Mere Havvind – Nordsøen I

Underwater Noise Emission from Seismic Survey Activities
Energinet Eltransmission A/S

Date: 30 August 2022

Contents

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1 Introduction

This note describes underwater sound propagation prognosis carried out by NIRAS for seismic survey activities planned by Energinet in the "Nordsøen I" Offshore Wind Farm (OWF) area, located in the Danish North Sea, approximately 15 km west of the coast of Jutland, see Figure 1.1.

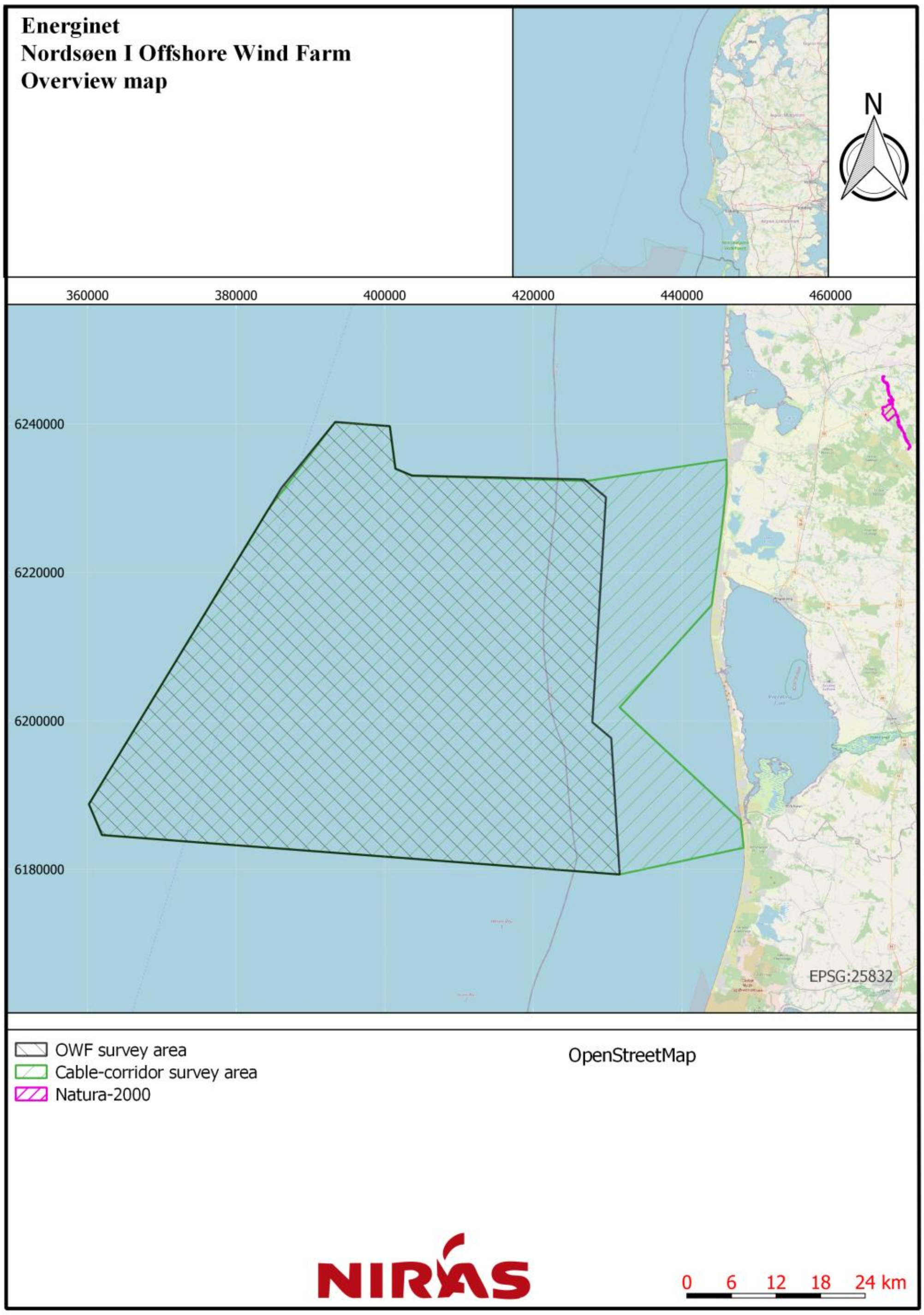

Figure 1.1: Overview map of OWF survey area (black) and cable-corridor survey area (green) at Nordsøen I Offshore Wind Farm.

