Neart na Gaoithe

Neart na Gaoithe Offshore Wind Farm

Unexploded Ordnance – Underwater Noise Monitoring Report

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Neart na Gaoithe Offshore Wind Farm

Unexploded Ordnance Underwater Noise Monitoring Report

Pursuant to Condition 3.2.7 & 3.5.4 of Marine Licence (Ref 07103/20/1)

Document Approval

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Acronyms and Abbreviations

TERM	DESCRIPTION
ADD	Acoustic Deterrent Device
EPS	European Protected Species
ML	Marine Licence
MS-LOT	Marine Scotland Licensing Operations Team
NEQ	Net Explosive Quantity
NnG	Neart Na Gaoithe
NnGOWL	Neart na Gaoithe Offshore Wind Limited
UXO	Unexploded Ordnance

1 Introduction

1.1 Background and Purpose of this Document

1. Neart na Gaoithe Offshore Wind Limited (NnGOWL) recently completed an unexploded ordnance (UXO) clearance campaign within the boundaries of the Neart na Gaoithe (NnG) Offshore Wind Farm Area and Export Cable Corridor to prepare for construction activities.
2. The following licences were issued by the Marine Scotland Licensing Operations Team (MS-LOT) in relation to the clearance works:
    - Licence to Disturb European Protected Species (EPS) ('EPS Licence') under the Conservation (Natural Habitats, &c.) Regulations 1994 (as amended), Ref MS EPS 27/2019/1.
    - Licence to deposit or use any explosive substance or article within the Scottish marine area either in the sea or on or under the seabed and to use a vehicle to remove any substance or object from the seabed within the Scottish marine area ('Marine Licence'), Ref 07103/20/1.
3. The original Marine Licence (07103/20/0) was granted based on a total of 50 UXO items requiring clearance. Following the identification of additional UXO above the consented allowance, a Marine Licence variation was requested on the 19th May 2020. Marine Licence 07103/20/1 was granted on 16th June 2020.
4. Condition 3.2.7, 'Noise Monitoring', of the Marine Licence states that:

   "The Licensee must carry out all monitoring in accordance with the UXO Clearance Noise Monitoring Scope Overview Document (NNG-SMR-ECR-REP-0001) but subject to any modifications or amendments made within this licence. Monitoring must be undertaken at a minimum of 20 confirmed UXO targets, over a range of UXO sizes to maximum size and a range of water depths and substrates."
5. Condition 3.5.4, 'Monitoring Report', of the Marine Licence states that:

   "The Licensee must submit a final Monitoring Report, including any associated raw data, to the Licensing Authority, SNH and Marine Scotland Science no later than five months (or such other period as is agreed in writing by the Licensing Authority) following the Completion of the Licensed Activities.

   The Monitoring Report must:

    - predict the source level of UXO detonations;
    - characterise the propagation of noise from UXO detonations in the offshore environment;
    - assess how variations associated with the condition, location, age, type of UXO and environmental factors relate to noise emissions;
    - examine any changes in impulsive characteristics of UXO detonation noise with increasing distance from the source;
    - compare the modelled impact ranges; and
    - calculate weighted sound exposure level

   The Licensee must ensure full details of the recording equipment, deployment configuration, method of detonation and environmental data (sound speed profile of the water column, wind speed, significant wave height, tidal state, precipitation and presence of vessels within 10 km) is reported, alongside each measurement, in the Monitoring Report. Details of each UXO detonation (sequence in detonation, size, type, age, condition, position, burial, depth and donor charge used) must also be included in the Monitoring Report.

The licensee must also submit any reports associated with the Department for Business, Energy and Industrial Strategy funded project to the Licensing Authority as soon as reasonably practicable".

2 Noise Monitoring Survey

2.1 Overview

6. A total of 53 items of UXO were found across the Wind Farm Area (46 UXO) and Export Cable Corridor (seven UXO). Clearance operations began on site with the first detonation on the 3rd May 2020 and the last detonation on the 10th July 2020, with the campaign completing on 11th July 2020.
7. In response to the aforementioned Marine Licence conditions, noise monitoring was undertaken on 37 clearances within the Wind Farm Area between the 14th May and 24th June 2020.
8. Noise monitoring was recorded from four temporary acoustic monitoring buoys that were installed by the supply vessel *World Moon* on behalf of the Institute for Technical and Applied Physics GMBH (ITAP). In addition to noise monitoring of the UXO detonations, monitoring was also undertaken of all Acoustic Deterrent Device (ADD) deployments and soft starts.
9. The Technical Noise Monitoring Report, compiled by ITAP, is provided in Annex 1.
10. Of the 37 monitored clearances, four items successfully underwent high-order detonation, one was detonated (not high-order) and one showed evidence of partial deflagration. For all other items, the donor charge functioned as intended but a high order was not achieved. It is assumed therefore that any noise emissions at the time of detonation on those occasions are resulting from the donor charge. A 5kg donor charge was used for 34 of the monitored clearances, and a 2.5kg donor charge was used for three items.
11. Due to a technical fault, noise monitoring at one of the four monitoring locations was not successful for 11 clearance activities.

2.2 Conclusions

12. In response to Condition 3.2.7 of the Marine Licence, the required information is provided in the Sections of the Noise Monitoring Report (in Annex 1) outlined below:
    - Section 2 of Annex 1 confirms that noise monitoring was completed on a total of 37 UXO clearance activities; above the minimum requirement of 20 outlined in the condition. These UXO clearances occurred in water depths ranging from 45 to 58m, within sediments including sand, silt, mud, shell and clay. The detonations were monitored from a range of distances, as shown in Figure 8 of Annex 1.
    - Recording equipment information and associated deployment configurations are detailed in Section 5.2 of Annex 1. With four monitoring devices in place, 37 clearances and only 11 occasions of missing data at only one device, there are 137 data points in total.
13. In response to Condition 3.5.4 of the Marine Licence, the required information is provided in the sections of the Noise Monitoring Report (in Annex 1) outlined below:
    - **Predict the source level of UXO detonations:** Section 4 provides the methodology of how the source level of UXO detonations is predicted by using an empirical model (Soloway and Dahl, 2014). Appendix A.1 of Annex 1 provides summary illustrations of the noise monitoring results from each of the monitoring locations, for each of the UXO clearance activities. The detailed source levels of each UXO detonation are provided in Appendix A.3 of the Report.

Table 12 in Appendix A.3 of the Report provides the Sound Pressure Levels (SPL) and Sound Exposure Levels (SEL) for each UXO. The results in Table 12 demonstrate that noise emissions varied between clearances; as a summary of the range, the zero-to-peak SPL (Lp,pk) ranged between 209 dB re 1 µPa at 1.48 km distance from the source to 158 dB re 1 µPa at 33 km. Broadband SELs of the detonations were between 189.8 dB re 1 µPa²s at 1.7 km and 158 dB re 1 µPa²s at 33 km.

- **Characterise the propagation of noise from UXO detonations in the offshore environment:** Section 3.2 of Annex 1 provides calculations to predict the impact of distance and water depth influencing sound propagation. An assessment of the SEL and SPL as a function of distance from source is provided briefly in Section 6.2 and in more detail in Section 7.4. The key observation is that the recorded Transmission Loss was very high compared with expectations for similar conditions. This might be caused by the fact that the UXO was in most cases, partially buried with the seabed and not in the water column.

  Figure 13 illustrates the differences in measurements of one UXO detonation at 3.3 km, 4.6 km, 7 km and 11.2 km. Discussion on the potential observations of a seismic precursor (waves traveling in the seabed) in some measurements is included in Section 7.2. This precursor was detectable in distances of 5 to 6 km but not in closer distances.

- **Assess how variations associated with the condition, location, age, type of UXO and environmental factors relate to noise emissions:** Section 7.5 of Annex 1 provides a summary of the influence of environmental factors and bathymetry on noise emissions from the recorded UXO detonations, with the conclusion that it is of negligible importance. There were generally only limited differences in condition, age and type of UXO across those found and therefore influences on noise emissions were also not evident.

- **Examine any changes in impulsive characteristics of UXO detonation noise with increasing distance from the source:** Information on changing characteristics of detonation noise with distance is provided in Section 7.6 of Annex 1, which confirms that the pressure signal from the monitored detonations decrease with increasing distance, as would be expected.

14. In response to the final requirements of Condition 3.5.4 of the Marine Licence, Section 7.9 of Annex 1 provides a comparison between the predicted and measures results, with the information included as follows;

    - **Calculate weighted sound exposure level:** The species-specific frequency-weightings of NOAA 2018[1], as referenced in the Marine Licence and EPS Application ('the Application'), were applied to the unweighted third octave source spectra of the Sound Exposure Level for a number of measurements (E_MAG_0035_B (Sequence 11), ECR_O_MAG_0332_A (Seq. 14), D_MAG_0225 (Seq. 17), E_MAG_0070 (Seq. 28), E_MAG_0227 (Seq. 29), B_MAG_0023 (Seq. 42)), pre-selected for the reasons outlined in Table 7 of Annex 1. The resulting values are given in Table 9; presented as distance to the source, where Permanent Threshold Shift (PTS) or Temporary Threshold Shift (TTS) would occur in marine mammals.

    The estimated source levels based on measurement values and project specific transmission loss for a select number of measurements is presented in Section 7.10.

[1] NOAA (2018) National Marine Fisheries Service Revisions to: Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2.0): Underwater Thresholds for Onset of Permanent and Temporary Threshold Shifts. U.S. Dept. of Commer., NOAA. NOAA Technical Memorandum NMFS-OPR-59, 167 p

- **Compare the modelled impact ranges:** The predicted impact ranges for the pre-selected measurements are shown adjacent to the predicted impact ranges for a 5kg and 10kg UXO item in Table 8 and Table 9 of Annex 1, for unweighted SPL and frequency-weighted SEL respectively.

It should be noted however that the methods for determining the impact ranges differ significantly in terms of the used source spectra as well as the transmission loss, due to differences experienced in the noise monitoring campaign. The measurement uncertainty as well as the different assumed charge weights must be considered when comparing the results.

Annex 1

Neart na Gaoithe Offshore Wind Farm UXO Clearance – Underwater Noise Measurements (ITAP, 2021)

Neart na Gaoithe
Offshore Wind Farm
UXO clearance

Underwater noise measurements

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Version	Date	Revision
Version 1	11.08.2020	First version (Draft)
Version 2	31.08.2020	Comments from client (NNG, NPL, LU)
Version 3	11.09.2020	Updated after online meeting with client
Version 4	10.11.2020	Corrected typing error for min/max SEL/$L_{p,pk}$ values in summary
Version 5	08.12.2020	Added chapter 7.9, Comparison of prediction and measurements
Version 6	11.12.2020	Updated with comments from client
Version 7	15.12.2020	Changed clearance result for UXO42 to "Detonation – not high order"
Version 8	29.03.2021	Revision with comments from MSS, including source level estimation at 1m distance
Version 9	31.03.2021	Revision loop with NnGOWL

Latest version replaces all previous versions.

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Units:

μm/s - micrometer per second

dB - decibel

kg - kilogram

km - kilometer

min - minute

Pa - pascal

s - second

Metrics:

R - radius

W - explosive charge weight in kg TNT

λ - wave length

ρ - density of a medium

E - Sound Exposure

L_{hg} - background noise level

$L_{p,pk}$ - zero-to-peak Sound Pressure Level

$L_{pk,pk}$ - peak-to-peak Sound Pressure Level

SEL - single impulse Sound Exposure Level

SPL - (energy-) equivalent continuous Sound Pressure Level

T - averaging time

Z - Acoustic Characteristic Impedance

c - Sound Velocity

n - count

p - Sound Pressure

$p(t)$ - time variant Sound Pressure

$p0$ - reference Sound Pressure

p_{pk} - peak Sound Pressure

v - Particle Velocity

Abbreviations:

BEIS - Department for Business, Energy and Industrial Strategy

CTD - Conductivity, Temperature and Depth

EIA - Environmental Impact Assessment

itap - Institute for Technical and Applied Physics GmbH

NEQ - Net Explosive Quantity

NnGOWL - Neart na Gaoithe Offshore Wind Limited

NPL - National Physical Laboratory

OTM - offshore transformer module

OWF - Offshore Wind Farm

PTS - *permanent threshold shift*

rms - root mean square

TL - Transmission Loss

TNT - Trinitrotoluol

TTS - *temporary threshold shift*

UXO - Unexploded ordnance

1. Executive summary

Neart na Gaoithe Offshore Wind Limited (*NnGOWL*, the client) are currently developing the 450 MW offshore wind farm (OWF) project *Neart na Gaoithe* (NnG), to be located in the outer Firth of Forth in the Scottish part of the North Sea.

The UXO (unexploded ordnance) survey points out that a total of 53 pcs of UXOs requiring removal by detonation have been found within the OWF NnG area and across the export cable. An UXO clearance campaign was planned in close coordination with the R&D project BEIS.

The *itap – Institute for Technical and Applied Physics GmbH* was commissioned to carry out the underwater noise monitoring during unexploded ordnance (UXO) clearance activities (min. 20 pcs) at OWF *Neart na Gaoithe* array area and in the export cable corridor.

The various types of UXO were ranged between 4" to 15"in diameter with assumed charge weights between less than 1 kg and up to 102 kg TNT-equivalent. A seal scarer in combination with several pre-detonations with loads of 50, 100 and 150 g were used to scare marine mammals out of the danger zone.

The measuring concept as aligned to Scope of Works states that noise measurements have to be taken at least at four measurement positions (MPs) in distances to the UXOs of approximately 1 to 3 km, 3 to 5 km, 6 to 8 km and ≥10 km.

The monitored UXO clearances took place from 14th May 2020 until 24th June 2020. Within this period 37 pcs detonations were performed. No noise abatement techniques were used during the detonations. All 37 pcs detonations were measured at all four measurement positions by *itap GmbH,* but due to a malfunction the last 11 pcs UXO clearance recordings (UXO33 to UXO43) from measurement position MP3 must be classified as not valid. At measurement position MP4 an additional very sensitive measurement device (SM2M devices from *wildlife acoustics*) was used as well to measure the ambient noise within this OWF. During most of the UXO clearance activities this measured devices was overloaded (clipping effects). But for some smaller TNT-equivalent loads in distances > 10 km the detonation noise was also measured successfully with a sampling frequency of 96 kHz, means up to 48 kHz.

All underwater noise measurements as well as post-processing activities were performed in accordance to the ISO 18406 (2017). Raw data as well as post processed data incl. figures are available on separated hard drive, as contractually agreed.

Zero-to-peak Sound Pressure Levels ($L_{p,pk}$) of the water borne shock wave ranged between 209 dB re 1 µPa at 1.48 km distance from the explosions to 173 dB re 1 µPa at 33.02 km.

Broadband Sound Exposure Levels (SELs) of the explosions were between 190 dB re 1 µPa²s at 1.42 km and 158 dB re 1 µPa²s at 33.02 km; the values include the low-frequency bubble oscillation phase of the detonations.

A seismic precursor was partly identified only for measurement positions in distances of < 2 km. This seismic precursor was minimum a factor 30 dB lower than the water borne shock wave so that this seismic precursor does not influence the overall noise levels.

A stable approximation of the transmission loss for the Sound Exposure Level (SEL) and zero-to-peak Sound Pressure Level ($L_{p,pk}$) was determined. The derived transmission loss (TL) for the UXO clearance activity, however, is uncommonly high in comparison to semi-empirical approaches in comparable waters; the factor ranged between 24 and 25 $\log_{10}$(distance-ratio) for the sound propagation till 10 km. This leads to a decrease of 7.0 to 7.5 dB per doubling the distance between source and receiver. Based on the semi-empirical approach of Thiele & Schellstede (1980) a decrease of 4.5 dB per doubling the distance was expected till 10 km and a bit higher for longer distances due to the frequency depending absorption in water. The measured transmission loss for the pre-detonations, which are located in the middle of the water column ranged between 19 and 17. That means that the untypical high transmission loss factor is most likely not caused by the fact that the UXO was on top of the seabed or inside the seabed. It is likely that the factor of 7.5 dB decrease might be influenced by the type of the sediment (soil layers) in this area.

Nevertheless, the water depth of 45 to 55 m within the OWF *Neart na Gaoithe* will have a lower cut-off frequency of approximately 20 Hz which means that lower frequencies are not able to transmit into the water. Based on experiences from previous UXO clearances the lower frequency range of detonation noise is < 10 Hz.

Comparison between ambient and detonation noise in distances > 10 km indicates that the signal-to-noise ratio is > 30 dB for frequencies between 20 Hz and several kHz. At 40 kHz the signal-to noise ratio decreases to about 15 dB. This result shows that the ambient noise levels will not bias the determined detonation noise levels. Furthermore, the high frequency range (at several kHz) includes significant detonation noise over great distances.

A clear correlation between the TNT-equivalent weight or the UXO types and the measured underwater noise levels was not measured. Based on predictions from Soloway and Dahl (2014) the underwater noise should be increase with increasing TNT-equivalent weight. Reason for this non-compliance might be the fact that it is not clear how many of the TNT-equivalent weight of the UXO types really detonated during the clearance activities since these UXO types are remaining in water over the last approximately 75 years. However, pre-detonations with 50, 100 and 150 g prior the UXO clearance activity were used to scare marine mammals out of the dangerous zone. For these small detonations it can be expected that 100% of the TNT equivalent weight has detonated. Measurements of these pre-detonations indicates an increase of measured sound levels with increasing TNT-equivalent weight. However, differences between the measurement results and the expected noise levels by applying the model of Soloway & Dahl (2014) are relatively low these pre-detonations. For the UXO clearance activities the measured results correlate good to the predicted underwater noise levels with the charger weight of 2.5 and 5 kg.

All UXO clearance activities were performed during good weather conditions (calm sea, < 1.4 m/s sign. wave height). A CTD-probe measurement indicates that no distinct sound profile occurs under these conditions which indicates that the sound profile might only have an influence on the sound propagation over large distances. Based on that, it can be concluded that no site- or project-specific factors such as rain, water depth, ambient noise, UXO weight and type etc. influence the measurements.

The seal scarer used as acoustic deterrence device with an operational frequency of 14 to 15 kHz was measured partly before the pre-detonations and UXO clearance activity took place, and was detectable even in distances of 11 km.

Measurements in compressed (MPEG3) and uncompressed (WAV) format were performed during this measurement campaign. A comparison between uncompressed and compressed format show differences in the broadband level of $\leq$ 0,2 dB. Differences are only visible for low frequencies (< 20 Hz) and high frequencies (> 4 kHz) which are caused by the MPEG3 conversion itself. Nevertheless, MPEG3 format is only able to record till 20 or 24 kHz.

A comparison of the measurements results with the Marine Licence and European Protected Species (EPS) Licence Application for UXO Clearance Activities ('the Application'), NnGOWL (2019) in terms of impact ranges was made. The Impact ranges for unweighted zero to peak Sound Pressure Levels from the measurements are already in a good agreement to the Application. The impact ranges for weighted Sound Exposure Levels SEL show much larger differences based on the used sound source spectra and weighting. The results from UXO17 demonstrate that there are also results which exceed the Application results. The reason for the partly significantly differences between the predictions and the measurements of UXO17 can only partly be explained within this report.

2. Objectives and project description

Neart na Gaoithe Offshore Wind Limited (*NnGOWL*, the client) are currently developing the 450 MW offshore wind farm (OWF) project *Neart na Gaoithe* (NnG), to be located in the outer Firth of Forth, approximately 15 km from Fife Ness and 16 km from the Isle of May within the Scottish North Sea (see Figure 1). It is planned for the OWF NnG to build 54 pcs offshore wind turbine generators (OWTG) of each 8 MW incl. 2 pcs of offshore transformer modules (OTM) and 2 pcs export cables between summer 2020 and December 2022. The water depth within the OWF ranged between 45 and 55 m (LAT).

Unexploded ordinance (UXO) are a major health and safety concern and environmental issue that poses significant risk to offshore construction projects and its collaborator. As part of construction projects, developers are required to locate, identify and dispose of any UXO that are located in areas of development before construction phase starts. The UXO (unexploded ordnance) survey points out that a total of 53 pcs of UXOs requiring detonation have been found within the OWF *Neart na Gaoithe* and across the export cable. Disposal is typically carried out by detonation of the munition which generates underwater noise which poses a possible risk to marine wildlife in proximity. Marine mammals may be at risk of fatality, auditory injury and disturbance (NnGOWL, 2020)(NnGOWL, 2020a).

However, there is a lack of scientific understanding of how the noise emitted during UXO detonations vary with differences in UXO type as well as e.g. age, size, donor charge weights, environmental conditions etc. Typical assessments are usually based on relatively simple semi-empirical models of the noise generated during detonations and model predictions have not been widely validated in a wide range of environments or at ranges beyond a few kilometers. Therefore, *NnGOWL* was planning an underwater noise monitoring during the UXO clearance to collect as much as possible data to be able to extent the currently knowledge about underwater noise caused by UXO clearance activities incl. identification of possible main influencing factors.

The measurement data shall also be provided in a suitable raw data format to be included in the “Department for Business, Energy and Industrial Strategy” (BEIS) funded project being led by *National Physical Laboratory* (*NPL*) and *Loughborough University*, and managed by Hartley Anderson environmental consultants. The measurement concept (see chapter 5) was also discussed with *NPL* and *Loughborough University* before the offshore measurement campaign starts.

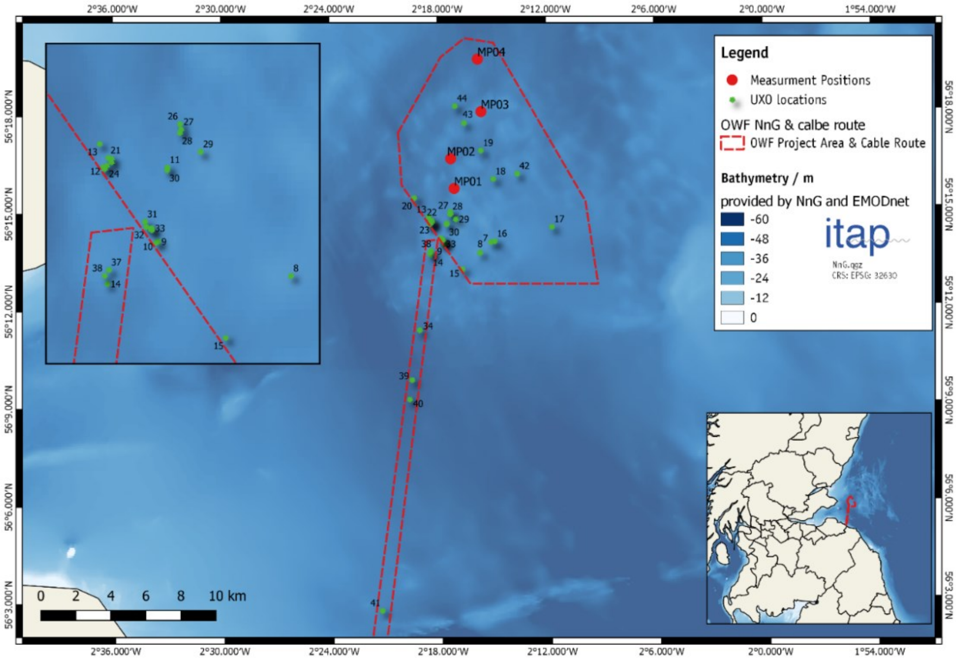


Figure 1: *Location of OWF Neart na Gaoithe incl. the four measurement positions and the identified unexploded ordinances (UXO); source: itap GmbH; coordinates provided by NnGOWL, 2020.*

The *itap – Institute for Technical and Applied Physics GmbH* was commissioned to carry out the underwater noise monitoring during unexploded ordnance (UXO) clearance activities (min. 20 pcs) at OWF *Neart na Gaoithe* array area and in the export cable corridor.

