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Seagreen Alpha and Bravo Site UXO clearance – Noise monitoring and mitigation summary

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1. Introduction

Seagreen Wind Energy Limited (SWEL, hereafter referred to as 'Seagreen') was awarded consents by Scottish Ministers in October 2014 for the Seagreen Alpha and Seagreen Bravo Offshore Wind Farms (OWFs) and the Offshore Transmission Asset (OTA), which includes the wind farm export cables. The project is located in the North Sea, in the outer Firth of Forth and Firth of Tay.

In advance of commencing offshore construction Seagreen undertook a campaign of unexploded ordnance (UXO) clearance of the Alpha and Bravo site between May and October 2021. Activities included ROV survey of targets for UXO identification, relocation of non-UXO items, and relocation and disposal of UXOs. A detailed description of activities is provided in Report LF000009-SWY001-REP-H05-004-01 'Field Operations Report UXO ID & Disposal'. UXO disposal activities were undertaken under Marine Licence MS-00009502 and with European Protected Species (EPS) licence EPS/BS-00009503 obtained for disturbance and potential injury of cetaceans. In support of EPS licence applications, an EPS Risk Assessment (LF000009-CST-OF-LIC-REP-0007) was undertaken to estimate the extent of potential injury and disturbance to cetaceans and seals, and an accompanying Marine Mammal Mitigation Plan was developed to minimise the risk of injury. EPS licences and the Marine Licence included conditions to implement the MMMP and undertake monitoring of the noise generated by UXO clearance.

This report provides a summary of the UXO clearance activities, the mitigation procedures implemented and the measured noise levels. The purpose is to compare this information with the EPS Risk Assessment and MMMP to: (1) identify any discrepancies between predicted and measured noise levels; and, (2) assess the implementation and likely effectiveness of the mitigation measures. This report draws upon the following key documents, to which the reader is referred for further details of operations:

- EPS Risk Assessment and MMMP (LF000009-CST-OF-LIC-REP-0007)
- Field Operations Report UXO ID & Disposal (LF000009-SWY001-REP-H05-004-01), including Appendix F – Marine Mammal Observers Report and log sheet.
- Seagreen UXO Clearance Noise Monitoring – Underwater Noise Analysis Final Report (P1516-REPT-01-R3) (Cook and Banda, 2021)

2. Confirmed UXO

Of approximately 1,000 targets investigated, only 4 confirmed UXO were identified. One of these, a small naval projective (Target ID 6A_G-00961) was safely relocated to a location 35 m from where it was found. The remaining 3 UXO were disposed of in situ using the HYDRA low yield method, each with a donor charge ('disruptor') of 750 g of plastic explosives (SEMTEX 1A). None of the UXO required clearing shots (detonation of subsequent small charges to neutralise residual unstable material before recover). Summary details of these 3 UXO are presented in Table 2.1.

The HYDRA low-yield method uses one or more shaped charges to direct high pressure water jets at the UXO, resulting in the rupture or split of the UXO casing and disintegration of the primary energetic components. The method disrupts and disintegrates the UXO without combustion of the explosive material contained within. Therefore, the noise generated by the method is expected to be proportional to the size of the shaped 'donor' charge only.

Table 2.1. Summary details of UXO disposed in situ

UXO Target ID	Type	Estimated size (NEQ†)	Water depth (m LAT)	Burial depth (m)	Location	Date and time (UTC) of disposal
6A_G-00577	Sea mine	25 kg	54.5	0	E 589687.8 N 6270226.4	26/09/2021, 08:55
	6A_G-00577 notes: Misfire on initial attempt at 08:15. Crater of 1.6 m x 1 m x 0.3 m caused by detonation. UXO related debris (including remaining HYDRA unit parts) were recovered to deck.					
6A_G-00167	Buoyant mine	227 kg	57.5	0.8	E 587776.5 N 6272534.0	08/10/2021, 10:15
	6A_G-00167 notes: Only the top 0.5 m of the mine was exposed after dredging. Crater of 2.18 m x 1.7 m x 0.5 m caused by detonation. UXO related debris (including remaining HYDRA unit parts) were recovered to deck.					
6A_G-00170	Sea mine	25 kg	56.7	0.3	E 587901.0 N 6272697.0	09/10/2021, 12:15
	6A_G-00170 notes: Crater of 2.28 m x 1.6 m x 0.5 m caused by detonation. UXO related debris (including remaining HYDRA unit parts) were recovered to deck.					

Notes: † Net explosive quantity.

2.1 Comparison of activities with application and consent

The disposal of three UXO was far fewer than the conservative 20 UXO for which the assessment and licence application was based. Similarly, the UXO disposed of ranged in size from 25-227 kg NEQ (Net Explosive Quantity), and were therefore within the scope of those anticipated, assessed and consented. Donor charges were also as anticipated, in fact each UXO only requiring a single 750 g charge compared to the minimum of two (total 1.5 kg) assumed in the EPS Risk Assessment.

