GREENLINK
MARINE ENVIRONMENTAL IMPACT ASSESSMENT REPORT- IRELAND

APPENDIX C

Underwater Sound Modelling

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Greenlink Interconnector
- connecting the power markets
in Ireland and Great Britain

Greenlink
INTERCONNECTOR

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1. Introduction

1.1 Objective

One of the most important environmental concerns related to the installation, operation (including maintenance and repair) and decommissioning of Greenlink is the potential effects of underwater sound. Sound inputs to the marine environment will be generated by vessel movements, sand wave preparation (pre-sweeping), cable trenching, rock placement and if required, unexploded ordnance (UXO) detonations.

To determine the zone of influence for each activity (the spatial extent over which the activities are predicted to have an effect on the receiving environment) an assessment has been conducted which combines literature review with underwater sound modelling. This Technical Appendix presents the findings of the assessment. It has informed the EIA process and assessment of significant effects presented in Chapter 8 – Fish and Shellfish and Chapter 10 – Marine Mammals and Reptiles.

1.2 Underwater sound

Sounds in the ocean originate from natural causes such as earthquakes, rainfall, and animal noises; and anthropogenic activities such as shipping, fishing activities, seismic survey, research activities, sonars and recreation activities. As sound waves travel through water, they spread, dissipate and reflect off the sea surface and seabed. The local oceanographic conditions will affect the path of the sound in the water column, how much sound is transmitted, and the levels received by the receptor at distance from the source. Variables such as water depth, source and receiver depths, temperature gradients, salinity, seabed ground conditions and many other factors can affect received levels.

Although some sound sources can be identified, the sources of others cannot, and they are considered part of the background noise. How a receptor is affected by a change in underwater sound is linked to the current exposure levels and associated background noise.

1.2.1 Background sound

Measurements on anthropogenic sounds were recorded to quantify background noise levels in the UK, as part of the European Union (EU) Marine Strategy Framework Directive (MSFD) (Merchant et al. 2016). These were taken across locations in the Celtic Sea, southern North Sea (SNS) and northern North Sea (NNS). Recordings were taken at four frequency ranges (63Hz, 125Hz, 250Hz and 500Hz). Noise levels in the Celtic Sea ranged from 99.9dB (500Hz) to 102.9dB re1μPa (250Hz) (RMS[1]) (Merchant et al. 2016). These levels are lower on average than the NNS and SNS, noting that only one location was recorded in the Celtic Sea in comparison to ten in the NNS. Little is known on ambient sound levels in the vicinity of Greenlink

[1] The EU MSFD recommends the use of root mean square (RMS) noise levels as environmental indictor.

development. Background sound levels in the vicinity of the project will influence how marine species react to the introduction of new sound as part of the installation and then maintenance of the marine cable.

1.2.2 Sound categories

Underwater sound is classified between two distinct types: impulsive and continuous (i.e. non-pulse).

Impulsive sound is defined as a discrete or a series of events, for example an explosion or a seismic airgun (Southall et al. 2007). Produced impulsive sounds are generally transient and brief; peak sound pressure has a rapid rise and a rapid decline (NMFS 2018). Single pulse sound results from a single event, such as UXO detonation and pile strike (Southall et al. 2007). A repetition of pulses is considered as a multiple pulse sound source and is a series of discrete acoustic events within a 24hr period, for example a seismic survey (Southall et al. 207).

Continuous events, such as shipping noise, produce non-pulse sound and are generally broadband, narrowband or tonal. Continuous sound can either be intermittent or continuous within a 24hr period (NMFS 2018). Cable installation activities include trenching, rock placement, pre-sweeping and the use of thrusters for dynamically positioning (DP) on vessels; all of which produce continuous sound over a period of 24hrs.

2. Receptor Sensitivity to Underwater Sound Changes

2.1 Introduction

Research has largely focused on effects of underwater sound on marine mammals, but in the last few years evidence of effects in other species such as fish (Popper *et al*. 2014), crustaceans (Solan *et al*. 2016, Tidau and Briffa 2016) and zooplankton (McCauley *et al*. 2017) have been reported.

2.2 Marine mammals

Both cetaceans and pinnipeds have evolved to use sound as an important aid in navigation, communication and hunting (Richardson *et al*. 1995). It is generally accepted that exposure to anthropogenic sound can induce a range of behaviour effects to permanent injury in marine mammals. Loud and prolonged sound above background levels is considered to be noise and may have an effect on marine life. This may mask communicative or hunting vocalisations, preventing social interactions and effective hunting.

High intensity noises such as from seismic survey, explosions and pile driving can cause temporary or permanent changes to animals' hearing if the animal is exposed to the sound in close proximity and, in some circumstances, can lead to the death of the animal (Richardson *et al*. 1995). Where the threshold of hearing is temporarily damaged, it is considered a temporary threshold shift (TTS), and the animal is expected to recover. If there is permanent damage (permanent threshold shift (PTS)) where the animal does not recover, social isolation and a restricted ability to locate food may occur, potentially leading to the death of the animal (Southall *et al*. 2007).

