Marine noise inputs

Technical Note on Underwater Noise

Statoil ASA

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Integrated Services
Total Field Development

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1 INTRODUCTION

The Hywind turbine represents the world's first full-scale floating wind turbine. Statoil's concept for the Hywind turbine was to create a floating wind turbine that can be operated in waters in excess of 100 m depth that is based on conventional technology and has a simple substructure design. In 2009 a full-scale demonstration turbine (Hywind I) was installed 10 km off the Norwegian west-coast. In order to continue towards achieving the long term vision for developing floating wind on a commercial scale, Statoil is planning to develop a Pilot Park offshore Peterhead which will be used to demonstrate technological improvements, operation of multiple units, and cost reductions in a park configuration.

The Hywind Scotland Pilot Park will consist of up to five Wind Turbine Generator (WTG) Units with a maximum installed capacity of 30 MW. The five WTG Units will be located between 800 m and 1,600 m apart and will be attached to the seabed by a three-point mooring spread. Each WTG Unit will have three anchors and in total there will be a maximum of 15 anchors for the Pilot Park, although some anchors may be shared between units.

The base case is for the WTG Units to be secured to the seabed using suction anchors which are likely to have a diameter of maximum 7 m. However, due to the likely presence of mobile sediments in the area scour protection around the anchors will be required to some extent (e.g. rock dumping, mattresses). The mooring lines are likely to consist of offshore grade mooring chains of 100 mm to 140 mm diameter. The mooring chains will weigh approximately 200 - 400 kg/m (dry). Concrete-block or ballasted steel-frame clump weights, which in principle will reduce peak loads in the mooring lines, may also need to be attached to the chains as part of the mooring arrangement. The mooring radius per WTG Unit is expected to be in the range of approximately between 600 m – 1,200 m.

The export cable will transport electricity from the Pilot Park to a landfall located along the coast at Peterhead. The length of the export cable corridor will be 25 km to 35 km depending on the location of the WTG Units, mooring configuration and arrangement of the inter-array cables. The export cable will be buried within a trench which will be approximately maximum 6 m wide and less than 2m in depth. Depending on seabed conditions along the seabed it may not be possible to bury the full length of cable to desired depth, in which case rock dumping, mattresses or sand / grout bags may be required to protect the cable. Cable protection may also be required along each 3.5 km inter array cable connecting the wind turbines.

Noise is readily transmitted underwater and there is potential for sound emissions from construction and operation of Hywind to affect marine mammals and fish. By using a floating structure, the installation noise is much reduced by removing the need for driven piles. However, there are likely to be noise impacts due to operation of the turbines as well as other construction activities, such as export cable installation and use of vessels. At long ranges the introduction of additional noise could potentially cause short-term behavioural changes, for example to the ability of cetaceans to communicate and to determine the presence of predators, food, underwater features and obstructions. At close ranges and with high noise source levels, permanent or temporary hearing damage might occur, while at very close range, gross physical trauma is possible. This report provides an overview of the potential impacts due to underwater noise from the Hywind Pilot Park on the surrounding environment. Due to the relatively low level of risks associated with underwater noise from this project, no detailed noise modelling has been undertaken. Instead, this report includes a synthesis of analysis already undertaken and typical impact ranges for the types of source likely to be utilised in the Project based on work presented in noise impact assessments for other developments.

2 ACOUSTIC CONCEPTS AND TERMINOLOGY

Sound travels through the water as vibrations of the fluid particles in a series of pressure waves. The waves comprise a series of alternating compressions (positive pressure variations) and rarefactions (negative pressure fluctuations). Because sound consists of variations in pressure, the unit for measuring sound is usually referenced to a unit of pressure, the Pascal (Pa). The unit usually used to describe sound is the decibel (dB) and, in the case of underwater sound, the reference unit is taken as 1 µPa, whereas airborne sound is usually referenced to a pressure of 20 µPa. To convert from a sound pressure level referenced to 20 µPa to one referenced to 1 µPa, a factor of 20 log (20/1) i.e. 26 dB has to be added to the former quantity. Thus a sound pressure of 60 dB re 20 µPa is the same as 86 dB re 1 µPa, although care also needs to be taken when converting from in air to in water noise levels due to the different sound speeds and densities of the two mediums, resulting in a conversion factor of 62 dB. All underwater sound pressure levels in this report are described in dB re 1 µPa. In water the sound source strength is defined by its sound pressure level in dB re 1µPa, referenced back to a representative distance of 1 m from an assumed (infinitesimally small) point source. This allows calculation of sound levels in the far-field. For large distributed sources, the actual sound pressure level in the near-field will be lower than predicted.

There are several descriptors used to characterise a sound wave. The difference between the lowest pressure variation (rarefaction) and the highest pressure variation (compression) is the peak to peak (or pk-pk) sound pressure level. The difference between the highest variation (either positive or negative) and the mean pressure is called the peak pressure level. Lastly, the root mean square (rms) sound pressure level is used as a description of the average amplitude of the variations in pressure over a specific time window. These descriptions are show graphically in Figure 2.1.

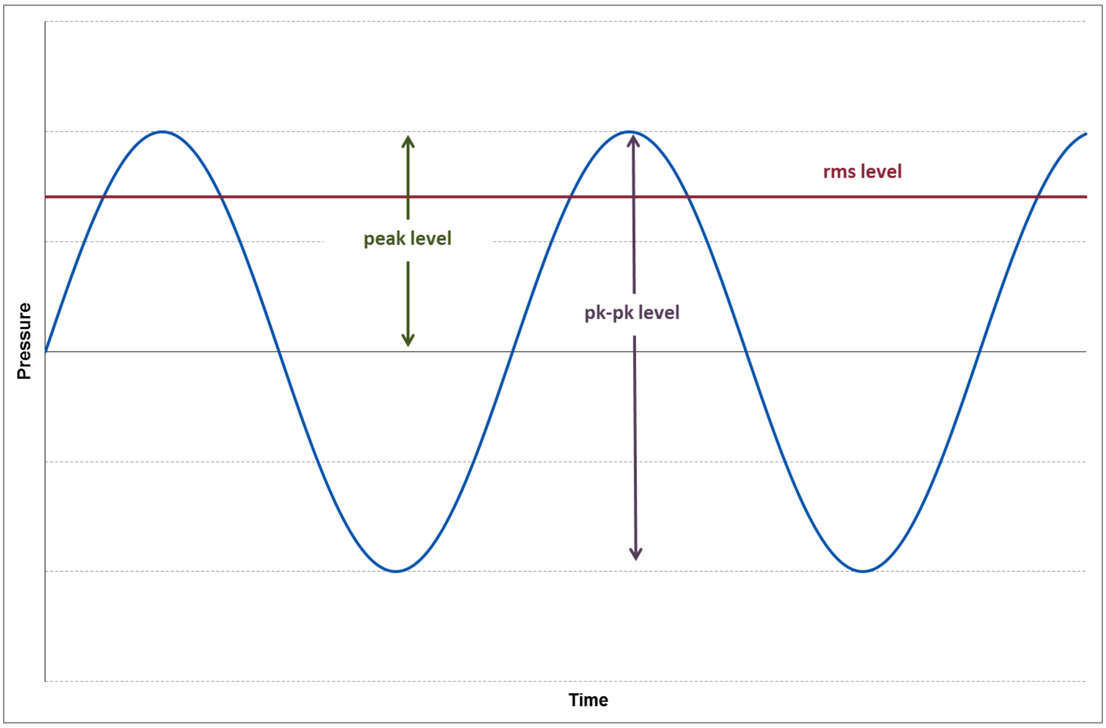

Figure 2.1 Graphical representation of acoustic wave descriptors

Another useful measure of sound used in underwater acoustics is the Sound Exposure Level, or SEL. This descriptor is used as a measure of the total sound energy of an event or a number of events (e.g. over the course of a day) and is normalised to one second. This allows the total acoustic energy contained in events lasting a different amount of time to be compared on a like for like basis. Historically, use was primarily made of rms and peak sound pressure level metrics for assessing the potential effects of sound on marine life. However, the SEL is increasingly being used as it allows exposure duration and the effect of exposure to multiple events to be taken into account.