Licence conditions (EPS: 11-13; ML: 3.3.7-9) required a preference for avoidance or relocation of UXO where it was safe to do so, then the HYDRA low yield approach, then a low order approach, with high-order approaches only to be used where these have failed. The operations successfully completed a single relocation and three low yield detonations.

3. Mitigation measures

3.1 MMMP

Aside from a preference for UXO avoidance, relocation and low yield/order approaches, prior to any detonations, the MMMP required the use of:

- visual observations by Marine Mammal Observers (MMOs);
- acoustic observations by a Passive Acoustic Monitoring (PAM) Operator;
- deployment of an Acoustic Deterrent Device (ADD; specifically, the Lofitech Seal Scarer); and,
- for certain UXOs and disposal methods, the use of 'soft-start' charges.

For ease of reference, the UXO clearance mitigation flow-chart presented in the MMMP is reproduced below in Figure 1. As all UXO disposals involved the low-yield approach, the following procedures were required for each disposal:

1. MMO / PAM monitoring of 1 km mitigation zone for minimum of 60 minutes prior to detonation
2. Continue monitoring. Activate ADD for 22 min prior to detonation.
3. Conduct post-detonation search of the mitigation zone for minimum of 15 min.

Note: The above procedures assume no marine mammals detected within the mitigation zone and no clearing charge required.

The MMMP specified the use of two MMOs, one on the main vessel and one on the RHIB/Fast Rescue Craft (FRC) used to connect firing lines and deploy the ADD at the site of detonation.

The MMMP specified the use of real-time PAM, deployed from the FRC, during periods of low visibility (due to adverse weather and/or sea states of 3 or higher).

3.2 Mitigation measures implemented

Two MMOs were used: one positioned on the bridge of the main vessel (*Glomar Worker*) at 13 m height above sea level, and one on the FRC who was also responsible for operating PAM and ADD equipment and conducting the post-detonation search. The MMOs, the UXO disposal team and the vessel crew maintained radio communications throughout operations.

All detonations took place in daylight and under good visibility and low swell, albeit with Beaufort Sea State 3 or 4 reported. PAM was deployed for all detonations.

Throughout all detonations the *Glomar Worker* was located at her safe distance – 900 m from the UXO location – with her bow pointed towards the detonation and an MMO watch maintained throughout the operations. After the ROV had prepared the UXO for detonation and was recovered, the FRC was deployed and transited to the UXO location where PAM and ADD (Lofitech Seal Scarer) were deployed. Once the ADD had been deployed for sufficient time, both ADD and PAM were recovered and the FRC moved to 100 m leeward of the *Glomar Worker* with the detonation occurring a few minutes later.

The PAM system was the Mark 3 Mobile Heterodyne PAM system, supplied by Essan Bioacoustic Solutions, a portable detector specially modified to monitor odontocetes. PAM was undertaken in accordance with the *Marine Mammal Observer and Passive Acoustic Monitoring Handbook*.

A summary of the timings of observations and ADD deployment for each of the UXO detonations is presented in Table 3.1.

Table 3.1. Summary details of mitigation procedures for each detonation

UXO Target ID	Date and time of disposal	MMO observations (*Glomar Worker*)	MMO & PAM observations (FRC)	ADD	Notes
6A_G-00577	26/09/2021, 08:55	05:40 - 09:11 (3 h 31 min)	07:25 – 09:11 (1 h 46 min)	07:42 – 08:04 (22 min) 08:40 – 08:50 (10 min)	Misfire at 08:15, hence additional ADD.
6A_G-00167	08/10/2021, 10:15	06:40 – 12:36 (5 h 56 min)	09:38 – 10:32 (54 min)	09:49 – 10:13 (24 min)	-
6A_G-00170	09/10/2021, 12:15	07:30 – 13:36 (6 h 6 min)	11:30 – 12:36 (1 h 6 min)	11:50 – 12:14 (24 min)	-

A 15-20 min post-detonation search of the mitigation zone was conducted by the FRC after each detonation. Only one arising was reported: a 25 cm fish (*Trisopterus minutes,* poor cod) following the detonation of 6A_G-00170.

No marine mammals were sighted or acoustically detected throughout operations.

3.3 Appraisal of mitigation measures

The operations were conducted in compliance with the MMMP and alongside the logistical and safety requirements of the UXO disposal operations. Some lessons can be learned from their implementation that may help guide future operations and mitigation plans.

3.3.1 Pre-detonation search

The required duration of 60 min visual observations was met by the MMO on the *Glomar Worker* for all detonations. The second MMO / PAM operator on the FRC commenced observations once the ROV was recovered and it was safe to locate at the detonation site, therefore less than 60 min of visual and PAM observations were conducted at the detonation site for two detonations (37 and 45 min). It is likely that there may be practical constraints on how far in advance the FRC can be positioned over the detonation site and commence observations; however, if possible, the scheduling of activities to facilitate a full 60 min of observations from the FRC would be preferable.