Behavioural disturbance from underwater sound sources is more difficult to assess than injury and is dependent upon many factors related to the circumstances of the exposure (Southall *et al*. 2007, NMFS 2018). An animal's ability to detect sounds produced by anthropogenic activities depends on its hearing sensitivity and the magnitude of the noise compared to the amount of natural ambient and background anthropogenic sound. In simple terms for a sound to be detected it must be louder than background and above the animal's hearing sensitivity at the relevant sound frequency.

Behavioural responses caused by disturbance may include animals changing or masking their communication signals, which may affect foraging and reproductive opportunities or restrict foraging, migratory or breeding behaviours; and factors that significantly affect the local distribution or abundance of the species. An animal may swim away from the zone of disturbance and remain at a distance until the activities have passed. Behavioural disturbance to a marine mammal is hereafter considered as the disruption of behavioural patterns, for example: migration, breeding and nursing.

2.3 Sea turtles

Sea turtles are known to be able to detect (Ridgway et al. 1969, Bartol et al. 1999, Bartol & Ketten 2006) and respond to acoustic stimuli (Lavender et al. 2014, Martin et al. 2012, O'Hara & Wilcox 1990, DeRuitter & Doukara 2012), which they may use for navigation, prey location, predator avoidance as well as general environmental awareness (Piniak et al. 2016). Sea turtles have adapted their hearing for use underwater. It is likely that their body serves as a receptor while the turtle is underwater (Lenhardt 1983, 1985).

Electrophysiological and behavioural studies have demonstrated that sea turtles are able to detect low-frequency sounds both underwater and in air (Piniak et al. 2016). Sea turtles respond to aerial sounds between 50 and 2000 Hz and vibrational stimuli between 30 and 700 Hz, with maximum sensitivity values recorded between 300 and 500 Hz for both sounds (Ridgway et al. 1969).

Green turtles respond to underwater signals between 50 Hz to 1600 Hz, with maximum sensitivity between 200 and 400 Hz (Piniak et al. 2016). These values are similar to findings by Bartol & Ketten (2006).

Similarly, adult Loggerhead sea turtle responded to underwater stimuli between 50 and 800 Hz with best sensitivity at 100 Hz using behavioural response techniques, while between 100 and 1131 Hz with best sensitivity between 200 and 400 Hz when using AEP techniques (Martin et al. 2012).

Overall, the biological significance of hearing in sea turtles remains poorly understood, but as low-frequency sound is most prevalent and travels the farthest in the marine environment there may be some advantage to sea turtles in specializing in low-frequency sound detection. It is therefore believed that acoustic sound may provide important environmental cues for sea turtles (Piniak et al. 2016).

Popper et al. (2014) provide sound exposure guidelines for injury to sea turtles.

2.4 Fish

In general, most fish hear well in the range within which most energy from anthropogenic noise sources is emitted, i.e. relatively low frequency sound below 1 kHz, with peak perception between approximately 100-400 Hz.

Several features of a fish's anatomy, life cycle and habitats will determine the potential effects of sound on fish. Popper et al. (2014) classified sensitivity of fish species to underwater sound based on the presence or absence of swim bladder; the otolith organ acts as a particle motion detector and where linked to the swim bladder, converts sound pressure into particle motion, which is detected by the inner ear. Specialist hearing species include species such as herring, sprat, twaite shad and allis shad.

Swim bladder are used by certain fish species for buoyancy control, hearing, respiration etc. Pressure changes for fish with a swim bladder, in particular from impulsive sound, can result in physiological trauma.

Popper et al. (2014) provide sound exposure guidelines for injury to fish, which have been used in the modelling presented in Table 3-3.

2.5 Crustaceans

Little is known about how crustacean species are impacted by underwater sound changes (Tidau and Briffa 2016). Recent studies identified that crustaceans, both freshwater and marine species, are likely to be impacted by underwater sound changes. Unlike fish species, crustaceans do not have an air-filled chamber; therefore, they are unlikely to detect sound pressure but can be sensitive to particle motion (Tidau and Briffa 2016).

Studies have considered the impact and the behavioural responses of crustaceans to airgun sounds. Results from these studies produced varied results. A field study on shrimp species and American lobster did not identify an avoidance behaviour while a behavioural response was identified during laboratory test (Andriguetto-Filho et al. 2005; Parry and Gason, 2006 in Tiday and Briffa 2016). A stress response to noise (airguns) was noticed (increase in food intake). Impacts of impulsive pile driving on Norway lobster showed a change in behaviour, as such reduced burrowing and mobility (Solan et al. 2016).

These studies identified a large array of responses to underwater sound pressure, from an increase in behaviour (for example an increase in food intake in lobsters), stress responses, slower or reduced behaviour, change in foraging habitats etc. The current knowledge on how these reactions are displayed however is based on a limited range of studies (Tidau and Briffa 2016).