The frequency, or pitch, of the sound is the rate at which the oscillations occur and is measured in cycles per second, or Hertz (Hz). When sound is measured in a way which approximates to how a human would perceive it using an A-weighting filter on a sound level meter, the resulting level is described in values of dBA. However, the hearing faculties of marine mammals and fish are not the same as humans, with marine mammals hearing over a wider range of frequencies, fish over a typically smaller range of frequencies and both with different sensitivities. It is therefore important to understand how an animal's hearing varies over the entire frequency range in order to assess the effects of sound on marine life. Consequently use can be made of frequency weighting scales to determine the level of the sound in comparison with the auditory response of the animal concerned. A comparison between the typical hearing response curves for fish, humans and marine mammals is shown in Figure 2.2. It is worth noting that hearing thresholds are sometimes shown as audiograms with sound level on the y axis rather than sensitivity, resulting in the graph shape being the inverse of the graph shown. It is also worth noting that some fish are sensitive to particle velocity rather than pressure, although paucity of data relating to particle velocity levels for anthropogenic noise sources means that it is often not possible to quantify this effect.

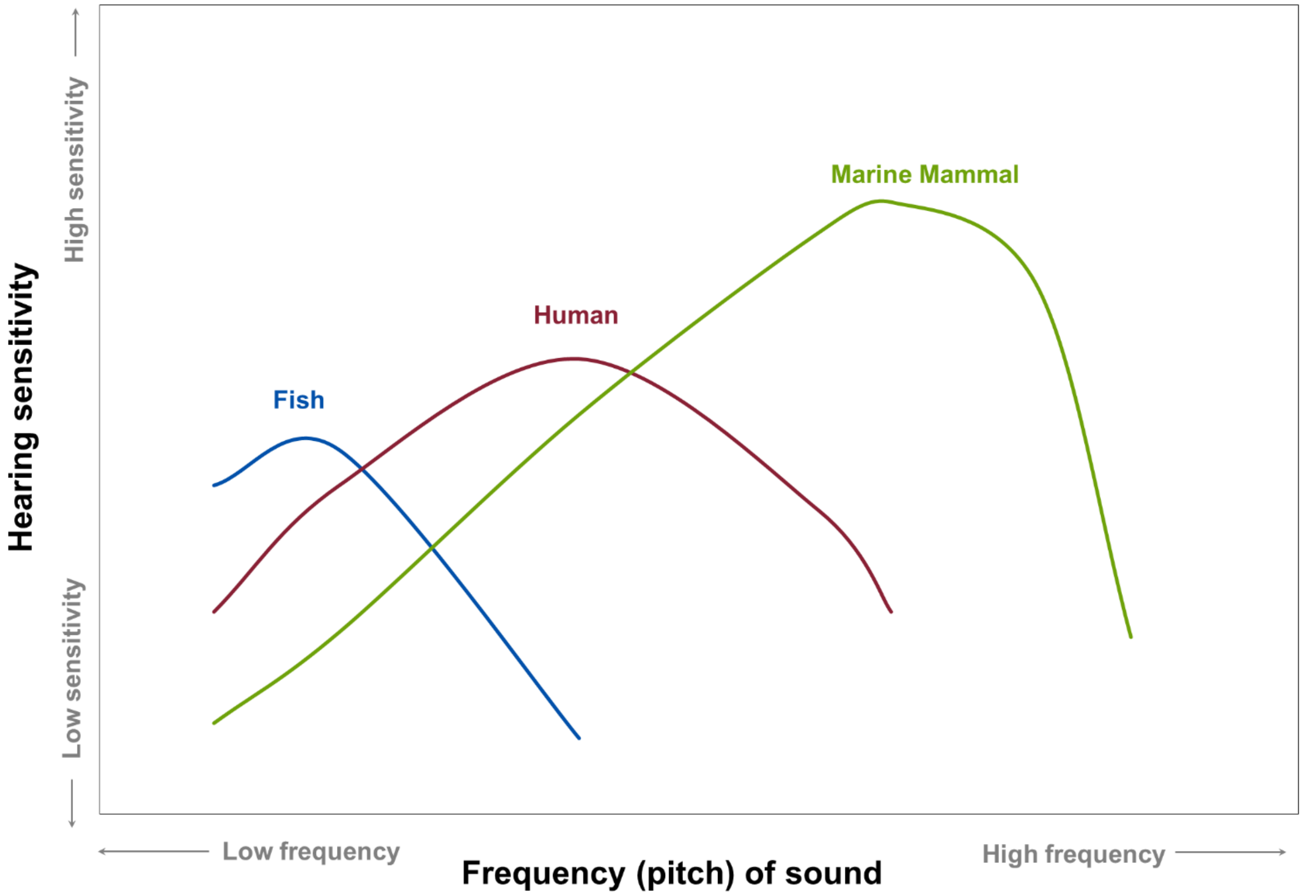

Figure 2.2 Comparison between hearing thresholds of different animals

3 THRESHOLDS FOR ASSESSING THE EFFECTS OF SOUND ON MARINE MAMMALS AND FISH

3.1 General

In order to determine the potential spatial range of injury and disturbance, a review has been undertaken of available evidence including national and international guidance and scientific literature. The following sections summarise the relevant thresholds for onset of effects and describe the evidence base used to derive them.

3.2 Marine Mammals

3.2.1 Injury to Marine Mammals

To determine the consequence of received sound levels on any marine mammal it is useful to relate the levels to known or estimated impact thresholds. The draft Joint Nature Conservation Committee guidance[1] (JNCC, 2010 in prep) and Marine Scotland guidance (Marine Scotland, 2014) both recommend using the injury criteria proposed by Southall *et al.* (2007), which are based on a combination of linear (i.e. un-weighted) peak pressure levels and mammal hearing weighted (M-weighted) sound exposure levels (SEL). The M-weighting function is designed to represent the bandwidth for each group within which acoustic exposures can have auditory effects. The categories include low-, mid- and high-frequency cetaceans (the order Cetacea includes the marine mammals commonly known as whales, dolphins, and porpoises) and pinnipeds in water (Pinnipedia are a suborder of carnivorous aquatic mammals that includes the seals, walruses and similar animals having finlike flippers). The M-weighting curves are shown graphically in Figure 3.1.

