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Seagreen UXO Clearance Noise Monitoring

Underwater Noise Analysis Final Report

Common dolphin (Delphinus delphis)

Document Control

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Executive Summary

This document reports the underwater sound generated during the clearance of unexploded ordinance (UXO) at the site of the Seagreen Offshore Wind Farm in the North Sea. Monitoring of the noise generated by UXO clearance was undertaken in accordance with the monitoring guidance provided by the National Physical Laboratory for UXO clearance, and as required by the Marine License conditions. The clearance was undertaken using the novel HYDRA-Jet Disrupter system. This system works by detonating a small explosive charge (750 g) close to the UXO, which generates a high-pressure jet of water, which generates a high-pressure jet of water that clears the UXO. Due to the small mass of explosives being detonated, this is a safer and lower noise alternative to simply detonating or deflagration of the UXO itself.

Seiche deployed underwater noise monitoring equipment to measure the noise from three UXO clearance operations. Expected noise levels were calculated based on the mass of explosive material used during the clearance, and noise levels were also calculated based on the mass of explosive material within the UXO itself, to allow comparison with traditional methods of clearance.

From the measurements taken it was found that noise from the HYDRA-jet method of UXO clearance was higher than was anticipated based on theoretical calculations. However, it was also found that the noise level measured at the same distance from each UXO was similar in each case irrespective of the estimated size of the residual UXO charge itself, indicating that the HYDRA-jet method was successfully deployed and that it is unlikely that the UXO charge was accidentally detonated. It was further confirmed that noise due to the use of the HYDRA-jet is lower than would have been expected from a first order UXO detonation and is therefore effective for mitigating the impact of underwater noise on marine mammals and fish.

The measurement results further show that there is potential for injury to harbour porpoise within approximately 4 km, to minke whale within 1.1 km, to grey and harbour seal within 560 m and to white-beaked and bottlenose dolphin within 130 m of the clearance operations.

1 Introduction

1.1 Objective

This document reports the methodology and results of underwater sound monitoring during unexploded ordinance (UXO) clearance operations at the Seagreen Offshore Wind Farm. UXO clearance operations took place between 20th September and 12th October 2021. The UXOs were located in the North Sea, approximately 60 km (32 nm) east of Montrose, Scotland, in approximately 55 m water depth. The work was carried out from the 60 m DP2 dive support / ROV vessel Glomar Worker. The location of the UXOs is illustrated in Figure 1.1.

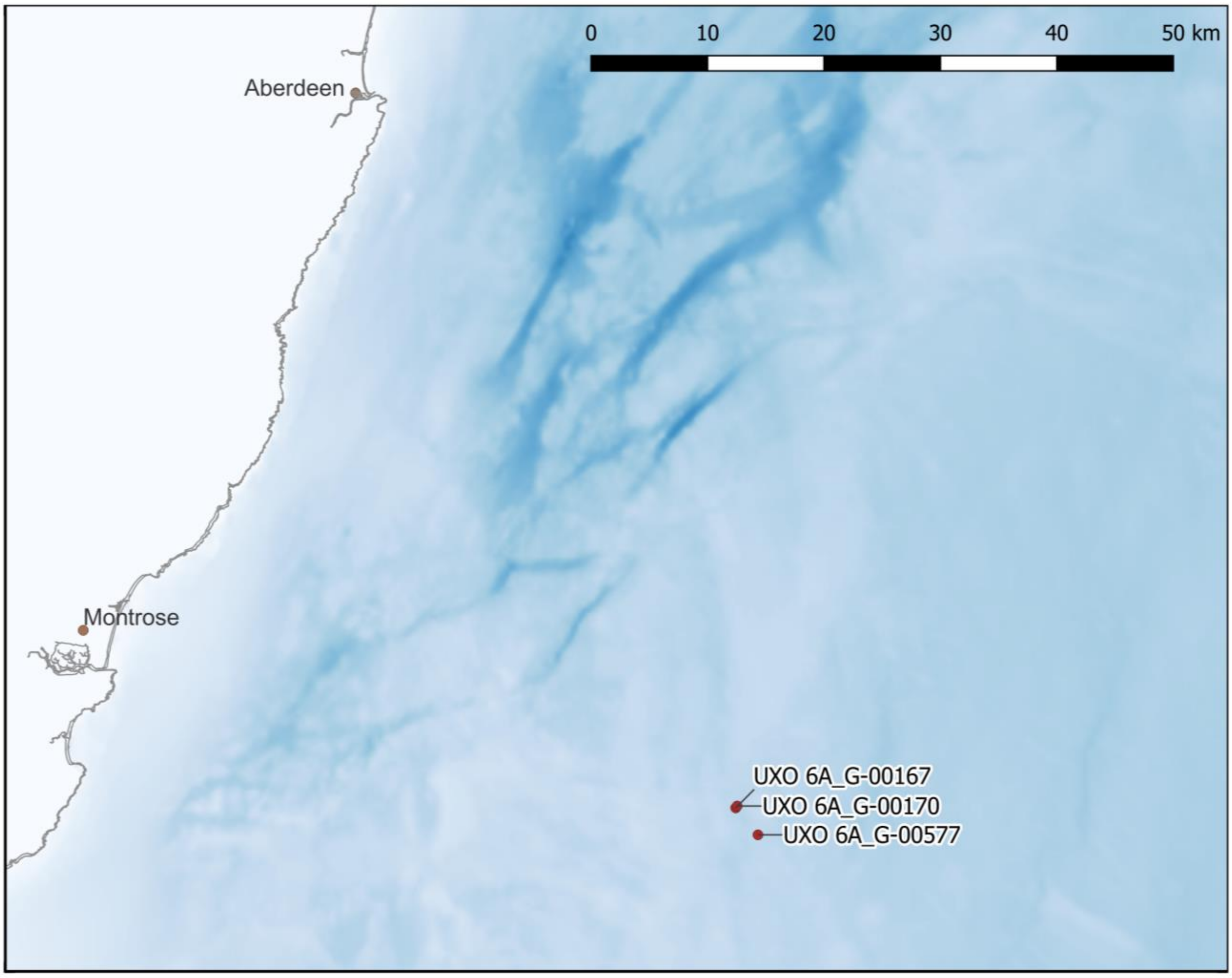

Figure 1.1: UXO locations - overview

The UXO clearance was undertaken using the HYDRA-Jet Disrupter system which, according to the manufacturer's literature, can guarantee a low yield result when prosecuting the UXO target candidate. The HYDRA technique uses a high-pressure water jet instead of a high temperature plasma jet to achieve the penetration and disruption, meaning that no heat is introduced to the UXO. Each Hydra disruptor is filled with primary energetic, explosive contents.

Noise is readily transmitted underwater and there is potential for sound emissions from the survey to affect marine mammals and fish. At long ranges the introduction of additional noise could potentially cause short-term behavioural changes, for example to the ability of species to communicate and to determine the presence of predators, food, underwater features, and obstructions. At close ranges and with high noise source levels, permanent or temporary hearing damage may occur, while at very close range, gross physical trauma is possible.