The scope of this document is to summarize all measured underwater noise data as well as to identify possible influencing factors on the underwater noise levels during UXO clearance activities. Therefore, the measured underwater noise generated by detonations are assessed under various aspects, e.g., such as its distance depending impulsive characteristics, the determined transmission loss (TL) and regarding the influence of environmental factors and variations in UXO conditions.

During the measurement campaign from May 14th to June 24th in total 37 out of 53 pcs UXO clearances were cleared and underwater noise measurements were performed successfully.

The net Explosive quantity (in kg) of the UXO to be cleared ranged from approx. 0.1 kg to 102 kg based on information provided by client. The charge weight used for the detonations was either 2,5 kg or 5 kg. For the purpose of acoustic deterrence of maritime life, in some cases so-called pre-detonations (soft-starts) were performed using 50 g, 100 g or 150 g detonations. Before starting any detonation, marine mammals were cleared from the mitigation zone by application of an acoustic deterrence device for approximately 30 minutes, (see chapter 6.4).

3. Acoustic background

Sound is a rapid, often periodic variation of pressure, which additively overlays the ambient pressure (in water the hydrostatic pressure). This involves a reciprocating motion of water particles, which is usually described by particle velocity v. Particle velocity means the alternating velocity of a particle oscillating about its rest position in a medium. Particle velocity is not to be confused with sound velocity c_{water}, thus, the propagation velocity of sound in a medium, which generally is c_{water} = 1,500 m/s in water. Particle velocity v is considerably slower than sound velocity c.

Sound Pressure p and Particle Velocity v are associated by the Acoustic Characteristic Impedance Z, which characterizes the wave impedance of a medium as follows:

$$Z = \frac{p}{v}$$

Equation *1*

In the far field, that means in a distance[1] of some wavelengths (frequency dependent) from the source of sound, the impedance is:

$$Z = \rho c$$

Equation *2*

with ρ – density of a medium and c – Sound Velocity.

For instance, when the sound pressure amplitude is 1 Pa (with a sinusoidal signal, it is equivalent to a Sound Pressure Level of 117 dB re 1 µPa or a zero-to-peak Sound Pressure Level of 120 dB re 1 µPa), a particle velocity in water of approx. 0.7 µm/s is obtained.

3.1 Acoustic noise metrics

In acoustics, sound is generally not described by the measured Sound Pressure (or Particle Velocity), but by the level in dB (decibel) known from the telecommunication engineering. There are different sound levels, however:

- (energy-) equivalent continuous Sound Pressure Level – SPL,
- single impulse Sound Exposure Level – SEL,

[1] The boundary between near and far field in hydro sound is not exactly defined or measured. It is a frequency-dependent value. In airborne sound, a value of ≥ 2λ is assumed. For underwater sound, values of ≥ 5λ can be found in literature.

- zero-to-peak Sound Pressure Level $L_{p,pk}$.

SPL and SEL can be specified independent of frequency, which means as broadband single values, as well as frequency-resolved, for example, in one-third octave bands (third spectrum).

In the following, the level values mentioned above are briefly described.

3.1.1 (Energy-) equivalent continuous Sound Pressure Level (SPL)

The SPL is the most common measurand in acoustics and is defined as:

$$SPL = 10\ \log_{10}\left(\frac{1}{T}\int_{0}^{T}\frac{p(t)^2}{p_0^2}\,\mathrm{d}t\right)\ [\mathrm{dB}]$$

Equation 3

with

$p(t)$ - time-variant Sound Pressure,

p_0 - reference Sound Pressure (in underwater sound 1 µPa),

T - averaging time.

Sometimes in literature the label SPL is used for a Sound Pressure Level without time averaging. According to this definition the continuous Sound Pressure Level over an interval is than labeled as SPL_{rms} with the index rms for root mean square. In this report, the terminology according to DIN ISO 18406 (2018-08) is used and the index rms is omitted, since a definition according to Equation 3 already implies averaging.

3.1.2 Sound Exposure Level

For the characterization of impulsive sounds, the SPL solely is an insufficient measure, since it does not only depend on the strength of the sound impulse, but also on the averaging time. The Sound Exposure – E or rather the resulting Sound Exposure Level – SEL is more appropriate. Both values are defined as follows:

$$E = \frac{1}{T_0}\int_{T_1}^{T_2}\frac{p(t)^2}{p_0^2}\,\mathrm{d}t$$

Equation 4

$$SEL = 10\ \log_{10}\left(\frac{1}{T_0}\int_{T_1}^{T_2}\frac{p(t)^2}{p_0^2}\,\mathrm{d}t\right)\ [\mathrm{dB}]$$

Equation 5

with

T_1 and T_2 - starting and ending time of the averaging (should be determined, so that the sound event is between T_1 and T_2),

T_0 - reference 1 second.

Therefore, the Sound Exposure Level of a sound impulse is the (SPL) level of a continuous sound of 1 s duration and the same acoustic energy as the impulse.

The Sound Exposure Level (SEL) and the Sound Pressure Level (SPL) can be converted into each other:

$$SEL = 10\ \log_{10}\left(10^{\frac{SPL}{10}} - 10^{\frac{L_{hg}}{10}}\right) - 10\ \log_{10}\left(\frac{nT_0}{T}\right)\ [\text{dB}]$$

Equation 6

with

n - number of sound events (impulses), within the time T,

T_0 - 1 s,

L_{hg} - noise and background level between the single sound impulses.

Thus, Equation 6 provides the average Sound Exposure Level (SEL) of n sound events from just one Sound Pressure Level (SPL) measurement. In case, that the background level between the sound impulses is significantly smaller than the sound impulse itself (for instance > 10 dB), it can be calculated with a simplification of Equation 6 and a sufficient degree of accuracy as follows:

$$SEL \approx SPL - 10\ \log_{10}\left(\frac{nT_0}{T}\right)\ [\text{dB}]$$

Equation 7

In some guidelines for measuring underwater noise, i.e. Germany (BSH, 2011) as well as Taiwan, an averaged Sound Exposure Level of 30 s is defined (SEL_{30s}), according to Equation 7.

3.1.3 Zero-to-peak Sound Pressure Level

This parameter is a measure for sound pressure peaks. Compared to Sound Pressure Level (SPL) and Sound Exposure Level (SEL), there is no average determination:

$$L_{p,pk} = 20 \log_{10}\left(\frac{|p_{pk}|}{p_0}\right) \text{ [dB]}$$

Equation 8

with
$|p_{pk}|$ - maximum determined Sound Pressure.

Figure 2 depicts an example. The zero-to-peak Sound Pressure Level ($L_{p,pk}$) is always higher than the Sound Exposure Level (SEL). Some authors prefer the peak-to-peak value ($L_{pk,pk}$) instead of $L_{p,pk}$. A visual definition of this parameter is given in Figure 2 but this metric is not defined in the ISO 18405 (2017). This factor does not describe the maximum achieved (absolute) Sound Pressure Level, but the difference between the maximum negative and the maximum positive amplitude of an impulse. This value is maximal 6 dB higher than the zero-to-peak Sound Pressure Level $L_{p,pk}$.

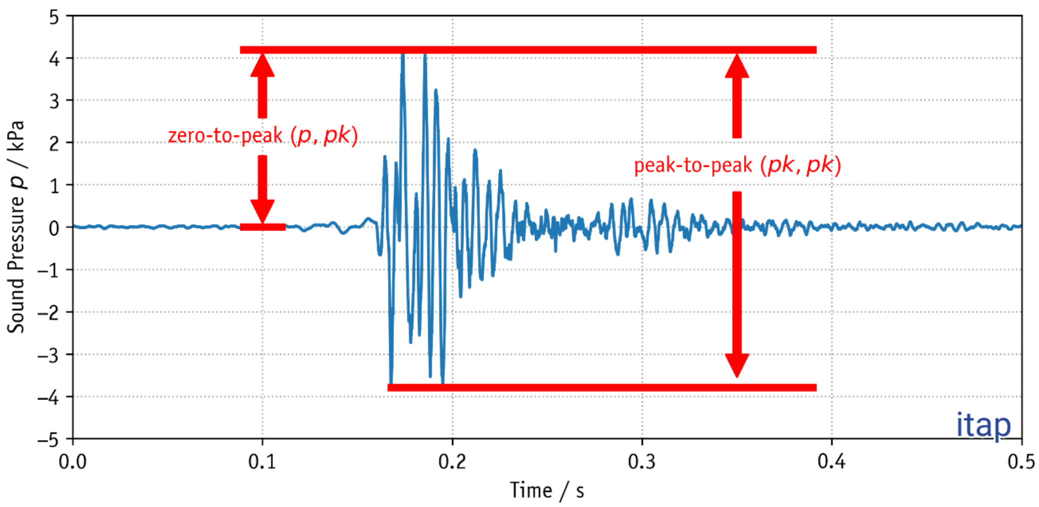


Figure 2: *Typical measured time signal of underwater sound in a distance of several 100 m.*

3.2 Sound propagation in the North Sea

3.2.1 Impact of the distance

For approximate calculations, it can be assumed, that the sound pressure decreases with the distance according to a basic power law. The level in dB is then reduced about:

$$TL = k \cdot \log_{10}\left(\frac{r_2}{r_1}\right) \text{ [dB]}$$

Equation 9

with:

r_1 and r_2 - the distance to the source of sound increases from r_1 to r_2,
TL - Transmission Loss,
k - absolute term (for the North Sea: $k = 15$).

Often, the transmission loss (TL) is indicated for a distance $r_1 = 1$ m (fictitious distance to an assumed point source). The sound power in 1 m distance, that has to be calculated from this, is also called source level. Equation *9* then simplifies to $TL = k \log_{10} (r/meter)$. However, this simple calculation does not consider the frequency-dependent decrease of the sound pressure with increasing distance. Additionally, the above mentioned equation only applies for the "far-field" of an acoustic signal, means in some distance (frequency-dependent) from the source. Moreover, in case of distances of several kilometers, the absorption in the water has an impact and causes a further decrease of the sound pressure. In case of such large distances, the weather also has an influence on the sound level in the water; in case of strong wind and heavy sea, the sound pressure level is lower. This is because of the higher surface roughness of the sea and especially because of the increased air introduction due to the breaking of the waves into the upper ocean layer.

Thiele and Schellstede (1980) have published approximation formulas for the calculation of the sound propagation for different areas of the North Sea as well as for "calm sea" (IIg) and for "rough sea" (IIr) (Betke *et al.*, 2004)). In comparison of the approximation formulas with measurement data from previous projects (see Figure 3), the approximation formula for shallow waters at calm sea (IIg) led to the smallest deviations.

Thus, for the forecast, the same propagation loss (IIg) will be considered:

$$TL = (23 + 0.7F) \log_{10}(R) + (0.3 + 0.05F + 0.005F^2) R \; 10^{-3} \text{ [dB]}$$

Equation *10*

with:

F $= 10 \log_{10}(f/[\text{kHz}])$,
R – distance.

Strictly speaking, the correlations from Equation *10* do only apply for the North Sea (mainly German Bight) under wintry conditions and calm sea with a good mixing of the water and without a strong sound velocity profile. It is assumed for the forecast, that at the time of the sound measurements, there is a full mixing of the water and no strong sound velocity profile in the survey area. In Figure 3 propagation losses are compared to real measured values.

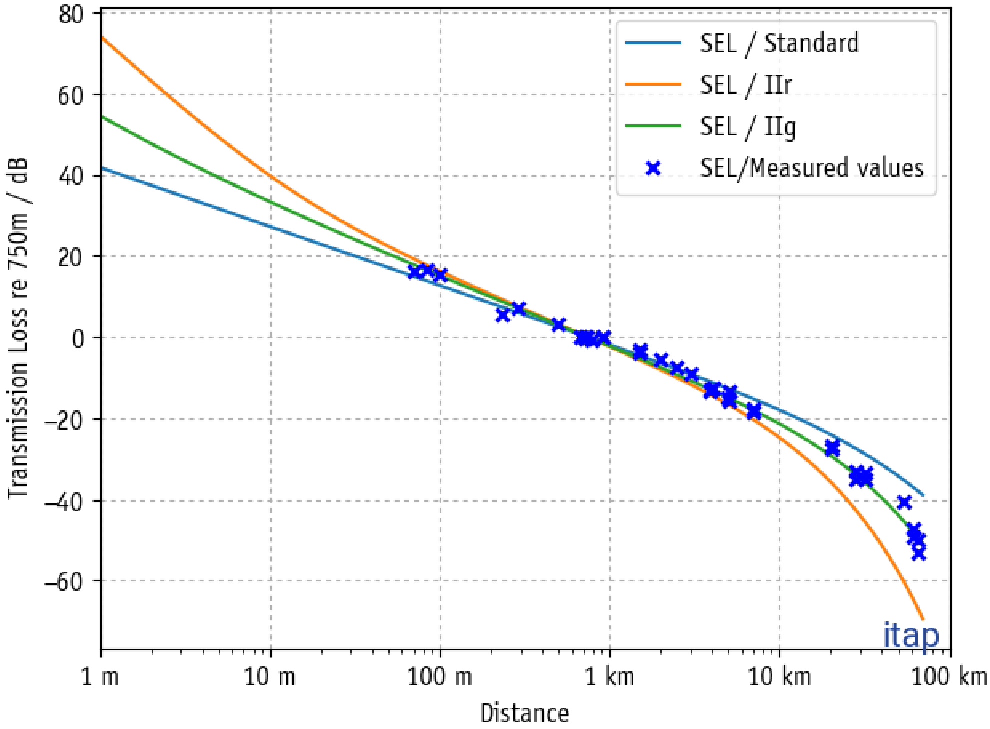


Figure 3: *Comparison of different propagation losses according to Thiele and Schellstede (1980) with available measurement values. IIr: shallow water at rough sea, IIg: shallow water at calm sea and Standard: general formula (conservative approach).*

3.2.2 Impact of the water depth

The sound propagation in the sea is also influenced by the water depth. Below a certain cut-off frequency f_g, a continuous sound propagation is impossible. The shallower the water, the higher this frequency is.

From water depths around 30 m, the cut-off frequency f_g depending on the sediment type is in the size of significantly under 50 Hz (Urick, 1983). Figure 4 shows the lower cut-off frequency for mainly sandy soils as a function of the water depth. Moreover, the band widths of the lower cut-off frequency at different soil layers, such as clay and till, are depicted shaded (Jensen *et al.*, 2010) . Sound near the cut-off frequency is decreased superiorly resp. dampened with growing distance to the sound source than calculated e. g. by Equation *10*.

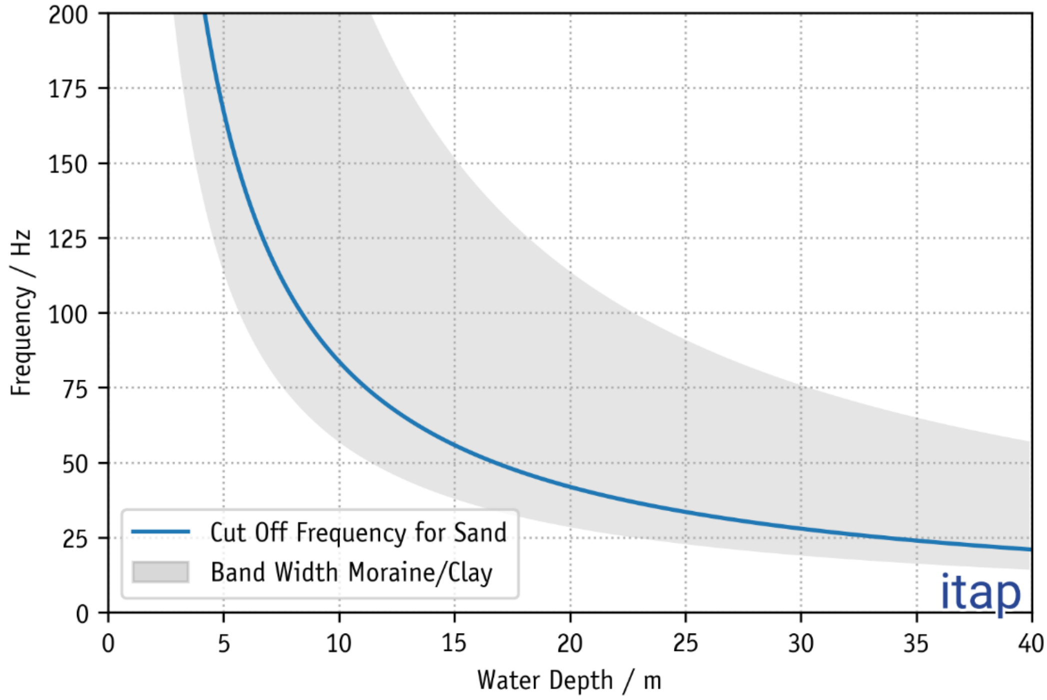


Figure 4: *Theoretical lower cut-off frequency f_g for an undisturbed sound propagation in water as a function of the water depth for different soil layers (Urick, 1983; Jensen et al., 2000).*

4. Estimated noise levels during UXO clearance activities

Soloway and Dahl (2014) developed an empirical model to calculate the expected noise level of underwater explosions. This model does take into account the distance to the detonation as well as the assumed charge weight in kg TNT-equivalent. Measurement data from unmitigated explosions at distances of up to 7 km as well as different charge weight served as input data. This model considers a frequency independent transmission loss in shallow water which might lead to larger uncertainties in distances > 10 km since the absorption of water significantly depending on frequency by sound propagation over large distances (examples of pile-driving noise sound propagation over large distances are summarized in Bellmann et al., 2020).

Furthermore, the influence of the weather condition might have an influence on sound propagation. The underwater noise will be more attenuated in bad weather conditions with strong wind and heavy sea. This is the consequence of a higher surface roughness of the sea and stronger air inclusion in the upper ocean layer due to wave action, which is particularly effective at higher frequencies. Nevertheless, the sound propagation might also be influenced by the bathymetry as shown in chapter 3.2.2 which is also not included in the model of Soloway and Dahl (2014).

However, the UXO clearance activities within the OWF *Neart na Gaoithe* took place only during "good" weather conditions with calm sea: wave height <1.4 m, and rather low current <2 knts, so that the influence of weather conditions on the underwater noise measurements might be limited. Based on the nearly flat bathymetry within the OWF with water depth ranged between 45 and 55 m also no significant influence of the water depth is expected.

According to Soloway and Dahl (2014) the peak Sound Pressure can be calculated as follows:

$$p_{pk} = 52.4 \times 10^6 \left(\frac{R}{W^{\frac{1}{3}}}\right)^{-1.13}$$

Equation *11*

with

R - distance in meter

W - explosive charge weight in kg TNT.

Additionally, a semi-empirical formula for the SEL is also given in Soloway and Dahl (2014) based on their evaluated measurement data:

$$SEL = 6.14 \times log_{10}\left(W^{\frac{1}{3}}\left(\frac{R}{W^{\frac{1}{3}}}\right)^{-2.12}\right) + 219$$

Equation *12*

The estimated peak Sound Pressure Level and Sound Exposure Level as source level (re 1 m to source) for the different UXO findings are summarized in Table 1 to predict the source level of UXO detonations.

Table 1: *Predicted source levels at 1 m distance for the Sound Exposure Level (SEL) in dB (re 1µPa²s) and for the zero-to-peak Sound Pressure Level ($L_{p,pk}$) in dB (re 1 µPa respectively) for a given charge weight of TNT (TNT-equivalent weight).*

TNT equivalent charge weight	SEL in dB re 1 µPa² s	$L_{p,pk}$ in dB re 1 µPa
1 kg	219	274
5 kg	223	280
10 kg	225	282
100 kg	232	289

5. Measurement execution

In the period from May 14th to June 24th 2020 in total 37 UXO clearance activities were measured by means of standalone "offline" underwater noise devices (4 pcs "standard offline", 1 pcs "high sensitive offline" and only at #1 UXO7 1 pcs "vessel based online monitoring"- see chapter 5.1). The measurement equipment was deployed once prior to this time span and recovered once afterwards by *itap GmbH* employees from aboard of the supply vessel *World Moon*; means during the six weeks no offshore personal was present within the OWF area. A guard vessel checked the marker buoys at sea surface each two weeks. No marker buoy was defect nor lost.

Technical note: In case of loss of any marker buoy within the first two weeks of the measurement campaign a maintenance tour on short notice was planned.

For quality assurance reason the supply vessel *World Moon* was in standby mode during the first measured UXO clearance activity on May 14th/15th within the OWF area and performed an additional vessel based underwater noise measurement on one detonation. Additionally, all stand-alone measurement devices were recovered after the first explosion, data stored and a quality check of all recordings (avoidance of clipping effects) were performed. After successful quality assurance check all stand-alone measurement devices were redeployed successfully.

Furthermore, during the deployment of all measurement devices on May 14th/15th the sound velocity profile from the sea surface to the seabed was measured once by application of a so-called CTD probe (technical description see chapter 5.2).

5.1 Measurement positions

In total 4 pcs measurement positions were used to record the UXO clearance activities (explosions) in different distances to source, Figure 1 (p. 9). The planned measurement positions were pre-selected by *NnGOWL* and checked regarding safety issues (UXO free, cables etc.) in advance. Furthermore, the measurement positions were discussed with the R&D project BEIS and the local regulatory authority. Table 2 states the as-laid coordinates of the corresponding marker boys (coordinates logged during recovery of the measurement devices). These are the most accurate coordinates nearest to the position of the actual measurement devices.

Table 2: Measurement positions used.

Measurement position:	Coordinates (WGS84) dd°mm.mmm'N ddd°mm.mmm'W
MP1	56°15.605' N 002°16.690' W
MP2	56°16.307' N 002°16.994' W
MP3	56°17.769' N 002°14.932' W
MP4	56°20.097' N 002°14.219' W

With respect to the different UXO locations (Figure 1, page 9) but unaltered measurement positions a multitude of distances between the explosions and measurement positions result, with 1.4 km being the shortest distance between MP1 and UXO clearance activity for UXO26 and 33 km being the largest distance between MP4 and UXO clearance UXO41.

On the one hand, this manifold of measurement distance is advantageous for, e.g., the analysis of the project specific transmission loss as well as the analysis of the UXO clearance prediction. Since measurements at a multitude of distances can be used to better verify the distance dependencies of the applied sound propagation models. On the other hand, it is disadvantageous for a direct comparison of measurement results.

5.2 Measurement devices used

In total 6 pcs different measurement devices for recording the underwater noise during UXO clearance activities were used:

- **(i)** 1 pc real time (online monitoring, vessel based) devices with standard sampling rate of 44.1 kHz only for the 1st explosion within this measurement campaign (May 14th/15th),
- **(ii)** 4 pcs offline measurement devices with standard sampling rate of 44.1 kHz and high dynamic ranges for measuring the detonation noise of all explosions and
- **(iii)** 1 pcs offline device with high sampling rate (96 kHz) and a sensitive sensor to be able to measure the permanent background noise (ambient noise) as well as some of the explosions in greater distances.

(i) Real-time devices

The real time measurement was carried out with a Reson TC 4033 hydrophone and a calibrated charge amplifier (Metra, Germany). The signals were converted to WAV format with a high quality 24-bit sound card and then evaluated in real-time with a laptop computer. The hydrophone was deployed from the supply vessel *World Moon* with a gravity anchor in the lower half of the water column. The real-time vessel based underwater noise measurement device was developed and constructed by *itap GmbH*.

(ii) Standard offline devices

The 4 pcs offline measurement devices are developed and built by the *itap GmbH*. Four autonomous measurement devices were deployed at the four pre-selected measurement positions to record the time signals (proportionally to the sound pressure course of time) of the underwater noise from the explosions. Each measurement position was fitted with one Teledyne-Reson TC4033 hydrophones, preamplifier built by *itap GmbH*, and Marantz PMD 620 audio recorder. Hydrophone signals were recorded in compressed MPEG1 format with a sampling frequency of 44.1 kHz, 16 Bit resolution and a bandwidth of 10 Hz to 20 kHz. For sufficient headroom, the maximum record level was set between 208 dB and 224 dB zero-to-peak Sound Pressure Level re 1 µPa. The hydrophones were positioned at about 2 m above the seabed by means of a floating ball. The entire measurement sensor technology and power supply of the underwater noise measurement devices is located in the submersion body, which also serves as a weight anchor. Each location was marked by a 3 m spar buoy and a yellow marker ball (see Figure 5 and Figure 6).