[1] *Defra is in the process of preparing guidance on the protection of marine European Protected Species (EPS) from injury and disturbance which will provide the offshore industry with best practice guidance for minimising impacts to marine species. The Defra guidance will be aimed at the English, Welsh and UK offshore marine areas and, although not legally binding, will form the basis of the UK's legal obligation to adequately transpose the Habitats Directive. It is understood that the Defra guidance will be a re-release of the draft JNCC guidance which, in the meantime, can be considered to be the most relevant guidance on EPS for UK offshore marine areas.*

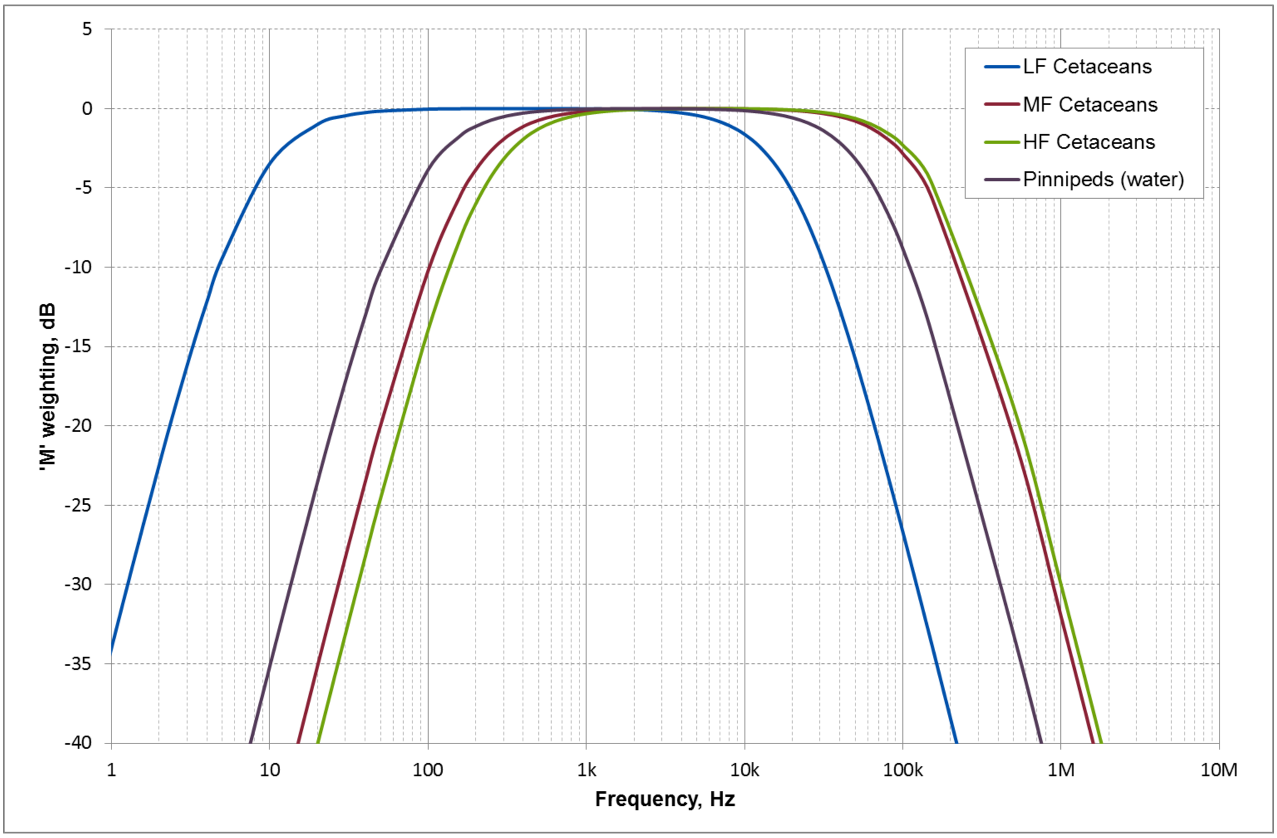

Figure 3.1 M-weighting functions for pinnipeds and cetaceans in water (LF = low-frequency, MF = mid-frequency, HF = high-frequency (Southall *et al*., 2007))

The injury criteria proposed in (Southall *et al*., 2007) are for three different types of sound. These sound types include multiple pulsed sound (i.e. sound comprising two or more discrete acoustic events per 24 hour period, such as impact piling and seismic exploration), single pulse sound (i.e. a single acoustic event in any 24 hour period, such as an underwater explosion) and continuous sound (i.e. non-pulsed sound such as continuous running machinery or drilled piling).

The relevant criteria proposed by Southall *et al.* (2007) for assessing the potential for permanent threshold shift due to multiple and single pulse sounds are considered to be an un-weighted peak pressure level of 230 dB re 1 µPa and an M-weighted SEL of 198 dB re 1 µPa^{2}s for all cetaceans. The criteria for pinnipeds are an un-weighted peak pressure level of 218 dB re 1 µPa and an M-weighted SEL of 186 dB re 1 µPa^{2}s. These injury criteria values are derived from values for onset of Temporary Threshold Shift (TTS) with an additional allowance of +6 dB for peak sound and +15 dB for SEL to estimate the potential onset of Permanent Threshold Shift (PTS). Southall *et al.* (2007) states that these thresholds represent suitable levels for a precautionary approach.

It has been reported by Lucke *et al.* (2008) that the onset of TTS in harbour porpoises might have a lower threshold, with the onset of TTS at 200 dB re 1 µPa peak-peak (equivalent to 194 dB re 1 µPa peak) and a sound exposure level of 164.3 dB re 1 µPa^{2}s (un-weighted). This work has been supported by more recent studies (Kastelein *et al.*, 2012). JNCC guidance (JNCC, 2010 in prep) suggests that these lower thresholds for TTS could be used to provide an estimation of PTS for these mammals. By applying the PTS onset calculation from Southall *et al.* (2007) this results in a peak level injury criterion of 200 dB re 1 µPa (i.e. by adding +6 dB to the peak level for TTS) and a SEL injury criterion of 179.3 dB re 1 µPa^{2}s (i.e. by adding +15 dB to the SEL level for TTS). The SEL value is, however, an un-weighted SEL and it is therefore necessary to apply the HF M-weighting to the received SELs reported by Lucke *et al.* (2008) in order to compare against HF M-weighted SELs due to other activities. Based on the frequency spectrum information presented in the Lucke *et al.* (2008) paper, it is estimated that applying the HF M-weighting would result in a correction of -2.5 dB. An M-weighted SEL criterion of 177 dB re 1 µPa^{2}s has therefore been adopted in order to estimate the potential injury ranges for harbour porpoise.

For non-pulsed sound, the relevant criteria proposed by Southall *et al.* (2007) are an un-weighted peak pressure level of 230 dB re 1 μPa and an M-weighted SEL of 215 dB re 1 μPa²s for all cetaceans. The criteria for pinnipeds are an un-weighted peak pressure level of 218 dB re 1 μPa and an M-weighted SEL of 203 dB re 1 μPa²s.

It is important to note that the above criteria are very precautionary. This is because:

i. The criteria were developed using a precautionary approach at every step;

ii. The criteria do not take into account the potential for recovery in hearing between subsequent pulses or days of exposure, and are therefore likely to overestimate hearing damage caused by time varying exposure;

iii. The M-weighting curves are "flatter" in shape than the relevant marine mammal hearing curves;

iv. The regions of best hearing sensitivity for most species are considerably narrower than the relevant M-weighting curve;

v. The peak pressure difference between TTS and PTS was arbitrarily taken to be 6 dB for pulsed sound, compared to 15 dB for continuous sound, meaning that the pulsed sound criteria are potentially very precautionary.

The criteria proposed for use to assess the likelihood of injury due to the Hywind Pilot Park Project are summarised in Table 3.1.