1.2 Marine Mammal Diversity in the Area

There are five species of cetacean (whales, dolphins and porpoises) known to regularly occur in the waters off north-east Scotland. These are the harbour porpoise (*Phocoena phocoena*), white-beaked dolphin (*Lagenorhynchus albirostris*), bottlenose dolphin (*Tursiops truncatus*) and minke whale (*Balaenoptera acutorostrata*) (Hammond *et al*., 2004). In additional there are occasional at sea sightings of a further nine species including the humpback whale (*Megaptera novaeangliae*) (Hammond *et al*., 2004). Since 2017, the Firth of Forth has seen an increase in the occurrence of humpback whales during winter (O'Neil *et al*., 2018).

In addition to cetaceans, two species of pinniped are commonly recorded in the area, the grey seal (*Halichoerus grypus*) and harbour seal (*Phoca vitulina*) (Hammond *et al*., 2004). The largest east coast breeding colony of grey seals in Scotland is present on the Isle of May in the entrance to the Firth of Forth (JNCC, 2021a). In addition, the Firth of Tay and Eden Estuary supports a nationally important breeding colony of harbour seals (JNCC, 2021b).

Within the Seagreen Offshore Wind Farm project area, site specific aerial and boat-based surveys recorded harbour seal, grey seal, harbour porpoise, minke whale and white-beaked dolphin (Seagreen Wind Energy, 2018).

1.3 Legislation

All cetaceans and seals are listed as European Protected Species (EPS) and afforded protection under The Conservation (Natural Habitats, &c.) Regulations 1994 (as amended) which applies to Scottish territorial waters, and The Conservation of Offshore Marine Habitats and Species Regulations (OMRs) 2017 which apply to waters between 12 and 200 nm. Marine mammals are also protected under the Wildlife and Countryside Act 1981. These regulations make it an offence to deliberately or recklessly capture, injure or kill, deliberately disturb, or damage or destroy a breeding site or resting place.

Seagreen Wind Energy Limited was awarded Section 36 Consent under the Electricity Act 1989 for the Seagreen Alpha and Seagreen Bravo Offshore Wind Farms (OWFs) in October 2014. A Marine Licence required under the Marine and Coastal Access Act 2009 was issued in July 2021 for the use of explosive substance or article for disposal of UXOs.

The license conditions pertaining to the UXO clearance activities (Licence Number: MS-00009272) contains the following requirements:

"3.1.10 The Licensee must carry out noise monitoring of each UXO clearance event (including low yield, low order and high order techniques) in line with National Physical Laboratory guidance. The Licensee must ensure that monitoring of the noise generated by the Licensed Activity is recorded in a manner suitable to provide for clear reports on underwater noise to be submitted to the Licensing Authority within 28 days of the Completion of the Licensed Activities.

3.4.3 *The Licensee must complete and submit a Close-out Report for all aspects of the Licensed Activity that produced loud, low to medium frequency (10Hz-10kHz) impulsive noise in the online Marine Noise Registry no later than 12 weeks from the Completion of the Licensed Activity.*

3.4.8 *The Licensee must provide a report based on the noise monitoring to the Licensing Authority no later than 28 days following Completion of the Licensed Activity. This report must clearly detail the underwater noise levels generated by the Licensed Activity."*

This report provides an analysis of the noise monitoring methodology and results in accordance with conditions 3.1.10 and 3.4.8 of the Marine License. The results of this report can be used by the client to fulfil condition 3.4.3.

2 Acoustic Concepts and Terminology

2.1 The Propagation of Sound Underwater

Sound travels through the water as vibrations of the fluid particles in a series of pressure waves. The waves comprise a series of alternating compressions (positive pressure) and rarefactions (negative pressure). Because sound consists of variations in pressure, the unit for measuring sound is usually referenced to a unit of pressure, the Pascal (Pa). The decibel (dB) scale is used to conveniently communicate the large range of acoustic pressures encountered, with a known pressure amplitude chosen as a reference value (i.e., 0 dB). In the case of underwater sound, the reference value (P_{ref}) is taken as 1 µPa, whereas the airborne sound is usually referenced to a pressure of 20 µPa. To convert from a sound pressure level referenced to 20 µPa to one referenced to 1 µPa, a factor of 20 log (20/1) i.e., 26 dB has to be added to the former quantity. Thus 60 dB re 20 µPa is the same as 86 dB re 1 µPa, although differences in sound speeds and different densities mean that the decibel level difference in sound intensity is much more than the 26 dB when converting pressure from air to water. All underwater sound pressure levels in this report are quantified in dB re 1 µPa.

2.2 Metrics of Underwater Sound

There are several descriptors used to characterise a sound wave. The difference between the lowest pressure variation (rarefaction) and the highest-pressure variation (compression) is called the peak to peak (or pk-pk) sound pressure level. The difference between the highest variation (either positive or negative) and the mean pressure is called the peak pressure level. Lastly, the root mean square (rms) sound pressure level is used as a description of the average amplitude of the variations in pressure over a specific time window. Decibel values reported should always be quoted along with the P_{ref} value employed during calculations. For example, the measured SPL_{rms} value of a pulse may be reported as 100 dB re 1 µPa. These descriptions are shown graphically in Figure 2.1.

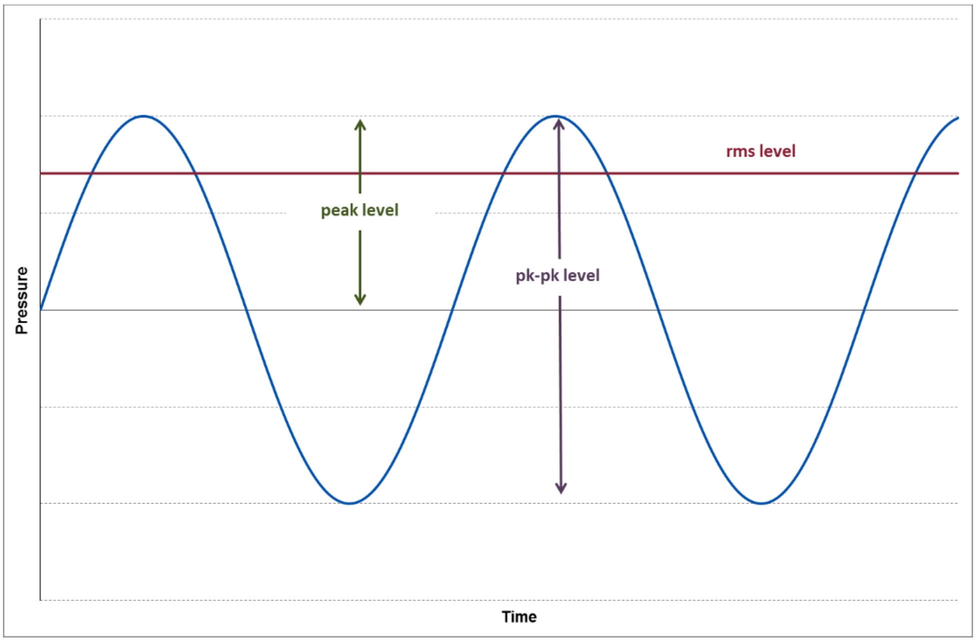

Figure 2.1: Graphical representation of acoustic wave descriptors

The rms sound pressure level (SPL) is defined as follows:

$$SPL_{rms} = 10log_{10}\left(\frac{1}{T}\int_{0}^{T}\left(\frac{p^2}{p_{ref}^2}\right)dt\right).$$

The magnitude of the rms sound pressure level for an impulsive sound (such as that from a seismic source array) will depend upon the integration time, T, used for the calculation (Madsen 2005). It has become customary to utilise the T90 time period for calculating and reporting rms sound pressure levels. This is the interval over which the cumulative energy curve rises from 5% to 95% of the total energy and therefore contains 90% of the sound energy.

