Intended for
Nord Stream 2 AG

Date
December, 2016

Document number
W-PE-EIA-PFI-REP-805-030600EN-05

NORD STREAM 2
UNDERWATER NOISE MODELLING, FINLAND

RAMBOLL

Revision	**05**
Date	**2016-12-07**

Document ID	W-PE-EIA-PFI-REP-805-030600EN-05
Ref	1100019533 / PO16-5068

CONTENTS

ABBREVIATION LIST

DGPS	Differential Global Positioning System
dB	decibel
EEZ	exclusive economic zone
EU	European Union
FTA	Finnish hydrographic office of Finnish Transport Agency
ICES	International Council for the Exploration of the Sea
HELCOM	Baltic Marine Environment Protection Commission
M	munitions clearance
NSP	Nord Stream Pipeline system
NSP2	Nord Stream 2 Pipeline system
P	pressure
P_0	reference pressure
Pa	Pascal
PEAK	peak pressure level
PTS	permanent threshold shift
RMS	root mean square
ROV	remotely operated vehicle
RP	rock placement
SEL	sound exposure level
SEL(cum)	cumulative sound exposure level
SPL	sound pressure level
TTS	temporary threshold shift

1. INTRODUCTION

The construction and operation of the proposed Nord Stream 2 pipeline system (NSP2) will generate underwater sound that can potentially be an environmental impact on the marine life. An underwater noise propagation study and noise mapping is performed for the Finnish sections of the pipeline and will be used to assess the potential environmental impacts on marine mammals and fish for the proposed pipeline and is part of the NSP2 environmental impact assessment.

The impact assessment methodology and impact threshold limits comply with the guidance described in Descriptor 11 of the European Commission decision on good environmental status of marine waters (2010/477/EU) which generally states: "Introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment".

2. PROJECT DESCRIPTION

NSP2 is a pipeline system through the Baltic Sea planned to deliver natural gas from vast reserves in Russia directly to the European Union (EU) gas market. The pipeline system will contribute to the EU's security of supply by filling the growing gas import gap and by covering demand and supply risks expected by 2020.

The twin 1,200-kilometre subsea pipelines will have the capacity to supply about 55 billion cubic metres of gas per year in an economic, environmentally safe and reliable way. The privately funded €8 billion infrastructure project will enhance the ability of the EU to acquire gas, a clean and low carbon fuel necessary to meet its ambitious environmental and decarbonisation objectives.

NSP2 builds on the successful construction and operation of the existing Nord Stream Pipeline, which has been recognised for its high environmental and safety standards, green logistics as well as its transparent public consultation process. NSP2 is developed by a dedicated project company: Nord Steam 2 AG.

3. UNDERWATER NOISE SOURCES

The potentially significant underwater noise sources, as part of the construction and operation of the proposed pipeline in Finland that have actual potential underwater noise impacts on fish and/or marine mammals, are listed here:

- Rock placement
- Munitions clearance
- Pipeline operation
- Pipelay

Underwater noise source levels and frequency data has been collected, analysed and corrected to be applicable for each specific activity.

Each noise source's activity length (time) has been determined in order to predict the cumulative, average and maximum noise levels/map. Ramboll acoustics experts and marine biologists worked together to determine the applicable underwater sound parameters needed to assess potential impacts on the identified fish and marine mammal species.

3.1 Modeling activities/positions in Finland

Underwater noise modelling/monitoring were performed for pipe-lay and trenching for NSP with results showing that the noise levels from these construction activities were in line with the surrounding background noise from other ship traffic.

As well, underwater noise baseline noise measurements (Luode, 2016) performed close to the existing operating Nord Stream pipeline were unable to measure noise from the pipeline, due to the existing ship noise levels in the Finnish waters of the Baltic Sea. Therefore, underwater noise from pipeline operation in Finnish waters is not considered to be a significant noise source.

To supplement these results, NSP2 has performed underwater noise modelling in the Finnish EEZ for:

- Rock placement (RP) activities for two locations where rock placement is expected to occur (see Figure 3-1 and Table 3-1).
- Munitions clearance (M) for four typical locations where munitions clearance potentially is required and close to sensitive areas (see Figure 3-2 and Table 3-1).

3.1.1 Rock placement

Installation of subsea rock will take place by using a rock installation vessel and suspended fall pipe. A rock installation vessel can have a loading capacity of 24,000 tonnes with a maximum rock installation speed of 2,000 tonnes per hour. A fall pipe vessel is a dedicated rock placement vessel which can accurately place gravel and/or rock material in a controlled manner up to a water depth of 600m. The vessel is equipped with a fall pipe, which is deployed through a moonpool in the centre part of the vessel, and which guides the material down to the sea bottom. ROV monitors the bottom of the fall pipe. The fall pipe consists of pipe sections, allowing the length of the pipe to be adapted to the water depth. On site the fall pipe is deployed and a feeder controls the rate at which material is unloaded onto the central conveyor belt, which transports the material into the fall pipe. The vessel is positioned by DGPS (Differential Global Positioning System) and/or radio positioning, which are used as input for the dynamic positioning system of the vessel, which controls two main variable pitch propellers and rudders, two bow thrusters and two azimuth thrusters.

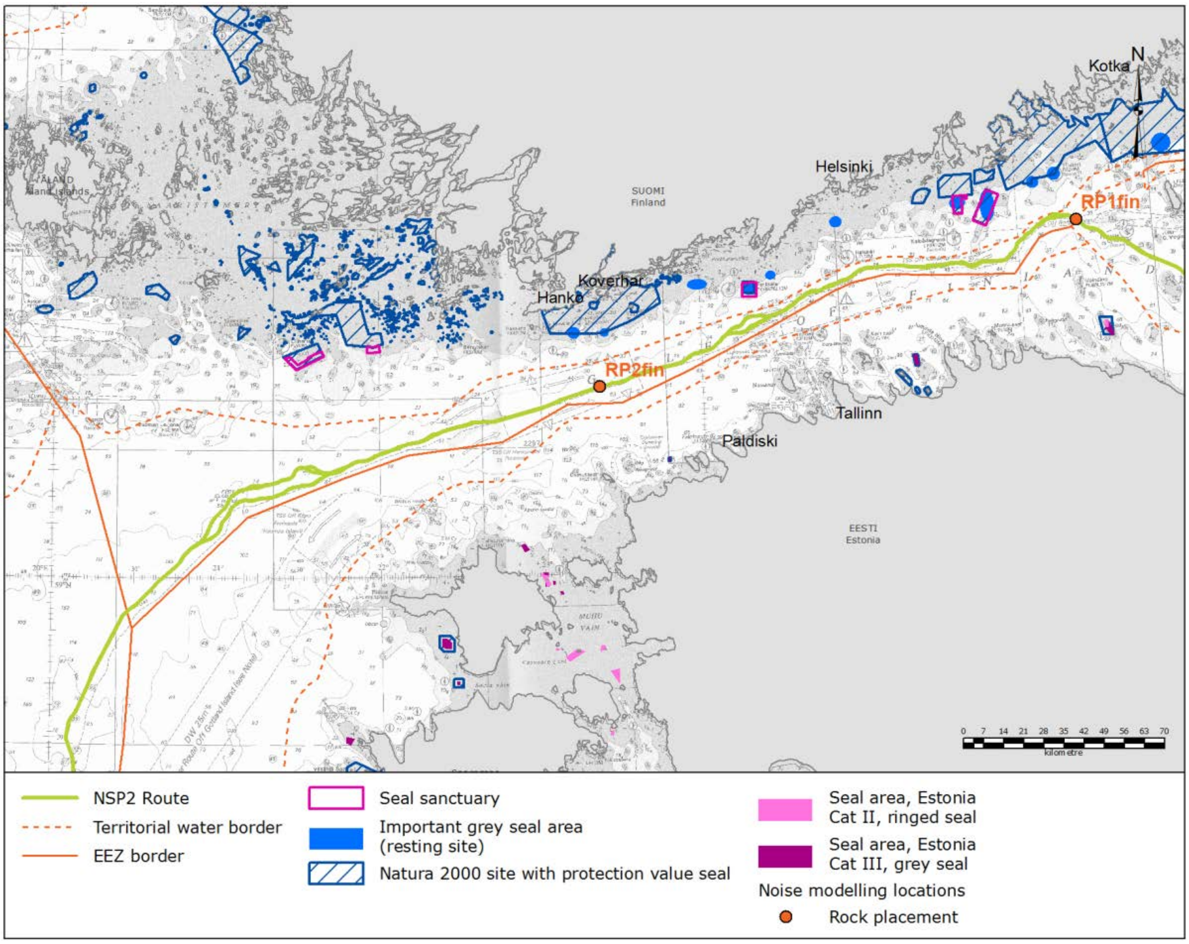

Figure 3-1 Locations for noise modelling for rock placement (RP).

Table 3-1 Reasons for chosen locations for noise modelling for rock placement.

Locations	Description
RP1 Finland	Large rock berms for pipeline crossing; Close to Russian and Estonian border: potential transboundary impacts; Baltic ringed seal populations in eastern Gulf of Finland;
RP2 Finland	Large rock berms for tie-in at around KP 300

3.1.2 Munitions clearance

The basic principle applied in the clearance of munitions involves placing a small explosive charge next to the munitions object on the seabed by means of a Remotely Operated Vehicle (ROV). The charge is then detonated from a ship located at a safe distance from the target thereby destroying the munitions object. Prior to the munitions clearance activity calculations are made as to the appropriate amount of explosive charge necessary to detonate the munitions object. The quantity required depends upon the size and shape of the munitions object and the amount of explosive it contains.

The munitions clearance underwater sound source levels used for the Finnish locations are based on actual maximum and average measured peak pressure data collected during munitions clearance for the first Nord Stream pipeline (Witteveen+Bos, Nord Stream, Munitions clearance in the Finnish EEZ, 2011).