Based on a list of proposed equipment, operational parameters and timeline, intended for the seismic survey activities, the prognosis evaluates the potential for inflicting harmful doses of underwater noise on relevant marine mammal species. The note serves as an input for the impact assessment.

2 Underwater sound propagation prognosis

The prognosis provides impact ranges to relevant marine mammal threshold criteria, including behaviour response, Temporary Threshold Shift (TTS) and Permanent Threshold Shift (PTS). The relevant threshold values are described further in section 2.1.

The effect of underwater noise on marine mammals is determined through sound propagation modelling, utilizing best available source and environmental data. NIRAS uses the commercial underwater noise modelling tool dBSea (version 2.3.4), with the input settings provided in section 2.2.

A source model for each equipment type planned to be used in the survey is described in section 0 and implemented in dBSea along with bathymetry, sediment and sound speed input data, as described in section 2.4 to predict the sound propagation in 1/3 octave bands for the frequency range relevant to the marine mammal species. Resulting impact ranges are documented in tables, see section 2.5.

2.1 Evaluation criteria

Underwater noise emission is evaluated against the marine mammal threshold levels, agreed with Energinet, see Table 2.1. Threshold levels include Temporary Threshold Shift (TTS) and Permanent Threshold Shift (PTS) for Low Frequency (LF) Cetaceans, High Frequency (HF) Cetaceans, Very High Frequency (VHF) Cetaceans and Phocid Pinniped (PW) weighting (NOAA, 2018), (Southall, et al., 2019), and for harbour porpoise also behaviour impact (Tougaard, 2021).

Table 2.1: Species specific thresholds for the relevant marine mammal species. (NOAA, 2018), (Southall, et al., 2019), (Tougaard, 2021).

<table>
<tr><th rowspan="3">Hearing group</th><th rowspan="3">Representative species</th><th rowspan="3">Weighting (xx)</th><th colspan="2">Species specific weighted thresholds (non-impulsive)</th><th colspan="3">Species specific weighted thresholds (impulsive)</th></tr>
<tr><th colspan="2">$L_{E,cum,24h,xx}$</th><th colspan="2">$L_{E,cum,24h,xx}$</th><th>$L_{p,rms,xx}$</th></tr>
<tr><th>TTS [dB]</th><th>PTS [dB]</th><th>TTS [dB]</th><th>PTS [dB]</th><th>Behaviour [dB]</th></tr>
<tr><td>**Low frequency**</td><td>Minke whale</td><td>LF</td><td>179</td><td>199</td><td>168</td><td>183</td><td>-</td></tr>
<tr><td>**High Frequency**</td><td>White-beaked dolphin</td><td>HF</td><td>178</td><td>198</td><td>170</td><td>185</td><td>-</td></tr>
<tr><td>**Very high frequency**</td><td>Harbour porpoise</td><td>VHF</td><td>153</td><td>173</td><td>140</td><td>155</td><td>103</td></tr>
<tr><td>**Phocid Pinniped**</td><td>Harbour seal and Grey seal</td><td>PCW</td><td>181</td><td>201</td><td>170</td><td>185</td><td>-</td></tr>
</table>

Threshold criteria include both non-impulsive and impulsive noise criteria. An impulsive noise source is characterised as a fast onset of noise with a significant amplitude, such as explosions, impact pile driving, airguns and pingers. Non-impulsive noise sources on the other hand has less of an impulsive nature, while still being able to exhibit variations in the noise level.

Non-impulsive noise is less damaging for the marine mammal hearing compared to impulsive noise, as indicated by the higher tolerance/threshold level of non-impulsive noise. For seismic surveys, most sources are of impulsive nature when evaluated individually, however when surveys include multiple simultaneously active sound sources as well as noise from the survey vessel and the local ambient noise from waves, wind, biological sources and other nearby anthropogenic sources, it is less clear whether a marine mammal at several km of distance from the survey will experience the noise as impulsive or non-impulsive.