Another useful measure of sound used in underwater acoustics is the Sound Exposure Level, or SEL. This descriptor is used as a measure of the total sound energy of an event or a number of events (e.g., over the course of a day) and is normalised to one second. This allows the total acoustic energy contained in events lasting a different amount of time to be compared on a like for like basis[1]. The SEL is defined as follows:

$$SEL = 10log_{10}\left(\int_{0}^{T}\left(\frac{p^2(t)}{p_{ref}^2 t_{ref}}\right)dt\right).$$

The frequency, or pitch, of the sound is the rate at which the acoustic oscillations occur in the medium (air/water) and is measured in cycles per second, or Hertz (Hz). When sound is measured in a way which approximates to how a human would perceive it using an A-weighting filter on a sound level meter, the resulting level is described in values of dBA. However, the hearing faculty of marine mammals is not the same as humans, with marine mammals hearing over a wider range of frequencies and with a different sensitivity. It is therefore important to understand how an animal's hearing varies over its entire frequency range to assess the effects of anthropogenic sound on marine mammals. Consequently, use can be made of frequency weighting scales (m-weighting) to determine the level of the sound in comparison with the auditory response of the animal concerned. A comparison between the typical hearing response curves for fish, humans and marine mammals is shown in Figure 2.2. (It is worth noting that hearing thresholds are sometimes shown as audiograms with sound level on the y-axis rather than sensitivity, resulting in the graph shape being the inverse of the graph shown.)

1 Historically, use was primarily made of rms and peak sound pressure level metrics for assessing the potential effects of sound on marine life. However, the SEL is increasingly being used as it allows exposure duration and the effect of exposure to multiple events to be considered.

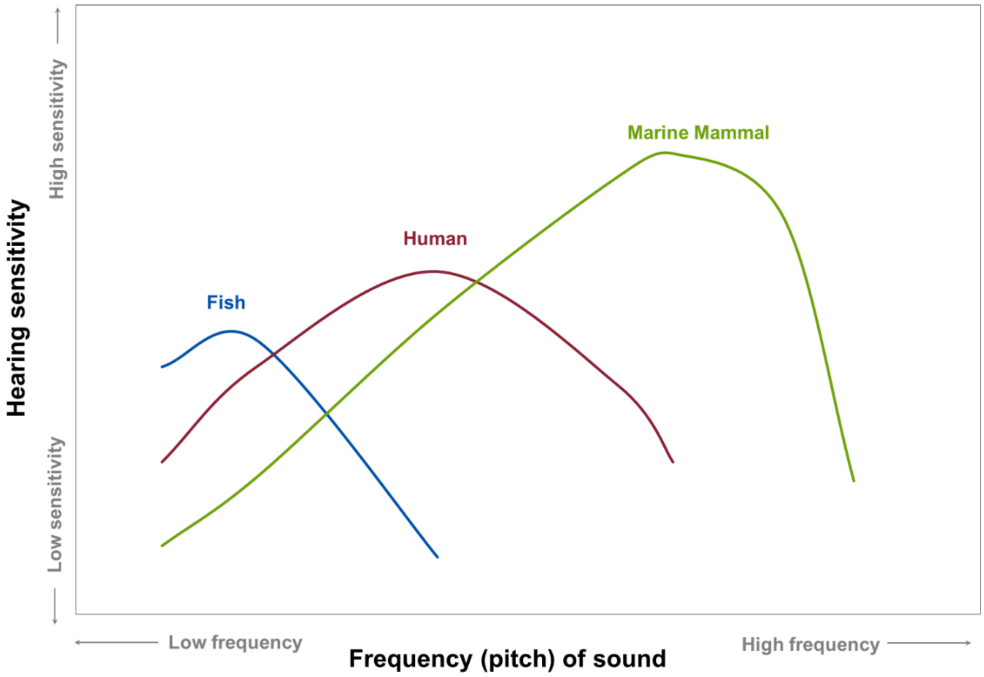

Figure 2.2: Comparison between hearing thresholds of different animals

2.3 Other Relevant Acoustic Terminology

Other relevant acoustic terminology and their definitions used in the report are detailed below.

2.3.1 1/3rd octave bands

The broadband acoustic power (i.e., containing all the possible frequencies) emitted by a sound source, measured/modelled at a location within the survey region is generally split into and reported in a series of frequency bands. In marine acoustics, the spectrum is generally reported in standard 1/3rd octave band frequencies, where an octave represents a doubling in sound frequency.

2.3.2 Source level (SL)

The source level is the sound pressure level of an equivalent and infinitesimally small version of the source (known as *point source*) at a hypothetical distance of 1 m from it. The source level may be combined with the transmission loss (TL) associated with the environment to obtain the received level (RL) in the *far field* of the source. The far field distance is chosen so that the behaviour of the distributed source can be approximated to that of a point source. Source levels do not indicate the real sound pressure level at 1 m.

2.3.3 Transmission loss (TL)

TL at a frequency of interest is defined as the loss of acoustic energy as the signal propagates from a hypothetical (point) source location to the chosen receiver location. The TL is dependent on water depth, source depth, receiver depth, frequency, geology, and environmental conditions. The TL values are generally evaluated using an acoustic propagation model (various numerical methods exist) accounting for the above dependencies.

2.3.4 Received level (RL)

The RL is the sound level of the acoustic signal recorded (or modelled) at a given location, that corresponds to the acoustic pressure/energy generated by a known active sound source. This considers the acoustic output of a source and is modified by propagation effects. This RL value is strongly dependant on the source, environmental properties, geological properties and measurement location/depth. The RL is reported in dB either in rms or peak-to-peak SPL, and SEL metrics, within the relevant third-octave band frequencies. The RL is related to the SL as

$$RL = SL - TL$$

where TL is the transmission loss of the acoustic energy within the survey region.

The directional dependence of the source signature and the variation of TL with azimuthal direction α (which is strongly dependent on bathymetry) are generally combined and interpolated to report a 2-D plot of the RL around the chosen source point up to a chosen distance.

2.3.5 Kurtosis

The kurtosis (β) of the sound pressure, p(t), over a specified time interval, t_1 to t_2, can provide a useful measure of the impulsivity of a waveform. The kurtosis is given by the following equation:

$$\beta = \frac{\frac{1}{t_2 - t_1}\int_{t_1}^{t_2}(p(t) - \bar{p})^4\, dt}{\left(\frac{1}{t_2 - t_1}\int_{t_1}^{t_2}(p(t) - \bar{p})^2\, dt\right)^2}$$

where $\bar{p}$ is the mean sound pressure at the same time interval.

3 Description of UXO Clearance

3.1 UXO Details

The project involved the clearance of three UXOs (two sea mines and one buoyant mine, all British), as summarised in Table 3.1.