2.6 Zooplankton

Zooplankton are highly mobile at small scales or across small scales (McManus & Woodson 2012, Bianco et al. 2014, Visser 2007); however, research suggest that they cannot move away from an approaching air gun array (i.e. an impulsive sound) produced during seismic surveys. Recent scientific evidence also suggests that low-frequency impulse sound leads to significant mortality to zooplankton populations (McCauley et al. 2017).

A decrease in zooplankton abundance was recorded during experimental air gun signal exposure when compared to the absence of air gun signal, as measured by sonar (~3–4 dB drop within 15–30 min) and net tows (median 64% decrease within 1 hour). In addition, this caused an increase in mortality for adult and larval zooplankton (McCauley et al. 2017). The impacts of air guns on zooplankton have been observed out to the maximum 1.2 km range sampled (McCauley et al. 2017).

Further studies on larval invertebrates also showed significant malformations to scallop veliger larvae from simulated air gun exposure (de Soto et al. 2013), while no impacts were detected on larval hatching success or viability immediately after hatchment for lobster eggs exposed to an air gun in the field (Day et al. 2016).

The knowledge of effects from underwater sound on zooplankton communities is very sparse with little scientific evidence, besides from recent research by McCauley et al. (2017) described above.

3. Results and Discussion

3.1 Marine mammals

3.1.1 Injury and disturbance thresholds

Effects of underwater sound changes range from injury through to disturbance. To calculate the zone of influence for both levels of effect, sound propagation calculations have been used to determine the range at which the received sound attenuates to levels below a defined threshold. The thresholds used in the calculations are explained below.

3.1.1.1 Injury thresholds

The assessment has used both the recently published American National Marine Fisheries Service (NMFS) (2018) thresholds for the onset of PTS and TTS and the thresholds defined by Southall *et al.* (2007). Both approaches separate marine mammals into five groups based on their functional hearing, namely: low-frequency cetaceans; mid frequency cetaceans; high frequency cetaceans; pinnipeds (Phocid) in water; and pinnipeds (Otariid) in water. Table 3-1 presents the species identified as present along the Greenlink route according to their functional hearing category.

Table 3-1 Marine mammal auditory bandwidth

Group	Low-frequency cetaceans	Mid-frequency cetaceans	High-frequency cetaceans	Pinnipeds (Phocid) in water	Otariid and other non-phocid marine carnivores in water
Generalised hearing range (NMFS 2018)	7Hz - 35kHz	150hz - 160kHz	275Hz - 160kHz	50Hz - 86kHz	60Hz - 39kHz
Species	Baleen whales	Most toothed whales, dolphins	Certain toothed whales, porpoises	True seals	Otter
Species observed along Greenlink route	Minke whale Humpback whale Fin whale	Short-beaked common dolphin Common bottlenose dolphin Stripped dolphin Risso's dolphin Atlantic white-sided dolphin White-beaked dolphin Long-finned pilot whale Killer whale	Harbour porpoise	Grey seal Harbour seal	Common otter

Source: NMFS (2018)

The thresholds for the onset of PTS and TTS, as published in NMFS (2018) and Southall *et al.* (2007), are provided in Table 3-2. These reflect the current peer-reviewed published state of scientific knowledge.

Table 3-2 Injury thresholds for marine mammals from impulsive (SPL, unweighted) and continuous (SEL, weighted) sound

Group	SPL (unweighted) - impulsive sound				SEL (weighted) - continuous sound			
	NMFS (2018)		Southall *et al.* (2007) *		NMFS (2018)		Southall *et al.* (2007)	
	PTS (dB re 1 µPa (peak))	TTS (dB re 1 µPa (peak))	PTS (dB re: 1 µPa (peak))	TTS (dB re: 1 µPa (peak))	PTS (dB re 1 µPa^2 s)	TTS (dB re 1 µPa^2 s)	PTS (dB re: 1 µPa^2-s)	TTS (dB re: 1 µPa^2-s)
Low-frequency cetaceans	219	213	230	224	199	179	198	183
Mid-frequency cetaceans	230	224	230	224	198	178	198	183
High-frequency cetaceans	202	196	230	224	173	153	198	183
Pinnipeds (Phocid) in water	218	212	218	212	201	181	186	171
Pinnipeds (Otariid) in water	232	226	-	-	219	199	-	-

Source: Southall *et al.* (2007); NMFS (2018)

Note: * Single pulse

3.1.1.2 Disturbance thresholds

NMFS has not yet published guidelines on behaviour thresholds due to the complexity and variability of the responses of marine mammals to anthropogenic disturbance.

For the purposes of this assessment the threshold for behavioural disturbance has been assessed as 160 dB rms (SPL - impulsive sound) and 120 dB rms (SEL - continuous sound) for all cetacean species (Gomez et al. 2016, BOEM 2017, NMFS 2018).