2.2 Sound Propagation Model Settings

Sound propagation modelling is undertaken in dBSea (version 2.3.4) using the settings provided in Table 2.2.

Table 2.2: dBSea settings used for sound propagation model

Technical Specification		
Octave bands		1/3-octave
Grid resolution (range, depth)		25 m x 0.5 m
Number of transects		45 (8° resolution)
Sound Propagation Model Settings		
Model	Start frequency band	End frequency band
dBSeaRay (Ray tracing)	12.5 Hz	128 kHz

2.3 Source Model

According to Energinet, the following equipment types and operational setup is intended for the survey, see Table 2.3.

Table 2.3: Seismic survey equipment models and operational parameters intended.

Type	Equipment model	Source Level, L_s [dB re 1 μPa · m]	Primary Frequency Range (Hz)	Pulse Length	Beam Width	Sound exposure source level, $L_{S,E}$ [dB re 1 $\mu Pa^2 m^2 s$]	Duty cycle over a 24 hour period
Sub-bottom profiler	Innomar SES-2000 Medium 100 or similar	243 dB	1k – 150k	0.07 – 2 ms	2°	213 dB	10 Hz
Sparker	GeoSource 200-400 or similar	216 dB (@1000 J)	50 Hz – 4 kHz	2 ms	60° @ 1 kHz 30° @ 2 kHz 15° @ 4 kHz	189 dB	4 Hz
Ultrashort Baseline (USBL) positioning system*	HiPAP/HPR 400 or similar	179 dB	25 kHz	30 ms	5° (facing horizontally)	163 dB	2 Hz

*: No information on USBL system is available, and NIRAS experience from previous surveys is used to choose representative values.

For the OWF survey area, it is expected that all equipment models will be used, whereas only the Innomar and the USBL will be used for the cable-corridor survey area.

Very few measurements exist, documenting the underwater sound emission, and/or source characteristics in the horizontal plane, as these sources have their acoustic emission focused vertically towards the seabed. In connection with recent seismic survey activities for the Danish Energy Island in the North Sea, a source characterization study took place (Pace, et al., 2021), carrying out underwater sound measurements on a 360 tip Sparker system (assessed to be equivalent to the GeoSource 200-400), an Innomar SES-2000 medium 100 and a HiPAP/HPR 400 USBL system.

In the North Sea, sound propagation is fairly uniform geographically as well as temporally, and it is therefore considered likely that noise emission from the seismic survey will be similar to the results observed during the source characterisation study. In order to verify this, NIRAS constructed a digital 3D acoustic model in dBSea, representing the actual survey environment, based on the information supplied in the report and best available knowledge. Through the model, equivalent source models were derived for the sparker, Innomar and USBL, replicating the reported sound levels from the measurements. The equivalent source models were then used to represent the sparker, Innomar and USBL in the sound propagation model. While it must be recognized that the approach is considered an approximation of the actual sources, it is considered the best available data. To err on the side of caution, the maximum impact range over all calculated directions is reported.

The detailed sound source level (ESL), both species-specific frequency weighted for Low Frequency (LF) Cetaceans, High Frequency (HF) Cetaceans, Very High Frequency (VHF) Cetaceans and Phocid Pinniped (PCW) are included in the dBSea sound propagation modelling, and are presented in Appendix 1.

Further specifications regarding the dBSea source propagation model are listed in Table 2.4.

Table 2.4: Technical specifications of source and receiver behaviour for the seismic survey activities.

Technical specification		**Note**
Vessel speed	4 knots	
Time duration of the survey	24 h	
Fleeing behaviour	Included with 1.5 m/s swim speed	Fleeing behaviour considered is "negative phonotaxy" (Tougaard, 2016)
Number of transects	90 (4° resolution)	
Survey vessel route	Final routes not decided. Different likely worst-case options chosen for different areas of OWF and cable-corridor survey areas.	

2.4 Environmental Model

In this section, the environmental conditions of the site and surroundings are examined to determine the appropriate input parameters for the underwater sound propagation model. The sound propagation depends primarily on the site bathymetry, sediment and sound speed conditions. In the following, each input parameter is described.

2.4.1 Bathymetry

The bathymetry is obtained from EMODnet, (EMODnet, 2022), with the extract shown in Figure 2.1, for the OWF and cable-corridor survey areas. In this area the bathymetry ranges from a depth of 50 m, indicated by the darker colours, to a depth of 0 m (land), indicated by the lighter colours.

