04	0.96	1.89	1.93	1.12	2.14	2.23

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 5.28: Morven North: Ensonified areas (km²) from the conservative 16m monopile and near and far concurrent piling scenarios to maximum-over-depth peak (PK) impact thresholds for marine mammals from National Marine Fisheries Service (2024a) and fish from Popper *et al.* (2014)

Hearing group	Eff.	PK (dB)	Ensonified area to level (km²)											
			A			B			C			D		
			Sgl	Nr	Far	Sgl	Nr	Far	Sgl	Nr	Far	Sgl	Nr	Far
LF cetaceans	INJ	222	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	TTS	216	0.04	0.08	0.08	0.06	0.11	0.11	0.06	0.12	0.12	0.08	0.16	0.16
HF cetaceans	INJ	230	-	-	-	-	-	-	-	-	-	-	-	-
	TTS	224	-	-	-	<0.01	<0.01	<0.01	-	-	-	<0.01	<0.01	<0.01
VHF cetaceans	INJ	202	1.95	3.40	3.89	2.41	4.05	4.82	1.94	3.38	3.87	2.49	4.17	4.98
	TTS	196	11.7	15.5	23.3	11.8	15.7	23.7	10.2	13.8	20.5	13.4	17.5	26.8
Phocid pinnipeds	INJ	223	-	-	-	<0.01	<0.01	<0.01	-	-	-	<0.01	<0.01	<0.01
	TTS	217	0.02	0.05	0.05	0.04	0.08	0.08	0.06	0.11	0.11	0.07	0.13	0.13
Fish Group 1	Inj.	213	0.08	0.16	0.16	0.09	0.17	0.17	0.10	0.19	0.19	0.14	0.28	0.28
Fish Group 2, 3, 4, Fish eggs, and fish larvae	Inj.	207	0.85	1.68	1.69	0.92	1.81	1.84	0.82	1.63	1.64	0.95	1.86	1.91

A dash (-) indicates that the level was not reached within the resolution of the model.

5.5.1.4 Table 5.29 and Table 5.30 show the total ensonified areas (km²) to SPL values due to the single pile, two nearby piles, and two distant piles for the 5.3m pin pile for the representative and conservative cases respectively. Similarly, Table 5.31 and Table 5.32 show total ensonified areas (km²) to PK threshold values from NMFS (2024a) and Popper *et al.* (2014) due to the single pile, two nearby piles, and two distant piles for the 5.3m pin pile for the representative and conservative cases respectively.

Table 5.29: Morven North: Ensonified areas (km²) from the representative 5.3m pin pile and near and far concurrent piling scenarios to maximum-over-depth sound pressure level values for each analysed penetration depth

SPL (dB re 1μPa²)	Ensonified area to level (km²)											
	A			B			C			D		
	Sgl	Near	Far	Sgl	Near	Far	Sgl	Near	Far	Sgl	Near	Far
140	2579	2636	4598	2628	2686	4676	4092	4164	6708	6239	6331	9536
145	1681	1727	3226	1877	1926	3542	2674	2732	4731	3835	3905	6359
150	1020	1056	2039	1275	1315	2537	1754	1801	3343	2245	2299	4101
155	334	355	668	594	622	1188	1142	1179	2283	1206	1245	2409
160	184	199	368	249	266	497	439	463	878	353	375	707
165	91.8	103	184	123	136	246	208	224	415	157	171	314
170	45.7	53.2	91.5	63.8	72.7	128	83.6	93.7	167	49.7	57.5	99.4
175	21.6	26.7	43.2	29.8	35.8	59.6	29.5	35.6	59.1	14.8	19.0	29.6
180	7.71	10.8	15.4	11.8	15.6	23.6	10.5	14.1	21.1	3.08	4.96	6.16
185	1.87	3.27	3.73	2.70	4.44	5.40	1.88	3.30	3.77	0.80	1.61	1.61
190	0.34	0.68	0.68	0.50	1.00	1.00	0.34	0.68	0.68	0.14	0.28	0.28
195	0.09	0.19	0.19	0.12	0.24	0.24	0.08	0.15	0.15	0.02	0.05	0.05
200	0.02	0.05	0.05	0.03	0.07	0.07	0.02	0.04	0.04	<0.01	0.01	0.01
205	-	-	-	-	-	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
210	-	-	-	-	-	-	-	-	-	-	-	-

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 5.30: Morven North: Ensonified areas (km²) from the conservative 5.3m pin pile and near and far concurrent piling scenarios to maximum-over-depth sound pressure level values for each analysed penetration depth

SPL (dB re 1μPa²)	Ensonified area to level (km²)											
	A			B			C			D		
	Sgl	Near	Far	Sgl	Near	Far	Sgl	Near	Far	Sgl	Near	Far
140	5097	5177	8062	4750	4827	7615	7431	7530	11046	12639	12774	17308
145	3107	3169	5358	3149	3212	5430	4723	4800	7570	7347	7446	10910
150	1771	1818	3367	2044	2094	3803	2788	2847	4910	3939	4009	6496
155	924	958	1848	1232	1271	2456	1693	1739	3247	1976	2026	3687
160	295	314	590	436	459	871	963	997	1926	778	809	1555
165	147	160	293	191	207	383	300	319	600	226	243	452
170	68.1	77.3	136	95.5	106	191	129	142	259	67.1	76.3	134
175	29.4	35.5	58.9	42.8	50.1	85.6	43.9	51.4	87.8	18.2	22.9	36.3
180	11.1	14.7	22.1	15.7	20.1	31.4	13.8	17.9	27.6	3.69	5.77	7.38
185	2.19	3.73	4.37	3.07	4.94	6.15	3.00	4.85	6.00	0.86	1.70	1.72
190	0.40	0.80	0.80	0.86	1.71	1.72	0.67	1.34	1.34	0.17	0.34	0.34
195	0.08	0.16	0.16	0.12	0.24	0.24	0.07	0.13	0.13	0.02	0.05	0.05
200	0.02	0.05	0.05	0.04	0.08	0.08	0.02	0.05	0.05	<0.01	<0.01	<0.01
205	-	-	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
210	-	-	-	-	-	-	-	-	-	-	-	-

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 5.31: Morven North: Ensonified areas (km²) from the representative 5.3m pin pile and near and far concurrent piling scenarios to maximum-over-depth peak (PK) impact thresholds for marine mammals from National Marine Fisheries Service (2024a) and fish from Popper *et al.* (2014)

Hearing group	Eff.	PK (dB)	Ensonified area to level (km²)											
			A			B			C			D		
			Sgl	Nr	Far	Sgl	Nr	Far	Sgl	Nr	Far	Sgl	Nr	Far
LF cetaceans	INJ	222	-	-	-	-	-	-	-	-	-	-	-	-
	TTS	216	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	0.02	<0.01	<0.01	<0.01
HF cetaceans	INJ	230	-	-	-	-	-	-	-	-	-	-	-	-
	TTS	224	-	-	-	-	-	-	-	-	-	-	-	-
VHF cetaceans	INJ	202	1.01	1.96	2.01	0.98	1.92	1.96	0.43	0.87	0.87	0.12	0.24	0.24
	TTS	196	2.53	4.21	5.07	2.68	4.41	5.35	1.96	3.42	3.93	0.80	1.60	1.60
Phocid pinnipeds	INJ	223	-	-	-	-	-	-	-	-	-	-	-	-
	TTS	217	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fish Group 1	Inj.	213	0.06	0.11	0.11	0.05	0.11	0.11	0.03	0.06	0.06	<0.01	<0.01	<0.01
Fish Group 2, 3, 4, Fish eggs, and fish larvae	Inj.	207	0.17	0.35	0.35	0.17	0.35	0.35	0.10	0.20	0.20	0.03	0.05	0.05

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 5.32: Morven North: Ensonified areas (km²) from the conservative 5.3m pin pile and near and far concurrent piling scenarios to maximum-over-depth peak (PK) impact thresholds for marine mammals from National Marine Fisheries Service (2024a) and fish from Popper *et al.* (2014)

Hearing group	Eff.	PK (dB)	Ensonified area to level (km²)											
			A			B			C			D		
			Sgl	Nr	Far	Sgl	Nr	Far	Sgl	Nr	Far	Sgl	Nr	Far
LF cetaceans	INJ	222	-	-	-	-	-	-	-	-	-	-	-	-
	TTS	216	0.02	0.05	0.05	<0.01	0.02	0.02	0.01	0.03	0.03	<0.01	<0.01	<0.01
HF cetaceans	INJ	230	-	-	-	-	-	-	-	-	-	-	-	-
	TTS	224	-	-	-	-	-	-	-	-	-	-	-	-
VHF cetaceans	INJ	202	0.85	1.67	1.69	0.88	1.74	1.77	0.40	0.81	0.81	0.12	0.25	0.25
	TTS	196	3.04	4.91	6.09	3.06	4.92	6.11	2.86	4.66	5.72	0.66	1.32	1.32
Phocid pinnipeds	INJ	223	-	-	-	-	-	-	-	-	-	-	-	-
	TTS	217	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fish Group 1	Inj.	213	0.06	0.12	0.12	0.06	0.11	0.11	0.04	0.08	0.08	<0.01	<0.01	<0.01
Fish Group 2, 3, 4, Fish eggs, and fish larvae	Inj.	207	0.17	0.34	0.34	0.16	0.33	0.33	0.09	0.17	0.17	0.05	0.11	0.11

A dash (-) indicates that the level was not reached within the resolution of the model.

5.5.1.5 Table 5.33 and Table 5.34 show the total ensonified areas (km²) to SPL values due to the single pile, two nearby piles, and two distant piles for the 3.7m pin pile for the representative and conservative cases respectively. Similarly, Table 5.35 and Table 5.36 show total ensonified areas (km²) to PK threshold values from NMFS (2024a) and Popper *et al.* (2014) due to the single pile, two nearby piles, and two distant piles for the 3.7m pin pile for the representative and conservative cases respectively.

Table 5.33: Morven North: Ensonified areas (km²) from the representative 3.7m pin pile and near and far concurrent piling scenarios to maximum-over-depth sound pressure level values for each analysed penetration depth

SPL (dB re 1μPa²)	Ensonified area to level (km²)											
	A			B			C			D		
	Sgl	Near	Far	Sgl	Near	Far	Sgl	Near	Far	Sgl	Near	Far
140	2086	2137	3868	5055	5136	8010	7116	7213	10639	7648	7751	11295
145	1300	1341	2583	2503	2559	4486	3963	4034	6530	4358	4433	7058
150	564	591	1127	1394	1436	2747	2127	2179	3922	2309	2363	4188
155	250	268	501	609	636	1217	1144	1182	2288	1122	1160	2245
160	140	154	281	236	253	471	328	348	655	300	319	600
165	80.3	90.3	161	107	119	214	145	158	290	115	127	230
170	43.6	50.9	87.2	48.3	56.0	96.7	52.2	60.2	104	38.7	45.6	77.4
175	20.5	25.5	41.0	21.1	26.1	42.1	18.8	23.6	37.6	13.0	16.9	25.9
180	7.05	9.94	14.1	7.13	10.1	14.3	5.46	7.98	10.9	2.99	4.84	5.98
185	1.62	2.91	3.23	1.53	2.80	3.07	1.44	2.66	2.88	0.66	1.32	1.32
190	0.27	0.54	0.54	0.30	0.60	0.60	0.25	0.50	0.50	0.12	0.25	0.25
195	0.09	0.19	0.19	0.07	0.14	0.14	0.05	0.09	0.09	0.02	0.05	0.05
200	0.01	0.02	0.02	0.02	0.05	0.05	0.02	0.04	0.04	<0.01	0.01	0.01
205	-	-	-	-	-	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
210	-	-	-	-	-	-	-	-	-	-	-	-

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 5.34: Morven North: Ensonified areas (km²) from the conservative 3.7m pin pile and near and far concurrent piling scenarios to maximum-over-depth sound pressure level values for each analysed penetration depth

SPL (dB re 1µPa²)	Ensonified area to level (km²)											
	A			B			C			D		
	Sgl	Near	Far	Sgl	Near	Far	Sgl	Near	Far	Sgl	Near	Far
140	3649	3717	6119	7716	7819	11409	12445	12580	17110	14980	15131	20052
145	2171	2223	3994	3651	3720	6132	6462	6554	9824	7906	8011	11616
150	1238	1277	2466	1990	2040	3722	3481	3547	5878	4005	4077	6582
155	522	547	1043	1103	1140	2207	1708	1755	3267	1746	1793	3322
160	254	272	508	333	353	665	709	738	1417	548	574	1095
165	141	154	282	182	196	363	225	241	450	166	181	333
170	71.8	81.1	144	78.4	88.2	157	75.1	84.7	150	53.6	61.8	107
175	32.5	38.7	65.0	32.8	39.0	65.6	27.2	32.9	54.4	16.7	21.2	33.3
180	11.3	15.0	22.6	11.3	15.0	22.6	9.07	12.4	18.1	3.54	5.59	7.08
185	1.93	3.38	3.85	1.97	3.48	3.95	1.55	2.82	3.10	0.87	1.73	1.74
190	0.41	0.82	0.82	0.33	0.66	0.66	0.29	0.59	0.59	0.13	0.27	0.27
195	0.08	0.16	0.16	0.06	0.12	0.12	0.05	0.10	0.10	0.02	0.05	0.05
200	0.02	0.05	0.05	0.02	0.05	0.05	0.02	0.04	0.04	<0.01	0.02	0.02
205	-	-	-	-	-	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
210	-	-	-	-	-	-	-	-	-	-	-	-

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 5.35: Morven North: Ensonified areas (km²) from the representative 3.7m pin pile and near and far concurrent piling scenarios to maximum-over-depth peak (PK) impact thresholds for marine mammals from National Marine Fisheries Service (2024a) and fish from Popper *et al.* (2014)

Hearing group	Eff.	PK (dB)	Ensonified area to level (km²)											
			A			B			C			D		
			Sgl	Nr	Far	Sgl	Nr	Far	Sgl	Nr	Far	Sgl	Nr	Far
LF cetaceans	INJ	222	-	-	-	-	-	-	-	-	-	-	-	-
	TTS	216	0.05	0.10	0.10	0.03	0.07	0.07	0.02	0.04	0.04	<0.01	0.01	0.01
HF cetaceans	INJ	230	-	-	-	-	-	-	-	-	-	-	-	-
	TTS	224	-	-	-	-	-	-	-	-	-	-	-	-
VHF cetaceans	INJ	202	1.35	2.52	2.71	1.09	2.10	2.18	0.60	1.20	1.20	0.23	0.47	0.47
	TTS	196	4.64	6.99	9.27	2.78	4.56	5.57	2.19	3.76	4.37	1.23	2.33	2.46
Phocid pinnipeds	INJ	223	-	-	-	-	-	-	-	-	-	-	-	-
	TTS	217	0.03	0.05	0.05	0.02	0.05	0.05	0.01	0.03	0.03	<0.01	<0.01	<0.01
Fish Group 1	Inj.	213	0.08	0.17	0.17	0.05	0.11	0.11	0.04	0.07	0.07	0.02	0.04	0.04
Fish Group 2, 3, 4, Fish eggs, and fish larvae	Inj.	207	0.21	0.41	0.41	0.16	0.32	0.32	0.11	0.22	0.22	0.05	0.10	0.10

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 5.36: Morven North: Ensonified areas (km²) from the conservative 3.7m pin pile and near and far concurrent piling scenarios to maximum-over-depth peak (PK) impact thresholds for marine mammals from National Marine Fisheries Service (2024a) and fish from Popper *et al.* (2014)

Hearing group	Eff.	PK (dB)	Ensonified area to level (km²)											
			A			B			C			D		
			Sgl	Nr	Far	Sgl	Nr	Far	Sgl	Nr	Far	Sgl	Nr	Far
LF cetaceans	INJ	222	-	-	-	-	-	-	-	-	-	-	-	-
	TTS	216	0.04	0.08	0.08	0.03	0.06	0.06	0.02	0.05	0.05	<0.01	0.02	0.02
HF cetaceans	INJ	230	-	-	-	-	-	-	-	-	-	-	-	-
	TTS	224	-	-	-	-	-	-	-	-	-	-	-	-
VHF cetaceans	INJ	202	1.78	3.15	3.56	0.94	1.85	1.89	0.54	1.08	1.08	0.27	0.54	0.54
	TTS	196	7.82	10.9	15.7	4.16	6.40	8.32	2.62	4.36	5.24	1.29	2.42	2.57
Phocid pinnipeds	INJ	223	-	-	-	-	-	-	-	-	-	-	-	-
	TTS	217	0.03	0.07	0.07	0.02	0.05	0.05	0.02	0.04	0.04	<0.01	<0.01	<0.01
Fish Group 1	Inj.	213	0.08	0.16	0.16	0.06	0.11	0.11	0.04	0.08	0.08	0.02	0.04	0.04
Fish Group 2, 3, 4, Fish eggs, and fish larvae	Inj.	207	0.37	0.74	0.74	0.23	0.46	0.46	0.15	0.29	0.29	0.08	0.16	0.16

A dash (-) indicates that the level was not reached within the resolution of the model.

5.6 Concurrent piles – Multiple strikes

5.6.1.1 This section provides tabulated results of the concurrent piling scenarios, where the total sound field from concurrent piling operations is considered. The scenarios are as listed in Table 2.7.

5.6.1.2 As detailed in Section 4.7, the SEL fields from contributing piles are summed, such that the sound level at any given point ensonified by both sources will be elevated. Fish have been treated as static receivers and marine mammals as moving receivers as described in Section 4.8.

5.6.1.3 Table 5.37 and Table 5.38 show the distances to SEL impact thresholds for two concurrent 16m monopile piling operations in close proximity for representative and conservative cases, with and without ADD, for marine mammals and fish respectively. Similarly, Table 5.39 and Table 5.40 show results for two widely separated piles. These are directly comparable to the single 16m monopile results in Table 5.19 for marine mammals and Table 5.20 for fish.

Table 5.37: Morven North: Maximum horizontal distances in kilometres from two close proximity 16m monopile operations to maximum-over-depth sound exposure level impact thresholds for marine mammals from National Marine Fisheries Service (2024a). Sound levels are frequency-weighted for cetaceans according to the hearing group

Hearing group	Effect	SEL (dB)	Maximum horizontal distance to threshold (km)							
			Representative				Conservative			
			No ADD		ADD		No ADD		ADD	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
LF cetaceans	AUD INJ	183	7.06	6.24	2.95	2.50	14.2	13.5	10.1	9.44
	TTS	168	25.5	23.6	21.3	19.6	49.6	43.1	45.5	39.3
HF cetaceans	AUD INJ	193	-	-	-	-	-	-	-	-
	TTS	178	-	-	-	-	-	-	-	-
VHF cetaceans	AUD INJ	159	-	-	0.01	0.01	-	-	0.02	0.02
	TTS	144	-	-	1.57	1.36	0.02	0.02	1.57	1.38
PCW	AUD INJ	183	-	-	-	-	0.52	0.49	-	-
	TTS	168	5.84	5.20	2.59	2.28	12.2	11.5	9.00	8.33

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 5.38: Morven North: Maximum horizontal distances in kilometres from two close proximity 16m monopile operations to maximum-over-depth sound exposure level impact thresholds for fish from Popper *et al.* (2014)

Hearing group	Effect	SEL (dB)	Maximum horizontal distance to threshold (km)			
			Representative		Conservative	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
Fish Group 1	Mortality	219	2.36	2.05	2.82	2.52
	Injury	216	3.16	2.81	3.98	3.60
Fish Group 2	Mortality	210	5.30	4.81	6.97	6.52
	Injury	203	8.83	8.06	12.8	11.8
Fish Group 3 and, 4	Mortality	207	6.64	6.06	8.84	8.37
	Injury	203	8.83	8.06	12.8	11.8
All fish groups	TTS	186	26.8	24.9	38.1	35.5
Fish eggs, and fish larvae	Mortality	210	5.30	4.81	6.97	6.52

Table 5.39: Morven North: Maximum horizontal distances in kilometres from two widely separated 16m monopile operations to maximum-over-depth sound exposure level impact thresholds for marine mammals from National Marine Fisheries Service (2024a). Sound levels are frequency-weighted for cetaceans according to the hearing group

Hearing group	Effect	SEL (dB)	Maximum horizontal distance to threshold (km)							
			Representative				Conservative			
			No ADD		ADD		No ADD		ADD	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
LF cetaceans	AUD INJ	183	7.90	6.05	2.87	2.46	19.4	16.0	16.2	12.3
	TTS	168	26.9	21.4	24.2	19.5	47.7	38.3	43.9	34.9
HF cetaceans	AUD INJ	193	-	-	-	-	-	-	-	-
	TTS	178	-	-	-	-	-	-	-	-
VHF cetaceans	AUD INJ	159	-	-	-	-	-	-	-	-
	TTS	144	-	-	1.19	0.97	-	-	1.23	1.02
PCW	AUD INJ	183	-	-	-	-	-	-	-	-
	TTS	168	6.66	5.13	3.19	2.57	16.2	12.3	12.8	9.75

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 5.40: Morven North: Maximum horizontal distances in kilometres from two widely separated 16m monopile operations to maximum-over-depth sound exposure level impact thresholds for fish from Popper *et al.* (2014)

Hearing group	Effect	SEL (dB)	Maximum horizontal distance to threshold (km)			
			Representative		Conservative	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
Fish Group 1	Mortality	219	1.66	1.58	1.97	1.89
	Injury	216	2.39	2.27	2.86	2.74
Fish Group 2	Mortality	210	4.23	3.98	5.41	5.20
	Injury	203	7.21	6.78	9.59	9.20
Fish Group 3 and, 4	Mortality	207	5.40	5.06	7.12	6.81
	Injury	203	7.21	6.78	9.59	9.20
All fish groups	TTS	186	26.6	22.4	37.3	31.4
Fish eggs, and fish larvae	Mortality	210	4.23	3.98	5.41	5.20

5.6.1.4 Table 5.37 and Table 5.38 show the distances to SEL impact thresholds for two concurrent 5.3m pin pile piling operations in close proximity for representative and conservative cases, with and without ADD, for marine mammals and fish respectively. Similarly, Table 5.39 and Table 5.40 show results for two widely separated piles. These are directly comparable to the single 5.3m pin pile results in Table 5.21 for marine mammals and Table 5.21 for fish.

Table 5.41: Morven North: Maximum horizontal distances in kilometres from two close proximity 5.3m pin pile operations to maximum-over-depth sound exposure level impact thresholds for marine mammals from National Marine Fisheries Service (2024a). Sound levels are frequency-weighted for cetaceans according to the hearing group

Hearing group	Effect	SEL (dB)	Maximum horizontal distance to threshold (km)							
			Representative				Conservative			
			No ADD		ADD		No ADD		ADD	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
LF cetaceans	AUD INJ	183	2.73	2.37	-	-	7.17	6.68	3.04	2.71
	TTS	168	24.3	21.2	20.1	17.3	54.4	44.7	50.3	41.0
HF cetaceans	AUD INJ	193	-	-	-	-	-	-	-	-
	TTS	178	-	-	-	-	-	-	-	-
VHF cetaceans	AUD INJ	159	-	-	0.01	0.01	-	-	0.02	0.02
	TTS	144	-	-	1.44	1.27	0.02	0.02	1.55	1.33
PCW	AUD INJ	183	-	-	-	-	-	-	-	-
	TTS	168	2.46	2.10	0.01	0.01	5.95	5.48	2.69	2.39

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 5.42: Morven North: Maximum horizontal distances in kilometres from two close proximity 5.3m pin pile operations to maximum-over-depth sound exposure level impact thresholds for fish from Popper *et al.* (2014)

Hearing group	Effect	SEL (dB)	Maximum horizontal distance to threshold (km)			
			Representative		Conservative	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
Fish Group 1	Mortality	219	0.95	0.79	1.09	0.93
	Injury	216	1.64	1.39	1.96	1.69
Fish Group 2	Mortality	210	3.26	2.94	4.14	3.76
	Injury	203	6.71	6.18	8.59	8.12
Fish Group 3 and, 4	Mortality	207	4.46	4.08	5.70	5.29
	Injury	203	6.71	6.18	8.59	8.12
All fish groups	TTS	186	27.6	25.5	37.3	35.0
Fish eggs, and fish larvae	Mortality	210	3.26	2.94	4.14	3.76

Table 5.43: Morven North: Maximum horizontal distances in kilometres from two widely separated 5.3m pin pile operations to maximum-over-depth sound exposure level impact thresholds for marine mammals from National Marine Fisheries Service (2024a). Sound levels are frequency-weighted for cetaceans according to the hearing group

Hearing group	Effect	SEL (dB)	Maximum horizontal distance to threshold (km)							
			Representative				Conservative			
			No ADD		ADD		No ADD		ADD	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
LF cetaceans	AUD INJ	183	3.19	2.40	-	-	8.66	6.58	2.14	1.73
	TTS	168	26.2	20.3	23.5	19.1	45.7	38.6	42.0	35.1
HF cetaceans	AUD INJ	193	-	-	-	-	-	-	-	-
	TTS	178	-	-	-	-	-	-	-	-
VHF cetaceans	AUD INJ	159	-	-	-	-	-	-	-	-
	TTS	144	-	-	1.17	0.93	-	-	1.20	0.99
PCW	AUD INJ	183	-	-	-	-	-	-	-	-
	TTS	168	2.77	2.09	-	-	6.98	5.31	2.14	1.68

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 5.44: Morven North: Maximum horizontal distances in kilometres from two widely separated 5.3m pin pile operations to maximum-over-depth sound exposure level impact thresholds for fish from Popper *et al.* (2014)

Hearing group	Effect	SEL (dB)	Maximum horizontal distance to threshold (km)			
			Representative		Conservative	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
Fish Group 1	Mortality	219	0.64	0.60	0.70	0.67
	Injury	216	0.97	0.93	1.14	1.08
Fish Group 2	Mortality	210	2.38	2.27	2.91	2.80
	Injury	203	5.08	4.80	6.52	6.24
Fish Group 3 and, 4	Mortality	207	3.35	3.18	4.18	4.02
	Injury	203	5.08	4.80	6.52	6.24
All fish groups	TTS	186	27.2	22.5	36.7	30.4
Fish eggs, and fish larvae	Mortality	210	2.38	2.27	2.91	2.80

5.6.1.5 Table 5.37 and Table 5.38 show the distances to SEL impact thresholds for two concurrent 3.7m pin pile operations in close proximity for representative and conservative cases, with and without ADD, for marine mammals and fish respectively. Similarly, Table 5.39 and Table 5.40 show results for two widely separated piles. These are directly comparable to the single 3.7m pin pile results in Table 5.23 for marine mammals and Table 5.24 for fish.

Table 5.45: Morven North: Maximum horizontal distances in kilometres from two close proximity 3.7m pin pile operations to maximum-over-depth sound exposure level impact thresholds for marine mammals from National Marine Fisheries Service (2024a). Sound levels are frequency-weighted for cetaceans according to the hearing group

Hearing group	Effect	SEL (dB)	Maximum horizontal distance to threshold (km)							
			Representative				Conservative			
			No ADD		ADD		No ADD		ADD	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
LF cetaceans	AUD INJ	183	3.99	3.48	-	-	9.75	9.00	5.61	5.00
	TTS	168	43.8	37.3	39.6	33.4	75.6	64.6	71.8	61.5
HF cetaceans	AUD INJ	193	-	-	-	-	-	-	-	-
	TTS	178	-	-	-	-	-	-	-	-
VHF cetaceans	AUD INJ	159	-	-	0.01	0.01	-	-	0.02	0.02
	TTS	144	0.49	0.44	1.49	1.29	0.93	0.79	1.61	1.40
PCW	AUD INJ	183	-	-	-	-	-	-	-	-
	TTS	168	4.00	3.46	0.84	0.73	8.96	8.16	5.70	5.04

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 5.46: Morven North: Maximum horizontal distances in kilometres from two close proximity 3.7m pin pile operations to maximum-over-depth sound exposure level impact thresholds for fish from Popper *et al.* (2014)

Hearing group	Effect	SEL (dB)	Maximum horizontal distance to threshold (km)			
			Representative		Conservative	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
Fish Group 1	Mortality	219	0.62	0.52	0.66	0.57
	Injury	216	0.91	0.75	1.18	0.95
Fish Group 2	Mortality	210	2.19	1.94	2.74	2.47
	Injury	203	4.60	4.19	5.97	5.55
Fish Group 3 and, 4	Mortality	207	3.02	2.72	3.87	3.55
	Injury	203	4.60	4.19	5.97	5.55
All fish groups	TTS	186	24.6	22.7	31.8	30.3
Fish eggs, and fish larvae	Mortality	210	2.19	1.94	2.74	2.47

Table 5.47: Morven North: Maximum horizontal distances in kilometres from two widely separated 3.7m pin pile operations to maximum-over-depth sound exposure level impact thresholds for marine mammals from National Marine Fisheries Service (2024a). Sound levels are frequency-weighted for cetaceans according to the hearing group

Hearing group	Effect	SEL (dB)	Maximum horizontal distance to threshold (km)							
			Representative				Conservative			
			No ADD		ADD		No ADD		ADD	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
LF cetaceans	AUD INJ	183	4.52	3.35	-	-	12.9	9.37	6.66	4.90
	TTS	168	40.6	31.9	36.9	28.8	65.8	55.7	61.6	52.3
HF cetaceans	AUD INJ	193	-	-	-	-	-	-	-	-
	TTS	178	-	-	-	-	-	-	-	-
VHF cetaceans	AUD INJ	159	-	-	-	-	-	-	-	-
	TTS	144	0.06	0.06	1.17	0.94	0.95	0.73	1.29	1.03
PCW	AUD INJ	183	-	-	-	-	-	-	-	-
	TTS	168	4.39	3.33	-	-	9.92	7.44	6.54	4.95

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 5.48: Morven North: Maximum horizontal distances in kilometres from two widely separated 3.7m pin pile operations to maximum-over-depth sound exposure level impact thresholds for fish from Popper *et al.* (2014)

Hearing group	Effect	SEL (dB)	Maximum horizontal distance to threshold (km)			
			Representative		Conservative	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
Fish Group 1	Mortality	219	0.38	0.35	0.42	0.39
	Injury	216	0.66	0.61	0.70	0.66
Fish Group 2	Mortality	210	1.59	1.48	1.99	1.86
	Injury	203	3.44	3.21	4.46	4.28
Fish Group 3 and, 4	Mortality	207	2.24	2.10	2.87	2.71
	Injury	203	3.44	3.21	4.46	4.28
All fish groups	TTS	186	20.1	18.5	31.4	25.8
Fish eggs, and fish larvae	Mortality	210	1.59	1.48	1.99	1.86

5.7 Vessel scenarios

5.7.1 Overview

5.7.1.1 The following tables provide distances to impact thresholds for sound generated as considered for the vessel scenarios. The behavioural threshold level is based on the unweighted SPL from NOAA (2019) and TTS and AUD INJ are from NMFS (2024a). For the calculation of SEL_{24h}, marine mammals are mobile as described in Section 4.8.

5.7.1.2 Most scenarios include multiple sources. The distances provided are the maximum distance to the identified threshold level from the closest sound source. For behavioural disturbance, this is the 120dB SPL value for continuous sounds as described in Section 3.2.3.

5.7.1.3 It is noted that direct source level measurements are not available for the installation vessel operating on DP but have been scaled from sound levels from a smaller vessel. Additionally, sound levels for DP operation are strongly dependent on environmental factors such as current and wind speed. Lastly, it is noted that the propagation loss curve becomes flatter with increased distance such that small changes in the source level can result in large changes in the reported distance to identified sound levels. Consequently, distances to the behavioural threshold of 120dB for continuous sound sources are difficult to predict accurately, and thus conservative results are presented.

5.7.2 Foundation installation

5.7.2.1 Table 5.49 contains SPL results for Scenario V1, for the foundation installation operation; the scenario comprises the pile installation vessel, the jacket installation vessel, four tugs, and a guard vessel. Results for the SEL are provided in Table 5.50.

Table 5.49: Morven North Scenario V1: Foundation installation. Maximum horizontal distances in kilometres to maximum-over-depth sound pressure level

SPL (dB re 1µPa^2)	Maximum horizontal distance to level (km)	
	R_{max}	$R_{95\%}$
120	51.2	39.7
125	27.2	21.3
130	14.4	11.5
135	8.30	6.45
140	4.67	3.53
145	2.44	1.85
150	0.99	0.86
155	0.47	0.42
160	0.20	0.18
165	0.06	0.06
170	0.03	0.03
175	<0.01	<0.01
180	<0.01	<0.01
185	<0.01	<0.01
190	<0.01	<0.01

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 5.50: Morven North Scenario V1: Foundation installation. Maximum horizontal distances in kilometres to maximum-over-depth sound exposure level impact thresholds for marine mammals from National Marine Fisheries Service (2024a). Sound levels are frequency-weighted for cetaceans according to the hearing group

Hearing group	Effect	Metric	Level (dB)	Maximum horizontal distance to threshold	
				R_{max} (km)	$R_{95\%}$ (km)
LF cetaceans	AUD INJ	$SEL_{24h,LF}$	197	-	-
	TTS	$SEL_{24h,LF}$	177	0.71	0.58
HF cetaceans	AUD INJ	$SEL_{24h,HF}$	201	-	-
	TTS	$SEL_{24h,HF}$	181	0.01	0.01
VHF cetaceans	AUD INJ	$SEL_{24h,VHF}$	181	-	-
	TTS	$SEL_{24h,VHF}$	161	0.01	0.01
PCW	AUD INJ	$SEL_{24h,PPW}$	195	-	-
	TTS	$SEL_{24h,PPW}$	175	0.08	0.08

A dash (-) indicates that the level was not reached within the resolution of the model.

5.7.3 Turbine installation

5.7.3.1 Table 5.51 contains SPL results for Scenario V2, for the turbine installation operation; the scenario comprises the turbine installation vessel, the offshore support vessel, and a guard vessel. Results for the SEL are provided in Table 5.52.

Table 5.51: Morven North Scenario V2: Turbine installation. Maximum horizontal distances in kilometres to maximum-over-depth Sound Pressure Level

SPL (dB re 1μPa^2)	Maximum horizontal distance to level (km)	
	R_{max}	$R_{95\%}$
120	44.2	31.7
125	22.4	17.7
130	12.2	9.93
135	6.81	5.37
140	3.81	2.93
145	1.96	1.52
150	0.76	0.69
155	0.35	0.30
160	0.15	0.14
165	0.06	0.05
170	0.03	0.03
175	0.03	0.03
180	0.03	0.03
185	0.03	0.03
190	0.03	0.03

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 5.52: Morven North Scenario V2: Turbine installation. Maximum horizontal distances in kilometres to maximum-over-depth sound exposure level impact thresholds for marine mammals from National Marine Fisheries Service (2024a). Sound levels are frequency-weighted for cetaceans according to the hearing group

Hearing group	Effect	Metric	Level (dB)	Maximum horizontal distance to threshold	
				R_{max} (km)	$R_{95\%}$ (km)
LF cetaceans	AUD INJ	$SEL_{24h,LF}$	197	0.01	0.01
	TTS	$SEL_{24h,LF}$	177	0.41	0.32
HF cetaceans	AUD INJ	$SEL_{24h,HF}$	201	-	-
	TTS	$SEL_{24h,HF}$	181	0.01	0.01
VHF cetaceans	AUD INJ	$SEL_{24h,VHF}$	181	-	-
	TTS	$SEL_{24h,VHF}$	161	0.01	0.01
PCW	AUD INJ	$SEL_{24h,PPW}$	195	-	-
	TTS	$SEL_{24h,PPW}$	175	0.01	0.01

A dash (-) indicates that the level was not reached within the resolution of the model.