3.1.1.3 Modelling

Sound attenuates as it propagates through water and the local oceanographic conditions will affect both the path of the sound into the water column and how much sound is transmitted. An in-house geometric spreading calculation was used to determine the propagation of underwater sound from the activities. The spreading model assumes that sound is spread geometrically away from the source with an additional frequency-dependent absorption loss; it therefore provides conservative estimates. It also does not take into consideration the conditions within the area, such as bathymetry, water depth or sediment type and thickness.

Attenuation used in the geometric spreading calculation can be calculated using the equation below:

> SPL = SL – 15log (R). In this equation:
>
> SPL = sound pressure level
>
> SL = source level
>
> R = the distance from a source level (SL)
>
> 15 = attenuation value associated with spreading in shallow water, allowing for losses to the seabed.

This equation does not include any terms relating to frequency (MMO 2015).

The NMFS recently developed a spreadsheet tool to estimate at which range (or distances) PTS (permanent injury) could effect marine mammals (NMFS 2018). This spreading model considers weighting factor adjustments and frequency, as well as source level, as part of its calculation. It was used to confirm the PTS results obtained from the geometric spreading modelling. The NMFS (2018) spreadsheet does not provide values for TTS.

A literature review was performed to obtain the source levels to inform this assessment and modelling (results provided in Table 3-3). No project-specific data was available, and the literature review identified appropriate sound sources to use.

Nedwell et al. (2003) provided an unweighted source level for trenching operations during trenching at North Hoyle; this is assumed to be 178dB re μPa @ 1m. The trenching noise was considered to be a mixture of broadband noise, tonal machinery noise and transients. During trenching at North Hoyle, sound was recorded as highly variable, and assumed to be dependent on the physical properties of the particular area of seabed that was being cut at the time (Nedwell et al. 2003). There is no publicly available data providing sound exposure levels (SEL) associated with trenching operations. The source level provided in Nedwell et al. (2003) is unweighted; therefore, this has been compared against SPL (unweighted) thresholds from the NMFS (2018) and Southall et al. (2007).

Genesis Oil and Gas Consultants (2011) listed the sound levels of DP vessels; a worst-case 184dB B re 1 µPa @ 1m was used for the assessment below.

Studies showed that rock placement did not generate a noticeable rise in the level of underwater sound, compared to the presence of vessels (including those using dynamic positioning). This indicates the sound levels are dominated by the vessel noise and not the rock dumping activities (Nedwell and Edwards 2004). Wyatt (2008) recommended the use of 188dB (rms) 1µPa @1m, which was converted to 191dB (0-peak) 1µPa @1m.

Received sound by marine mammals from the geophysical survey are considered as near-continuous, rather than impulsive. However, there are no publicly available data on sound exposure levels (SEL) for the geophysical equipment. For the purpose of this assessment, sound pressure levels (SPL), which are more readily available, have been used instead to compare the sound levels of the geophysical equipment and borehole drilling against PTS and TTS thresholds (for near-continuous noise the thresholds are provided in SEL as this accounts for the time element as well as the noise level whereas impulsive just considers the noise).

Modelling results, i.e. the distances from the source at which sound levels will diminish to below the injury and disturbance thresholds, are summarised in Table 3-3.

Table 3-3 Summary of results – cable installation and geophysical survey

Auditory group	Threshold			Distance in metres at which threshold is exceeded						
				DP vessel *	Trenching **	Rock placement ***	Geophysical survey			
							Multibeam echosounder (MBES)*	Sidescan sonar (SSS)*	Sub-bottom profiling: chirper / pinger*	Sub-bottom profiling: boomer *
				SPL: 184dB dB re 1 μPa @ 1m Frequency: 63Hz	SPL: 178dB re 1 μPa @ 1 m Frequency: 125Hz	SPL(0-peak): 191dB re: 1μPa @1m Frequency: 10kHz	SPL: 232dB(rms)re 1μPa @1m (converted to 235 dB0-peak re 1μPa2-s) * Frequency: 95kHz	SPL: 226dB(rms) re 1μPa @1m (converted to 229 dB0-peak re 1μPa2-s) * Frequency: 114kHz	SPL: 208dB(rms) re 1μPa @1m (converted to 211 dB0-peak re 1μPa2-s) * Frequency: 1.5kHz	SPL: 208dB(rms) re 1μPa @1m (converted to 211 dB0-peak re 1μPa2-s) * Frequency: 2.5kHz
Low-frequency cetaceans	PTS (dB re 1 μPa (peak))	NMFS	219	Threshold not exceeded	Threshold not exceeded	Threshold not exceeded	15	5	Threshold not exceeded	Threshold not exceeded
		Southall *et al.*	230	Threshold not exceeded	Threshold not exceeded	Threshold not exceeded	2.6	Threshold not exceeded	Threshold not exceeded	Threshold not exceeded
	TTS (dB re 1 μPa (peak))	NMFS	213	Threshold not exceeded	Threshold not exceeded	Threshold not exceeded	40	13	Threshold not exceeded	Threshold not exceeded
		Southall	224	Threshold not exceeded	Threshold not exceeded	Threshold not exceeded	7	2.6	Threshold not exceeded	Threshold not exceeded
Mid-frequency cetaceans	PTS (dB re 1 μPa (peak))	NMFS	230	Threshold not exceeded	Threshold not exceeded	Threshold not exceeded	2.6	Threshold not exceeded	Threshold not exceeded	Threshold not exceeded
		Southall								
	TTS (dB re 1 μPa (peak))	NMFS	224	Threshold not exceeded	Threshold not exceeded	Threshold not exceeded	7	2.6	Threshold not exceeded	Threshold not exceeded
		Southall								
High-frequency cetaceans	PTS (dB re 1 μPa (peak))	NMFS	202	Threshold not exceeded	Threshold not exceeded	Threshold not exceeded	110	60	4.6	4.6
		Southall	230	Threshold not exceeded	Threshold not exceeded	Threshold not exceeded	2.6	Threshold not exceeded	Threshold not exceeded	Threshold not exceeded