Table 3.1: UXO descriptions and details

UXO 577	
Target ID	6A_G-00577
Target location	SN-P26
Target position	589687.8 mE 6270226.4 mN
Water depth	-54.5 m (LAT)
Burial depth	0 m
Type of UXO	Sea mine
Type of explosive content	Amatol
NEQ (kg)	25.0 kg
Substrate type	Sand

UXO 167	
Target ID	6A_G-00167
Target location	SN-Q23
Target position	587776.5 mE 6272534.0 mN
Water depth	-57.5 m (LAT)
Burial depth	0.8 m
Type of UXO	Buoyant mine
Type of explosive content	TNT or Amatol
NEQ (kg)	227 kg
Substrate type	Sand and pebbles

UXO 170	
Target ID	6A_G-00170
Target location	SN-Q23
Target position	587901.0 mE 6272697.0 mN
Water depth	-56.7 m (LAT)
Burial depth	0.3 m
Type of UXO	Sea mine
Type of explosive content	Amatol
NEQ (kg)	25.0 kg
Substrate type	Sand

3.2 UXO Clearance Methodology

To dispose of the UXOs, a HYDRA-Jet “hyper high pressure water jet disintegration technique” was used, whereby a 750 g explosive charge is placed such that its intended effect will be a high pressure water jet which splits the UXO casing without causing a high-order explosion. The primary explosive material of the target UXO should then dissipate. This methodology is referred to as “low-yield disposal”, in contrast to “low-order disposal”, or deflagration, where the explosive material is induced to combust at a slower rate that would be caused by a “high-order” explosion.

3.3 Operations Vessel

The DP2 dive support / ROV vessel Glomar Worker (Figure 3.1) was used to conduct UXO clearance operations and deploy and recover noise monitoring equipment between 20th September and 12th October 2021. Vessel specifications can be found in Table 3.2.

Figure 3.1: DP2 dive support / ROV vessel Glomar Worker

Table 3.2: Vessel specifications

Glomar Worker Vessel Specifications	
Type	Multi-purpose vessel / DP2
Class	Rina
Flag	Panama
Rebuilt	2008/2020
Length	60 m
Breadth	15.6 m
Depth	6 m
Gross Tonnage	1969 T
Maximum speed	11 knots

4 Methodology

4.1 Monitoring Locations

The location of the four Acoustic recording units (ARU) deployed during survey measurements and the three UXO units are shown in Figure 4.1.

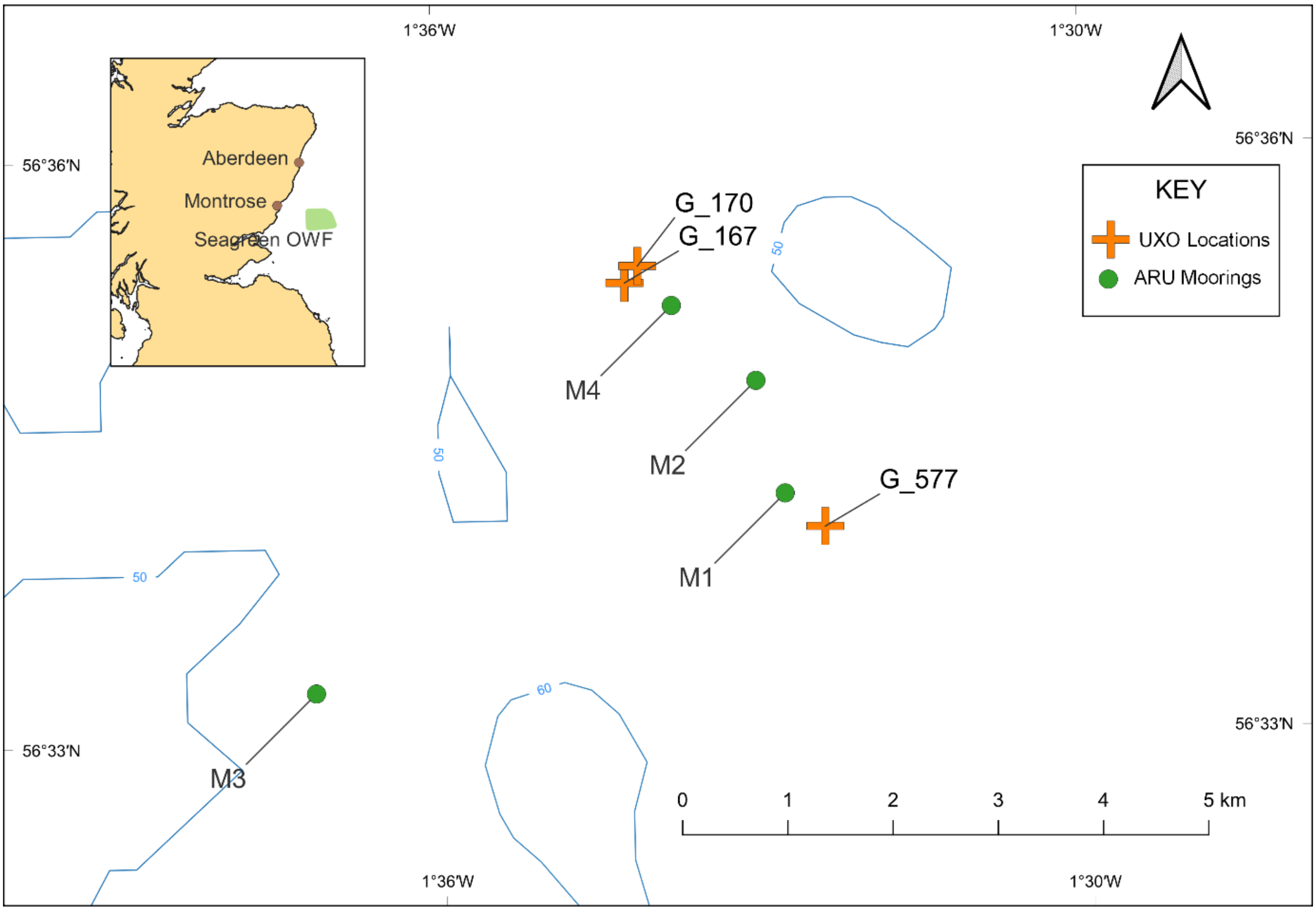

Figure 4.1: Location of ARUs (green dots) and UXOs (tallow crosses)

Moorings at locations M1, M2 and M3 were deployed prior to clearance operations, and UXO G_577 was cleared on 26th September 2021. The ARU at M1 was recovered and checked, then a double-ARU mooring was deployed at location M4. UXOs G_167 and G_170 were detonated on 5th and 6th October 2021 respectively. It was not possible to retrieve the ARU at location M3 until after the first three clearance operations had been completed.

4.2 Equipment Specification

Each ARU location consisted of either a single or double ARU mooring. All ARUs were Wildlife Acoustic SM4M units (Figure 4.2), equipped with an HTI-hydrophone with a sensitivity of either -165 dB re 1 V/µPa (standard) or -240 dB re 1 V/µPa (high-SPL). A gain could then be applied to the unit prior to deployment.

Figure 4.2: SM4M Autonomous Recording Unit

The moorings deployed, and corresponding ARU hydrophones and gains, were as follows:

- **M1**: single ARU, high-SPL (10 dB gain);
- **M2**: double ARU, high-SPL (25 dB gain) and standard (0 dB gain);
- **M3**: single ARU, standard (0 dB gain);
- **M4**: double ARU, high-SPL (10 dB gain) and standard (0 dB gain).

