

ALCATEL SUBMARINE NETWORK

Havingsten

Appendix G - Underwater Sound Modelling



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Appendix G - Underwater Sound Modelling

Author/s

Helene Soubies

Project Manager

Paula Daglish

Authoriser

Patricia Adams

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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 Havhingsten 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 and rock placement.

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 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 re1 μ Pa (250Hz) (RMS¹) (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.

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

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

(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.

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 Havingsten 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 Havingsten 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 μPa2 s)	TTS (dB re 1 μPa2 s)	PTS (dB re: 1 μPa2-s)	TTS (dB re: 1 μPa2-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:

$SPL = SL - 15 \log(R)$. 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 $1 \mu\text{Pa}$ @ 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) $1\mu\text{Pa}$ @1m, which was converted to 191dB (0-peak) $1\mu\text{Pa}$ @1m.

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

Table 3-3 Summary of results – cable installation

Auditory group	Threshold (dB re: 1 µPa (peak))			Distance in metres at which threshold is exceeded		
				DP vessel *	Trenching **	Rock placement ***
				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
Low-frequency cetaceans	PTS	NMFS	219	Threshold not exceeded	Threshold not exceeded	Threshold not exceeded
		Southall et al.	230	Threshold not exceeded	Threshold not exceeded	Threshold not exceeded
	TTS	NMFS	213	Threshold not exceeded	Threshold not exceeded	Threshold not exceeded
		Southall	224	Threshold not exceeded	Threshold not exceeded	Threshold not exceeded
Mid-frequency cetaceans	PTS	NMFS	230	Threshold not exceeded	Threshold not exceeded	Threshold not exceeded
		Southall	230	Threshold not exceeded	Threshold not exceeded	Threshold not exceeded
	TTS	NMFS	224	Threshold not exceeded	Threshold not exceeded	Threshold not exceeded
		Southall	224	Threshold not exceeded	Threshold not exceeded	Threshold not exceeded
High-frequency cetaceans	PTS	NMFS	202	Threshold not exceeded	Threshold not exceeded	Threshold not exceeded
		Southall	230	Threshold not exceeded	Threshold not exceeded	Threshold not exceeded
	TTS	NMFS	196	Threshold not exceeded	Threshold not exceeded	Threshold not exceeded
		Southall	224	Threshold not exceeded	Threshold not exceeded	Threshold not exceeded
Pinnipeds (Phocid) in water	PTS	NMFS	218	Threshold not exceeded	Threshold not exceeded	Threshold not exceeded
		Southall	218	Threshold not exceeded	Threshold not exceeded	Threshold not exceeded
	TTS	NMFS	212	Threshold not exceeded	Threshold not exceeded	Threshold not exceeded
		Southall	212	Threshold not exceeded	Threshold not exceeded	Threshold not exceeded
Otter in water	PTS	NMFS	232	Threshold not exceeded	Threshold not exceeded	Threshold not exceeded
	TTS	NMFS	226	Threshold not exceeded	Threshold not exceeded	Threshold not exceeded
All cetaceans	Disturbance	BOEM, NMFS	160	50	17	130

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 are highly conservative, precautionary and are based on limited knowledge of cetacean hearing and assumptions in their responses. The modelling does however provide regulators with a zone of potential influence and indicates which activities are likely to generate the most amount of sound that could affect harbour porpoise and other marine mammal species:

indicate that for activities which generate continuous or near-continuous (cable installation activities) 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).

3.2 Fish

3.2.1 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 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.

3.2.1.1 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 below.

Table 3-4 Summary of continuous sound results - fish

		Threshold	Recoverable injury	TTS
			173†	161†
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

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.

3.2.1.2 Zone of influence

The geometric spreading model results are highly conservative, precautionary and are based on limited knowledge of fish hearing and assumptions in their responses. The modelling does however provide regulators with a zone of potential influence and indicates which activities are likely to generate the most amount of sound that could affect fish species:

- 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.

The potential worst case zones of influence identified above support the OSPAR Commission (2012) where the potential for likely significant effects to fish from cable installation activities are considered to be minor.

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 4-1 Zones of influence for continuous received 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	-	-	-

No injurious effects to marine mammal are expected from the cable installation. Animals may experience mild disturbance up to 130m from the installation vessel. This zone is highly conservative.

Fish may experience temporary injury if within 50m of the installation vessel and 110m of rock placement. This zone is extremely conservative.

In reality marine mammals and fish are likely to be habituated to a high level of background noise in the North Sea from anthropogenic sources. This includes from oil and gas exploration, wind farm development and shipping. The effects of noise from cable installation are likely to be minor to negligible against background levels.

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