2.4.2 Seabed sediment

In dBSea, the sound interaction with the seabed is handled through specifying the thickness and acoustic properties of the seabed layers from seabed to bedrock. In the modelling for "Nordsøen I", the upper sediment layer is primarily sand, with local occurrences of coarse substrates. Deeper layers include moraine and chalk.

Literature studied to provide details on layer composition include (Danmarks Geologiske Undersøgelse (DGU), 1994), (GEO, 2020), (COWI, 2020), (EMODnet, 2021), The geoacoustic properties of the different layers are set from literature documenting in situ measurements, see Table 2.5, based on (Jensen, et al., 2011), (Hamilton, 1980).

In Figure 2.1, the upper sediment types for the area are shown, and represent the sediment model implemented in dBSea.

Table 2.5: Geoacoustic properties used for environmental sediment model

Sediment	Sound Speed [m/s]	Density [kg/m^3]	Attenuation factor [dB/λ]
Clay	1500	1500	0.2
Silt	1575	1700	1.0
Mud (clay-silt)	1550	1500	1.0
Sandy mud	1600	1550	1.0
Sand	1650	1900	0.8
Muddy sand	1600	1850	0.8
Coarse substrate	1800	2000	0.6
Gravel	1800	2000	0.6
Mixed sediment	1700	1900	0.7
Moraine	1950	2100	0.4
Moraine Boulders	2200	2200	0.3
Rock and boulders	5000	2700	0.1
Chalk	2400	2000	0.2

2.4.3 Source positions

Sound propagation modelling is carried out for two positions; one within the OWF survey area and one within the cable-corridor survey area. Both positions are intended to represent likely worst case sound propagation properties. The positions are shown in Figure 2.1.

The position within the OWF survey area, was selected as it represents a deeper part of the area with a sandy topsoil. It is expected to be a good representative worst case position for the area. The position within the cable-corridor is located in the very shallow near coastal area where the sound propagation in the offshore direction is of specific interest as the water depth increases with distance from the source position.