At each measurement position, at least two independent measurement devices were deployed since the storage capacity of each measurement device is limited to 4 weeks. The recording systems have been set up to record consecutively: for the first four weeks the 1st devices were active and the 2nd devices per positions was activated automatically after four weeks.

The evaluation of all measurement data is usually done onshore after the recovery of the "offline" measurement devices.

(iii) Sensitive offline measurement device

At position MP4, a supplementary measurement system was used in addition to the above-mentioned proprietary measurement devices.

This measurement device was a Song Meter SM2M device from *wildlife acoustics* (www.wildlifeacoustics.com). This SM2M measurement device is able to record the underwater noise with 16-bit and a sampling frequency of 96 kHz. Based on the aim to measure at measurement position MP4 the ambient / background noise the version with a sensitive hydrophone was pre-selected.

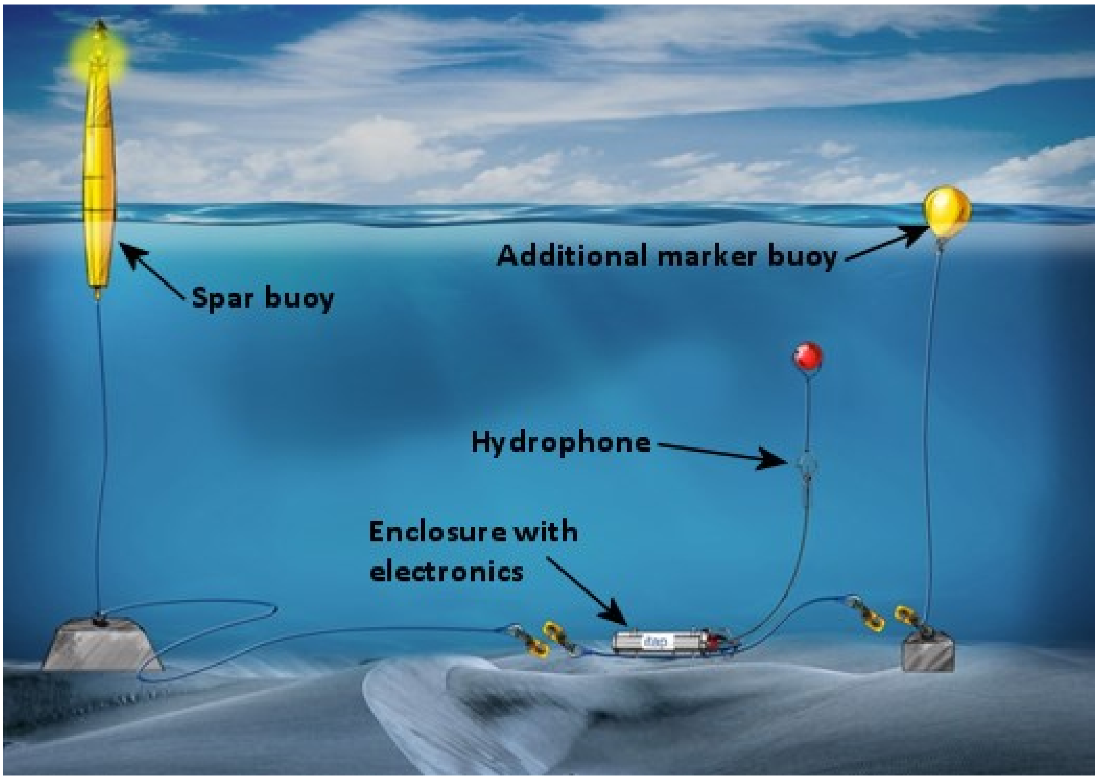


Figure 5: *Setup at each measurement point (note: the four yellow rings near the sea bottom are so-called C link rope connectors. Normally the adjacent C links are attached to each other.*

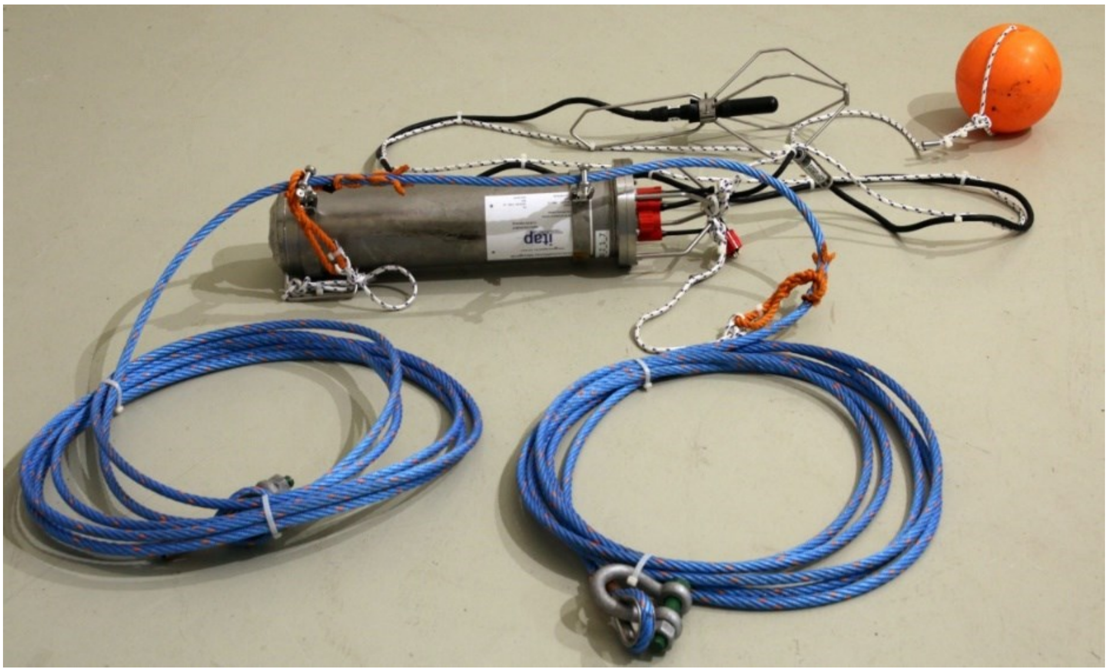


Figure 6: *Example of the used recording devices, developed and build by the itap GmbH.*

Technical note: Based on the limited range of any underwater noise measurement devices, especially the hydrophone used, it was expected that this measurement device will partly have some clipping events in case of high levels during UXO clearance activities occurred.

All used underwater noise devices are stand-alone applications and working independent from each other; only handmade time synchronization is possible.

All used devices fulfill the requirements of ISO 18406 (2017). All measurement devices are calibrated every two years in accordance to ISO 18406 and ISO 17025 (2018). Before deployment and after recovery factory assurance test (FAT) was performed. Both FATs for each measurement devices show no significant difference to each other.

In the following Table 3, all applied devices are given.

Table 3: *Specifications of the used measurement devices.*

Device	Manufacturer	Important technical data	Comments
independent underwater noise measurement system „offline“	itap	frequency range: 10 Hz - 20 kHz	
vessel-based underwater noise measurement system „online“	itap	frequency range: 10 Hz - 20 kHz	
hydrophone TC 4033 (passive)	RESON	sensitivity: approx. 0,5 pC/Pa	
charge amplifier	itap	0,1 mV/pC	in conjunction with the hydrophones of the company RESON
electric calibrator	itap	1000 Hz; 10, 100 mV; 10, 100 pC	IEC 17025-compliant calibration
pressure chamber	itap	125 Hz, 154 and 171 dB re 1µPa adjustable	
ISO/IEC 17025 (UKAS) calibrated hydrophone TC 4013 as reference in pressure chamber	RESON		
hydrophone-pistonphone 4229 with adapter WA 0658	Brüel & Kjær	250 Hz, 152 dB re 1µPa	
DKD-calibrated digital multimeter / oscilloscope U1610A	Agilent		verification of the electric calibrators
SM2M at MP4	Wildlife Acoustics Inc.	Frequency range: 3 Hz – 48 kHz	

CTD multimeter probe

A multiparameter probe "CTD48" from *Sea & Sun Technology GmbH* (www.sea-sun-tech.com) was used to measure the temperature, the static pressure and the salinity in the water column. On basis of these parameters it is possible to determine the sound velocity profile over the water column.

The mooring system of this device consisted of a rope (max. length 100 m) with an anchor weight of 2 kg at one end of the rope.

The sound velocity profile was recorded directly after the deployment of the noise logger at position MP4.

A factory assurance test (FAT) was performed once before offshore measurements.

5.3 Technical issues

During post-processing and evaluation of the measurement data it turned out that one of the used hydrophones at measurement position MP3 has a defect. Each long-time measurement position consists of two separate measurement devices with a recording duration of 4 weeks each. The second measurement device at MP3 has a drop in frequencies below 1 kHz, so the measured data of MP3 from June 11th onwards (UXO33 to UXO43) must be classified as not valid.

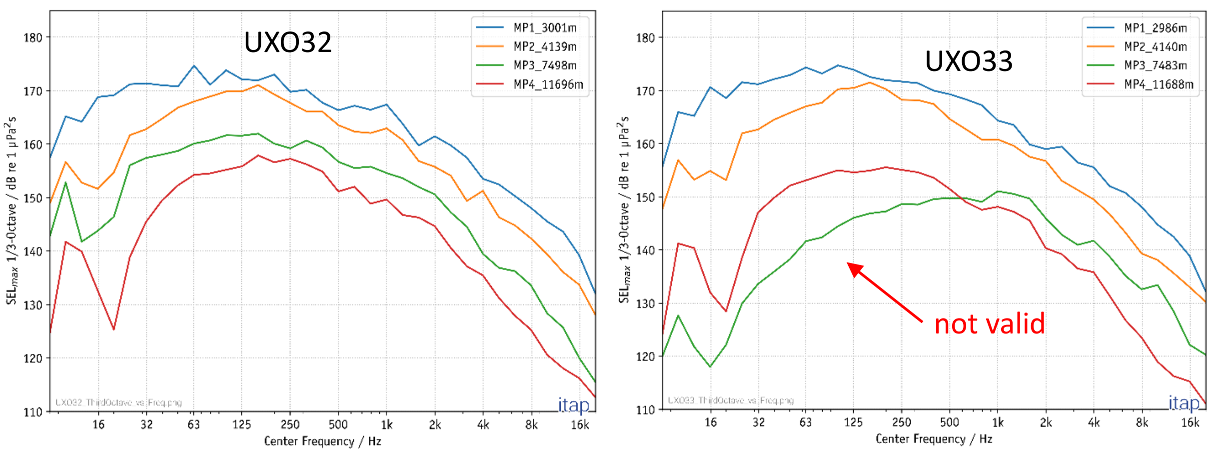


Figure 7: *Left: 1/3 octave spectra of the measurement positions MP1 to MP4 during the UXO clearance activity of UXO32 (NEQ: 102 kg, charge weight: 5 kg); all hydrophones used have had no defect. Right: 1/3 octave spectra of the measurement positions MP1 to MP4 during the UXO clearance activity of UXO33 (NEQ: 102 kg, charge weight: 5 kg); hydrophone used at MP3 have had a defect which was identified during the calibration process after measurement was conducted.*

Figure 7 shows that the levels for low frequencies (< 1 kHz) for MP3 are much lower than expected for the UXO clearance activity UXO33. Possible reason is a micro perforation at the hydrophone cable; means water enters into the cable.

Since the SM2M device of *wildlife acoustics,* that was used to measure frequencies up to 48 kHz, has a fixed quite high sensitivity, only ambient noise as well as measurements in 10 km distance or more for UXO clearance activities could be evaluated. At measurements closer than 10 km to the UXO clearance activity the high sensitivity of the SM2M hydrophone yields to clipping of the audio data that makes them not evaluable.

6. Measurement results

6.1 General

Overall, 37 pcs of UXO clearances were measured between May 14th and June 24th 2020 within the OWF *Neart na Gaoithe*. The UXO types, charge weight, ADD protocols, water depths as well as some weather data are summarized in an external document (see Appendix A.2). The most relevant information for the further analysis of the underwater noise measurement data are summarized in Table 4.

Table 4: *Relevant information regarding UXO clearance within OWF Neart na Gaoithe.*

Parameter	Minimum	Maximum	Comment
NEQ value (kg)	5 (once 0.25)	102	
Distance source – receiver (m)	MP1: 1,362 MP2: 1,715 MP3: 1,708 MP4: 5,065	MP1: 24,337 MP2: 25,557 MP3: 28,745 MP4: 33,020	The biggest UXO found was 181 kg but this clearance activity was not measured
Charge weight (kg)	2.5	5.0	
Pre-detonation (NEQ value. Kg)	N/A or 50 g	150 g	Up to 3 pcs pre-detonation with 50, 100 and 150 g. No pre-detonation (soft-start) for UXO types with < 50 kg NEQ
Sign. wave height (m)	0.4	1.3	Mostly < 1.0 m
Wind speed (knts)	8	25	
Sound Exposure Level (dB)	148.1	190.3	These values do not indicate that the lowest value was measured at the shortest distances.
Zero-to-peak Sound Pressure Level (dB)	165.5	209.3	

Technical note: Based on the overall measurement uncertainty for any underwater noise measurements all decibel values are rounded to natural numbers: 160.4 dB indicates 160 dB and 160.5 dB indicates 161 dB.

Technical note: All measured raw data as well as post-processed data incl. calibration information are stored on an external hard drive for further investigations within the R&D project BEIS. Nevertheless, for each single detonation measurement at each single measurement position the following figures are generated and stored on this external hard drive as well:

- Level vs. Time plot
- Histogram plot of levels
- Third octave spectrogram
- Third octave spectrum

Figure 8 shows a histogram with the number of measurements as a function of the distance to the four measurement points.

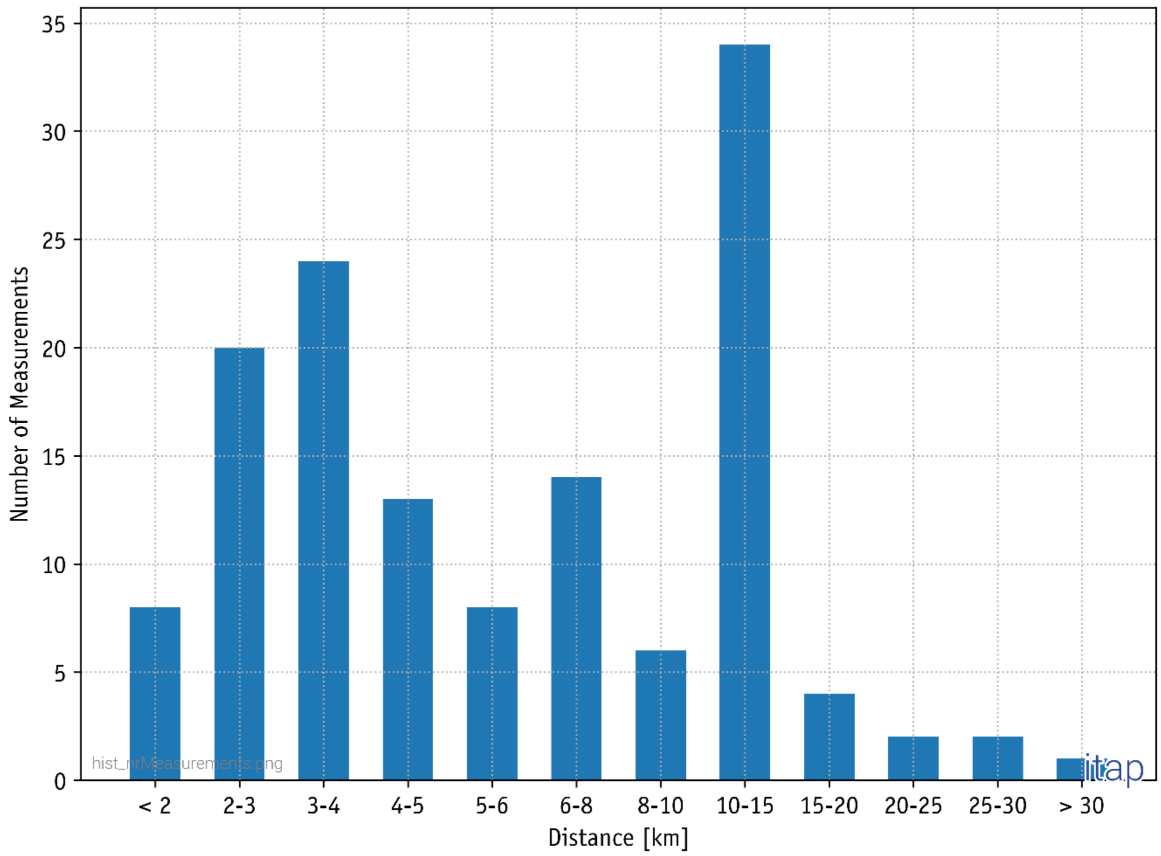


Figure 8: *Histogram of the number of measurements per distance to the UXO detonation, based on the measurement locations and UXO locations with recorded detonations.*

The minimum distance between UXO clearance activity and measurement device was 1,362 m, the maximum distance 33,020 m.

The Sound Exposure Level (SEL) is determined for a single impulse according to the measurement specification for underwater noise (BSH (2011)) resp. the ISO 18406 (2018-08), where each impulse is analyzed individually as soon as the signal-to-noise-ratio is ≥ 10 dB. For the presentation of the results, the 1/3 octave spectra (IEC 61260 (2014)) are limited to the frequency range of 12,5 Hz to 16 or 20 kHz unless otherwise specified.

Even for distances of 33 km the signal-to noise ratio (detonation noise – ambient noise) was > 10 dB.

In Figure 9 the Sound Pressure Level (SPL) as well as Sound Exposure Level (SEL) and zero-to-peak Sound Pressure Level ($L_{p,pk}$) measured for UXO16 (NEQ value 102 kg) as well as for the three pre-detonations with 50, 100 and 150 g TNT-equivalent at MP2 in 4.672 m distance are shown. The levels increase with increasing size of the TNT-equivalent weight of the pre-detonations slightly from approximately 180 dB with 50 g to 186 dB with 150 g for the $L_{p,pk}$., as expected by the prediction model of Soloway and Dahl (2014). The UXO clearance activity of UXO16 with 102 kg NEQ ranged at 195 dB. Based on the predictions of Soloway and Dahl (2014) a difference of approximately 20 dB between 50 g and 102 kg was expected.

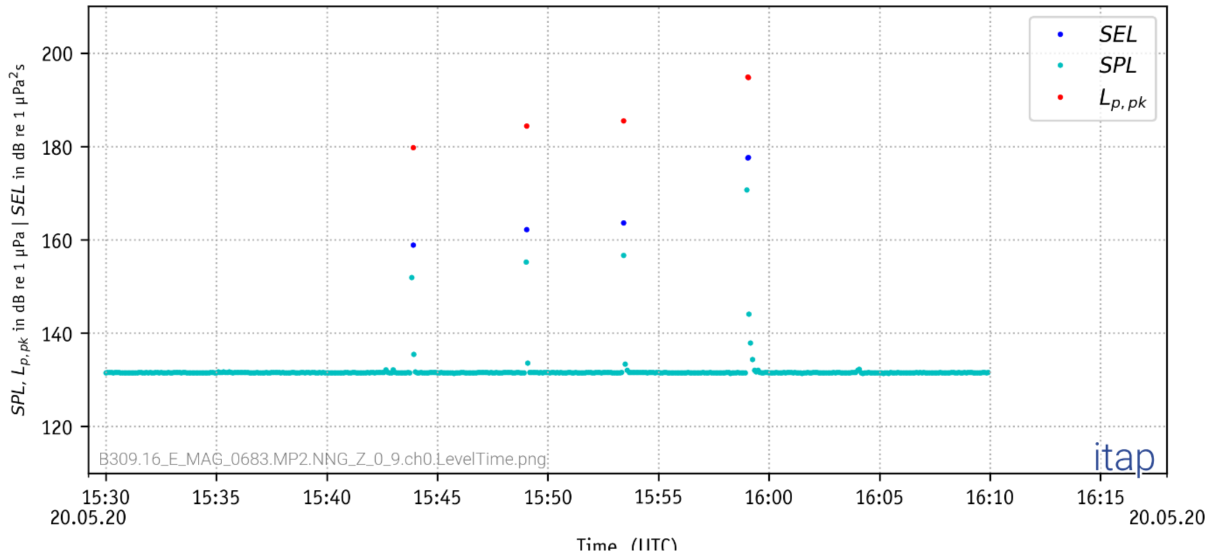


Figure 9: *Sound Pressure Level (SPL), as well as Sound Exposure Level (SEL) and zero-to-peak Sound Pressure Level ($L_{p,pk}$) measured for UXO16 (NEQ: 102 kg, charge weight: 5 kg) as well as the three pre-detonations with 50, 100 and 150 g TNT-equivalent at MP2 in 4.672 m distance.*

6.2 Influencing factors on measured noise levels

In Figure 10 the Sound Exposure Level (SEL) and zero-to-peak Sound Pressure Level ($L_{p,pk}$) measured at measurement location MP1 (top) and MP4 (bottom) as function of distances to UXO clearance are summarized. For MP1 the measured Sound Exposure Level decrease from 190 dB in approximately 1.5 to 1.8 km distance down to 162 dB in 24.3 km distance. Based on the double logarithmic scaling the measured data indicates a proper linear correlation between the noise levels and the distance; independent from TNT-equivalent and UXO type. The measured zero-to-peak Sound Pressure Levels ranged between 209 dB and 176 dB in distances of 1.5 and 24.3k m. The differences between the SEL and $L_{p,pk}$ ranged between 14 and 23.5 dB (averaged 19 dB).

For MP4 the SEL ranged between 178 dB in 5.0 km distance to 158 dB at 33 km; $L_{p,pk}$ ranged between 198 dB and 173 dB in distances of 5.0 and 33.0k m. The variances between measured SEL values at similar distances increased partly for MP4 in comparison to MP1.

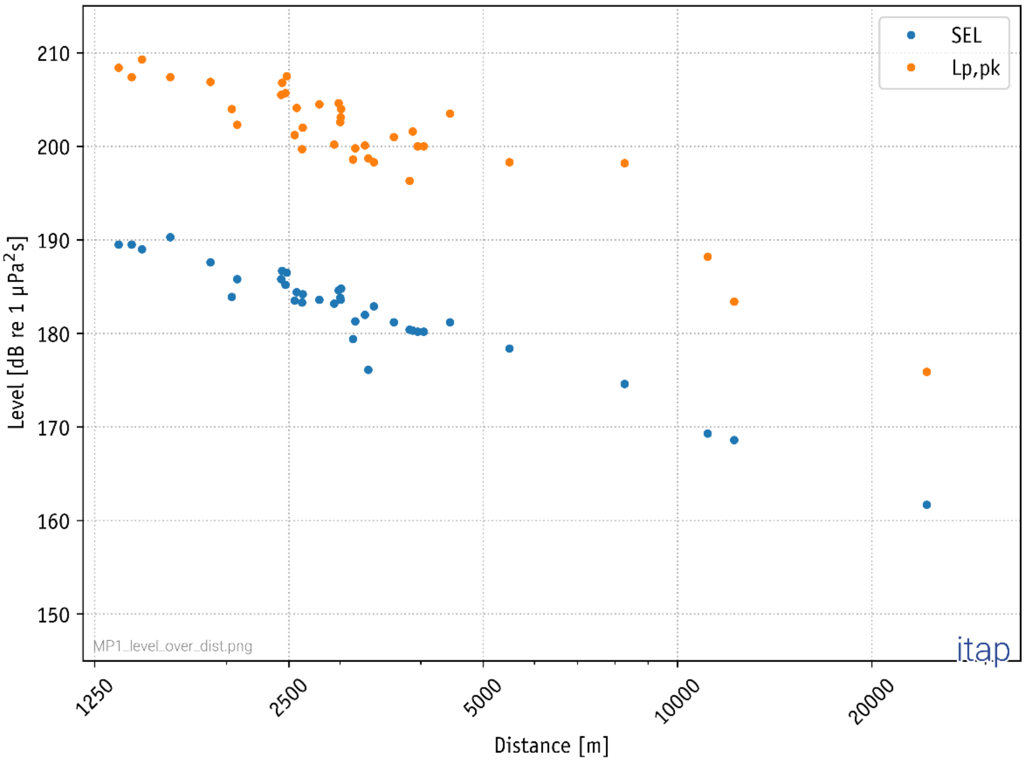
Figure 11 indicates the TNT equivalent weight (NEQ) of each UXO clearance activity in comparison to Figure 10. The differences of the measured noise levels in similar distances between NEQ values of 5 kg are not significantly lower than for values of 102 kg. Based on predictions (chapter 4) the differences for such NEQ values should be 9 dB. A charge weight (detonator) of 2.5 or 5.0 kg was used for all UXO clearance activities.