It is noted that the *Glomar Worker* was positioned 900 m from the detonation site throughout each operation. This was within the expected range of 200-1,000 m, but results in a low likelihood of detecting marine mammals, particularly harbour porpoise and seals, throughout the 1 km mitigation zone centred on the detonation site. The mitigation zone on the far side of the detonation site would have received particularly poor coverage from the MMO on the *Glomar Worker*, even with the 13 m elevation of the bridge. The likelihood of detecting marine mammals in the mitigation zone was increased by visual observations from the FRC, and for frequently vocalising species (i.e. harbour porpoise, dolphins) via PAM, although the low vantage point that this provided, combined with a Beaufort sea state of 3-4 (and a limited detection range of PAM for harbour porpoise (a few hundred metres at most)), would have been insufficient for reliable monitoring of the entire mitigation zone. Indeed, the MMO's report noted: "*It is recommended that future UXO clearance projects continue to use two MMOs. It is not possible to effectively monitor the large mitigation zone from the low vantage point of the EOD FRC in addition to performing additional duties. The MMO observing from the Glomar Worker ensured that the mitigation zone was continually monitored throughout the operation.*"

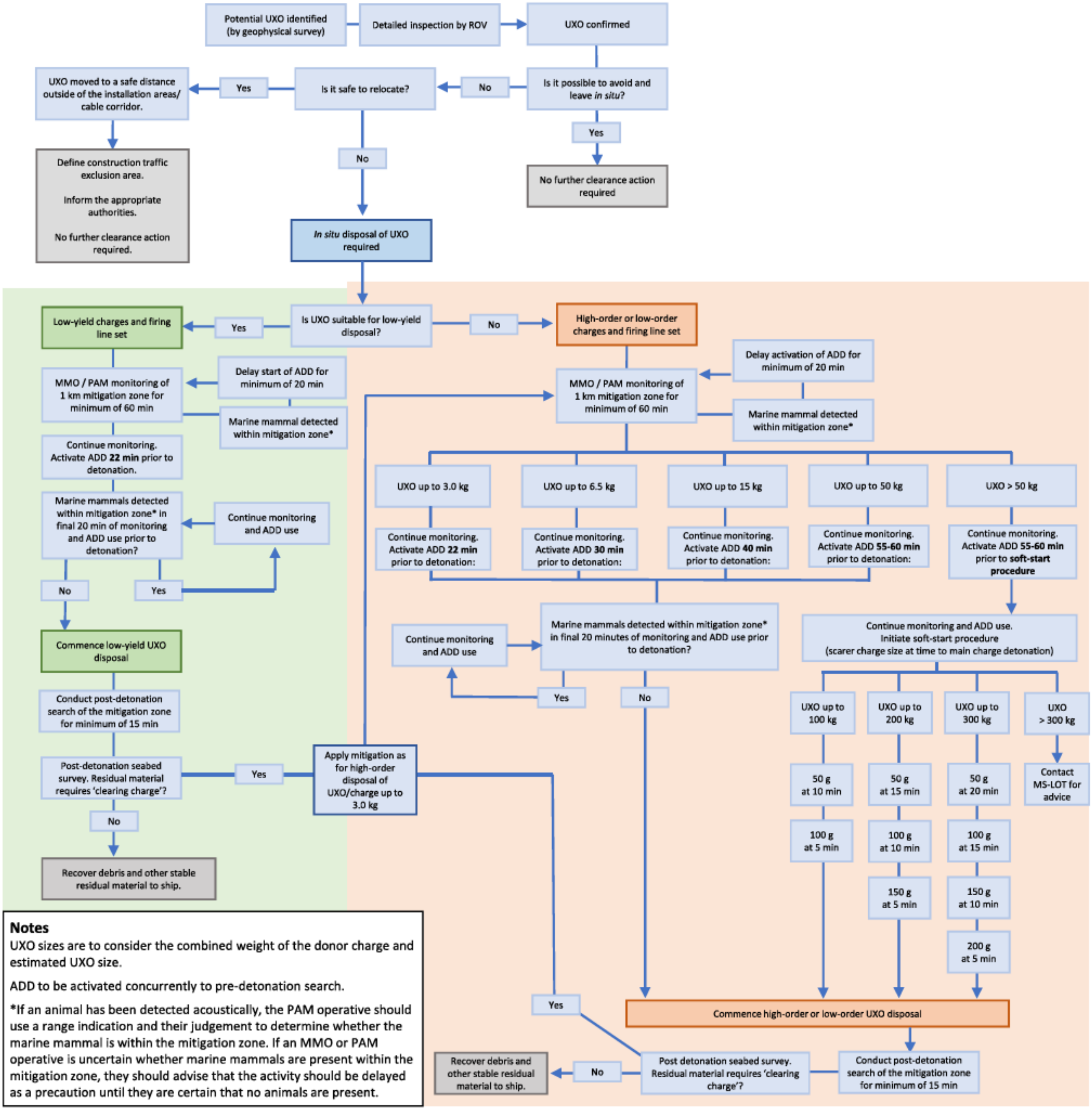
Further to the above recommendation from the MMO report, it is recommended that the duties of ADD deployment, PAM operation and visual observations from the FRC are split between at least two people, to increase the effectiveness of monitoring.