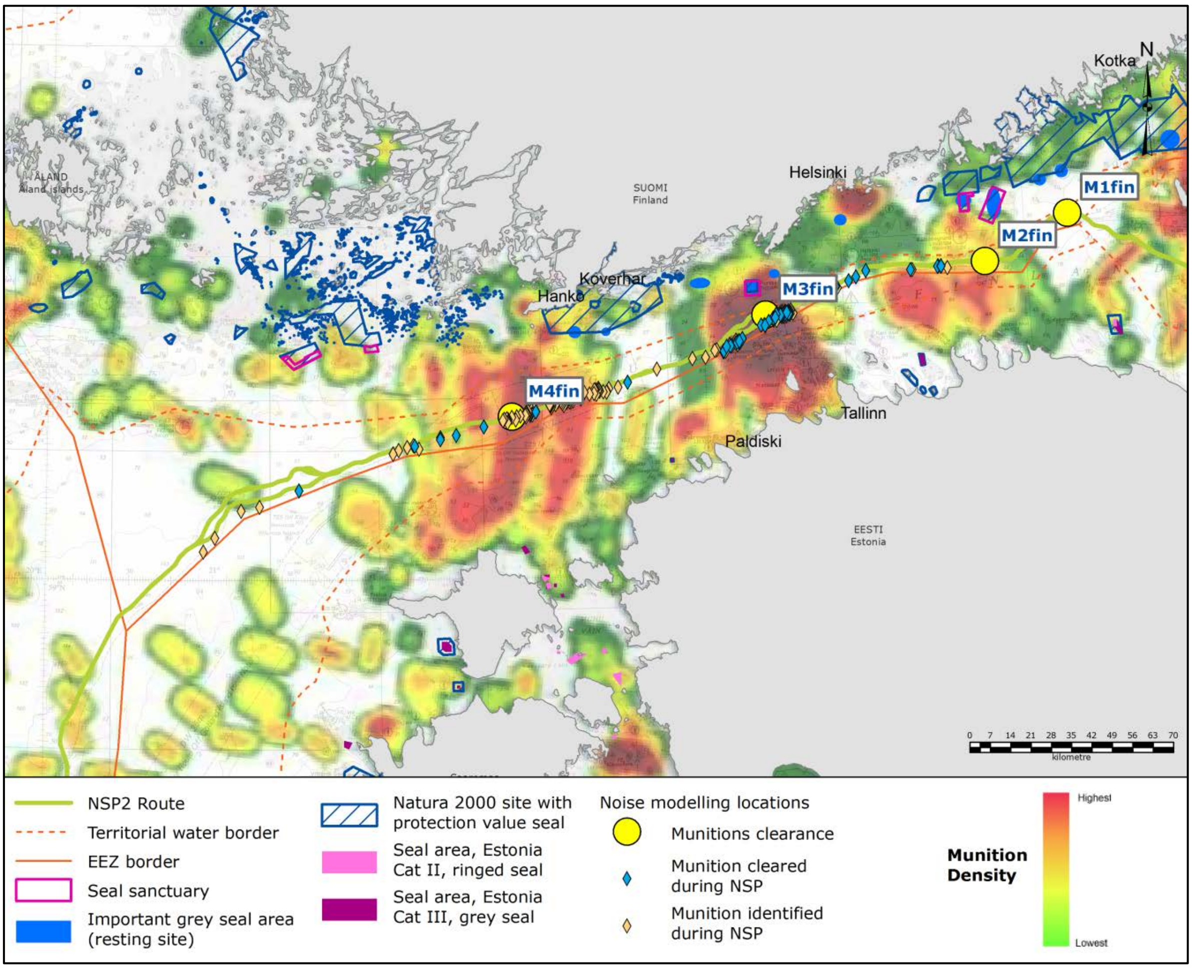

Figure 3-2 Locations for noise modelling for munitions clearance (M1-M4). The density of munitions and munitions identified and cleared during NSP are shown since these have been part of choosing the 4 modelled locations (M1-M4).

Table 3-2 Reasons for chosen locations for noise modelling for munitions clearance.

Locations	Description (east to west)
$M1_{Finland}$	Baltic ringed seal populations in eastern Gulf of Finland; Shallow areas and important grey seal areas to the north, close to Russian and Estonia borders: potential transboundary impacts
$M2_{Finland}$	High munitions density; South of Sandkallan Natura 2000 and Sandkallan and Stora Kolhallan seal sanctuaries
$M3_{Finland}$	High munitions density; Closest to Kallbådan seal sanctuary and Kallbådan Islets and Waters Natura 2000 protected for grey seals
$M4_{Finland}$	High munitions density; observations of ringed seals based on BALSAM data

4. UNDERWATER SOUND

Underwater sound, like sound in the air, is disturbances from a source in a medium (in this case water) travelling in a three-dimensional manner, as the disturbance propagates with the speed of sound.

Sound travels at different speed in different media. The speed of sound is determined by the density and compressibility of the medium. Density is the amount of material in a given volume, and compressibility is a measure of how much a substance could be compacted for a given pressure. The denser and the more compressible, the slower the sound waves would travel. Water is much denser than air, but since it is nearly incompressible the speed of sound is about four times faster in water than in air. The speed of sound can also be affected by temperature. Sound waves tend to travel faster at higher temperatures.

Underwater sound can be measured as a change in pressure and is described as sound pressure and can be measured with a pressure sensitive device (hydrophone).

Because of the large range pressure amplitudes of sound, it is convenient to use a decibel (dB) logarithmic scale to quantify pressure levels. The underwater sound pressure level in dB is defined in the following equation:

Sound Pressure Level (SPL) = $20\log_{10}(P/P_0)$

P is the pressure and P_0 is the reference pressure. The reference pressure is 1 micropascal (µPa) for underwater sound which is different for sound pressure levels in the air. For this reason sound pressure levels in the water and air cannot be directly compared.

Because sound consists of variations in pressure, the unit for measuring sound is usually referenced to a unit of pressure, the Pascal (Pa). The unit usually used to describe sound is the decibel (dB) and, in the case of airborne sound, it has become customary to reference the sound to the lowest sound pressure level detectable by the human ear, taken to be 20 µPa. For underwater sound, the reference unit is taken as 1 µPa. To convert from a sound pressure level referenced to 20 µPa to one referenced to 1 µPa, a factor of 20 log (20/1) i.e. 26 dB has to be added to the former quantity. Thus 60 dB re 20 µPa in air is the same as 86 dB re 1 µPa in water. All underwater sound pressure levels are described in dB re 1 µPa. In water, the noise source strength is defined by its sound pressure level in dB re 1 µPa, referenced back to a fictitious distance of 1 m from an assumed point source.

The difference in reference pressure level is one complication in comparing sound in air with sound in water. Another is that, because the impedances of air and water differ, the actual power flow in them differs even if the pressures are the same. Thus, great care must be taken in comparing sound levels in air with sound levels in water.

Underwater sound levels vary in accordance to the sound source's time signature and acoustic environmental conditions and can be defined in terms of exposure, average and/or maximum levels. The following acoustic parameters are commonly used to assess the noise impact from underwater noise sources for the identified local marine life.

4.1 Applicable acoustic parameters

The following key terms are used in this document:

<u>Sound Pressure Level (SPL)</u> – this quantifies the magnitude of a sound at a given point, i.e. how loud it is, and is measured in dB. As a relative unit, dB are quoted relative to 1 microPascal in underwater studies (so, dB re 1 µPa);

Sound Exposure Level (SEL) – this is a decibel measure for describing how much sound energy a receptor (e.g. a marine mammal) has received from an event and is normalised to an interval of one second (quoted in dB re 1 μPa^2s). It can be thought of as a logarithmic measure of Sound Exposure and hence a 3 dB increase in SEL equates to a doubling of sound energy;

Cumulative Sound Exposure (SEL(cum)) – this is the time integral of the squared pressures over the duration of a sound or series of sounds. It enables sounds of differing duration and level to be characterised in terms of total sound energy (quoted in dB re 1 μPa^2s).

Peak pressure level (PEAK) – the zero-to-peak sound pressure at a given point in time;

Root mean square (RMS) – the sound pressure averaged over a given time;

Pulsed/impulsive sound – a discontinuous sound source comprising one or more instantaneous sounds as during munitions clearance

Continuous sound – sound source, like a vessel engine, or humming as in pipeline operation.

The RMS SPL is commonly used to evaluate the effects of continuous noise sources. The RMS sound pressure level or SPL is the mean square pressure level over a time window containing the impulse.

4.2 Underwater sound source levels

Based on existing measured underwater sound measurements, source data and studies from NSP, we have estimated the sound source levels and frequency spectrum for the identified significant sound sources for potential underwater noise impacts.

For rock placement, in order to obtain an equivalent source level at 1 m from the source, for the purpose of acoustic propagation modelling, we back-propagated the pressure field according to cylindrical/hemispherical spreading loss, or 15·log(r). The purpose of the back-propagation step is to determine the effective conservative source level at 1 m that is used in the acoustic propagation model.

For munitions clearance a more accurate, detailed back-propagation sound source level calculation was performed using actual measured peak pressure data from NSP. This method included site-specific seabed conditions, actual measurement position (distance, depth), and applicable seasonal water column data. The purpose of the back-propagation step is to determine a more accurate source level at 1 m that is used in the acoustic propagation model.

5. UNDERWATER SOUND PROPAGATION MODEL

The underwater sound propagation model calculates estimates of the sound field generated from underwater sound sources. The modelling results are used to determine the potential impact distances (noise maps/contour plots) from the identified significant underwater noise sources for the various identified marine life for the area. Based on source location and underwater source sound level, the acoustic field at any range from the source is estimated using dBSEA's acoustic propagation model (Parabolic equation method (≤500 Hz), Jensen 2011 and ray tracing (> 500 Hz)). The sound propagation modelling uses acoustic parameters appropriate for the specific geographic region of interest, including the expected water column sound speed profile, the bathymetry, and the bottom geo-acoustic properties, to produce site-specific estimates of the radiated noise field as a function of range and depth. The acoustic model is used to predict the directional transmission loss from source locations corresponding to receiver locations. The received level at any three-dimensional location away from the source is calculated by combining the source level and transmission loss, both of which are direction-dependent. Underwater acoustic transmission loss and received underwater sound levels are a function of depth, range, bearing, and environmental properties. The output values can be used to compute or estimate specific noise metrics relevant to safety criteria filtering for frequency-dependent marine mammal hearing capabilities.

Underwater sound source levels are used as input for the underwater sound propagation program, which computes the sound field as a function of range, depth, and bearing relative to the source location.

The model assumes that outgoing energy dominates over scattered energy, and computes the solution for the outgoing wave equation. An approximation is used to provide two-dimensional transmission loss values in range and depth, i.e., computation of the transmission loss as a function of range and depth within a given radial plane is carried out independently of neighbouring radials (reflecting the assumption that sound propagation is predominantly away from the source).