Auditory group	Threshold			Distance in metres at which threshold is exceeded						
				DP vessel *	Trenching **	Rock placement ***	Geophysical survey			
							Multibeam echosounder (MBES)*	Sidescan sonar (SSS)*	Sub-bottom profiling: chirper / pinger*	Sub-bottom profiling: boomer *
				SPL: 184dB dB re 1 µPa @ 1m Frequency: 63Hz	SPL: 178dB re 1 µPa @ 1 m Frequency: 125Hz	SPL(0-peak): 191dB re: 1µPa @1m Frequency: 10kHz	SPL: 232dB(rms)re 1µPa @1m (converted to 235 dB0-peak re 1µPa2-s) * Frequency: 95kHz	SPL: 226dB(rms) re 1µPa @1m (converted to 229 dB0-peak re 1µPa2-s) * Frequency: 114kHz	SPL: 208dB(rms) re 1µPa @1m (converted to 211 dB0-peak re 1µPa2-s) * Frequency: 1.5kHz	SPL: 208dB(rms) re 1µPa @1m (converted to 211 dB0-peak re 1µPa2-s) * Frequency: 2.5kHz
	TTS (dB re 1 µPa (peak))	NMFS	196	Threshold not exceeded	Threshold not exceeded	Threshold not exceeded	180	110	11	11
		Southall	224	Threshold not exceeded	Threshold not exceeded	Threshold not exceeded	7	2.6	Threshold not exceeded	Threshold not exceeded
Pinnipeds (Phocid) in water	PTS (dB re 1 µPa (peak))	NMFS	218	Threshold not exceeded	Threshold not exceeded	Threshold not exceeded	15	7	Threshold not exceeded	Threshold not exceeded
		Southall								
	TTS (dB re 1 µPa (peak))	NMFS	212	Threshold not exceeded	Threshold not exceeded	Threshold not exceeded	40	15	Threshold not exceeded	Threshold not exceeded
		Southall								
Otter in water	PTS (dB re 1 µPa (peak))	NMFS	232	Threshold not exceeded	Threshold not exceeded	Threshold not exceeded	2	Threshold not exceeded	Threshold not exceeded	Threshold not exceeded
	TTS (dB re 1 µPa (peak))	NMFS	226	Threshold not exceeded	Threshold not exceeded	Threshold not exceeded	4.6	2	Threshold not exceeded	Threshold not exceeded
All cetaceans	Disturbance (dB rms)	BOEM, NMFS	160	50	17	130	940	720	2,600	2,500

Source: Southall *et al.* (2007), Popper *et al.* (2014), BOEM (2017), NMFS (2018)

Source: * Genesis Oil & Gas Consultants (2011), ** Nedwell *et al.* (2003), *** Wyatt (2008), † Based on 734kg explosive (sea mine).

Note: Sound generated by vessel movement, pre-sweeping, trenching and rock placement is continuous. However, there is no publicly available data on SEL for these activities. Therefore, SPL input values and thresholds have been used to assess sound generated by these activities.

3.1.1.4 Zone of influence

The geometric spreading model results indicate that for activities which generate continuous (cable installation) or near-continuous (geophysical survey) sound:

- Cable installation activities (DP vessels, rock placement and trenching):
  - No cetaceans, pinnipeds or otters are at risk of permanent or temporary injury.
  - The zone of influence for disturbance is 130m (all cetaceans).
- Geophysical survey (multi-bean echosounder, side-scan sonar, sub-bottom profiler)
  - The zone of influence for permanent injury is 110m (high-frequency cetaceans).
  - The zone of influence for temporary injury is 180m (high-frequency cetaceans).
  - The zone of influence for disturbance is 2.6km (all cetaceans).
  - Otters are at risk of permanent injury within 2m of the source.
  - Otters are at risk of temporary injury within 4.6m of the source.