Prior to deployment, a 250 Hz signal from a pistonphone was recorded on each ARU in order to act as a calibration check.

4.3 Deployment

Following the pistonphone check, the ARUs were attached to the mooring, comprising two ground weights, connecting lines and recovery and marker buoys. A schematic of the mooring can be seen in Figure 4.3.

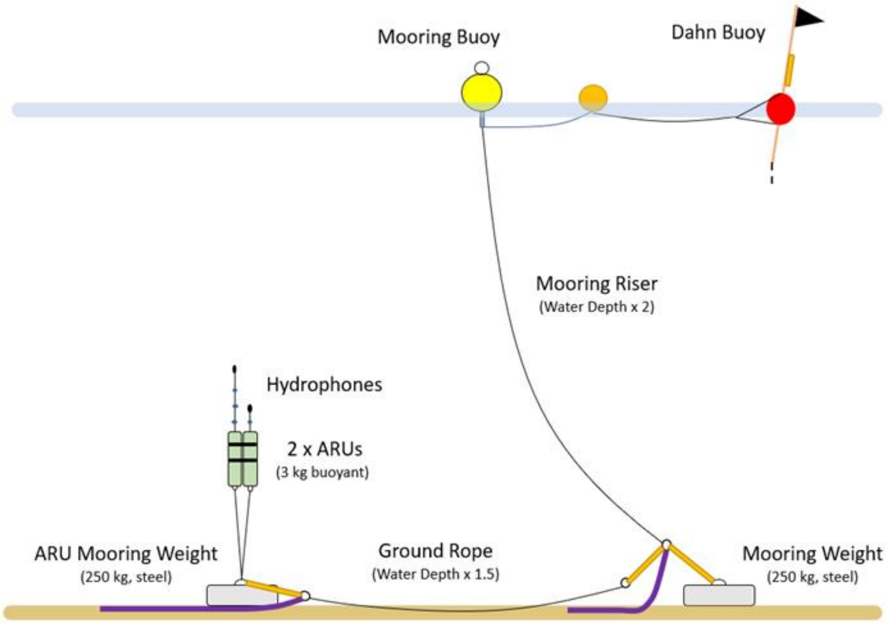

Figure 4.3: Schematic of a double-ARU mooring

For each ARU location, the ARU weight and ARUs were deployed from the stern roller, with the ground line paid out until the ARU weight sat on the sea-bed. Next, the vessel moved slowly to a position at least 50 meters from the ARU position, where the mooring weight and buoys were deployed.

As noted above, ARU location M1 was deployed only for the detonation of UXO G_577, and M4 was deployed only for the detonation of UXOs G_167 and G_170. The remaining moorings, M2 and M3, remained in place for the duration of activities and were not recovered between detonation activities.

4.4 Analysis Methodology

For each UXO operation and each ARU location, the file containing the event was located and manually inspected to check for clipping. Data where clipping was detected was not used in any analysis. Audio files were then converted into acoustic pressure using the hydrophone sensitivities and gain settings. This pressure data was used to calculate the peak SPL, SEL and kurtosis of the detonation event.

The energy of the signal was used to find the T90 window, which was then used to compute the SPL rms. Finally, the signal was filtered to get third-octave bands which, with marine mammal hearing weightings (Southall et al., 2019), can be used to determine injury ranges to marine mammals. The above measures are used to calculate the expected threshold ranges for temporary threshold shift (TTS) and permanent threshold shift (PTS) for different marine mammal hearing groups.

4.5 Noise Modelling Methodology

In order to provide a baseline comparison (i.e.,to compare the likely noise levels which would have resulted from traditional UXO clearance methodologies), noise modelling has been undertaken for the various UXOs found at the Seagreen site.

Noise modelling for UXO clearance has been undertaken using the methodology described in Soloway and Dahl (2014). The equation provides a simple relationship between distance from an explosion and the weight of the charge (or equivalent TNT weight) but does not take into account bottom topography or sediment characteristics.

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

where W is the equivalent TNT charge weight and R is the distance from source to receiver.

Since the charge is assumed to be freely standing in mid-water, unlike a UXO which would be resting on the seabed and could potentially be buried, degraded or subject to other significant attenuation, this estimation of the source level can be considered conservative.

According to Soloway and Dahl (2014), the SEL can be estimated by the following equation:

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

5 Monitoring Results and Discussion

5.1 Speed of Sound Measurement

The speed of sound measurements taken from the Star Oddi CTD device were compiled using the SeaStar software. The collected speed of temperature (T), water depth measurement (z) was employed to calculate the speed of sound in the water column using the following equation

$$C = 1449.2 + 4.6T - 0.055T^2 + 0.0029\,T^3 + (1.34-0.01T)\,(S-35) + 0.16z.$$

The results are reported in Figure 5.1 which shows the speed of sound at various water depths. The speed of sound varies between 1,500 m/s and 1,530 m/s.

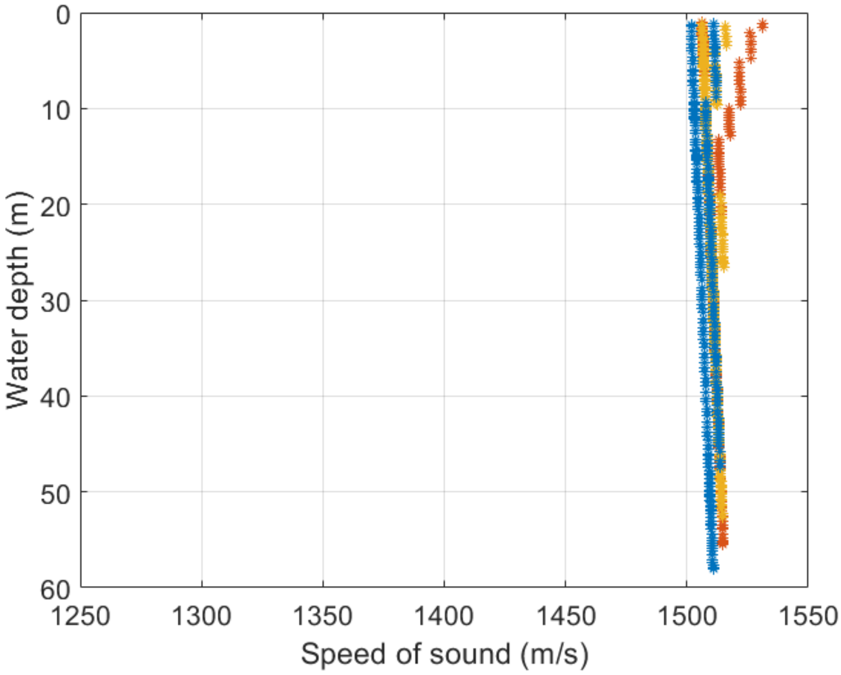

Figure 5.1: A compilation of all speed of sound measurements using the CTD probe

5.2 UXO Noise Measurement Results

The expected sound level produced by this UXO clearance operation was unknown prior to sound recording. It was planned therefore, to deploy the ARUs for the first clearance event and then to retrieve and inspect the data prior to deployment for the later events. This would provide an opportunity to confirm the choice of hydrophone sensitivity on the single 5,000 m ARU and if necessary, swap out the hydrophone for a high SPL hydrophone. However, due to weather and time constraints, the 5,000 m ARU was not retrieved until after the third detonation event. Inspection of the data showed that the standard SPL hydrophone had clipped – the standard SPL hydrophone was too sensitive and the received sound pressure level exceeded the maximum level that was able to be recorded on this ARU. The decision was taken to swap it for a high SPL hydrophone for the remaining clearance activities. However, following further investigations of candidate UXO targets it transpired that no further detonations were required and consequently, no measurements were recorded at 5,000 m range using a high SPL hydrophone. As a result, no valid measurements were available at 5,000 m range (Location M3).