Further discussion regarding the influence of the TNT-equivalent weight (NEQ) of each detonation is summarized in chapter 7.6.

Figure 12 shows the SEL and $L_{p,pk}$ over distance for all measurement positions and UXOs with only 102 kg NEQ.

In Figure 13 the 1/3 octave spectrum of one representative UXO clearance activity measured in different distances is shown.

In comparison of impact pile-driving noise the detonation spectrum is much broader and produce sound entries in water with high amplitudes between 30 and 800 Hz. For higher frequencies the level will decrease with 6 to 8 dB per octave. For frequencies < 30 Hz the amplitude decreases with approximately 5 dB per octave. The differences between the ambient noise and the detonation noise is quantified and discussed in chapter 7.7.



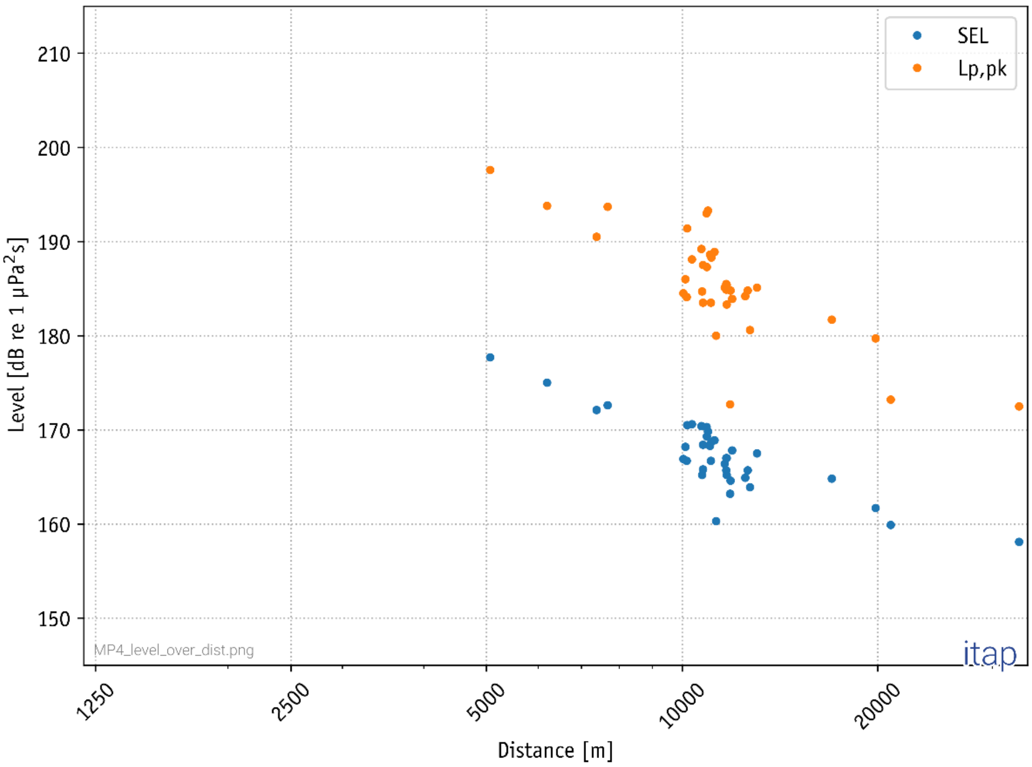


Figure 10: *Sound Exposure Level (SEL) and zero-to-peak Sound Pressure Level ($L_{p,pk}$) measured at measurement location MP1 (top) and MP4 (bottom) as function of distances to UXO clearance.*

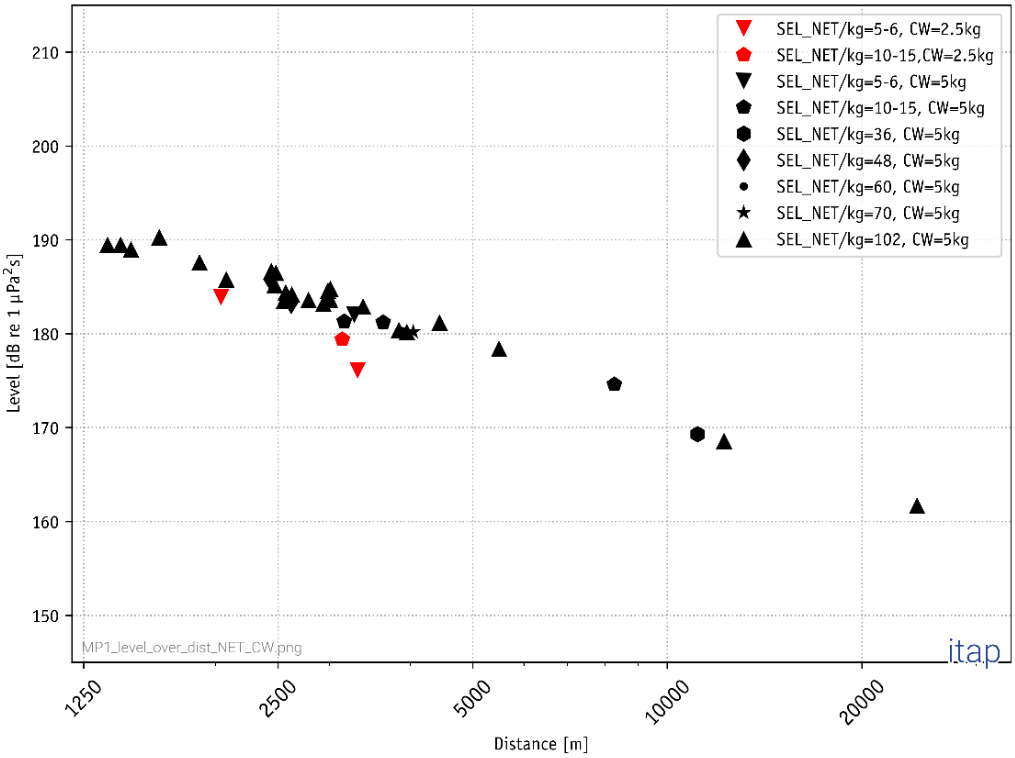


Figure 11: *Sound Exposure Level (SEL) measured at measurement location MP1 as function of distance and distinguishing the NEQ and charge weight.*

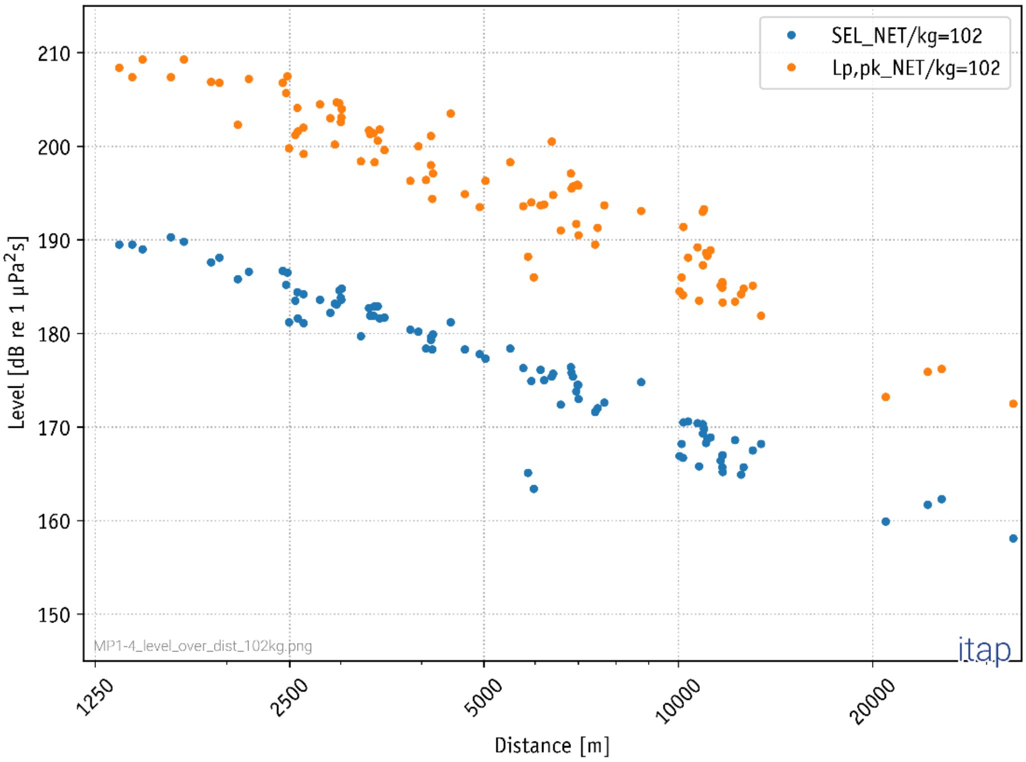


Figure 12: *Sound Exposure Level (SEL) and zero-to-peak Sound Pressure Level ($L_{p,pk}$) measured at measurement locations MP1 to MP4 as function of distances to UXO clearance, only for UXOs with 102 kg NEQ and charge weight of 5 kg.*

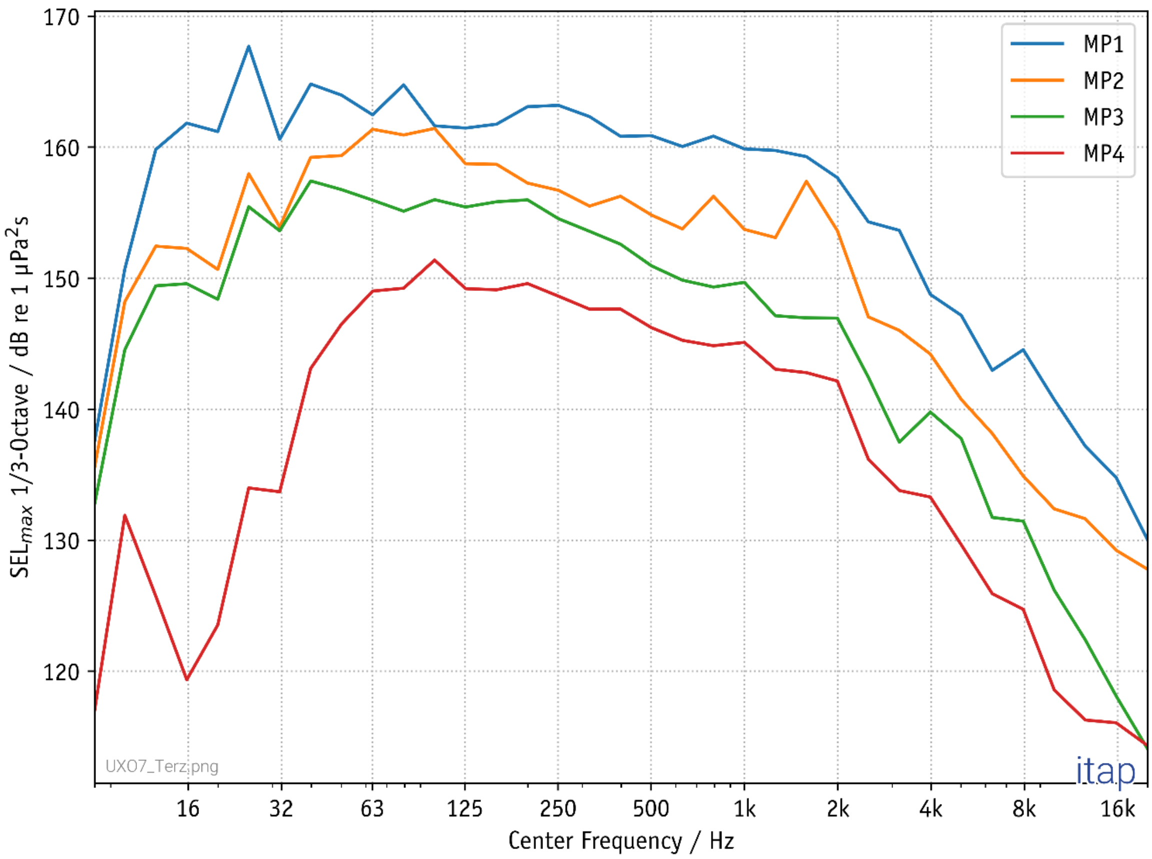


Figure 13: *1/3-ocatve spectrum of the Sound Exposure Level (SEL) of UXO07 clearance activity (NEQ: 0.25kg, charge weight: 2.5 kg) measured in different distances at MP1 (3.319 m), MP2 (4.625 m), MP3 (7.025 m) and MP4 (11.281 m).*

6.3 Sound speed profile measurements by CTD probe

In Figure 14 the sound velocity profile measured on May 14th 2020 at measurement position MP4 within the OWF *Neart na Gaoithe* is depicted. The sound velocity decreases slightly from approximately 1.484 m/s on the sea surface down to 1.480 m/s on top of the seabed. Means there is an unincisive sound profile during this measurement. The partly a bit higher sound velocity on the sea surface is caused by the bit warmer surface water temperature but will most likely not have any significant influence on the sound propagation over short distances.

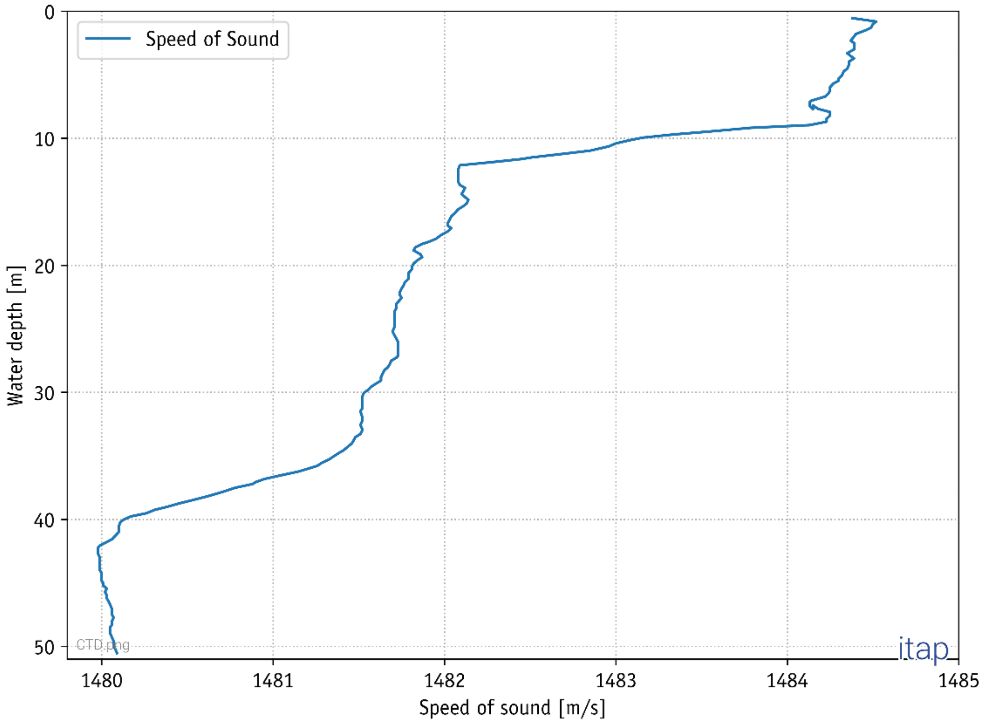


Figure 14: *Sound speed profile measured on 14.05.2020 at measurement position MP4.*

Similar CTD probe measurements were partly performed during the construction phases of German OWFs in Baltic and North Sea (e.g. Bellmann et al., 2020). Within the North Sea no distinct sound profile was measured anyhow even during long good weather periods in the summer. Background is that the water will be mixed twice per day by the tide current in the North Sea. However, in the Baltic Sea once a distinct sound profile during impact pile-driving measurements were observed after a long and stable good weather period. This phenomenon is partly named Baltic duct. Hydrophone measurements below, inside and above the Baltic ducts indicates that this sound profile have had no significant influence on the sound propagation of low frequency percussive pile-driving noise (Bellmann et al., 2020).

6.4 Acoustic Deterrence Device (Seal Scarer)

In order to make sure that no marine mammals get injured during the detonations, a seal scarer device was deployed about 30 minutes in advance of the first pre-detonation as an acoustic deterrence device – ADD (http://www.lofitech.no). This ADD was deployed from the vessel which was performing the UXO clearance activities. The frequencies emitted by the seal scarer are ranged between 14 and 15 kHz.

Figure 15 shows the underwater noise measurements at measurement position MP4 with the SM2M measurement devices in a distance of 13 km to UXO clearance (UX014; 70 kg). The 30 min seal scarer application can be seen from minute 15 to 47. Several minutes after the active seal scarer two independent pre-detonations of several grams (50 g and 100 g) of TNT equivalent were used before (~50 and 55 min) the UXO clearance activity (~60 min) was performed.

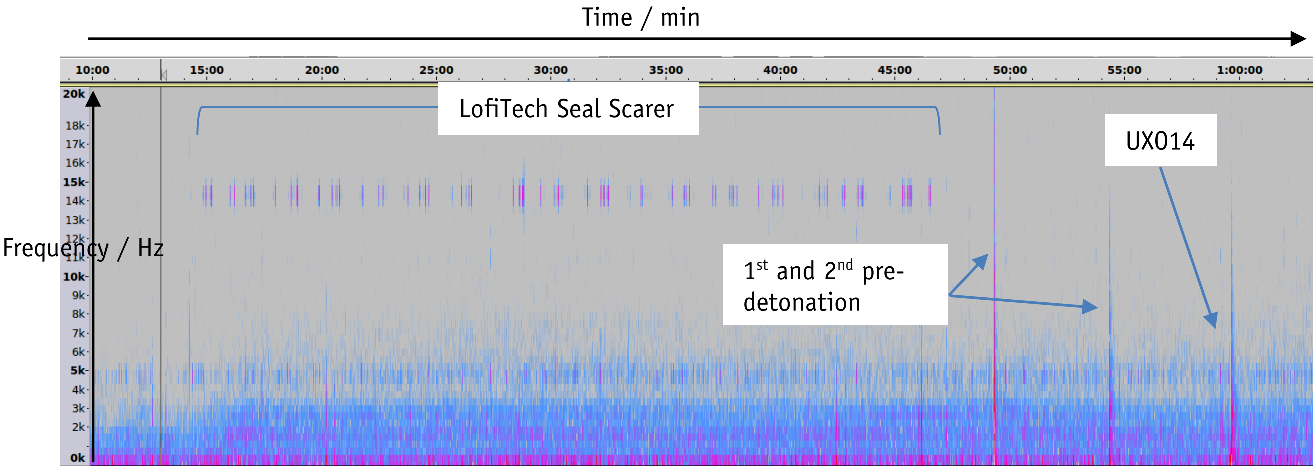


Figure 15: *Spectrogram of the sound pressure caused by the acoustic deterrence device seal scarer (minute 15 to 47) as well as two pre-detonations 10 and 5 minutes before the main detonation at ~1 hrs recording time. The UXO clearance activity was performed on May 18th 2020 for UX014 (NEQ: 70 kg, charge weight: 5 kg) and measurements were performed in 13 km distance to source.*

7. Evaluations and discussions

7.1 Shock wave and bubble oscillations

An explosion of a TNT-equivalent material in water is usually described as a so called shock wave, followed by oscillations of the gas bubble produced by the explosion (Figure 16). The shock wave impulse has an extremely short rise time, and also a short decay time constant in the order of 1 ms (Ross 1987, section 7.10). The latter value depends on the charge and on the distance of the observer; the value of 1 ms holds for a 100 kg charge at 500 m distance. The shock wave initially propagates with supersonic speed. Due to the short duration of the shock wave impulse, the acoustical spectrum of the explosion is flat up to 1 kHz (for the above example value); above that frequency, it decreases with 10 to 20 dB/decade.

The delay time T between the shock wave impulse and the first bubble impulse is approximately given by Ross 1987 (several similar formulas published by other authors, as well):

$$T = 1.6 \frac{W^{1/3}}{(h+10)^{5/6}}$$

Equation *13*

where W is the charge in lbs (1 kg= 2.2 lbs) and h is the depth in metres. T is in seconds. The reciprocal of T is the fundamental bubble oscillating frequency. For a detonation depth (not water depth) of approximately 50 m (on the seabed) and charges between 5 kg and 102 kg, as in this investigation, the frequencies are about 3.1 Hz to 8.5 Hz, means very low frequencies.

A separation of the shock phase from the bubble phase, as shown schematically in Figure 16, was not feasible using the measurement data of the OWF *Neart na Gaoithe* UXO clearance. It is only possible under certain ideal conditions: detonation at relatively large water depth and short distance between detonation and receiver, e.g. < 500 m. This was not possible, based on the available measurement devices (see chapter 5.2).

However, sound with such low frequencies does not propagate unmitigated in shallow water (Urick 1983 section 6.6). Based on the site-specific water depth between 45 and 55 m (LAT) unmitigated sound propagation within this OWF is possible for frequencies > ~20 Hz. In the setup described in this report, all measured sound thus originates from the shock wave. Due to numerous reflections from the seabed and the sea surface, even at the observation distance of 1.4 km, the initial shock pulse is turned into a complex and lengthened pattern.

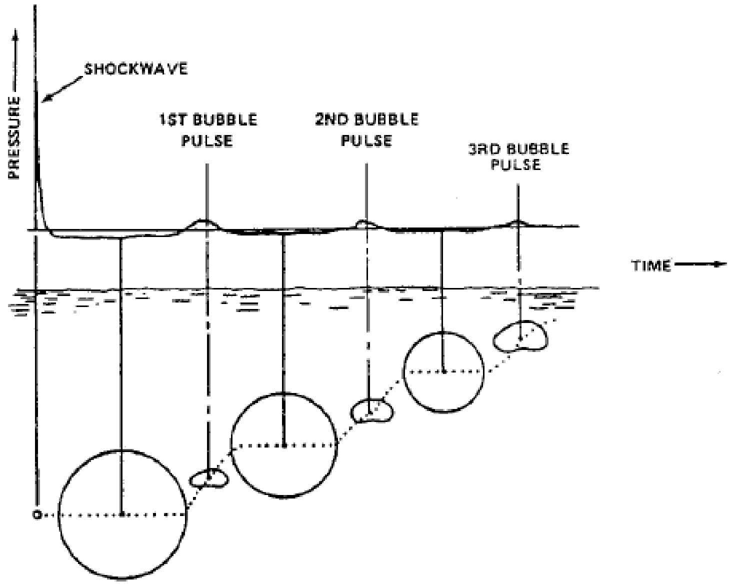


Figure 16: *Sound Pressure versus time for a TNT explosion (Geers and Hunter 2002).*

7.2 Seismic precursor

In some of the time signals of the detonation noise recordings a low frequency oscillation can be seen prior to the main front. One example is shown in Figure 17. These "seismic precursors" are waves traveling in the seabed. Since the sound velocity is mostly slightly higher in the sediment than in water, the signal arrives earlier at the receiver than the one that travels through water only. Sometimes this phenomenon is also associated with the so-called head wave or Scholte-wave, a wave type that initially starts as sound in water, and then propagates some distance in or along the sediment (Medwin, 2005).