5.7.4 Cable laying

5.7.4.1 Table 5.53 contains SPL results for Scenario V3, for the cable laying operation; the scenario comprises the pile installation vessel, the jacket installation vessel, four tugs, and a guard vessel. Results for the SEL are provided in Table 5.54.

Table 5.53: Morven North Scenario V3: Cable laying. Maximum horizontal distances in kilometres to maximum-over-depth Sound Pressure Level

SPL (dB re 1µPa^2)	Maximum horizontal distance to level (km)	
	R_{max}	$R_{95\%}$
120	31.9	25.5
125	17.3	14.5
130	9.86	7.89
135	5.62	4.62
140	2.92	2.52
145	1.48	1.19
150	0.60	0.55
155	0.28	0.26
160	0.08	0.07
165	0.04	0.04
170	<0.01	<0.01
175	<0.01	<0.01
180	<0.01	<0.01
185	<0.01	<0.01
190	<0.01	<0.01

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 5.54: Morven North Scenario V3: Cable laying. Maximum horizontal distances in kilometres to maximum-over-depth sound exposure level impact thresholds for marine mammals from National Marine Fisheries Service (2024a). Sound levels are frequency-weighted for cetaceans according to the hearing group

Hearing group	Effect	Metric	Level (dB)	Maximum horizontal distance to threshold	
				R_{max} (km)	$R_{95\%}$ (km)
LF cetaceans	AUD INJ	$SEL_{24h,LF}$	197	0.01	0.01
	TTS	$SEL_{24h,LF}$	177	0.20	0.20
HF cetaceans	AUD INJ	$SEL_{24h,HF}$	201	-	-
	TTS	$SEL_{24h,HF}$	181	0.01	0.01
VHF cetaceans	AUD INJ	$SEL_{24h,VHF}$	181	0.01	0.01
	TTS	$SEL_{24h,VHF}$	161	0.10	0.10
PCW	AUD INJ	$SEL_{24h,PPW}$	195	<0.01	<0.01
	TTS	$SEL_{24h,PPW}$	175	0.01	0.01

A dash (-) indicates that the level was not reached within the resolution of the model.

5.7.5 Crew transfer

5.7.5.1 Table 5.55 contains SPL results for Scenario V4 crew transfer; the scenario comprises a single crew transfer vessel. Results for the SEL are provided in Table 5.56. It is noted that no threshold is exceeded when moving receivers are considered, so the table is included solely for consistency.

Table 5.55: Morven North Scenario V4: Crew transfer. Maximum horizontal distances in kilometres to maximum-over-depth Sound Pressure Level

SPL (dB re 1μPa^2)	Maximum horizontal distance to level (km)	
	R_{max}	$R_{95\%}$
120	0.59	0.54
125	0.28	0.27
130	0.10	0.10
135	0.04	0.04
140	0.03	0.03
145	<0.01	<0.01
150	<0.01	<0.01
155	<0.01	<0.01
160	<0.01	<0.01
165	-	-
170	-	-
175	-	-
180	-	-
185	-	-
190	-	-

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 5.56: Morven North Scenario V4: Crew transfer. Maximum horizontal distances in kilometres to maximum-over-depth sound exposure level impact thresholds for marine mammals from National Marine Fisheries Service (2024a). Sound levels are frequency-weighted for cetaceans according to the hearing group

Hearing group	Effect	Metric	Level (dB)	Maximum horizontal distance to threshold	
				R_{max} (km)	$R_{95\%}$ (km)
LF cetaceans	AUD INJ	$SEL_{24h,LF}$	197	-	-
	TTS	$SEL_{24h,LF}$	177	-	-
HF cetaceans	AUD INJ	$SEL_{24h,HF}$	201	-	-
	TTS	$SEL_{24h,HF}$	181	-	-
VHF cetaceans	AUD INJ	$SEL_{24h,VHF}$	181	-	-
	TTS	$SEL_{24h,VHF}$	161	-	-
PCW	AUD INJ	$SEL_{24h,PPW}$	195	-	-
	TTS	$SEL_{24h,PPW}$	175	-	-

A dash (-) indicates that the level was not reached within the resolution of the model.

5.8 Geophysical survey sources

5.8.1.1 Table 5.57 presents the distances to the PK impact thresholds, as defined by NMFS (2024a), for the geophysical survey sources. All devices except the Sparker are classified as non-impulsive and therefore do not have defined PK thresholds for AUD INJ or TTS. However, due to the characteristics of the source signals, there are instances where the distances to impulsive PK thresholds exceed those for SEL thresholds.

5.8.1.2 There is no specific recommendation from NMFS (2024a) to provide distances to the PK threshold for non-impulsive sources. As a conservative precautionary measure, however, and in the absence of defined PK thresholds for non-impulsive sources, the impulsive source threshold has been applied when evaluating peak sound levels for all sources as described in NMFS (2024b). This conservative approach is explained further in Appendix D.2.4.

5.8.1.3 Table 5.58 provides distances to the SEL impact thresholds defined by NMFS (2024a) resulting from a pass of single survey line of the geophysical survey sources. Note that a different threshold exists for the Sparker being impulsive in nature; all other sources use the non-impulsive threshold.

5.8.1.4 Note that the dual metric approach applies when determining distances to impact thresholds, (i.e. the maximum distance across equivalent cells in Table 5.57 and Table 5.58 should be taken as the result for the device).

5.8.1.5 Table 5.59 shows results to the unweighted behavioural disturbance SPL thresholds defined by NOAA (2019). As discussed in Section 3.2.3, the threshold for behavioural disturbance for these sources is an SPL of 160 dB for intermittent source types.

Table 5.57: Morven North: Maximum horizontal distances in kilometres from the geophysical sources to maximum-over-depth peak (PK) impact thresholds for marine mammals from National Marine Fisheries Service (2024a)

Hearing group	Effect	PK (dB)	Maximum horizontal distance to threshold (km)					
			Non-impulsive					Impulsive
			MBES	SSS	SBES	CHIRP 2.0kHz	CHIRP 3.5kHz	Sparker
LF cetaceans	AUD INJ	222	0.015	0.004	0.007	-	0.007	-
	TTS	216	0.029	0.007	0.007	0.001	0.013	0.002
HF cetaceans	AUD INJ	230	0.007	0.002	0.002	-	0.003	-
	TTS	224	0.013	0.003	0.004	-	0.006	-
VHF cetaceans	AUD INJ	202	0.105	0.032	0.007	0.006	0.064	0.009
	TTS	196	0.165	0.036	0.007	0.010	0.126	0.018
PCW	AUD INJ	223	0.014	0.004	0.005	-	0.006	-
	TTS	217	0.026	0.007	0.007	0.001	0.012	0.002

A dash (-) indicates that the level was not reached within the resolution of the model.
Distances to the PK thresholds are not shown for the non-impulsive sources because it was assessed based on the intermittent source criteria which does not include PK thresholds.

Table 5.58: Morven North: Maximum horizontal distances in kilometres from the geophysical sources to maximum-over-depth sound exposure level impact thresholds for marine mammals from National Marine Fisheries Service (2024a)

Hearing group	Effect	Maximum horizontal distance to threshold (km)							
		Non-impulsive						Impulsive	
		SEL (dB)	MBES	SSS	SBES	CHIRP 2.0kHz	CHIRP 3.5kHz	SEL (dB)	Sparker
LF cetaceans	AUD INJ	197	-	-	0.002	0.003	0.071	183	0.016
	TTS	177	-	-	0.007	0.057	0.712	168	0.110
HF cetaceans	AUD INJ	201	0.016	0.002	0.003	-	0.039	193	-
	TTS	181	0.124	0.036	0.007	0.022	0.406	178	0.002
VHF cetaceans	AUD INJ	181	0.181	0.036	0.007	-	0.114	159	-
	TTS	161	0.505	0.200	0.064	0.030	1.129	144	0.004
PCW	AUD INJ	195	0.058	-	0.005	0.003	0.091	183	0.004
	TTS	175	0.262	0.020	0.007	0.066	0.907	168	0.040

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 5.59: Morven North: Maximum horizontal distances in kilometres from the geophysical sources to behavioural threshold for marine mammals from intermittent (impulsive and non-impulsive) sources from National Marine Fisheries Service (2024a)

Hearing group	Effect	SPL (dB)	Maximum horizontal distance to threshold (km)					
			MBES	SSS	SBES	CHIRP 2.0kHz	CHIRP 3.5kHz	Sparker
Marine mammals	Behaviour	160	0.682	0.229	0.153	0.316	3.798	0.501

A dash (-) indicates that the level was not reached within the resolution of the model.

5.9 Unexploded ordnance

5.9.1.1 The following tables show results for the distances to identified sound level thresholds for the UXO scenarios. Table 5.60 shows distances to stepped SPL values for the four scenarios.

Table 5.60: Morven North: Maximum horizontal distances in kilometres from the unexploded ordnance to maximum-over-depth Sound Pressure Level values

SPL (dB re 1μPa²)	Maximum horizontal distance to level (km)							
	554kg		132kg		25kg		0.25kg	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
160	>150	>144	112	95.4	52.6	47.7	9.41	8.88
165	118	101	70.8	60.8	34.0	32.2	6.59	6.21
170	78.0	65.7	43.0	40.2	24.0	22.5	4.38	4.16
175	48.3	44.4	29.4	27.8	16.6	15.4	2.73	2.63
180	32.7	31.0	21.0	19.7	9.45	8.92	1.65	1.52
185	23.4	22.0	12.8	11.7	6.39	5.99	0.81	0.76
190	16.0	14.8	8.13	7.61	4.21	3.99	0.30	0.30
195	9.25	8.73	5.34	5.04	2.73	2.61	0.15	0.15
200	6.14	5.79	3.52	3.36	1.65	1.51	0.07	0.07
205	4.05	3.85	2.24	2.14	0.79	0.72	0.02	0.02
210	2.57	2.48	1.09	0.99	0.30	0.29	0.02	0.02
215	1.47	1.38	0.53	0.49	0.15	0.14	-	-
220	0.73	0.68	0.23	0.22	0.07	0.07	-	-
225	0.28	0.27	0.10	0.10	0.02	0.02	-	-
230	0.13	0.12	0.04	0.04	0.02	0.02	-	-
235	0.05	0.05	0.02	0.02	-	-	-	-
240	0.02	0.02	-	-	-	-	-	-

A dash (-) indicates that the level was not reached within the resolution of the model.
The maximum modelled distance was 150km; an entry of ">150" is used where sound levels exceeding the threshold exist outside the modelled domain.

Table 5.61: Morven North: Maximum horizontal distances in kilometres from the unexploded ordnance maximum-over-depth peak (PK) impact thresholds for marine mammals from National Marine Fisheries Service (2024a) and fish from Popper *et al.* (2014)

Hearing group	Effect	PK (dB)	Maximum horizontal distance to threshold (km)							
			554kg		132kg		25kg		0.25kg	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
LF cetaceans	AUD INJ	222	2.94	2.76	2.07	1.88	0.81	0.73	0.04	0.04
	TTS	216	4.74	4.39	2.98	2.80	1.86	1.67	0.09	0.09
HF cetaceans	AUD INJ	230	1.65	1.47	0.68	0.62	0.28	0.27	-	-
	TTS	224	2.55	2.44	1.69	1.52	0.63	0.56	0.02	0.02
VHF cetaceans	AUD INJ	202	16.4	14.2	9.58	8.20	5.29	4.72	0.53	0.49
	TTS	196	23.2	21.4	17.1	14.9	8.82	7.62	1.36	1.17
PCW	AUD INJ	223	2.72	2.59	1.89	1.70	0.69	0.62	0.04	0.04
	TTS	217	4.38	4.09	2.74	2.61	1.67	1.47	0.07	0.07
Fish	Injury	229	1.86	1.68	0.77	0.69	0.32	0.31	0.02	0.02
		234	0.91	0.71	0.49	0.46	0.17	0.16	-	-

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 5.62: Morven North: Maximum horizontal distances in kilometres from the Unexploded Ordnance to maximum-over-depth Sound Exposure Level impact thresholds for marine mammals from National Marine Fisheries Service (2024a). Sound levels are frequency-weighted for cetaceans according to the hearing group

Hearing group	Effect	SEL (dB)	Maximum horizontal distance to threshold (km)							
			554kg		132kg		25kg		0.25kg	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
LF cetaceans	AUD INJ	183	8.75	8.14	5.39	5.04	2.83	2.67	0.15	0.14
	TTS	168	31.7	30.0	21.2	19.9	9.92	9.38	1.43	1.29
HF cetaceans	AUD INJ	193	0.02	0.02	0.02	0.02	-	-	-	-
	TTS	178	0.28	0.27	0.20	0.20	0.07	0.07	-	-
VHF cetaceans	AUD INJ	159	1.72	1.52	0.91	0.83	0.37	0.35	0.02	0.02
	TTS	144	6.04	5.64	4.16	3.90	2.66	2.49	0.20	0.20
PCW	AUD INJ	183	2.89	2.73	1.82	1.64	0.77	0.67	0.02	0.02
	TTS	168	9.98	9.40	7.10	6.60	4.14	3.88	0.30	0.29

A dash (-) indicates that the level was not reached within the resolution of the model.

6 Results – Morven South

6.1 Overview

6.1.1.1 This section provides results of the sound field modelling for each of the sources, for all considered metrics for the Morven South Boundary. Where appropriate, these are compared against impact thresholds in scientific literature. Distances are provided in terms of the Rmax, the maximum distance to the identified sound level, and the $R_{95\%}$, the maximum distance to the threshold after removing the most distant 5% of the ensonified area. Further details of these are provided in Appendix F.

6.2 Impact pile driving – Forcing functions and near-field results

6.2.1 Pile forcing functions

6.2.1.1 The three different piles considered each have a specific hammer and anvil setup. The key parameters are shown in Table 2.4 and Table 2.5. As described, the force at the top of the pile is calculated using GRLWEAP, which takes the specific hammer, anvils, hammer energy, and pile geometry into account in the calculation. The forcing cunctions are shown in Table 6.1 in the time domain and in decidecade bands.

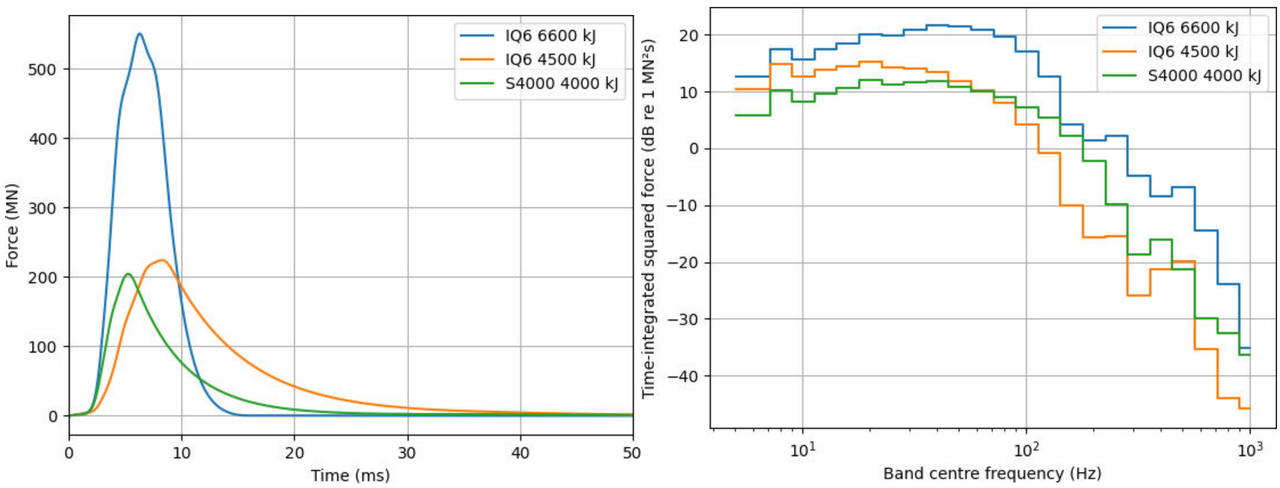

Figure 6.1: Morven South: Forcing functions at the top of the piles in the time domain (left) and in decidecade bands (right)

6.2.2 Sound levels close to the pile

6.2.2.1 It is not physically meaningful to provide a point source level for a driven pile. As described in the previous section, the source function comprises many individual monopile sources that, when combined, recreate the wavefront generated by the impacted pile. To provide a meaningful illustration of 'source levels', the following sections show sound levels 10m from the centre of each pile.

6.2.2.2 As described, source functions for the piling scenarios were generated for the three pile designs, each at four different piling penetrations, for the median and maximum reflectivity environments. Figure 6.2, Figure 6.3, and Figure 6.4 show the maximum-over-depth received per-pulse SEL in decidecade bands 10m from the centre of the pile for the 16m monopile, 5.3m diameter pin pile, and

3.7m diameter pin pile respectively. Each figure shows the considered combinations of analysed penetration depths and environments.

6.2.2.3 The spectrum is extended to higher frequencies (up to 25kHz) by applying a 20dB per decade decay rate to match measurements of impact pile driving (Matuschek and Betke 2009, Bellmann *et al.* 2020). Levels presented are the maximum over the water column for each scenario.

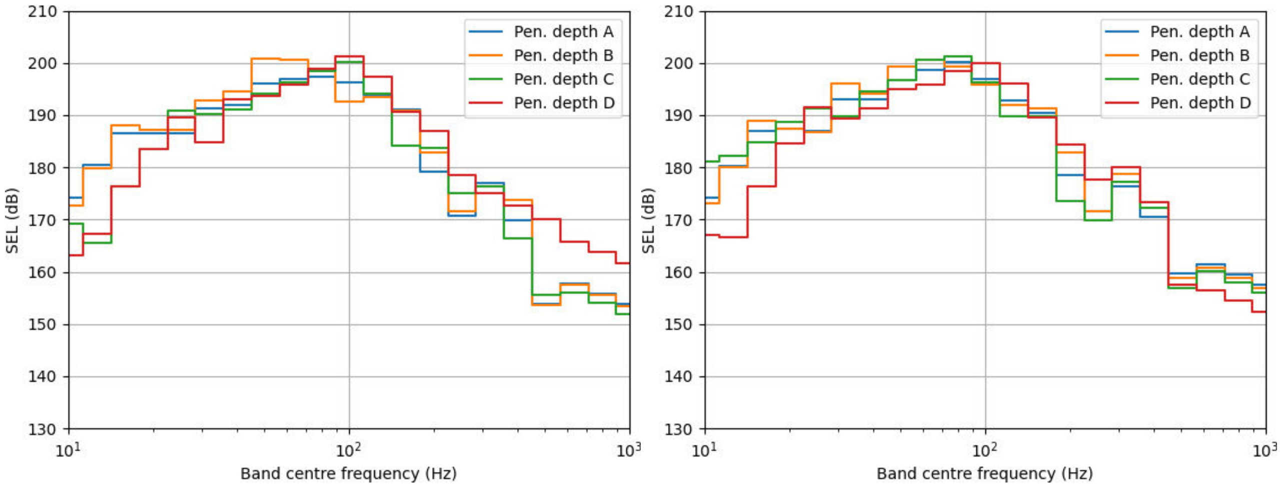

Figure 6.2: Morven South: Maximum-over-depth per-pulse sound exposure level in decidecade bands, 10m from the pile centre for the 16m monopile in median reflectivity environment (left) and maximum reflectivity environment (right)

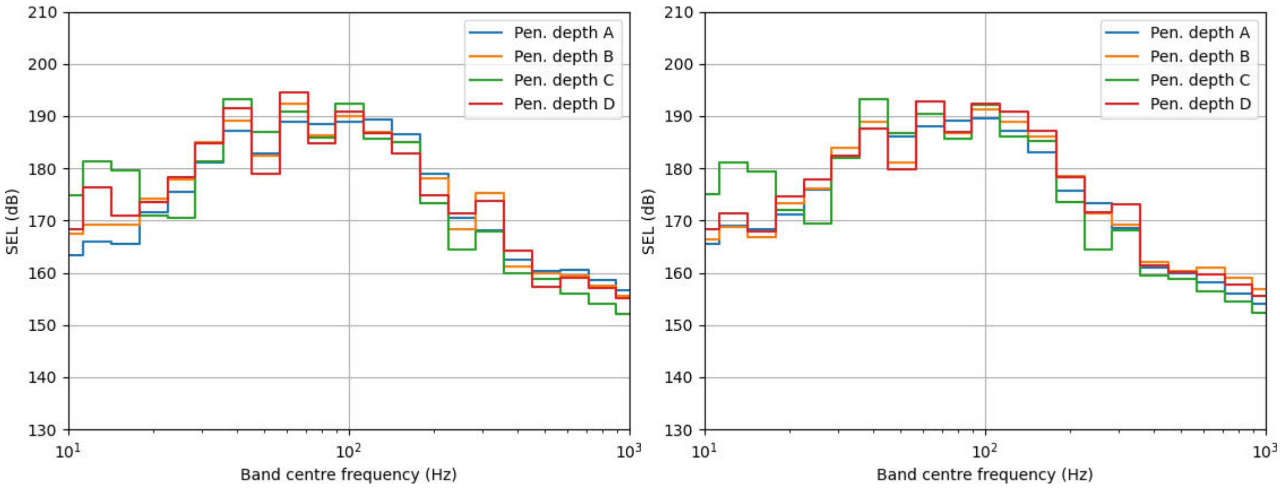

Figure 6.3: Morven South: Maximum-over-depth per-pulse sound exposure level in decidecade bands, 10m from the pile centre for the 5.3m pin pile in median reflectivity environment (left) and maximum reflectivity environment (right)

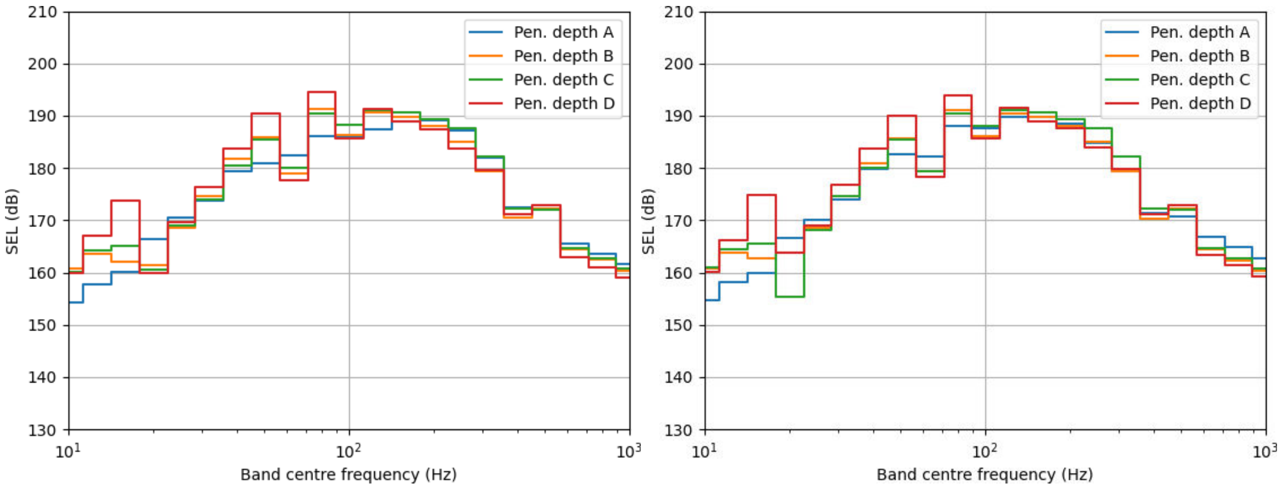

Figure 6.4: Morven South: Maximum-over-depth per-pulse Sound Exposure Llevel in decidecade bands, 10m from the pile centre for the 3.7m pin pile in median reflectivity environment (left) and maximum reflectivity environment (right)

6.3 Single pile – Single strikes

6.3.1.1 This section provides results of the impact pile driving when considering single impacts. Results are presented for each of the three considered pile at each of the four penetration depths.

6.3.1.2 Table 6.1 and Table 6.2 show the maximum distances to specified SPL values from the 16m monopile at each analysed penetration depth for representative and conservative cases respectively. Similarly, Table 6.3 and Table 6.4 contain SPL results for the 5.3m pin pile, and Table 6.5 and Table 6.6 show results for the 3.7m pin pile.

6.3.1.3 Table 6.7 and Table 6.8 show the maximum distances to specified unweighted per-pulse SEL values from the 16m monopile at each analysed penetration depth for representative and conservative cases respectively. Similarly, Table 6.9 and Table 6.10 contain unweighted per-pulse SEL results for the 5.3m pin pile, and Table 6.11 and Table 6.12 show results for the 3.7m pin pile.

6.3.1.4 Table 6.13 and Table 6.14 show the maximum distances to identified AUD INJ and TTS PK impact thresholds for marine mammals from NMFS (2024a) and fish from Popper *et al.* (2014) from the 16m monopile at each analysed penetration depth for representative and conservative cases respectively. Similarly, Table 6.15 and Table 6.16 contain equivalent results for the 5.3m pin pile, and Table 6.17 and Table 6.18 show results for the 3.7m pin pile.

Table 6.1: Morven South: Maximum horizontal distances in kilometres from the representative 16m monopile to maximum-over-depth Sound Pressure Level values for each analysed penetration depth

SPL (dB re 1μPa^2)	Maximum horizontal distance to level (km)							
	A		B		C		D	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
120	84.7	72.9	103	88.6	91.8	79.4	125	105
125	69.6	60.3	86.8	75.6	76.3	66.3	99.5	82.3
130	56.8	50.9	73.2	63.1	63.0	55.2	75.3	64.2
135	47.4	43.1	59.1	52.2	50.4	45.8	57.2	50.9
140	40.0	36.3	47.2	42.9	41.8	37.9	45.6	41.4
145	33.2	30.6	37.7	34.5	33.8	31.1	36.8	33.6
150	27.4	25.5	29.3	27.3	27.4	25.6	28.7	26.6
155	22.1	20.8	22.8	21.5	22.2	20.9	22.6	21.3
160	17.0	15.8	17.4	16.3	16.7	15.5	17.4	16.2
165	9.82	9.36	9.86	9.45	9.67	9.21	9.89	9.43
170	7.46	7.00	7.45	7.02	7.08	6.60	7.48	7.00
175	5.07	4.77	5.17	4.87	4.96	4.64	5.23	4.90
180	3.39	3.21	3.57	3.39	3.36	3.18	3.51	3.33
185	2.06	1.99	2.26	2.17	2.13	2.05	2.23	2.14
190	0.94	0.90	0.99	0.96	0.98	0.94	1.10	1.04
195	0.42	0.41	0.54	0.52	0.53	0.50	0.54	0.51
200	0.20	0.20	0.20	0.20	0.21	0.21	0.24	0.23
205	0.10	0.10	0.10	0.10	0.13	0.13	0.14	0.14
210	-	-	0.02	0.02	-	-	0.02	0.02

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 6.2: Morven South: Maximum horizontal distances in kilometres from the conservative 16m monopile to maximum-over-depth Sound Pressure Level values for each analysed penetration depth

SPL (dB re 1µPa^2)	Maximum horizontal distance to level (km)							
	A		B		C		D	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
120	133	114	>150	>138	>150	>138	>150	>140
125	109	93.8	135	114	134	113	131	111
130	87.8	76.2	112	94.0	109	92.5	103	88.7
135	70.6	61.3	89.1	75.9	87.1	73.8	84.1	72.4
140	55.7	49.8	69.6	60.0	66.3	56.9	66.1	57.7
145	45.2	41.0	52.0	46.7	48.7	43.4	50.8	46.0
150	36.3	33.4	38.8	35.4	37.2	33.8	39.3	36.0
155	28.6	26.6	28.7	26.8	28.4	26.2	29.1	27.3
160	21.9	20.5	21.5	20.4	21.5	20.2	22.0	20.8
165	15.7	14.3	15.2	13.9	14.1	12.9	16.3	15.0
170	9.44	8.94	9.30	8.74	8.68	8.13	9.62	9.10
175	6.47	6.08	6.44	6.07	6.01	5.66	6.81	6.35
180	4.04	3.87	4.40	4.15	4.04	3.84	4.51	4.26
185	2.43	2.34	2.75	2.64	2.48	2.38	2.70	2.60
190	1.16	1.09	1.46	1.37	1.22	1.17	1.43	1.34
195	0.56	0.54	0.61	0.58	0.56	0.54	0.63	0.61
200	0.17	0.17	0.21	0.20	0.21	0.20	0.23	0.22
205	0.12	0.12	0.12	0.12	0.12	0.12	0.14	0.14
210	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03

A dash (-) indicates that the level was not reached within the resolution of the model.
The maximum modelled distance was 150km; an entry of ">150" is used where sound levels exceeding the threshold exist outside the modelled domain.

Table 6.3: Morven South: Maximum horizontal distances in kilometres from the representative 5.3m diameter pin pile to maximum-over-depth Sound Pressure Level values for each analysed penetration depth

SPL (dB re 1µPa²)	Maximum horizontal distance to level (km)							
	A		B		C		D	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
120	82.2	67.0	85.3	70.1	131	109	142	121
125	58.9	51.3	61.7	52.8	99.6	83.4	116	97.6
130	46.0	42.1	44.5	40.6	74.3	62.7	89.9	77.4
135	38.2	35.0	37.0	34.1	52.1	47.1	70.6	60.1
140	30.8	28.5	31.1	28.9	40.9	37.3	51.5	46.4
145	24.5	22.9	26.0	24.4	32.0	29.6	38.8	35.4
150	19.1	17.9	21.2	20.0	25.3	23.7	28.6	26.6
155	11.5	10.5	15.3	14.2	20.1	19.0	20.5	19.3
160	8.04	7.50	9.32	8.80	13.1	12.1	11.6	10.8
165	5.68	5.30	6.67	6.26	8.44	7.98	7.22	6.83
170	3.93	3.73	4.78	4.49	5.27	5.00	4.01	3.84
175	2.68	2.57	3.20	3.06	3.06	2.94	2.16	2.09
180	1.62	1.54	1.99	1.91	1.81	1.75	0.99	0.97
185	0.78	0.75	0.94	0.91	0.77	0.74	0.51	0.48
190	0.34	0.33	0.39	0.38	0.33	0.32	0.20	0.20
195	0.17	0.17	0.18	0.18	0.15	0.15	0.08	0.08
200	0.06	0.06	0.08	0.08	0.06	0.06	0.03	0.03
205	-	-	-	-	-	-	-	-
210	-	-	-	-	-	-	-	-

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 6.4: Morven South: Maximum horizontal distances in kilometres from the conservative 5.3m pin pile to maximum-over-depth Sound Pressure Level values for each analysed penetration depth

SPL (dB re 1µPa^2)	Maximum horizontal distance to level (km)							
	A		B		C		D	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
120	125	103	126	105	>150	>143	>150	>144
125	90.7	78.2	90.7	76.6	139	118	>150	>142
130	73.1	63.3	67.1	59.0	99.7	84.8	146	121
135	57.4	51.1	53.3	47.8	73.9	63.8	106	89.8
140	44.4	40.6	42.6	39.0	56.4	50.2	79.3	67.9
145	33.6	31.4	33.9	31.5	42.6	39.3	54.7	49.3
150	25.1	23.5	27.3	25.3	31.9	29.8	38.7	35.3
155	18.5	17.1	21.0	19.6	24.4	23.0	26.5	24.8
160	10.2	9.52	13.2	12.0	18.6	17.4	16.6	15.6
165	7.26	6.80	8.34	7.79	10.1	9.58	8.80	8.32
170	4.88	4.58	5.83	5.47	6.63	6.30	4.70	4.50
175	3.14	3.01	3.80	3.63	3.74	3.60	2.41	2.32
180	1.92	1.84	2.27	2.19	2.09	2.02	1.09	1.06
185	0.84	0.81	0.99	0.96	0.97	0.93	0.51	0.50
190	0.36	0.34	0.52	0.50	0.45	0.44	0.23	0.23
195	0.16	0.15	0.20	0.19	0.14	0.14	0.09	0.09
200	0.09	0.09	0.10	0.10	0.08	0.08	0.05	0.05
205	-	-	-	-	-	-	-	-
210	-	-	-	-	-	-	-	-

A dash (-) indicates that the level was not reached within the resolution of the model.
The maximum modelled distance was 150km; an entry of ">150" is used where sound levels exceeding the threshold exist outside the modelled domain.

Table 6.5: Morven South: Maximum horizontal distances in kilometres from the representative 3.7m diameter pin pile to maximum-over-depth Sound Pressure Level values for each analysed penetration depth

SPL (dB re 1μPa²)	Maximum horizontal distance to level (km)							
	A		B		C		D	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
120	111	93.5	>150	>144	>150	>145	>150	>144
125	79.5	66.7	>150	>130	>150	>142	>150	>132
130	52.2	46.5	109	91.4	126	106	114	96.7
135	36.7	33.9	74.6	61.7	86.0	72.6	83.7	70.6
140	28.0	26.0	46.3	41.8	55.4	49.7	57.6	51.3
145	21.6	20.3	31.0	28.7	39.3	36.1	41.3	37.6
150	15.2	14.0	22.5	21.1	27.8	26.1	28.9	26.8
155	9.43	8.87	15.1	14.2	20.0	19.0	19.7	18.5
160	7.13	6.65	9.04	8.55	11.0	10.2	9.89	9.48
165	5.36	5.01	5.95	5.64	6.98	6.60	6.18	5.81
170	3.93	3.66	3.94	3.77	4.16	3.94	3.50	3.36
175	2.68	2.51	2.64	2.51	2.46	2.37	2.04	1.97
180	1.58	1.50	1.54	1.44	1.30	1.23	0.97	0.92
185	0.72	0.69	0.69	0.66	0.66	0.63	0.45	0.44
190	0.31	0.25	0.31	0.30	0.28	0.28	0.20	0.20
195	0.16	0.15	0.14	0.14	0.10	0.10	0.08	0.08
200	0.03	0.03	0.06	0.06	0.03	0.03	0.03	0.03
205	-	-	-	-	-	-	-	-
210	-	-	-	-	-	-	-	-

A dash (-) indicates that the level was not reached within the resolution of the model.
The maximum modelled distance was 150km; an entry of ">150" is used where sound levels exceeding the threshold exist outside the modelled domain.