Table 5.1 presents the compilation of different acoustic metrics for all UXO signatures recorded using the ARUs.

Table 5.1: Summary of measured acoustic metrics and other parameters for all three UXO measurements.

Parameter		UXO G_577 (25 kg)		UXO G_167 (227 kg)		UXO G_170 (25 kg)	
	Range:	**497 m**	**1534 m**	**494 m**	**1555 m**	**495 m**	**1566 m**
SPL_{pk}, dB re 1 µPa (pk)		220.6	210.8	218.9	209.1	217.5	209.2
SPL_{rms}, dB re 1 µPa (rms_{T90})		199.8	192.2	199.5	192.1	198.5	191.5
SEL, dB re 1 µPa²s	*Unweighted*	191.1	185.0	190.8	185.9	190.0	185.1
	LF weighted	188.2	181.5	186.6	181.4	186.1	180.8
	HF weighted	165.9	158.1	170.0	162.5	165.9	161.5
	VHF weighted	162.8	154.2	167.6	159.6	164.1	158.8
	OCW weighted	179.8	173.6	179.5	172.5	177.0	171.7
	PCW weighted	179.8	173.3	179.4	172.6	177.0	171.8
T90 length (ms)		133.6	185.6	138.1	243.3	139.0	227.3
Kurtosis		24.2	10.0	16.1	7.5	19.0	7.7

For impulsive sounds such as detonations the interaction with the seafloor and the water column is complex. In these cases, a combination of dispersion (i.e., where the waveform shape elongates), and multiple reflections from the sea surface and bottom and molecular absorption of high frequency energy, the sound will lose its impulsive shape after some distance. This elongation of the waveform can be clearly observed in the T90 results where the length of the waveform increases from between 133 and 139 ms at 500 m to between 185 and 243 ms at 1,500 m. Likewise, the kurtosis significantly reduces with range for all UXOs measured, providing further evidence of a reduction in “impulsivity” for larger ranges.

The measured pressure-time curve recorded at two different sites M1 and M2 for the UXO G_577 for corresponding distances of 497 m and 1,534 m. These signatures are plotted in Figure 5.2 with the peak recorded value locally aligned to 0.2 s time stamp. Waveforms for other UXOs can be found in Appendix A.

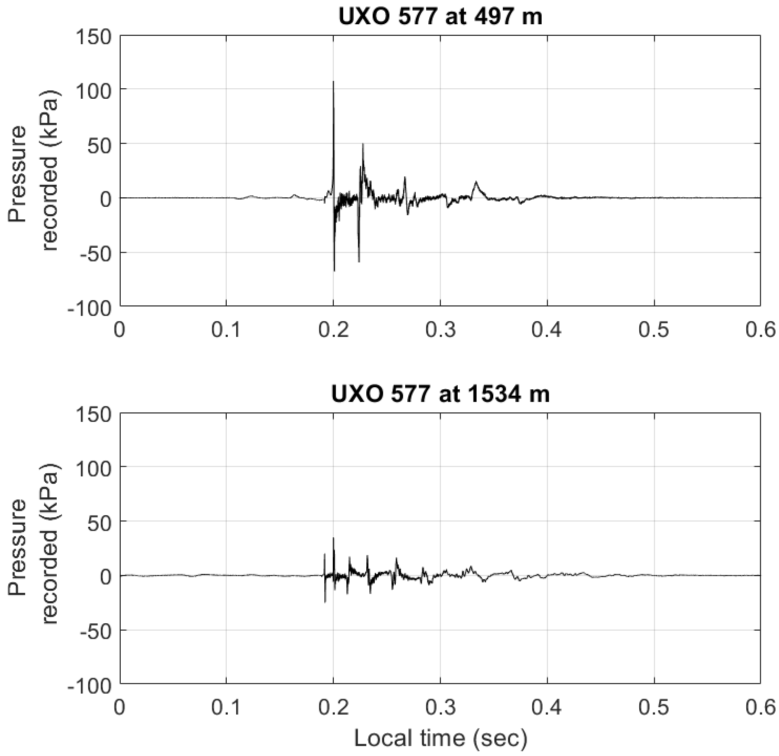

Figure 5.2: Pressure time plot at two distances for UXO G_577

A recent article by Southall (2021) discusses this aspect in detail, and notes that *"…when onset criteria levels were applied to relatively high-intensity impulsive sources (e.g., pile driving), TTS onset was predicted in some instances at ranges of tens of kilometers from the sources. In reality, acoustic propagation over such ranges transforms impulsive characteristics in time and frequency (see Hastie et al., 2019; Amaral et al., 2020; Martin et al., 2020). Changes to received signals include less rapid signal onset, longer total duration, reduced crest factor, reduced kurtosis, and narrower bandwidth (reduced high-frequency content). A better means of accounting for these changes can avoid overly precautionary conclusions, although how to do so is proving vexing"*. The point is reenforced later in the discussion which points out that *"…it should be recognized that the use of impulsive exposure criteria for receivers at greater ranges (tens of kilometers) is almost certainly an overly precautionary interpretation of existing criteria"*.

The recorded signatures from all three UXO measurements was processed into one-third octave band frequencies and evaluated using the SEL metric. Figure 5.3 presents the third-octave band SEL levels at 500 m on the left and 1,500 m on right. These third octave band levels were employed along with marine mammal weightings to calculated TTS and PTS impact ranges.

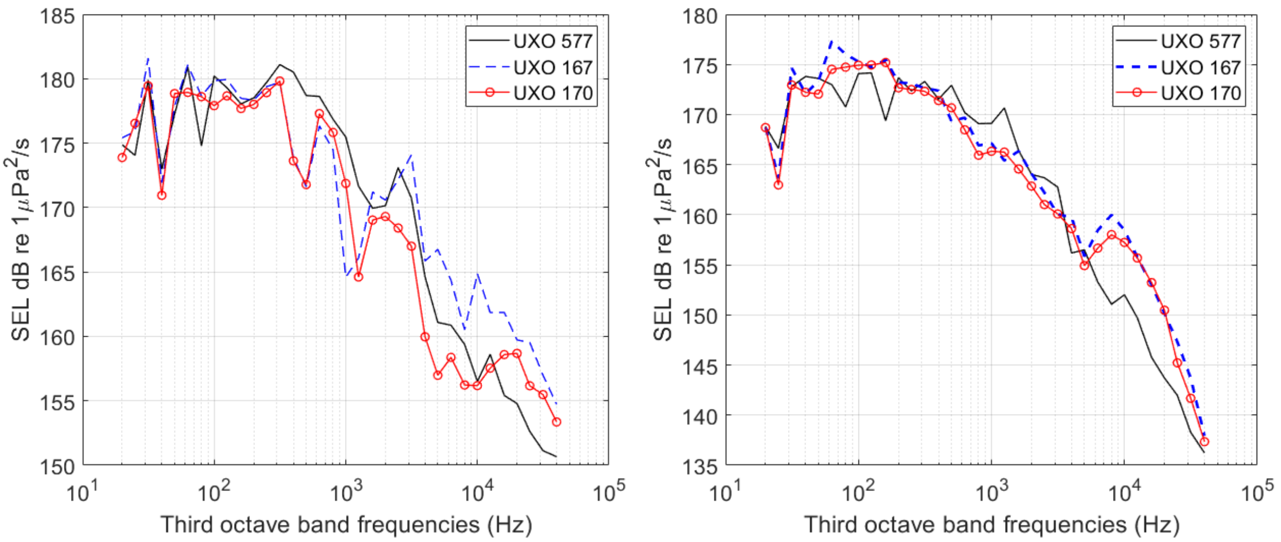

Figure 5.3: Third octave band SEL at 500 m (left) and at 1500 m (right)