Assuming a sound speed of approximately 1,500 m/s in water and of 1,700 m/s in the seabed, the measurement at 5.7 km distance from the UXO, one would expect a precursor about 470 ms in advance of the main wave. This value is in rough agreement with the pattern in Figure 17.

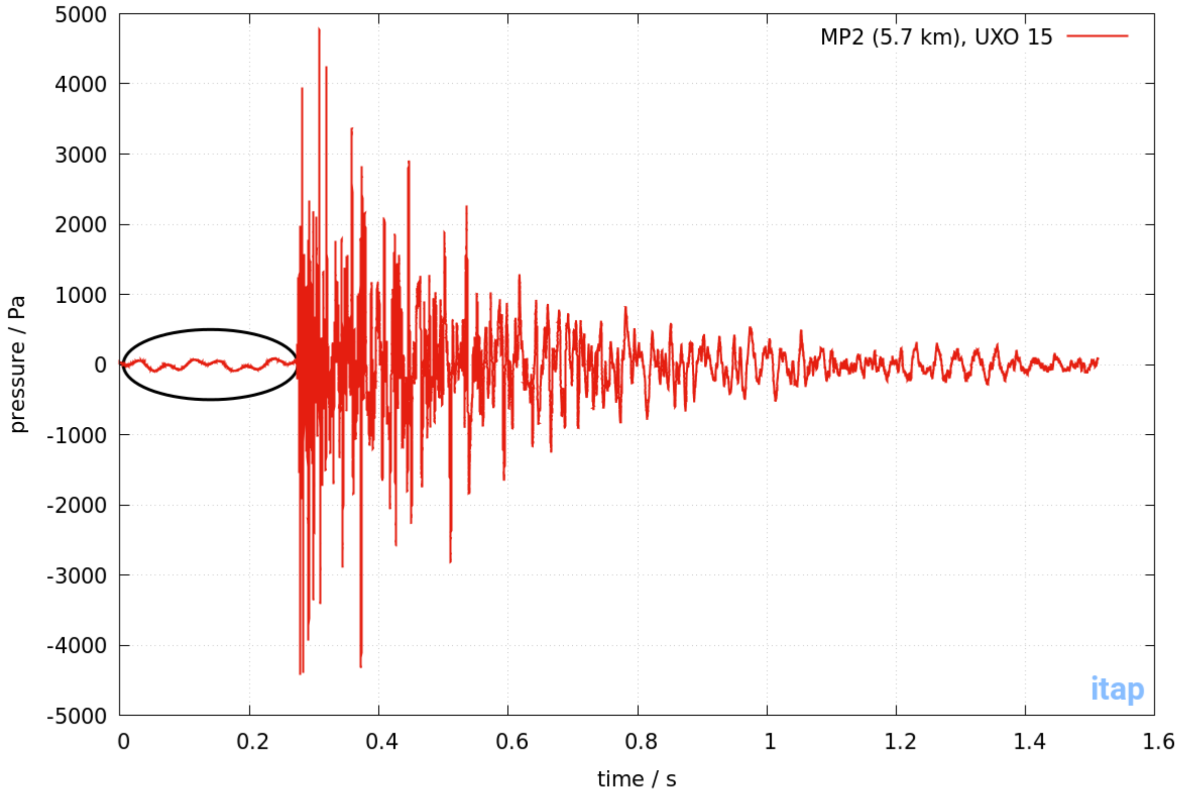


Figure 17: *Sound pressure measured in a distance of 5.7 km (MP2) distance to UXO15 (NEQ: 102 kg, charge weight: 5 kg) clearance as a function of time. The seismic precursor is marked by black oval before the water borne shock wave.*

In the measurements in this report, the seismic precursor's contribution to the SPL or SEL can be neglected since its peak level is more than 30 dB below the water borne shock wave.

This precursor was not measured for all UXO clearance activities nor at all measurement positions. Partly this precursor was detectable in distance of 5 to 6 km (MP2) but not in closer distances (MP1). A reason might by the soil layer conditions within the OWF area.

7.3 Pre-detonations

Before the detonation of the larger UXOs up to three pre-detonations with charge weights between 50 g and 150 g were ignited 15, 10 and 5 minutes in advance to the UXO clearance activity. An example is shown in Figure 18 for the UXO clearance UXO16 measured in a distance of 6.8 km (MP3). The first pre-detonation was with 50 g TNT-equivalent approximately at 3:43 pm (UTC time) on May 20th 2020, the 2nd and 3rd pre-detonation followed 5 and 10 min later with 100 and 150 g TNT-equivalent. The UXO clearance activity UXO16 was performed at 3:58 pm with 102 kg TNT-equivalent and a charger weight of 5 kg.

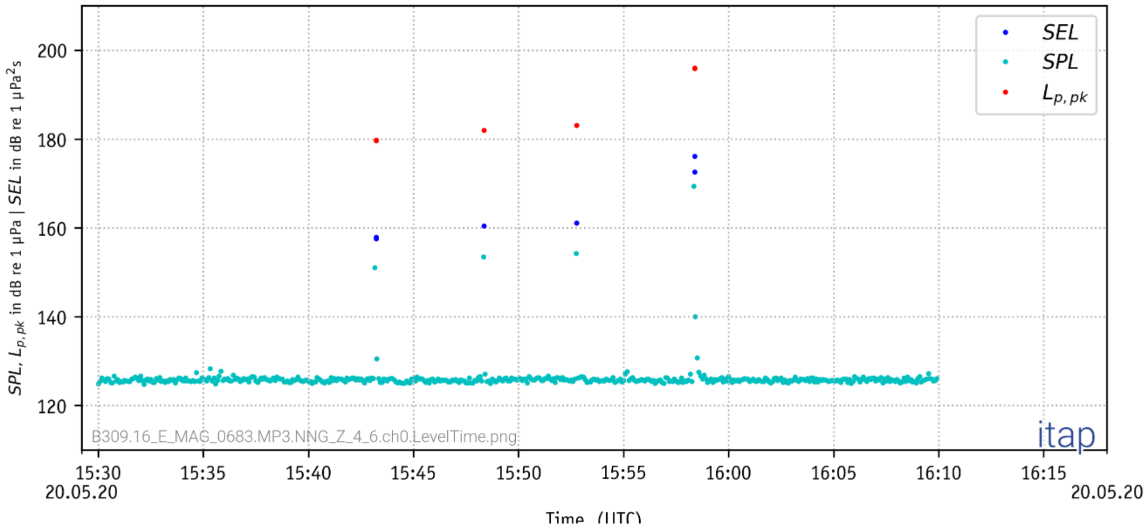


Figure 18: *Sound Exposure Level (SEL), Sound Pressure Level (SPL) and zero-to-peak Sound Pressure Level ($L_{p,pk}$) measured at MP3 in 6.8 km distance to the UXO16 location. The three pre-detonations are recorded 15, 10 and 5 minutes before the UXO detonation at about 15:58 UTC. (pre-detonations with 50, 100 and 150 g TNT-equivalent weight; UXO16 with 102 kg TNT-equivalent and charger weight of 5kg TNT-equivalent)*

Figure 18 shows that the sound metrics in a distance of 6.8 km distance to source increased with the TNT equivalent weight of the detonation. Figure 18 also shows the Sound Pressure Level (SPL) before, during and after the pre-detonations as well as the UXO clearance. The levels before and after the detonations might be biased by the dynamic range of the applied measurement devices so that it is very likely that the approx. 128 dB does not indicate the ambient noise but the lower dynamic range of the devices used.

7.4 Transmission Loss and source levels

In order to estimate the transmission loss, i.e. the decrease of sound level with increasing distance, a least-squares-fit for the SEL and $L_{p,pk}$ was performed. Figure 19 shows an example of such a fit for the measured levels during detonation of UXO27. The best-fit lines show a slope with a factor of 24 to 25, which is much more than the factor of 15 $\log_{10}$(distance) for the geometric transmission loss factor or the semi-empirical factor provided by Thiele & Schellstede (1980), both often used as Transmission Loss for pile-driving noise. A factor of 15 $\log_{10}$ indicates a level decrease of 4.5 dB per doubling the distances (geometrical transmission loss). The semi-empirical transmission loss of Thiele & Schellstede (1980) indicates also a decrease of 4.5 dB per doubling of distance till approximately 10 km. For more distant sound propagation, the absorption for higher frequencies increases significantly which leads to much higher and nonlinear transmission loss factors. A factor of 24 to 25 $\log_{10}$(distance) indicates a level decrease of approximately 7.0 to 7.5 dB per doubling the distance.

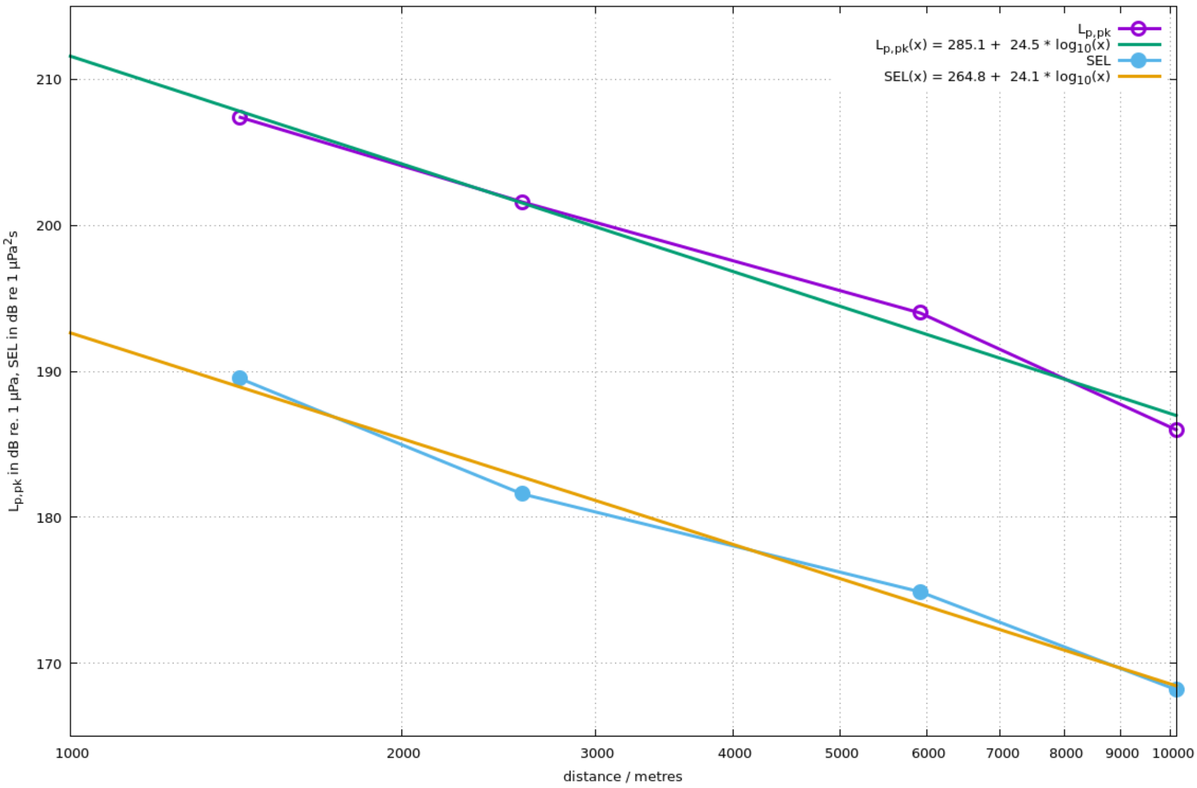


Figure 19: *Measured Sound Exposure Level (SEL) and zero-to-peak Sound Pressure Level ($L_{p,pk}$) (marked by symbols) as a function of distance to the location of UX027 (NEQ: 102 kg, charger weight: 5 kg). The least-squares-fit functions are also shown.*

Figure 20 shows another example for the transmission loss recorded during the detonation of UX029 (102 kg TNT-equivalent and charger weight of 5 kg). Here only the peak level is shown and the least-squares-best fit as well as two theoretical transmission loss curves according *Equation* 11 for the source level (Soloway & Dahl, 2014) for charge weights of 5 kg and 102 kg as well as measured data incl. least-square-fit (24.6 $\log_{10}$(distance)).

The UXO was assumed to have a charge weight of 102 kg, but the amount of explosives detonated must have been lower, based on the measurement results. The calculated curve for 5 kg TNT fits the data much better to the measured results and is nearly identical to the fitted curve (24.6 $\log_{10}$(distance)).

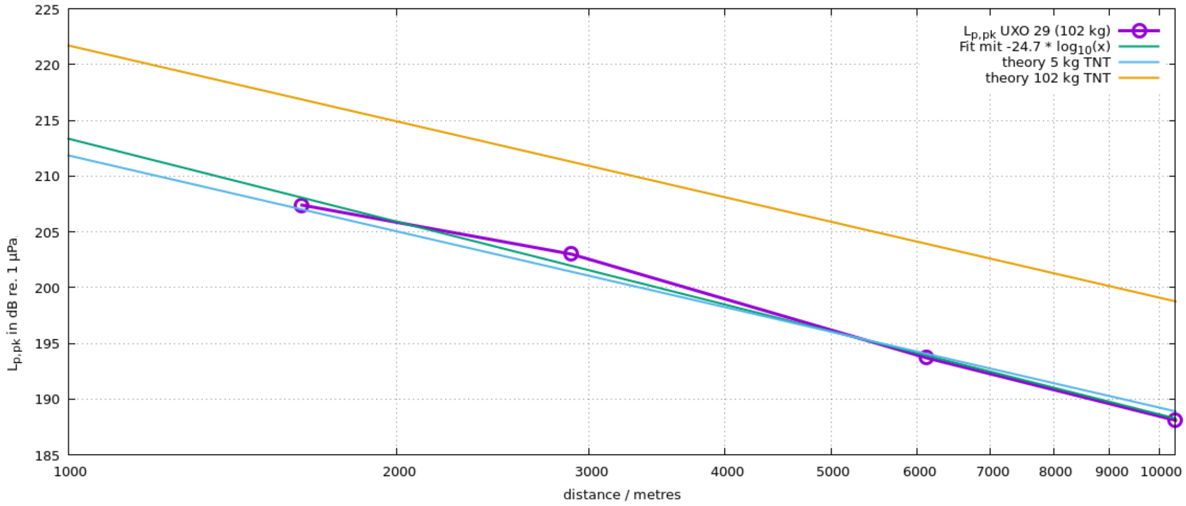


Figure 20: *Measured Sound Exposure zero-to-peak Sound Pressure Level ($L_{p,pk}$) (marked by symbols) as a function of distance to the location of UXO29 (NEQ: 102 kg, charge weight: 5kg). The least-square-fit as well as the estimated levels over distance for a TNT equivalent of 5 and 102 kg in accordance to* Equation *11 are also shown.*

Based on these two examples it can be summarized that the level decrease within 10 km distance is a linear function with approximately 7.0 to 7.5 dB per doubling the distances and much higher than referencing to Thiele & Schellstede (1980). This might be caused by the fact that the UXO is placed in or on top of the seabed and not in the water column as it was the case in Thiele & Schellstede (1980). Additionally, the max. frequencies used by the predictions are < 10 Hz which are not be able to propagate unmitigated in shallow water (here 45 to 55 m) so that not all sound energies might be emitted to the water.

However, Figure 20 indicates that not 100% of the TNT equivalent of the unexploded ordinance was detonated during the UXO clearance activity since the prediction for a 5 kg TNT-equivalent correlates significantly with the measured results and the least square fit. This leads to much lower sound entries during detonation compared to the assumption of a combined explosive weight (NEQ + charge weight). Similar findings were also observed by *itap GmbH* (not published data during UXO clearance activities within German OWF construction phases). This finding is supported by the fact that several UXOs were recovered on deck of the supply vessel after the clearance activity, see Appendix 2.

In order to investigate whether the high propagation loss is caused by the fact that the UXOs were lying on the seabed some of the pre-detonations were analyzed more closely. The small charges were detonated approx. 20 m above the ground i. e. nearly in the middle of the water column; which is in line with the set-up of Thiele & Schellstede (1980).

Figure 21 shows measured zero-to-peak Sound Levels and SELs of the detonation of a 100 g charge before the detonation of UXO14. Also shown are the least-squares-fits for those two levels as well as the predicted levels according to Soloway & Dahl (2014).

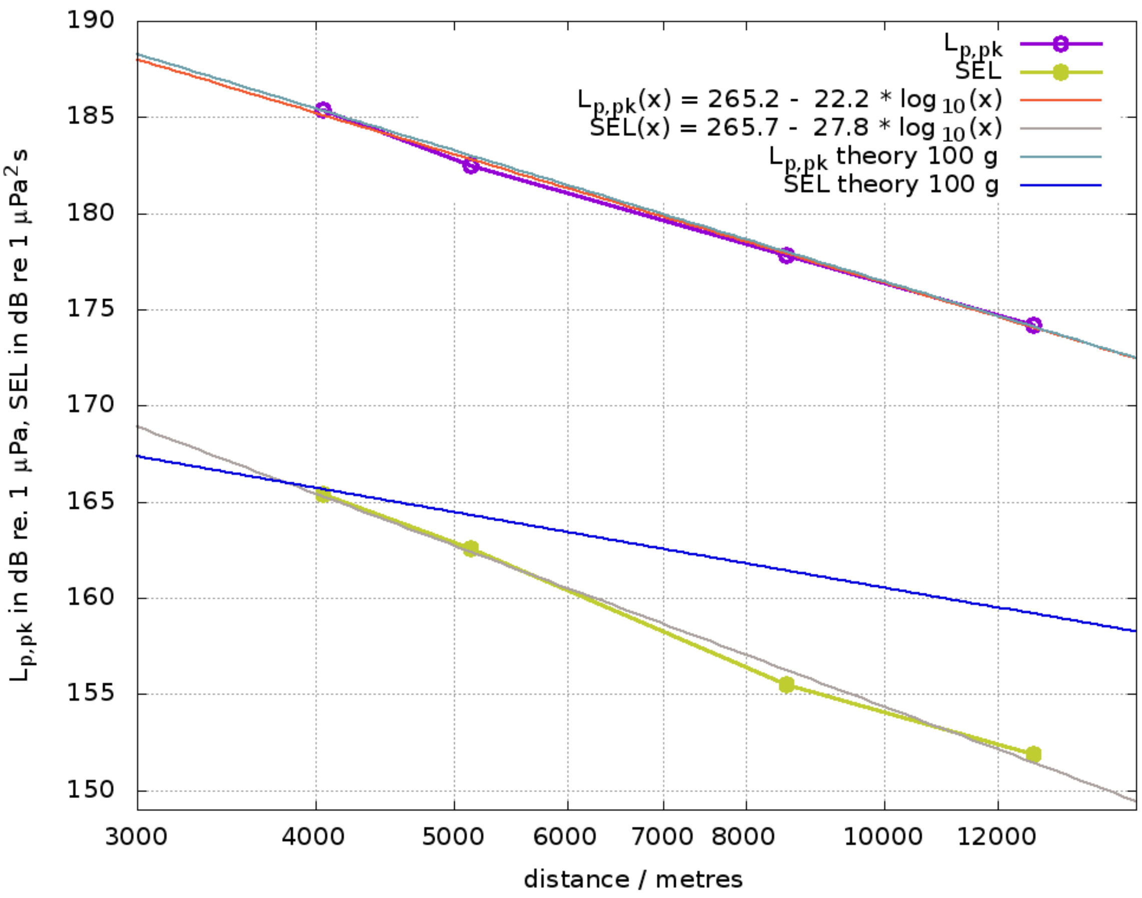


Figure 21: *Measured Sound Exposure Level (SEL) and zero-to-peak Sound Pressure Level ($L_{p,pk}$) (marked by symbols) as a function of distance to the location of pre-detonation of a 100 g charge near UXO14. The least-squares-fit functions are also shown. Moreover, the levels expected according to Soloway & Dahl (2014) are depicted.*

The measured zero-to-peak Sound Pressure Levels ($L_{p,pk}$) show very good agreement with the fitted curve as well as with the levels that are computed according to Equation 11 by applying the model from Soloway and ahl (2014). In contrast the Sound Exposure Level (SEL) has a propagation loss that is higher than it was predicted from the model of Soloway and Dahl (2014) based on Equation 12.

The best-fit propagation loss factors of 22.2 for the $L_{p,pk}$ and 27.8 for the SEL are much larger than the proposed factor of about 15 according to Thiele & Schellstede. The fact that the theoretical peak level for a 100 g charge of TNT and the measurement fit closely while the SEL drops much faster with distance may be due to absorption of the sediment.

The peak level is caused by the shockwave front and thus is caused by line-of-sight propagation. Contrary the SEL is a metric of the total energy contained in the pressure pulse. The SEL is thus caused by sound waves that have undergone a multitude of ground reflections (multi path propagation) where with every ground contact a part of the acoustic energy enters into the sediment.

Figure 22 shows another example of a detonation of a 50 g soft-start charge shortly before the clearance of UX015.

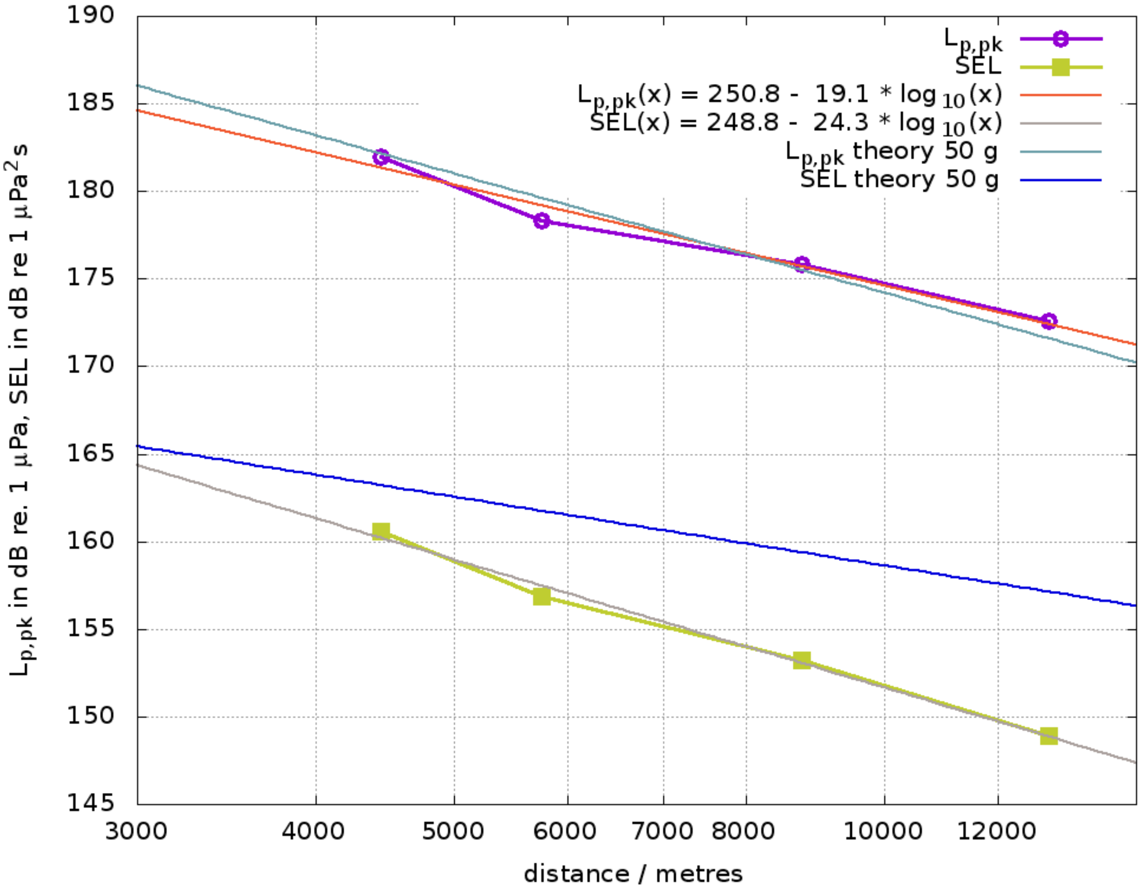


Figure 22: *Measured Sound Exposure Level (SEL) and zero-to-peak Sound Pressure Level ($L_{p,pk}$) (marked by symbols) as a function of distance to the location of pre-detonation of a 50 g charge near UX015. The least-squares-fit functions are also shown. Moreover, the levels expected according to Soloway & Dahl are depicted.*

The levels measured and computed by applying the model of Soloway and Dahl (2014) show the same characteristics as those in Figure 21. The zero-to-peak Sound Pressure Level agrees quite well with the theory, the Sound Exposure Level drops much faster with distance than expected.