Table 6.6: Morven South: Maximum horizontal distances in kilometres from the conservative 3.7m pin pile to maximum-over-depth Sound Pressure Level values for each analysed penetration depth

SPL (dB re 1µPa^2)	Maximum horizontal distance to level (km)							
	A		B		C		D	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
120	144	121	>150	>144	>150	>145	>150	>145
125	103	86.9	>150	>144	>150	>144	>150	>144
130	70.0	58.7	140	119	>150	>142	>150	>141
135	48.4	43.7	93.9	79.2	120	101	122	105
140	36.8	34.0	56.3	50.9	78.9	66.5	87.1	74.6
145	27.9	26.1	37.3	34.2	50.4	45.9	56.7	50.9
150	20.8	19.7	26.8	25.1	35.9	33.3	38.4	35.4
155	15.1	13.8	19.9	18.7	24.5	23.1	24.5	23.2
160	9.49	8.96	12.0	10.9	16.1	15.0	14.4	13.1
165	7.24	6.74	7.98	7.50	8.80	8.33	7.46	7.04
170	5.08	4.76	5.15	4.91	5.04	4.79	4.16	4.00
175	3.34	3.18	3.34	3.18	3.02	2.88	2.33	2.24
180	1.99	1.90	1.99	1.89	1.81	1.72	1.18	1.12
185	0.94	0.90	0.93	0.89	0.74	0.70	0.56	0.53
190	0.37	0.35	0.33	0.32	0.30	0.29	0.20	0.20
195	0.16	0.15	0.14	0.14	0.12	0.12	0.09	0.09
200	0.05	0.05	0.08	0.08	0.05	0.05	0.05	0.05
205	-	-	-	-	-	-	-	-
210	-	-	-	-	-	-	-	-

A dash (-) indicates that the level was not reached within the resolution of the model.
The maximum modelled distance was 150km; an entry of ">150" is used where sound levels exceeding the threshold exist outside the modelled domain.

Table 6.7: Morven South: Maximum horizontal distances in kilometres from the representative 16m monopile to maximum-over-depth Sound Exposure Level per-pulse values for each analysed penetration depth

SEL per-pulse (dB re 1µPa²s)	Maximum horizontal distance to level (km)							
	A		B		C		D	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
120	67.0	58.3	82.1	71.2	71.7	61.8	87.8	75.0
125	54.2	48.7	66.7	57.8	57.2	50.9	68.9	58.9
130	44.9	40.9	52.2	47.1	46.2	42.2	52.4	47.0
135	37.2	34.1	42.0	38.2	37.9	34.7	41.6	37.6
140	30.3	28.2	33.2	30.7	30.4	28.3	32.5	30.0
143	*26.8*	*25.0*	*28.8*	*26.9*	*26.7*	*24.9*	*28.1*	*26.1*
145	24.6	23.1	26.3	24.6	24.5	22.9	25.6	23.8
150	19.7	18.6	20.8	19.7	19.3	18.2	20.1	18.9
155	13.0	12.1	14.5	13.4	12.3	11.3	13.5	12.4
160	8.76	8.22	9.19	8.65	8.52	7.96	8.88	8.32
165	6.08	5.72	6.40	6.04	5.96	5.58	6.24	5.84
170	4.01	3.79	4.29	4.05	3.98	3.76	4.16	3.92
175	2.43	2.32	2.65	2.53	2.46	2.36	2.60	2.49
180	1.16	1.10	1.33	1.26	1.21	1.15	1.39	1.33
185	0.62	0.60	0.59	0.58	0.62	0.60	0.66	0.63
190	0.23	0.21	0.24	0.23	0.24	0.23	0.25	0.25
195	0.14	0.14	0.14	0.14	0.14	0.14	0.16	0.16
200	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
205	-	-	-	-	-	-	-	-
210	-	-	-	-	-	-	-	-

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 6.8: Morven South: Maximum horizontal distances in kilometres from the conservative 16m monopile to maximum-over-depth Sound Exposure Level per-pulse values for each analysed penetration depth

SEL per-pulse (dB re 1µPa²s)	Maximum horizontal distance to level (km)							
	A		B		C		D	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
120	110	94.6	129	111	124	106	127	111
125	87.4	77.0	103	88.9	97.6	84.6	102	88.1
130	70.9	61.4	81.9	70.0	78.2	66.6	80.9	69.4
135	55.1	49.2	61.6	54.2	58.4	51.9	60.5	53.8
140	43.7	39.6	46.7	42.3	45.0	40.6	46.2	42.0
143	*37.6*	*34.5*	*40.0*	*36.5*	*38.3*	*34.9*	*39.4*	*36.1*
145	33.9	31.3	35.8	32.9	34.1	31.4	35.2	32.6
150	26.4	24.6	27.2	25.4	25.8	24.0	26.9	25.1
155	20.4	19.2	20.9	19.7	19.7	18.6	20.8	19.6
160	13.3	12.1	14.4	13.2	12.6	11.3	14.2	12.9
165	8.46	7.96	8.98	8.44	8.26	7.75	8.89	8.32
170	5.35	5.07	5.82	5.52	5.35	5.07	5.72	5.41
175	3.06	2.95	3.43	3.30	3.17	3.03	3.34	3.21
180	1.56	1.48	1.88	1.79	1.67	1.61	1.79	1.71
185	0.63	0.62	0.78	0.75	0.73	0.70	0.73	0.70
190	0.22	0.22	0.28	0.27	0.28	0.27	0.30	0.29
195	0.14	0.14	0.14	0.14	0.14	0.14	0.15	0.15
200	0.04	0.04	0.05	0.05	0.04	0.04	0.04	0.04
205	-	-	-	-	-	-	-	-
210	-	-	-	-	-	-	-	-

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 6.9: Morven South: Maximum horizontal distances in kilometres from the representative 5.3m diameter pin pile to maximum-over-depth Sound Exposure Level per-pulse values for each analysed penetration depth

SEL per-pulse (dB re 1μPa²s)	Maximum horizontal distance to level (km)							
	A		B		C		D	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
120	53.8	48.0	54.0	48.5	83.8	71.1	101	85.9
125	42.8	39.0	43.7	39.9	63.1	54.9	79.4	67.1
130	34.3	31.5	35.8	33.0	47.8	43.6	58.6	51.6
135	27.1	25.2	29.1	27.1	38.0	34.8	43.4	39.6
140	21.2	20.0	23.5	22.1	29.7	27.6	32.1	29.8
143	*17.9*	*16.7*	*20.5*	*19.4*	*25.6*	*24.0*	*26.6*	*24.8*
145	15.1	14.0	18.4	17.3	23.1	21.8	23.4	21.9
150	9.36	8.84	11.1	10.1	16.9	15.8	15.4	14.4
155	6.82	6.38	8.13	7.62	9.60	9.18	8.63	8.12
160	4.72	4.43	5.66	5.33	6.31	6.01	5.01	4.75
165	3.08	2.94	3.72	3.56	3.73	3.56	2.70	2.61
170	1.88	1.80	2.29	2.20	2.15	2.07	1.43	1.37
175	0.88	0.84	1.02	0.97	0.94	0.90	0.58	0.56
180	0.39	0.38	0.48	0.43	0.52	0.49	0.29	0.28
185	0.18	0.18	0.23	0.21	0.17	0.17	0.09	0.09
190	0.10	0.10	0.10	0.10	0.08	0.08	0.03	0.03
195	-	-	-	-	0.03	0.03	-	-
200	-	-	-	-	-	-	-	-
205	-	-	-	-	-	-	-	-
210	-	-	-	-	-	-	-	-

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 6.10: Morven South: Maximum horizontal distances in kilometres from the conservative 5.3m pin pile to maximum-over-depth Sound Exposure Level per-pulse values for each analysed penetration depth

SEL per-pulse (dB re 1µPa²s)	Maximum horizontal distance to level (km)							
	A		B		C		D	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
120	89.2	76.7	87.5	75.7	121	106	>150	>139
125	68.9	59.6	68.3	59.5	94.2	81.7	124	107
130	51.6	46.4	52.7	47.5	72.6	62.4	94.0	80.1
135	39.0	36.0	41.6	38.0	53.7	48.2	66.6	58.0
140	29.2	27.3	32.0	29.8	40.6	37.3	46.1	41.8
143	*24.7*	*23.1*	*27.5*	*25.6*	*34.0*	*31.7*	*37.0*	*34.0*
145	22.1	20.8	24.8	23.0	30.4	28.4	31.5	29.3
150	16.1	14.7	19.0	17.7	22.3	21.2	20.8	19.7
155	9.51	9.00	11.2	10.1	14.7	13.6	10.4	9.70
160	6.54	6.15	7.80	7.28	8.41	7.96	6.23	5.90
165	4.02	3.84	4.89	4.64	4.90	4.66	3.22	3.12
170	2.29	2.19	2.81	2.70	2.64	2.54	1.57	1.52
175	0.97	0.94	1.35	1.29	1.26	1.18	0.75	0.73
180	0.40	0.39	0.61	0.59	0.53	0.52	0.30	0.29
185	0.17	0.17	0.22	0.22	0.19	0.19	0.12	0.12
190	0.10	0.09	0.12	0.12	0.11	0.10	0.05	0.05
195	-	-	-	-	0.03	0.03	-	-
200	-	-	-	-	-	-	-	-
205	-	-	-	-	-	-	-	-
210	-	-	-	-	-	-	-	-

A dash (-) indicates that the level was not reached within the resolution of the model.
The maximum modelled distance was 150km; an entry of ">150" is used where sound levels exceeding the threshold exist outside the modelled domain.

Table 6.11: Morven South: Maximum horizontal distances in kilometres from the representative 3.7m diameter pin pile to maximum-over-depth Sound Exposure Level per-pulse values for each analysed penetration depth

SEL per-pulse (dB re 1µPa²s)	Maximum horizontal distance to level (km)							
	A		B		C		D	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
120	58.5	51.8	115	96.3	132	111	126	106
125	42.3	38.8	80.1	66.5	94.5	79.5	92.0	78.6
130	31.9	29.5	51.3	46.1	64.4	55.9	66.5	57.0
135	24.3	22.7	35.4	32.9	44.3	40.6	45.9	41.6
140	18.8	17.5	25.6	23.9	31.7	29.6	32.2	29.8
143	*14.8*	*13.6*	*21.1*	*19.9*	*26.0*	*24.4*	*25.8*	*24.1*
145	11.7	10.6	18.3	17.2	22.8	21.4	22.2	20.8
150	8.44	7.90	9.88	9.45	14.5	13.5	12.8	11.8
155	6.25	5.83	6.98	6.57	8.36	7.89	7.44	7.00
160	4.42	4.14	4.57	4.35	5.00	4.72	4.21	4.02
165	2.97	2.77	3.00	2.82	2.86	2.74	2.37	2.28
170	1.81	1.72	1.79	1.69	1.58	1.52	1.19	1.12
175	0.79	0.75	0.80	0.74	0.78	0.73	0.52	0.51
180	0.39	0.38	0.35	0.34	0.33	0.31	0.25	0.25
185	0.17	0.17	0.15	0.15	0.13	0.13	0.09	0.09
190	0.09	0.09	0.08	0.08	0.06	0.06	0.03	0.03
195	-	-	-	-	-	-	-	-
200	-	-	-	-	-	-	-	-
205	-	-	-	-	-	-	-	-
210	-	-	-	-	-	-	-	-

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 6.12: Morven South: Maximum horizontal distances in kilometres from the conservative 3.7m pin pile to maximum-over-depth Sound Exposure Level per-pulse values for each analysed penetration depth

SEL per-pulse (dB re 1µPa²s)	Maximum horizontal distance to level (km)							
	A		B		C		D	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
120	88.2	74.9	>150	>133	>150	>144	>150	>144
125	63.0	55.0	107	90.2	137	118	>150	>123
130	45.1	41.3	69.9	61.1	96.6	82.6	103	87.2
135	33.6	31.1	47.2	43.1	65.3	57.3	69.6	60.2
140	25.4	23.7	33.3	31.0	44.2	40.5	45.4	41.2
143	*22.0*	*20.7*	*27.4*	*25.6*	*35.2*	*32.7*	*34.9*	*32.4*
145	20.2	19.0	24.2	22.7	30.2	28.3	29.1	27.3
150	13.9	12.6	17.1	16.0	20.5	19.4	18.3	17.2
155	9.08	8.51	9.65	9.18	10.8	9.86	9.47	8.99
160	6.27	5.86	6.53	6.22	6.68	6.33	5.48	5.20
165	3.93	3.75	4.03	3.85	3.78	3.61	2.94	2.83
170	2.29	2.17	2.31	2.20	2.13	2.03	1.51	1.43
175	1.04	0.98	1.05	0.99	0.96	0.92	0.63	0.60
180	0.54	0.49	0.48	0.46	0.39	0.35	0.28	0.27
185	0.17	0.17	0.15	0.15	0.16	0.16	0.10	0.09
190	0.10	0.09	0.09	0.09	0.08	0.08	0.05	0.05
195	-	-	-	-	-	-	-	-
200	-	-	-	-	-	-	-	-
205	-	-	-	-	-	-	-	-
210	-	-	-	-	-	-	-	-

A dash (-) indicates that the level was not reached within the resolution of the model.
The maximum modelled distance was 150km; an entry of ">150" is used where sound levels exceeding the threshold exist outside the modelled domain.

Table 6.13: Morven South: Maximum horizontal distances in kilometres from the representative 16m monopile to maximum-over-depth peak (PK) impact thresholds for marine mammals from National Marine Fisheries Service (2024a) and fish from Popper *et al.* (2014)

Hearing group	Effect	PK (dB)	Maximum horizontal distance to threshold (km)							
			A		B		C		D	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
LF cetaceans	AUD INJ	222	-	-	0.03	0.03	-	-	0.02	0.02
	TTS	216	0.10	0.10	0.10	0.10	0.14	0.14	0.18	0.17
HF cetaceans	AUD INJ	230	-	-	-	-	-	-	-	-
	TTS	224	-	-	-	-	-	-	-	-
VHF cetaceans	AUD INJ	202	0.86	0.83	0.95	0.93	0.80	0.77	0.84	0.81
	TTS	196	1.67	1.60	1.87	1.79	1.67	1.59	1.86	1.75
PCW	AUD INJ	223	-	-	-	-	-	-	-	-
	TTS	217	0.09	0.09	0.09	0.09	0.10	0.10	0.16	0.15
Fish Group 1	Injury	213	0.16	0.16	0.18	0.17	0.20	0.20	0.23	0.23
Fish Group 2, 3, 4, Fish eggs, and fish larvae	Injury	207	0.54	0.52	0.56	0.55	0.55	0.52	0.55	0.51

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 6.14: Morven South: Maximum horizontal distances in kilometres from the conservative 16m monopile to maximum-over-depth peak (PK) impact thresholds for marine mammals from National Marine Fisheries Service (2024a) and fish from Popper *et al.* (2014)

Hearing group	Effect	PK (dB)	Maximum horizontal distance to threshold (km)							
			A		B		C		D	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
LF cetaceans	AUD INJ	222	-	-	0.03	0.03	0.03	0.03	0.03	0.03
	TTS	216	0.11	0.10	0.12	0.12	0.14	0.14	0.16	0.15
HF cetaceans	AUD INJ	230	-	-	-	-	-	-	-	-
	TTS	224	-	-	-	-	-	-	-	-
Very high-frequency (VHF) cetaceans	AUD INJ	202	0.81	0.79	0.93	0.90	0.81	0.78	0.91	0.88
	TTS	196	1.93	1.85	2.07	1.98	1.85	1.77	2.10	2.02
PCW	AUD INJ	223	-	-	-	-	-	-	-	-
	TTS	217	0.09	0.09	0.10	0.10	0.13	0.12	0.14	0.14
Fish Group 1	Injury	213	0.16	0.15	0.19	0.16	0.17	0.17	0.21	0.20
Fish Group 2, 3, 4, Fish eggs, and fish larvae	Injury	207	0.54	0.52	0.56	0.54	0.52	0.50	0.57	0.55

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 6.15: Morven South: Maximum horizontal distances in kilometres from the representative 5.3m pin pile to maximum-over-depth peak (PK) impact thresholds for marine mammals from National Marine Fisheries Service (2024a) and fish from Popper *et al.* (2014)

Hearing group	Effect	PK (dB)	Maximum horizontal distance to threshold (km)							
			A		B		C		D	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
LF cetaceans	AUD INJ	222	-	-	-	-	-	-	-	-
	TTS	216	0.03	0.03	0.03	0.03	0.03	0.03	-	-
HF cetaceans	AUD INJ	230	-	-	-	-	-	-	-	-
	TTS	224	-	-	-	-	-	-	-	-
Very high-frequency (VHF) cetaceans	AUD INJ	202	0.57	0.55	0.56	0.53	0.36	0.35	0.20	0.20
	TTS	196	0.92	0.88	0.94	0.91	0.80	0.77	0.51	0.45
PCW	AUD INJ	223	-	-	-	-	-	-	-	-
	TTS	217	0.02	0.02	-	-	-	-	-	-
Fish Group 1	Injury	213	0.13	0.13	0.13	0.13	0.09	0.09	0.03	0.03
Fish Group 2, 3, 4, Fish eggs, and fish larvae	Injury	207	0.23	0.23	0.24	0.23	0.18	0.17	0.09	0.09

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 6.16: Morven South: Maximum horizontal distances in kilometres from the conservative 5.3m pin pile to maximum-over-depth peak (PK) impact thresholds for marine mammals from National Marine Fisheries Service (2024a) and fish from Popper *et al.* (2014)

Hearing group	Effect	PK (dB)	Maximum horizontal distance to threshold (km)							
			A		B		C		D	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
LF cetaceans	AUD INJ	222	-	-	-	-	-	-	-	-
	TTS	216	0.08	0.08	0.04	0.04	0.05	0.05	-	-
HF cetaceans	AUD INJ	230	-	-	-	-	-	-	-	-
	TTS	224	-	-	-	-	-	-	-	-
VHF cetaceans	AUD INJ	202	0.51	0.49	0.55	0.52	0.44	0.42	0.20	0.19
	TTS	196	1.03	0.97	0.99	0.96	0.95	0.92	0.53	0.50
PCW	AUD INJ	223	-	-	-	-	-	-	-	-
	TTS	217	-	-	-	-	0.03	0.03	-	-
Fish Group 1	Injury	213	0.13	0.12	0.12	0.12	0.11	0.10	0.04	0.04
Fish Group 2, 3, 4, Fish eggs, and fish larvae	Injury	207	0.23	0.22	0.23	0.22	0.17	0.16	0.12	0.12

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 6.17: Morven South: Maximum horizontal distances in kilometres from the representative 3.7m pin pile to maximum-over-depth peak (PK) impact thresholds for marine mammals from National Marine Fisheries Service (2024a) and fish from Popper *et al.* (2014)

Hearing group	Effect	PK (dB)	Maximum horizontal distance to threshold (km)							
			A		B		C		D	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
LF cetaceans	AUD INJ	222	-	-	-	-	-	-	-	-
	TTS	216	0.09	0.09	0.06	0.06	0.03	0.03	0.02	0.02
HF cetaceans	AUD INJ	230	-	-	-	-	-	-	-	-
	TTS	224	-	-	-	-	-	-	-	-
VHF cetaceans	AUD INJ	202	0.67	0.62	0.60	0.54	0.51	0.38	0.28	0.27
	TTS	196	1.43	1.30	1.08	0.96	0.92	0.83	0.71	0.60
PCW	AUD INJ	223	-	-	-	-	-	-	-	-
	TTS	217	0.03	0.03	0.03	0.03	0.03	0.03	-	-
Fish Group 1	Injury	213	0.16	0.14	0.13	0.10	0.09	0.09	0.06	0.06
Fish Group 2, 3, 4, Fish eggs, and fish larvae	Injury	207	0.25	0.24	0.21	0.21	0.18	0.18	0.12	0.10

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 6.18: Morven South: Maximum horizontal distances in kilometres from the conservative 3.7m pin pile to maximum-over-depth peak (PK) impact thresholds for marine mammals from National Marine Fisheries Service (2024a) and fish from Popper *et al.* (2014)

Hearing group	Effect	PK (dB)	Maximum horizontal distance to threshold (km)							
			A		B		C		D	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
LF cetaceans	AUD INJ	222	-	-	-	-	-	-	-	-
	TTS	216	0.10	0.09	0.09	0.09	0.07	0.07	0.05	0.05
HF cetaceans	AUD INJ	230	-	-	-	-	-	-	-	-
	TTS	224	-	-	-	-	-	-	-	-
VHF cetaceans	AUD INJ	202	0.77	0.74	0.60	0.57	0.54	0.52	0.39	0.34
	TTS	196	1.78	1.66	1.36	1.25	1.00	0.96	0.68	0.64
PCW	AUD INJ	223	-	-	-	-	-	-	-	-
	TTS	217	0.05	0.05	0.08	0.08	0.05	0.05	0.03	0.03
Fish Group 1	Injury	213	0.14	0.14	0.13	0.12	0.11	0.10	0.07	0.07
Fish Group 2, 3, 4, Fish eggs, and fish larvae	Injury	207	0.36	0.34	0.28	0.26	0.20	0.20	0.15	0.15

A dash (-) indicates that the level was not reached within the resolution of the model.

6.4 Single pile – Multiple strikes

6.4.1.1 This section provides modelled results of the total radiated sound from single pile operations as defined in Table 2.6, taking into account the multiple penetration depths and number of strikes at each analysed depth.

6.4.1.2 Table 6.19 provides results of the distances from the 16m monopile driving operation to frequency-weighted SEL impact thresholds levels as defined by NMFS (2024a) for marine mammals for the cases of without and with an ADD; the animals are modelled as moving away from the pile as described in Section 4.8.

6.4.1.3 Table 6.20 shows distances to from the 16m monopile to unweighted SEL impact thresholds as defined by Popper *et al.* (2014) for fish for the representative and conservative environments; fish have been modelled as static receivers.

Table 6.19: Morven North: Maximum horizontal distances in kilometres from the modelled 16m monopile to maximum-over-depth Sound Exposure Level impact thresholds for marine mammals from National Marine Fisheries Service (2024a). Sound levels are frequency-weighted for cetaceans according to the hearing group

Hearing group	Effect	SEL (dB)	Maximum horizontal distance to threshold (km)							
			Representative				Conservative			
			No ADD		ADD		No ADD		ADD	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
LF cetaceans	AUD INJ	183	4.81	4.45	0.66	0.62	11.3	10.3	7.16	6.46
	TTS	168	23.6	21.3	19.5	17.3	38.4	34.3	34.2	30.4
HF cetaceans	AUD INJ	193	-	-	-	-	-	-	-	-
	TTS	178	-	-	-	-	-	-	-	-
VHF cetaceans	AUD INJ	159	-	-	-	-	-	-	-	-
	TTS	144	-	-	0.77	0.74	-	-	0.85	0.81
PCW	AUD INJ	183	-	-	-	-	-	-	-	-
	TTS	168	4.02	3.72	0.75	0.72	9.28	8.42	6.04	5.42

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 6.20: Morven North: Maximum horizontal distances in kilometres from the modelled 16m monopile to maximum-over-depth Sound Exposure Level impact thresholds for fish from Popper *et al.* (2014)

Hearing group	Effect	SEL (dB)	Maximum horizontal distance to threshold (km)			
			Representative		Conservative	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
Fish Group 1	Mortality	219	1.62	1.54	2.05	1.97
	Injury	216	2.32	2.23	2.97	2.85
Fish Group 2	Mortality	210	4.16	3.92	5.68	5.38
	Injury	203	7.22	6.77	9.79	9.30
Fish Group 3 and, 4	Mortality	207	5.36	5.02	7.51	7.03
	Injury	203	7.22	6.77	9.79	9.30
All fish groups	TTS	186	24.3	22.7	33.1	30.8
Fish eggs, and fish larvae	Mortality	210	4.16	3.92	5.68	5.38

6.4.1.4 Table 6.21 provides results of the distances from the 5.3m pin pile driving operation to frequency-weighted SEL impact thresholds levels as defined by NMFS (2024a) for marine mammals for the cases of without and with an ADD; the animals are modelled as moving away from the pile as described in Section 4.8.

6.4.1.5 Table 6.22 shows distances to from the 5.3m pin pile to unweighted SEL impact thresholds as defined by Popper *et al.* (2014) for fish for the representative and conservative environments; fish have been modelled as static receivers.

Table 6.21: Morven North: Maximum horizontal distances in kilometres from the 5.3m pin pile to maximum-over-depth Sound Exposure Level impact thresholds for marine mammals from National Marine Fisheries Service (2024a). Sound levels are frequency-weighted for cetaceans according to the hearing group

Hearing group	Effect	SEL (dB)	Maximum horizontal distance to threshold (km)							
			Representative				Conservative			
			No ADD		ADD		No ADD		ADD	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
LF cetaceans	AUD INJ	183	1.53	1.41	-	-	4.76	4.30	0.56	0.54
	TTS	168	19.7	17.6	15.6	13.7	40.8	34.4	36.6	30.6
HF cetaceans	AUD INJ	193	-	-	-	-	-	-	-	-
	TTS	178	-	-	-	-	-	-	-	-
VHF cetaceans	AUD INJ	159	-	-	-	-	-	-	-	-
	TTS	144	-	-	0.75	0.73	-	-	0.83	0.80
PCW	AUD INJ	183	-	-	-	-	-	-	-	-
	TTS	168	1.35	1.22	-	-	3.87	3.51	0.59	0.56

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 6.22: Morven North: Maximum horizontal distances in kilometres from the 5.3m pin pile to maximum-over-depth Sound Exposure Level impact thresholds for fish from Popper *et al.* (2014)

Hearing group	Effect	SEL (dB)	Maximum horizontal distance to threshold (km)			
			Representative		Conservative	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
Fish Group 1	Mortality	219	0.62	0.59	0.69	0.66
	Injury	216	0.95	0.92	1.11	1.04
Fish Group 2	Mortality	210	2.34	2.26	2.88	2.78
	Injury	203	5.05	4.78	6.57	6.24
Fish Group 3 and, 4	Mortality	207	3.31	3.17	4.14	4.00
	Injury	203	5.05	4.78	6.57	6.24
All fish groups	TTS	186	23.9	22.4	32.1	29.9
Fish eggs, and fish larvae	Mortality	210	2.34	2.26	2.88	2.78

6.4.1.6 Table 6.23 provides results of the distances from the 3.7m pin pile driving operation to frequency-weighted SEL impact thresholds levels as defined by NMFS (2024a) for marine mammals for the cases of without and with an ADD; the animals are modelled as moving away from the pile as described in Section 4.8.

6.4.1.7 Table 6.24 shows distances to from the 3.7m pin pile to unweighted SEL impact thresholds as defined by Popper *et al.* (2014) for fish for the representative and conservative environments; fish have been modelled as static receivers.

Table 6.23: Morven North: Maximum horizontal distances in kilometres from the 3.7m pin pile to maximum-over-depth Sound Exposure Level impact thresholds for marine mammals from National Marine Fisheries Service (2024a). Sound levels are frequency-weighted for cetaceans according to the hearing group

Hearing group	Effect	SEL (dB)	Maximum horizontal distance to threshold (km)							
			Representative				Conservative			
			No ADD		ADD		No ADD		ADD	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
LF cetaceans	AUD INJ	183	2.38	2.21	-	-	6.24	5.63	2.06	1.84
	TTS	168	32.5	28.9	28.3	25.0	58.2	48.5	54.1	44.7
HF cetaceans	AUD INJ	193	-	-	-	-	-	-	-	-
	TTS	178	-	-	-	-	-	-	-	-
VHF cetaceans	AUD INJ	159	-	-	-	-	-	-	-	-
	TTS	144	0.02	0.02	0.77	0.74	0.24	0.24	0.86	0.83
PCW	AUD INJ	183	-	-	-	-	-	-	-	-
	TTS	168	2.52	2.30	-	-	5.84	5.31	2.59	2.34

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 6.24: Morven North: Maximum horizontal distances in kilometres from the 3.7m pin pile to maximum-over-depth sound exposure level impact thresholds for fish from Popper *et al.* (2014)

Hearing group	Effect	SEL (dB)	Maximum horizontal distance to threshold (km)			
			Representative		Conservative	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
Fish Group 1	Mortality	219	0.36	0.35	0.43	0.39
	Injury	216	0.63	0.59	0.69	0.67
Fish Group 2	Mortality	210	1.55	1.46	1.99	1.89
	Injury	203	3.40	3.23	4.47	4.28
Fish Group 3 and, 4	Mortality	207	2.22	2.13	2.85	2.72
	Injury	203	3.40	3.23	4.47	4.28
All fish groups	TTS	186	20.0	18.9	26.0	24.5
Fish eggs, and fish larvae	Mortality	210	1.55	1.46	1.99	1.89

6.5 Concurrent piles – Single strikes

6.5.1.1 This section provides tabulated results of the concurrent piling scenarios, where the total sound field from single strikes from concurrent piling operations is considered. The scenarios are as listed in Table 2.7. In all cases, values shown are the maximum distances to sound levels from the nearer source.

6.5.1.2 As detailed in Section 4.7, the SPL and PK sound fields are taken as the maximum over the two fields. Because of this, the maximum distance to any threshold remains the same as the maximum from the single pile case. In these cases, it is the ensonified area to a threshold sound level that is presented instead of the maximum distance.

6.5.1.3 Table 6.25 and Table 6.26 show the total ensonified areas (km²) to SPL values due to the single pile, two nearby piles, and two distant piles for the 16m monopile for the representative and conservative cases respectively. Similarly, Table 6.27 and Table 6.28 show total ensonified areas (km²) to PK threshold values from NMFS (2024a) and Popper *et al.* (2014) due to the single pile, two nearby piles, and two distant piles for the 16m monopile for the representative and conservative cases respectively.

Table 6.25: Morven South: Ensonified areas (km²) from the representative 16m monopile and near and far concurrent piling scenarios to maximum-over-depth Sound Pressure Level values for each analysed penetration depth

SPL (dB re 1μPa²)	Ensonified area to level (km²)											
	A			B			C			D		
	Sgl	Near	Far	Sgl	Near	Far	Sgl	Near	Far	Sgl	Near	Far
140	4264	4338	6370	5858	5945	8353	4615	4692	6820	5478	5562	7873
145	3068	3131	4836	3856	3927	5863	3162	3226	4964	3653	3721	5594
150	2138	2190	3587	2442	2498	4007	2145	2197	3597	2323	2377	3842
155	1428	1470	2573	1518	1562	2710	1433	1475	2582	1488	1532	2665
160	798	830	1575	862	895	1687	772	804	1532	845	878	1659
165	290	309	579	295	314	590	281	300	562	294	313	588
170	161	175	322	163	177	325	143	156	286	161	175	322
175	75.2	84.9	150	78.1	88.0	156	71.0	80.4	142	78.8	88.7	158
180	34.0	40.5	68.0	37.9	44.8	75.9	33.4	39.8	66.8	36.7	43.4	73.4
185	13.0	17.0	26.0	15.6	20.0	31.1	13.8	18.0	27.7	15.2	19.5	30.3
190	2.68	4.42	5.37	3.07	4.94	6.13	2.94	4.77	5.89	3.55	5.59	7.10
195	0.56	1.12	1.12	0.91	1.79	1.81	0.73	1.45	1.46	0.81	1.61	1.62
200	0.12	0.24	0.24	0.13	0.26	0.26	0.15	0.30	0.30	0.19	0.37	0.37
205	0.04	0.08	0.08	0.04	0.08	0.08	0.05	0.11	0.11	0.07	0.13	0.13
210	-	-	-	<0.01	<0.01	<0.01	-	-	-	<0.01	<0.01	<0.01

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 6.26: Morven South: Ensonified areas (km²) from the conservative 16m monopile and near and far concurrent piling scenarios to maximum-over-depth Sound Pressure Level values for each analysed penetration depth

SPL (dB re 1μPa²)	Ensonified area to level (km²)											
	A			B			C			D		
	Sgl	Near	Far	Sgl	Near	Far	Sgl	Near	Far	Sgl	Near	Far
140	7884	7983	10837	11069	11188	14610	10061	10174	13447	10285	10400	13694
145	5434	5517	7844	7007	7101	9766	6109	6196	8678	6777	6869	9489
150	3655	3723	5602	4106	4177	6167	3753	3822	5721	4250	4324	6359
155	2331	2385	3848	2369	2423	3896	2258	2311	3744	2453	2509	4015
160	1396	1438	2522	1370	1411	2481	1343	1384	2442	1430	1473	2574
165	668	697	1336	634	662	1267	546	573	1092	730	761	1452
170	264	283	529	253	271	505	218	235	436	274	293	548
175	122	135	244	122	134	244	106	118	212	133	146	266
180	49.4	57.2	98.8	57.1	65.6	114	48.7	56.6	97.5	60.0	68.6	120
185	18.1	22.8	36.2	23.0	28.3	46.0	18.8	23.7	37.7	22.4	27.6	44.8
190	3.91	6.01	7.83	6.19	8.86	12.4	4.51	6.80	9.03	5.95	8.57	11.9
195	0.98	1.91	1.96	1.09	2.10	2.19	0.96	1.89	1.93	1.22	2.31	2.44
200	0.10	0.19	0.19	0.14	0.28	0.28	0.14	0.28	0.28	0.16	0.33	0.33
205	0.04	0.08	0.08	0.05	0.10	0.10	0.05	0.10	0.10	0.06	0.11	0.11
210	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 6.27: Morven South: Ensonified areas (km²) from the representative 16m monopile and near and far concurrent piling scenarios to maximum-over-depth peak (PK) impact thresholds for marine mammals from National Marine Fisheries Service (2024a) and fish from Popper *et al.* (2014)

Hearing group	Eff.	PK (dB)	Ensonified area to level (km²)											
			A			B			C			D		
			Sgl	Nr	Far	Sgl	Nr	Far	Sgl	Nr	Far	Sgl	Nr	Far
LF cetaceans	INJ	222	-	-	-	<0.01	<0.01	<0.01	-	-	-	<0.01	<0.01	<0.01
	TTS	216	0.04	0.08	0.08	0.04	0.08	0.08	0.07	0.13	0.13	0.10	0.20	0.20
HF cetaceans	INJ	230	-	-	-	-	-	-	-	-	-	-	-	-
	TTS	224	-	-	-	-	-	-	-	-	-	-	-	-
VHF cetaceans	INJ	202	2.28	3.87	4.56	2.84	4.62	5.67	1.97	3.42	3.93	2.17	3.73	4.34
	TTS	196	8.44	11.7	16.9	10.6	14.2	21.3	8.35	11.5	16.7	10.1	13.7	20.3
Phocid pinnipeds	INJ	223	-	-	-	-	-	-	-	-	-	-	-	-
	TTS	217	0.02	0.05	0.05	0.03	0.06	0.06	0.04	0.08	0.08	0.08	0.16	0.16
Fish Group 1	Inj.	213	0.08	0.17	0.17	0.10	0.20	0.20	0.12	0.24	0.24	0.17	0.34	0.34
Fish Group 2, 3, 4, Fish eggs, and fish larvae	Inj.	207	0.66	1.31	1.31	0.97	1.90	1.94	0.78	1.56	1.57	0.77	1.53	1.53

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 6.28: Morven South: Ensonified areas (km²) from the conservative 16m monopile and near and far concurrent piling scenarios to maximum-over-depth peak (PK) impact thresholds for marine mammals from National Marine Fisheries Service (2024a) and fish from Popper *et al.* (2014)

Hearing group	Eff.	PK (dB)	Ensonified area to level (km²)											
			A			B			C			D		
			Sgl	Nr	Far	Sgl	Nr	Far	Sgl	Nr	Far	Sgl	Nr	Far
LF cetaceans	INJ	222	-	-	-	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	TTS	216	0.04	0.08	0.08	0.05	0.10	0.10	0.07	0.13	0.13	0.08	0.15	0.15
HF cetaceans	INJ	230	-	-	-	-	-	-	-	-	-	-	-	-
	TTS	224	-	-	-	-	-	-	-	-	-	-	-	-
VHF cetaceans	INJ	202	2.04	3.53	4.08	2.71	4.46	5.41	2.02	3.50	4.05	2.58	4.29	5.16
	TTS	196	11.4	15.1	22.8	12.9	16.9	25.9	10.4	14.0	20.8	13.4	17.4	26.8
Phocid pinnipeds	INJ	223	-	-	-	-	-	-	-	-	-	-	-	-
	TTS	217	0.03	0.06	0.06	0.04	0.07	0.07	0.05	0.11	0.11	0.07	0.13	0.13
Fish Group 1	Inj.	213	0.08	0.16	0.16	0.08	0.16	0.16	0.09	0.18	0.18	0.13	0.27	0.27
Fish Group 2, 3, 4, Fish eggs, and fish larvae	Inj.	207	0.90	1.77	1.79	0.98	1.91	1.96	0.82	1.63	1.64	1.00	1.94	2.00

A dash (-) indicates that the level was not reached within the resolution of the model.