5.3 Potential for Injury to Marine Mammals

A summary of the interpolated marine mammal PTS injury ranges based on the measured data is presented in Table 5.2. The injury ranges are determined based on the measured levels recorded around 500 m and 1,500 m, and therefore it is important to understand that there is potential for some error in the derivation of injury range based on the spread of data and extrapolation errors. The injury thresholds are based on those set out in Southall et al. (2019) and NMFS (2018).

Table 5.2: Estimated PTS injury ranges based on interpolation of measured noise levels

Marine Mammal Hearing Group	PTS Range (Interpolated from measured data)			
	SPL peak (unweighted)		SEL (hearing weighted)	
	Threshold	Range, m	*Threshold*	Range, m
LF (Minke Whale)	*219*	496	*183*	1,091
HF (White-Beaked Dolphin, Bottlenose Dolphin)	*230*	128	*185*	22
VHF (Harbour Porpoise)	*202*	3,990	*155*	2,314
PCW (Grey Seal, Harbour Seal)	*218*	560	*185*	156

5.4 Comparison to Theoretical Modelling Results

A comparison between the measured and predicted peak sound pressure levels is shown in Figure 5.4. This shows that the measured levels are approximately 4 to 7 dB higher than predicted for a 750 g charge (1.0125 kg equivalent weight TNT for the SEMTEX charge used) using Soloway and Dahl (2014) at 500 m range and 7 to 8 dB higher than predicted at 1.5 km range.

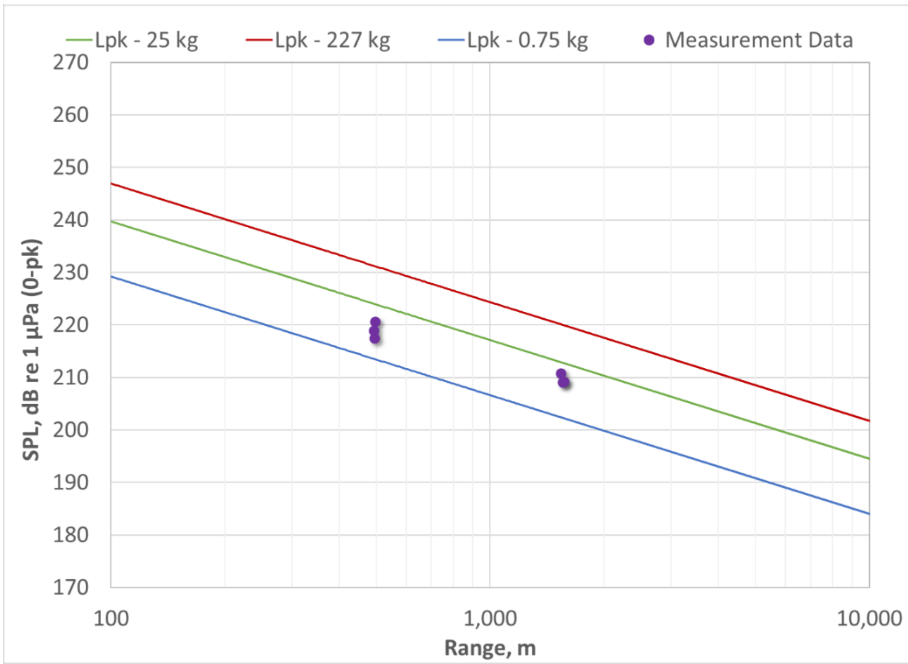

Figure 5.4: Comparison of measured and predicted peak sound pressure levels

A comparison between the modelled and measured unweighted SEL for each UXO against the predicted levels using Soloway and Dahl (2014) is shown in Figure 5.5. The comparison shows that measured SEL values were approximately 6 to 7 dB higher than predicted at 500 m range and 7 to 8 dB higher than predicted at 1.5 km range.

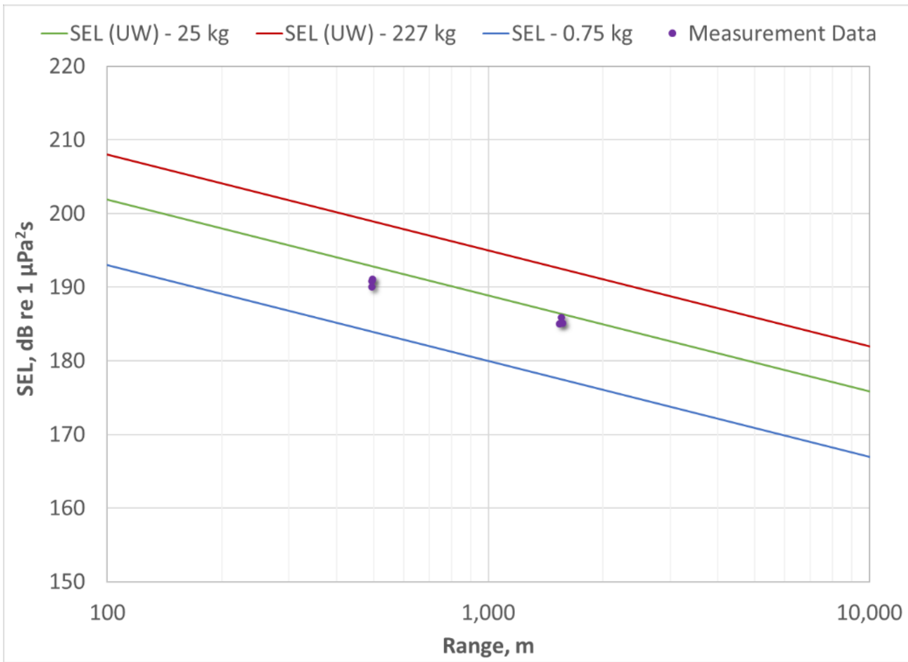

Figure 5.5: Comparison of measured and predicted SELs

The difference between the predicted and measured sound levels could be due several reasons including:

- limitations in the prediction methodology (e.g. because it is a semi-empirical method and does not take into account bathymetry, bottom conditions etc.); and
- due to differences in sound produced by the explosive due to the configuration of the HYDRA-Jet (e.g. since the prediction model is based on detonation of a freely suspended charge in open water).

It is not possible to determine the reasons for any difference between the modelled and measured sound levels based on the results of this study alone.