The received underwater sound levels at any location within the region of interest are computed from the 1/1-octave band source levels by subtracting the numerically modelled transmission loss at each 1/1-octave band centre frequency and summing across all frequencies to obtain a broadband value. For this study, transmission loss and received levels were modelled for 1/1-octave frequency bands between 10 and 3000 Hz. Because the source of underwater noise considered in this study are predominantly low-frequency sources, this frequency range is sufficient to capture essentially all of the energy output. The received levels will be converted to all the applicable underwater acoustic parameters.

Bathymetry data is provided from FTA (Finnish hydrographic office of Finnish Transport Agency) with varying horizontal resolution of 500 to 1000 meters.

Water column data (salinity, temperature, speed of underwater sound/depth) is provided from ICES (International Council for the Exploration of the Sea) HELCOM specific measurement stations positioned close to the selected modelling positions.

Seabed Conditions (sand, clay /depth) are provided from NSP geological survey data for areas close to the modelling positions.

Predictions have been performed for both winter (December-March) and summer (July-September) water column conditions which each have different underwater sound propagation characteristics and will show the maximum underwater noise level of the whole sea depth.

The sound propagation model will run with the model (Peak, RMS, SEL, SELcumulative (two-hour)) scenarios, source levels, activity time and environmental parameterisation and generate in to noise maps. The levels depicted in the noise maps will be the maximum predicted level for that location at any depth down to the bottom and will include the following acoustic parameters for each of the identified significant sound sources:

For rock placement:

- SELcum, Cumulative Sound Exposure Level (linear), dB re. 1 μPa^2s (2 hour period)

For munitions clearance:

- SEL, single event Sound Exposure Level (linear), dB re. 1 μPa^2s (1 event)

The results of the acoustic modelling (noise maps and impact distances) will be reported in terms of the underwater sound levels of each specific acoustic metric for distances up to 50 km. As well, a vertical sound propagation profile plot for the dominant sound source frequency band will be generated to show the variation in underwater sound propagation with regard to sea depth.

Sound source levels for munitions clearance is based on measured data from munition clearance activities during Nord Stream 1, thereby including effect of the mines being partially buried.

6. UNDERWATER NOISE IMPACT ASSESSMENT

The source sound exposure levels and associated impact zones can be viewed as indicative precautionary ranges. For continuous noise sources such as rock placement, It is important to note that it is highly unlikely that any marine mammal or fish would stay at a stationary location or within a fixed radius of a vessel (or any other noise source). Consequently, any resulting injury zones should be treated as a worst case scenario. Taking into account the various precautionary assumptions made in derivation of injury criteria as well as the potential overestimate in sound exposure due to use cumulative sound exposure level (SELcum) values, any estimated injury zones in this report should be treated as being a realistic assumption that is used in this assessment is a two-hour exposure to continuous noise sources.

6.1 Fish

Impacts to fish focus on physical damage and behavioural changes. Fish behaviour in response to noise is not well understood. Sound pressure levels that may deter some species may attract others.

In fish, physical damages to the hearing apparatus rarely lead to permanent changes in the detection threshold (permanent threshold shift, PTS), as the damaged sensory epithelium will regenerate in time (Smith et al 2006, Song et al 2008). However, temporary hearing loss (temporary threshold shift, TTS) may occur (Popper et al 2006). The sound intensity is an important factor for the degree of hearing loss, as is the frequency, the exposure duration, and the length of the recovery time.

There is little information available on the hearing abilities of species of particular relevance for the survey area; Atlantic cod and Atlantic herring therefore serve as models for other fish species (Halvorsen et al 2011).

The impact threshold level for fish has been selected by our marine biologists, based on "Popper, ASA S3/SC1.4 TR-2014, Sound Exposure Guidelines for Fishes and Sea Turtles" and is presented in section 6.3.

6.2 Marine mammals

Generally, the effect of noise on marine mammals can be divided into four broad categories that largely depend on the individual’s proximity to the sound source:

- Detection
- Masking
- Behavioural changes
- Physical damages

The limits of each zone of impact are not sharp, and there is a large overlap between the zones. The four categories are described below, based on Southhall et al 2007.

Detection ranges depend on background noise levels as well as hearing thresholds for the animals in question.

Masking is an impact where repeated or long-term underwater sound masks e.g. communication between individuals. Masking is not considered an issue in relation to munitions clearance.

Behavioural changes are difficult to evaluate. They range from very strong reactions, such as panic or flight, to more moderate reactions where the animal may orient itself towards the sound or move slowly away. However, the animals’ reaction may vary greatly depending on season, behavioural state, age, sex, as well as the intensity, frequency and time structure of the sound causing behavioural changes (Southhall et al 2007).

Physical damage to marine mammals relate to damage to the hearing apparatus. Physical damages to the hearing apparatus may lead to permanent changes in the animal's detection threshold (permanent threshold shift, PTS). This can be caused by the destruction of sensory cells in the inner ear, or by metabolic exhaustion of sensory cells, support cells or even auditory nerve cells. Hearing loss is usually only temporary (temporary threshold shift, TTS) and the animal will regain its original detection abilities after a recovery period. For PTS and TTS the sound intensity is an important factor for the degree of hearing loss, as is the frequency, the exposure duration, and the length of the recovery time.

6.3 Marine mammals and fish criteria

Table 6-1 and 6-2 summarises threshold values for assessing impacts on marine mammals and fish. These threshold values are associated with different impacts (e.g. PTS, TTS).

Threshold values for inflicting impact have been established based on an assessment of available values from the most recent scientific literature (HELCOM Assessing the Impact of Underwater Clearance of Unexploded Ordnance on Harbour Porpoises in the Southern North Sea, Sveegaard, Teilmann and Tougaard, Marine mammals in the Baltic Sea in relation to NSP2 – Environmental Impact Assessment, DCE/Institute for Bioscience, 2016).

Table 6-1 Marine mammal threshold values for onset of PTS, TTS for munitions clearance rock placement and as recommended by the project's marine biologists. All levels are unweighted SEL.

Noise Source	Species	TTS (dB re 1 µPa2s SEL cum)	PTS (dB re 1 µPa2s SEL cum)
Rock placement	Grey seal and ringed seal	188	200
Rock placement	Harbour porpoise	188	203
Munitions clearance	Grey seal and ringed seal	164	179
Munitions clearance	Harbour porpoise	164	179

All levels are broadband, unweighted sound exposure levels (dB re. 1 µPa^{2}s).
Rock placement noise should be cumulated over a precautionary estimation of the amount of time that the animal is likely to spend around the noise source.

Table 6-2 Threshold values for fish as recommended by the project's marine biologists (based on Popper 2014).

	Munitions Clearance	
		Assessment levels
Marine group		SEL(Cum*)
	Effect	dB re 1µPa²s
Fish	Mortality (mortal injury)	207 dB (229-234 dB peak)
	Injury	203 dB

* Cumulative SEL (1 event)

7. UNDERWATER SOUND PROPAGATION MODEL INPUTS

The following parameters were used as input to the underwater sound propagation model.

7.1 Rock placement sound source levels and frequency spectrum

Noise measurement data (Nedwell, 2004, Wyatt 2008) indicate that the dominating underwater noise from rock placement activity is from the surface activities (ship engines, thrusters, conveyors, rock pouring) rather than the noise from the actual placement of the rock on the seabed. The noise emissions from the vessel(s) that may be used in the project are quantified based on a review of publicly available data. In the table, a correction of +3 dB has been applied to the rms sound pressure level to estimate the likely peak sound pressure level. SELs have been estimated for each source based on two hours' continuous operation. Source noise levels for vessels depend on the vessel size and speed as well as propeller design and other factors. There can be considerable variation in noise magnitude and character between vessels even within the same class. Therefore, source data for this project has been based largely on worst-case assumptions (i.e. using noise data toward the higher end of the scale for the relevant class of ship as a proxy).

Table 7-1 Continuous construction activity.

Activity	Sound source pressure level at 1 meter	
	RMS, dB re. 1µPa	SEL, dB re. 1µPa^{2}s
Rock Placement (Dynamic positioning) Wyatt 2008	188	226 (Cumulative 2 hr.)

Rock placement sound source spectrum

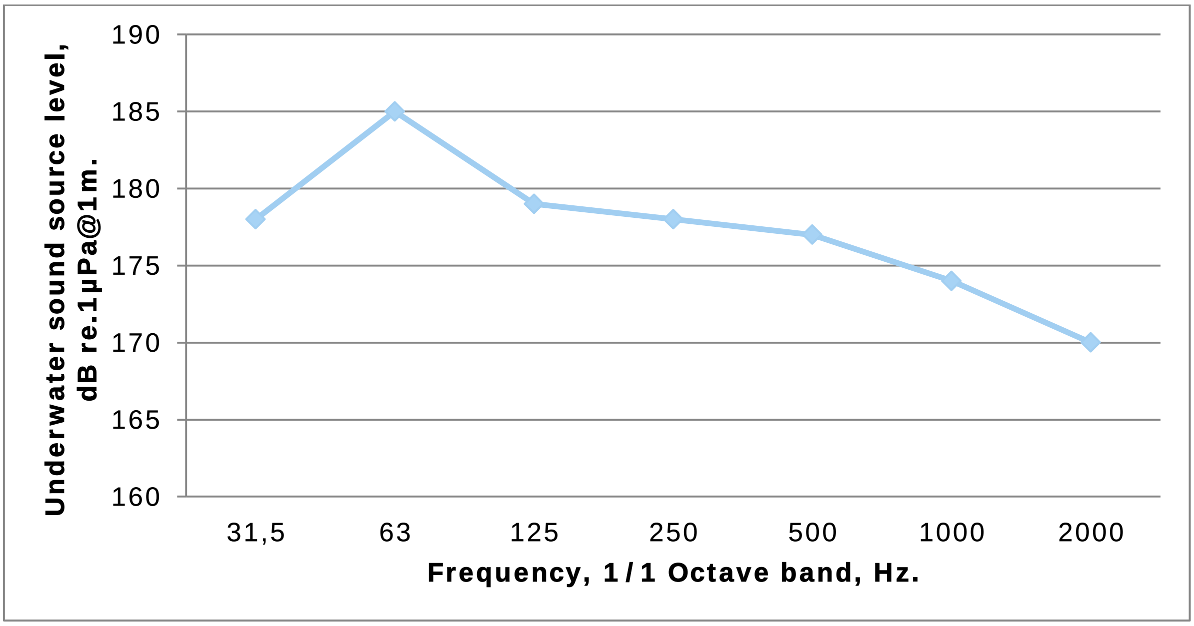

Figure 7-1 Rock placement sound source spectrum(Wyatt 2008).