Despite the aforementioned limitations to effective monitoring of the mitigation zone, the use of an ADD for all possible scenarios of UXO disposal would have ensured that animals were absent from zones of potential trauma and deterred from zones of predicted auditory injury. In the absence of ADD use, additional platforms (to the main vessel and single FRC) from which visual observations and PAM detections could occur would be required to effectively monitor the 1 km mitigation zone.

3.3.2 ADD use

The required duration of ADD use was met for each detonation with good accuracy (22-24 min). The short time period between ADD recovery and detonation (1-5 min), which is essential for the safe relocation of the FRC, is sufficiently short to have not resulted in substantial movement of deterred animals back towards the detonation site.

The misfire at 6A_G-00577 necessitated a re-deployment of the ADD following a gap of 36 min. This second ADD deployment only lasted 10 min, likely limited by the planned detonation time. Such circumstances (misfires) were not explicitly accounted for in the MMMP. While it is unlikely that animals may have started to return to the detonation location after 36 min without ADD, the re-deployment of the ADD for a short period was likely the only option available in the circumstances and is considered to have been a worthwhile precaution. It is recommended that future MMMPs specify recommended procedures should a misfire occur.



Notes

UXO sizes are to consider the combined weight of the donor charge and estimated UXO size.

ADD to be activated concurrently to pre-detonation search.

*If an animal has been detected acoustically, the PAM operative should use a range indication and their judgement to determine whether the marine mammal is within the mitigation zone. If an MMO or PAM operative is uncertain whether marine mammals are present within the mitigation zone, they should advise that the activity should be delayed as a precaution until they are certain that no animals are present.

Figure 1. Seagreen UXO clearance mitigation flow-chart

4. Noise monitoring

Licence conditions (EPS: 15-16; ML: 3.1.10-11) required noise monitoring to be conducted at each UXO clearance event, in line with National Physical Laboratory guidance (NPL, 2020), and to subsequently be reported to the Licensing Authority. Full details of the methods and results of the noise monitoring are provided in Cook and Banda (2021). Here, we provide a summary of the methods and results for the purpose of comparing measured noise levels with those predicted in the EPS Risk Assessment, and commenting on any discrepancies between the two.

Monitoring was undertaken in accordance with the NPL guidance. Archival noise recorders were positioned at distances of c. 500 m, 1,500 m and 5,000 m from each UXO clearance (Figure 2). No useable data were recovered from the 5,000 m distance due to noise levels exceeding the hydrophone sensitivity and resulting in 'clipping' of the data; due to weather and time constraints, it was not possible to check these data after the first clearance and deploy a lower sensitivity hydrophone as planned.