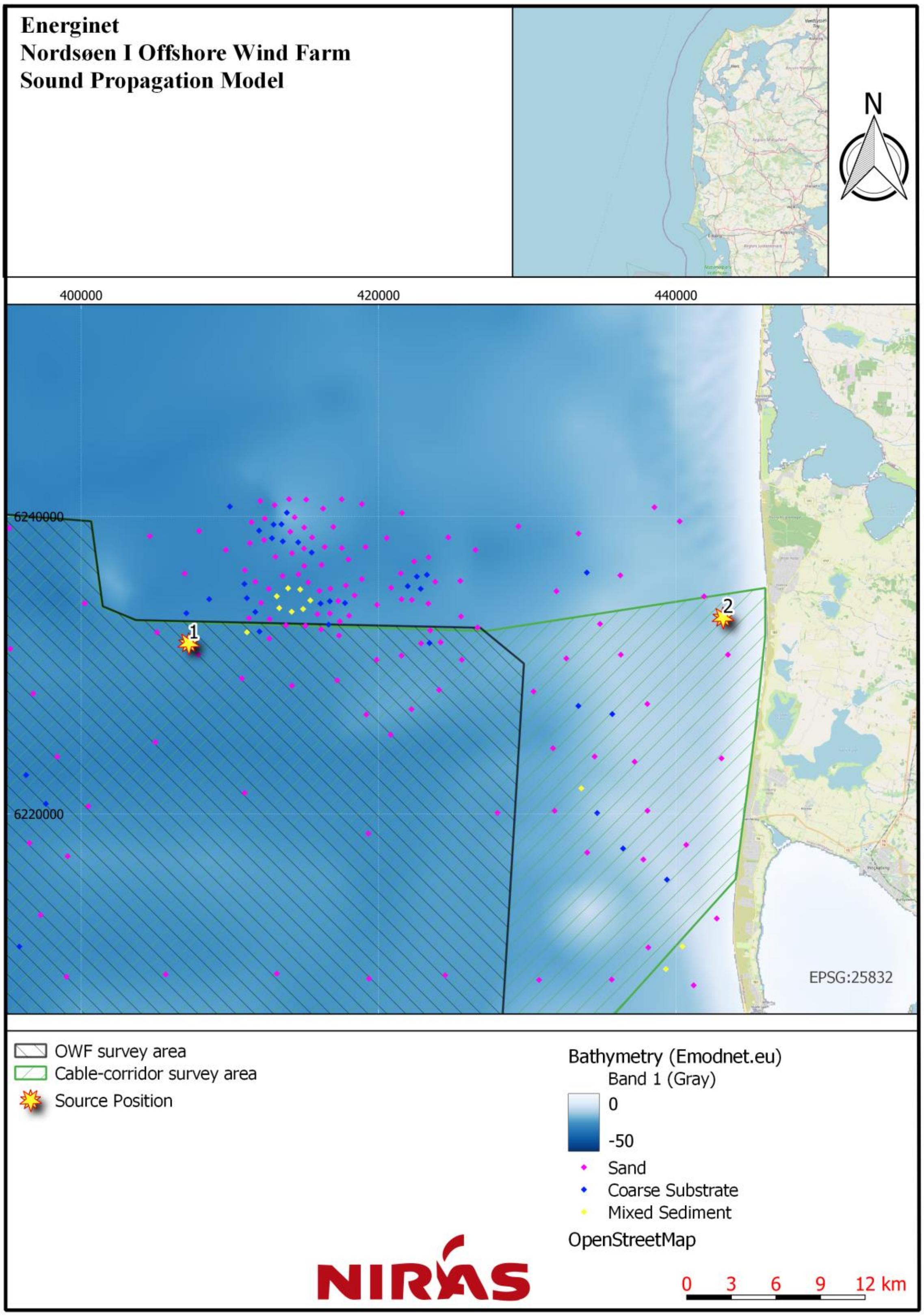

Figure 2.1: Environmental model showing bathymetry (Emodnet-bathymetry.eu), uppermost sediment layer and sound propagation model source positions.

2.4.4 Temperature, salinity and sound speed profile

The sound propagation also depends on the season dependent sound speed profile. To create an accurate sound speed profile, the temperature and salinity throughout the water column for the time of year where the surveys activities will take place are used. For the intended survey activities, Energinet has informed NIRAS that the survey will take place between January – December.

NIRAS examined NOAAs WOA18, freely available from the "National Oceanic and Atmospheric Administration" (NOAA) at https://www.nodc.noaa.gov/OC5/woa18/, (NOAA, 2019) which contains temperature and salinity information at multiple depths throughout the water column.

For each of the sediment model positions, the nearest available sound speed profile was calculated for the different months, see Figure 2.2, where available sound speed profiles are shown geographically arranged. Empty plots indicate presence of land mass.

From Figure 2.2, February was identified as the month, most likely to result in the strongest sound propagation (least loss over distance) within the survey timeframe (January – December). The sound propagation model therefore uses profiles from this month. For February, the average salinity was found to be 34 ppt, and the average temperature 5 °C.