7.2 Munitions clearance sound source levels and frequency spectrum

The munitions clearance underwater sound source levels used for the Finnish locations are based on actual maximum and average measured peak pressure data collected during munitions clearance for NSP (Nord Stream, Munitions clearance in the Finnish EEZ, 2011).

Review of the measured data shows that there is no direct correlation with the combined munitions charge weight and donor charge weight and the released peak pressure. This lack of correlation between munitions charge weight and measured peak pressure is assumably from the fact that for each munitions clearance there is a complete destruction of the munitions but only a partial detonation of same.

The following figure shows the measured peak pressure levels from the munitions clearance during NSP relative to the pipeline.

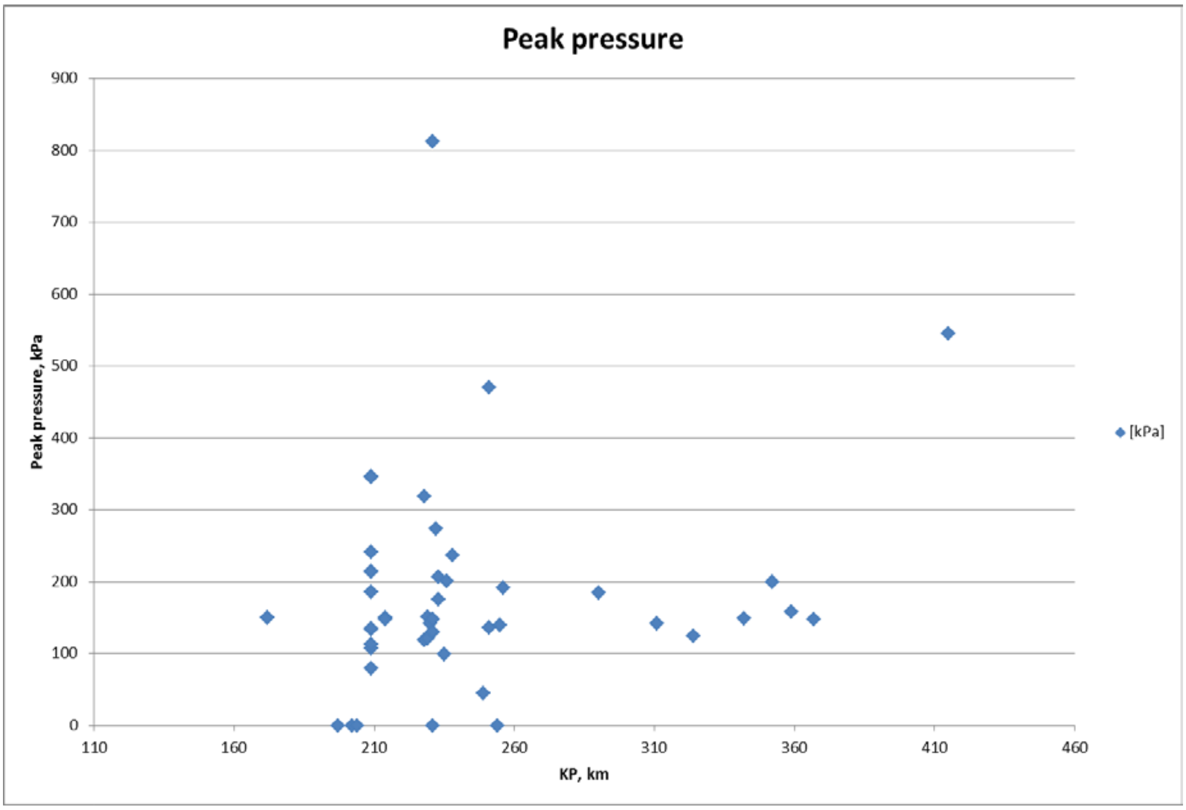

Figure 7-2 Measured peak pressure data from munitions clearance during NSP (Nord Stream, Munitions clearance in the Finnish EEZ, 2011).

All of the measured munitions clearance peak pressure data was divided up in four sections along the length of the pipeline corridor in Finnish territory around each modelling positon. The maximum and average measured data for each representative section was used to calculate the underwater sound source levels for munitions clearance for each of the modelling locations (see Table 7-2).

Table 7-2 Number of cleared munitions during NSP divided on the M1-M4 sections (performed during spring time).

Section	Number of munition cleared during NSP (Pipeline range KP)	Average measured peak pressure data collected during munitions clearance for NSP with measurement distance and depth	Maximum measured peak pressure data collected during munitions clearance for NSP with distance and depth
M1 Finland	2 (KP110-175)	150 KPa 300 meter dist. 20 meter depth	150 KPa 300 meter dist. 20 meter depth
M2 Finland	20 (KP175-230)	187 KPa 300 meter dist. 34 meter depth	346 KPa 356 meter dist. 37 meter depth
M3 Finland	20 (KP230-260)	213 KPa 338 meter dist. 39 meter depth	812 KPa 338 meter dist. 33 meter depth
M4 Finland	8 (KP260-415)	206 KPa 300 meter dist. 67 meter depth	545 KPa 297 meter dist. 98 meter depth

A detailed back-propagation (dBSEA) sound source level calculation was performed using actual measured peak pressure data from NSP. This method included site specific seabed conditions, actual measurement position (distance, depth), and applicable seasonal water column data. The purpose of the back-propagation step is to determine a more accurate source level at 1 m that is used in the acoustic propagation model.

This method, based on actual measured data, is expected to be representative of the actual average and worst case scenario for each modelling location.

Table 7-3 Munitions clearance overall sound source levels (dB SEL, @ 1 meter).

Position / area		Sound Source SEL, dB re. 1µPa2-sec. @ 1 meter
M1 Finland	Max.	238
M1 Finland	Avg.	238
M2 Finland	Max.	243
M2 Finland	Avg.	238
M3 Finland	Max.	255
M3 Finland	Avg.	241
M4 Finland	Max.	252
M4 Finland	Avg	246

These sound source levels are used as input to the models (four positions, winter, summer, maximum (max), average (avg)).

Munitions sound source spectrum

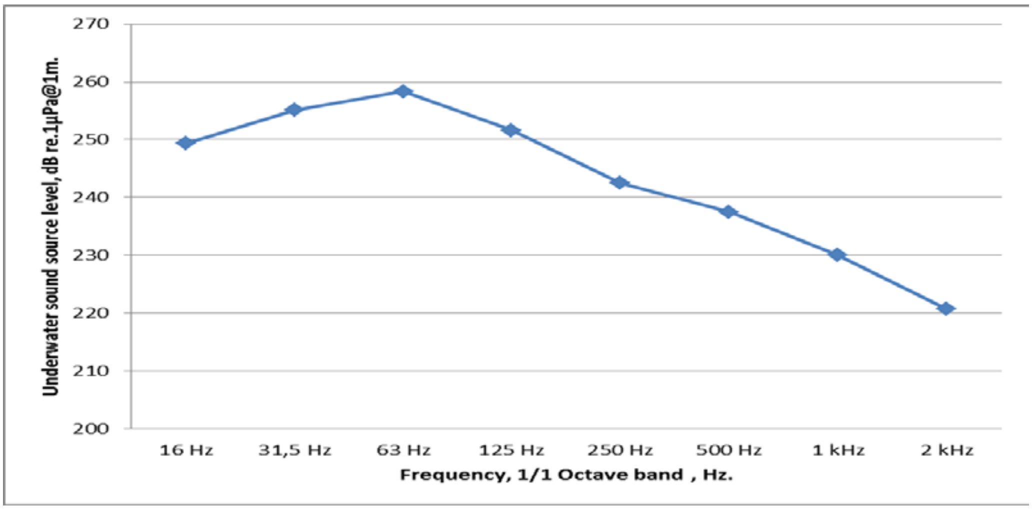

Figure 7-3 **Munitions clearance sound source spectrum (Maxon, Nuuk measurements 2015).**

7.3 Bathymetry

The relief of the sea floor is an important parameter affecting the propagation of underwater sound, and detailed bathymetric data are therefore essential to accurate modelling. A bathymetric dataset for the entire study area was obtained from FTA.