Currently it can not be excluded that the specific soil conditions within the OWF area lead to such high factors for the transmission loss, since the semi-empirical approach from Thiele & Schellstede (1980) is based on measurements with small charger weights within the EEZ of the German North Sea.

Other environmental factors could also influence the results of the transmission loss determination. The measurements in the German EEZ of the North Sea used in Thiele & Schellstede (1980) were performed during different environmental circumstances. Different sound speed profiles, swell, precipitation, seasons etc. might have an influence in the transmission loss determination. It was not the task and with the given information it is also not possible to quantify these influences of the mentioned possible factors. Nevertheless, the transmission loss postulated by Thiele & Schellstede (1980) are often used for underwater noise predictions, so they can be understood as state of the art and are therefore used here for comparison.

7.5 Environmental factors

No influence of wind, wave or precipitation on the recorded levels could be detected or identified, as expected. Since all UXO clearance activities were determined under "good" weather conditions at calm sea (wind mostly < 20 knts, sign wave height < 1.4 m). Moreover, the water column in the North-Sea doesn't exhibit strong salinity gradients since it is well-mixed by the tides. Precipitation would cause a rise in the high frequency part of the spectrum, but the measurement devices are much too insensitive to detect such a small increase in level, except for heavy rain or hail. An influence on the results can thus be excluded.

Bathymetry has an influence on the low-frequency cut-off frequency and so on the low-frequent part of the sound pressure spectrum. Since the bathymetry in the area where the UXO clearance took place, doesn't vary much more than about 4 m from 50 m depth, this factor is of negligible importance for the measurement results too.

7.6 Changes in impulsive characteristics detonation noise with increasing distance

Figure 23 shows the time signals of the measured sound pressure at the four measurement locations during detonation of UXO15. The distance of MP1 to MP4 to the UXO location UXO15 (102 kg; charger weight 5 kg) was 2.5 km, 3.3 km, 6.8 km and 10.9 km, respectively. It clearly can be seen that the pressure signal is being stretched by dispersion in time with increasing distance, as expected. The pressure also decreases significantly as expected.

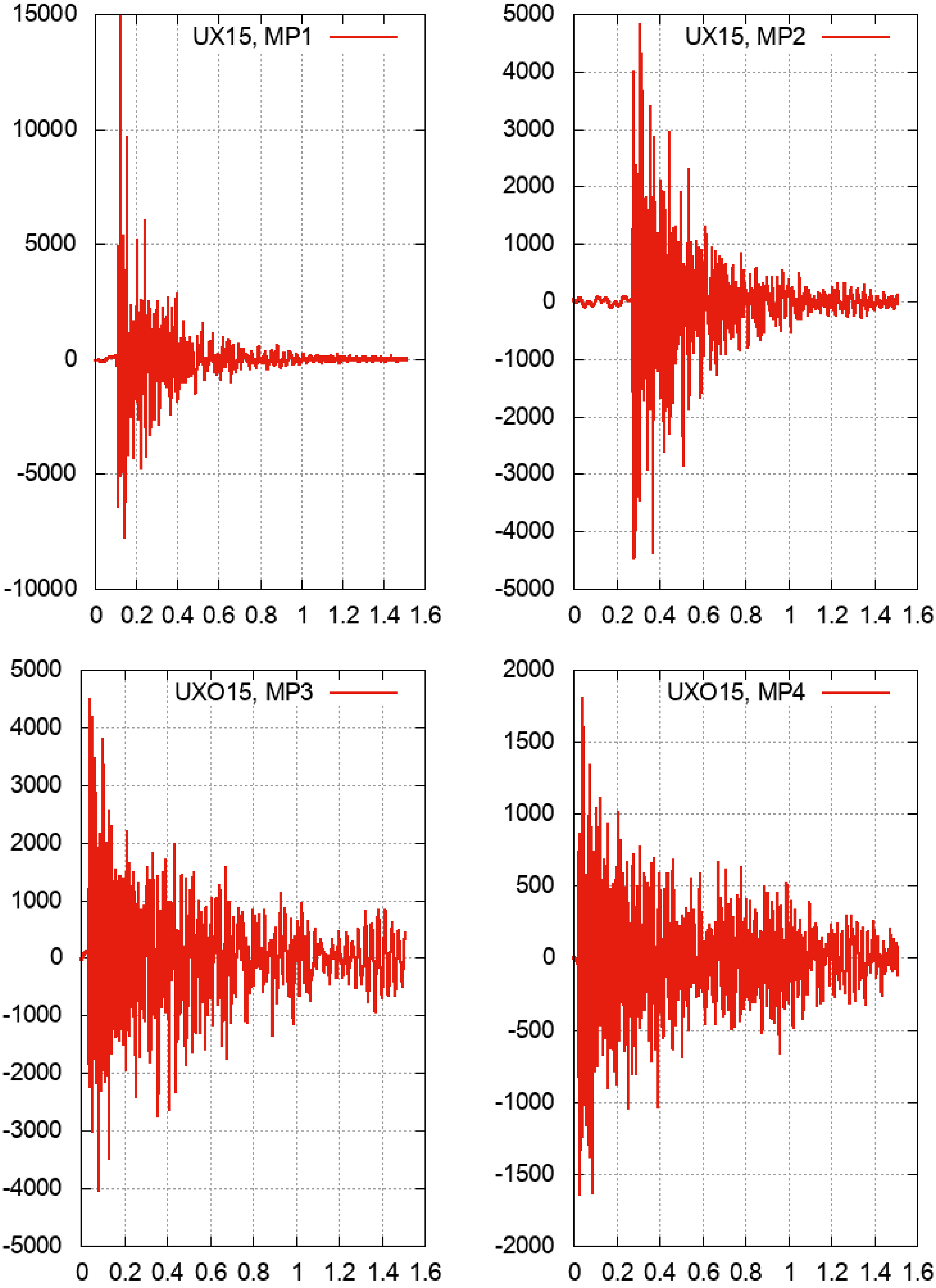


Figure 23: *Sound pressure in Pascal over time in seconds during the detonation of UXO 15 (NEQ: 102 kg, charge weight: 5kg). The distance of MP1 to MP4 to the UXO location was 2.5 km, 3.3 km, 6.8 km and 10.9 km respectively.*

7.7 Background noise level and high frequencies

Figure 24 shows 1/3-octave spectra of the Sound Pressure Level (SPL) for the detonation of UXO10 in 12 km distance to MP4. Also shown is the spectrum of the ambient noise approximately 5 minutes before the detonation. The measurements were performed with the SM2M device with a bandwidth of up to 48 kHz. The ambient noise is more than 30 dB below the UXO spectrum where the detonation emits most sound energy. At higher frequencies of 40 kHz the detonation spectrum is only about 15 dB above ambient noise.

According to the ISO 18406 (2017) criterion a signal-to-noise ratio of at least 10 dB is required. This condition is surely met by all measurements carried out for the UXO measurement campaign even at frequencies of 40 kHz.

Technical note: Based on the high sensitivity of the SM2M measurement device most of the UXO clearance activities are overloaded (clipping effects) so that only very few examples were biased free measured.

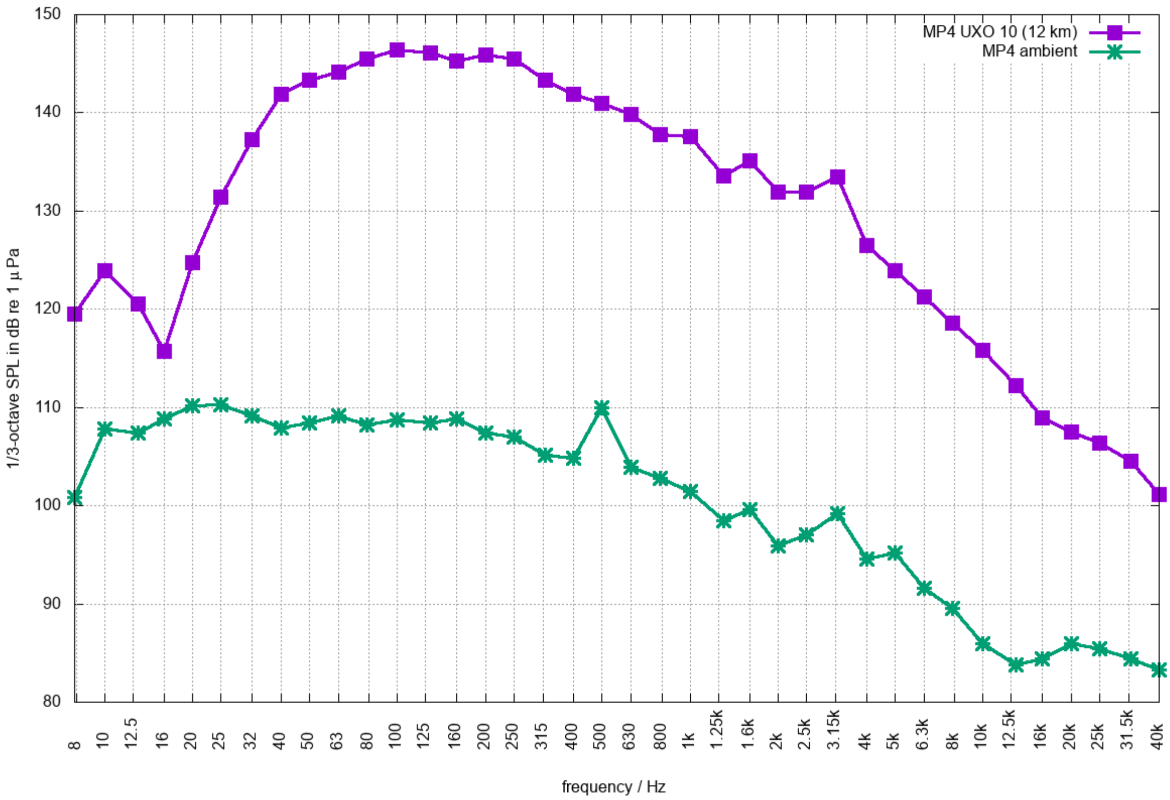


Figure 24: *1/3-octave spectrum of the Sound Pressure Level of the detonation of UXO10 (NEQ: 10 kg, charge weight: 5 kg) in 10 km distance to measurement location MP4. Also shown is the ambient noise spectrum measured 5 minutes before the detonation at the same position.*

Based on literature (Jensen et al., 2010; Urick, 1983) the lower cut-off frequency based on water depth is about 20 Hz which correlates with the break-in for the detonation noise measurement for UXO10.

7.8 Comparison of WAV and MPEG recordings

The colloquially named file format mp3, accurately called MPEG-1 Audio Layer 3 (ISO/IEC 11172-3 (1993)) is a compressed audio data format. During the MPEG data compression, psychoacoustic aspects are taken into account in order to obtain the audio signal with the best possible sound quality and the smallest possible memory consumption.

Roughly summarized, MPEG data compression can be divided into the following three points:

- Limiting of the frequency range to maximum 18 kHz,
- inaudible parts of the signal are represented with reduced accuracy (this is the point where MPEG becomes a lossy recording),
- Efficient lossless compression of the obtained data (Huffman-coding)

The grade of compression and thus the loss of accuracy can be regulated by the bitrate of the resulting data. Common values for the bitrate of mono-signals are 32 kbps, 64 kbps, 96 kbps and 128 kbps.

Decisive for the suitability of MPEG-encoded signals for measurement purposes is the extent to which sound measurement quantities such as broadband levels and 1/3-octave levels due to compression can be influenced. It is shown that the error in typical measurements of underwater sound, piling noise, for example, is low. This is partly because the masking phenomenon in MPEG encoding is used relatively cautiously. The reason is that the strength of the masking effect depends on the playback volume, at low volume, fewer sound components are masked. The MPEG encoder does not know the playback volume and must therefore assume a small value, so that the reproduction is in any case unaltered.

In the following the differences between recordings in WAV and MPEG will be analyzed based on two examples.

7.8.1 Comparison at UXO7

At the first detonation at UXO7 the real time vessel based measurement device was used, which records in the uncompressed WAV file format. Figure 25 shows the measured Sound pressure in Pascal over time of the real time vessel based measurement system in different audio formats. The original recording was made in WAV and has been converted to MPEG and back to WAV. As to be seen in this figure the difference in pressure is marginal. Even the detailed extract of the peak at second 0.05 shows that the difference in sound pressure between the audio formats is close to zero.

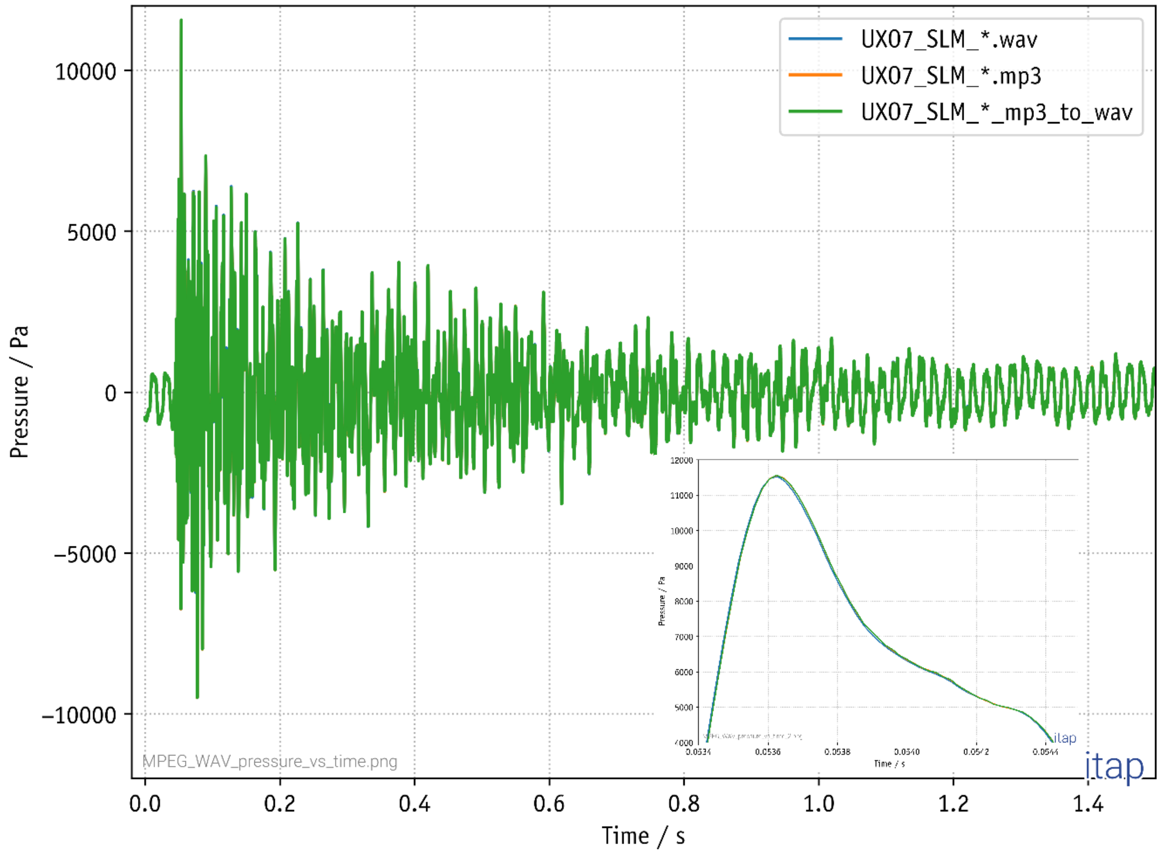


Figure 25: *Sound pressure in Pascal over time in seconds during the detonation of UXO7 (NEQ: 0.25kg, charge weight: 2.5 kg). Original recording was in WAV (blue), converted in MPEG (orange) and back to WAV (green). Detailed extract of the peak at 0.05 s in the lower right corner.*

The 1/3-octave spectra of the SEL for the different audio formats is depicted in Figure 26. The mismatch between WAV (uncompressed) and MPEG (compressed data format) can be seen at frequencies above 4 kHz which is uncritical for the broadband single evaluation of explosion measurements, see the broadband SEL and $L_{p,pk}$ values are summarized in Table 5. At frequencies below 20 Hz there is a mismatch between the back conversion from MPEG to WAV compared to WAV and MPEG. This difference is caused by the decoding from MPEG to WAV. The SLM online device has been deployed close to MP4, exact location during detonation of UXO 7 is unknown. The SEL values for the SLM online device are 2 dB above MP4. The $L_{p,pk}$ values are ~1 dB above MP4. The difference between the different audio types (WAV, WAV->MPEG, MPEG->WAV) are in the range of 0.1 dB for both SEL and $L_{p,pk}$.

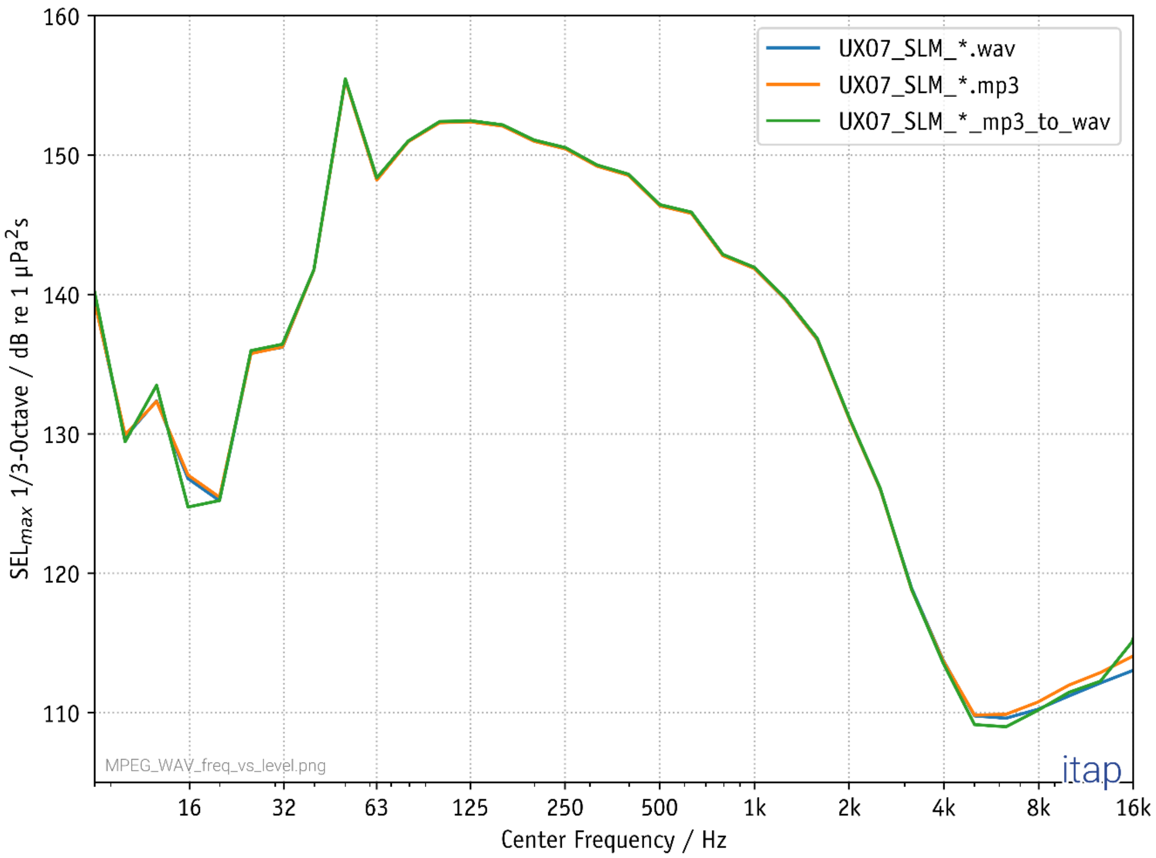


Figure 26: *1/3-ocatve spectrum of the Sound Exposure Level (SEL) at UX07 (NEQ: 0.25kg, charge weight: 2.5 kg) measured with the SLM vessel based real time measurement system. Original recording was in WAV (blue), converted in MPEG (orange) and back to WAV (green).*

Table 5: *Results at measurement positions MP1 to MP4 and vessel based real time measurement (SLM) with different audio formats during UXO clearance activity at UX07(NEQ: 0.25 kg, charger weight: 2.5 kg).*

UXO-No.	Measurement position	Distance [m]	Type of device	Type of audio	SEL [dB]	$L_{p,pk}$ [dB]
7	MP1	3,319	Offline	MPEG	176.1	198.7
	MP2	4,625	Offline	MPEG	170.7	192.5
	MP3	7,025	Offline	MPEG	167.5	187.9
	MP4	11,281	Offline	MPEG	160.3	180.0
	SLM	Close to MP4	Online	WAV	162.5	181.2
			Online	WAV->MPEG	162.5	181.3
			Online	MPEG->WAV	162.6	181.3

7.8.2 Comparison at UX038

Another comparison of WAV and MPEG was made based on the measurements at UX038. The aim was to select a measurement with the high sensitive hydrophone of the SM2M measurement device which was not clipped during that detonation. This was only the case at the pre-detonation (150 g TNT-equivalent) at UX038.

Figure 27 shows the measured Sound Pressure in Pascal over time of the SM2M measurement system with different audio formats. The original WAV-file was first down sampled to 48 kHz before converted into MPEG since SM2M device measured with a sampling rate of 96 kHz which is not applicable for MPEG conversion.

A mismatch can only be seen at the MEPG file format (mp3) compared to WAV in 96 kHz, WAV in 48 kHz and MPEG to WAV around second 0.05 at the beginning of the pre-detonation. This results from the application of a psychoacoustic model, whereby quieter signal events followed by a louder event are represented in less detail in the mp3 format. To evaluate whether this mismatch has an influence on the spectrum or the broadband levels (SEL and $L_{p,pk}$) the 1/3-octave spectrum is depicted in Figure 28 and the broadband levels are shown in Table 6.