3.1.2 Activities generating impulsive sound

This section models and discusses the detonation of UXO. This activity, if required, would be undertaken during the installation phase, and potentially during operation (principally maintenance and repair).

3.1.2.1 Modelling

Should UXO be found, which require clearance by detonation, there would be a relatively large release of impulsive sound energy. Peak source levels would depend on the quantity and nature of explosive material.

A desk-based UXO risk assessment conducted for Greenlink by 1st Line Defence (2018), identified that of the UXO that could be present along the cable route, size would range from 14kg up to 794kg. British sea mines were considered as a worst-case, containing up to 794kg of explosives. It is important to note that the desk-based study has not identified the number or locations of UXOs but provides a review of the type most likely to occur.

The source level of explosives can be predicted if certain parameters are known, such as the weight of the charge (w) and depth of detonation. The SPL (0-peak) of the initial shock wave, the largest amplitude component, is given by the formulae:

SPL (0-peak) dB re1µPa @ 1m = 271 dB + 7.533(log)(w)

Using this equation and based on 794kg as the weight of charge, the worst-case SPL(0-peak) is 293dB re1µPa @ 1m.

The results from the equation have been compared to measured SPLs from UXO detonations. Genesis Oil and Gas Consultants (2011) summarise information collected by Nedwell *et al.* (2001) during explosive operations in support of wellhead decommissioning. Measurements of sound pressure levels were taken at two locations: the CSO Seawell in a standoff position 600-800m from the wellhead; and seabed mounted hydrophones at different ranges. Sound pressure levels were recorded for charge sizes between 36kg and 81kg at varying water depths (see Table 3-4).

If the formula is used to calculate the SPL (0-peak) for a 36kg charge it concludes a value of 283 dB re1μPa @ 1m. Assuming spherical spreading from the explosion, then the SPL will attenuate to 227 dB re1μPa @ 600m. This figure is 6dB higher than the measured SPL @ 650m recorded by Nedwell *et al.* (2001) presented in row 1 of Table 3-4 above, suggesting that the calculations using the formula are conservative.

Table 3-4 SPLs (0-peak) recorded from the detonation of explosive charges measured from the CSO Seawell adapted from Nedwell *et al.* (2001)

Range (m)	Charge size (kg)	Depth of hydrophone	Received level (0-Peak) dB re1μPa @ range
650	36	30	221 dB re1μPa @ 650m
650	36	25	222 dB re1μPa @ 650m
800	36	30	221 dB re1μPa @ 800m
575	45	30	211 dB re1μPa @ 575m
575	45	25	211 dB re1μPa @ 575m
600	45	40	213 dB re1μPa @ 600m
600	45	35	214 dB re1μPa @ 600m
600	45	30	214 dB re1μPa @ 600m
600	45	25	214 dB re1μPa @ 600m
650	45	40	216 dB re1μPa @ 650m
650	45	35	218 dB re1μPa @ 650m
650	45	40	218 dB re1μPa @ 650m
650	45	35	217 dB re1μPa @ 650m
650	45	40	221 dB re1μPa @ 650m
650	45	35	217 dB re1μPa @ 650m
650	45	40	221 dB re1μPa @ 650m
650	45	35	221 dB re1μPa @ 650m
650	45	30	218 dB re1μPa @ 650m
650	45	25	217 dB re1μPa @ 650m
75	45	116	227 dB re1μPa @ 75m
125	45	87	226 dB re1μPa @ 125m
200	45	110	225 dB re1μPa @ 200m
300	45	91	232 dB re1μPa @ 300m
300	45	84	230 dB re1μPa @ 300m

Range (m)	Charge size (kg)	Depth of hydrophone	Received level (0-Peak) dB re1μPa @ range
400	45	108	223 dB re1μPa @ 400m
600	73	30	220 dB re1μPa @ 600m
650	73	25	226 dB re1μPa @ 650m
600	81	30	220 dB re1μPa @ 600m
600	81	25	226 dB re1μPa @ 600m

Source: Genesis Oil and Gas Consultants (2011)

Table 3-5 presents the results of the modelling assuming a SPL(0-peak) of 293dB re: 1μPa @1m for a 794kg charge.