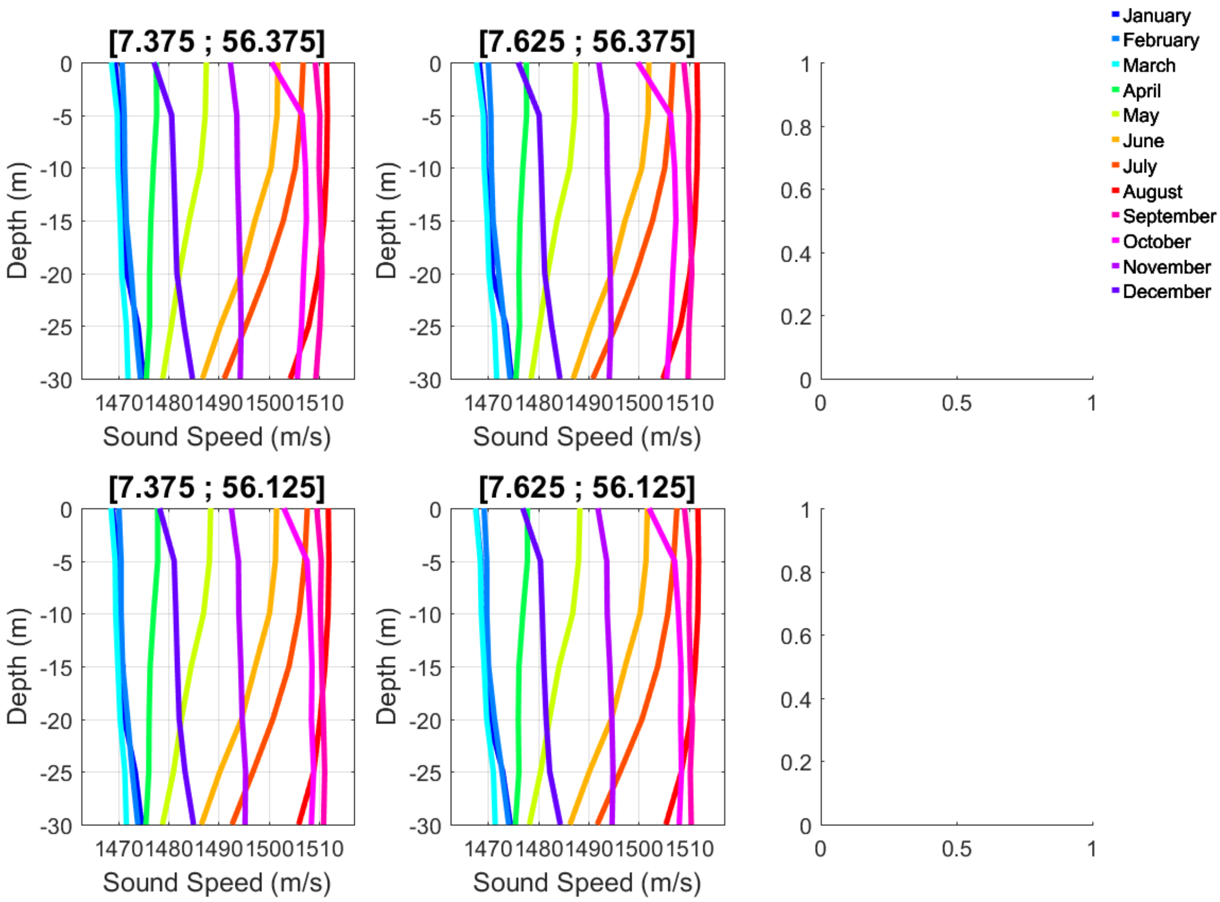

Figure 2.2: Sound speed profiles for the combined survey area and surroundings. Data source: WOA18v2 (NOAA, 2019)

2.5 Sound Propagation Results

Sound propagation modelling using the approach and inputs described in this note, provide the results listed in Table 2.6 for impulsive noise threshold criteria, and in Table 2.7 for continuous noise threshold criteria.

Both TTS and PTS threshold criteria impact ranges assume marine mammal fleeing behaviour, 1.5 m/s directly away from the survey vessel (Tougaard, 2016).

Table 2.6: Distance-to-threshold (DTT) (impulsive threshold criteria) for the seismic survey activities. Distances for PTS and TTS indicate, at which range, from the survey vessel, a marine mammal must at least be at the onset of full survey activities in order to avoid each of the given impacts. Distance for behaviour indicates impact ranges at any time during full survey activities.

Marine mammal hearing group and species (xx)	Active equipment	Position	Distance to Threshold (impulsive)		
			PTS $L_{E,cum,24h,xx}$	TTS $L_{E,cum,24h,xx}$	Behaviour $L_{p,rms,xx}$
LF (Minke whale)	Sparker, Innomar & USBL	1	< 10 m	75 – 225 m	
	Innomar & USBL	1	< 10 m	< 10 m	
		2	< 10 m	< 10 m	
HF (white-beaked dolphin)	Sparker, Innomar & USBL	1	< 10 m	25 – 75 m	
	Innomar & USBL	1	< 10 m	25 – 75 m	
		2	< 10 m	50 – 125 m	
VHF (Harbour porpoise)	Sparker, Innomar & USBL	1	425 – 900 m	1.5 – 2.8 km	4 km
	Innomar & USBL	1	425 – 900 m	1.5 – 2.8 km	4 km
		2	425 – 925 m	1.5 – 2.8 km	3.9 km
PCW (Harbour seal and grey seal)	Sparker, Innomar & USBL	1	< 10 m	10 – 30 m	
	Innomar & USBL	1	< 10 m	< 25 m	
		2	< 10 m	15 – 40 m	