6.5.1.4 Table 6.29 and Table 6.30 show the total ensonified areas (km²) to SPL values due to the single pile, two nearby piles, and two distant piles for the 5.3m pin pile for the representative and conservative cases respectively. Similarly, Table 6.31 and Table 6.32 show total ensonified areas (km²) to PK threshold values from NMFS (2024a) and Popper *et al.* (2014) due to the single pile, two nearby piles, and two distant piles for the 5.3m pin pile for the representative and conservative cases respectively.

Table 6.29: Morven South: Ensonified areas (km²) from the representative 5.3m pin pile and near and far concurrent piling scenarios to maximum-over-depth Sound Pressure Level values for each analysed penetration depth

SPL (dB re 1μPa²)	Ensonified area to level (km²)											
	A			B			C			D		
	Sgl	Near	Far	Sgl	Near	Far	Sgl	Near	Far	Sgl	Near	Far
140	2660	2718	4295	2753	2812	4416	4498	4574	6657	6848	6942	9552
145	1728	1775	3012	1959	2008	3334	2876	2937	4580	4075	4148	6138
150	1045	1082	1989	1325	1366	2418	1850	1898	3183	2331	2385	3849
155	343	364	685	644	673	1287	1189	1228	2213	1230	1269	2273
160	185	200	370	256	274	512	471	496	943	359	381	718
165	92.5	103	185	129	142	258	210	226	420	154	168	308
170	45.8	53.4	91.7	66.4	75.5	133	82.6	92.8	165	48.7	56.5	97.5
175	21.9	27.1	43.8	30.8	37.0	61.7	28.5	34.5	57.1	14.5	18.7	28.9
180	7.89	11.0	15.8	12.1	15.9	24.2	10.1	13.6	20.3	3.07	4.95	6.15
185	1.85	3.26	3.70	2.72	4.47	5.45	1.81	3.20	3.63	0.78	1.56	1.56
190	0.36	0.72	0.72	0.49	0.98	0.98	0.34	0.68	0.68	0.13	0.26	0.26
195	0.10	0.19	0.19	0.11	0.22	0.22	0.08	0.15	0.15	0.02	0.04	0.04
200	<0.01	0.02	0.02	0.01	0.03	0.03	0.01	0.03	0.03	<0.01	<0.01	<0.01
205	-	-	-	-	-	-	-	-	-	-	-	-
210	-	-	-	-	-	-	-	-	-	-	-	-

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 6.30: Morven South: Ensonified areas (km²) from the conservative 5.3m pin pile and near and far concurrent piling scenarios to maximum-over-depth Sound Pressure Level values for each analysed penetration depth

SPL (dB re 1μPa²)	Ensonified area to level (km²)											
	A			B			C			D		
	Sgl	Near	Far	Sgl	Near	Far	Sgl	Near	Far	Sgl	Near	Far
140	5366	5448	7758	4927	5005	7217	8001	8101	10973	13766	13903	17805
145	3235	3299	5058	3254	3318	5082	5022	5102	7331	7810	7910	10752
150	1832	1880	3155	2107	2158	3540	2918	2979	4640	4105	4178	6182
155	968	1003	1858	1270	1310	2332	1751	1798	3039	2038	2088	3444
160	300	319	599	468	492	935	1003	1039	1914	804	837	1585
165	153	167	305	200	216	401	303	323	607	229	246	458
170	69.5	78.8	139	99.1	110	198	131	144	262	66.9	76.0	134
175	30.0	36.1	59.9	43.6	50.9	87.1	42.9	50.2	85.8	17.8	22.5	35.6
180	11.2	15.0	22.5	15.9	20.3	31.7	13.5	17.6	27.0	3.70	5.77	7.40
185	2.16	3.68	4.32	3.02	4.87	6.04	2.88	4.68	5.77	0.82	1.63	1.63
190	0.40	0.80	0.80	0.76	1.53	1.53	0.64	1.29	1.29	0.17	0.35	0.35
195	0.08	0.16	0.16	0.13	0.26	0.26	0.07	0.13	0.13	0.03	0.05	0.05
200	0.02	0.05	0.05	0.04	0.07	0.07	0.02	0.04	0.04	<0.01	0.02	0.02
205	-	-	-	-	-	-	-	-	-	-	-	-
210	-	-	-	-	-	-	-	-	-	-	-	-

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 6.31: Morven South: Ensonified areas (km²) from the representative 5.3m pin pile and near and far concurrent piling scenarios to maximum-over-depth peak (PK) impact thresholds for marine mammals from National Marine Fisheries Service (2024a) and fish from Popper *et al.* (2014)

Hearing group	Eff.	PK (dB)	Ensonified area to level (km²)											
			A			B			C			D		
			Sgl	Nr	Far	Sgl	Nr	Far	Sgl	Nr	Far	Sgl	Nr	Far
LF cetaceans	INJ	222	-	-	-	-	-	-	-	-	-	-	-	-
	TTS	216	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	-	-
HF cetaceans	INJ	230	-	-	-	-	-	-	-	-	-	-	-	-
	TTS	224	-	-	-	-	-	-	-	-	-	-	-	-
VHF cetaceans	INJ	202	0.83	1.63	1.66	0.77	1.53	1.54	0.40	0.81	0.81	0.12	0.25	0.25
	TTS	196	2.60	4.31	5.20	2.71	4.46	5.42	1.97	3.44	3.95	0.62	1.24	1.24
Phocid pinnipeds	INJ	223	-	-	-	-	-	-	-	-	-	-	-	-
	TTS	217	<0.01	<0.01	<0.01	-	-	-	-	-	-	-	-	-
Fish Group 1	Inj.	213	0.05	0.11	0.11	0.05	0.11	0.11	0.02	0.05	0.05	<0.01	<0.01	<0.01
Fish Group 2, 3, 4, Fish eggs, and fish larvae	Inj.	207	0.18	0.35	0.35	0.19	0.37	0.37	0.10	0.20	0.20	0.03	0.06	0.06

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 6.32: Morven South: Ensonified areas (km²) from the conservative 5.3m pin pile and near and far concurrent piling scenarios to maximum-over-depth peak (PK) impact thresholds for marine mammals from National Marine Fisheries Service (2024a) and fish from Popper *et al.* (2014)

Hearing group	Eff.	PK (dB)	Ensonified area to level (km²)											
			A			B			C			D		
			Sgl	Nr	Far	Sgl	Nr	Far	Sgl	Nr	Far	Sgl	Nr	Far
LF cetaceans	INJ	222	-	-	-	-	-	-	-	-	-	-	-	-
	TTS	216	0.02	0.04	0.04	<0.01	0.01	0.01	<0.01	0.02	0.02	-	-	-
HF cetaceans	INJ	230	-	-	-	-	-	-	-	-	-	-	-	-
	TTS	224	-	-	-	-	-	-	-	-	-	-	-	-
VHF cetaceans	INJ	202	0.79	1.57	1.57	0.87	1.74	1.74	0.47	0.94	0.94	0.13	0.26	0.26
	TTS	196	3.11	5.01	6.22	3.02	4.88	6.05	2.66	4.37	5.33	0.72	1.45	1.45
Phocid pinnipeds	INJ	223	-	-	-	-	-	-	-	-	-	-	-	-
	TTS	217	-	-	-	-	-	-	<0.01	<0.01	<0.01	-	-	-
Fish Group 1	Inj.	213	0.05	0.11	0.11	0.05	0.10	0.10	0.04	0.08	0.08	<0.01	0.01	0.01
Fish Group 2, 3, 4, Fish eggs, and fish larvae	Inj.	207	0.16	0.33	0.33	0.16	0.32	0.32	0.08	0.16	0.16	0.05	0.10	0.10

A dash (-) indicates that the level was not reached within the resolution of the model.

6.5.1.5 Table 6.33 and Table 6.34 show the total ensonified areas (km²) to SPL values due to the single pile, two nearby piles, and two distant piles for the 3.7m pin pile for the representative and conservative cases respectively. Similarly, Table 6.35 and Table 6.36 show total ensonified areas (km²) to PK threshold values from NMFS (2024a) and Popper *et al.* (2014) due to the single pile, two nearby piles, and two distant piles for the 3.7m pin pile for the representative and conservative cases respectively.

Table 6.33: Morven South: Ensonified areas (km²) from the representative 3.7m pin pile and near and far concurrent piling scenarios to maximum-over-depth Sound Pressure Level values for each analysed penetration depth

SPL (dB re 1µPa²)	Ensonified area to level (km²)											
	A			B			C			D		
	Sgl	Near	Far	Sgl	Near	Far	Sgl	Near	Far	Sgl	Near	Far
140	140	2226	2279	3707	5649	5735	8096	7916	8017	10836	8388	8492
145	145	1365	1407	2480	2707	2765	4354	4258	4333	6372	4608	4686
150	150	617	645	1233	1470	1513	2634	2234	2287	3720	2367	2421
155	155	259	277	518	657	686	1313	1183	1222	2204	1125	1163
160	160	145	158	289	241	259	483	336	357	671	297	317
165	165	82.4	92.6	165	105	116	210	144	157	288	112	123
170	170	44.2	51.7	88.5	46.9	54.5	93.7	51.3	59.3	103	37.3	44.0
175	175	20.7	25.9	41.5	20.8	25.9	41.6	18.5	23.3	37.0	12.8	16.8
180	180	7.02	10.1	14.1	6.66	9.58	13.3	5.04	7.48	10.1	2.80	4.59
185	185	1.56	2.84	3.12	1.42	2.63	2.85	1.28	2.39	2.56	0.62	1.25
190	190	0.20	0.40	0.40	0.30	0.59	0.59	0.26	0.52	0.52	0.12	0.24
195	195	0.07	0.15	0.15	0.07	0.13	0.13	0.04	0.08	0.08	0.02	0.04
200	200	<0.01	<0.01	<0.01	0.01	0.03	0.03	<0.01	<0.01	<0.01	<0.01	<0.01
205	205	-	-	-	-	-	-	-	-	-	-	-
210	210	-	-	-	-	-	-	-	-	-	-	-

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 6.34: Morven South: Ensonified areas (km²) from the conservative 3.7m pin pile and near and far concurrent piling scenarios to maximum-over-depth Sound Pressure Level values for each analysed penetration depth

SPL (dB re 1μPa²)	Ensonified area to level (km²)											
	A			B			C			D		
	Sgl	Near	Far	Sgl	Near	Far	Sgl	Near	Far	Sgl	Near	Far
140	3797	3867	5781	8428	8533	11488	13643	13778	17649	16265	16414	20708
145	2240	2294	3726	3867	3938	5874	6873	6966	9597	8364	8468	11422
150	1276	1317	2344	2075	2126	3496	3652	3720	5594	4124	4198	6210
155	590	618	1179	1157	1196	2158	1768	1816	3062	1775	1823	3076
160	265	283	530	371	393	741	745	776	1478	560	588	1120
165	149	163	299	186	201	372	229	247	459	164	178	328
170	74.8	84.7	150	79.5	89.6	159	76.1	85.8	152	52.9	61.0	106
175	33.5	39.9	66.9	33.4	39.9	66.9	27.4	33.2	54.8	16.6	21.2	33.3
180	11.9	15.8	23.8	11.8	15.6	23.5	9.67	13.2	19.3	4.00	6.23	7.99
185	2.29	3.95	4.58	2.34	4.03	4.68	1.62	2.94	3.25	0.86	1.71	1.72
190	0.41	0.83	0.83	0.34	0.68	0.68	0.29	0.58	0.58	0.13	0.27	0.27
195	0.08	0.16	0.16	0.06	0.12	0.12	0.05	0.10	0.10	0.03	0.05	0.05
200	<0.01	0.02	0.02	0.02	0.04	0.04	<0.01	0.02	0.02	<0.01	0.02	0.02
205	-	-	-	-	-	-	-	-	-	-	-	-
210	-	-	-	-	-	-	-	-	-	-	-	-

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 6.35: Morven South: Ensonified areas (km²) from the representative 3.7m pin pile and near and far concurrent piling scenarios to maximum-over-depth peak (PK) impact thresholds for marine mammals from National Marine Fisheries Service (2024a) and fish from Popper *et al.* (2014)

Hearing group	Eff.	PK (dB)	Ensonified area to level (km²)											
			A			B			C			D		
			Sgl	Nr	Far	Sgl	Nr	Far	Sgl	Nr	Far	Sgl	Nr	Far
LF cetaceans	INJ	222	-	-	-	-	-	-	-	-	-	-	-	-
	TTS	216	<0.01	0.01	0.01	0.01	0.03	0.03	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
HF cetaceans	INJ	230	-	-	-	-	-	-	-	-	-	-	-	-
	TTS	224	-	-	-	-	-	-	-	-	-	-	-	-
VHF cetaceans	INJ	202	1.21	2.31	2.42	0.72	1.44	1.44	0.48	0.96	0.96	0.23	0.47	0.47
	TTS	196	4.78	7.38	9.57	2.91	4.77	5.82	2.21	3.76	4.41	0.98	1.93	1.97
Phocid pinnipeds	INJ	223	-	-	-	-	-	-	-	-	-	-	-	-
	TTS	217	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	-	-
Fish Group 1	Inj.	213	0.05	0.11	0.11	0.04	0.08	0.08	0.03	0.06	0.06	0.01	0.03	0.03
Fish Group 2, 3, 4, Fish eggs, and fish larvae	Inj.	207	0.20	0.40	0.40	0.15	0.30	0.30	0.11	0.22	0.22	0.04	0.08	0.08

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 6.36: Morven South: Ensonified areas (km²) from the conservative 3.7m pin pile and near and far concurrent piling scenarios to maximum-over-depth peak (PK) impact thresholds for marine mammals from National Marine Fisheries Service (2024a) and fish from Popper *et al.* (2014)

Hearing group	Eff.	PK (dB)	Ensonified area to level (km²)											
			A			B			C			D		
			Sgl	Nr	Far	Sgl	Nr	Far	Sgl	Nr	Far	Sgl	Nr	Far
LF cetaceans	INJ	222	-	-	-	-	-	-	-	-	-	-	-	-
	TTS	216	0.03	0.07	0.07	0.02	0.05	0.05	0.01	0.02	0.02	<0.01	<0.01	<0.01
HF cetaceans	INJ	230	-	-	-	-	-	-	-	-	-	-	-	-
	TTS	224	-	-	-	-	-	-	-	-	-	-	-	-
VHF cetaceans	INJ	202	1.79	3.18	3.58	0.90	1.79	1.79	0.68	1.36	1.36	0.32	0.63	0.63
	TTS	196	8.93	12.3	17.9	4.81	7.36	9.62	2.91	4.78	5.81	1.34	2.52	2.68
Phocid pinnipeds	INJ	223	-	-	-	-	-	-	-	-	-	-	-	-
	TTS	217	<0.01	0.02	0.02	0.02	0.04	0.04	<0.01	0.02	0.02	<0.01	<0.01	<0.01
Fish Group 1	Inj.	213	0.07	0.13	0.13	0.05	0.11	0.11	0.04	0.08	0.08	0.02	0.04	0.04
Fish Group 2, 3, 4, Fish eggs, and fish larvae	Inj.	207	0.40	0.79	0.79	0.22	0.43	0.43	0.13	0.27	0.27	0.08	0.15	0.15

A dash (-) indicates that the level was not reached within the resolution of the model.

6.6 Concurrent piles – Multiple strikes

6.6.1.1 This section provides tabulated results of the concurrent piling scenarios, where the total sound field from concurrent piling operations is considered. The scenarios are as listed in Table 2.7.

6.6.1.2 As detailed in Section 4.7, the SEL fields from contributing piles are summed, such that the sound level at any given point ensonified by both sources will be elevated. Fish have been treated as static receivers and marine mammals as moving receivers as described in Section 4.8.

6.6.1.3 Table 6.37 and Table 6.38 show the distances to SEL impact thresholds for two concurrent 16m monopile piling operations in close proximity for representative and conservative cases, with and without ADD, for marine mammals and fish respectively. Similarly, Table 6.39 and Table 6.40 show results for two widely separated piles. These are directly comparable to the single 16m monopile results in Table 6.19 for marine mammals and Table 6.20 for fish.

Table 6.37: Morven South: Maximum horizontal distances in kilometres from two close proximity 16m monopile operations to maximum-over-depth sound exposure level impact thresholds for marine mammals from National Marine Fisheries Service (2024a). Sound levels are frequency-weighted for cetaceans according to the hearing group

Hearing group	Effect	SEL (dB)	Maximum horizontal distance to threshold (km)							
			Representative				Conservative			
			No ADD		ADD		No ADD		ADD	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
LF cetaceans	AUD INJ	183	7.32	6.60	3.16	2.83	14.9	13.6	10.7	9.68
	TTS	168	29.2	26.1	25.1	22.3	49.5	42.8	45.3	39.0
HF cetaceans	AUD INJ	193	-	-	-	-	-	-	-	-
	TTS	178	-	-	-	-	-	-	-	-
VHF cetaceans	AUD INJ	159	-	-	0.03	0.03	-	-	-	-
	TTS	144	-	-	1.44	1.27	-	-	1.59	1.38
PCW	AUD INJ	183	-	-	-	-	0.54	0.52	-	-
	TTS	168	5.97	5.34	2.74	2.42	12.9	11.8	9.65	8.75

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 6.38: Morven South: Maximum horizontal distances in kilometres from two close proximity 16m monopile operations to maximum-over-depth sound exposure level impact thresholds for fish from Popper *et al.* (2014)

Hearing group	Effect	SEL (dB)	Maximum horizontal distance to threshold (km)			
			Representative		Conservative	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
Fish Group 1	Mortality	219	2.30	2.02	2.92	2.60
	Injury	216	3.13	2.77	4.11	3.72
Fish Group 2	Mortality	210	5.31	4.77	7.38	6.77
	Injury	203	8.83	8.08	14.0	12.6
Fish Group 3 and, 4	Mortality	207	6.68	6.05	9.29	8.58
	Injury	203	8.83	8.08	14.0	12.6
All fish groups	TTS	186	27.7	25.8	39.0	35.7
Fish eggs, and fish larvae	Mortality	210	5.31	4.77	7.38	6.77

Table 6.39: Morven South: Maximum horizontal distances in kilometres from two widely separated 16m monopile operations to maximum-over-depth sound exposure level impact thresholds for marine mammals from National Marine Fisheries Service (2024a). Sound levels are frequency-weighted for cetaceans according to the hearing group

Hearing group	Effect	SEL (dB)	Maximum horizontal distance to threshold (km)							
			Representative				Conservative			
			No ADD		ADD		No ADD		ADD	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
LF cetaceans	AUD INJ	183	8.84	6.41	3.28	2.63	16.9	14.2	15.2	13.5
	TTS	168	28.5	23.0	25.0	19.6	44.3	37.8	40.4	34.0
HF cetaceans	AUD INJ	193	-	-	-	-	-	-	-	-
	TTS	178	-	-	-	-	-	-	-	-
VHF cetaceans	AUD INJ	159	-	-	-	-	-	-	-	-
	TTS	144	-	-	1.11	0.92	-	-	1.24	1.02
PCW	AUD INJ	183	-	-	-	-	-	-	-	-
	TTS	168	7.04	5.24	3.18	2.49	15.7	13.6	14.9	13.0

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 6.40: Morven South: Maximum horizontal distances in kilometres from two widely separated 16m monopile operations to maximum-over-depth Sound Exposure Level impact thresholds for fish from Popper *et al.* (2014)

Hearing group	Effect	SEL (dB)	Maximum horizontal distance to threshold (km)			
			Representative		Conservative	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
Fish Group 1	Mortality	219	1.64	1.55	2.06	1.97
	Injury	216	2.33	2.23	2.99	2.85
Fish Group 2	Mortality	210	4.16	3.92	5.71	5.40
	Injury	203	7.25	6.78	9.98	9.38
Fish Group 3 and, 4	Mortality	207	5.37	5.02	7.58	7.07
	Injury	203	7.25	6.78	9.98	9.38
All fish groups	TTS	186	26.9	23.1	37.1	32.0
Fish eggs, and fish larvae	Mortality	210	4.16	3.92	5.71	5.40

6.6.1.4 Table 6.41 and Table 6.42 show the distances to SEL impact thresholds for two concurrent 5.3m pin pile piling operations in close proximity for representative and conservative cases, with and without ADD, for marine mammals and fish respectively. Similarly, Table 6.43 and Table 6.44 show results for two widely separated piles. These are directly comparable to the single 5.3m pin pile results in Table 6.21 for marine mammals and Table 6.22 for fish.

Table 6.41: Morven South: Maximum horizontal distances in kilometres from two close proximity 5.3m pin pile operations to maximum-over-depth sound exposure level impact thresholds for marine mammals from National Marine Fisheries Service (2024a). Sound levels are frequency-weighted for cetaceans according to the hearing group

Hearing group	Effect	SEL (dB)	Maximum horizontal distance to threshold (km)							
			Representative				Conservative			
			No ADD		ADD		No ADD		ADD	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
LF cetaceans	AUD INJ	183	2.96	2.56	-	-	8.44	7.49	4.28	3.70
	TTS	168	27.5	23.9	23.4	20.2	56.9	47.6	52.8	43.9
HF cetaceans	AUD INJ	193	-	-	-	-	-	-	-	-
	TTS	178	-	-	-	-	-	-	-	-
VHF cetaceans	AUD INJ	159	-	-	0.03	0.03	-	-	-	-
	TTS	144	-	-	1.44	1.26	-	-	1.54	1.35
PCW	AUD INJ	183	-	-	-	-	-	-	-	-
	TTS	168	2.60	2.24	-	-	6.74	6.04	3.52	3.08

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 6.42: Morven South: Maximum horizontal distances in kilometres from two close proximity 5.3m pin pile operations to maximum-over-depth Sound Exposure Level impact thresholds for fish from Popper *et al.* (2014)

Hearing group	Effect	SEL (dB)	Maximum horizontal distance to threshold (km)			
			Representative		Conservative	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
Fish Group 1	Mortality	219	0.93	0.78	1.06	0.91
	Injury	216	1.58	1.36	1.92	1.67
Fish Group 2	Mortality	210	3.27	2.92	4.11	3.74
	Injury	203	6.75	6.16	8.97	8.23
Fish Group 3 and, 4	Mortality	207	4.50	4.05	5.80	5.34
	Injury	203	6.75	6.16	8.97	8.23
All fish groups	TTS	186	28.2	26.2	39.3	36.0
Fish eggs, and fish larvae	Mortality	210	3.27	2.92	4.11	3.74

Table 6.43: Morven South: Maximum horizontal distances in kilometres from two widely separated 5.3m pin pile operations to maximum-over-depth Sound Exposure Level impact thresholds for marine mammals from National Marine Fisheries Service (2024a). Sound levels are frequency-weighted for cetaceans according to the hearing group

Hearing group	Effect	SEL (dB)	Maximum horizontal distance to threshold (km)							
			Representative				Conservative			
			No ADD		ADD		No ADD		ADD	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
LF cetaceans	AUD INJ	183	3.37	2.55	-	-	14.7	9.59	4.22	3.13
	TTS	168	26.3	20.7	23.0	18.0	50.6	42.0	46.6	38.5
HF cetaceans	AUD INJ	193	-	-	-	-	-	-	-	-
	TTS	178	-	-	-	-	-	-	-	-
VHF cetaceans	AUD INJ	159	-	-	-	-	-	-	-	-
	TTS	144	-	-	1.11	0.92	-	-	1.21	1.00
PCW	AUD INJ	183	-	-	-	-	-	-	-	-
	TTS	168	2.96	2.24	-	-	8.11	6.03	3.59	2.67

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 6.44: Morven South: Maximum horizontal distances in kilometres from two widely separated 5.3m pin pile operations to maximum-over-depth Sound Exposure Level impact thresholds for fish from Popper *et al.* (2014)

Hearing group	Effect	SEL (dB)	Maximum horizontal distance to threshold (km)			
			Representative		Conservative	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
Fish Group 1	Mortality	219	0.62	0.58	0.70	0.66
	Injury	216	0.95	0.89	1.12	1.05
Fish Group 2	Mortality	210	2.34	2.21	2.89	2.79
	Injury	203	5.06	4.69	6.73	6.33
Fish Group 3 and, 4	Mortality	207	3.31	3.10	4.18	4.02
	Injury	203	5.06	4.69	6.73	6.33
All fish groups	TTS	186	24.7	22.5	37.4	31.9
Fish eggs, and fish larvae	Mortality	210	2.34	2.21	2.89	2.79

6.6.1.5 Table 6.45 and Table 6.46 show the distances to SEL impact thresholds for two concurrent 3.7m pin pile piling operations in close proximity for representative and conservative cases, with and without ADD, for marine mammals and fish respectively. Similarly, Table 6.47 and Table 6.48 show results for two widely separated piles. These are directly comparable to the single 3.7m pin pile results in Table 6.23 for marine mammals and Table 6.24 for fish.

Table 6.45: Morven South: Maximum horizontal distances in kilometres from two close proximity 3.7m pin pile operations to maximum-over-depth Sound Exposure Level impact thresholds for marine mammals from National Marine Fisheries Service (2024a). Sound levels are frequency-weighted for cetaceans according to the hearing group

Hearing group	Effect	SEL (dB)	Maximum horizontal distance to threshold (km)							
			Representative				Conservative			
			No ADD		ADD		No ADD		ADD	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
LF cetaceans	AUD INJ	183	4.22	3.76	0.45	0.45	10.7	9.71	6.55	5.84
	TTS	168	48.3	40.4	44.2	36.6	79.6	66.4	76.8	63.4
HF cetaceans	AUD INJ	193	-	-	-	-	-	-	-	-
	TTS	178	-	-	-	-	-	-	-	-
VHF cetaceans	AUD INJ	159	-	-	0.03	0.03	-	-	-	-
	TTS	144	0.48	0.48	1.50	1.29	0.71	0.61	1.64	1.41
PCW	AUD INJ	183	-	-	-	-	-	-	-	-
	TTS	168	4.14	3.70	0.98	0.86	9.81	8.86	6.54	5.83

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 6.46: Morven South: Maximum horizontal distances in kilometres from two close proximity 3.7m pin pile operations to maximum-over-depth Sound Exposure Level impact thresholds for fish from Popper *et al.* (2014)

Hearing group	Effect	SEL (dB)	Maximum horizontal distance to threshold (km)			
			Representative		Conservative	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
Fish Group 1	Mortality	219	0.58	0.49	0.68	0.56
	Injury	216	0.87	0.73	1.21	1.01
Fish Group 2	Mortality	210	2.19	1.93	2.85	2.50
	Injury	203	4.64	4.14	6.15	5.63
Fish Group 3 and, 4	Mortality	207	3.03	2.68	3.97	3.58
	Injury	203	4.64	4.14	6.15	5.63
All fish groups	TTS	186	24.7	23.1	33.0	30.8
Fish eggs, and fish larvae	Mortality	210	2.19	1.93	2.85	2.50

Table 6.47: Morven South: Maximum horizontal distances in kilometres from two widely separated 3.7m pin pile operations to maximum-over-depth Sound Exposure Level impact thresholds for marine mammals from National Marine Fisheries Service (2024a). Sound levels are frequency-weighted for cetaceans according to the hearing group

Hearing group	Effect	SEL (dB)	Maximum horizontal distance to threshold (km)							
			Representative				Conservative			
			No ADD		ADD		No ADD		ADD	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
LF cetaceans	AUD INJ	183	4.95	3.64	-	-	15.1	13.4	11.2	7.53
	TTS	168	41.9	35.0	38.1	31.4	72.9	60.5	68.8	57.1
HF cetaceans	AUD INJ	193	-	-	-	-	-	-	-	-
	TTS	178	-	-	-	-	-	-	-	-
VHF cetaceans	AUD INJ	159	-	-	-	-	-	-	-	-
	TTS	144	-	-	1.19	0.93	0.68	0.51	1.30	1.05
PCW	AUD INJ	183	-	-	-	-	-	-	-	-
	TTS	168	4.86	3.53	-	-	14.7	12.1	8.84	6.28

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 6.48: Morven South: Maximum horizontal distances in kilometres from two widely separated 3.7m pin pile operations to maximum-over-depth Sound Exposure Level impact thresholds for fish from Popper *et al.* (2014)

Hearing group	Effect	SEL (dB)	Maximum horizontal distance to threshold (km)			
			Representative		Conservative	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
Fish Group 1	Mortality	219	0.37	0.34	0.43	0.39
	Injury	216	0.63	0.56	0.71	0.66
Fish Group 2	Mortality	210	1.53	1.42	1.98	1.86
	Injury	203	3.42	3.17	4.50	4.21
Fish Group 3 and, 4	Mortality	207	2.22	2.08	2.85	2.68
	Injury	203	3.42	3.17	4.50	4.21
All fish groups	TTS	186	21.1	19.1	29.2	26.2
Fish eggs, and fish larvae	Mortality	210	1.53	1.42	1.98	1.86

6.7 Vessel scenarios

6.7.1 Overview

6.7.1.1 The following tables provide distances to impact thresholds for sound generated as considered for the vessel scenarios. The behavioural threshold level is based on the unweighted SPL from NOAA (2019) and TTS and AUD INJ are from NMFS (2024a). For the calculation of SEL_{24h}, marine mammals are mobile as described in Section 4.8.

6.7.1.2 Most scenarios include multiple sources. The distances provided are the maximum distance to the identified threshold level from the closest sound source. For behavioural disturbance, this is the 120dB SPL value for continuous sounds as described in Section 3.2.3.

6.7.1.3 It is noted that direct source level measurements are not available for the installation vessel operating on DP but have been scaled from sound levels from a smaller vessel. Additionally, sound levels for DP operation are strongly dependent on environmental factors such as current and wind speed. Lastly, it is noted that the propagation loss curve becomes flatter with increased distance such that small changes in the source level can result in large changes in the reported distance to identified sound levels. Consequently, distances to the behavioural threshold of 120dB for continuous sound sources are difficult to predict accurately, and thus conservative results are presented.

6.7.2 Foundation installation

6.7.2.1 Table 6.49 contains SPL results for Scenario V1, for the foundation installation operation; the scenario comprises the pile installation vessel, the jacket installation vessel, four tugs, and a guard vessel. Results for the SEL are provided in Table 6.50.

Table 6.49: Morven South Scenario V1: Foundation installation. Maximum horizontal distances (km) to maximum-over-depth Sound Pressure Level

SPL (dB re 1µPa²)	Maximum horizontal distance to level (km)	
	R_{max}	$R_{95\%}$
120	59.3	45.3
125	31.4	24.7
130	16.1	13.0
135	8.68	7.12
140	4.93	3.99
145	2.44	1.96
150	1.00	0.90
155	0.46	0.42
160	0.20	0.19
165	0.06	0.06
170	0.03	0.03
175	<0.01	<0.01
180	<0.01	<0.01
185	<0.01	<0.01
190	<0.01	<0.01

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 6.50: Morven South Scenario V1: Foundation installation. Maximum horizontal distances (km) to maximum-over-depth sound exposure level impact thresholds for marine mammals from National Marine Fisheries Service (2024a). Sound levels are frequency-weighted for cetaceans according to the hearing group

Hearing group	Effect	Metric	Level (dB)	Maximum horizontal distance to threshold	
				R_{max} (km)	$R_{95\%}$ (km)
LF cetaceans	AUD INJ	$SEL_{24h,LF}$	197	-	-
	TTS	$SEL_{24h,LF}$	177	0.74	0.67
HF cetaceans	AUD INJ	$SEL_{24h,HF}$	201	-	-
	TTS	$SEL_{24h,HF}$	181	-	-
VHF cetaceans	AUD INJ	$SEL_{24h,VHF}$	181	-	-
	TTS	$SEL_{24h,VHF}$	161	-	-
PCW	AUD INJ	$SEL_{24h,PPW}$	195	-	-
	TTS	$SEL_{24h,PPW}$	175	0.07	0.07
All marine mammals	Behaviour	SPL	120	59.4	45.7

A dash (-) indicates that the level was not reached within the resolution of the model.

6.7.3 Turbine installation

6.7.3.1 Table 6.51 contains results for Scenario V2, for the turbine installation operation; the scenario comprises the turbine installation vessel, the offshore support vessel, and a guard vessel. Results for the SEL are provided in Table 6.52.