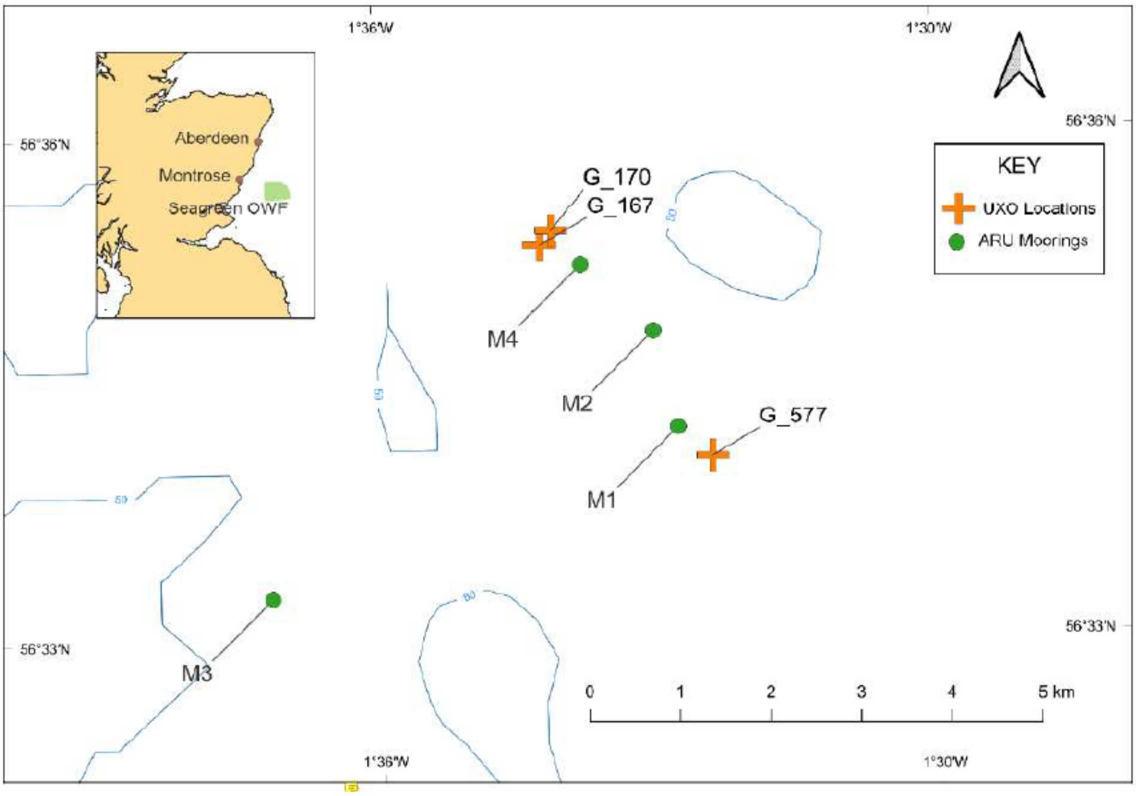


Figure 2. Noise recorder (ARU = acoustic recording unit) and UXO locations. Source: Cook and Banda (2021).

4.1 Predicted vs measured noise levels

Measured noise levels, including sound pressure level (SPL), unweighted and species hearing group-weighted sound exposure level (SEL), and two measures of impulsiveness (pulse length (T90) and kurtosis) are provided in Table 4.1. It should be noted that for the low-yield method, noise emissions are expected to be proportional to that of only the donor charge, with no detonation of the explosive material contained within the UXO itself. The third octave band frequency spectrum of each detonation is also presented in Figure 3, illustrating the dominance of energy at lower frequencies approximately between 300 Hz and 1 kHz.

Table 4.1. Summary of measured acoustic metrics and other parameters for all three UXO measurements. Source: Cook and Banda (2021).

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

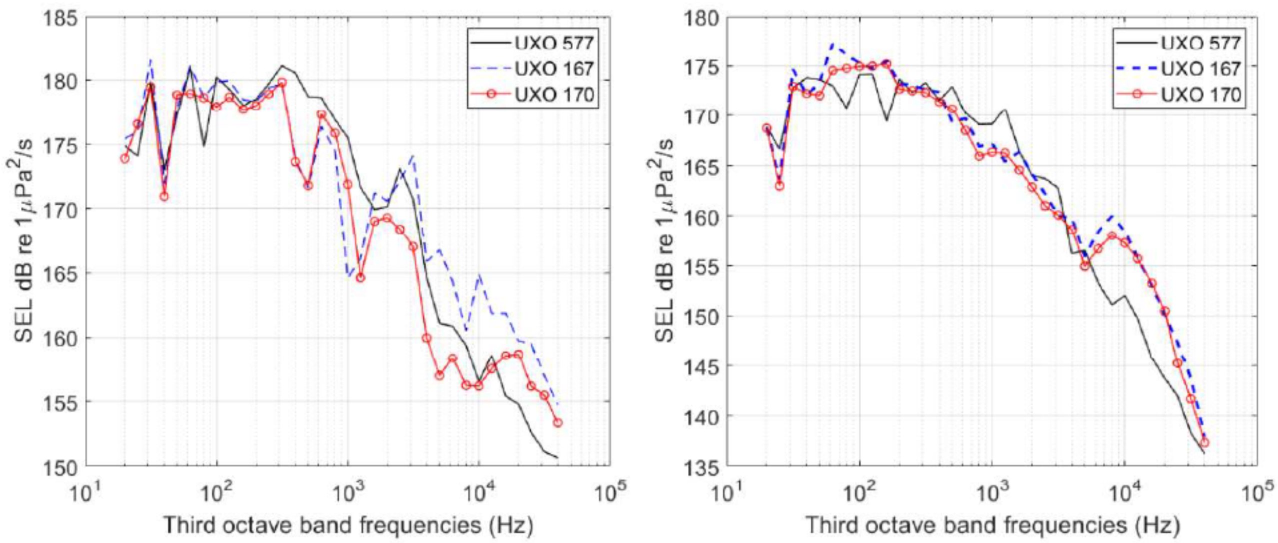


Figure 3. Measured third octave band Sound Exposure Level at 500 m (left) and at 1500 m (right) for each UXO detonation. Source: Cook and Banda (2021).

Comparisons with noise level predictions from the EPS Risk Assessment are complicated by the use of a smaller low-yield HYDRA disruptor donor charge than was modelled, and that the TNT-equivalent of SEMTEX 1A was taken to be 1:1 (based on advice from UXOcontrol), but has subsequently been clarified as

1:1.35. Therefore, predicted impact ranges presented in the EPS Risk Assessment for donor charges alone are underestimated by approximately 30%.

As an alternative to revising the predictions made in the EPS Risk Assessment, we draw upon Cook and Banda (2021), who provide comparable predictions for the 750 g HYDRA low-yield charge (modelled as 1.0 kg, as noted above) alongside high-order detonation of a 25 kg or 227 kg UXO, plotted against the measured noise levels (Figure 4). As per the EPS Risk Assessment, these predictions are based on the semi-empirical Soloway and Dahl (2014) equation for shallow-water detonations.