DTT for PTS and TTS indicate, at which range of distances, in meters, from the survey vessel, a marine mammal must at least be at the onset of full survey activities in order to avoid each of the given impacts. Minimum distances represent marine mammals located "behind" or perpendicular to the vessel, while maximum distances represent marine mammals located in front of the vessel. The results can be used to define the minimum distance, a marine mammal must be deterred to, relative to the survey vessel at the onset of full activities, in order to avoid the respective impact. Sufficient soft start/ramp up procedures should be carried out prior to the seismic survey.

DTT for behaviour indicates the distance to which, at any time during full survey activities, behaviour reactions are likely to occur for that species.

Table 2.7: Distance-to-threshold (DTT) (continuous threshold criteria) for the seismic survey activities. Distances for PTS and TTS indicate, at which range, from the survey vessel, a marine mammal must at least be at the onset of full survey activities in order to avoid each of the given impacts. Distance for behaviour indicates impact ranges at any time during full survey activities.

Marine mammal hearing group and species (xx)	Active equipment	Position	Distance to Threshold (continuous)		
			PTS $L_{E,cum,24h,xx}$	TTS $L_{E,cum,24h,xx}$	Behaviour $L_{p,rms,xx}$
LF (Minke whale)	Sparker, Innomar & USBL	1	< 10 m	< 10 m	
	Innomar & USBL	1	< 10 m	< 10 m	
		2	< 10 m	< 10 m	
HF (white-beaked dolphin)	Sparker, Innomar & USBL	1	< 10 m	< 10 m	
	Innomar & USBL	1	< 10 m	< 10 m	
		2	< 10 m	< 25 m	
VHF (Harbour porpoise)	Sparker, Innomar & USBL	1	30 m	0.5 – 1.1 km	
	Innomar & USBL	1	30 m	0.5 – 1.1 km	
		2	55 m	0.5 – 1.1 km	
PCW (Harbour seal and grey seal)	Sparker, Innomar & USBL	1	< 10 m	< 10 m	
	Innomar & USBL	1	< 10 m	< 10 m	
		2	< 10 m	< 10 m	

3 Conclusion

A sound propagation model was used to determine underwater noise emission from three seismic survey equipment types; Sparker, Innomar and USBL. Calculations were carried out as worst case scenario, with regards to seabed sediment conditions, sound speed profile, temperature and salinity.

Results show impact ranges up to 2.8 km for Temporary Threshold Shift (TTS) in Harbour porpoise, up to 925 m Permanent Threshold Shift (PTS) and up to 4 km behaviour reaction distance, when comparing underwater noise levels to impulsive threshold criteria.

Evaluation by continuous threshold criteria instead give impact ranges of 1.1 km for TTS and 55 m for PTS.

All other species of marine mammals considered relevant to evaluate, are unlikely to be impacted by TTS at distances further than 250 m from the vessel and exposure to PTS is unlikely at any distance.