Table 6.51: Morven South Scenario V2: Turbine installation. Maximum horizontal distances (km) to maximum-over-depth Sound Pressure Level

SPL (dB re 1µPa²)	Maximum horizontal distance to level (km)	
	R_{max}	$R_{95\%}$
120	53.1	36.2
125	29.0	20.5
130	14.0	10.7
135	6.98	6.27
140	4.04	3.18
145	1.99	1.59
150	0.79	0.72
155	0.36	0.34
160	0.16	0.16
165	0.04	0.04
170	0.03	0.03
175	<0.01	<0.01
180	<0.01	<0.01
185	<0.01	<0.01
190	<0.01	<0.01

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 6.52: Morven South Scenario V2: Turbine installation. Maximum horizontal distances (km) to maximum-over-depth Sound Exposure Level impact thresholds for marine mammals from National Marine Fisheries Service (2024a). Sound levels are frequency-weighted for cetaceans according to the hearing group

Hearing group	Effect	Metric	Level (dB)	Maximum horizontal distance to threshold	
				R_{max} (km)	$R_{95\%}$ (km)
LF cetaceans	AUD INJ	$SEL_{24h,LF}$	197	-	-
	TTS	$SEL_{24h,LF}$	177	0.47	0.44
HF cetaceans	AUD INJ	$SEL_{24h,HF}$	201	-	-
	TTS	$SEL_{24h,HF}$	181	-	-
VHF cetaceans	AUD INJ	$SEL_{24h,VHF}$	181	-	-
	TTS	$SEL_{24h,VHF}$	161	-	-
PCW	AUD INJ	$SEL_{24h,PPW}$	195	-	-
	TTS	$SEL_{24h,PPW}$	175	0.08	0.08
All marine mammals	Behaviour	SPL	120	53.4	36.6

A dash (-) indicates that the level was not reached within the resolution of the model.

6.7.4 Cable laying

6.7.4.1 Table 6.53 contains results for Scenario V3, for the cable laying operation; the scenario comprises the pile installation vessel, the jacket installation vessel, four tugs, and a guard vessel. Results for the SEL are provided in Table 6.54.

Table 6.53: Morven South Scenario V3: Cable laying. Maximum horizontal distances in kilometres to maximum-over-depth Sound Pressure Level

SPL (dB re 1µPa^2)	Maximum horizontal distance to level (km)	
	R_{max}	$R_{95\%}$
120	40.4	29.5
125	21.0	16.0
130	10.9	8.67
135	5.65	5.07
140	3.18	2.53
145	1.52	1.25
150	0.62	0.57
155	0.28	0.26
160	0.09	0.08
165	0.04	0.04
170	<0.01	<0.01
175	<0.01	<0.01
180	<0.01	<0.01
185	<0.01	<0.01
190	<0.01	<0.01

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 6.54: Morven South Scenario V3: Cable laying. Maximum horizontal distances in kilometres to maximum-over-depth Sound Exposure Level impact thresholds for marine mammals from National Marine Fisheries Service (2024a). Sound levels are frequency-weighted for cetaceans according to the hearing group

Hearing group	Effect	Metric	Level (dB)	Maximum horizontal distance to threshold	
				R_{max} (km)	$R_{95\%}$ (km)
LF cetaceans	AUD INJ	$SEL_{24h,LF}$	197	-	-
	TTS	$SEL_{24h,LF}$	177	0.23	0.23
HF cetaceans	AUD INJ	$SEL_{24h,HF}$	201	-	-
	TTS	$SEL_{24h,HF}$	181	-	-
VHF cetaceans	AUD INJ	$SEL_{24h,VHF}$	181	-	-
	TTS	$SEL_{24h,VHF}$	161	0.10	0.10
PCW	AUD INJ	$SEL_{24h,PPW}$	195	-	-
	TTS	$SEL_{24h,PPW}$	175	0.03	0.03
All marine mammals	Behaviour	SPL	120	40.7	29.8

A dash (-) indicates that the level was not reached within the resolution of the model.

6.7.5 Crew transfer

6.7.5.1 Table 6.55 contains SPL results for Scenario V4 crew transfer; the scenario comprises a single crew transfer vessel. Results for the SEL are provided in Table 6.56. It is noted that no threshold is exceeded when moving receivers are considered, so the table is included solely for consistency.

Table 6.55: Morven South Scenario V4: Crew transfer. Maximum horizontal distances in kilometres to maximum-over-depth Sound Pressure Level

SPL (dB re 1µPa²)	Maximum horizontal distance to level (km)	
	R_{max}	$R_{95\%}$
120	0.63	0.60
125	0.27	0.27
130	0.13	0.13
135	0.04	0.04
140	0.03	0.03
145	<0.01	<0.01
150	<0.01	<0.01
155	<0.01	<0.01
160	<0.01	<0.01
165	-	-
170	-	-
175	-	-
180	-	-
185	-	-
190	-	-

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 6.56: Morven South Scenario V4: Crew transfer. Maximum horizontal distances in kilometres to maximum-over-depth Sound Exposure Level impact thresholds for marine mammals from National Marine Fisheries Service (2024a). Sound levels are frequency-weighted for cetaceans according to the hearing group

Hearing group	Effect	Metric	Level (dB)	Maximum horizontal distance to threshold	
				R_{max} (km)	$R_{95\%}$ (km)
LF cetaceans	AUD INJ	$SEL_{24h,LF}$	197	-	-
	TTS	$SEL_{24h,LF}$	177	-	-
HF cetaceans	AUD INJ	$SEL_{24h,HF}$	201	-	-
	TTS	$SEL_{24h,HF}$	181	-	-
VHF cetaceans	AUD INJ	$SEL_{24h,VHF}$	181	-	-
	TTS	$SEL_{24h,VHF}$	161	-	-
PCW	AUD INJ	$SEL_{24h,PPW}$	195	-	-
	TTS	$SEL_{24h,PPW}$	175	-	-
All marine mammals	Behaviour	SPL	120	-	-

A dash (-) indicates that the level was not reached within the resolution of the model.

6.8 Geophysical survey sources

6.8.1.1 Table 6.57 presents the distances to the PK impact thresholds, as defined by NMFS (2024a) NMFS (2024a), for the geophysical survey sources. All devices except the Sparker are classified as non-impulsive and therefore do not have defined PK thresholds for AUD INJ or TTS. However, due to the characteristics of the source signals, there are instances where the distances to impulsive PK thresholds exceed those for SEL thresholds.

6.8.1.2 There is no specific recommendation from NMFS (2024a) to provide distances to the PK threshold for non-impulsive sources. As a conservative precautionary measure, however, and in the absence of defined PK thresholds for non-impulsive sources, the impulsive source threshold has been applied when evaluating peak sound levels for all sources as described in NMFS (2024b). This conservative approach is explained further in Appendix D.2.4.

6.8.1.3 Table 6.58 provides distances to the SEL impact thresholds defined by NMFS (2024a) resulting from a pass of single survey line of the geophysical survey sources. Note that a different threshold exists for the Sparker being impulsive in nature; all other sources use the non-impulsive threshold.

6.8.1.4 Note that the dual metric approach applies when determining distances to impact thresholds, i.e., the maximum distance across equivalent cells in Table 6.57 and Table 6.58 should be taken as the result for the device.

6.8.1.5 Table 6.59 shows results to the unweighted behavioural disturbance SPL thresholds defined by NOAA (2019). As discussed in Section 3.2.3, the threshold for behavioural disturbance for these sources is an SPL of 160 dB for intermittent source types.

Table 6.57: Morven South: Maximum horizontal distances in kilometres from the geophysical sources to maximum-over-depth peak (PK) impact thresholds for marine mammals from National Marine Fisheries Service (2024a)

Hearing group	Effect	PK (dB)	Maximum horizontal distance to threshold (km)					
			Non-impulsive					Impulsive
			MBES	SSS	SBES	CHIRP 2.0kHz	CHIRP 3.5kHz	Sparker
LF cetaceans	AUD INJ	222	0.015	0.004	0.007	-	0.007	-
	TTS	216	0.029	0.007	0.007	0.001	0.013	0.002
HF cetaceans	AUD INJ	230	0.007	0.002	0.002	-	0.003	-
	TTS	224	0.013	0.003	0.004	-	0.006	-
VHF cetaceans	AUD INJ	202	0.105	0.032	0.007	0.006	0.064	0.009
	TTS	196	0.165	0.036	0.007	0.010	0.126	0.018
PCW	AUD INJ	223	0.014	0.004	0.005	-	0.006	-
	TTS	217	0.026	0.007	0.007	0.001	0.012	0.002

A dash (-) indicates that the level was not reached within the resolution of the model.
Distances to the PK thresholds are not shown for the non-impulsive sources because it was assessed based on the intermittent source criteria which does not include PK thresholds.

Table 6.58: Morven South: Maximum horizontal distances in kilometres from the geophysical sources to maximum-over-depth sound exposure level impact thresholds for marine mammals from National Marine Fisheries Service (2024a)

Hearing group	Effect	Maximum horizontal distance to threshold (km)							
		Non-impulsive						Impulsive	
		SEL (dB)	MBES	SSS	SBES	CHIRP 2.0kHz	CHIRP 3.5kHz	SEL (dB)	Sparker
LF cetaceans	AUD INJ	197	-	-	0.002	0.003	0.071	183	0.016
	TTS	177	-	-	0.007	0.057	0.712	168	0.110
HF cetaceans	AUD INJ	201	0.016	0.002	0.003	-	0.039	193	-
	TTS	181	0.124	0.036	0.007	0.022	0.406	178	0.002
VHF cetaceans	AUD INJ	181	0.181	0.036	0.007	-	0.114	159	-
	TTS	161	0.505	0.200	0.064	0.030	1.129	144	0.004
PCW	AUD INJ	195	0.058	-	0.005	0.003	0.091	183	0.004
	TTS	175	0.262	0.020	0.007	0.066	0.907	168	0.040

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 6.59: Morven South: Maximum horizontal distances in kilometres from the geophysical sources to behavioural threshold for marine mammals from intermittent (impulsive and non-impulsive) sources from National Marine Fisheries Service (2024a).

Hearing group	Effect	SPL (dB)	Maximum horizontal distance to threshold (km)					
			MBES	SSS	SBES	CHIRP 2.0kHz	CHIRP 3.5kHz	Sparker
Marine mammals	Behaviour	160	0.682	0.229	0.153	0.316	3.798	0.501

A dash (-) indicates that the level was not reached within the resolution of the model.

6.9 Unexploded ordnance

6.9.1.1 The following tables show results for the distances to identified sound level thresholds for the UXO scenarios. Table 6.60 shows distances to stepped SPL values for the four scenarios.

Table 6.60: Morven South: Maximum horizontal distances in kilometres from the Unexploded Ordnance to maximum-over-depth Sound Pressure Level values

SPL (dB re 1μPa^2)	Maximum horizontal distance to level (km)							
	554kg		132kg		25kg		0.25kg	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
160	>150	>144	124	103	55.7	50.0	9.44	8.96
165	130	108	74.6	63.8	36.5	33.3	6.61	6.23
170	81.3	69.4	46.7	41.9	24.7	23.1	4.35	4.13
175	51.7	46.2	30.8	28.4	17.1	15.8	2.73	2.62
180	34.7	31.8	21.3	20.0	9.50	8.99	1.62	1.54
185	23.8	22.4	13.1	12.0	6.41	6.03	0.83	0.77
190	16.2	15.0	8.15	7.62	4.21	4.01	0.37	0.33
195	9.26	8.75	5.32	5.04	2.77	2.63	0.15	0.15
200	6.10	5.78	3.50	3.36	1.68	1.56	0.06	0.06
205	4.03	3.84	2.26	2.16	0.80	0.71	0.03	0.03
210	2.59	2.48	1.09	1.01	0.35	0.30	-	-
215	1.45	1.38	0.52	0.47	0.15	0.15	-	-
220	0.73	0.65	0.23	0.23	0.06	0.06	-	-
225	0.28	0.28	0.10	0.10	0.03	0.03	-	-
230	0.13	0.13	0.03	0.03	-	-	-	-
235	0.06	0.06	0.03	0.03	-	-	-	-
240	0.03	0.03	-	-	-	-	-	-

A dash (-) indicates that the level was not reached within the resolution of the model.
The maximum modelled distance was 150km; an entry of ">150" is used where sound levels exceeding the threshold exist outside the modelled domain.

Table 6.61: Morven South: Maximum horizontal distances in kilometres from the Unexploded Ordnance maximum-over-depth peak (PK) impact thresholds for marine mammals from National Marine Fisheries Service (2024a) and fish from Popper *et al.* (2014)

Hearing group	Effect	PK (dB)	Maximum horizontal distance to threshold (km)							
			554kg		132kg		25kg		0.25kg	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
LF cetaceans	AUD INJ	222	2.96	2.79	2.10	1.96	0.77	0.66	0.03	0.03
	TTS	216	4.78	4.42	3.06	2.83	1.93	1.75	0.09	0.09
HF cetaceans	AUD INJ	230	1.68	1.53	0.69	0.62	0.41	0.35	-	-
	TTS	224	2.63	2.48	1.76	1.59	0.63	0.55	0.03	0.03
VHF cetaceans	AUD INJ	202	16.3	14.2	9.31	8.27	5.22	4.82	0.56	0.50
	TTS	196	24.5	22.3	17.4	14.9	8.50	7.65	1.40	1.25
PCW	AUD INJ	223	2.79	2.62	1.93	1.79	0.67	0.59	0.03	0.03
	TTS	217	4.43	4.12	2.84	2.65	1.75	1.57	0.09	0.09
Fish	Injury	229	1.87	1.73	0.77	0.68	0.44	0.39	-	-
		234	0.8	0.73	0.51	0.45	0.17	0.17	-	-

A dash (-) indicates that the level was not reached within the resolution of the model.

Table 6.62: Morven South: Maximum horizontal distances in kilometres from the unexploded ordnance to maximum-over-depth sound exposure level impact thresholds for marine mammals from National Marine Fisheries Service (2024a). Sound levels are frequency-weighted for cetaceans according to the hearing group

Hearing group	Effect	SEL (dB)	Maximum horizontal distance to threshold (km)							
			554kg		132kg		25kg		0.25kg	
			R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
LF cetaceans	AUD INJ	183	8.90	8.22	5.44	5.08	2.94	2.73	0.15	0.15
	TTS	168	33.4	30.7	21.8	20.4	9.96	9.46	1.47	1.33
HF cetaceans	AUD INJ	193	0.03	0.03	-	-	-	-	-	-
	TTS	178	0.30	0.29	0.20	0.20	0.06	0.06	-	-
VHF cetaceans	AUD INJ	159	1.84	1.64	0.95	0.87	0.48	0.41	0.02	0.02
	TTS	144	6.34	5.90	4.41	4.09	2.85	2.61	0.20	0.20
PCW	AUD INJ	183	3.06	2.81	1.94	1.75	0.85	0.70	0.03	0.03
	TTS	168	10.3	9.53	7.22	6.74	4.35	4.05	0.31	0.31

A dash (-) indicates that the level was not reached within the resolution of the model.

7 Comparison with background levels

7.1 Sound levels in the North Sea

7.1.1.1 The North Sea is one of the most intensively used marine areas in the world, and its underwater soundscape reflects this. Ambient sound levels are shaped by a combination of natural sources, such as wind, waves, and biological activity, and anthropogenic sources, most notably commercial shipping, offshore construction, and seismic surveys.

7.1.1.2 Early large-scale, validated maps of shipping noise in the Northeast Atlantic, including the North Sea were produced by Farcas et al. (2020). The study produced broadband SPL predictions across the 125Hz to 5kHz range from AIS ship-tracking data, wind speed, and environmental parameters, with modelled values agreeing within ±3dB of field measurements for 93% of cases. These maps revealed that areas such as the English Channel, Norwegian Trench, and regions near major ports and offshore infrastructure consistently exhibit median SPLs exceeding 120dB re 1µPa, with ship noise often surpassing natural wind-generated sound by more than 20dB. The study also highlighted seasonal variability, with ship noise excess peaking in summer months due to increased vessel activity and reduced wind noise.

7.1.1.3 More recently, major European projects, including the JOMOPANS and the NAVISON (portmanteau of the Latin words, *Navis*, meaning boat and *Sonus*, meaning sound) project led by the European Maritime Safety Agency (EMSA), have provided detailed spatial and temporal maps of underwater SPLs. These studies show that broadband SPLs in the North Sea typically range from 100 to 130dB re 1µPa, with the highest levels observed in areas like the English Channel, southern North Sea, and major shipping lanes (de Jong *et al.* 2022, Sertlek *et al.* 2024). Construction activities, particularly pile driving for offshore wind farms, can temporarily elevate local acoustic levels by 30–50dB above ambient (Basan *et al.* 2024).

7.1.1.4 The spectral composition of underwater sound in the North Sea is strongly influenced by source type. Commercial shipping dominates the low-frequency bands, particularly around 63Hz and 125Hz, which are the focus of EU Marine Strategy Framework Directive Descriptor D11C2. Tankers and cargo vessels contribute most significantly at 63Hz, whilst roll-on/roll-off and container vessels are more prominent at 125Hz (Sertlek *et al.* 2024).

7.1.1.5 Wind-generated sound becomes more relevant above 500Hz, especially in deeper or more remote areas. Spatial variability is also shaped by bathymetry and seasonal changes in sound speed profiles: deeper areas like the northern North Sea exhibit stronger seasonal stratification, which affects sound propagation, whilst shallow areas like the southern North Sea show more uniform propagation characteristics (Basan *et al.* 2024). In general, low-frequency sounds propagate further in winter due to reduced stratification and higher sound speeds at depth.

7.1.1.6 In addition to the continuous sound from shipping activities, there are plans for other wind farms to be constructed off the east coast of Scotland. These include Campion wind farm, a 2GW floating offshore wind farm construction starting in 2026; Bowdun wind farm, a 1GW fixed-foundation wind farm with construction starting in 2029; and Ossian wind farm, a 3.6GW floating offshore wind farm to be constructed in the early 2030s. These are shown in Figure 7.1.

7.1.1.7 Similarly to Morven North and Morven South, these projects will involve large-scale turbine foundation installations, with construction phases including pile driving and dynamic positioning of vessels. Consequently, each of these have potential to contribute significantly to the regional underwater soundscape.

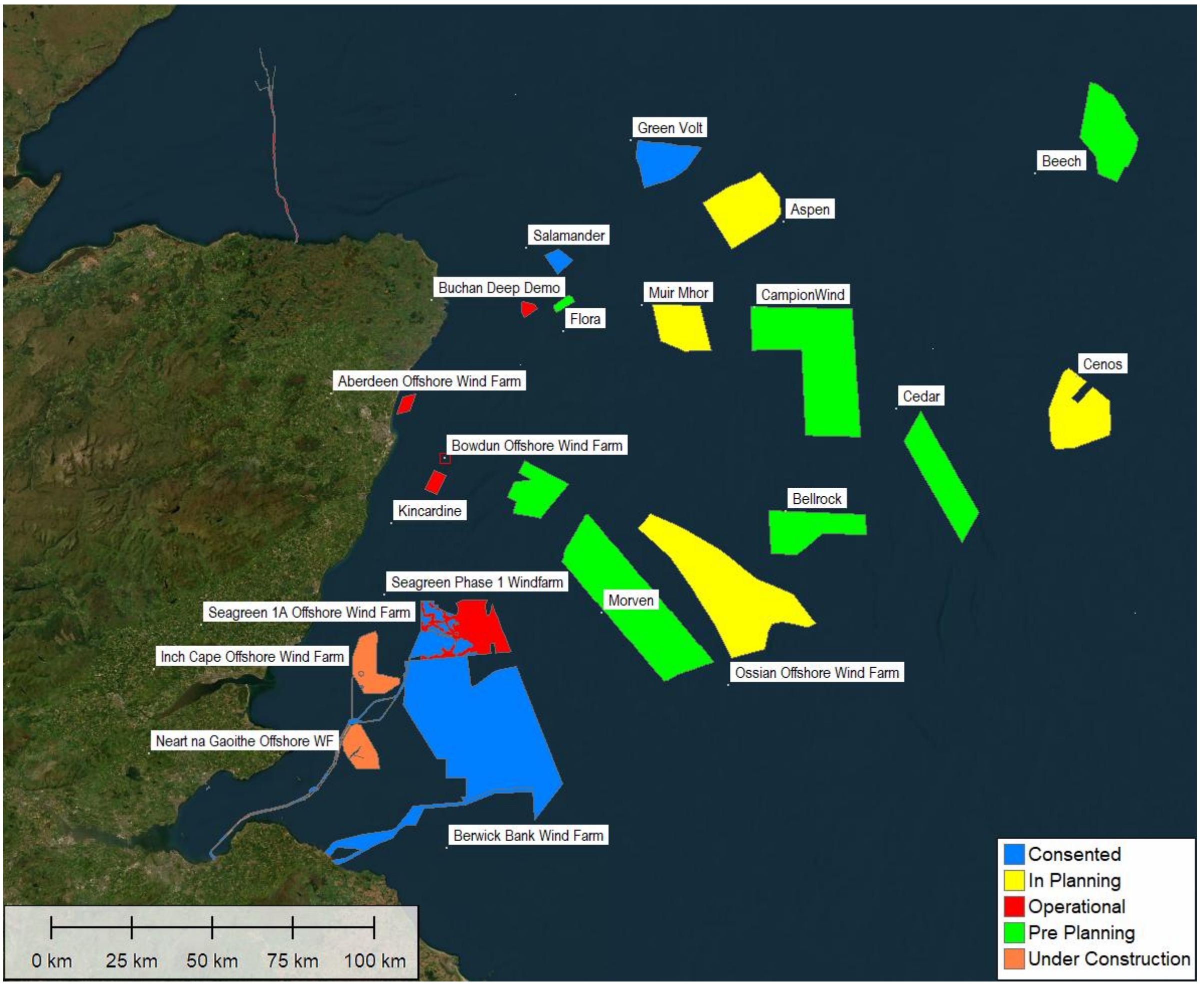

Figure 7.1: Wind farms close to Morven Contains public sector information, licensed under the Open Government Licence v3.0, from Crown Estate Scotland (Accessed 04/11/2025)

7.2 Sound levels at the Morven Site

7.2.1.1 Figure 7.2 shows the estimated percentage time that anthropogenic sound exceeded the ambient levels by more than 20dB over the year 2019. Also shown are the locations of measurement stations from the JOMOPANS project across the North Sea, as well as indicating the proportion of vessel classes transiting within 35km of each station. Station 15-SC-CNS is closest to the Morven site being approximately 30km east; the results for 2019 indicated that anthropogenic sound exceeded ambient levels by 20dB for 2.5% of the year. Measurements at this station were made from November 2019 to January 2020.

7.2.1.2 The spectrum of received measurements at Station 15-SC-CNS is shown in Figure 7.3. In the study, three frequency ranges were chosen, each spanning one decade and broadly representing the hearing ranges of different animal groups (de Jong *et al.* 2022): 20Hz to 160Hz, 200Hz to 1.6kHz, and 2kHz to 16kHz. Due to missing data at some stations, the lower limit was increased to 25Hz and the upper limit reduced to 10kHz. At Station 15-SC-CNS, the broadband averaged SPL was 107dB across both the 25Hz to 160Hz and 200Hz to 1.6kHz bands.

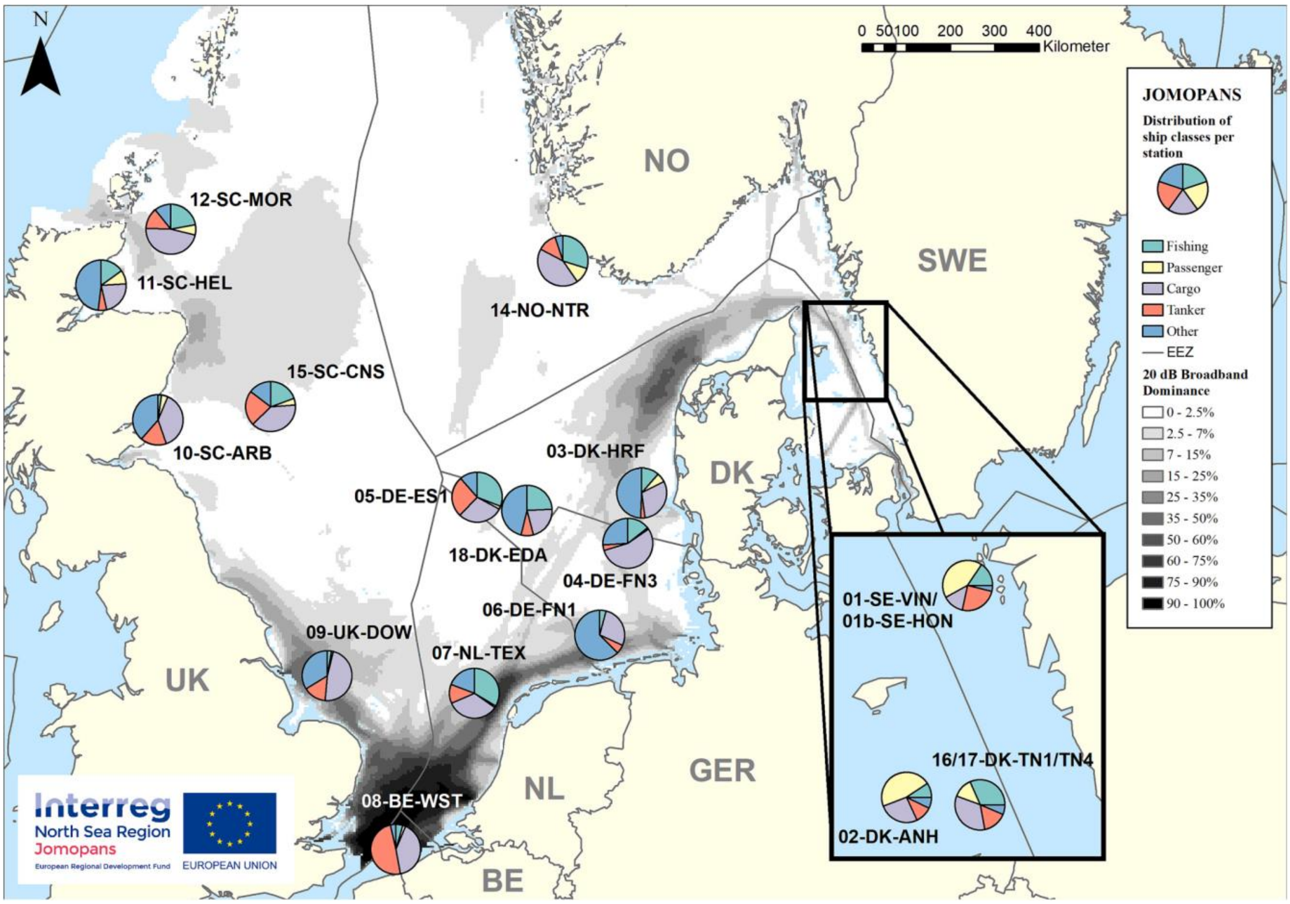

Figure 7.2: Positions of underwater acoustic measurement stations showing pie charts of share of ship classes within 35km of the station. The contour map indicates over what percentage of the year 2019 predicted anthropogenic sound dominated natural ambient levels by 20dB or more. Reproduced from Basan *et al.* (2024)

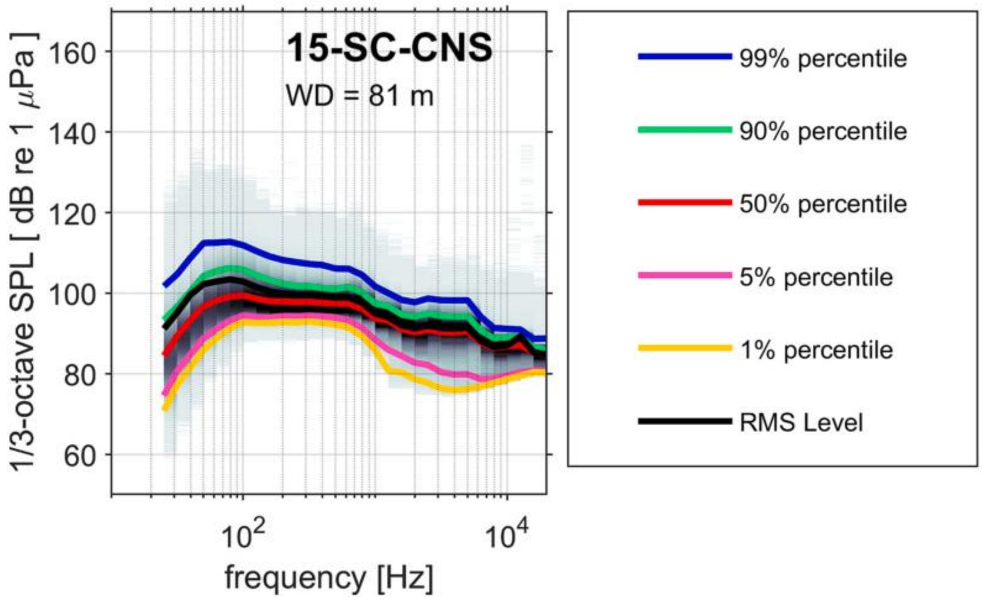

Figure 7.3: Spectral probability densities, cumulative probability distributions of 1%, 5%, 50%, 95%, and 99% percentiles, and root-mean squared level from measurements at Station 15-SC-CNS from November 2019 to January 2020

7.2.1.3 The spectral characteristics observed at Station 15-SC-CNS suggest that the dominant contributions to the measured sound levels fall within frequency bands typically associated with vessel traffic and industrial activity. Given the proximity of this station to the Morven Site, it is reasonable to infer that construction-related activities such as pile driving or vessel operations would elevate local sound levels, particularly in the low- to mid-frequency range, and that SPLs above 120dB will be audible above background levels. These increases may have implications for marine species sensitive to sound at these frequencies, especially during peak construction periods.

7.2.1.4 Assuming that ambient sound levels, including those from shipping, have remained constant since 2019, construction operations for Morven North and Morven South would be expected to produce sound levels higher than the existing regional baseline. Given the increase in vessel traffic and offshore construction activity in the area since 2019, however, it is considered likely that ambient sound levels have also risen. As a result, the relative increase in sound levels attributable specifically to construction at Morven North and Morven South may be less pronounced than estimated from 2019 noise levels.

7.2.1.5 A further study investigating radiated noise from the Hywind floating offshore wind farm had a control device measuring background noise located approximately 150km from the Morven North and Morven South boundaries (Burns *et al.* 2022); the measurements were taken from October 2020 to January 2021 and are shown in Figure 7.3, which illustrates thatbackground broadband SPLs are highly variable from 110 to 125dB across the reporting period, with almost all energy coming from frequencies below 1kHz.

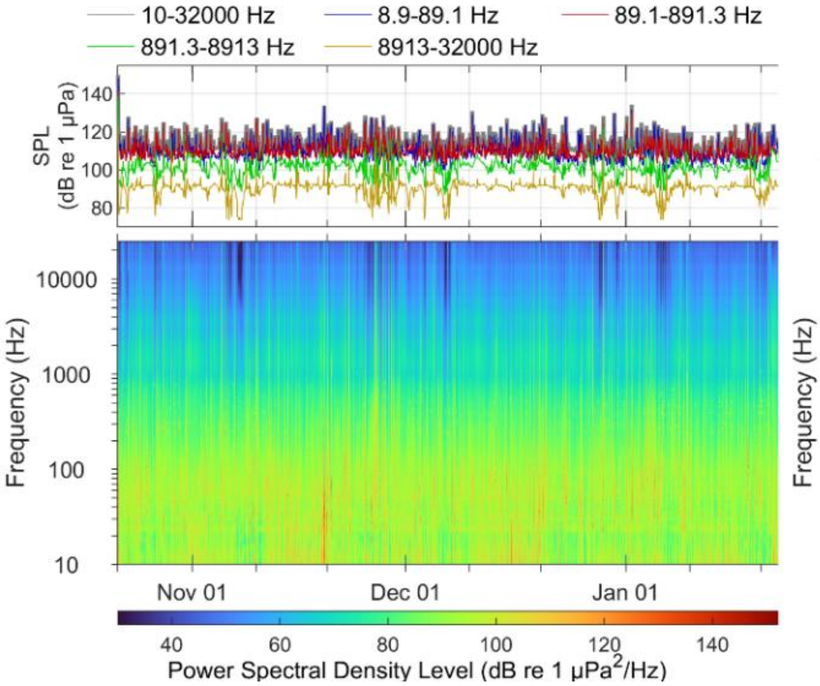

Figure 7.4: Sound levels recorded at a control site for Hywind Scotland from October 2020 to January 2021 (Burns et al. 2022)

7.2.1.6 The Hywind measurement was taken further away from the Morven North and Morven South sites than the JOMOPANS recording; it does, however, indicate that there are regions of elevated levels in the North Sea comparatively local to farm, outside of main shipping lanes.

7.2.1.7 Continued monitoring at this and nearby stations is recommended to assess the cumulative acoustic impact of ongoing and future developments in the region. Comparing future measurements with the 2019 baseline will help determine the extent of anthropogenic influence and inform mitigation strategies. Such data will also support compliance with environmental regulations and contribute to broader regional assessments under initiatives like JOMOPANS.

8 Summary

8.1 Overview

8.1.1.1 This underwater modelling report covers numerous sound sources associated with the construction of Morven North and Morven South. The main sound sources considered was that of pile driving, with multiple sizes, environments, and combinations of piles. Additionally, sounds from vessel operations, geophysical surveys, and UXO clearance (using high order and low order techniques) were also studied.

8.1.1.2 Sound propagation characteristics across the two sites were broadly similar between Morven North and Morven South with Morven South typically having slightly greater distances due to the general water depth to be greater. Despite similarities, they are treated separately in the following sections.

8.1.1.3 It should be noted that the distances provided consider the maximum sound level over all depths in the water column. In the case of the moving receiver scenarios, this implies that the animal is effectively always swimming at the depth where sound levels are greatest. Sound levels reduce close to the water surface, so there will be a natural reduction in exposed sound for animals that come to the surface to breathe that is not considered here.

8.1.1.4 Distances have been presented in terms of the R_{max} and $R_{95\%}$. Additionally, many modelling runs have been calculated for representative and conservative sites. For further assessment of these results, it is recommended to use $R_{95\%}$ from conservative sites when considering general radiated sound from specific solitary acoustic events. When considering wider trends, however, as it is anticipated that there will be some situations where the sound propagation will be lower than those predicted, we would recommend use of the $R_{95\%}$ from representative sites to calculate further results. Finally, for critical situations that warrant the worst-case to be considered, the R_{max} at conservative sites would be recommended.

8.1.1.5 Sound field maps for each source, environment, and metric are provided digitally.

8.2 Morven North

8.2.1 Single strike assessments

8.2.1.1 Section 5.3 provides the results of the impact piling at Morven North for individual pulses. For each of the three piles, four penetration depths were analysed, in conservative and representative environments. Distances were provided to the behavioural thresholds from the per-pulse SEL and SPL, along with AUD INJ and TTS onset criteria. The key results are summarised here.

8.2.1.2 Table 8.1 summarises the distances to single strike behavioural thresholds. Distances to the 160dB SPL threshold are greatest for the 16m monopile, being between 16km and 22km from the pile. Distances to the 143dB SEL per-pulse threshold for behavioural reaction in harbour porpoise are also greatest for the 16m monopile, being from 25km to 39km.