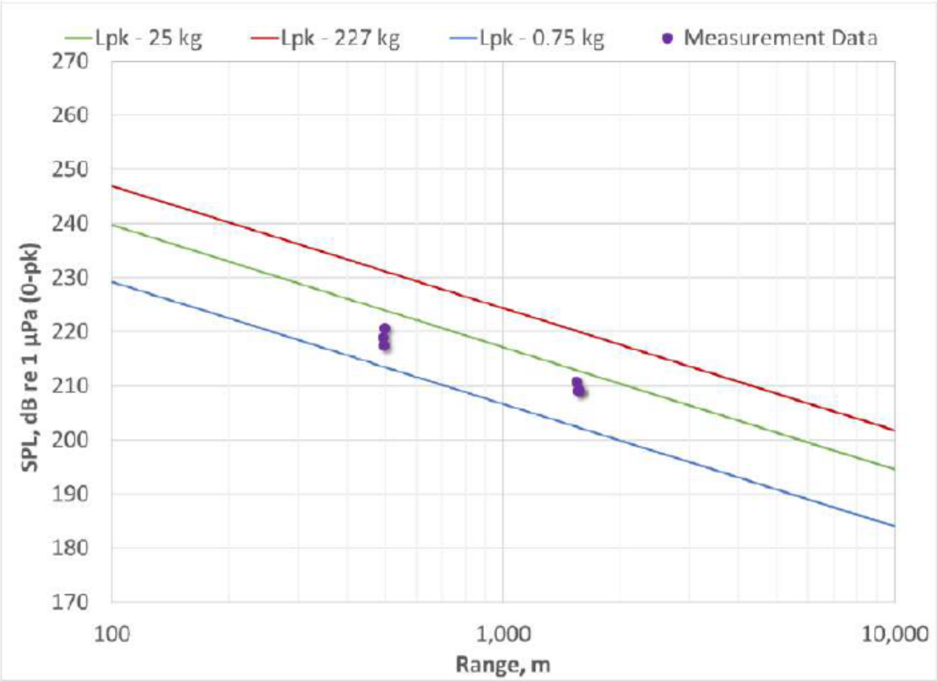


Figure 4. Plot of measured noise levels by range alongside predicted noise levels for low-yield charge (750 g of SEMTEX 1A) and high-order detonations of 25 kg and 227 kg UXOs. Source: Cook and Banda (2021).

The comparison between the measured and predicted peak sound pressure levels shows that the measured levels are approximately 4 to 7 dB higher than predicted for the single low-yield charge at 500 m range and 7 to 8 dB higher than predicted at 1.5 km range. As identified in the noise monitoring report, it is not possible to determine the exact reasons for the differences between predicted and measured sound levels from the results presented, but possible contributing factors are limitations in the prediction methodology, such as being based on explosive configurations and an environment with acoustic properties which differ to that of the current operations. For example, bottom-mounted specialist charges (Seagreen) vs freely-suspended charges in the water column (Soloway and Dahl, 2014), and water depth of 50-60 m (Seagreen) vs c. 15 m (Soloway and Dahl, 2014).

While measured noise levels were higher than predicted for a donor charge of equivalent size, the measured noise levels were below those that would be expected based on a high-order detonation of each

UXO, and were relatively consistent between UXOs, despite different total NEQs. This indicates that no high-order detonations occurred.

4.2 Predicted impact ranges

As measured noise levels were higher than predicted for the size of donor charge used, it is likely that impact ranges presented in the EPS Risk Assessment are underestimates, which may have implications for the effectiveness of the mitigation measures implemented.

4.2.1 Physical trauma

Measured noise levels at the 500 m locations were all ≤ 220.6 dB (SPL_{peak}) and ≤ 185.9 dB (SEL), which is well below the thresholds of 240 dB (SPL_{peak}) for potentially lethal physical trauma (Parvin et al., 2007)and > 203 dB (SEL) for very likely blast wave-induced ear trauma (Ketten, 2004; von Benda-Beckmann et al., 2015). Therefore, the MMMP is considered to have been effective for mitigating physical trauma to marine mammals.

4.2.2 Auditory injury (Permanent Threshold Shift, PTS)

As agreed in consultation with NatureScot and Marine Scotland Science through the consents process, PTS impact ranges were estimated based on SPL thresholds presented in Southall et al. (2019) due to uncertainty over the frequency spectrum of UXO clearance. We note that the noise measurement report (Cook and Banda, 2021) also provides noise levels and estimates of PTS impact ranges using marine mammal hearing-group frequency-weighted SEL, based on the frequency spectrum of the monitoring UXO clearances. Here, we largely focus on comparisons in the unweighted SPL_{peak} metric, as this is the metric upon which the assessment and mitigation was based.