Nevertheless, some useful conclusions can be drawn from the monitoring data. Based on the comparison to the modelled noise levels for the HYDRA-Jet charge weight and the noise level that would be expected due to first order detonation of the UXOs it can be seen that noise due to UXO clearance activities using the HYDRA-Jet is lower than would be expected from first order detonation of the UXOs. This confirms that the HYDRA-Jet technique is a useful noise mitigation tool for reducing the potential injury ranges for marine mammals and other aquatic life. Furthermore, the noise level due to the clearance activities is similar at each range irrespective of the UXO size, demonstrating that a first order UXO detonation is unlikely to have occurred during the survey.

6 Conclusions

Based on the results of the noise monitoring it is concluded that:

- Noise due to use of the HYDRA-Jet for UXO clearance was 4 to 8 dB higher than the theoretical model predictions for the HYDRA-Jet charge.
- The reasons for the higher than expected sound levels are not known at this time but could be due to limitations of the semi-empirical model or an oversimplification of assumptions (e.g. because the noise modelling technique assumes a freely suspended charge in open water).
- The noise level due to the clearance activities is similar at each range irrespective of the UXO size, indicating that a high order UXO detonation did not occur.
- Noise due to use of HYDRA-Jet was lower than would be expected for a high order UXO detonation in all cases, meaning that the technique is a useful tool in reducing the potential impact due to underwater sound on marine life.
- The measurement results show that there is potential for injury (PTS) to harbour porpoise within approximately 4 km, to minke whale within 1.1 km, to grey and harbour seal within 560 m and to white-beaked and bottlenose dolphin within 130 m of the clearance operations.
- The results show significant elongation of the waveform with range, resulting in longer pulse durations, lower peak pressures compared to SEL and lower kurtosis. This adds to the evidence that the Southall et al. (2019) thresholds for impulsive sound may not be applicable for assessing injury at larger ranges, although it is not possible based on the results of this study alone to provide a definitive range beyond which the impulsive thresholds are no longer applicable.

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Appendix A. Measurement Results

Figure A.1 to Figure A.4 show the waveforms for UXO G_167 and UXO G_170. The waveforms for UXO G_577 are shown above in Figure 5.2 5.2.

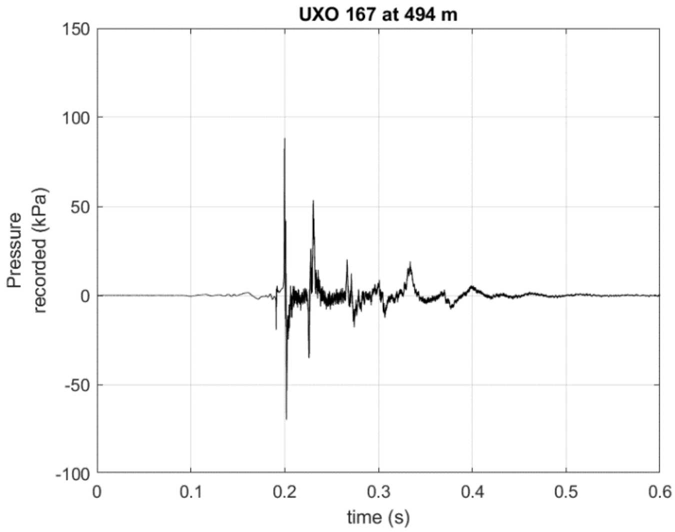

Figure A.1: UXO G_167 measured from ARU station M4

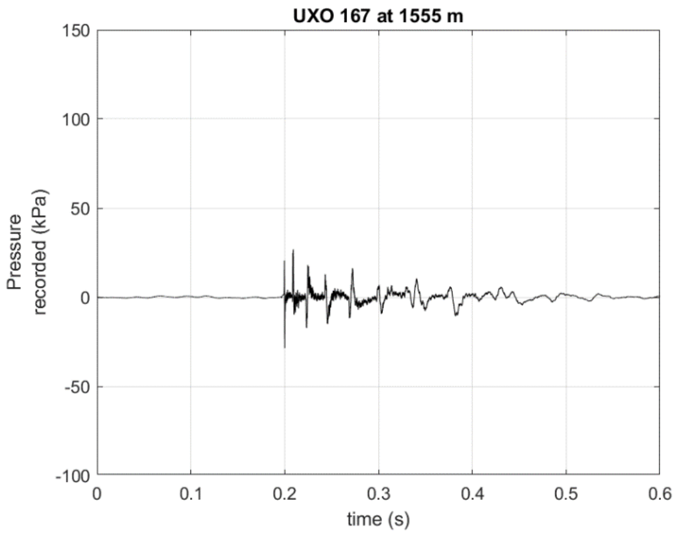

Figure A.2: UXO G_167 measured from ARU station M2.

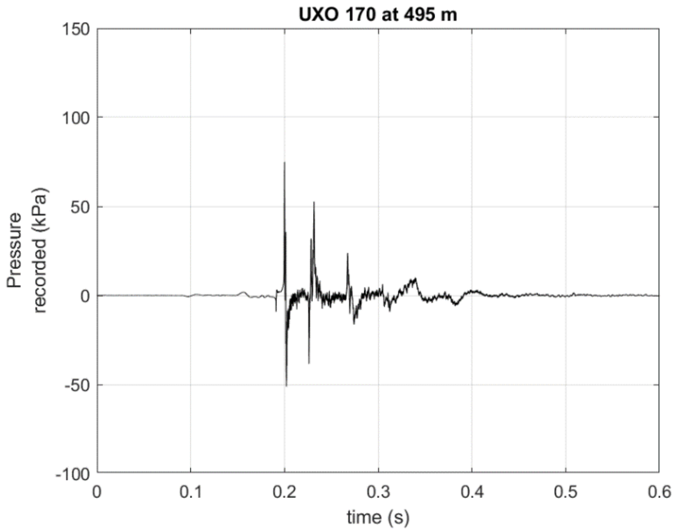

Figure A.3: UXO G_170 measured from ARU station M4.

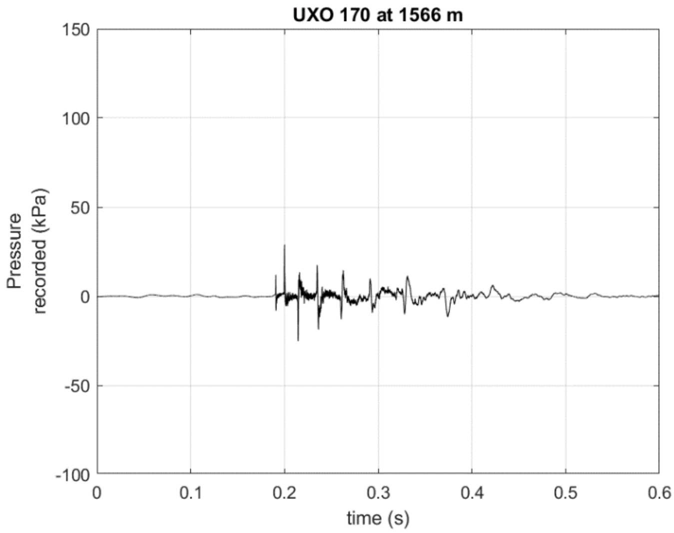

Figure A.4: UXO G_170 measured from ARU station M2.