Table 8.1: Maximum horizontal distances in kilometres from the 16m monopile to behavioural thresholds

Metric	Maximum horizontal distance to level (km)											
	16m monopile				5.3m pin pile				3.7m pin pile			
	Rep.		Con.		Rep.		Con.		Rep.		Con.	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
SPL: 160dB	17.1	15.7	21.7	20.8	12.8	11.8	18.0	17.1	10.9	9.99	15.6	14.7
SEL: 143dB	27.2	25.4	38.8	36.3	26.3	24.4	35.6	33.3	25.7	23.9	33.9	32.0

SPL in dB re 1μPa², SEL in dB re 1μPa²s, Rep.: Representative, Con: Conservative.

8.2.1.3 Distances to PK thresholds that exceeded AUD INJ and TTS criteria in very high-frequency cetaceans are shown in Table 8.2; the focus is on very high-frequency cetaceans as they have the lowest onset thresholds and consequently produce the greatest distances to thresholds levels. Again, the greatest distances are universally seen for the 16m monopile with AUD INJ distances from 0.87km to 0.95km, and TTS distances being 1.82km to 2.09km. It is noted that the conservative environment does not always generate the greatest ranges to thresholds; the environment selection study considered the long propagation of sound energy metrics, and so departures from this for near-field PK results are not remarkable.

Table 8.2: Maximum horizontal distances in kilometres from the 16m monopile to auditory injury and temporary threshold shift peak (PK) thresholds for very high-frequency cetaceans

Threshold PK	Maximum horizontal distance to level (km)											
	16m monopile				5.3m pin pile				3.7m pin pile			
	Rep.		Con.		Rep.		Con.		Rep.		Con.	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
AUD INJ	0.95	0.92	0.90	0.87	0.57	0.54	0.54	0.52	0.66	0.64	0.76	0.74
TTS	1.90	1.82	2.09	2.01	0.94	0.90	0.99	0.96	1.44	1.32	1.73	1.59

PK in dB re 1μPa², Rep.: Representative, Con: Conservative.

8.2.2 Multiple strike assessments

8.2.2.1 Section 5.4 provides results of the total sound energy accumulated over time over the course of a single piling operation for marine mammals (moving) and fish (static). In all cases, the distances for marine mammals are greatest for low-frequency cetaceans. The moving receivers move away from the pile as the first hammer initiation blow occurs or at the first pulse of the ADD, and swim at a constant speed away from the pile thereafter. Table 8.3 shows animal starting distances to the low-frequency cetacean AUD INJ and TTS thresholds for piling a single pile with and without ADD.

Table 8.3: Maximum horizontal distances in kilometres from the 16m monopile to auditory injury and temporary threshold shift thresholds for low-frequency cetaceans

Threshold $SEL_{24h,LF}$	Maximum horizontal distance to level (km)											
	16m monopile				5.3m pin pile				3.7m pin pile			
	Rep.		Con.		Rep.		Con.		Rep.		Con.	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
No ADD												
AUD INJ	4.73	4.37	10.6	9.98	1.44	1.34	4.25	3.92	2.17	2.03	5.59	5.21
TTS	21.2	19.7	40.0	34.9	17.1	15.8	38.8	32.3	29.6	26.8	56.6	46.6
ADD												
AUD INJ	0.54	0.53	6.49	5.98	-	-	0.01	0.01	-	-	1.44	1.29
TTS	17.0	15.7	35.9	31.0	13.0	11.8	34.7	28.5	25.5	22.9	52.5	42.7

SEL in dB re 1μPa²s, Rep.: Representative, Con: Conservative. A dash (-) indicates that the level was not reached within the resolution of the model.

8.2.2.2 From Table 8.3 we see a maximum distance of AUD INJ exposure to from the 16m monopile (10.6km) but the TTS from the 3.7m pin pile (56.6km). The 16m monopile generates greater broadband levels, with sound levels close to the pile being greater than that for the 3.7m pin pile; the 3.7m pin pile, however, has more energy at frequencies that propagate well than the 16m monopile, such that the rate of decay is lower for the 3.7m pin pile and this we see greater ranges for the lower-level thresholds.

8.2.2.3 Considering the moving marine mammal receivers following use of an ADD, the $R_{95\%}$ distances are reduced such that AUD INJ is 530m for the representative environment, and 5.98km in the conservative environment.

8.2.2.4 It is noted that modelling the ADD with no soft start itself introduces additional entries into the table for very high-frequency cetaceans under the TTS criterion for the SEL_{24h} metric, which are not present in the non-ADD scenario. These entries, however, remain somewhat below the corresponding threshold distances when assessed against the PK criterion, and therefore do not affect the reported dual-criteria outcomes. Use of a soft start in the ADD would reduce these distances.

8.2.3 Concurrent piling assessments

8.2.3.1 The concurrent piling assessments consider the radiated sound field from simultaneous piling operations at different locations within the Morven North Boundary. Section 4.7 provides detail of how the concurrent piling assessment is carried out.

8.2.3.2 As previously described, the PK and SPL metrics are based on the instantaneous and near-instantaneous sound levels generated by the piling. Consequently, there is no change to the maximum distance to identified sound level when considering multiple piles over the single pile results reported in Table 8.1 and Table 8.2.

Cumulative SEL results for the concurrent piling modelling assessment are shown in Table 8.4 for the 16m monopile,

Table 8.5 for the 5.3m pin pile, and

8.2.3.3 Table 8.6 for the 3.7m pin pile. Each table presents results for the single pile (duplicated from Table 8.3), two nearby piling operations, and two distant operations for low-frequency cetaceans.

Table 8.4: Maximum horizontal distances in kilometres from single and concurrent 16m monopile operations to auditory injury and temporary threshold shift thresholds for low-frequency cetaceans

Threshold $SEL_{24h,LF}$	Maximum horizontal distance to level (km)											
	Single monopile				Close monopiles				Distant monopiles			
	Rep.		Con.		Rep.		Con.		Rep.		Con.	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
No ADD												
AUD INJ	4.73	4.37	10.6	9.98	7.06	6.24	14.2	13.5	7.90	6.05	19.4	16.0
TTS	21.2	19.7	40.0	34.9	25.5	23.6	49.6	43.1	26.9	21.4	47.7	38.3
ADD												
AUD INJ	0.54	0.53	6.49	5.98	2.95	2.50	10.1	9.44	2.87	2.46	16.2	12.3
TTS	17.0	15.7	35.9	31.0	21.3	19.6	45.5	39.3	24.2	19.5	43.9	34.9

Table 8.5: Maximum horizontal distances in kilometres from single and concurrent 5.3m pin pile operations to auditory injury and temporary threshold shift thresholds for low-frequency cetaceans

Threshold $SEL_{24h,LF}$	Maximum horizontal distance to level (km)											
	Single 5.3m pin pile				Close 5.3m pin piles				Distant 5.3m pin piles			
	Rep.		Con.		Rep.		Con.		Rep.		Con.	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
No ADD												
AUD INJ	1.44	1.34	4.25	3.92	2.73	2.37	7.17	6.68	3.19	2.40	8.66	6.58
TTS	17.1	15.8	38.8	32.3	24.3	21.2	54.4	44.7	26.2	20.3	45.7	38.6
ADD												
AUD INJ	-	-	0.01	0.01	-	-	3.04	2.71	-	-	2.14	1.73
TTS	13.0	11.8	34.7	28.5	20.1	17.3	50.3	41.0	23.5	19.1	42.0	35.1

SEL in dB re 1µPa²s, Rep.: Representative, Con: Conservative. A dash (-) indicates that the level was not reached in modelled results.

Table 8.6: Maximum horizontal distances in kilometres from single and concurrent 3.7m pin pile operations to auditory injury and temporary threshold shift thresholds for low-frequency cetaceans

Threshold $SEL_{24h,LF}$	Maximum horizontal distance to level (km)											
	Single 3.7m pin pile				Close 3.7m pin piles				Distant 3.7m pin piles			
	Rep.		Con.		Rep.		Con.		Rep.		Con.	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
No ADD												
AUD INJ	2.17	2.03	5.59	5.21	3.99	3.48	9.75	9.00	4.52	3.35	12.9	9.37
TTS	29.6	26.8	56.6	46.6	43.8	37.3	75.6	64.6	40.6	31.9	65.8	55.7
ADD												
AUD INJ	-	-	1.44	1.29	-	-	5.61	5.00	-	-	6.66	4.90
TTS	25.5	22.9	52.5	42.7	39.6	33.4	71.8	61.5	36.9	28.8	61.6	52.3

SEL in dB re 1µPa²s, Rep.: Representative, Con: Conservative. A dash (-) indicates that the level was not reached in modelled results.

8.2.3.4 Piling at two sites simultaneously generates more sound energy in the water column. This is reflected in the distance increase in the concurrent scenarios.

8.2.3.5 In terms of the distance from the pile to AUD INJ and TTS impact thresholds, pile sufficiently far away from each other can be treated more independently in terms of the higher-level thresholds. If the piling operations are in close proximity, however, there is a direct effect on the distance to the impact thresholds where sound fields directly overlap. The separation of piles does, however, substantially increase the areas ensonified.

8.2.3.6 The use of an ADD 30 minutes prior to piling results in a substantial reduction in the AUD INJ distances, bringing values down from almost 8km to less than 3km in representative environments for the monopile, with levels not exceeded at all for the pin piles for the same environment. The reduction is not as pronounced for results reaching greater distances. Additionally, the ADD is less effective where the rate at which sound levels fall with distance is not great, (i.e. where the conservative environment is used).

8.2.3.7 It is noted that the ADD appears to have less influence on the starting distance to the AUD INJ threshold for concurrent piling than for single piling. For example, for low-frequency cetaceans and the 16m monopile, the inclusion of an ADD reduced $R_{95\%}$ AUD INJ distances from 4.37km to 0.53km for the single pile; the two close piles, however, saw a reduction of 6.24km to 2.50km, and the two distant piles reduced from 6.05km to 2.46km. This is due to the direction the receiver moves during the operation. For single piling, the movement direction is always directly away from the pile. Where two piles are considered, any receiver positioned between the two sources are prescribed to move perpendicularly to the line between the two sources. Consequently, the path taken is not necessarily the optimal path and accumulated sound levels are higher.

8.2.3.8 The adoption of the suboptimal path in the presence of two piles also results in AUD INJ thresholds for very high-frequency cetaceans to be exceeded very close to the pile for the close piles concurrent case (Table 5.37), but not the single pile case (Table 5.19). Again, as distances reported here are below the corresponding threshold distances when assessed against the PK criterion, they do not affect the reported dual-criteria outcomes.

8.2.4 Sound from vessel operations

8.2.4.1 Section 5.7 provides the results of radiated sound from vessels for moving receivers, with scenarios defined in Section 2.5.

8.2.4.2 The distances to effects were greatest for the low-frequency cetaceans throughout the vessel scenarios. The results for only the low-frequency cetaceans are summarised in Table 8.7. The accumulated sound level is taken over 24h for the assessment of the AUD INJ and TTS criteria. Given that the sound levels closer to the source drop off rapidly and the distance travelled after 24h, ranges to the TTS threshold are limited to 0.71km, and to 0.01km for the AUD INJ threshold.

Table 8.7: Maximum horizontal distances in kilometres from vessel operations to auditory injury and temporary threshold shift thresholds for low-frequency cetaceans

Threshold $SEL_{24h,LF}$	Maximum horizontal distance to level (km)							
	Foundation installation		Turbine installation		Cable laying		Crew transfer	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
AUD INJ	-	-	0.01	0.01	0.01	0.01	-	-
TTS	0.71	0.58	0.41	0.32	0.20	0.20	-	-

SEL in dB re 1µPa²s. A dash (-) indicates that the level was not reached in modelled results.

8.2.4.3 The greatest ranges are associated with the foundation installation scenario. Here, we have two vessels operating on DP that use scaled source levels to account for the increase in power associated with the expected larger vessels. The additional vessels in the scenario contribute only a negligible amount to the sound field.

8.2.4.4 The source levels for the installation vessels on DP were scaled from the maximum of 95th percentile recorded levels. The genuine source levels would be dependent on the local wind speed and direction, the wave height, the current speed and direction, and the propulsion method. The inclusion of scaling for power and taking 95th percentile levels are both conservative measures in estimating the radiated sound.

8.2.4.5 The behavioural metric for sound from continuous sources is an unweighted SPL of 120dB re 1µPa². For the larger operations, where the source levels are higher, the 120dB SPL isopleth is tens of kilometres away. At these distances from the source the rate of decay is very small such that a small change in the sound level can result in a large change in the impact distances. Consequently, a reduction in source level of, for example, 5dB would reduce distance to the 120dB SPL substantially – from 51.2km to 27.2km for Scenario V1, from 44.2km to 22.4km for Scenario V2, and from 31.9km to 17.3km for Scenario V3.

8.2.4.6 In practical applications, the DP is unlikely to be working at 95th percentile levels most of the time; consequently, the distance to the behavioural threshold is likely to be much reduced for the representative case.

8.2.5 Geophysical survey sources

8.2.5.1 Section 5.8 provides results for the geophysical survey sources considered in the project. The propagation is based on simplified spreading equations as outlined in Section 4.4, with the cumulative assessment considering a single survey line passing by a static receiver. Consequently, Morven North and Morven South share identical results.

8.2.5.2 Table 8.8 shows the maximum distance to the NMFS (2024a) AUD INJ and TTS onset thresholds over both the SEL and the PK. The greatest distance to AUD INJ is 0.181km for very high-frequency cetaceans resulting from the MBES; for TTS it is 1.13km, still for very high-frequency cetaceans but for the CHIRP taken at 3.5kHz. The maximum range to the 160dB SPL behavioural threshold level was 3.8km for the CHIRP.

Table 8.8: Maximum horizontal distances in kilometres from the geophysical sources to maximum-over-depth peak (PK) impact thresholds for marine mammals from National Marine Fisheries Service (2024a)

Hearing group	Effect	Maximum horizontal distance to threshold (km)					
		MBES	SSS	SBES	CHIRP 2.0kHz	CHIRP 3.5kHz	Sparker
LF cetaceans	AUD INJ	0.015	0.004	0.007	0.003	0.071	0.016
	TTS	0.029	0.007	0.007	0.057	0.712	0.110
HF cetaceans	AUD INJ	0.016	0.002	0.003	-	0.039	-
	TTS	0.124	0.036	0.007	0.022	0.406	0.002
VHF cetaceans	AUD INJ	0.181	0.036	0.007	0.006	0.114	0.009
	TTS	0.505	0.200	0.064	0.030	1.129	0.018
PCW	AUD INJ	0.058	0.004	0.005	0.003	0.091	0.004
	TTS	0.262	0.020	0.007	0.066	0.907	0.04

A dash (-) indicates that the level was not reached within the resolution of the model.
Distances to the PK thresholds are not shown for the non-impulsive sources because it was assessed based on the intermittent source criteria which does not include PK thresholds.

8.2.5.3 The modelling of the HRG sources uses a generalised approach to account for levels outside of the main beam, based on the main-beam beam width. True devices exhibit complex beam patterns that vary with frequency and device design, often featuring lobes and nulls at specific angles. In this project, the 3.5 kHz CHIRP source was treated conservatively, with no level offset applied for out-of-beam angles due to its 90° beam width. This simplification results in a uniform level assumption across all directions, effectively treating the source as omnidirectional within the model.

8.2.5.4 This approach, while suitable for most cases, leads to an overestimation of propagation distance in this instance. The long distance to the SPL threshold results from a combination of the high source level, low frequency (resulting in minimal attenuation), and broad beam width meaning that no directional correction was applied. As a result, the model predicts similar levels whether the device is oriented vertically or horizontally.

8.2.5.5 A more accurate representation would require detailed beam pattern data for the specific device, allowing for angular-dependent attenuation to be incorporated. In the absence of such data, the conservative modelling approach provides a worst-case estimate, ensuring that potential impacts are not underestimated.

8.2.6 Unexploded ordnance

8.2.6.1 Section 5.9 provides results of the underwater radiated sound from explosion, with details of three detonated charges, and a deflagration scenario.

8.2.6.2 Table 5.60 to Table 5.62 provide distances to modelled sound levels associated with specific impact thresholds. It highlights particularly the effectiveness of using deflagration to defuse a device in terms of the overall generated sound.

8.2.6.3 The maximum distance to AUD INJ thresholds for the largest charge is for very high-frequency cetaceans at 16.4km in response to the PK level; this is followed by 8.75km for low-frequency cetaceans in SEL. These reduce to 0.53km and 0.15km respectively for the deflagration scenario.

8.3 Morven South

8.3.1 Single strike assessments

8.3.1.1 Section 6.3 provides the results of the impact piling at Morven South for individual pulses. For each of the three piles, four penetration depths were analysed, in conservative and representative environments. Distances were provided to the behavioural thresholds from the per-pulse SEL and SPL, along with AUD INJ and TTS onset criteria. The key results are summarised here.

8.3.1.2 Table 8.9 summarises the distances to single strike behavioural thresholds. Distances to the 160dB SPL threshold are greatest for the 16m monopile, being between 16km and 22km from the pile. Distances to the 143dB SEL per-pulse threshold for behavioural reaction in harbour porpoise are also greatest for the 16m monopile, being from 27km to 40km.

Table 8.9: Maximum horizontal distances in kilometres from the 16m monopile to behavioural thresholds

Metric	Maximum horizontal distance to level (km)											
	16m monopile				5.3m pin pile				3.7m pin pile			
	Rep.		Con.		Rep.		Con.		Rep.		Con.	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
SPL: 160dB	17.4	16.3	22.0	20.8	13.1	12.1	18.6	17.4	11.0	10.2	16.1	15.0
SEL: 143dB	28.8	26.9	40.0	36.5	26.6	24.8	37.0	34.0	26.0	24.4	35.2	32.7

SPL in dB re 1µPa², SEL in dB re 1µPa²s, Rep.: Representative, Con: Conservative.

8.3.1.3 Distances to PK thresholds that exceeded AUD INJ and TTS criteria in very high-frequency cetaceans are shown in Table 8.10; the focus is on very high-frequency cetaceans as they have the lowest onset thresholds and consequently produce the greatest distances to thresholds levels. Again, the greatest distances are universally seen for the 16m monopile with AUD INJ distances from 0.90km to 0.95km, and TTS distances being 1.79km to 2.10km. It is noted that the conservative environment does not always generate the greatest ranges to thresholds; the environment selection study considered the long propagation of sound energy metrics, and so departures from this for near-field PK results are not remarkable.

Table 8.10: Maximum horizontal distances in kilometres from the 16m monopile to auditory injury and temporary threshold shift peak (PK) thresholds for very high-frequency cetaceans

Threshold PK	Maximum horizontal distance to level (km)											
	16m monopile				5.3m pin pile				3.7m pin pile			
	Rep.		Con.		Rep.		Con.		Rep.		Con.	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
AUD INJ	0.95	0.93	0.93	0.90	0.57	0.55	0.55	0.52	0.67	0.62	0.77	0.74
TTS	1.87	1.79	2.10	2.02	0.94	0.91	1.03	0.97	1.43	1.30	1.78	1.66

PK in dB re 1µPa², Rep.: Representative, Con: Conservative.

8.3.2 Multiple strike assessments

8.3.2.1 Section 6.4 provides results of the total sound energy accumulated over time over the course of a single piling operation for marine mammals (moving) and fish (static). In all cases, the distances for marine mammals are greatest for low-frequency cetaceans. The moving receivers move away from the pile as the first hammer initiation blow occurs or at the first pulse of the ADD, and swim at a constant speed away from the pile thereafter. Table 8.11 shows animal starting distances to the low-frequency cetacean AUD INJ and TTS thresholds for piling a single pile with and without ADD.

Table 8.11: Maximum horizontal distances in kilometres from the 16m monopile to auditory injury and temporary threshold shift thresholds for low-frequency cetaceans

Threshold $SEL_{24h,LF}$	Maximum horizontal distance to level (km)											
	16m monopile				5.3m pin pile				3.7m pin pile			
	Rep.		Con.		Rep.		Con.		Rep.		Con.	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
No ADD												
AUD INJ	4.81	4.45	11.3	10.3	1.53	1.41	4.76	4.30	2.38	2.21	6.24	5.63
TTS	23.6	21.3	38.4	34.3	19.7	17.6	40.8	34.4	32.5	28.9	58.2	48.5
ADD												
AUD INJ	0.66	0.62	7.16	6.46	-	-	0.56	0.54	-	-	2.06	1.84
TTS	19.5	17.3	34.2	30.4	15.6	13.7	36.6	30.6	28.3	25.0	54.1	44.7

SEL in dB re 1µPa²s, Rep.: Representative, Con: Conservative. A dash (-) indicates that the level was not reached within the resolution of the model.

8.3.2.2 From Table 8.11 we see a maximum distance of AUD INJ exposure to from the 16m monopile (11.3km) but the TTS from the 3.7m pin pile (58.2km). The 16m monopile generates greater broadband levels, with sound levels close to the pile being greater than that for the 3.7m pin pile; the 3.7m pin pile, however, has more energy at frequencies that propagate well than the 16m monopile, such that the rate of decay is lower for the 3.7m pin pile and this we see greater ranges for the lower-level thresholds.

8.3.2.3 Considering the moving marine mammal receivers following use of an ADD, the $R_{95\%}$ distances are reduced such that AUD INJ is 620m for the representative environment, and 6.46km in the conservative environment.

8.3.2.4 It is noted that modelling the ADD with no soft start itself introduces additional entries into the table for very high-frequency cetaceans under the TTS criterion for the SEL_{24h} metric, which are not present in the non-ADD scenario. These entries, however, remain somewhat below the corresponding threshold distances when assessed against the PK criterion, and therefore do not affect the reported dual-criteria outcomes. Use of a soft start in the ADD would reduce these distances.

8.3.3 Concurrent piling assessments

8.3.3.1 The aggregate assessments consider the radiated sound field from simultaneous piling operations at different locations within the Morven South Boundary. Section 4.7 provides detail of how the concurrent piling assessment is carried out.

8.3.3.2 As previously described, the PK and SPL metrics are based on the instantaneous and near-instantaneous sound levels generated by the piling. Consequently, there is no change to the maximum distance to identified sound level when considering multiple piles over the single pile results reported in Table 8.9 and Table 8.10.

8.3.3.3 Cumulative SEL results for the concurrent piling modelling assessment are shown in Table 8.12 for the 16m monopile, Table 8.13 for the 5.3m pin pile, and Table 8.14 for the 3.7m pin pile. Each table presents results for the single pile (duplicated from Table 8.11), two nearby piling operations, and two distant operations for low frequency cetaceans.

Table 8.12: Maximum horizontal distances in kilometres from single and concurrent 16m monopile operations to auditory injury and temporary threshold shift thresholds for low-frequency cetaceans

Threshold $SEL_{24h,LF}$	Maximum horizontal distance to level (km)											
	Single monopile				Close monopiles				Distant monopiles			
	Rep.		Con.		Rep.		Con.		Rep.		Con.	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
No ADD												
AUD INJ	4.81	4.45	11.3	10.3	7.32	6.60	14.9	13.6	8.84	6.41	16.9	14.2
TTS	23.6	21.3	38.4	34.3	29.2	26.1	49.5	42.8	28.5	23.0	44.3	37.8
ADD												
AUD INJ	0.66	0.62	7.16	6.46	3.16	2.83	10.7	9.68	3.28	2.63	15.2	13.5
TTS	19.5	17.3	34.2	30.4	25.1	22.3	45.3	39.0	25.0	19.6	40.4	34.0

SEL in dB re 1µPa²s, Rep.: Representative, Con: Conservative. A dash (-) indicates that the level was not reached within the resolution of the model.

Table 8.13: Maximum horizontal distances in kilometres from single and concurrent 5.3m pin pile operations to auditory injury and temporary threshold shift thresholds for low-frequency cetaceans

Threshold $SEL_{24h,LF}$	Maximum horizontal distance to level (km)											
	Single 5.3m pin pile				Close 5.3m pin piles				Distant 5.3m pin piles			
	Rep.		Con.		Rep.		Con.		Rep.		Con.	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
No ADD												
AUD INJ	1.53	1.41	4.76	4.30	2.96	2.56	8.44	7.49	3.37	2.55	14.7	9.59
TTS	19.7	17.6	40.8	34.4	27.5	23.9	56.9	47.6	26.3	20.7	50.6	42.0
ADD												
AUD INJ	-	-	0.56	0.54	-	-	4.28	3.70	-	-	4.22	3.13
TTS	15.6	13.7	36.6	30.6	23.4	20.2	52.8	43.9	23.0	18.0	46.6	38.5

SEL in dB re 1μPa²s, Rep.: Representative, Con: Conservative. A dash (-) indicates that the level was not reached in modelled results.

Table 8.14: Maximum horizontal distances in kilometres from single and concurrent 3.7m pin pile operations to auditory injury and temporary threshold shift thresholds for low-frequency cetaceans

Threshold $SEL_{24h,LF}$	Maximum horizontal distance to level (km)											
	Single 3.7m pin pile				Close 3.7m pin piles				Distant 3.7m pin piles			
	Rep.		Con.		Rep.		Con.		Rep.		Con.	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
No ADD												
AUD INJ	2.38	2.21	6.24	5.63	4.22	3.76	10.7	9.71	4.95	3.64	15.1	13.4
TTS	32.5	28.9	58.2	48.5	48.3	40.4	79.6	66.4	41.9	35.0	72.9	60.5
ADD												
AUD INJ	-	-	2.06	1.84	0.45	0.45	6.55	5.84	-	-	11.2	7.53
TTS	28.3	25.0	54.1	44.7	44.2	36.6	76.8	63.4	38.1	31.4	68.8	57.1

SEL in dB re 1μPa²s, Rep.: Representative, Con: Conservative. A dash (-) indicates that the level was not reached in modelled results.

8.3.3.4 Piling at two sites simultaneously generates more sound energy in the water column. This is reflected in the distance increase in the concurrent scenarios.

8.3.3.5 In terms of the distance from the pile to AUD INJ and TTS impact thresholds, pile sufficiently far away from each other can be treated more independently in terms of the higher-level thresholds. If the piling operations are in close proximity, however, there is a direct effect on the distance to the impact thresholds where sound fields directly overlap. The separation of piles does, however, substantially increase the areas ensonified.

8.3.3.6 The use of an ADD 30 minutes prior to piling results in a substantial reduction in the AUD INJ distances, bringing values down from almost 9km to just over 3km in representative environments for the monopile, with levels exceeded only in one case for the pin piles for the same environment. The reduction is not as pronounced for results reaching greater distances. Additionally, the ADD is less effective where the rate at which sound levels fall with distance is not great, i.e., where the conservative environment is used.

8.3.3.7 It is noted that the ADD appears to have less influence on the starting distance to the AUD INJ threshold for concurrent piling than for single piling. For example, for low-frequency cetaceans and the 16m monopile, the inclusion of an ADD reduced $R_{95\%}$ AUD INJ distances from 4.45km to 0.62km for the single pile; the two close piles, however, saw a reduction of 6.60km to 2.83km, and the two distant piles reduced from 6.41km to 2.63km. This is due to the direction the receiver moves during the operation. For single piling, the movement direction is always directly away from the pile. Where two piles are considered, any receiver positioned between the two sources are prescribed to move perpendicularly to the line between the two sources. Consequently, the path taken is not necessarily the optimal path and accumulated sound levels are higher.

8.3.3.8 The adoption of the suboptimal path in the presence of two piles also results in AUD INJ thresholds for very high-frequency cetaceans to be exceeded very close to the pile for the close piles concurrent case (Table 6.37), but not the single pile case (Table 6.19). Again, as distances reported here are below the corresponding threshold distances when assessed against the PK criterion, they do not affect the reported dual-criteria outcomes.

8.3.4 Sound from vessel operations

8.3.4.1 Section 6.5 provides the results of radiated sound from vessels for moving receivers, with scenarios defined in Section 2.5.

8.3.4.2 The distances to effects were greatest for the low-frequency cetaceans throughout the vessel scenarios. The results for only the low-frequency cetaceans are summarised in Table 8.15. The accumulated sound level is taken over 24h for the assessment of the AUD INJ and TTS criteria. Given that the sound levels closer to the source drop off rapidly and the distance travelled after 24h, ranges to the TTS threshold are limited to 0.74km, and the AUD INJ threshold is not exceeded at any receiver starting distance.

Table 8.15: Maximum horizontal distances in kilometres from vessel operations to auditory injury and temporary threshold shift thresholds for low-frequency cetaceans

Threshold $SEL_{24h,LF}$	Maximum horizontal distance to level (km)							
	Foundation installation		Turbine installation		Cable laying		Crew transfer	
	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$	R_{max}	$R_{95\%}$
AUD INJ	-	-	-	-	-	-	-	-
TTS	0.74	0.67	0.47	0.44	0.23	0.23	-	-

SEL in dB re 1µPa²s. A dash (-) indicates that the level was not reached in modelled results.

8.3.4.3 The greatest ranges are associated with the foundation installation scenario. Here, we have two vessels operating on DP that use scaled source levels to account for the increase in power associated with the expected larger vessels. The additional vessels in the scenario contribute only a negligible amount to the sound field.

8.3.4.4 The source levels for the installation vessels on DP were scaled from the maximum of 95th percentile recorded levels. The genuine source levels would be dependent on the local wind speed and direction, the wave height, the current speed and direction, and the propulsion method. The inclusion of scaling for power and taking 95th percentile levels are both conservative measures in estimating the radiated sound.

8.3.4.5 The behavioural metric for sound from continuous sources is an unweighted SPL of 120dB re 1μPa². For the larger operations, where the source levels are higher, the 120dB SPL isopleth is tens of kilometres away. At these distances from the source the rate of decay is very small such that a small change in the sound level can result in a large change in the impact distances. Consequently, a reduction in source level of, for example, 5dB would reduce distance to the 120dB SPL substantially – from 59.3km to 31.4km for Scenario V1, from 53.1km to 29.0km for Scenario V2, and from 40.4 to 21.0km for Scenario V3.

8.3.4.6 In practical applications, the DP is unlikely to be working at 95th percentile levels most of the time; consequently, the distance to the behavioural threshold is likely to be much reduced for the representative case.

8.3.5 Geophysical survey sources

8.3.5.1 Section 6.8 provides results for the geophysical survey sources considered in the project. The propagation is based on simplified spreading equations as outlined in Section 4.4, with the cumulative assessment considering a single survey line passing by a static receiver. Consequently, Morven North and Morven South share identical results.

8.3.5.2 Table 8.16 shows the maximum distance to the NMFS (2024a) AUD INJ and TTS onset thresholds over both the SEL and the PK. The greatest distance to AUD INJ is 0.181km for very high-frequency cetaceans resulting from the MBES; for TTS it is 1.13km, still for very high-frequency cetaceans but for the CHIRP taken at 3.5kHz. The maximum range to the 160dB SPL behavioural threshold level was 3.8km for the CHIRP.

Table 8.16: Maximum horizontal distances in kilometres from the geophysical sources to maximum-over-depth peak (PK) impact thresholds for marine mammals from National Marine Fisheries Service (2024a)

Hearing group	Effect	Maximum horizontal distance to threshold (km)					
		MBES	SSS	SBES	CHIRP 2.0kHz	CHIRP 3.5kHz	Sparker
LF cetaceans	AUD INJ	0.015	0.004	0.007	0.003	0.071	0.016
	TTS	0.029	0.007	0.007	0.057	0.712	0.110
HF cetaceans	AUD INJ	0.016	0.002	0.003	-	0.039	-
	TTS	0.124	0.036	0.007	0.022	0.406	0.002
VHF cetaceans	AUD INJ	0.181	0.036	0.007	0.006	0.114	0.009
	TTS	0.505	0.200	0.064	0.030	1.129	0.018
PCW	AUD INJ	0.058	0.004	0.005	0.003	0.091	0.004
	TTS	0.262	0.020	0.007	0.066	0.907	0.04

A dash (-) indicates that the level was not reached within the resolution of the model.
Distances to the PK thresholds are not shown for the non-impulsive sources because it was assessed based on the intermittent source criteria which does not include PK thresholds.

8.3.5.3 The modelling of the HRG sources uses a generalised approach to account for levels outside of the main beam, based on the main-beam beam width. True devices exhibit complex beam patterns that vary with frequency and device design, often featuring lobes and nulls at specific angles. In this project, the 3.5 kHz CHIRP source was treated conservatively, with no level offset applied for out-of-beam angles due to its 90° beam width. This simplification results in a uniform level assumption across all directions, effectively treating the source as omnidirectional within the model.

8.3.5.4 This approach, while suitable for most cases, leads to an overestimation of propagation distance in this instance. The long distance to the SPL threshold results from a combination of the high source level, low frequency (resulting in minimal attenuation), and broad beam width meaning that no directional correction was applied. As a result, the model predicts similar levels whether the device is oriented vertically or horizontally.

8.3.5.5 A more accurate representation would require detailed beam pattern data for the specific device, allowing for angular-dependent attenuation to be incorporated. In the absence of such data, the conservative modelling approach provides a worst-case estimate, ensuring that potential impacts are not underestimated.

8.3.6 Unexploded ordnance

8.3.6.1 Section 6.9 provides results of the underwater radiated sound from explosion, with details of three detonated charges, and a deflagration scenario.

8.3.6.2 Table 6.60 to Table 6.62 provide distances to modelled sound levels associated with specific impact thresholds. It highlights particularly the effectiveness of using deflagration to defuse a device in terms of the overall generated sound.

8.3.6.3 The maximum distance to AUD INJ thresholds for the largest charge is for very high-frequency cetaceans at 16.3km in response to the PK level; this is followed by 8.90km for low-frequency cetaceans in SEL. These reduce to 0.56 and 0.15km respectively for the deflagration scenario.

8.4 Recommended reported distances

8.4.1.1 Given the range of modelling scenarios and acoustic metrics assessed across both Morven North and South, this section provides guidance on the most appropriate distances to report for injury thresholds. These recommendations are intended to support consistent and conservative application in environmental assessments and mitigation planning.

8.4.1.2 The choice of reported distance should be based on the temporal and spatial characteristics of the acoustic metric:

- Peak Sound Pressure Level (PK) thresholds are associated with instantaneous exposure and typically occur at short ranges. Therefore, the maximum distance from the conservative environment (R_{max}, UB) is recommended for reporting. Where distances exceed a few kilometres, the $R_{95\%}$ better considers the variation in seabed properties and so is presented for the largest of the UXO results.
- Cumulative Sound Exposure Level (SEL_{24h}) thresholds, which assess injury risk over extended durations, are more appropriately represented by the 95th percentile distance from the representative environment ($R_{95\%}$, BE). This approach balances realism with precaution, accounting for variability in propagation conditions without excessive conservatism.
- For non-impulsive sources (e.g. vessels, geophysical surveys), where injury thresholds are rarely exceeded, the maximum modelled distance should be reported where applicable.

8.5 Conclusions

8.5.1.1 This report presents a comprehensive assessment of underwater acoustic impacts associated with the Morven North and South developments. The modelling demonstrates that of the activities associated with construction, the impact piling, particularly from the 16m monopile, generates the greatest ranges to behavioural and injury thresholds.