For all 3 UXO clearances, measured noise levels at 1,500 m exceeded the PTS threshold for harbour porpoise, indicating that the impact range for this species was > 1,500 m. For all other species, the measured noise levels at 1,500 m did not exceed the PTS threshold, indicating that the impact range for all other species was < 1,500 m.

Cook and Banda (2021) present estimated PTS ranges from an interpolation of the noise measurement data, i.e. a best fit function between the 6 data points, therefore representing an average across the 3 low-yield UXO detonations. Below, these are presented alongside predicted impact ranges based on Soloway & Dahl (2014) as was performed in the EPS Risk Assessment, for a single low yield donor charge (1 kg), the worst-case scenario low-yield donor charge assessed in the EPS Risk Assessment (3 kg), and, for comparison a high-order detonation of the relevant UXO sizes (Table 4.2).

As expected, given the higher than predicted noise levels, estimated PTS impact ranges based on an interpolation of the measured data are larger than predicted by the Soloway & Dahl (2014) model as was used in the EPS Risk Assessment. For minke whale, dolphins and seals, the difference is minor – no more than 0.3 km larger than predicted for low yield donor charges. For harbour porpoise, the difference is greater, with the interpolated PTS impact range 2.4 km larger than predicted for a single low-yield charge, and 1.7 km larger than the worst-case low-yield charge size. The latter value is the most important as it is this value upon which mitigation was based for low-yield disposal, and therefore where there is potential for mitigation to have been inadequate.

It is important to note that there is potential for some error in the derivation of impact ranges based on the spread of data and extrapolation errors, considering only 6 data points are available. In particular, with data only available at 500 m and 1,500 m, estimates from greater ranges are subject to particular uncertainty.

Table 4.2. Estimated impact ranges for auditory injury (PTS) based on the functional hearing group-specific unweighted impulsive noise SPL_{peak} threshold proposed by Southall et al. (2019). Estimates are provided for (1) an interpolation of the noise levels measured at Seagreen (average across all 3 low-yield UXO detonations); and (2) predictions for relevant charge/UXO sizes based on the Soloway & Dahl (2014) equations for shallow water.

Charge/UXO size (NEQ)	PTS impact range (km) for each species			
	Minke whale	Dolphins	Harbour porpoise	Seals
1. Estimated impact ranges based on an interpolation from measured data				
na	0.5	0.1	4.0	0.6
2. Predicted impact ranges based on Soloway & Dahl (2014)				
Low-order and low-yield donor charge configurations				
1 kg †	0.3	0.1	1.6	0.3
3 kg ‡	0.4	0.1	2.3	0.5
Potential UXOs (assuming full high-order detonation)				
25 kg	0.8	0.3	4.7	0.9
227 kg	1.7	0.6	9.7	1.9

Notes: † NEQ (TNT-equivalent) of a single 750 g low-yield donor charge as used in the Seagreen UXO clearance; this charge size was not modelled in the EPS Risk Assessment. ‡ Assumed worst-case low yield donor charge size (4 x 750 g) modelled in the EPS Risk Assessment, upon which the mitigation for low-yield disposal was based.

<u>Frequency-weighted SEL</u>

The third octave band frequency spectrum of each detonation (Figure 3) shows that the signals generated by the UXO clearances were dominated by energy at lower frequencies approximately between 300 Hz and 1 kHz, which is below the region of peak hearing sensitivity for harbour porpoise, dolphins and seals. Consequently, when marine mammal hearing group-specific frequency weighting was applied to the measured noise levels, and associated SEL_{24} thresholds for PTS applied (Southall et al., 2019), the predicted impact ranges for PTS for porpoise (2.3 km), dolphins (< 0.1 m) and seals (0.2 km) were considerably lower than those for unweighted SPL. For minke whale (1.1 km), there is a slight increase in predicted impact ranges, due to the estimated low-frequency hearing sensitivity of this species.

4.2.3 Behavioural disturbance

As agreed through consultation with NatureScot and Marine Scotland Science, the EPS Risk Assessment estimated the extent of behavioural disturbance using thresholds for the onset of TTS from impulsive sounds for different functional hearing groups presented in Southall et al. (2019).

As measured noise levels were higher than predicted for low-yield methods, the extent of behavioural disturbance for these methods will have been underestimated. However, behavioural disturbance was not a key driver of mitigation procedures, and the significance of disturbance was assessed for worst-case scenarios of high-order detonation of UXO of 300 kg or more, which was predicted to generate far higher noise levels than those measure during low-yield disposal operations. Therefore, a quantitative comparison of the number of animals disturbed from predictions and measured noise levels is not provided here. Nonetheless, it is emphasised that the lower number of detonations than was anticipated, and the avoidance of any high-order detonations, resulted in far lower potential for behavioural disturbance than was assessed prior to operations.

5. Assessment of effectiveness of mitigation measures

The MMMP is considered to have been effective for mitigating physical trauma to marine mammals.