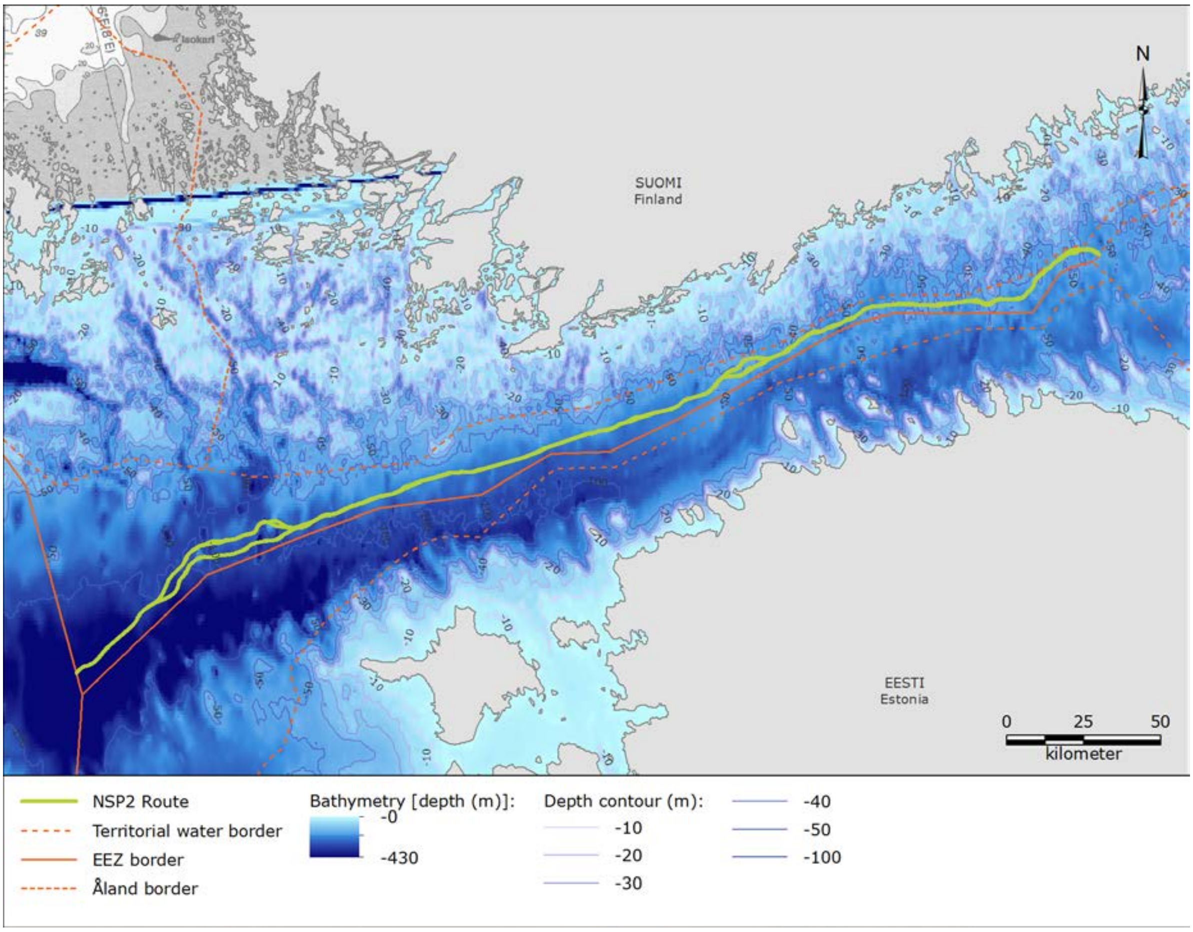

Figure 7-4 **Bathymetry in the Finnish sector of Nord Stream 2.**

7.4 Geoacoustic properties

Seabed layer information was gathered from the NSP's geological survey data for areas close to the modelling positons and used in the modeling. The layers used in the modelling and the main parameters are depicted from Table 7-4 to Table 7-8. The sea bed conditions vary throughout the Gulf of Finland, but the sea bed conditions are based on the average layer in each are and are considered to be conservative with relation to underwater sound propagation.

Table 7-4 Overview of seabed geoacoustic profile used for the modelling for position $M1_{Finland}$ $RP1_{Finland}$ (C_p = compressed wave speed, α = compressional attenuation).

Seabed layer (m)	Material	Geoacoustic property
0 – 3 meters	Very soft clay	C_p = 1700 m/s α = 1 dB/λ
3 – 11 meters	Clay with coarse sediment	C_p = 1500 m/s α = 0,2 dB/λ
11 – meters	Bedrock	C_p = 5250 m/s α = 0.1 dB/λ

Table 7-5 Overview of seabed geoacoustic profile used for the modelling for position $M1_{Finland}$ $RP1_{Finland}$ (C_p = compressed wave speed, α = compressional attenuation).

Seabed layer (m)	Material	Geoacoustic property
0 – 3 meters	Very soft clay	C_p = 1700 m/s α = 1 dB/λ
3 – 6 meters	Clay with coarse sediment	C_p = 1500 m/s α = 0,2 dB/λ
6 – meters	Bedrock	C_p = 5250 m/s α = 0.1 dB/λ

Table 7-6 Overview of seabed geoacoustic profile used for the modelling for position $M2_{Finland}$ (C_p = compressed wave speed, α = compressional attenuation).

Seabed layer (m)	Material	Geoacoustic property
0 – 1 meters	Very soft clay	C_p = 1700 m/s α = 1 dB/λ
1 – 3 meters	Clay with coarse sediment	C_p = 1500 m/s α = 0,2 dB/λ
3 – meters	Bedrock	C_p = 5250 m/s α = 0.1 dB/λ

Table 7-7 Overview of seabed geoacoustic profile used for the modelling for position $M3_{Finland}$ (C_p = compressed wave speed, α = compressional attenuation).

Seabed layer (m)	Material	Geoacoustic property
0 – 2 meters	Very soft clay	C_p = 1700 m/s α = 1 dB/λ
2 – 10 meters	Clay with coarse sediment	C_p = 1500 m/s α = 0,2 dB/λ
10 – meters	Bedrock	C_p = 5250 m/s α = 0.1 dB/λ

Table 7-8 Overview of seabed geoacoustic profile used for the modelling for position $M4_{Finland}$ (C_p = compressed wave speed, α = compressional attenuation).

Seabed layer (m)	Material	Geoacoustic property
0 – 4 meters	Very soft clay	C_p = 1700 m/s α = 1 dB/λ
4 – 14 meters	Clay with coarse sediment	C_p = 1500 m/s α = 0,2 dB/λ
14 – meters	Bedrock	C_p = 5250 m/s α = 0.1 dB/λ

7.5 Sound speed profiles

Water column data (salinity, temperature/depth) is provided from ICES' HELCOM specific measurement stations positioned close to the selected modelling positions. This data is used to calculate the sound speed profile for the modelling positions and used as input in the underwater sound propagation model.

Predictions will be performed for both winter (December-March) and summer (July-September) water column conditions which each have different underwater sound propagation characteristics.

Table 7-9 Speed of sound profile data.

Depth (m)	M1, $RP1_{fin}$ Winter Speed of sound m/s	M1, $RP2_{Fin}$ Summer Speed of sound m/s	$M2_{Fin}$ Winter Speed of sound m/s	$M2_{Fin}$ Summer Speed of sound m/s	$M3_{Fin}$ Winter Speed of sound m/s	$M3_{Fin}$ Summer Speed of sound m/s	$M4_{Fin}$ Winter Speed of sound m/s	$M4_{Fin}$ Summer Speed of sound m/s	$RP2_{Fin}$ Winter Speed of sound m/s	$R2_{Fin}$ Summer Speed of sound m/s
0	1430	1480	1427	1460	1428	1475	1422	1480	1435	1475
10	1423	1460	1428	1450	1428	1460	1423	1470	1435	1463
20	1421	1448	1429	1438	1428	1445	1424	1450	1435	1450
30	1420	1436	1430	1430	1428	1435	1425	1440	1435	1438
40	1422	1427	1431	1425	1429	1430	1426	1433	1435	1428
50	1425	1423	1432	1423	1430	1428	1428	1428	1435	1423
60	1428	1425	1433	1425	1430	1428	1430	1428	1435	1425
70	1433	1435	1433	1433	1431	1429	1432	1430	1435	1433
80	1435	1435	1433	1434	1433	1430	1435	1432	1435	1435
90	1435	1435	1433	1434	1434	1435	1440	1435	1435	1435
100	1435	1435	1433	1434	1435	1435	1440	1435	1435	1435

8. UNDERWATER NOISE MODELLING RESULTS

The following results of the modelling, which include distances from the activities and contour plots (areas) to the impact threshold limits, are given here to be utilized in the impact assessment.

8.1 Sound propagation model scenarios

The sound propagation model was run with the model scenario, source levels, and environmental parameterisation described in previous sections. The following figures (8-1, 8-2) are examples of vertical cross section plots of the underwater sound propagation for rock placement and munitions clearance showing the variation in levels from the surface to the seabed. The distances predicted to the various threshold limits are the maximum at any depth down to the bottom. The plot is greatly out of proportion as the depth is 80 meter the width is 50 km and is only illustrative of the vertical variation in sound levels and the fact that the modelling is three dimensional.

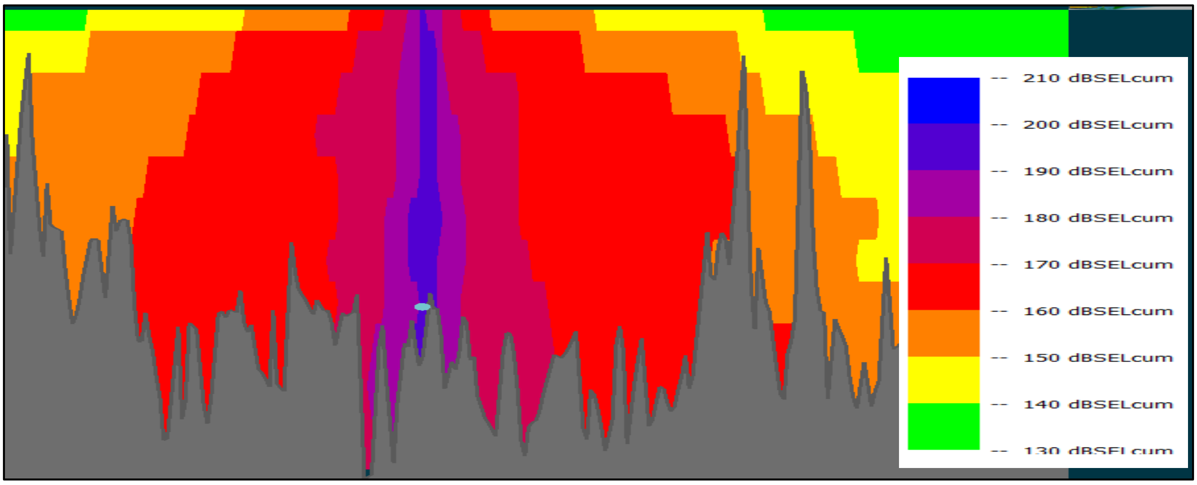

Figure 8-1 Example of vertical plot of rock placement sound propagation (colour scale) vs. depth (Y axis, 60 metres) and distance (X axis 50 KM).

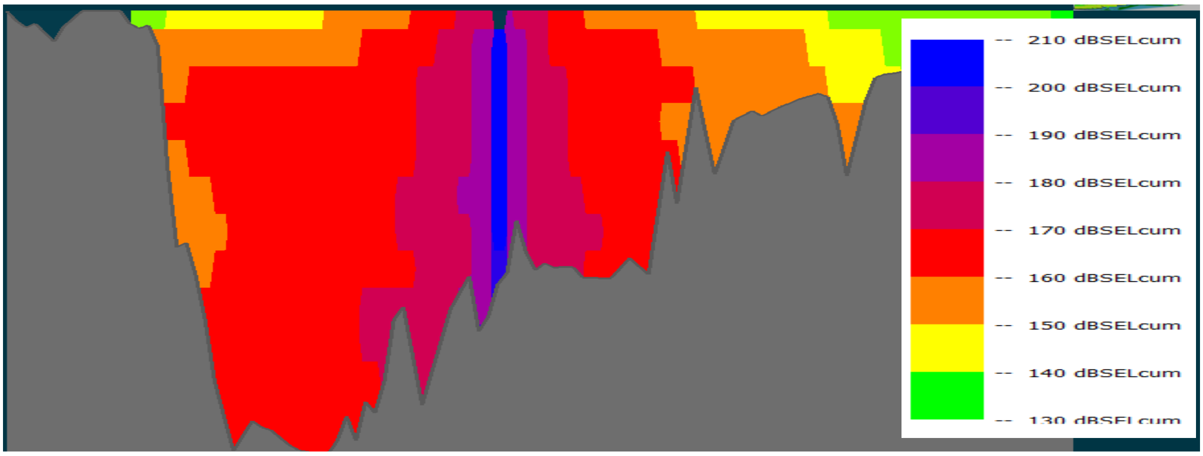

Figure 8-2 Examples of vertical plot of munitions clearance sound propagation (colour scale) vs. depth (Y axis, 80 meters) and distance (X axis, 50 km).