Marine mammal group	Type of sound	Injury criteria	
		Peak pressure, dB re 1 μPa	SEL, dB re 1 μPa²s (M-weighted)
Low-frequency cetaceans	Single or multiple pulses	230	198
	Non-pulses	230	215
Mid-frequency cetaceans	Single or multiple pulses	230	198
	Non-pulses (e.g. continuous sound)	230	215
High-frequency cetaceans	Single or multiple pulses (excluding harbour porpoise)	230	198
	Single or multiple pulses (harbour porpoise only)	194	177
	Non-pulses	230	215
Pinnipeds in water	Single or multiple pulses	218	186
	Non-pulses	218	203

Table 3.1 Suggested marine mammal criteria for onset of injury (per 24 hr period)

3.2.2 Disturbance to Marine Mammals

Beyond the area in which injury may occur, the effect on marine mammal behaviour is the most important measure of impact. The JNCC guidance (JNCC, 2010 in prep) proposes that a disturbance offence may occur when there is a risk of animals incurring sustained or chronic disruption of behaviour or when animals are displaced from an area, with subsequent redistribution being significantly different from that occurring due to natural variation. Marine Scotland guidance (2014) for inshore waters (i.e. for the cable route) recommends a precautionary approach in light of the uncertainties surrounding the issue of disturbance and marine mammals. The guidance notes that it is an offence in Scottish inshore waters to *"deliberately or recklessly disturb any dolphin, porpoise or whale (cetacean)"*. Only in cases where there is i) a licensable purpose to the activity; ii) there are no satisfactory alternatives; and iii) the actions will not be detrimental to the maintenance of the population of the species at favourable conservation status in their natural range can an exception be considered.To consider the possibility of a disturbance offence resulting from the project, it is necessary to consider both the likelihood that the sound could cause non-trivial disturbance and the likelihood that the sensitive receptors (marine mammals) will be exposed to that sound. Southall *et al*. (2007) recommended that the only currently feasible way to assess whether a specific sound could cause disturbance is to compare the circumstances of the situation with empirical studies. The JNCC guidance (JNCC, 2010 in prep) indicates that a score of 5 or more on the Southall *et al*. (2007) behavioural response severity scale could be significant. The more severe the response on the scale, the lower the amount of time that the animals will tolerate it before there could be significant negative effects on life functions, which would constitute a disturbance under the relevant regulations.

Southall *et al.* (2007) present a summary of observed behavioural responses for various mammal groups exposed to different types of noise (single pulse, multiple pulse and non-pulse).

For non-pulsed sound (e.g. vessels etc.), the lowest sound pressure level at which a score of 5 or more occurs for low frequency cetaceans is 90 - 100 dB re 1 μPa (rms). However, this relates to a study involving migrating grey whales. The only study for minke whales showed a response score of 3 at a received level of 100 – 110 dB re 1 μPa (rms), with no higher severity score encountered for this species. For mid frequency cetaceans, a response score of 8 was encountered at a received level of 90 - 100 dB re 1 μPa (rms), but this was for one mammal (a sperm whale) and might not be applicable for the species likely to be encountered near this development (e.g. Atlantic white-beaked dolphin). For these species, a response score of 3 was encountered for received levels of 110 – 120 dB re 1 μPa (rms), with no higher severity score encountered. For high frequency cetaceans, a number of individual responses with a response score of 6 are noted ranging from 80 dB re 1 μPa (rms) and upwards. There is a significant increase in the number of mammals responding at a response score of 6 once the received sound pressure level is greater than 140 dB re 1 μPa (rms).

Southall *et al*. (2007) presents a summary of observed behavioural responses due to multiple pulsed sound, although the data are primarily based on responses to seismic exploration activities. Although these datasets contain much relevant data for low-frequency cetaceans, there are no strong data for mid-frequency or high-frequency cetaceans. Low frequency cetaceans, other than bow-head whales, were typically observed to respond significantly at a received level of 140 – 160 dB re 1 μPa (rms). Behavioural changes at these levels during multiple pulses may have included visible startle response, extended cessation or modification of vocal behaviour, brief cessation of reproductive behaviour or brief / minor separation of females and dependent offspring. The data available for mid-frequency cetaceans indicate that some significant response was observed at a sound pressure level of 120 - 130 dB re 1μPa (rms), although the majority of cetaceans in this category did not display behaviours of this severity until exposed to a level of 170 – 180 dB re 1μPa (rms). Furthermore, other mid-frequency cetaceans within the same study were observed to have no behavioural response even when exposed to a level of 170 – 180 dB re 1μPa (rms).

According to Southall *et al*. (2007) there is a general paucity of data relating to the effects of sound on pinnipeds in particular. One study using ringed, bearded and spotted seals (Harris, Miller, & Richardson, 2001) found onset of a significant response at a received sound pressure level of 160 – 170 dB re 1 μPa (rms), although larger numbers of animals showed no response at noise levels of up to 180 dB re 1 μPa (rms). It is only at much higher sound pressure levels in the range of 190 – 200 dB re 1 μPa (rms) that significant numbers of seals were found to exhibit a significant response. For non-pulsed sound, one study elicited a significant response on a single harbour seal at a received level of 100 – 110 dB re 1 μPa (rms), although other studies found no response or non-significant reactions occurred at much higher received levels of up to 140 dB re 1 μPa (rms). No data is available for higher noise levels and the low number of animals observed in the various studies means that it is difficult to make any firm conclusions from these studies.

Southall *et al*. (2007) also notes that, due to the uncertainty over whether high-frequency cetaceans may perceive certain sounds and due to paucity of data, it was not possible to present any data on responses of high frequency-cetaceans. However, Lucke *et al.* 2008 showed a single harbour porpoise consistently showed aversive behavioural reactions to pulsed sound at received sound pressure levels above 174 dB re 1 μPa (peak-peak) or a SEL of 145 dB re 1 μPa^{2}s, equivalent to an estimated[2] rms sound pressure level of 166 dB re 1 μPa.

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[2] *Based on an analysis of the time history graph in Lucke et al. (2007) the T90 period is estimated to be approximately 8 ms, resulting in a correction of 21 dB applied to the SEL to derive the rms$_{T90}$ sound pressure level. However, the T90 was not directly reported in the paper.*

Clearly, there is much intra-category and perhaps intra-species variability in behavioural response. As such, a conservative approach should be taken to ensure that the most sensitive cetaceans remain protected.

The High Energy Seismic Survey workshop on the effects of seismic (i.e. pulsed) sound on marine mammals (HESS, 1997) concluded that mild behavioural disturbance would most likely occur at rms sound levels greater than 140 dB re 1 μPa (rms). This workshop drew on studies by (Richardson, 1995) but recognised that there was some degree of variability in reactions between different studies and mammal groups. Consequently, for the purposes of this study, a precautionary level of 140 dB re 1 μPa (rms) is proposed to indicate the onset of low level marine mammal disturbance effects for all mammal groups for impulsive sound.

The US National Marine Fisheries Service guidance (NMFS, 2005) sets the Level B harassment threshold[3] for marine mammals at 160 dB re 1 μPa (rms) for impulsive noise and 120 dB re 1 μPa (rms) for continuous noise. These values are therefore proposed as the basis for onset of strong behavioural reaction in this assessment.

Southall *et al*. (2007) presents criteria for disturbance due to exposure to single-pulsed sound. These are an un-weighted peak pressure level of 224 dB re 1 μPa and an M-weighted SEL of 183 dB re 1 μPa^{2}s for all cetaceans. The criteria for pinnipeds are an un-weighted peak pressure level of 212 dB re 1 μPa and an M-weighted SEL of 171 dB re 1 μPa^{2}s.

The criteria proposed for use in assessing the spatial extent of marine mammal disturbance due to different types of sound is summarised in Table 3.2.