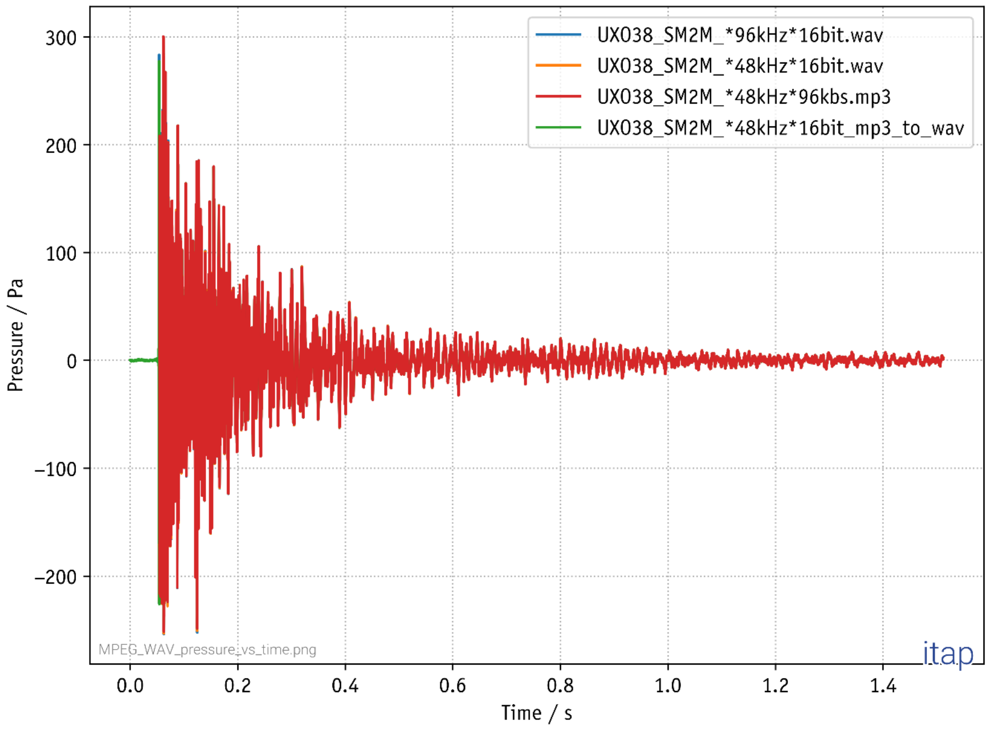


Figure 27: *Sound pressure in Pascal over time in seconds during the detonation of UX038 (NEQ: 102 kg, charge weight: 5 kg). Original recording was in WAV 96 kHz (blue, uncompressed data format), down sampled to WAV 48 kHz (orange), converted in MPEG (red, compressed data format) and back to WAV (green).*

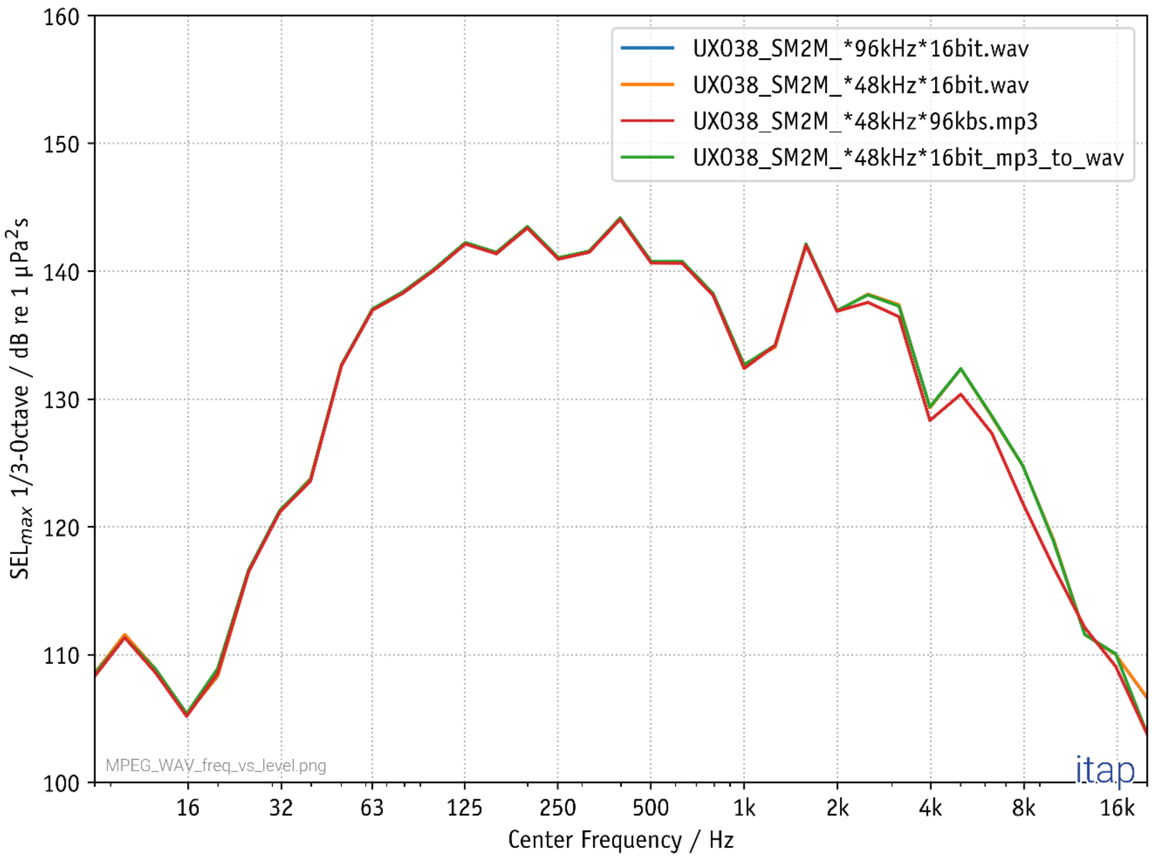


Figure 28: *1/3-ocatve spectrum of the Sound Exposure Level (SEL) at UX038 (NEQ: 102 kg, charge weight: 5 kg) measured with the SM2M system. Original recording was in WAV 96 kHz (blue, uncompressed data format), down sampled to WAV 48 kHz (orange), converted in MPEG (red, compressed data format) and back to WAV (green).*

Figure 28 shows that the compressed MPEG (mp3) recording differs slightly from the others in uncompressed WAV format in the frequencies above 2 kHz. At frequencies below 2 kHz all four spectra's show the same values. Table 6 summarizes the broadband levels. The SEL has a maximum deviation of 0.1 dB and the $L_{p,pk}$ of 0.2 dB.

Table 6: *Results of first pre-detonation at UX038 (NEQ: 102 kg, charge weight: 5 kg) of MP1-MP4 and SM2M (high sensitive hydrophone) with different audio formats.*

UXO-No.	Measurement position	Distance [m]	Type of device	Type of audio	Sampling frequency [Hz]	SEL [dB]	$L_{p,pk}$ [dB]
38	MP4	12,614	SM2M	WAV	96k	153.4	169.6
			SM2M	WAV	48k	153.4	169.4
			SM2M	WAV->MPEG	48k	153.4	169.4
			SM2M	MPEG->WAV	48k	153.3	169.6

The comparison of recordings in WAV (uncompressed) and MPEG (mp3, compressed) for underwater noise, in this case for measurements of UXO clearance detonations, based on two examples at the UXOs #7 and #38 has shown, that the differences between the audio formats are marginal and not relevant for the evaluation. Neither the broadband levels SEL and $L_{p,pk}$ nor the 1/3-octave spectrum shows significant differences between WAV and MPEG recordings.

7.9 Comparison of predicted and measured underwater noise results

The UXO clearance campaign was preceded by a Marine Licence and EPS Licence Application for UXO Clearance Activities ('the Application'), which was supported by a detailed impact assessment to predict the underwater noise for UXO clearance operations, see NnGOWL (2019), NnGOWL (2020) . A comparison of the predicted underwater noise in the Application and measured results is summarized within this chapter. The comparison is based on a representative and pre-selected subset of the measurements and aims to validate the quality of the predicted results within the Application, Table 7.

Table 7 Used UXO detonation measurements for EIA validation.

UXO Seq.	Position (Distance to UXO)	Charge Weight [kg]	NEQ [kg]	$L_{p,pk}$ [dB]	SEL [dB]	Remark (Why used for Application validation)
11	MP1 (2.02 km)	2.5	0.1	204	180	Confirmed high-order detonation, est. NEQ of 0.1 kg no relevant additional NEQ
14	MP1 (4.05 km)	0.1	-	200	178	Pre-detonation used chapter 7.4 for project specific Transmission Loss analysis
17	MP1 (5.49 km)	5	102	198	178	Potential exceeding of Application values due to high measured results
17	MP2 (6.37 km)	5	102	201	177	Potential exceeding of Application values due to high measured results
28	MP1 (1.48 km)	5	102	209	185	Loudest measured $L_{p,pk}$
29	MP1 (4.05 km)	5	102	207	187	UXO used to determine project specific Transmission Loss
42	MP1 (3.2 km)	5	6.5	201	180	Detonation – not high order

The resulting values are given as impact thresholds in km (distance to the UXO clearance) where underwater noise could potentially harm or lead to behavioral disturbance of marine mammals or fish based on the predictions within the Application. A distinction is made between mortality thresholds, permanent threshold shifts PTS i.e. a permanent change in hearing, or TTS i.e. a temporary/recoverable change in hearing.

The third octave source spectra for the Sound Exposure Level (SEL) are weighted according to NOAA (2018). A distinction is made between low frequency (LF), mid frequency (MF), high frequency (HF) cetaceans as well as phocid pinnipeds based on the Application.

The species-specific frequency-weightings of the NOAA study were applied to the unweighted third octave source spectra of the Sound Exposure Level for the pre-selected representative measurements shown in Figure 29. In order to determine the impact ranges by means of the measured values a project-specific determined Transmission Loss of 24.6 $\log_{10}$ (distance) independent from frequency was used (see chapter 7.4). All determined impact ranges based on measurements are well below 10 km, which justifies the use of an unweighted project specific Transmissions Loss.

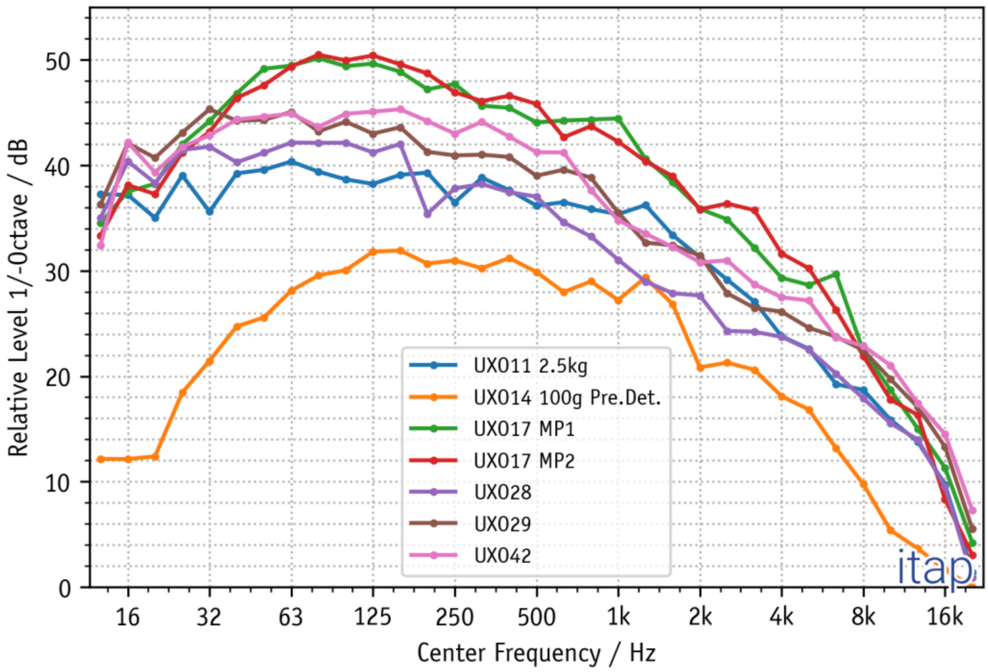


Figure 29 *Measured, unweighted third octave source spectra of the Sound Exposure Level (SEL) used for the validation of the predicted results of the EIA by determining impact ranges. Shown Spectra are normalized to same distance. Level values are normalized to absolute minimum off all shown levels, illustrating the relative differences. For UXO17,28,29 and 42 a 5 kg charge weight was used (see Table 7).*

In NnGOWL (2019) the modelling has been conducted for explosive weights between 10 kg to 1,000 kg. During the UXO clearance campaign charge weights up to 5 kg were used. The measured results during UXO clearance activities points out that the underwater noise levels fit significantly with the used charge weights which allows the conclusion that no or minor contributions to the overall underwater noise levels were caused by the UXO itself. The difference in the noise levels based on the predicted charge weight (5 kg to 10 kg) is roughly 2 dB (see Table 1 in chapter 4). This is in the same order of magnitude as the measurement uncertainty.

In the following sections the results for 10 kg charge weight from NnGOWL (2019) are compared with the impact ranges obtained from the measurement, assuming that only the explosive charge weight contributed to the measured noise values (see chapter 7.4).

Procedure to determine impact ranges from measurements:

- Broadband unweighted SEL and $L_{p.pk}$ values from measurement (see Annex A3) at their measured distance to the explosion are used as reference.
- In terms of unweighted $L_{p.pk}$ impact ranges broadband values are used for Transmission Loss propagation.
- In terms of frequency weighted impact ranges in accordance with NOAA study measured SEL third octave spectra are used and weighted accordingly (NOAA SEL_{cum} weightings) -> Frequency-weighted spectra are summed to get the overall broadband values. These frequency-weighted broadband values are used for transmission loss propagation.
- The project specific, frequency-unweighted transmission loss (24.6 $\log_{10}$ R) (R= distance to source) is applied on either the unweighted zero-to-peak Sound Pressure Level $L_{p,pk}$ or the summed and frequency-weighted SEL values.
- impact ranges (distances) for the threshold values (criteria), in NnGOWL (2019), are determined.

In Table 8 and Table 9 the resulting impact ranges are given for the unweighted zero-to-peak Sound Pressure level $L_{p,pk}$, and frequency-weighted SEL for different species, respectively. The used criteria (threshold values) as well as the results from the Application, NnGOWL (2019), for a charge weight of 10 kg are given in column 3 and 4. Column 5 in Table 8 shows predicted distances for a charge weight of 5 kg from NnGOWL (2020).

The majority of the UXO clearances was conducted with 5 kg charge weight. But in the Application (NnGOWL (2019), NnGOWL (2020)) impact ranges for 5kg charge weight are only given for a small subset of the used threshold values (3 out of 18). Therefore, mainly the 10kg charge weight are used for comparison here.

Table 8 Impact ranges obtained for unweighted zero-to-peak Sound Pressure Level $L_{p,pk}$. Column „Criteria "and „Prediction" are adapted from NnGOWL (2019) and NnGOWL (2020).

Species	Behavior	Criteria [dB]	Pre-diction [km]		UX017 MP1 [km]	UX017 MP2 [km]	UX028 MP1 [km]	UX029 MP1 [km]	UX042 MP1 [km]	UX011 MP1 [km]	UX014 MP1 [km]
Charge weight			10 kg	5 kg	5 kg					2.5 kg	0.1 kg
Fish	Mortality Threshold	229	0.22	-	0.31	0.45	0.23	0.22	0.24	0.20	0.07
Marine Mammels	Mortality Threshold	240	0.08	-	0.11	0.16	0.08	0.08	0.08	0.07	0.02
LF cetaceans	PTS	219	0.60	0.50	0.80	1.14	0.60	0.55	0.60	0.50	0.17
LF cetaceans	TTS	213	1.10	-	1.40	1.99	1.04	0.97	1.06	0.88	0.30
MF cetaceans	PTS	230	0.20	0.10	0.28	0.41	0.21	0.20	0.22	0.18	0.06
MF cetaceans	TTS	224	0.40	-	0.50	0.71	0.37	0.35	0.38	0.32	0.11
HF cetaceans	PTS	202	3.40	1.3	3.91	5.58	2.92	2.72	2.96	2.47	0.85
HF cetaceans	TTS	196	6.30	-	6.85	9.78	5.12	4.77	5.19	4.34	1.49
Phocid pinnipeds	PTS	218	0.70	-	0.87	1.25	0.65	0.61	0.66	0.55	0.19
Phocid pinnipeds	TTS	212	1.20	-	1.53	2.19	1.15	1.07	1.16	0.97	0.33

Table 9 Impact ranges obtained for frequency-weighted Sound Exposure Level SEL. Column „Criteria "and „Prediction" are adapted from NnGOWL (2019).

Species	Behavior	Criteria [dB]	Pre-diction [km]	UX017 MP1 [km]	UX017 MP2 [km]	UX028 MP1 [km]	UX029 MP1 [km]	UX042 MP1 [km]	UX011 MP1 [km]	UX014 MP1 [km]
Charge weight			10 kg	5 kg					2.5 kg	0.1 kg
LF cetaceans	PTS	183	0.90	2.22	2.28	0.98	1.31	1.56	1.03	0.51
LF cetaceans	TTS	168	8.50	9.05	9.27	4.00	5.34	6.35	4.18	2.06
MF cetaceans	PTS	185	0.10	0.16	0.16	0.08	0.11	0.13	0.09	0.05
MF cetaceans	TTS	170	0.50	0.64	0.66	0.33	0.46	0.52	0.37	0.19
HF cetaceans	PTS	155	1.80	1.62	1.63	0.92	1.28	1.44	0.99	0.48
HF cetaceans	TTS	140	7.40	6.59	6.62	3.75	5.22	5.87	4.03	1.97
Phocid pinnipeds	PTS	185	0.20	0.76	0.76	0.31	0.44	0.49	0.41	0.20
Phocid pinnipeds	TTS	170	1.80	3.08	3.11	1.26	1.78	2.01	1.65	0.82

It should be stated that the methods for determining the impact ranges differ significantly in terms of the used source spectra as well as the transmission loss used.

The project specific, frequency-unweighted transmission loss (24.6 $\log_{10}$ distance) differs from the transmissions loss proposed in Thiele & Schellstede (1980) as well as from Soloway and Dahl (2015) and in NnGOWL (2019) a proprietary, frequency dependent adaptation of the transmission loss from Soloway and Dahl (2014) was used.

Nonetheless, the results shown in Table 8 and Table 9 are fairly comparable. The measurement uncertainty as well as the different assumed charge weights must also be considered when comparing the results.

For the unweighted zero-to-peak Sound Pressure Level $L_{p,pk}$ all, but UXO 17, impact ranges are very close or below the predicted impact ranges of the EIA-study (NnGOWL, 2019). The reason for UXO17 might be the overall higher broad band level (see Figure 29).

The resulting impact ranges for frequency-weighted SEL are to be evaluated more closely. For UXO 17 the lf, mf and pinniped frequency weighted impact ranges exceed the predicted ones from the EIA-study by partly a factor of 3 (TTS criterium for pinniped). Whereas the criteria for hf weighting undershoots the predicted values slightly. For the other UXO clearance activities a more or less similar outcome can be observed as the factors for over- and undershooting are much lower. These results point out that not only the overall broad band level is important for the determination of impact ranges but also the spectra of each detonation. Figure 29 shows that UXO17 seems to be slightly "louder" than the other detonations based on normalized results but also that the frequency content slightly differs.

These results point out that the Application predictions are comparable to most of the pre-selected criteria for the frequency weighted Sound Exposure Levels (SEL), except UXO17. The reason for the partly significantly differences between the predictions and the measurements of UXO17 can only partly be explained within this report. It might happen that other unidentified factors might have an influence on the determination of impact ranges, including the position of the UXO (if half buried) on the seabed, sediment type, possibly partial explosion of the original NEQ or other unknown factors.

7.10 Source level estimation

With the project-specific transmission loss and the determined measurement values, an estimation of the source levels at 1m distance to the detonations is possible. It is important to reflect that the stated estimated source level is technically only valid with the model it was designed with or used for. It is a theoretical number that is meant to be used to determine the correct value at range. A comparison with other source level estimations, based on other computational models, is therefore not advisable and should not be made at all or only with caution. Thus, a direct comparison with the theoretical values in Table 1 is not advisable. The values given in Table 1 are computed with different semi-empirical formulas from Soloway and Dahl (2014). In Table 10 the broadband SEL and $L_{p,pk}$ source level estimations are shown, derived from an representative set of measurement results from the recorded UXO clearance campaign with unique combinations of NEQ values and charge weights. The used project-specific transmission loss was set to 24.6 $\log_{10}$ (distance) (frequency independent). This is identical to what was used in chapter 7.4 and chapter 7.9.

Table 10 Estimated source levels based on measurements values and project specific transmission loss for different combinations of NEQ values and charge weights.

UXO-No.	NEQ in kg	Charge Weight in kg	Measurement Position (Distance in m)	Sound Level from Measurement (different distances to source)		Estimated Source Level (@1m)	
				$L_{p,pk,max}$ in dB	SEL in dB	$L_{p,pk,max}$ in dB	SEL in dB
8	10	5	MP1 (3,634)	201.0	181.2	**288.6**	**268.8**
9	15	2.5	MP1 (3,143)	198.6	179.4	**284.6**	**265.4**
11	0.1	2.5	MP1 (2,039)	204.0	180.3	**285.4**	**261.7**
12	48.3	5	MP1 (2,619)	199.7	183.3	**283.8**	**267.4**
14	70	5	MP1 (4,045)	200.0	178.2	**288.7**	**266.9**
Predetonation 14	0	0.1	MP1(4,045)	185.0	163.0	**273.7**	**251.7**
17	102	5	MP1 (5,492)	198.3	178.4	**290.3**	**270.4**
39	36	5	MP1 (11,132)	188.2	169.3	**287.7**	**268.8**
41	60	5	MP1 (24,337)	175.9	161.7	**283.8**	**269.6**
42	6.5	5	MP1 (3,278)	200.1	180.0	**286.6**	**266.5**
43	15	5	MP1 (3,889)	201.6	180.3	**289.9**	**268.6**

The estimated SEL source level with 5 kg charge weight are within a range of 3.9 dB, despite sometimes significant different distances from the measurement position to the UXO location. No consistent dependency with the (estimated) NEQ values can be found. With smaller charge weight also the estimated SEL source level decreases.

For the estimated $L_{p,pk}$ source level the linkage with the charge weight is not as pronounced. But also the estimated $L_{p,pk}$ source level shows the highest level with 5 kg charge load and decreases with deceasing charge weight. However, the span of 6.5 dB for the estimated $L_{p,pk}$ source level is larger and the values are in some instances below those with 2.5 kg charge weight. But due to its higher temporal and spatial sensitivity as an acoustic field quantity, the uncertainty of the $L_{p,pk}$ is expected to be larger than that of the SEL being an acoustic power quantity.