8.2 Distances to applicable assessment threshold level limits

The following table summarises the results of the acoustic modelling in terms of the maximum distances from the rock placement and munitions clearance activity to the applicable underwater noise threshold levels specified in Section 6. These distances will be used by the marine biologists to assess potential environmental impact on the marine life

Table 8-1 Rock placement assessment, distances to the assessment level limit thresholds.

	Rock placement		RP1 Finland	RP2 Finland
		Assessment levels	Threshold distances	Threshold distances
Marine group		SEL(Cum*)	SEL(Cum*)	SEL(Cum*)
	Effect	dB re 1µPa2-s	dB re 1µPa2-s	dB re 1µPa2-s
Seals	PTS	200 dB	0 meters	0 meters
	TTS	188 dB	80 meters	80 meters
Porpoises	PTS	203 dB	0 meters	0 meters
	TTS	188 dB	80 meters	80 meters
Fish	Mortality (mortal injury)	207 dB	0 meters	0 meters
	Injury	203 dB	0 meters	0 meters
* Cumulative SEL (two-hour rock placement)				

Table 8-2 Munitions clearance (maximum) distances to the assessment level limit thresholds.

	Munitions Clearance (Max)		$M1_{Fin, max}$	$M2_{Fin, max}$	$M3_{Fin,max}$	$M4_{Fin,max}$
		Assessment levels	Threshold distances, max	Threshold distances, max	Threshold distances, max	Threshold distances, max
Marine group		SEL(Cum*)	SEL(Cum*)	SEL(Cum*)	SEL(Cum*)	SEL(Cum*)
	Effect	dB re 1µPa2-s	dB re 1µPa2-s	dB re 1µPa2-s	dB re 1µPa2-s	dB re 1µPa2-s
Seals	PTS	179 dB	3500 meters	8000 meters	15000 meters	9000 meters
	TTS	164 dB	15000 meters	38000 meters	44000 meters	32000 meters
Porpoises	PTS	179 dB	3500 meters	8000 meters	15000 meters	9000 meters
	TTS	164 dB	15000 meters	38000 meters	44000 meters	32000 meters
Fish	Mortality (mortal injury)	207 dB (229-234 dB peak)	50 meters	200 meters	500 meters	400 meters
	Injury	203 dB	100 meters	300 meters	1500 meters	800 meters
* Cumulative SEL (one event)						

Table 8-3 Munitions clearance (average) distances to the assessment level limit thresholds.

	Munitions Clearance (Average)		$M1_{Fin, Average}$	$M2_{Fin, Average}$	$M3_{Fin, Average}$	$M4_{Fin, Average}$
		Assessment levels	Threshold distances, max	Threshold distances, max	Threshold distances, max	Threshold distances, max
Marine group		SEL(Cum*)	SEL(Cum*)	SEL(Cum*)	SEL(Cum*)	SEL(Cum*)
	Effect	dB re 1µPa2-s	dB re 1µPa2-s	dB re 1µPa2-s	dB re 1µPa2-s	dB re 1µPa2-s
Seals	PTS	179 dB	3500 meters	3500 meters	3500 meters	5000 meters
	TTS	164 dB	15000 meters	26000 meters	19000 meters	22000 meters
Porpoises	PTS	179 dB	3500 meters	3500 meters	3500 meters	5000 meters
	TTS	164 dB	15000 meters	26000 meters	19000 meters	22000 meters
Fish	Mortality (mortal injury)	207 dB (229-234 dB peak)	50 meters	50 meters	200 meters	300 meters
	Injury	203 dB	100 meters	100 meters	300 meters	400 meters
* Cumulative SEL (1 event)						

An estimate of the effect distance range as a function of SEL thresholds were made from all munitions clearance modelling scenarios and are shown in the following figure.

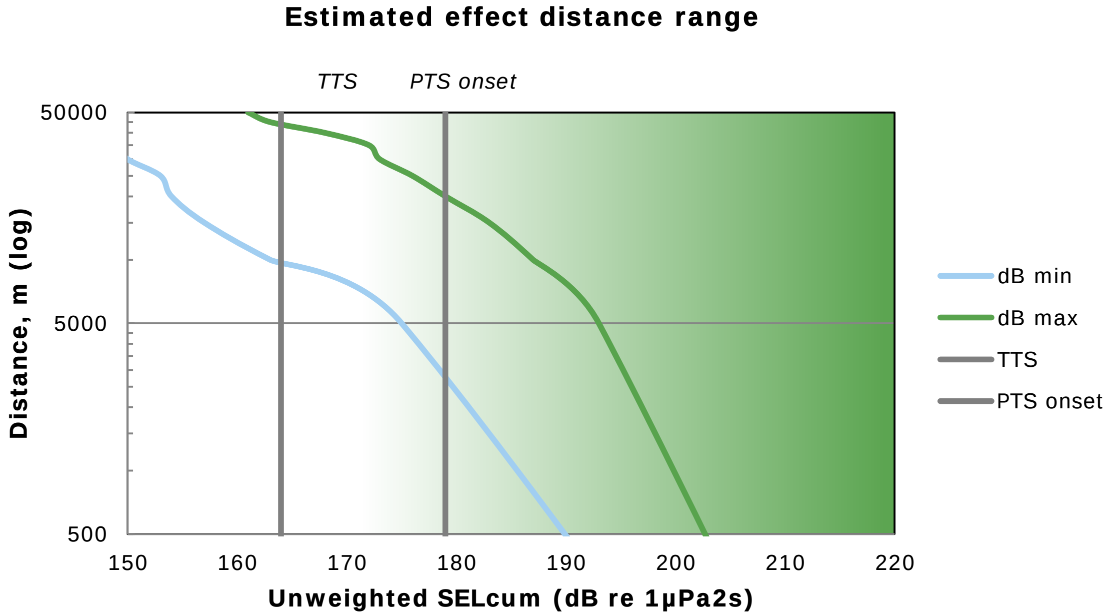

Figure 8-3 **Modelled effect distances range as a function of SEL threshold. The green curve is the maximum propagation and the blue curve represents minimum propagation for all the modelled locations conditions. Vertical lines bordering the green shaded areas represent the TTS, PTS, onset thresholds.**

8.1 Underwater noise contour plots

The following figures show underwater noise level contour plots for munitions clearance and rock placement showing the applicable acoustic parameters applicable to the impact threshold limits for both winter and summer water column conditions.

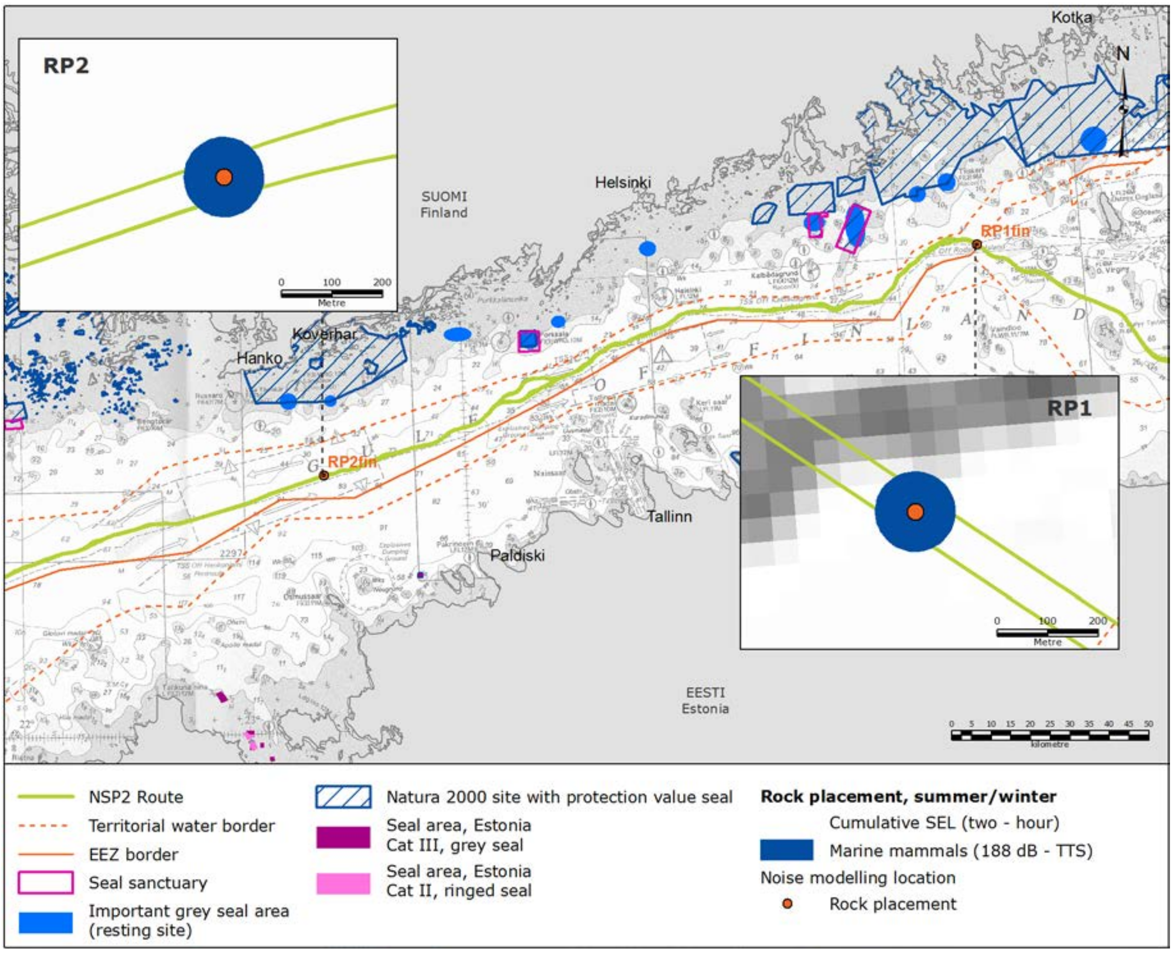

Figure 8-4 **Rock placement underwater sound exposure levels, noise level contour plots to the threshold limits, dB. (Summer/winter).**