Table 3-5 Summary of results - UXO detonation (worst-case 794kg explosive detonation)

Auditory group	Threshold			Distance in km at which threshold is exceeded SPL(0-peak): 293dB re: 1μPa @1m * Frequency: 10kHz
Low-frequency cetaceans	PTS (dB re 1 μPa (peak))	NMFS	219	13
		Southall *et al.*	230	5.8
	TTS (dB re 1 μPa (peak))	NMFS	213	16
		Southall	224	8.6
Mid-frequency cetaceans	PTS (dB re 1 μPa	NMFS	230	5.8
		Southall		
	TTS (dB re 1 μPa (peak	NMFS	224	8.6
		Southall		
High-frequency cetaceans	PTS (dB re 1 μPa (peak	NMFS	202	23
		Southall	230	5.8
	TTS (dB re 1 μPa (peak	NMFS	196	27
		Southall	224	8.6
Pinnipeds (Phocid) in water	PTS (dB re 1 μPa (pea)	NMFS	218	13
		Southall *et al.*		
	TTS (dB re 1 μPa (peak	NMFS	212	17
		Southall *et al.*		
Otters in water	PTS (dB re 1 μPa (pea)	NMFS	232	5
	TTS (dB re 1 μPa (p))	NMFS	226	7.6
All cetaceans	Disturbance (db rms)	BOEM, NMFS	160	54

Source: Southall *et al.* (2007), Popper *et al.* (2014), BOEM (2017), NMFS (2018)

Source: * Calculated using Ulrick (1975) equation, using 794kg weight

3.1.2.2 Zone of influence

The modelling indicates that for UXO detonation which generates impulsive sound:

- High-frequency cetaceans are at risk of permanent injury within 23km of the source.
- High-frequency cetaceans are at risk of temporary injury within 27km of the sound source.
- Seal are at risk of permanent injury within 13km of the source.
- Seal are at risk of temporary injury within 17km.
- The zone of influence for permanent injury for otters is 5km.
- The zone of influence for temporary injury for otters is 7.6km.
- All cetaceans are at risk of disturbance within 54km of source.

3.2 *Sea turtles*

3.2.1 Continuous sound

A review of sound exposure on sea turtles by Popper *et al.* (2014) identified no existing data regarding the effect of continuous sound.

3.2.2 Impulsive sound – UXO detonation

There is little information on the effects of impulsive sound on marine turtles. Some studies identified that the use of explosives in the Gulf of Mexico for oil and activities resulted in the mortality or injury of some individuals, probably due to the quick change in pressure associated with detonations (Popper *et al.* 2014).

Modelling, using the same approach as for cetaceans, presented in Table 3-6 indicates that sea turtles are risk of mortality and potential mortal injuries within 6.2km.

Table 3-6 Summary of results for UXO - sea turtles

Auditory group	Threshold			Distance in km at which threshold is exceeded
				SPL(0-peak): 293dB re: 1µPa @1m * Frequency: 10kHz
Sea turtles	Mortality and potential mortal injury	Popper *et al.*	229 -234dB re 1 µPa (peak)	4.2 - 6.2

3.3 *Fish*

3.3.1 Continuous sound source

Popper *et al.* (2014) identified that there is no direct evidence of permanent injury to fish species from shipping and other continuous noise (such as the cable installation and near-continuous sound produced by geophysical equipment). The Oslo and Paris (OSPAR) Commission (2012) considered that the potential for likely significant effects to fish from cable installation activities is considered to be minor.

Different fish species react differently to sound. Behavioural responses may include small movement or escape responses, based on studies conducted in laboratories (The University of Rhode Island 2017).

Continuous sound is detectable by fish species, and it is possible that this could lead to masking. However, masking and behavioural changes in fish from continuous sound is currently unknown (Popper *et al*. 2014). It is unlikely that fish species will be significantly affected by sound changes during the cable installation activities.

3.3.1.1 Modelling

Modelling results, i.e. the distances from the source at which sound levels will diminish to below the injury and disturbance thresholds, are summarised in Table 3-7.

Table 3-7 Summary of continuous sound results - fish

		Threshold	Recoverable injury	TTS
			173dB re 1 µPa†	161dB re 1 µPa†
Activity	Source	Frequency	Distance in metres at which threshold is exceeded	
DP vessel *	SPL: 184dB dB re 1 µPa @ 1m	Frequency: 63Hz	7	50
Trenching **	SPL: 178dB re 1 µPa @ 1 m	Frequency: 125Hz	2.6	16
Rock placement ***	SPL(0-peak): 191dB re: 1µPa @1m	Frequency: 10kHz	17	110
MBES*	SPL: 232dB(rms)re 1µPa @1m (converted to 235 dB0-peak re 1µPa2-s) *	Frequency: 95kHz	630	910
SSS*	SPL: 226dB(rms) re 1µPa @1m (converted to 229 dB0-peak re 1µPa2-s) *	Frequency: 114kHz	450	700
Chirper / pinger*	SPL: 208dB(rms) re 1µPa @1m (converted to 211 dB0-peak re 1µPa2-s) *	Frequency: 1.5kHz	350	2,200

		Threshold	Recoverable injury	TTS
			173dB re 1 µPa†	161dB re 1 µPa†
Activity	Source	Frequency	Distance in metres at which threshold is exceeded	
Boomer *	SPL: 208dB(rms) re 1µPa @1m (converted to 211 dB0-peak re 1µPa2-s) *	Frequency: 2.5kHz	350	2,200

Note: † Popper *et al*. (2014) provide thresholds in dB (rms) for recoverable injury and TTS. These have been derived in 0-peak. Recoverable injury threshold is 170dB rms for exposure of 48hrs and TTS threshold is 158dB rms for exposure of 14hrs.