8.5.1.2 Table 8.17 provides a succinct summary of maximum distances related to the AUD INJ threshold. Results are taken as the maximum across both windfarms, and the largest result considering the dual metric criteria (i.e., maximum of SEL_{24h} and PK results) where appropriate.

Table 8.17. Summary of maximum distances (km) to auditory injury thresholds across sources for considered marine groups. Distances related to Sound Exposure Level thresholds reported for piling presume Acoustic Deterrent Device use

Source	Scenario	LF cetaceans	HF cetaceans	VHF cetaceans	Phocid pinnipeds	Fish group I	Fish groups II+
Monopile	Single	0.62	–	0.95	0.02	2.36	7.22
	Concurrent	2.83	–	0.95	0.02	3.16	8.83
Pin pile	Single	–	–	0.77	–	0.96	5.06
	Concurrent	0.45	–	0.77	–	1.64	6.75
Vessels	All scenarios	0.01	–	0.01	–	NA	NA
HRG	All scenarios	0.07	0.04	0.18	0.09	NA	NA
UXO	554kg	8.22	1.53	14.2	2.81	1.73	1.73

A dash (-) indicates that the level was not reached within the resolution of the model.

8.5.1.3 The implementation of an ADD reduces distances from the single impacted pile to thresholds related to SEL_{24h}; this is most pertinent to the low-frequency cetaceans as indicated in Table 8.17

8.5.1.4 . Here, the distance represents the starting distance from the pile and presumes the animal to be swimming away from the source. Concurrent piling operations further extend the potential impact zones, though again, the use of ADDs reduce the distances for the assessment of multiple strikes and SEL_{24h} metrics.

8.5.1.5 Vessel operations and geophysical surveys, while contributing to the overall acoustic footprint, result in comparatively limited ranges to injury thresholds. Overall, the results provide a foundation for environmental planning, impact assessment, and regulatory compliance, highlighting the importance of spatial and temporal considerations in managing underwater noise.

9 References

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Appendix A Source location and geoacoustic study

This section provides details on the variation in radiated sound over 10km when considering different possible source locations and geoacoustic profiles. The study considers the 16m outer diameter monopile and the 5.3m diameter pin pile. Of the four penetration depths studied, the first and last have been taken for this study. At each location, the sound has been modelled travelling in the four cardinal directions only.

A.1 Source location options – Morven North

To determine candidate source locations for the sound propagation modelling, the water depths across the Morven North Boundary were extracted and discretised at 100m resolution. Figure A.1 shows the histogram of water depths across the area encompassed by the Morven North Boundary.

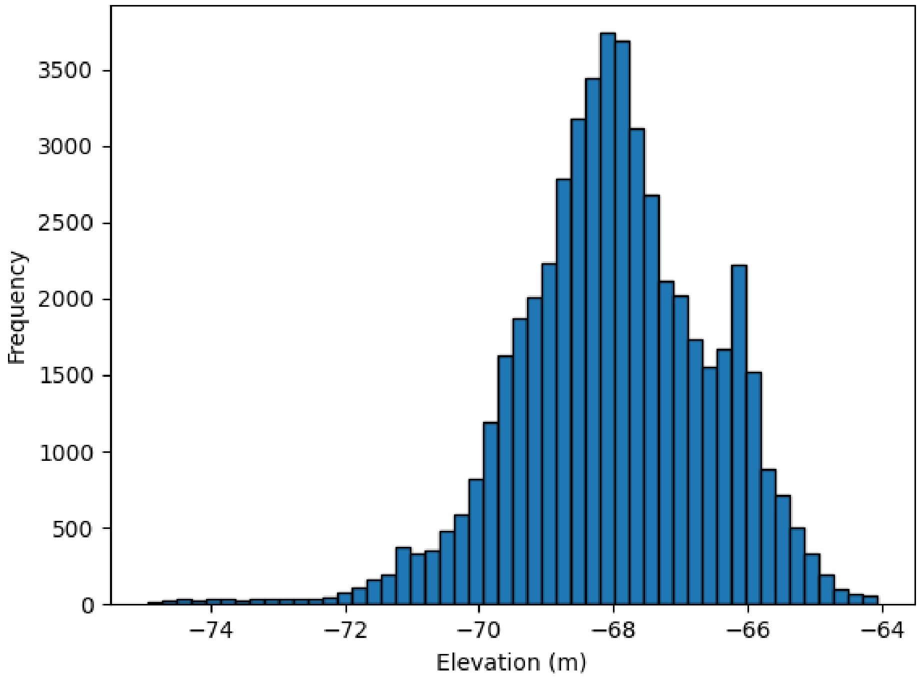


Figure A.1: Histogram of water depths across the Morven North Boundary

To establish a representative range of propagation conditions, the minimum, maximum, and modal water depths were selected. Where this did not yield a single unique position, the point at that water depth closest to the centroid of the Morven North Boundary was taken as the test location. These are shown in Table A.1.

Table A.1. Test source locations for Morven North

Description	Water depth (m)	Easting	Northing	Latitude	Longitude
Minimum	64.1	626605	6287813	56°42.954′N	0°55.893′W
Modal peak	68.1	623841	6290108	56°44.235′N	0°58.534′W
Maximum	74.9	619805	6283413	56°40.691′N	1°02.677′W

A.2 Source location options – Morven South

The identical process to Morven North was used for Morven South. Again, candidate locations were identified firstly by extracting and discretising the water depths across the Morven South Boundary. Figure A.2 shows the histogram of water depths across the Morven South Boundary.

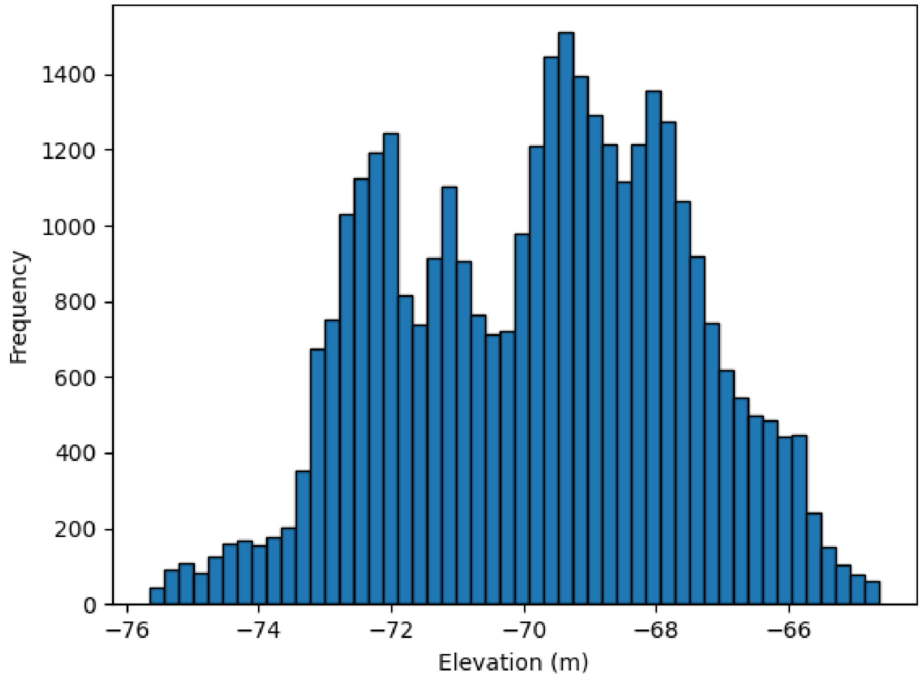


Figure A.2: Histogram of water depths across the Morven South Boundary

To establish a representative range of propagation conditions, the minimum, maximum, and modal water depths were selected. Where this did not yield a single unique position, the point at that water depth closest to the centroid of the Morven South Boundary was taken as the test location. These are shown in Table A.2.

Table A.2: Test source locations for Morven South

Description	Water depth (m)	Easting m)	Northing (m)	Latitude	Longitude
Minimum	64.7	639374	6273532	56°35.044'N	0°43.850'W
Modal peak A	67.8	641168	6269114	56°32.633'N	0°42.243'W
Modal peak B	69.6	641681	6269798	56°32.992'N	0°41.721'W
Modal peak C	72.0	642875	6272675	56°34.520'N	0°40.461'W
Maximum	75.6	651774	6268032	56°31.852'N	0°31.942'W

A.3 Geoacoustic Profiles

Borehole data at 13 sites across the region were provided to JASCO. The data included compressional wave speed, shear wave speed, and unit weight, from which the sediment density can be calculated. Extracting the plots, and overlaying provides an indication of the envelope of sediment profiles within the region.

From results of the compressional wave speed and the sediment density, profiles representing the minimum value, the median value, and the maximum value of each were generated. These are shown in Figure A.3.

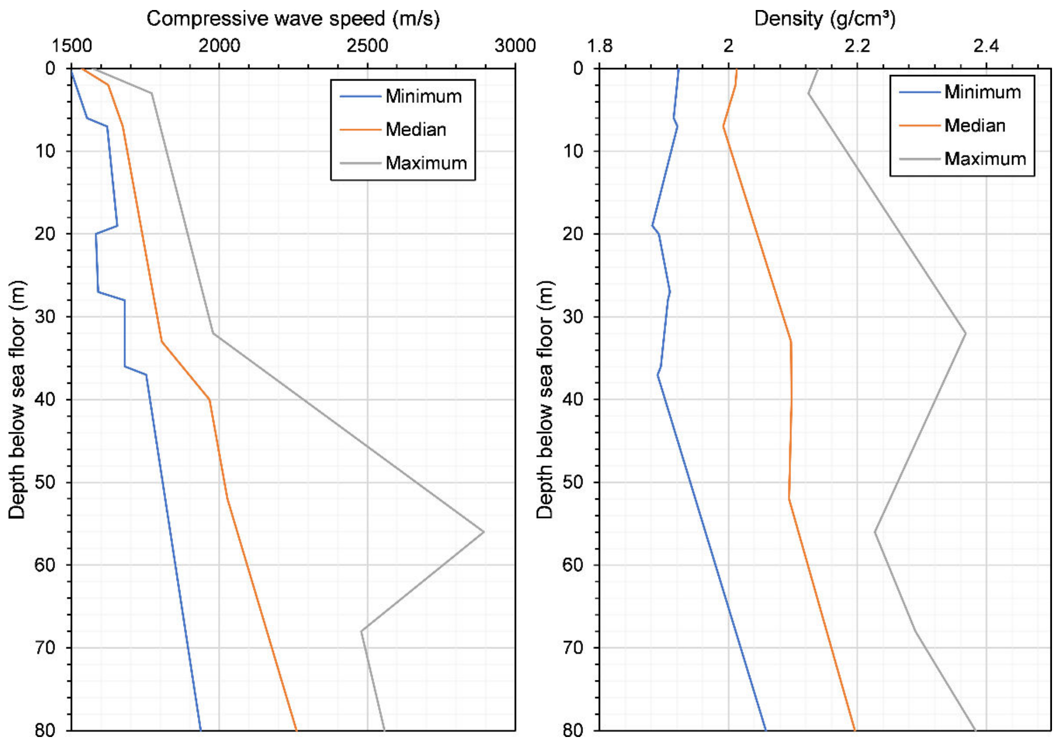


Figure A.3: Minimum, median, and maximum geoacoustic profiles showing the compressive wave speed (left) and sediment density (right) as a function of depth in the seabed

The associated compressive wave attenuation was calculated based on equations by Hamilton (1980) using results for the compressive wave speed and the porosity; these are shown in Figure A.4.

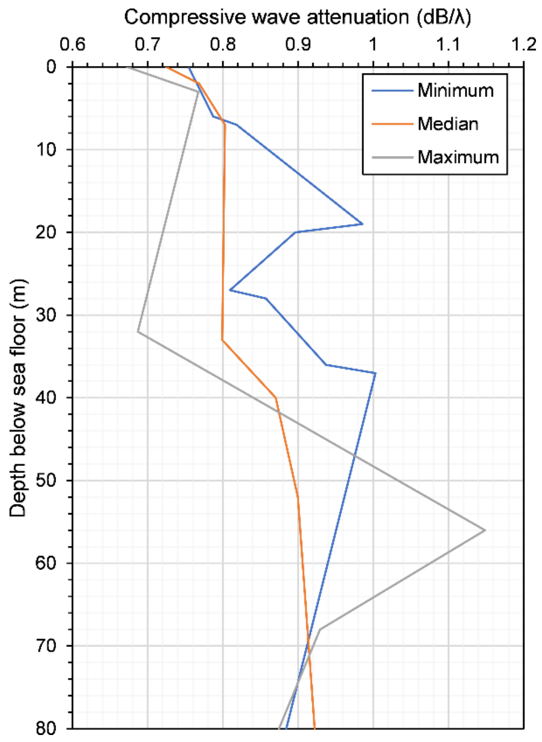


Figure A.4: Compressional wave attenuation associated with each of the minimum, median, and maximum profiles for sensitivity studies

The borehole data included results for the shear wave speed. The propagation modelling does not allow for depth-dependent properties for the shear wave speed but requires the value at the sediment water interface. Consequently, the average shear wave speed over the top 20 metres of the seabed is used as a single representative value for all depths. There is no equivalent data for shear wave speed attenuation from the borehole data and so values are taken from work by Buckingham (Buckingham (2000)).

A.4 Sound Propagation Study

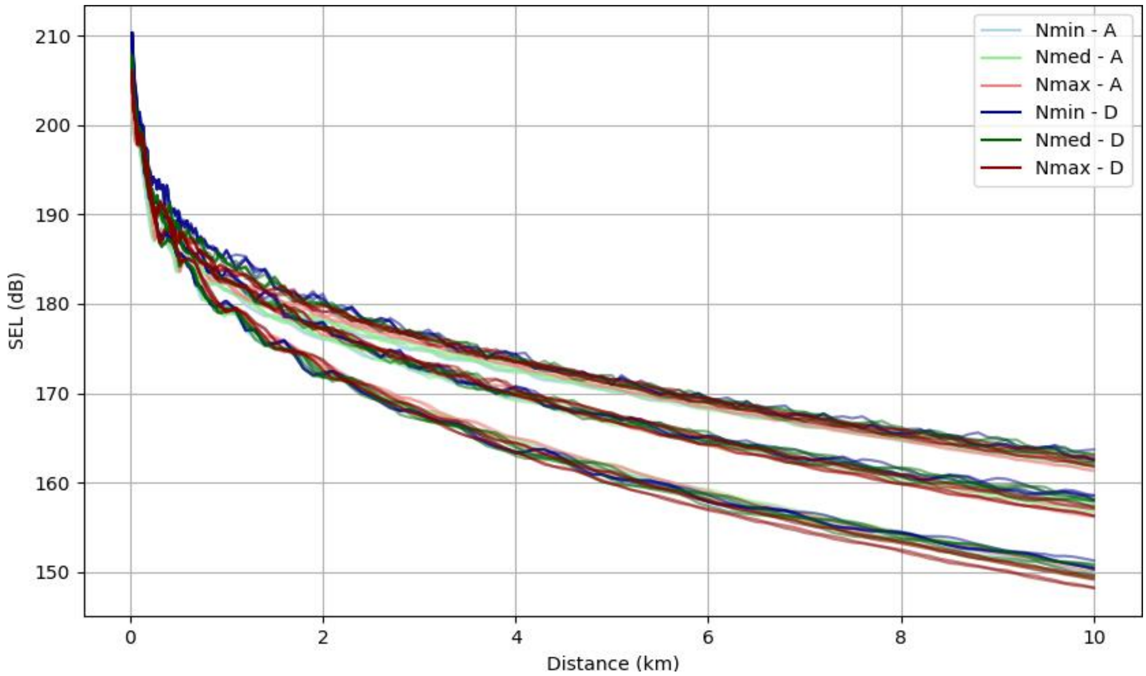
A preliminary sound modelling study was conducted to determine the effect of the different choices in source location and geoacoustic profile. These were done for both the 16.0m diameter monopile and the 5.3m diameter pin pile, at the shallowest and deepest penetration depth, and over four transects (north, east, south, and west) to a maximum distance of 10km. Given the choice of three/five source locations and three geoacoustic profiles, this gave a total of 144/240 transects.

The study considered frequencies only up to 447Hz and are not frequency-weighted. A review of the available driveability studies resulted in estimations of the penetration per blow as shown in Table A.3.

Table A.3: Driveability parameters for the sound propagation study

Pile	Penetration analysis	Penetration depth (m)	Penetration per blow (cm)	Reflection coefficient
16.0m monopile	A (shallow)	8.0	1.3	0.25
16.0m monopile	D (deep)	50.0	0.4	-0.30
5.3m pin pile	A (shallow)	9.0	1.8	-0.27
5.3m pin pile	D (deep)	70.0	0.3	-0.80

To determine general trends, results of the per-pulse SEL against distance are shown in the following plots. Figure A.5 and Figure A.6 show the per-pulse SEL as a function of distance for the monopole and pin pile respectively; here, results are grouped according to the source location and the analysis penetration depth (where A is the shallowest and D is the deepest).



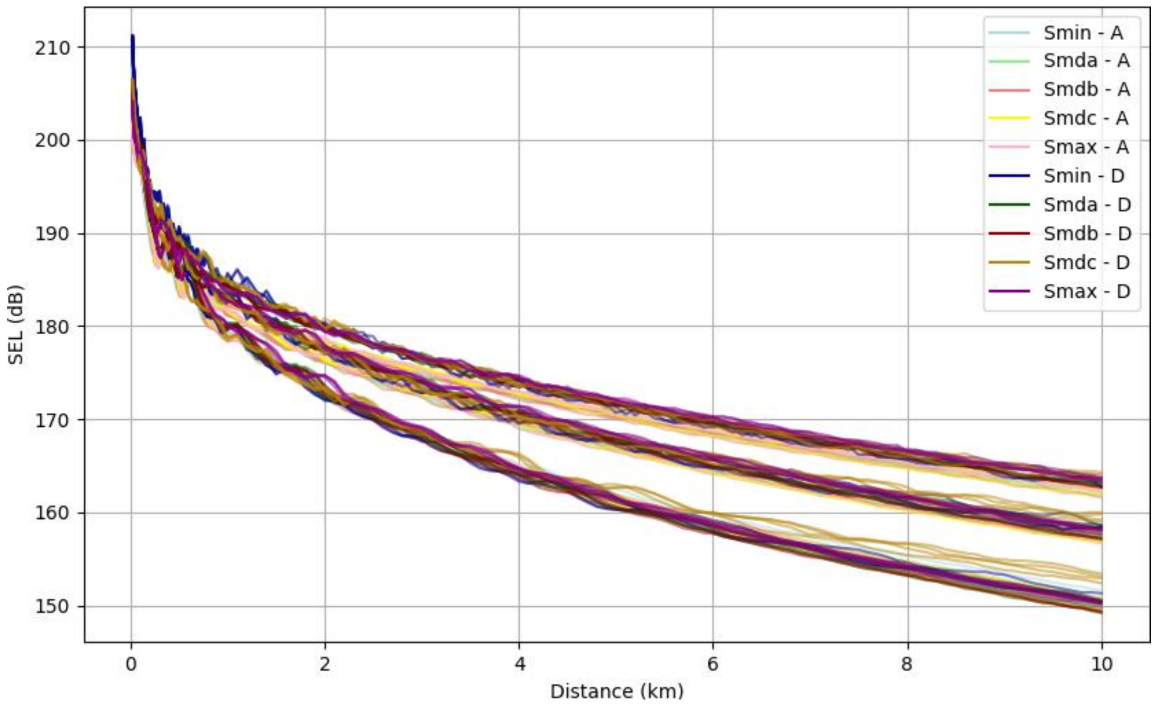


Figure A.5: Per-pulse Sound Exposure Level as a function of distance of the 16.0m monopile split by location and analysis depth for Morven North (top) and Morven South (bottom). Colours distinguish the different source locations and the analysed penetration depth (A: shallowest; D: deepest)

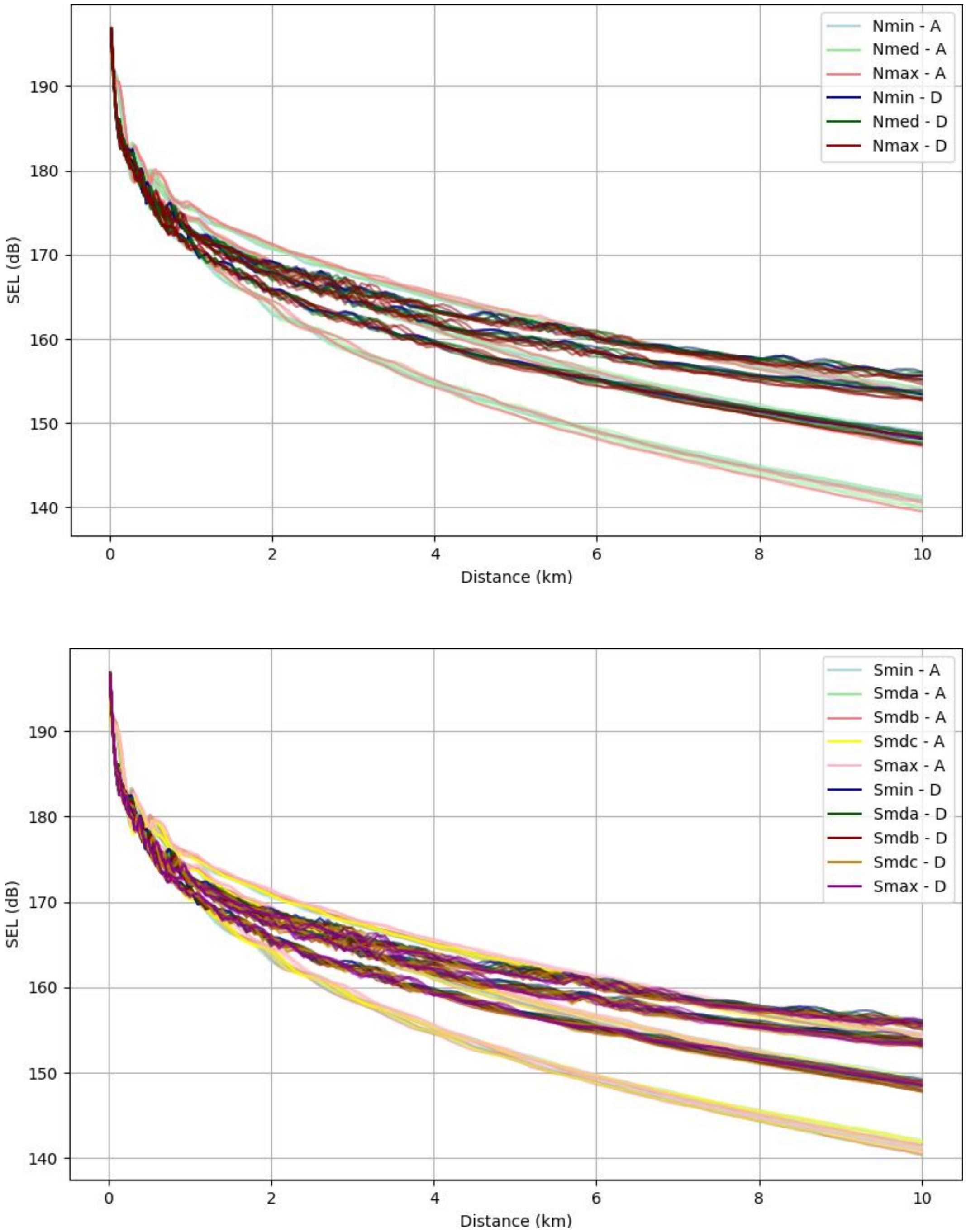


Figure A.6: Per-pulse Sound Exposure Level as a function of distance of the 5.3m pin pile split by location and analysis depth for Morven North (top) and Morven South (bottom). Colours distinguish the different source locations and the analysed penetration depth (A: shallowest; D: deepest)

The results show that there is little difference in radiated sound fields across the range of source locations considered. In terms of penetration depth, we see very little difference in the results for the 16m monopile, whereas results for the pin pile diverge based on the penetration depth with the deeper pile generating higher levels.

In terms of the pin pile, it is worth noting that although it is the deepest analysed penetration depth there is still 23m of pile in the water column and so it still encompasses a substantial portion of the water column. The increase in level with increased penetration is due to the resistance to driving encapsulated in Table A.3. The reflection coefficient is a value between -1 and +1 and represents the proportion of energy that is radiated back up the pile once the stress wave hits the pile toe. This value is dependent primarily on the anticipated penetration per blow of the pile with larger penetrations per blow generating reflection coefficients close to

+1, and smaller increments in penetration resulting in values closer to -1. We see that the reflection coefficient for the two 16m monopile analyses, although are of opposite phase, have similar amplitudes. For the pin pile, however, results suggest that there is a high resistance to driving for the deeper case, and consequently a large proportion of energy is reflected back up the pile. It is the large difference in the amplitudes of the reflection coefficient of the pin pile in Table A.3 that results in the bifurcation of otherwise equivalent results in Figure A.6.

Whilst the change in source location has little difference, there is evident grouping that originates from another factor. Figure A.7 and Figure A.8 show the per-pulse SEL as a function of distance for the monopile and the pin pile, grouped by penetration depth and geoacoustic profile.

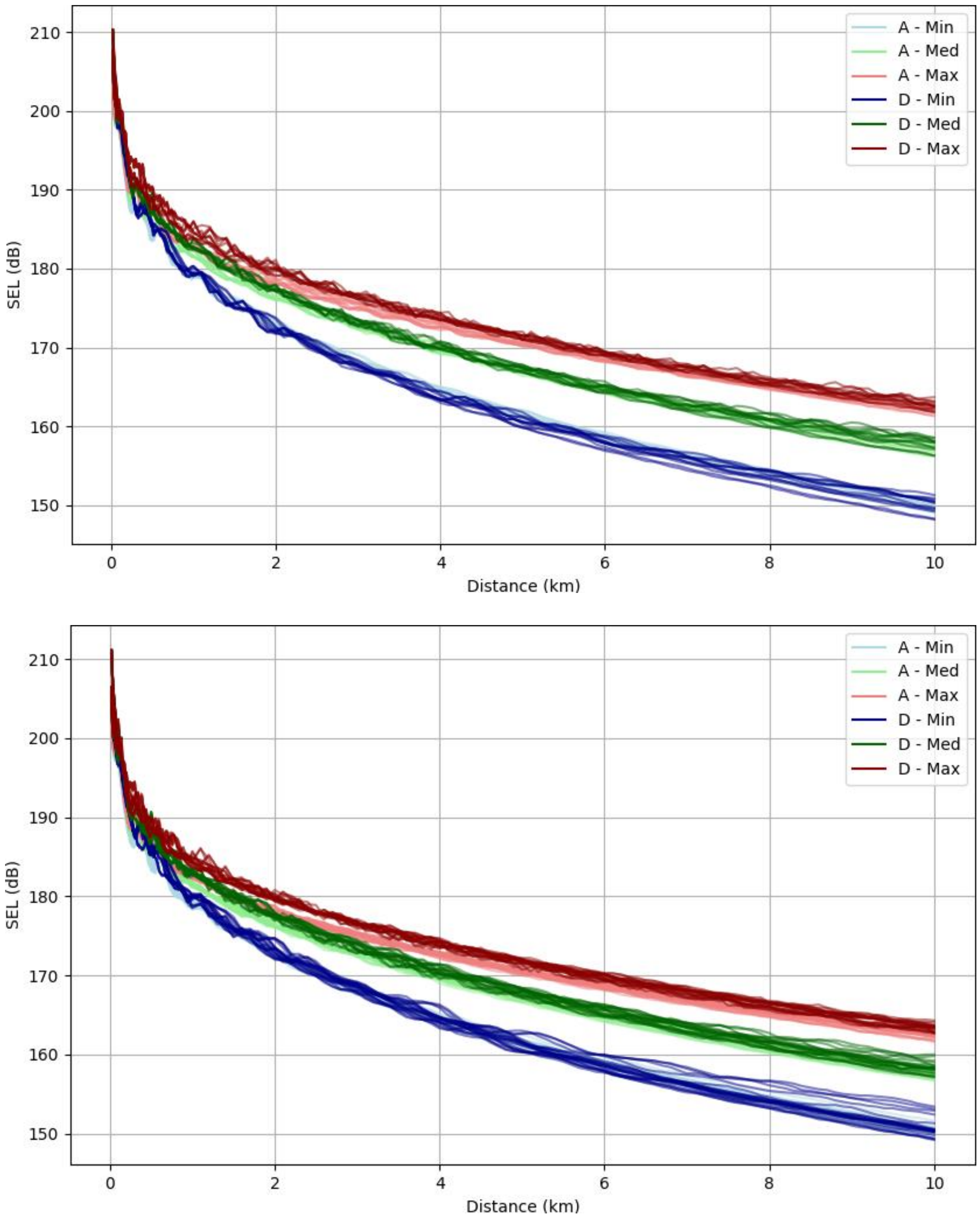


Figure A.7: Per-pulse Sound Exposure Level as a function of distance of the 16.0m monopile split by geoacoustic profile and analysis depth for Morven North (top) and Morven South (bottom). Colours distinguish the different geoacoustic profiles and the analysed penetration depth (A: shallowest; D: deepest)

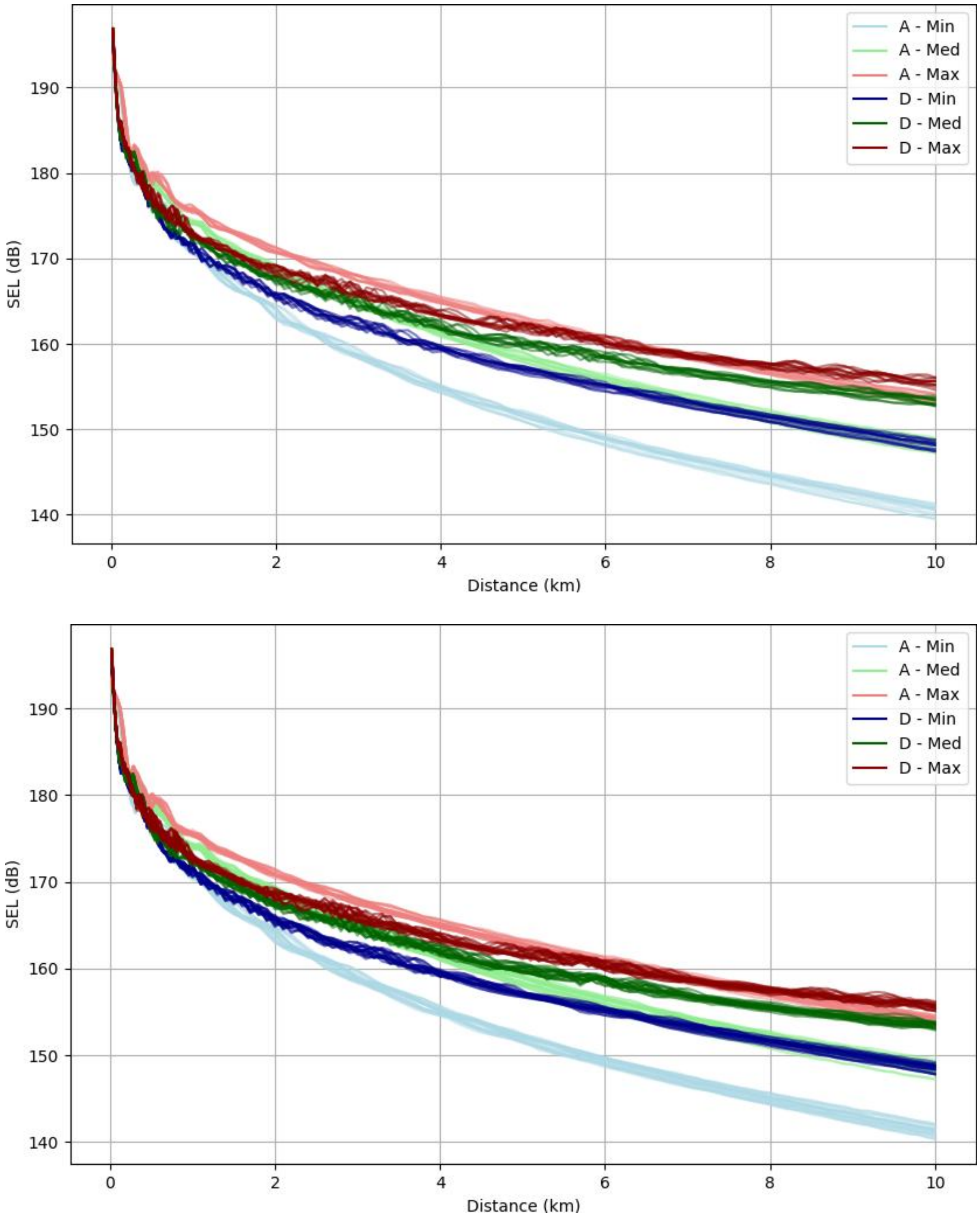


Figure A.8: Per-pulse Sound Exposure Level as a function of distance of the 5.3m pin pile split by geoacoustic profile and analysis depth for Morven North (top) and Morven South (bottom). Colours distinguish the different geoacoustic profiles and the analysed penetration depth (A: shallowest; D: deepest)

Here we see distinct grouping based on the penetration depth and geoacoustic profile. In each case, the 'Max' geoacoustic profile exhibits the higher sound levels across all distances. The maximum geoacoustic profile has the higher values of sound speed and sediment density. This results in a higher impedance mismatch between the water and the sediment and consequently more sound energy reflected from the seabed back up into the water column.

It is worth noting that the higher impedance mismatch results in less transmission of the energy across the interface. This is the situation for both the energy travelling from the water to the sediment and vice versa. In the case of in water mitigation systems, if energy in the water is eliminated, then most of the energy would be contained within the sediment. In the high impedance mismatch case, less energy would be transmitted to the water and so may result in lower sound energy in the water column. For this reason, the minimum geoacoustic profile cases should not be discounted when studying sound propagation in any future mitigated cases.

For unmitigated modelling, the proposed environments for the scenarios are to use the median water depth location with the median sound speed profile as the representative case, and the minimum water depth location with the maximum geoacoustic profile as the upper-bound case.

Appendix B Acoustic metrics

Underwater sound pressure amplitude is quantified in decibels (dB) relative to a fixed reference pressure of p_0 = 1μPa. Because the perceived loudness of sound, especially pulsed sound 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 sound and its effects on marine life. Here we provide specific definitions of relevant metrics used in the accompanying report. Where possible, International Organisation for Standardisation definitions and symbols for sound metrics are followed (e.g., ISO 18405:2017, ANSI S1.1-2013).

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

$$L_{p,\mathrm{pk}} = 10\log_{10}\frac{p_{\mathrm{pk}}^2}{p_0^2} = 20\log_{10}\frac{p_{\mathrm{pk}}}{p_0} = 20\log_{10}\frac{\max|p(t)|}{p_0}\ . \quad \text{(B-1)}$$

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 an acoustic event, it is generally a poor indicator of perceived loudness.