Type of sound / criteria metric	Effect	Marine mammal hearing group	
		All cetaceans	Pinnipeds
Single pulses:			
Peak pressure level, dB re 1 μPa	Potential strong behavioural reaction	224	212
SEL, dB re 1 μPa^{2}s		183	171
Multiple pulses:			
RMS sound pressure level, dB re 1 μPa	Potential strong behavioural reaction	160	
	Low level marine mammal disturbance	140	
Continuous sound:			
RMS sound pressure level, dB re 1 μPa	Potential strong behavioural reaction	120	

Table 3.2 Suggested marine mammal criteria for onset of disturbance

3.3 Fish

3.3.1 Injury to Fish

Adult fish not in the immediate vicinity of the noise generating activity are generally able to vacate the area and avoid physical injury. However, larvae and spawn are not highly mobile and are therefore more likely to incur injuries from the sound energy, including damage to their hearing, kidneys, hearts and swim bladders. Such effects are unlikely to happen outside of the immediate vicinity of even the highest energy sound sources.

For fish, the most relevant criteria for injury are considered to be those contained in ASA S3/SC1.4 TR-2014, Sound Exposure Guidelines for Fishes and Sea Turtles (Popper *et al.,* 2014). The guidelines set out criteria for injury due to different sources of noise. Those relevant to the Project are considered to be those for injury due to impulsive piling noise (although no impulsive piling required for the Project these criteria have been used to inform the assessment of snapping as recorded on the Hywind Demo) and those for injury due to continuous noise (which are

[3] *Level B Harassment is defined as having the potential to disturb a marine mammal or marine mammal stock in the wild by causing disruption of behavioural patterns, including, but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering but which does not have the potential to injure a marine mammal or marine mammal stock in the wild.*

applicable for shipping, drilled piles and turbines)[4]. The criteria include a mixture of indices including SEL, rms and peak sound pressure levels where insufficient data exists to determine a quantitative guideline value the risk is categorised in relative terms as “high”, “moderate” or “low” at three distances from the source: “near” (i.e. in the tens of meters), “intermediate” (i.e. in the hundreds of meters) or “far” (i.e. in the thousands of meters). It should be noted that these qualitative criteria cannot differentiate between exposures to different noise levels and therefore all sources of noise, no matter how noisy, would theoretically elicit the same assessment result. However, because the qualitative risks are generally qualified as “low”, with the exception of a moderate risk at “near” range (i.e. within tens of meters) for some types of animal and impairment effects, this is not considered to be a significant issue with respect to determining the potential effect of noise on fish due to continuous sound, although some caution is necessary in applying the guidelines if sounds of particularly high intensity are to be introduced.

Type of animal	Parameter	Mortality and potential mortal injury	Impairment	
			Recoverable injury	TTS
Fish: no swim bladder (particle motion detection)	SEL, dB re 1 μPa^{2}s	>219	>216	>>219
	Peak, dB re 1 μPa	>213	>213	-
Fish: where swim bladder is not involved in hearing (particle motion detection)	SEL, dB re 1 μPa^{2}s	210	203	>186
	Peak, dB re 1 μPa	>207	>207	-
Fish: where swim bladder is involved in hearing (primarily pressure detection)	SEL, dB re 1 μPa^{2}s	207	203	186
	Peak, dB re 1 μPa	>207	>207	-
Eggs and larvae	SEL, dB re 1 μPa^{2}s	>210	(Near) Moderate (Intermediate) Low (Far) Low	(Near) Moderate (Intermediate) Low (Far) Low
	Peak, dB re 1 μPa	>207		

Table 3.3 Suggested criteria for onset of injury to fish due to impulsive sound

[4] *Guideline exposure criteria for explosions, seismic airguns and low and mid-frequency naval sonar are also presented though are not applicable to this project.*

Type of animal	Mortality and potential mortal injury	Impairment	
		Recoverable injury	TTS
Fish: no swim bladder (particle motion detection)	(Near) Low (Intermediate) Low (Far) Low	(Near) Low (Intermediate) Low (Far) Low	(Near) Moderate (Intermediate) Low (Far) Low
Fish: where swim bladder is not involved in hearing (particle motion detection)	(Near) Low (Intermediate) Low (Far) Low	(Near) Low (Intermediate) Low (Far) Low	(Near) Moderate (Intermediate) Low (Far) Low
Fish: where swim bladder is involved in hearing (primarily pressure detection)	(Near) Low (Intermediate) Low (Far) Low	170 dB re 1 μPa (rms) for 48 hours	158 dB re 1 μPa (rms) for 12 hours
Eggs and larvae	(Near) Low (Intermediate) Low (Far) Low	(Near) Low (Intermediate) Low (Far) Low	(Near) Low (Intermediate) Low (Far) Low

Table 3.4 Suggested criteria for onset of injury to fish due to continuous sound

3.3.2 Disturbance to Fish

Behavioural reaction of fish to sound has been found to vary between species based on their hearing sensitivity. Typically, fish sense sound via particle motion in the inner ear which is detected from sound-induced motions in the fish's body. The detection of sound pressure is restricted to those fish which have air filled swim bladders; however, particle motion (induced by sound) can be detected by fish without swim bladders[5].

Highly sensitive species such as herring have elaborate specialisations of their auditory apparatus, known as an otic bulla - a gas-filled sphere, connected to the swim bladder, which enhances hearing ability. The gas filled swim bladder in species such as cod and salmon may be involved in their hearing capabilities, so although there is no direct link to the inner ear, these species are able to detect lower sound frequencies and as such are considered to be of medium sensitivity to noise. Flat fish and elasmobranchs have no swim bladders and as such are considered to be relatively less sensitive to sound pressure.

For assessing the likelihood of behavioural effects in fish, use can be made of the dB_{ht} (*species*) scale (Nedwell *et al.*, 2007). This is simply a decibel scale reflecting the level above the hearing threshold (i.e. quietest perceptible sound) of that species. In order to determine the dB_{ht} (*species*) level it is necessary to possess audiometric data for that species. However, for this project (where operational noise levels will be primarily low frequency tonal in nature) there is limited audiometric data available for the species of interest.

The most recent criteria for disturbance are considered to be those contained in ASA S3/SC1.4 TR-2014, Sound Exposure Guidelines for Fishes and Sea Turtles (Popper *et al.,* 2014) which set out criteria for disturbance due to different sources of noise. The risk of behavioural effects is categorised in relative terms as "high", "moderate" or "low" at three distances from the source: "near" (i.e. in the tens of meters), "intermediate" (i.e. in the hundreds of meters) or "far" (i.e. in the thousands of meters).