3.3.1.2 Zone of influence

The geometric spreading model results indicate for activities which generate continuous (cable installation) or near-continuous (geophysical survey) sound:

- Cable installation (DP vessels, rock placement and trenching):
  - The zone of influence for fish recoverable injury is 17m.
  - The zone of influence for temporary injury for fish is 110m.
- Geophysical survey (multi-bean echosounder, side-scan sonar, sub-bottom profiler)
  - The zone of influence for fish recoverable injury is 630m.
  - The zone of influence for temporary injury for fish is 2,200m.

3.3.2 Impulsive sound – UXO

Underwater explosion produces a pressure waveform with rapid oscillations from positive pressure to negative pressure which results in rapid volume changes in gas-containing organs. Damage to visceral organs is most often the cause of fish mortality following exposure to underwater explosions. The most commonly injured organs are those with air spaces that are affected by the explosion's shock wave passing through the body of the fish, these include the body cavity, the pericardial sack and gut, however injuries of the swim bladder are most common. The swim bladders are subject to rapid contraction and overextension in response to explosive shock waveforms. Species which do not possess a swim bladder or have small swim bladders are likely to be more resistant to noise generated from explosions (Keevin and Hempen 1997).

Popper *et al* (2014) also highlighted that there is no data on the effects of an explosion (such as UXO for example) on hearing or behaviour available. It is possible that a detonation can lead to temporary or partial loss of hearing at high sound levels, especially for fish species having a swim bladder which enhances sound detection. The time interval between explosions can also a key factor in fish species resilience to detonation (Popper *et al*. 2014).

If an UXO detonation is required, it is likely that any individual adult and juvenile fish present in vicinity of the explosion zone of influence will be injured or killed.

3.3.2.1 Modelling and zone of influence

Modelling, using the same approach as for cetaceans, presented in Table 3-8 indicates that fish are risk of mortality and potential mortal injuries within 6.2km.

Table 3-8 Summary of results for UXO - fish

Auditory group	Threshold			Distance in km at which threshold is exceeded SPL(0-peak): 293dB re: 1μPa @1m * Frequency: 10kHz
Fish	Mortality and potential mortal injury	Popper *et al.*	229 -234 dB re 1 μPa (peak)	4.2 - 6.2

3.4 *Crustaceans*

There is no threshold for the assessment of sound exposure for crustaceans (Tidau and Briffa 2016).

3.5 *Zooplankton*

There is no threshold for the assessment of sound exposure for zooplankton (Solan *et al*. 2016, McCauley *et al*. 2017).

4. Conclusion

4.1 *Zones of Influence*

The zones of influence to be used in the EIA process are summarised in the Tables below as follows:

- Table D4-1 - Continuous sound from cable installation;
- Table D4-2 – Continuous sound from geophysical survey (MBES, SBP, SSS); and
- Table D4-3 – Impulsive sound from UXO detonation (worst-case 794kg explosive).

Table 4-1 Zones of influence for continuous sound – cable installation

Species	Permanent Injury (PTS)	Temporary Injury (TTS)	Disturbance
Low-frequency cetaceans	Not exceeded	Not exceeded	130m
Mid-frequency cetaceans	Not exceeded	Not exceeded	130m
High-frequency cetaceans	Not exceeded	Not exceeded	130m
Seals in water	Not exceeded	Not exceeded	130m
Otters in water	Not exceeded	Not exceeded	130m
Fish (swim bladder used for hearing, primary pressure detection)	-	50m	-
Sea turtles	-	-	-
Zooplankton	-	-	-
Crustaceans	-	-	-

Table 4-2 Zones of influence used in EIA process for continuous sound – geophysical survey

Species	Permanent Injury (PTS)	Temporary Injury (TTS)	Disturbance
Low-frequency cetaceans	15m	40m	2,600m
Mid-frequency cetaceans	2.6m	7m	2,600m
High-frequency cetaceans	110m	180m	2,600m
Seals in water	15m	40m	2,600m
Otters in water	2m	4.6m	2,600m
Fish (swim bladder used for hearing, primary pressure detection)	-	2,200m	-
Sea turtles	-	-	-
Zooplankton	-	-	-
Crustaceans	-	-	-

Table 4-3 Zones of influence used in EIA process for impulsive sound – UXO detonation

Species	Permanent Injury (PTS)	Temporary Injury (TTS)	Disturbance
Low-frequency cetaceans	13km	16km	54km
Mid-frequency cetaceans	5.8km	8.6km	54km
High-frequency cetaceans	23km	27km	54km
Seals in water	13km	17km	54km
Otters in water	5km	7.6km	54km
All fish species	6.2km	-	-
Sea turtles	6.2km	-	-
Zooplankton	-	-	-
Crustaceans	-	-	-

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