The sound pressure level (SPL or $L_{p,rms}$; dB re 1μPa) is the rms pressure level in a stated frequency band over a specified time window (T; s):

$$L_{p,\mathrm{rms}} = 10\log_{10}\frac{p_{\mathrm{rms}}^2}{p_0^2} = 10\log_{10}\left(\frac{1}{T}\int_T p^2(t)\,dt \Big/ p_0^2\right). \quad \text{(B-2)}$$

It is important to note that SPL always refers to a rms pressure level (i.e., a quadratic mean over a time interval) and therefore not instantaneous pressure at a fixed point in time. The SPL can also be defined as the *mean-square* pressure level, given in decibels relative to a reference value of 1μPa^2 (i.e., in dB re 1μPa^2). The two definitions of SPL are numerically equivalent, differing only in reference value.

The SPL can also be calculated using a time weighting function, $g(t)$:

$$L_{p,\mathrm{rms}} = 10\log_{10}\left(\frac{1}{T}\int_T g(t)\,p^2(t)\,dt \Big/ p_0^2\right)\ \mathrm{dB}\ . \quad \text{(B-3)}$$

In many cases, the start time of the integration is marched forward in small time steps to produce a time-varying SPL function. For short acoustic events, such as sonar pulses and marine mammal vocalisations, 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 emphasises more recent pressure signals. This function mimics the leaky integration nature of mammalian hearing. A related simpler approach used in underwater acoustics sets $g(t)$ to a boxcar (unity amplitude) function.

The sound exposure level (SEL or $L_{E,p}$; dB re 1μPa^{2}s) is the time integral of the squared acoustic pressure over a duration (T):

$$L_{E,p} = 10\log_{10}\left(\int_T p^2(t)\,dt \Big/ T_0 p_0^2\right)\ \mathrm{dB}\ , \quad \text{(B-4)}$$

where T_0 is a reference time interval of 1s. SEL 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 for its relevance to 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 pulsed sounds, SEL can be calculated by summing the SEL of the N individual pulses. For a fixed duration, the square pressure is integrated over the duration of interest. For multiple events, the SEL can be computed by summing (in linear units) the SEL of the N individual events:

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

Because the SPL and SEL are both computed from the integral of square pressure, these metrics are related numerically by the following expression, which depends only on the duration of the time window *T*:

$$L_p = L_E - 10\log_{10}(T). \quad \text{(B-6)}$$

Appendix C Marine mammal auditory frequency-weighting

The potential for sound to affect animals of a certain species depends on how well the animals can hear it; sounds are less likely to disturb or injure an animal if they are at frequencies that the animal cannot hear well. An exception occurs when the sound pressure is so high that it can physically injure an animal by non-auditory means (i.e. barotrauma). For sound levels below such extremes, the importance of sound components at particular frequencies can be scaled by frequency-weighting relevant to an animal's sensitivity to those frequencies (Nedwell and Turnpenny 1998, Nedwell *et al.* 2007)

In 2015, a US Navy technical report by Finneran (2015) recommended new auditory weighting functions. The frequency-weighting functions are expressed as:

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

Here, using the nomenclature from NMFS (2024a), with terms defined in Table C.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), and in the guidance by Southall et al. (2019); these works also redefined the mid-frequency and high-frequency cetacean groups to be the high-frequency and very high-frequency cetacean groups respectively. These have been further refined following continuing developments and the latest scientific research, with NMFS releasing their latest guidelines in 2024 (NMFS 2024a); being based on the latest science and recommendations, it is these guidelines that have been used in the present report.

It should be noted that there have been notable changes in the guidelines over successive publications. This includes changes to the frequency-weighting functions, the thresholds at which certain deleterious effects are expected, and the naming of the auditory groups. Table C.1 lists the most recent frequency-weighting parameters for each hearing group and Figure C.1 shows the resulting frequency-weighting curves.

Table C.1: Parameters for the auditory weighting functions recommended by NMFS (2024a) for hearing groups considered in this report

Functional hearing group	*a*	*b*	f_1 (kHz)	f_2 (kHz)	*C* (dB)
Low-frequency cetaceans	0.99	5	0.168	26.6	0.12
High-frequency cetaceans	1.55	5	1.73	129	0.32
Very-high-frequency cetaceans	2.23	5	5.93	186	0.91
Phocid pinnipeds in water	1.63	5	0.81	68.3	0.29

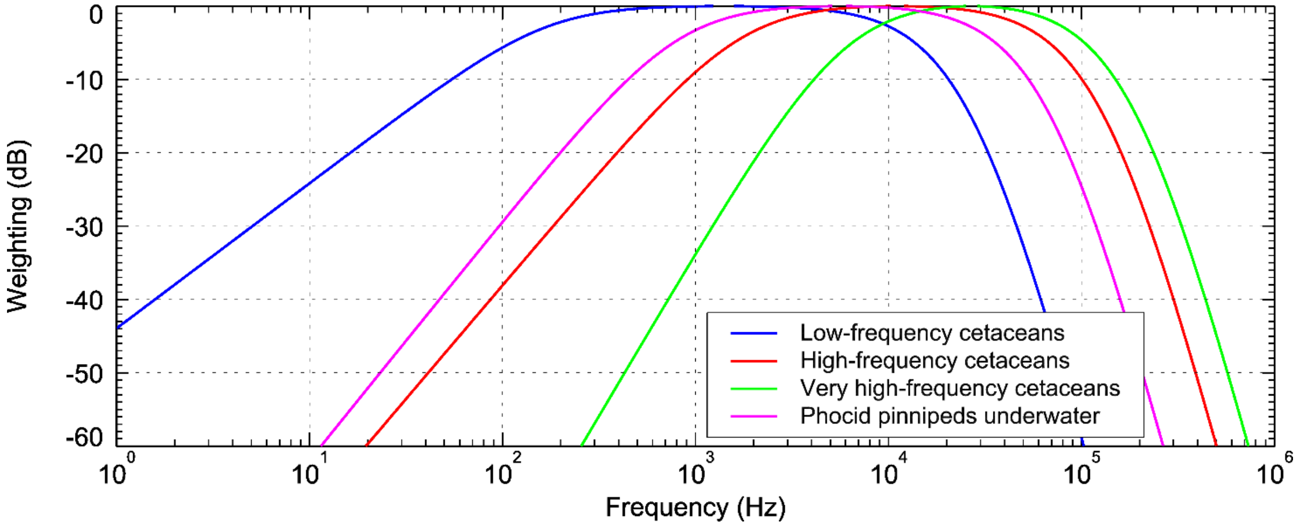


Figure C.1: Auditory weighting functions for the functional marine mammal hearing groups as recommended by National Marine Fisheries Service (2024a)

Appendix D Acoustic source modelling

D.1 Pile driving source model

A physical model of pile vibration and near-field sound radiation is used to appropriately model piles as acoustic sources. The physical model employed in this study computes the underwater vibration and sound radiation of a pile by solving the theoretical equations of motion for axial and radial vibrations of a cylindrical shell. These equations of motion are solved subject to boundary conditions, which describe the forcing function of the hammer at the top of the pile and the soil resistance at the base of the pile (Figure 3.1.1). Damping of the pile vibration due to radiation loading is computed for Mach waves emanating from the pile wall. The equations of motion are discretised using the Finite-Difference (FD) method and are solved on a discrete time and depth mesh.

To model the sound emissions from the piles, the force of the pile driving hammers also had to be modelled. The force at the top of each pile was computed using the GRLWEAP 2010 wave equation model (GRLWEAP, Pile Dynamics 2010), which includes a large database of simulated hammers—both impact and vibratory—based on the manufacturers' specifications. The forcing functions from GRLWEAP were used as inputs to the FD model to compute the resulting pile vibrations.

The sound radiating from the pile itself is simulated using a vertical array of discrete point sources. The point sources are centred on the pile axis. Their amplitudes are derived using an inverse technique, such that their collective particle velocity, calculated using a near-field wave-number integration model, matches the particle velocity in the water at the pile wall. The sound field propagating away from the vertical source array is then calculated using a time domain acoustic propagation model (see FWRAM; Appendix E). MacGillivray (2014) describes the theory behind the physical pile model in more detail.

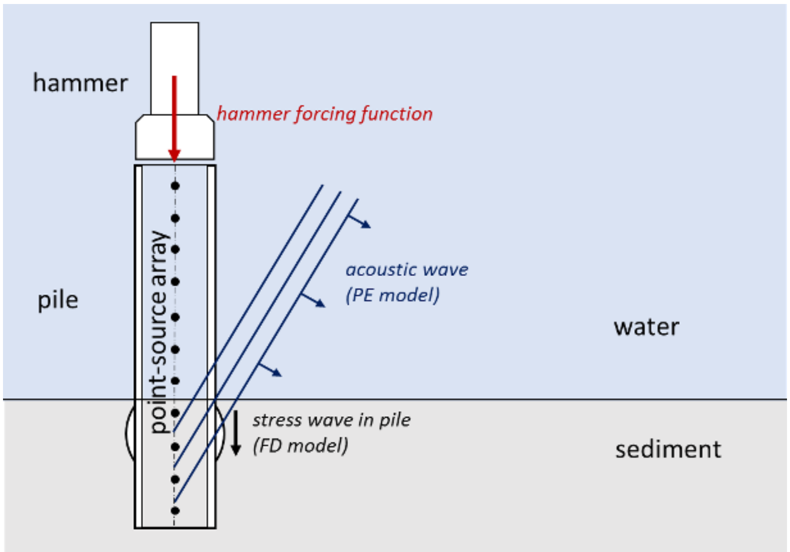


Figure C.1: Physical model geometry for impact driving of a cylindrical pile

D.2 Geophysical survey source modelling

D.2.1 Propagation Loss

The sonar equation is used to calculate the received sound pressure level:

$$SPL(r) = SL - PL(r), \tag{1}$$

where *SPL* is the sound pressure level (dB re 1µPa), *r* is the distance (slant range) from the source (m), *SL* is the source level (dB re 1µPa m), and *PL* is the propagation loss as a function of distance. The propagation loss is calculated using a modified spreading equation:

$$PL(r) = 20\log_{10}\left(\frac{r}{1\ \mathrm{m}}\right)\ \mathrm{dB} + \alpha(f)\cdot r/1000, \tag{2}$$

where $\alpha(f)$ is the absorption coefficient (dB/km) and f is frequency (kHz). The absorption coefficient is approximated by discarding the boric acid term from Ainslie (2010; p29; eq 2.2):

$$\alpha(f) \approx 0.000339f^2 + 48.5f^2/(75.6^2 + f^2)\ . \tag{3}$$

When a range of frequencies is produced by a source, we use the lowest frequency to determine the absorption coefficient.

The predicted received level is used to determine the distance at which a threshold level is reached.

D.2.2 Horizontal range estimation

For a downward-pointing source with a beam width less than 180°, the horizontal impact distance (R_{in}) is calculated from the in-beam slant range using:

$$R_{in} = r_{in}\cdot\sin\left(\frac{\delta\theta}{2}\right), \tag{4}$$

where $\delta\theta$ is the -3dB beamwidth.

To account for energy emitted outside of the primary beam of the source, we estimate a representative out-of-beam source level and propagate the energy horizontally (see Figure 4.8). In this method, the horizontal component R_{out} of the out-of-beam energy is equivalent to the out-of-beam slant range:

$$R_{out} = r_{out}. \tag{5}$$

The larger of the two horizontal range estimates was then selected for assessing impact distance:

$$R = \max(R_{in}, R_{out})\,. \tag{6}$$

For an omni-directional source the horizontal impact distance (*R*) was calculated based on horizontally propagating energy (i.e., this is equivalent to a beamwidth of 180°).

D.2.3 Out-of-beam source level adjustment

Side lobe energy is generally lower than the main lobe energy. An estimate of the reduction relative to the main lobe energy was generated as a function of the main lobe beam width. Separate approaches were taken for narrow-beam sources (up to 36° beam width), intermediate-beam sources (36°-90° beam width), and broad-beam sources. Broad-beam sources were treated as omni-directional and had no out-of-beam reduction. The out-of-beam reduction for narrow-beam sources was approximated using a theoretical beam pattern. The out-of-beam reduction for intermediate-beam sources was interpolated between the other two approximations.

The narrow-beam side lobe level reduction is estimated by taking the arithmetic average of the upper and lower bounds of the sidelobe levels of an unshaded circular transducer beam pattern. This beam pattern $b(u)$ is described as:

$$b(u) = (2\ J_1(u)/u)^2 \qquad 7)$$

where $J_1(u)$ is a first order Bessel function of the first kind, whose argument is a function of off-axis angle θ and beam width (full width at half maximum) $\delta\theta$

$$u = u_0 \frac{\sin\theta}{\sin\frac{\delta\theta}{2}} \qquad 8)$$

where $u_0 = 1.614$.

For the upper limit we choose the highest sidelobe level of the beam pattern, given by (Ainslie 2010; p265; Table 6.2)

$$B_{\mathrm{max}} = -17.6\ \mathrm{dB}. \qquad 9)$$

For the lower limit we consider the asymptotic behaviour of the beam pattern in the horizontal direction

$$J_1(u) \sim \sqrt{\frac{2}{\pi u}} \cos\left(u - \frac{3\pi}{4}\right), \qquad 10)$$

where

$$u = \frac{u_0}{\sin\frac{\delta\theta}{2}}. \qquad 11)$$

In this way we obtain the lower limit as

$$B_{\mathrm{min}} = 10 \log_{10}\left(\frac{8}{\pi\, u_0^3} \sin^3\frac{\delta\theta}{2}\right) \mathrm{dB}. \qquad 12)$$

Finally, the out-of-beam source level is found by reducing the in-beam source level by the arithmetic mean of B_{min} and B_{max}. The resulting correction as a function of beam width is shown in Figure D.1. Note that narrower beam sources have a larger reduction in sidelobe levels than wider beam sources.

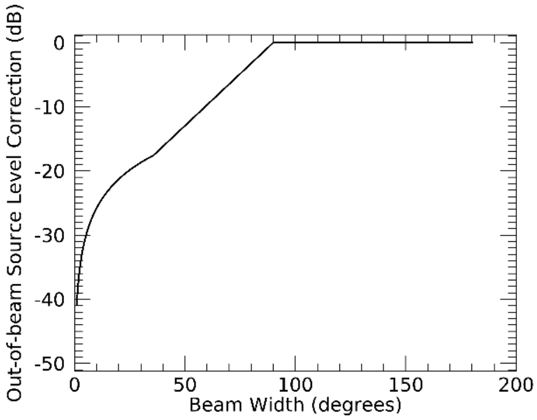


Figure D.1: Correction for calculating out-of-beam source level (i.e. in the horizontal direction) from in-beam source level, as a function of main lobe beam width

The out-of-beam source level for a given source was calculated by adding the dB correction (Figure D.1) to the in-beam source level.

D.2.4 Auditory Injury impact

This section describes the methods used to estimate the horizontal distances to the NMFS acoustic thresholds for injury (Table 3.1). There are different thresholds for impulsive and non-impulsive sounds. According to Southall et al. (2007b), "Harris (1998) proposed a measurement-based distinction of pulses and non-pulses that is adopted here in defining sound types. Specifically, a ≥3-dB difference in measurements between continuous and impulse [sound level meter] setting indicates that a sound is a pulse; a <3dB difference indicates that a sound is a non-pulse. We note the interim nature of this distinction for underwater signals and the need for an explicit distinction and measurement standard such as exists for aerial signals (ANSI 1986)."

Classification of impulsive signals is inconsistent across standards, criteria, and guidance. Southall *et al.* (2007b), Finneran *et al.* (2017), and NMFS (2018) each have different criteria for classifying a signal as impulsive or non-impulsive. The Southall *et al.* (2007b) method described above was used for all of the sources analysed in this work. Finneran *et al.* (2017) state that harmonic signals with more than 10 cycles in a pulse are considered steady state (i.e. non-impulsive). NMFS (2018) cites the standard for measurement of sound levels in-air (ANSI 2010), but removes the quantitative criteria resulting in a definition that impulsive sound sources "produce sounds that are typically transient, brief (less than 1 second), broadband, and consist of high peak sound pressure with rapid rise time and rapid decay." The ANSI (2010) classification, whilst more specific than NMFS (2018), does not preclude harmonic signals, especially frequency modulated signals, from being classified as impulsive.

NMFS has determined that sparkers and boomers are classified as impulsive sources, whilst sub-bottom profilers and multi-beam echosounders are non-impulsive. This classification is based on NMFS' qualitative assessment of the generated waveforms (personal communication, Benjamin Laws [NMFS] 2020).

NMFS provides a spreadsheet to calculate these distances, but it is not designed for high-resolution geophysical survey sources. The spreadsheet does not consider seawater absorption or beam patterns, both of which can substantially influence received sound levels. To account for these effects, we model sound levels as follows.

Distances to peak thresholds were calculated using the peak source level and applying modified spreading propagation loss equation. Peak levels were assessed for both in-beam and out-of-beam levels (the latter was assessed using the out-of-beam source level correction described previously).

Range to SEL thresholds were calculated for source locations along a hypothetical survey line. Source spacing was determined from the assumed vessel speed of 3.5kts and the repetition rate for each source. A single set of fixed receiver locations extended perpendicularly from the middle of the survey line. The propagation loss between each source and receiver pair was calculated and then using the appropriate (in-beam or out-of-beam) weighted source level and pulse length, the received level from all of the source locations for each receiver was determined. The received levels at a given receiver location from all source locations were summed. The greatest range where the summed SEL exceeded the criteria threshold was the range to impact. This range was determined separately for all sources and all studied functional hearing groups.

This method accounts for the hearing sensitivity of the marine mammal group, seawater absorption, and beam width for downwards-facing transducers.

D.2.5 Behavioural impact

Current guidance for assessing the behavioural impacts for intermittent sound sources, regardless of being impulsive or non-impulsive, is based on estimating the horizontal distance to the root-mean-square sound pressure level (SPL) of 160dB re 1µPa isopleth (NOAA 2019). Distances to SPL thresholds were calculated using the source level and applying the method described above. SPL values were assessed for both in-beam and out-of-beam levels (the latter was assessed using the out-of-beam source level correction described previously).

D.3 Unexploded Ordnance source model

The pressure wave generated by detonation of an explosive in water consists of an initial high-amplitude blast that exhibits an exponential decay, followed by pressure peaks generated by the expanding and contracting gas bubble that was formed after the detonation. The initial blast pressure varies over time, as per the equation of Gaspin (1983) and Richardson *et al.,* (1995):

$$p(t) = Pe^{-\frac{t}{\tau}}\,\text{Pa}\,, \quad \text{(D-13)}$$

where P is the maximum amplitude and τ is the exponential time constant. Near the charge, the maximum pressure is defined empirically as:

$$P = 5.24e^{7}\left(W^{1/3}/R\right)^{1.13}\,\text{Pa}\,, \quad \text{(D-14)}$$

where W is the (TNT-equivalent) mass of explosive in kilograms and R is the distance from the explosive (Richardson *et al.* 1995) in metres. The exponential time constant has the form:

$$\tau = 9.25e^{-5}W^{1/3}\left(W^{1/3}/R\right)^{-0.22}\,\text{s}\,. \quad \text{(D-15)}$$

These equations are characteristic of a shock wave, near the charge. The limiting range of validity, R_0, can be estimated using the Gaspin (1983) equation:

$$R_o = 4.76W^{1/3}\,\text{m}\,. \quad \text{(D-16)}$$

Thus, R_0 may be used to estimate the range at which sound from a blast may be modelled using typical sound propagation models (e.g., FWRAM).

At ranges greater than R_0, the wave may be said to follow weak-shock theory (Gaspin 1983, Richardson *et al.* 1995). Rogers (1977) applied weak-shock theory to derive expression for the peak amplitude and exponential time constant from a blast:

$$P(R) = \frac{P_o\left\{\sqrt{1 + 2\left(\frac{R_o}{L_o}\right) ln\left(\frac{R}{R_o}\right)} - 1\right\}}{\left[\left(\frac{R_o}{L_o}\right) ln\left(\frac{R}{R_o}\right)\right]}\,\text{Pa} \quad \text{(D-17)}$$

and

$$\tau(R) = t_o\sqrt{1 + 2\left(\frac{R_o}{L_o}\right) ln\left(\frac{R}{R_o}\right)}\,\text{s} \quad \text{(D-18)}$$

with

$$L_o = (\rho_o c_0^3 t_o)/(P_o\beta)\,\text{m}\,. \quad \text{(D-19)}$$

where ρ_o and c_o are the water density and sound speed in SI units, respectively, β = 3.5, and P_0 and t_0 are the peak and time constants from Equations D-14 and D-15, respectively, at range R_0.

Figure D.2 illustrates the general structure of the complete signature from the blasting, including the effect of an oscillating bubble. Gaspin (1983) provides the following expressions for the peak value and the time of occurrence of the oscillations:

$$P_{min} = -\frac{124405(3.28Z + 33)^{\frac{1}{3}}w^{\frac{1}{3}}}{R}\,\text{Pa} \quad \text{(D-20)}$$

$$P_1 = \frac{5331626w^{\frac{1}{3}}}{R}\,\text{Pa} \quad \text{(D-21)}$$

$$P_2 = 0.22P_1\,\text{Pa} \quad \text{(D-22)}$$

$$T_{PP} = \frac{0.427 w^{\frac{1}{3}}}{(3.28z + 33)^{5/6}}\ \text{s} \quad \text{(D-23)}$$

$$T_{nP} = \frac{2.382 w^{\frac{1}{3}}}{(3.28z + 33)^{5/6}}\ \text{s} \quad \text{(D-24)}$$

$$T_{bP} = \frac{0.845 w^{\frac{1}{3}}}{(3.28z + 33)^{5/6}}\ \text{s} \quad \text{(D-25)}$$

$$T_{2} = \frac{2.352 w^{\frac{1}{3}}}{(3.28z + 33)^{5/6}}\ \text{s} \quad \text{(D-26)}$$

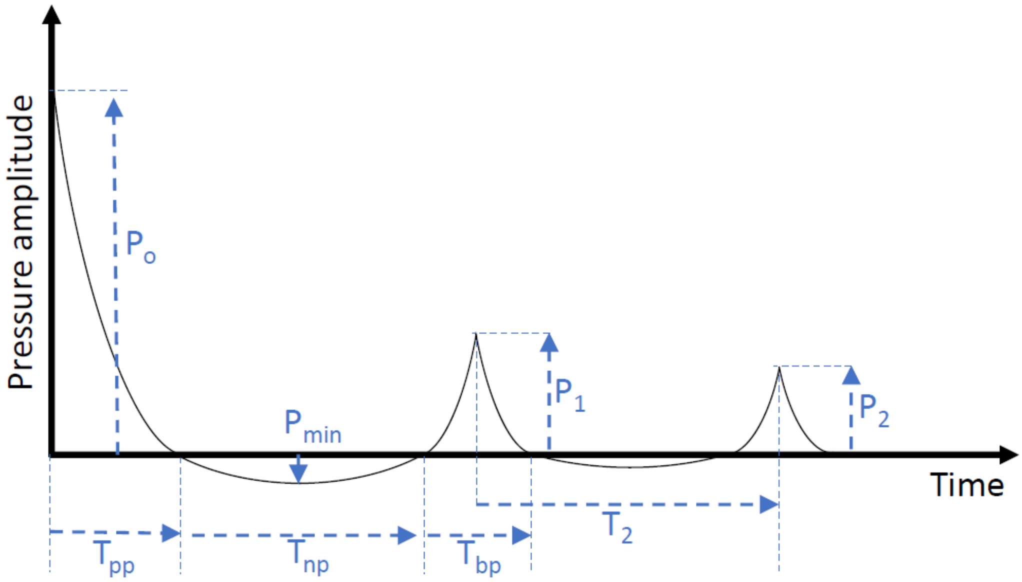


Figure D.2: Characteristics of an underwater blast waveform, showing the amplitude and timing of the initial blast of amplitude P_o, relative to pressure peaks originated from the gas bubble formed after the detonation

The amplitudes and timing relationships in this appendix were used to produce time signatures for charges at the three targets. The signature was calculated at range R_0, and then a simple model of spherical spreading was used to backpropagate to 1m from the charges to obtain source level characteristics for an equivalent acoustic point source.

Appendix E Sound propagation modelling

E.1 Full Waveform Range-dependent Acoustic Model

For impulsive sounds from impact pile driving, time domain representations of the pressure waves generated in the water are required for calculating SPL and peak pressure level. Furthermore, the pile must be represented as a distributed source to accurately characterise vertical directivity effects in the near-field zone.

For this study, synthetic pressure waveforms were computed using JASCO's Full Waveform Range-dependent Acoustic Model (FWRAM), which is a time domain acoustic model based on a wide-angle parabolic equation (PE) solution to the acoustic wave equation (Collins 1993).

FWRAM computes pressure waveforms via Fourier synthesis of the modelled acoustic transfer function in closely spaced frequency bands. Synthetic pressure waveforms are computed for receivers increasing in range from the source and at depths throughout the water column and seabed taking into account the environmental parameters. The synthetic pressure waveforms were post-processed, after applying a travel time correction, to calculate standard SEL, SPL, and PK metrics versus range and depth from the pile. FWRAM employs the array starter method to accurately model sound propagation from a spatially distributed source (MacGillivray and Chapman 2012).

E.2 Marine Operations Noise Model

Underwater sound propagation (i.e. transmission loss) was predicted with JASCO's MONM.

The MONM low-frequency module computes acoustic propagation via a wide-angle parabolic equation solution to the acoustic wave equation (Collins 1993) based on a version of the US Naval Research Laboratory's Range-dependent Acoustic Model (RAM), which has been modified to account for a solid seabed (Zhang and Tindle 1995). The parabolic equation method has been extensively benchmarked and is widely employed in the underwater acoustics community (Collins *et al.* 1996). MONM accounts for the additional reflection loss at the seabed, which results from partial conversion of incident compressional waves to shear waves at the seabed and sub-bottom interfaces, and it includes wave attenuations in all layers. MONM incorporates the following site-specific environmental properties: a bathymetric grid of the modelled area, underwater sound speed as a function of depth, and a geoacoustic profile based on the overall stratified composition of the seafloor.

Beyond the upper frequency range of the parabolic equation module of MONM, sound propagation is computed using the BELLHOP Gaussian beam acoustic ray-trace model (Porter and Liu 1994). This high-frequency module accounts for sound attenuation due to energy absorption through ion relaxation and viscosity of water in addition to acoustic attenuation due to reflection at the medium boundaries and internal layers (Fisher and Simmons 1977). The former type of sound attenuation is important for frequencies higher than 5kHz and cannot be neglected without noticeably affecting the model results.

MONM computes acoustic fields in three dimensions by modelling transmission loss within two dimensional (2-D) vertical planes aligned along radials covering a 360° swath from the source, an approach commonly referred to as N×2-D. These vertical radial planes are separated by an angular step size of $\Delta\theta$, yielding $N = 360°/\Delta\theta$ number of planes (Figure E.1). The angular step size of the radials is chosen to sufficiently sample the source beam pattern. MONM accounts for the variability of the sound level of the emitted pulse with both azimuth and depression angles according to the 3-D beam pattern of the source and estimates sound levels at various horizontal distances from the source as well as at various depths.

The received sound level at a sampling location is taken as the maximum value that occurs over all samples within the water column below (i.e. the maximum-over-depth received sound level (Figure E.1)). These maximum-over-depth levels are then presented as colour contours around the source (e.g. Figure E.2).

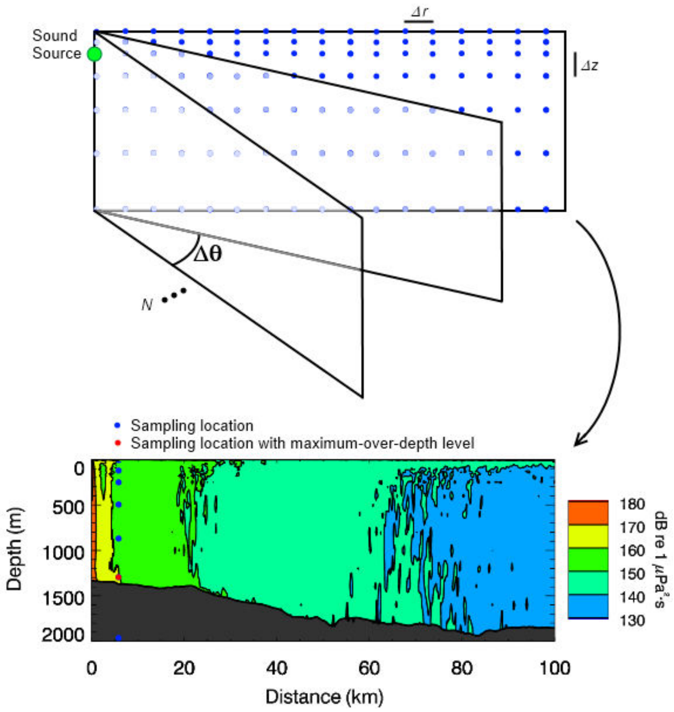


Figure E.1: Representation of the *N*×2-D and maximum-over-depth modelling approaches

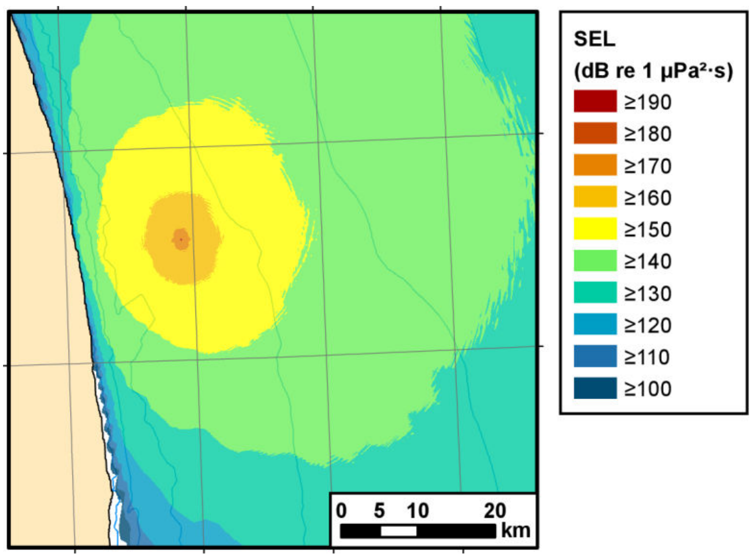


Figure E.2: Example of a maximum-over-depth Sound Exposure Level colour contour map for an unspecified source

Appendix F Ranges to threshold levels

Sound level contours were calculated based on the underwater sound fields predicted by the propagation models, sampled by taking the maximum value over all modelled depths above the seafloor for each location in the modelled region. The predicted distances to specific levels were computed from these contours. Two distances relative to the source are reported for each sound level: (1) R_{max}, the maximum range to the given sound level over all azimuths, and (2) $R_{95\%}$, the range to the given sound level after the 5% farthest points were excluded (see examples in Figure F.1).

The $R_{95\%}$ is used because sound field footprints are often irregular in shape. In some cases, a sound level contour might have small protrusions or anomalous isolated fringes. This is demonstrated in the image in Figure F.1a. In cases such as this, where relatively few points are excluded in any given direction, R_{max} can misrepresent the area of the region exposed to such effects, and $R_{95\%}$ is considered more representative. In contrast, in strongly radially asymmetric cases such as shown in Figure F.1b, $R_{95\%}$ neglects to account for substantial protrusions in the footprint. In such cases, R_{max} might better represent the region of effect in specific directions. Cases such as this are usually associated with bathymetric features that affect propagation. The difference between R_{max} and $R_{95\%}$ depends on the source directivity and the non-uniformity of the acoustic environment.

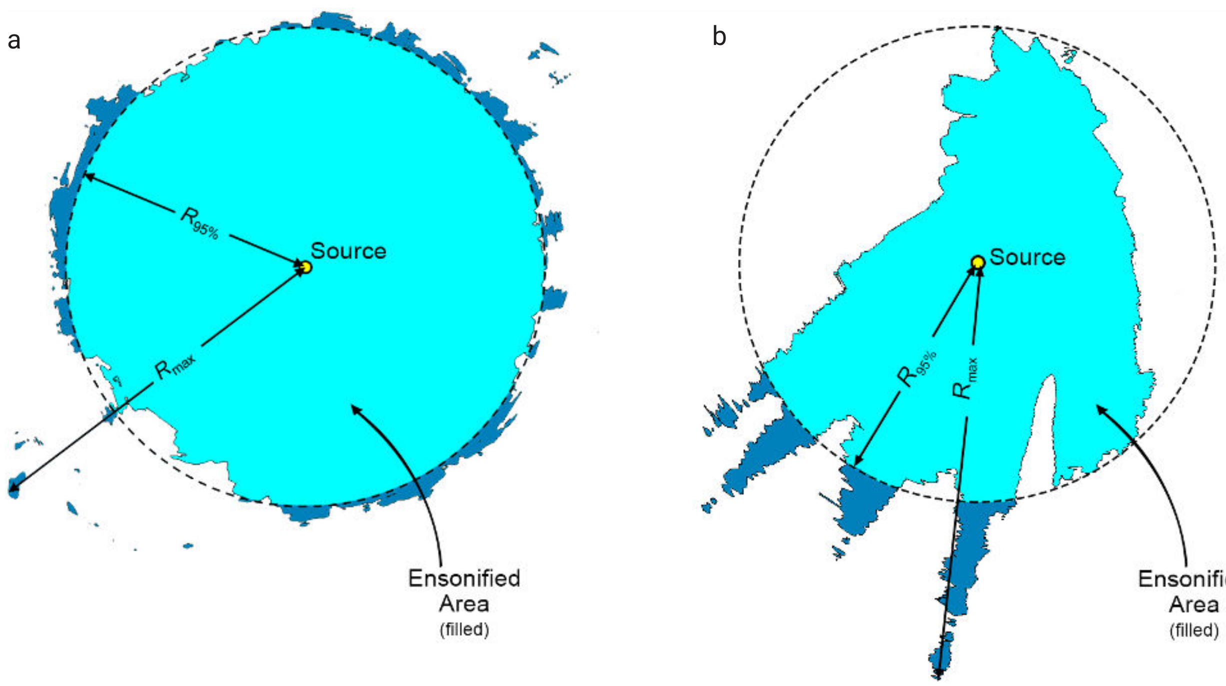


Figure F.1: Sample areas ensonified to an arbitrary sound level with R_{max} and $R_{95\%}$ ranges shown for two contrasting scenarios: (a) a largely radially symmetric sound level contour with small protrusions, for which $R_{95\%}$ best represents the ensonified area; and (b) a strongly asymmetric sound level contour with long protrusions, for which R_{max} best represents the ensonified areas in some directions. Light blue indicates the ensonified areas bounded by $R_{95\%}$; darker blue indicates the ensonified areas beyond $R_{95\%}$ that determine R_{max}