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Appendix 1

Detailed source levels

1/3 octave frequency band [Hz]	Detailed source level (ESL) for Sparker / Innomar / USBL (dB re 1 $\mu Pa^2 m^2 s$)											
	Sparker				Innomar				USBL			
Frequency weighting	LF	HF	VHF	PCW	LF	HF	VHF	PCW	LF	HF	VHF	PCW
Broadband	**167**	**148,1**	**147,5**	**161,6**	**128,8**	**152,7**	**154,5**	**136,2**	**161,4**	**170**	**169,5**	**166,1**
12,5 Hz	37	-28,9	-45	18,1	-33	-98,9	-115	-51,9	-	-	-	-
16 Hz	49,7	-15	-30,6	30,8	-30,8	-95,5	-111,1	-49,7	-	-	-	-
20 Hz	60,4	-3,1	-18,4	41,5	-28,9	-92,4	-107,7	-47,8	-	-	-	-
25 Hz	70	7,7	-7,2	51,1	-27	-89,3	-104,2	-45,9	-	-	-	-
31,5 Hz	78,3	17,2	2,7	59,4	-25	-86,1	-100,6	-43,9	-	-	-	-
40 Hz	83,9	24,1	10,1	65,1	-23	-82,8	-96,8	-41,8	-	-	-	-
50 Hz	93,8	35,3	21,7	75,2	-21,2	-79,7	-93,3	-39,8	-	-	-	-
63 Hz	100,7	43,6	30,3	82,2	-19,3	-76,4	-89,7	-37,8	-	-	-	-
80 Hz	106,5	50,9	38	88,2	-17,5	-73,1	-86	-35,8	-	-	-	-
100 Hz	115,1	61	48,5	97,2	-15,9	-70	-82,5	-33,8	-	-	-	-
125 Hz	120,6	68,1	56	103,1	-14,4	-66,9	-79	-31,9	-	-	-	-
160 Hz	128	77,5	65,9	111,2	-13	-63,5	-75,1	-29,8	-	-	-	-
200 Hz	132,1	83,6	72,3	116,1	-11,9	-60,4	-71,7	-27,9	-	-	-	-
250 Hz	137	90,7	79,8	122,1	-11	-57,3	-68,2	-25,9	-	-	-	-
315 Hz	143,7	99,9	89,4	130	-10,3	-54,1	-64,6	-24	-	-	-	-
400 Hz	150,2	109,2	99,2	138	-9,8	-50,8	-60,8	-22	-	-	-	-
500 Hz	154,5	116,3	106,7	143,9	-9,5	-47,7	-57,3	-20,1	-	-	-	-
630 Hz	158,7	123,5	114,3	149,7	-9,3	-44,5	-53,7	-18,3	-	-	-	-
800 Hz	160,6	128,5	119,7	153,2	-9,1	-41,2	-50	-16,5	-	-	-	-
1 kHz	160,2	131,2	122,8	154,4	93,5	64,5	56,1	87,7	-	-	-	-
1,2 kHz	158,8	132,7	124,7	154,3	97,8	71,7	63,7	93,3	-	-	-	-
1,6 kHz	157,4	134,7	127,1	154,3	103	80,3	72,7	99,9	-	-	-	-
2 kHz	153,7	134	126,8	151,6	100,2	80,5	73,3	98,1	-	-	-	-
2,5 kHz	147,9	131,1	124,4	146,6	103,1	86,3	79,6	101,8	-	-	-	-
3,2 kHz	147,3	133,5	127,3	146,7	105,6	91,8	85,6	105	-	-	-	-
4 kHz	141,7	130,9	125,4	141,7	110,2	99,4	93,9	110,2	-	-	-	-
5 kHz	138,5	130,4	125,4	138,9	110,1	102	97	110,5	-	-	-	-
6,3 kHz	137,2	131,7	127,4	138	113,3	107,8	103,5	114,1	-	-	-	-
8 kHz	135,7	132,6	129,1	136,9	113,4	110,3	106,8	114,6	-	-	-	-
10 kHz	134	133,1	130,3	135,7	116	115,1	112,3	117,7	-	-	-	-
12,5 kHz	132	133,3	131,2	134,3	112,5	113,8	111,7	114,8	-	-	-	-
16 kHz	130,5	134,2	132,8	133,5	105,2	108,9	107,5	108,2	-	-	-	-
20 kHz	128,7	134,7	133,8	132,5	103,6	109,6	108,7	107,4	-	-	-	-
25 kHz	126,4	135	134,5	131,1	101,4	110	109,5	106,1	161,4	170	169,5	166,1
32 kHz	124,5	136	135,9	130,1	95,1	106,6	106,5	100,7	-	-	-	-
40 kHz	122,4	136,8	137	128,9	90,5	104,9	105,1	97	-	-	-	-
50 kHz	120,1	137,4	137,9	127,2	94,5	111,8	112,3	101,6	-	-	-	-
64 kHz	117,3	137,5	138,4	124,9	101,7	121,9	122,8	109,3	-	-	-	-
80 kHz	114,7	137,4	138,7	122,6	119,1	141,8	143,1	127	-	-	-	-
100 kHz	112	136,9	138,7	120,1	127,2	152,1	153,9	135,3	-	-	-	-
128 kHz	107,8	134,7	137	116,1	111,8	138,7	141	120,1	-	-	-	-