8. References

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A Appendix

A.1 Overview of measured results for MP1, MP2, MP3 and MP4

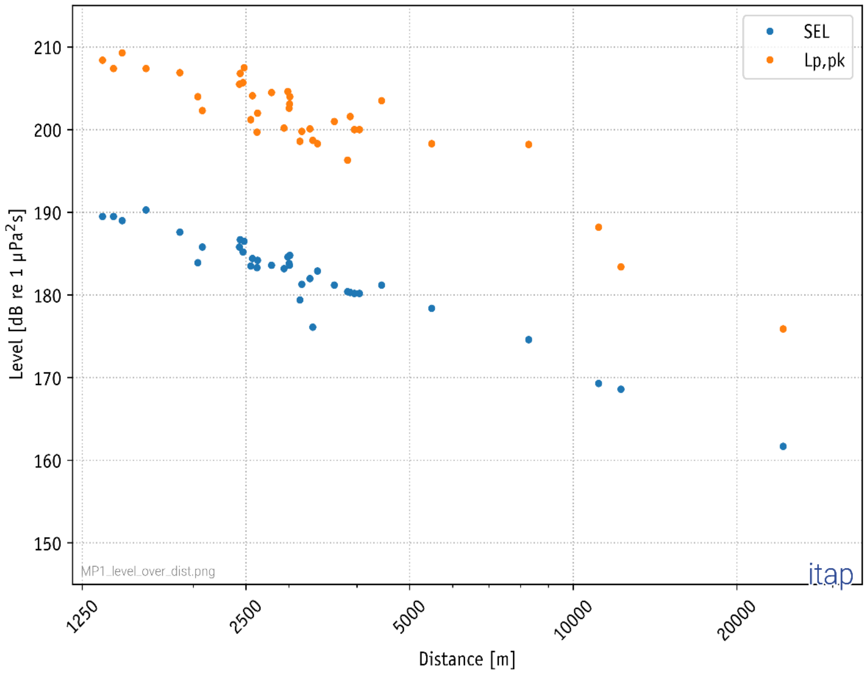

Figure 30: *Sound Exposure Level (SEL) and zero-to-peak Sound Pressure Level ($L_{p,pk}$) measured at measurement location MP1 as function of distances to UXO clearance. (same as in Figure 10)*

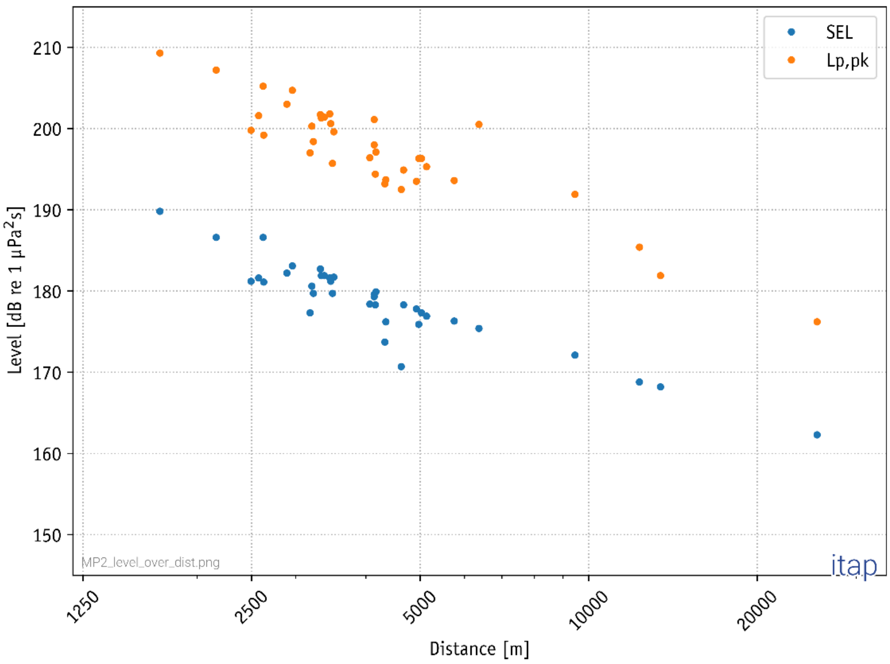

Figure 31: *Sound Exposure Level (SEL) and zero-to-peak Sound Pressure Level ($L_{p,pk}$) measured at measurement location MP2 as function of distances to UXO clearance.*

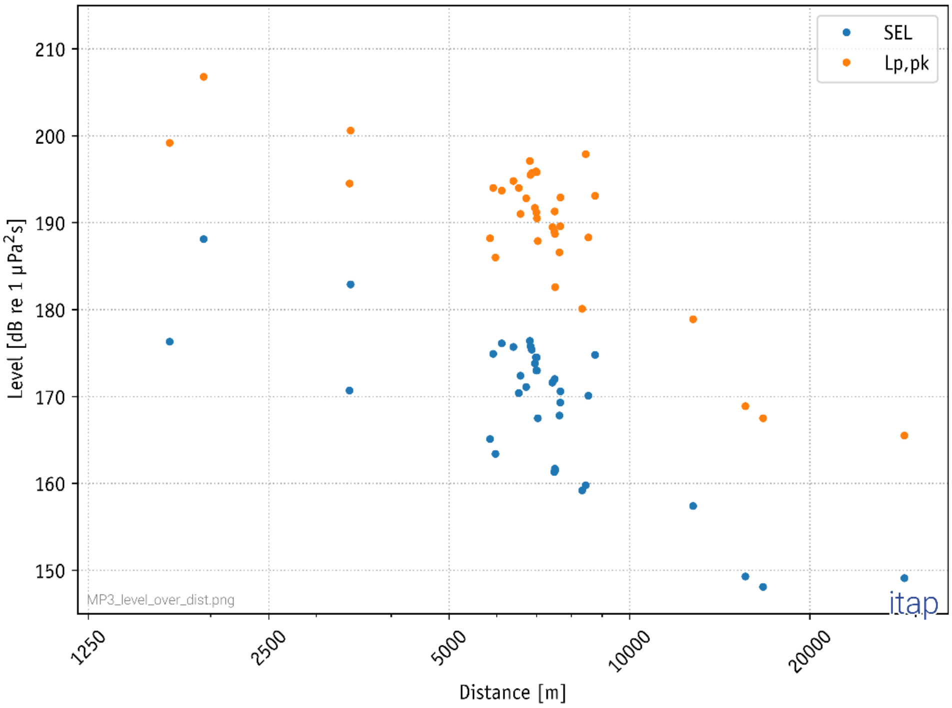

Figure 32: *Sound Exposure Level (SEL) and zero-to-peak Sound Pressure Level ($L_{p,pk}$) measured at measurement location MP3 as function of distances to UXO clearance.*

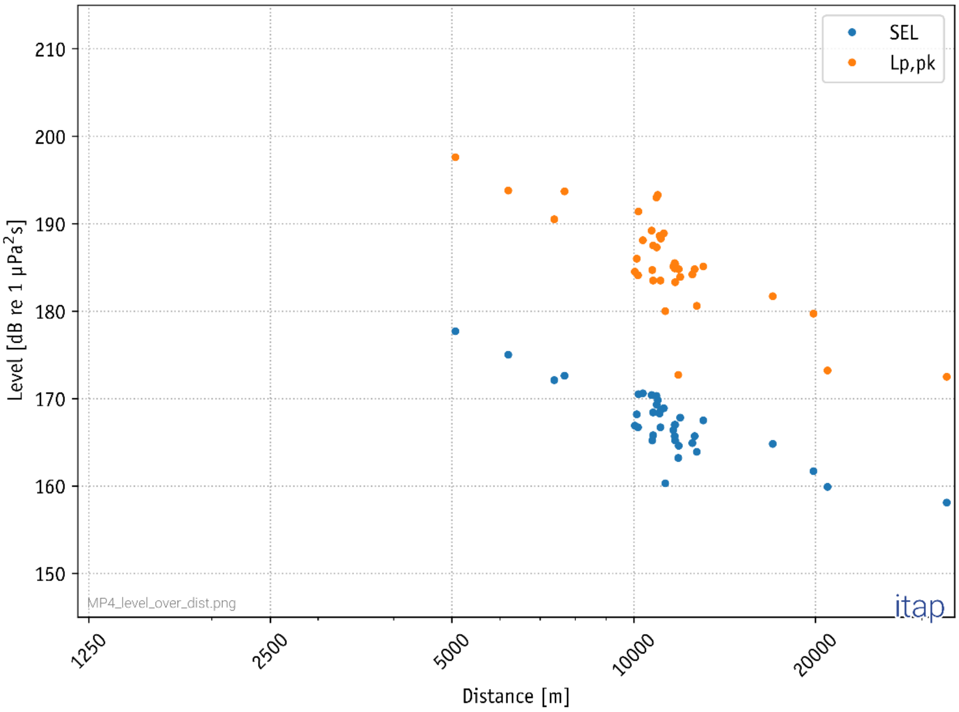

Figure 33: *Sound Exposure Level (SEL) and zero-to-peak Sound Pressure Level ($L_{p,pk}$) measured at measurement location MP4 as function of distances to UXO clearance. (same as in Figure 9)*

A.2 Corresponding information regarding the UXO types and clearance activities

Note: In order to present the data from the *UXO Clearance Tracker* table within this report, certain columns and images have been removed.

Table 11: *NnG UXO Clearance Tracker*

Seq	cUXO	Description	NEQ Value (kg)	Easting	Northing	Location	Date	Time	ADD (min)	Soft Start (x 50g)	Charge Weight	Wind speed (kts)	Wind Direction	Wave height (m)	Tidal state	Weather	Visbility	Result
7	E_MAG_0670_A	30mm project case	Unknown (0.25)	546347,40	6232370,60	IAC 16 - 28	14.05. 2020	15:00	28	N/A	2.5 kg	17knts	W	1.3	-	On Limit	Good	High order and no debris remaining
8	E_MAG_0587	8" projectile	10	545718,00	6231768,00	WTG 16	15.05. 2020	10:30	28	N/A	5 kg	10knts	W	1.1	0.3Kknts SE	Good	Good	High order and no debris remaining
9	E_MAG_0029_A	4" projectile	15	543678,60	6232294,50	IAC 4 - 5	15.05. 2020	17:30	28	N/A	2.5 kg	12knts	W	0.8	Tide 0.3 at 341 degrees	Good	Good	High order and no debris remaining
10	E_MAG_0808	8" Projectile	10	543645,99	6232281,01	IAC 4 - 5	16.05. 2020	11:00	28	N/A	5 kg	17knts	SW	1.3	0.4Kknts SW	On Limit	Good	Recovered to deck
11	E_MAG_0035_B	20mm AA round	N/A (0.1)	543820,60	6233429,50	IAC 4 - 13	17.05. 2020	10:00	28	N/A	2.5 kg	12knts	W	1.0	0.3Kknts SE	Good	Good	High order and no debris remaining
12	G_MAG_0018	15" projectile	48.3	542837,02	6233435,88	WTG 3	17.05. 2020	15:00	28	N/A	5 kg	25knts	SW	1.3	0.4Kknts SW	On Limit	Good	Wet stored
13	G_MAG_0309	7.5 inch Solid Shot	48.3	542781,09	6233789,49	IAC 2 - 3	18.05. 2020	12:30	28	N/A	5 kg	20knts	SW	1.3	0.3Kknts SW	On Limit	Good	Recovered to deck
14	ECR_O_MAG_0332_A	16" inch Projectile	70	542899,50	6231646,40	KP 31 - 32	18.05. 2020	16:30	38	50g at 10 mins 100g at 5 mins	5 kg	20knts	SW	1.1	0.1Kknts NE	Good	Good	Wet stored
15	E_MAG_0299	12" inch Solid Shot	102	544714,70	6230818,70	WTG 6	20.05. 2020	13:15	35	50g 15 mins 100g 10 mins 150g 5 mins	5 kg	17knts	S	0.5	1Kknts SW	Good	Good	Recovered to deck
16	E_MAG_0683	15" projectile	102	546555,50	6232420,40	WTG 28	20.05. 2020	17:00	35	50g 15 mins 100g 10 mins 150g 5 mins	5 kg	18knts	SE	0.7	1Kknts SW	Good	Good	Wet stored
17	D_MAG_0225	15" projectile	102	549824,50	6233244,90	IAC 68 - 69	21.05. 2020	11:30	38	50g 15 mins 100g 10 mins 150g 5 mins	5 kg	18knts	W	0.7	2Kknts NW	Good	Good	Recovered to deck
18	C_MAG_0078	15" projectile	102	546467,77	6235971,30	IAC 41 - 50	25.05. 2020	11:30	32	50g 15 mins 100g 10 mins 150g 5 mins	5 kg	8knts	SW	0.5	2Kknts N	Good	Good	Recovered to deck
19	B_MAG_0152	15" projectile	102	545760,55	6237588,51	WTG 49	25.05. 2020	16:45	32	50g 15 mins 100g 10 mins 150g 5 mins	5 kg	8knts	SW	0.8	2Kknts N	Good	Good	Recovered to deck
20	G_MAG_0109	10" projectile	102	541955,70	6234881,00	WTG 112	26.05. 2020	13:00	33	50g 15 mins 100g 10 mins 150g 5 mins	5 kg	14knts	SW	0.8	0.5Kknts N	Good	Good	Wet stored
21	G_MAG_0067	15" projectile	102	542912,30	6233574,90	WTG 3	26.05. 2020	17:00	33	50g 15 mins 100g 10 mins 150g 5 mins	5 kg	13knts	W	0.8	0.4Kknts N	Good	Good	Recovered to deck

Seq	cUXO	Description	NEQ Value (kg)	Easting	Northing	Location	Date	Time	ADD (min)	Soft Start (x 50g)	Charge Weight	Wind speed (kts)	Wind Direct ion	Wave height (m)	Tidal state	Weather	Visbility	Result
22	G_MAG_0065	15" projectile	102	542964,20	6233561,90	WTG 3	27.05. 2020	12:30	32	50g 15 mins 100g 10 mins 150g 5 mins	5 kg	8knts	W	0.5	0.4Kknts N	Good	Good	Recovered to deck
23	G_MAG_0051	15" projectile	102	542960,70	6233507,40	WTG 3	27.05. 2020	16:00	32	50g 15 mins 100g 10 mins 150g 5 mins	5 kg	8knts	NE	0.4	0.4Kknts SW	Good	Good	Recovered to deck
24	G_MAG_0029	15" projectile	102	542889,13	6233454,52	WTG 3	28.05. 2020	11:30	33	50g 15 mins 100g 10 mins 150g 5 mins	5 kg	12knts	SE	0.4	0.4Kknts N	Good	Good	Wet stored
25	G_MAG_0010	15" projectile	102	542856,70	6233407,10	WTG 3	28.05. 2020	16:30	33	50g 15 mins 100g 10 mins 150g 5 mins	5 kg	16knts	S	0.5	0.2Kknts N	Good	Good	Wet stored
26	E_MAG_0068	15" projectile	102	544013,66	6234094,13	WTG 13	29.05. 2020	15:30	32	50g 15 mins 100g 10 mins 150g 5 mins	5 kg	11knts	SE	0.4	0.4Kknts N	Good	Good	Wet stored
27	E_MAG_0076	15" projectile	102	544031,40	6234009,40	IAC 4 - 13	31.05. 2020	17:00	32	50g 15 mins 100g 10 mins 150g 5 mins	5 kg	9knts	SE	0.6	0.4Kknts N	Good	Good	Recovered to deck
28	E_MAG_0070	15" projectile	102	544010,50	6233959,50	IAC 4 - 13	01.06. 2020	17:45	32	50g 15 mins 100g 10 mins 150g 5 mins	5 kg	18knts	SE	0.6	0.4Kknts N	Good	Good	Wet stored
29	E_MAG_0227	15" projectile	102	544331,68	6233669,52	IAC 13 - 15	02.06. 2020	09:00	32	50g 15 mins 100g 10 mins 150g 5 mins	5 kg	4knts	SE	0.3	0.2Kknts NW	Good	Good	Wet stored
30	E_MAG_0036	15" projectile	102	543815,95	6233387,84	IAC 4 - 13	02.06. 2020	16:00	32	50g 15 mins 100g 10 mins 150g 5 mins	5 kg	9knts	E	0.3	0.2Kknts NE	Good	Good	Wet stored
31	E_MAG_0008	15" projectile	102	543476,30	6232598,10	WTG 4	09.06. 2020	10:45	33	50g 15 mins 100g 10 mins 150g 5 mins	5 kg	10knts	SW	1.3	0.5Kknts N	Good	Good	Wet stored
32	E_MAG_0012_A	15" projectile	102	543497,30	6232518,49	WTG 4	10.06. 2020	10:00	33	50g 15 mins 100g 10 mins 150g 5 mins	5 kg	12knts	SE	0.9 Hmax	02knts NE	Good	Good	Recovered to deck
33	E_MAG_0018	15" projectile	102	543579,00	6232500,10	IAC 4 - 5	16.06. 2020	16:00	33	50g 15 mins 100g 10 mins 150g 5 mins	5 kg	None	None	0.4Hmx	03knts NNE	Good	Good / Marginal	Recovered to deck
34	ECR_O_MAG_00 81	8" projectile	10	542272,70	6227349,50	KP 26 - 27	17.06. 2020	10:00	18	N/A	5 kg	6knts	NE	0.2Hmax	0.2knts SW	Good	Good / Marginal	Recovered to deck
35	E_MAG_0017	15" projectile	102	543568,92	6232481,05	IAC 4 - 5	18.06. 2020	11:00	33	50g 15 mins 100g 10 mins 150g 5 mins	5 kg	7kts	NNE	0.4 Hmax	0.2kts SW	Good	Good	Recovered to deck

Seq	cUXO	Description	NEQ Value (kg)	Easting	Northing	Location	Date	Time	ADD (min)	Soft Start (x 50g)	Charge Weight	Wind speed (kts)	Wind Direct ion	Wave height (m)	Tidal state	Weather	Visbility	Result
36	E_MAG_0021	15" projectile	102	543582,80	6232471,80	IAC 4 - 5	18.06. 2020	16:00	33	50g 15 mins 100g 10 mins 150g 5 mins	5 kg	12kts	NE	0.6 Hmax	0.2kts SSE	Good	Good	Recovered to deck
37	ECR_O_MAG_03 78	15" projectile	102	542923,47	6231859,05	KP 31 - 32	20.06. 2020	09:00	33	50g 15 mins 100g 10 mins 150g 5 mins	5 kg	16kts	WSW	1.2 Hmax	0.5kts N	Good	Good	Wet stored
38	ECR_O_MAG_03 62_A	15" projectile	102	542856,10	6231769,80	KP 31 - 32	20.06. 2020	15:00	33	50g 15 mins 100g 10 mins 150g 5 mins	5 kg	10kts	ESE	1.0 Hmax	0.5kts SSE	Good	Good	Wet stored
39	ECR_O_MAG_00 36	Paravane	36	541844,67	6224505,96	KP 23 - 24	22.06. 2020	10:00	16	N/A	5 kg	18kts	SSE	0.8 Hmax	0.5kts N	Good	Good	Recovered to deck
40	ECR_O_MAG_00 18	15" projectile	102	541715,90	6223397,50	KP 22 - 23	23.06. 2020	10:00	33	50g 15 mins 100g 10 mins 150g 5 mins	5 kg	12kts	SSE	0.8 Hmax	0.6kts N	Good	Good	Recovered to deck
41	ECR_M_MAG_07 08	12" RML projectile	60	540160,90	6211354,52	KP 10 - 11	23.06. 2020	16:00	33	50g 10 mins 100g 5 mins	5 kg	19kts	SSW	0.8 Hmax	0.5kts S	Good	Good	Partial deflagration achieved
42	B_MAG_0023	6" projectile	6.5	547836,80	6236264,80	BH65A	24.06. 2020	10:00	18	N/A	5 kg	15kts	SE	0.5Hmax	0.5kts NNE	Good	Good	Detonation not high order
43	B_MAG_0200	Air Dropped Weapon	15	544797,28	6239149,29	WTG 47	24.06. 2020	15:00	33	50g 10 mins 100g 5 mins	5 kg	12kts	SE	0.5Hmax	0.3kts WSW	Good	Good	Wet stored

A.3 Overview of underwater noise measurement results

Table 12: *Measurement results for all UXO detonations and all measurement positions.*

UXO-No.	MP1			MP2			MP3			MP4			NET /kg	wave height
	Dist.	SEL	$L_{p,pk,max}$	Dist.	SEL	$L_{p,pk,max}$	Dist.	SEL	$L_{p,pk,max}$	Dist.	SEL	$L_{p,pk,max}$		
7	3,319	176.1	198.7	4,625	170.7	192.5	7,025	167.5	187.9	11,281	160.3	180.0	5	1.3
8	3,634	181.2	201.0	4,973	175.9	196.3	7,665	170.6	192.9	11,942	167.8	183.9	10	1.1
9	3,143	179.4	198.6	4,324	173.7	193.2	7,635	167.8	186.6	11,854	163.2	172.7	15	0.8
10	3,166	181.3	199.8	4,343	176.2	193.7	7,660	169.3	189.6	11,876	164.6	184.8	10	1.3
11	2,039	180.3	204.0	3,181	177.3	197.0	6,534	170.4	194.0	10,729	165.2	184.7	5	1.0
12	2,619	183.3	199.7	3,488	179.7	195.7	6,988	173.0	191.2	11,070	166.7	183.5	48	1.3
13	2,431	185.8	205.5	3,203	180.6	200.3	6,720	171.1	192.8	10,769	168.4	187.5	48	1.3
14	4,045	178.2	200.0	5,134	176.9	195.3	8,538	170.1	188.3	12,715	163.9	180.6	70	1.1
15	4,442	181.2	203.5	5,750	176.3	193.6	8,757	174.8	193.1	13,037	167.5	185.1	102	0.5
16	3,384	182.9	198.3	4,672	178.3	194.9	6,975	174.5	195.9	11,218	168.9	188.9	102	0.7
17	5,492	178.4	198.3	6,367	177.4	200.5	6,997	174.5	195.8	10,709	170.4	189.2	102	0.7
18	1,890	187.6	206.9	2,161	186.6	207.2	3,423	182.9	200.6	7,682	172.6	193.7	102	0.5
19	2,551	183.5	201.2	1,715	189.8	209.3	1,947	188.1	206.8	6,196	175.0	193.8	102	0.8
20	2,786	183.6	204.5	2,956	183.1	204.7	6,396	175.7	194.8	10,180	170.5	191.4	102	0.8
21	2,469	185.2	205.7	3,330	181.9	201.3	6,830	175.8	195.5	10,913	169.3	187.3	102	0.8
22	2,440	186.7	206.8	3,319	182.7	201.7	6,814	176.4	197.1	10,905	170.3	193.0	102	0.5
23	2,481	186.5	207.5	3,370	181.9	201.4	6,863	175.4	195.7	10,957	169.8	193.3	102	0.4
24	2,569	184.4	204.1	3,448	181.6	201.8	6,945	173.8	191.7	11,033	168.3	188.6	102	0.4
25	2,626	184.2	202.0	3,505	181.7	199.6	7,002	173.0	190.5	11,089	168.7	188.3	102	0.5

UXO-No.	MP1			MP2			MP3			MP4			NET /kg	wave height
	Dist.	SEL	$L_{p,pk,max}$	Dist.	SEL	$L_{p,pk,max}$	Dist.	SEL	$L_{p,pk,max}$	Dist.	SEL	$L_{p,pk,max}$		
26	1,362	189.5	208.4	2,494	181.2	199.8	5,849	165.1	188.2	10,038	166.9	184.5	102	0.4
27	1,427	189.5	207.4	2,575	181.6	201.6	5,919	174.9	194.0	10,113	168.2	186.0	102	0.6
28	1,480	185.0	209.3	2,628	181.1	199.2	5,973	163.4	186.0	10,167	166.7	184.1	102	0.6
29	1,637	187.3	207.4	2,891	182.2	203.0	6,117	176.1	193.7	10,350	170.6	188.1	102	0.3
30	2,078	185.8	202.3	3,223	179.7	198.4	6,574	172.4	191.0	10,770	165.8	183.5	102	0.3
31	2,937	183.2	200.2	4,065	178.4	196.4	7,434	171.6	189.5	11,627	166.4	185.1	102	1.3
32	3,001	183.8	202.6	4,139	179.3	201.1	7,498	172.0	191.3	11,696	167.0	185.5	102	0.9
33	2,986	184.6	204.6	4,140	179.6	198.0	7,483	*	*	11,688	165.7	184.9	102	0.4
34	8,280	174.6	198.2	9,450	172.1	191.9	12,761	*	*	16,994	164.8	181.7	10	0.2
35	3,007	183.6	203.1	4,160	178.3	194.4	7,504	*	*	11,709	165.2	183.3	102	0.4
36	3,011	184.8	204.0	4,167	179.9	197.1	7,507	*	*	11,714	167.0	185.4	102	0.6
37	3,845	180.4	196.3	4,924	177.8	193.5	8,336	*	*	12,507	164.9	184.2	102	1.2
38	3,956	180.2	200.0	5,029	177.3	196.3	8,445	*	*	12,614	165.7	184.8	102	1.0
39	11,132	169.3	188.2	12,319	168.8	185.4	15,596	*	*	19,844	161.7	179.7	36	0.8
40	12,237	168.6	183.4	13,431	168.2	181.9	16,693	*	*	20,947	159.9	173.2	102	0.8
41	24,337	161.7	175.9	25,557	162.3	176.2	28,745	*	*	33,020	158.1	172.5	102	0.8
42	3,278	180.0	200.1	3,461	181.2	200.6	3,408	*	*	7,386	172.1	190.5	7	0.5
43	3,889	180.3	201.6	2,621	186.6	205.2	1,708	*	*	5,065	177.7	197.6	60	0.5

* Data has to be classified as not valid due a defect hydrophone.