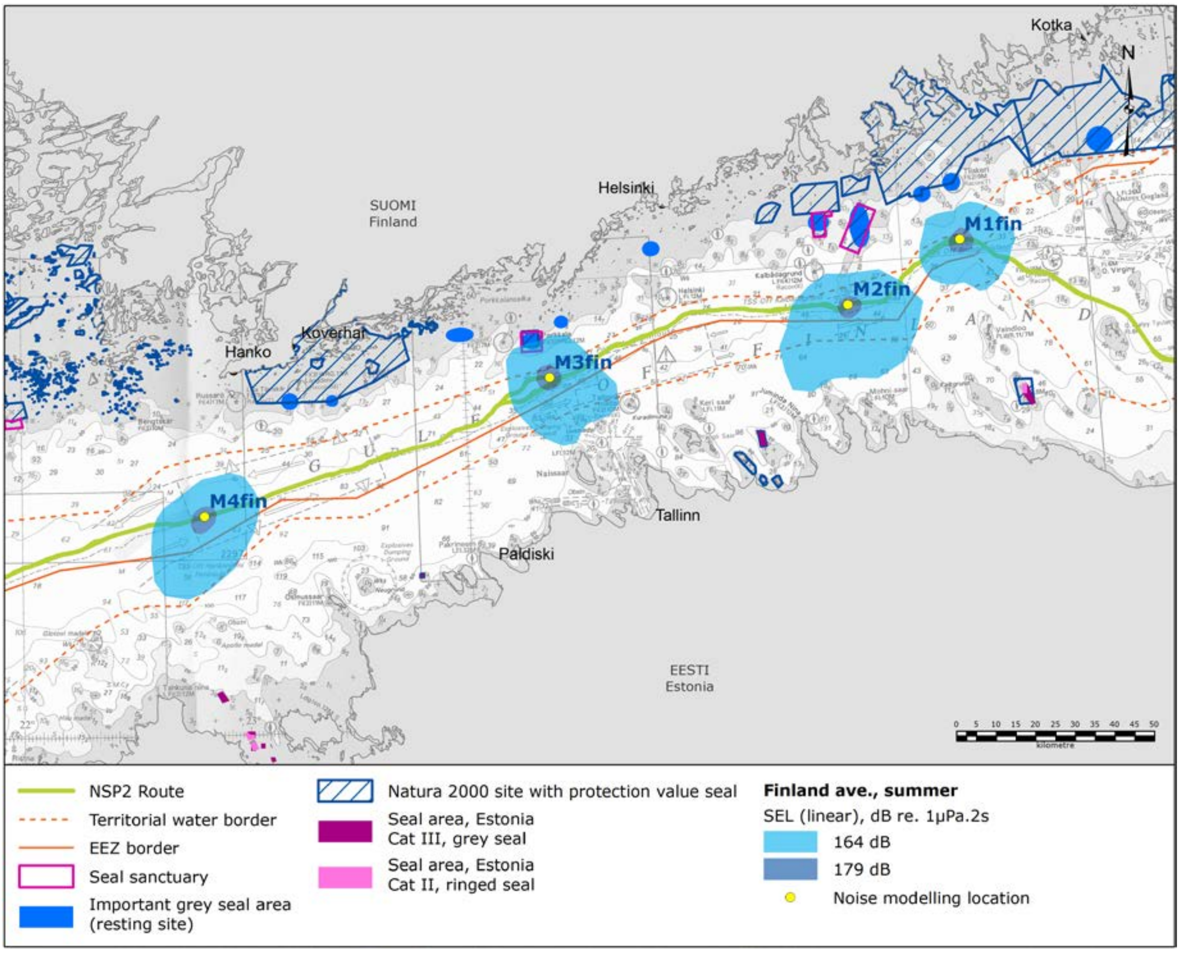

Figure 8-5 **Munitions clearance (average). Underwater sound exposure levels contour plots SEL (1 event), dB. (Summer).**

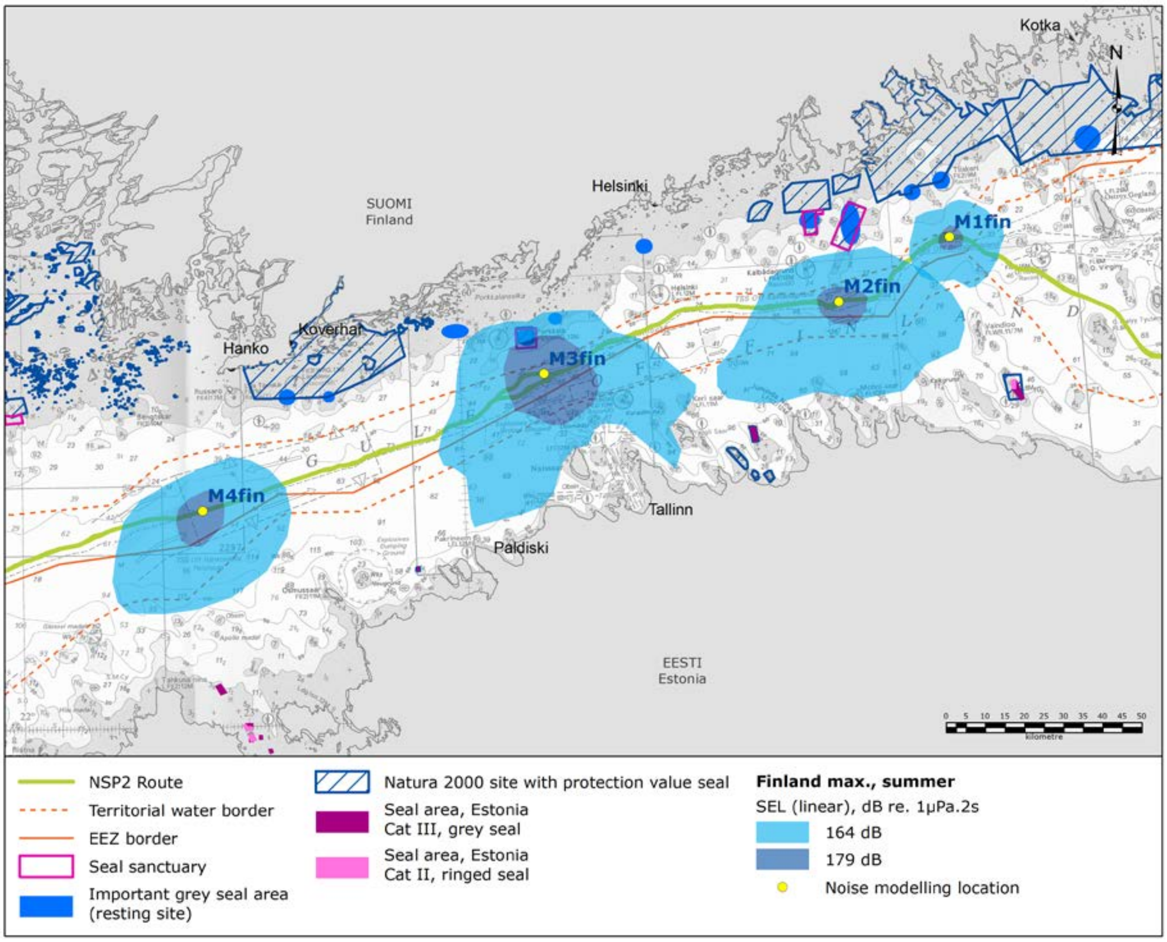

Figure 8-6 **Munitions clearance (Max) Underwater sound exposure levels contour plots SEL (1 event), dB. (Summer).**

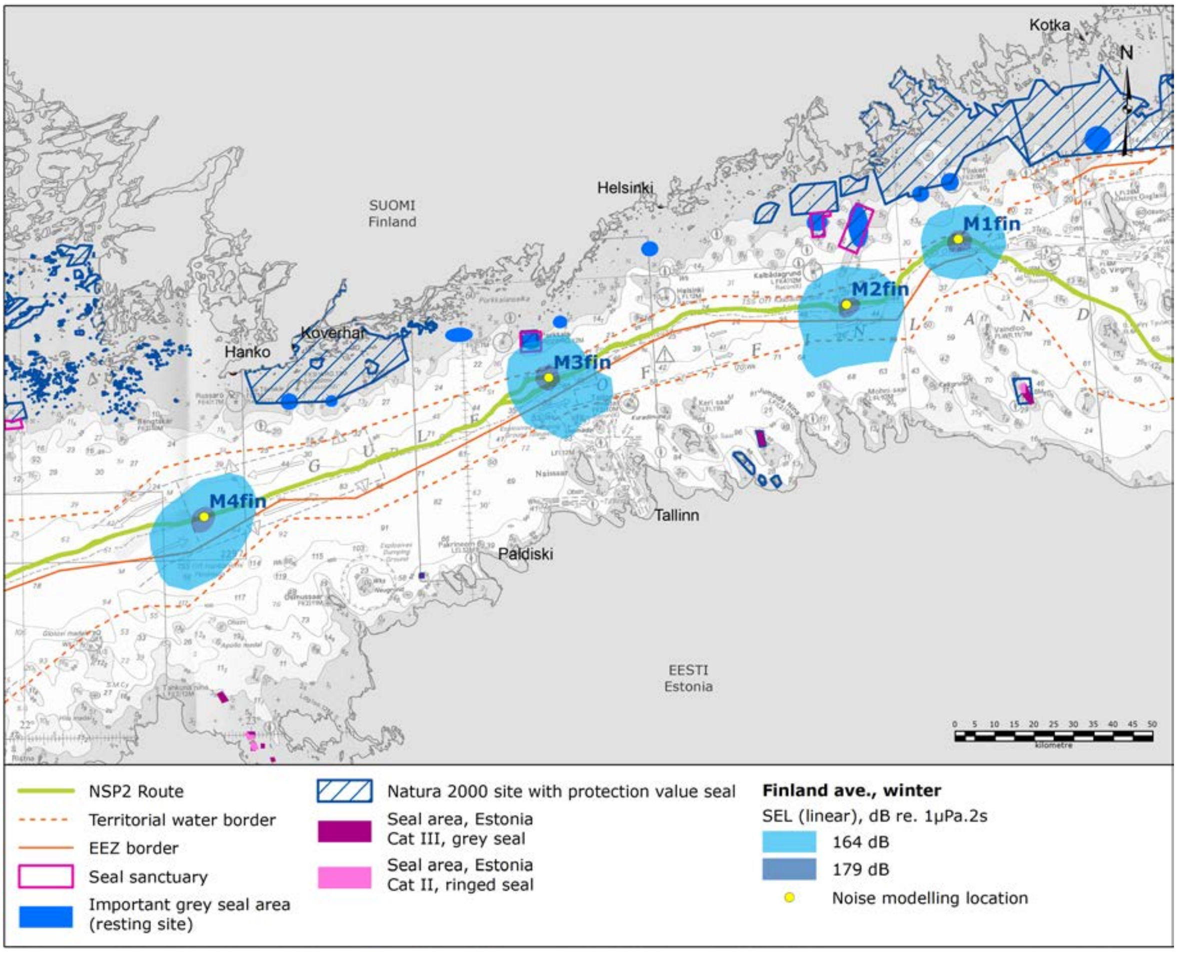

Figure 8-7 **Munitions clearance (Average) Underwater sound exposure levels contour plots SEL (1 event), dB. (Winter).**