The largest predicted PTS impact range from low-yield disposal assessed in the EPS Risk Assessment was for harbour porpoise, based on a charge of 3 kg TNT-equivalent. At a predicted 2.3 km, the predicted impact range extended beyond the limit of effective visual observation and acoustic detections; therefore, the MMMP required ADD use. A duration of 22 min was selected, which was expected to displace harbour porpoise to 2.5 km range, based on a swimming speed of 1.5 m/s directly away from the detonation site, and a start location of 500 m from the detonation site.

Based on an extrapolation of the noise measurements recorded during operations, Cook and Banda (2021) estimated that the harbour porpoise PTS impact range of the low-yield UXO disposal operations may have extended to 4.0 km. Therefore, while subject to uncertainty, there is evidence that the mitigation measures implemented, comprising 22-24 min of ADD use, were insufficient to fully deter harbour porpoise from exposure to noise levels which may have resulted in PTS. Assuming a density of 0.599 porpoise per km^2 (Hammond et al., 2017), this may have resulted in between 17-19 porpoise per detonation being exposed to noise levels with the potential to result in the onset of auditory injury. However, there are a number of other factors to consider which contribute to reducing the likelihood that porpoise experienced PTS, including:

- Porpoise are known to respond to vessel activity, with substantial reductions (-24%) in acoustic detections reported to 3 km from wind farm related construction vessels (not piling) (Benhemma-Le Gall et al., 2021). Considering the presence of the UXO clearance vessel in the vicinity of the detonation site for several hours prior to detonation, including ROV and FRC operations, it is likely that porpoise had already been displaced to beyond 500 m (assumed start point used in the assessment with regard to ADD durations) and were therefore displaced to a greater than anticipated distance by the ADD prior to detonation. At the least, vessel operations prior to the ADD activation and detonation would be expected to have reduced the local density of porpoise. The absence of any marine mammal sightings throughout operations provides some evidence to support this.

- Harbour porpoise exhibit substantial directivity in their hearing, with greatest sensitivity (upon which thresholds are based) within a beam focussed in front of the head (i.e. the direction of swimming) (Kastelein et al., 2005). Therefore, the application of threshold to a fleeing animal is likely to be conservative in terms of predicted impact ranges.

- When the frequency spectrum of noise was considered, alongside frequency-weighted hearing thresholds, the estimated PTS impact range for harbour porpoise was 2.3 km. This distance matches that of the worst-case low yield disposal assessed in the EPS Risk Assessment; therefore, based on the frequency-weighted SEL_{24} threshold, the mitigation measures applied (i.e. 22 min ADD duration) were sufficient to reduce the risk of PTS in harbour porpoise (and all species of marine mammal) to negligible.

While the potential for residual auditory injury effects on EPS was not anticipated from low-yield UXO disposal, EPS licences were obtained for injury to EPS based on the potential for impact ranges from high-order detonations of UXO that were sufficiently large that mitigation measures could not guarantee the complete exclusion of animals from the area over which PTS is predicted to occur.

6. Concluding remarks

UXO clearance operations at Seagreen were consistent with those consented (Section 2) and compliant with the MMMP (Section 3).

The number of UXO was substantially lower than anticipated, and the three detonations required were undertaken using low-yield methods (Section 2). Consequently, the potential effects of the operations, in terms of exposure of animals to noise and behavioural disturbance, were far lower than those predicted in the consent applications.

Practical challenges were encountered in effectively monitoring a 1 km mitigation zone around the UXO detonation site, emphasising the importance of ADDs in deterring animals from zones of potential trauma and auditory injury (Section 3).

Noise monitoring was undertaken, which provided the opportunity to assess the accuracy of predictions (Section 4). Measured noise levels at 500 m and 1,500 m distance from detonations were up to 8 dB higher than were expected based on the size of the donor charge and the semi-empirical Soloway and Dahl (2014) equation for shallow-water detonations, upon which the risk assessment and MMMP was based. Consequently, estimated impact ranges were larger than predicted for this method, and there is potential that mitigation measures were insufficient to prevent some exposure of harbour porpoise to noise levels with the potential to result in the onset of auditory injury. However, such an outcome is subject to considerable uncertainty, with several important sources of conservatism, and consideration of the frequency spectrum of noise levels and weighted hearing thresholds suggests that mitigation measures were adequate (see Section 5). As such, the likelihood that any harbour porpoise experienced auditory injury is considered to be very low.

Further investigation of the noise monitoring data are required, for example through contribution to the relevant BEIS-funded project by NPL/Loughborough University. Additionally, more noise monitoring data from the HYDRA low-yield method are required to provide a greater understanding of the noise levels generated by this approach and how they can be accurately predicted in order to ensure adequate mitigation measures are implemented to reduce the risk of auditory injury to marine mammals.

More broadly, as data accumulate, a comparison of the relative merits of low-yield, low-order (deflagration) and high-order UXO disposal are required to inform decisions on how best to minimise the impacts of UXO clearance on marine species.

7. References

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