[5] *It should be noted that the presence of a swim bladder does not necessarily mean that the fish can detect pressure. Some fish have swim bladders that are not involved in the hearing mechanism and can only detect particle motion.*

Type of Animal	Relative risk of behavioural effects	
	Impulsive sound	Continuous sound
Fish: no swim bladder (particle motion detection)	(Near) High (Intermediate) Moderate (Far) Low	(Near) Moderate (Intermediate) Moderate (Far) Low
Fish: where swim bladder is not involved in hearing (particle motion detection)	(Near) High (Intermediate) Moderate (Far) Low	(Near) Moderate (Intermediate) Moderate (Far) Low
Fish: where swim bladder is involved in hearing (primarily pressure detection)	(Near) High (Intermediate) High (Far) Moderate	(Near) High (Intermediate) Moderate (Far) Low
Eggs and larvae	(Near) Moderate (Intermediate) Low (Far) Low	(Near) Moderate (Intermediate) Moderate (Far) Low

Table 3.5 Proposed criteria for onset of behavioural effects in fish due to continuous sound and impulsive sound

It is important to note that the ASA criteria for disturbance due to sound are qualitative rather than quantitative criteria. Consequently, a source of noise of a particular type (e.g. piling or continuous sound from vessels etc.) would result in the same predicted impact, no matter the level of noise produced or the propagation characteristics. Consequently, use has also been made of alternative criteria presented in the Washington State Department of Transport Biological Assessment Preparation for Transport Projects Advanced Training Manual (WSDOT, 2011). The manual suggests an un-weighted sound pressure level of 150 dB re 1 µPa (rms) as the criterion for onset of behavioural effects, based on work by Hastings (2002). Sound pressure levels in excess of 150 dB re 1 µPa (rms) are expected to cause temporary behavioural changes, such as elicitation of a startle response, disruption of feeding, or avoidance of an area. The document notes that levels exceeding this threshold are not expected to cause direct permanent injury, but may indirectly affect the individual fish (such as by impairing predator detection). It is important to note that this threshold is for onset of potential effects, and not necessarily an 'adverse effect' threshold.

3.4 Diving Birds

An assessment of the effect of underwater noise on diving birds has been scoped out of the underwater noise study for the following reasons (Dooling & Therrien, 2012):

> There is a complete absence of measured data on the underwater hearing of birds;

> It is not known how birds use sound underwater (e.g. for communication, foraging, predator detection etc.);

> It is speculated (based on comparisons to human hearing underwater and an understanding of avian hearing physiology) that hearing is not a useful mechanism for birds underwater.

4 BASELINE NOISE

Background or "ambient" underwater noise is generated by a number of natural sources, such as rain, breaking waves, wind at the surface, seismic noise, biological noise and thermal noise. Biological sources include marine mammals (which use sound to communicate, build up an image of their environment and detect prey and predators) as well as certain fish and shrimp. Anthropogenic sources also add to the background noise, such as fishing boats, ships, industrial noise, seismic surveys and leisure activities. Generalised ambient noise spectra attributable to various noise sources (Wenz, 1962) are shown in Figure 4.1.

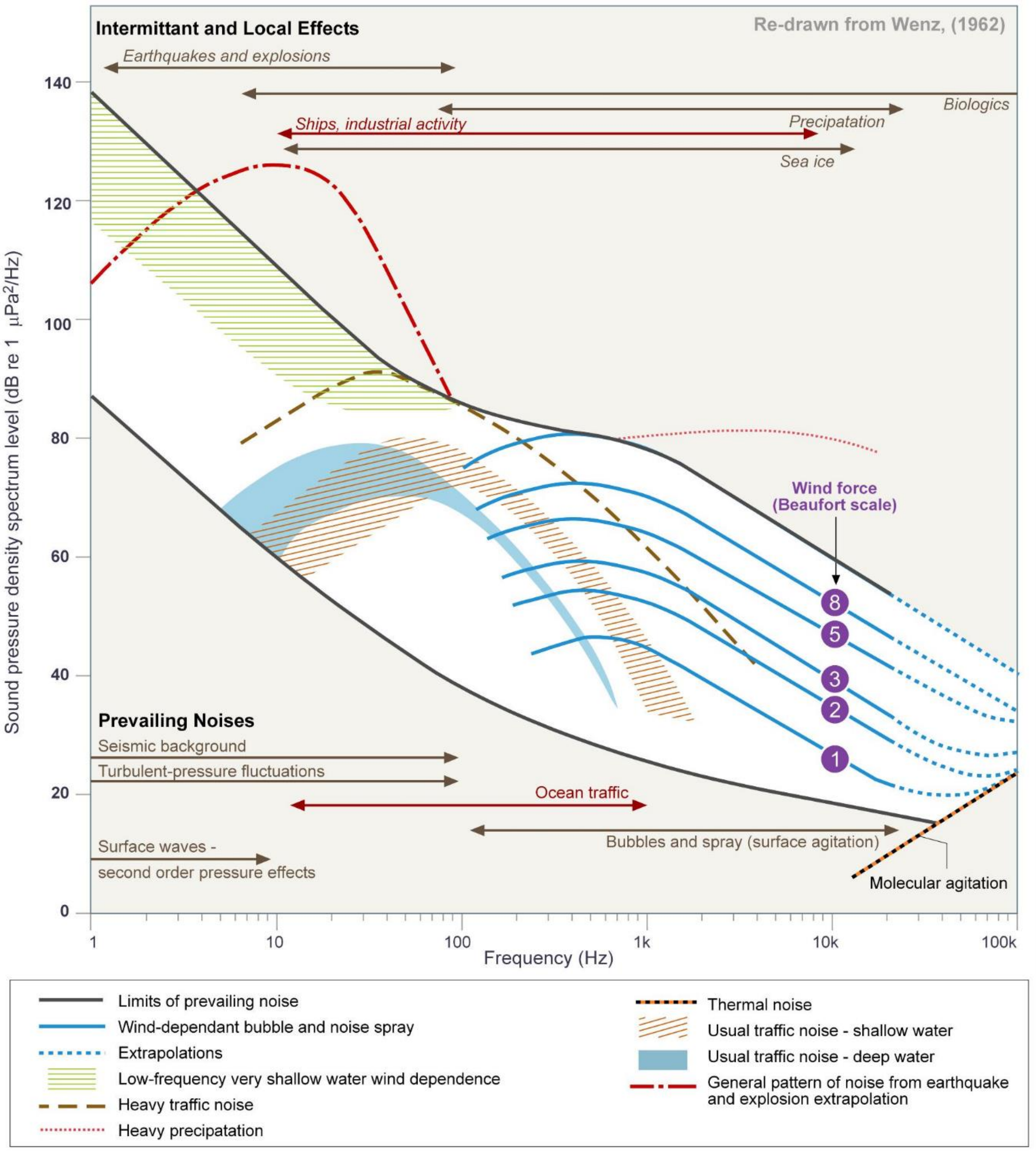

Figure 4.1 Generalised ambient noise spectra attributable to various noise sources

The vast majority of research relating to both physiological effects and behavioural disturbance due to noise on marine species is based on determining the absolute noise level for the onset of that effect. As a result, criteria for assessing the effects of noise on marine mammals and fish tend to be based on the absolute noise criteria, as opposed to the difference between the baseline noise level and the specific noise being assessed (Southall *et al*., 2007). Given the lack of evidence based studies investigating the effects of noise relative to background on marine wildlife, the value of establishing the precise baseline noise level is somewhat diminished. It is important to understand that baseline noise levels will vary significantly depending on, amongst other factors, seasonal variations and different sea states, meaning that the usefulness of establishing such a value would be very limited. Nevertheless, it can be useful (though not essential) when undertaking an assessment of underwater noise to have an understanding of the range of noise levels likely to be prevailing in the area so that any noise predictions can be placed in the context of the baseline. It is important to note, however, that even if an accurate baseline noise level could be determined, there is a paucity of scientific understanding regarding how various species distinguish anthropogenic sound relative to masking noise. An animal's perception of sound is likely to depend on numerous factors including the hearing integration time, the character of the sound and hearing sensitivity. It is not known, for example, to what extent marine mammals and fish can detect tones of lower magnitude than the background masking noise or how they distinguish time varying sound. Therefore, it is necessary to exercise considerable caution if attempting any comparison between noise from the development and the baseline noise level. For example, it does not follow that just because the broadband sound pressure level due to the source being considered is below the numeric value of the baseline level that this means that marine mammals or fish cannot detect that sound. This is particularly true where the background noise is dominated by low frequency sound which is outside the animal's range of best hearing acuity. Until such a time as further research is conducted to determine a dose response relationship between the "signal-to-noise" level and behavioural response, a precautionary approach should be adopted.