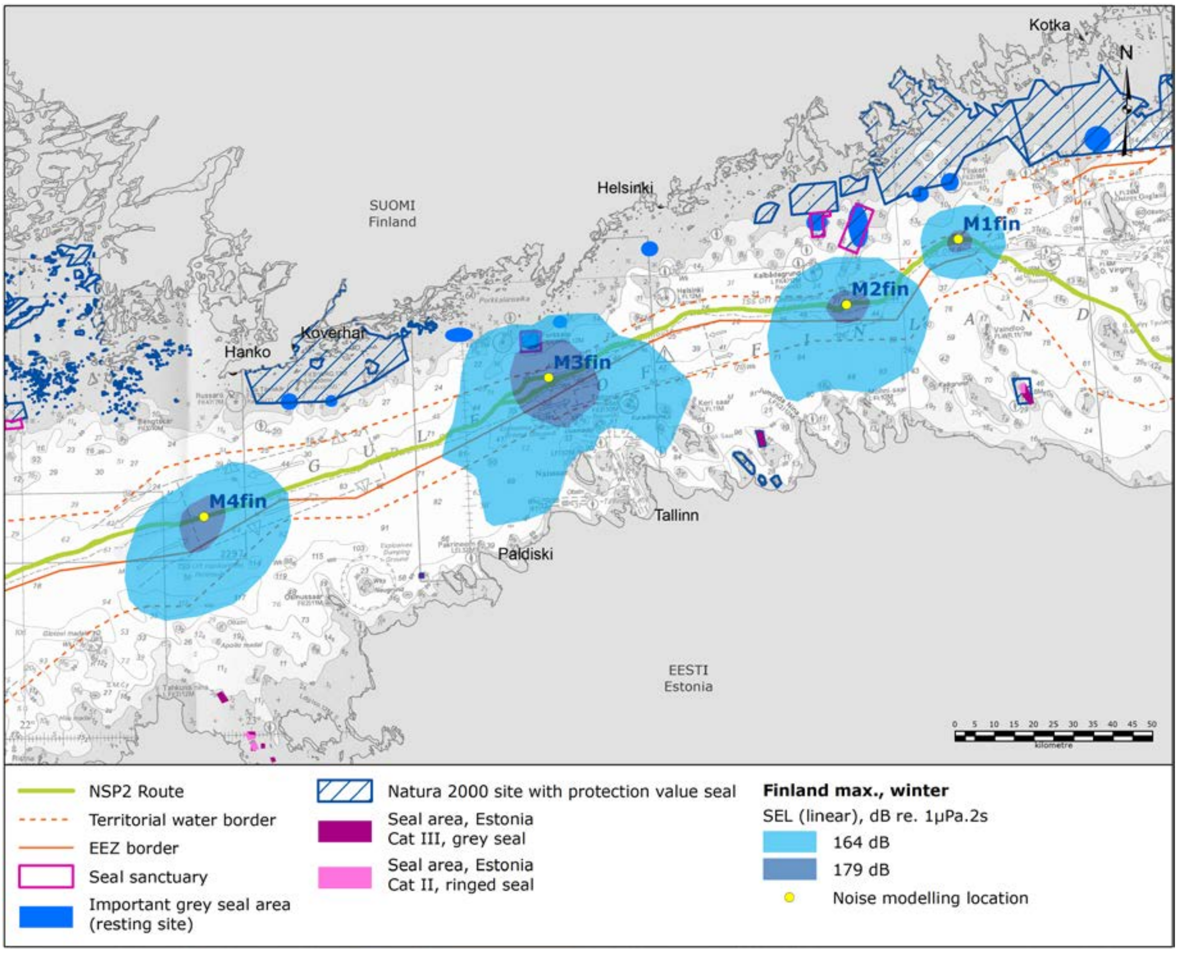

Figure 8-8 **Munitions clearance (Max) Underwater sound exposure levels contour plots SEL (1 event), dB. (Winter).**

9. CONCLUSION

An underwater noise propagation study and noise mapping of identified significant underwater noise sources, rock placement and munitions clearance, for the Finnish sections of the pipeline has been performed. The results are used to assess the potential environmental impacts on marine mammals and fish as part of the environmental impact assessment.

The results are tables of impact distances and figures showing underwater noise level contour plots for munitions clearance and rock placement showing the acoustic parameters applicable to the impact threshold limits for both winter and summer water column conditions. These results have been used by the marine biologists to assess potential environmental impact on the marine life.

Comparison to existing baseline underwater noise levels in the Baltic Sea
The Baltic Sea is a semi-enclosed sea with nine states bordering the sea. It consists of eight sub-catchment areas (sub-basins) and numerous harbours. It is estimated that about 2000 sizeable ships are at sea at any time, and each month around 3,500-5,000 ships traffic the waters of the Baltic Sea. Shipping is thereby the main source of human-induced underwater noise.

Based on the amount of ships passing and data from baseline underwater noise measurements in the Baltic Sea, the average existing background noise levels from shipping range from 100 dB (re. 1 µPa.) away from the ship lanes to up to 110 dB (re. 1 µPa.) close to the ship lanes.

The modelling results are in SELcum underwater sound exposure levels from munitions clearance and rock placement and are a summation of all the underwater sound energy of the activity (a two hour period for rock placement and a single event for munitions clearance) and cannot be directly compared to the existing background underwater noise levels. However, underwater noise source levels from rock placement activities are slightly than a large ship underwater noise source levels.

10. REFERENCES

Brandt, M.J., Höschle, C., Diederichs, A., Betke, K., Matuschek, R., and Nehls, G., 2013. Seal scarers as a tool to deter harbour porpoises from offshore construction sites. Mar.Ecol.Prog.Ser. 475, 291-302.

Fjälling, A., Wahlberg, M., and Westerberg, H., 2006. Acoustic harassment devices reduce seal interaction in the Baltic salmon-trap, net fishery. ICES J.Mar.Sci. 63, 1751-1758.

Götz, T. and Janik, V.M., 2013. Acoustic deterrent devices to prevent pinniped depredation: efficiency, conservation concerns and possible solutions. Rev. 2 21.01.2015 18/20 Mar.Ecol.Prog.Ser. 492, 285-302.

HELCOM, Assessing the Impact of Underwater Clearance of Unexploded Ordnance on Harbour Porpoises in the Southern North Sea, Baltic Marine Environment Protection Commission Expert Group on environmental risks of hazardous submerged objects, 2016.

Halvorsen, M.B., Casper, B.M., Woodley, C.M., Carlson, T.J., Popper, A.N., 2011. Predicting and mitigating hydroacoustic impacts on fish from pile installations.

Jensen, F.B., Kuperman, W.A., Porter, M., B.,, Schmidt, H., 2011. Computational Ocean Acoustics, Second Edition Springer, New York, Dordrecht, Heidelberg, London.

Luode Consulting, NORD STREAM 2 -PROJECT Environmental Baseline Surveys in the Finnish Exclusive Economic Zone - Interim report – 2016, NSP2 Document No: W-PE-EIA-PFI-REP-812-160229EN-01

Nedwell and Edwards. 2004. A review of measurements of underwater man-made noise carried out by Subacoustech Ltd, 1993 – 2003. Subacoustech Report ref: 534R0109.

Popper, ASA S3/SC1.4 TR-2014, Sound Exposure Guidelines for Fishes and Sea Turtles.

Popper, A. N., Smith; M. E., Cott, P. A., Hanna, B. W., MacGillivray, A. O., Austin, M. E., Mann, D. A. 2005. Effects of exposure to seismic airgun use on hearing of three fish species. J. Acoust. Soc. Am. 117(6): 3958-3971Schmidtke, E (2010). Schockwellendämpfung mit einem Luftblasenschleier zum Schutz der Meeressäuger.

Song, J., Mann, D. A., Cott, P. A., Hanna, B. W., Popper, A. N. 2008. The inner ears of Northern Canadian fishes following exposure to seismic airgun sounds. J. Acost. Soc. Am. 124(2): 1360-1366.

Southall, B.L., Bowles, A.E., Ellison, W.T., Finneran, J.J., Gentry, R.L., Greene, C.R.J., Kastak, D., Ketten, D.R., Miller, J.H., Nachtigall, P.E., Richardson, W.J., Thomas, J.A., Tyack, P., 2007. Marine mammal noise exposure criteria: initial scientific recommendations. Aquatic Mammals 33, 411-521.

Sveegaard, Teilmann and Tougaard, Marine mammals in the Baltic Sea in relation to the Nord Stream 2 project – Environmental Impact Assessment, DCE/Institute for Bioscience, 2016.

Witteveen+Bos, Nord Stream AG, Nord Stream, Munitions clearance in the Finnish EEZ, Final monitoring results on Munition by munition basis, G-PE-EIA-REP-000-MRMCLFIE-B-31jan11+A1-8, 2011.

Working Group 2014, Marine mammals and underwater noise in relation to pile driving, Energinet.dk Underwater noise and marine mammals Rev2 – 4. Marts 2015, Energinet.dk.

Wyatt, R. (2008). Joint Industry Programme on Sound and Marine Life - Review of Existing Data on Underwater Sounds Produced by the Oil and Gas Industry.