For the reasons given above, and due to the relatively low risk due to marine sound due to lack of impulsive piling for this project, it was considered that it would be disproportionate and unnecessary to undertake baseline noise measurements as part of this study. Instead, Xodus has reviewed baseline noise studies carried out in UK waters for other projects in order to determine the likely magnitude of noise encountered in such waters.

A review of noise data relating to other sites in UK waters was undertaken for the Beatrice wind farm included a review of baseline underwater noise measurements in UK coastal waters (Brooker *et al.*, 2012). These noise data are summarised in Table 4.1 and Power Spectral Density levels are shown graphically in Figure 4.2 (Sea State 1) and Figure 4.3 (Sea State 3).

	Overall (Un-weighted) Average Background Noise Levels, dB re 1 μPa (rms)	
	Sea State 1	Sea State 3
Minimum	92	94
Maximum	126	132
Mean	111	112

Table 4.1 Summary of average background levels of noise around the UK coast (Brooker *et al.*, 2012)

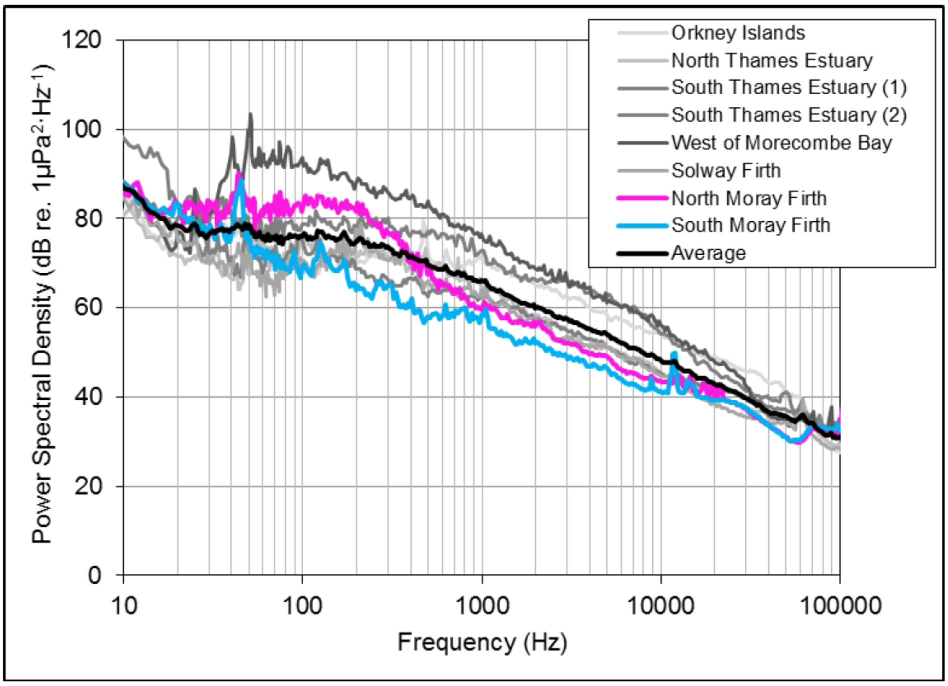

Figure 4.2 Summary of Power Spectral Density levels of background underwater noise at Sea State 1 at sites around the UK coast (Brooker *et al.*, 2012)

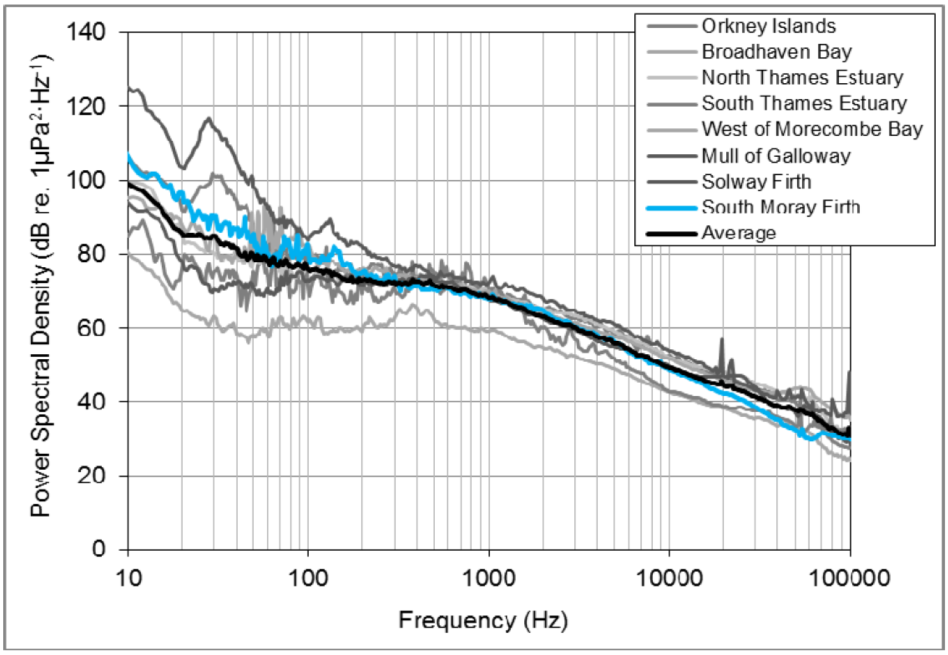

Figure 4.3 Summary of Power Spectral Density levels of background underwater noise at Sea State 3 at sites around the UK coast (Brooker *et al.*, 2012)

5 REVIEW OF ‘HYWIND I’ UNDERWATER NOISE DATA

Statoil commissioned Fugro GEOS and Jasco Applied Sciences to undertake underwater noise measurements in the vicinity of the Hywind I installation at a test site north-west of Stavanger, Norway. The purpose of the measurement exercise was to quantify potential underwater noise emissions from the Hywind turbines during operation in order to inform any impact assessments that will be required for future Hywind project sites.

Measurements were undertaken at a test location some 150 m from the main structure and the hydrophone was deployed at a depth of 91 m. Additional background noise level readings were undertaken at a remote control site with comparable natural environmental conditions, 10 km from the Hywind test site. The relative locations of the test site and control site are shown in Figure 5.1.

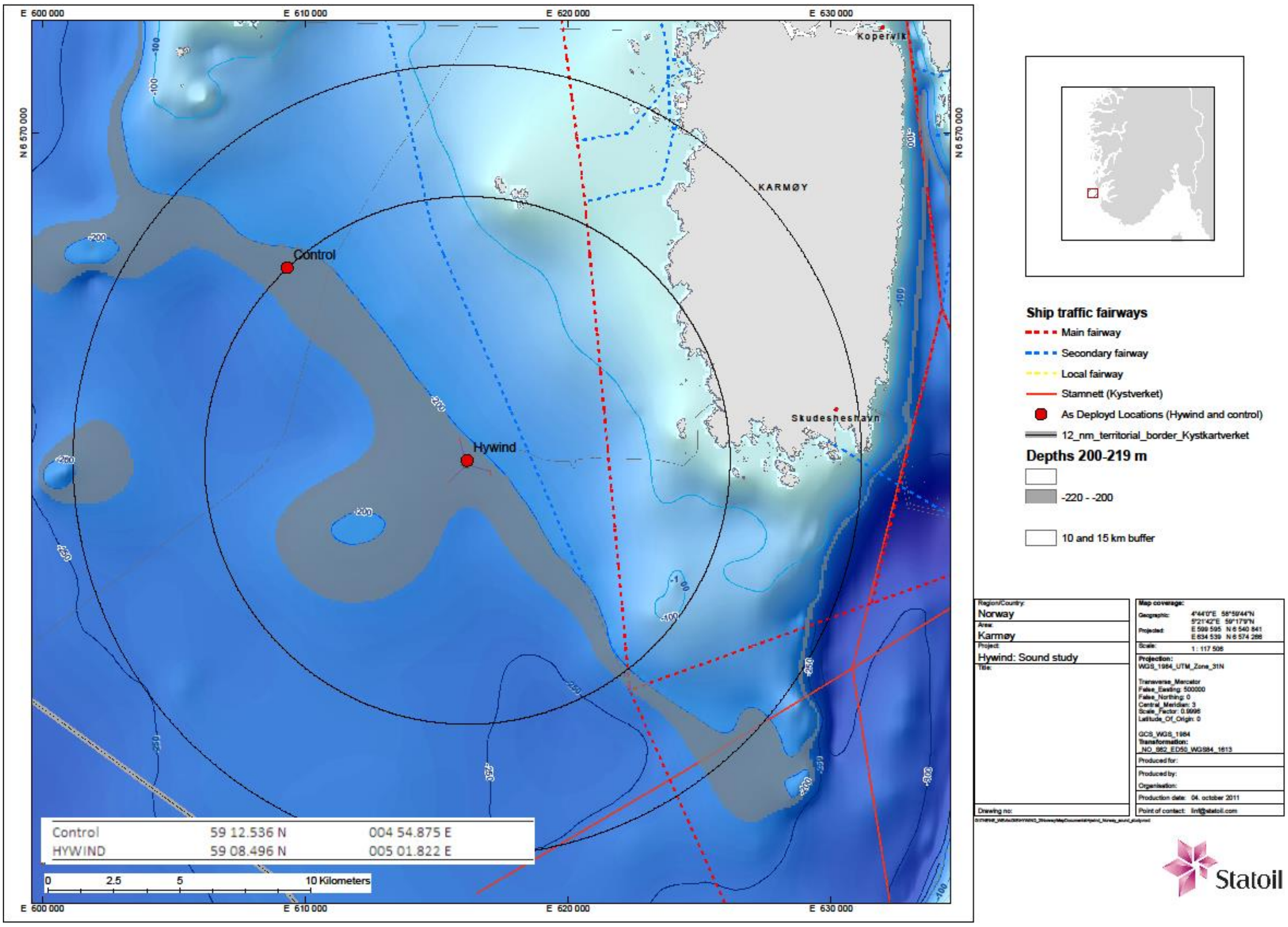

Figure 5.1 Location of the recording hydrophones for Hywind I and Control.

The recording equipment was first deployed on 28th March 2011 and recovered on 31st May 2011. The second deployment was on 31st May 2011 with recovery on 15th August 2011. A total of 148 days recording period was achieved during the project.

The study concluded that:

- The Hywind structure generates a variety of signature components that can be detected above the background noise level. These appear to be related to gear meshing and electrical generation. None of these components exhibited levels that exceeded a power spectral density (PSD) of 115 dB re 1 $\mu Pa^2 Hz^{-1}$.

- The Hywind structure produces occasional ‘snapping’ transients that have received peak levels (at a distance of 150 m) above 160 dB re 1 μPa. The frequency content of the transients extends throughout the recorded frequency range of 0 – 20 kHz. Between 0 and 23 of these transients occurred per day. These transients are thought to be related to tension releases in the mooring system.

6 ASSESSMENT OF NOISE

6.1 Construction and Installation

There is potential for installation vessels and other equipment to produce noise during installation of the anchors, anchor lines, turbines and export cable. It is not expected that HDD operations will produce any significant noise since the noise generating equipment will all be onshore with the exception of the drill bit and string which will be under the sea floor. The export cable will transport electricity from the Pilot Park to a landfall located along the coast at Peterhead. The length of the export cable corridor will be 25 km to 35 km depending on the location of the WTG Units, mooring configuration and arrangement of the inter-array cables. The export cable will be buried within a trench. The trench will be approximately maximum 6 m wide and less than 2m in depth. Depending on seabed conditions along the seabed it may not be possible to bury the full length of cable to desired depth. Where it is not possible to bury the cable, rock dumping, mattresses or sand / grout bags may be required to protect the cable.

The noise emissions from the vessels that may be used in the project are quantified in Table 6.1, based on a review of publicly available data. In the table, a correction of +3 dB has been applied to the rms sound pressure level to estimate the likely peak sound pressure level. SELs have been estimated for each source based on 24 hours continuous operation. Source noise levels for vessels depend on the vessel size and speed as well as propeller design and other factors. There can be considerable variation in noise magnitude and character between vessels even within the same class. Therefore, source data for this project has been based largely on worst-case assumptions (i.e. using noise data toward the higher end of the scale for the relevant class of ship as a proxy). The source sound pressure levels and associated impact zones can therefore be viewed as indicative precautionary ranges.

It is important to note that it is highly unlikely that any marine mammal or fish would stay at a stationary location or within a fixed radius of a vessel (or any other noise source) for 24 hours. Consequently, any resulting injury zones should be treated as a very pessimistic, worst case scenario. To put this into context, if an animal spent one hour instead of 24 hours being exposed to sound, this would result in a SEL 13 dB lower than predicted in this study which, in very ballpark terms, equates a potential injury radius of approximately a quarter of the size (and a reduction in the potential area over which injury might occur by one sixteenth). Taking into account the various precautionary assumptions made in derivation of injury criteria as well as the potential overestimate in sound exposure due to use of 24 hour SEL values, any estimated injury zones in this report should be treated as being precautionary over-estimates.

Item	Description/assumptions	Data source	Source sound pressure level at 1 m		
			Rms, dB re 1 µPa	Peak, dB re 1 µPa	SEL (24 h), dB re 1 μPa^2s
Anchor handling vessel	Tug used as proxy	Richardson (1995)	172	175	221
Ploughing vessel	‘Gerardus Mercator’ trailer hopper suction dredger using DP as proxy	Wyatt (2008)	188	191	237
Survey vessel	Tug used as proxy	Richardson (1995)	172	175	221
Rock placement vessel	‘Gerardus Mercator’ trailer hopper suction dredger using DP as proxy	Wyatt (2008)	188	191	237
Cable lay vessel	‘Gerardus Mercator’ trailer hopper suction dredger using DP as proxy	Wyatt (2008)	188	191	237

Table 6.1 Source noise data for construction and installation vessels

The peak pressure criterion described by Southall *et al*. (2007) will not be exceeded even in very close proximity to the vessels and no fatal injury is likely from the operations. An assessment of the distance to onset of injury from each vessel category is presented in Table 6.2 based on the SEL cumulative exposure criterion, along with an assessment of potential disturbance zones. The potential radii for injury are based on exposure levels over a 24 hour period and assume that all vessels are present at the same time. Thus, for example, a seal would need to stay within 50 m of cable laying operations for a period of 24 hours to experience any injury. The table also presents the potential radius of disturbance for marine mammals based on the conservative 120 dB re 1 μPa (rms) criterion. It is important to bear in mind when viewing these potential disturbance radii that the 120 dB re 1 μPa (rms) criterion is very precautionary and that ambient noise levels could well exceed this value.

Activity / vessel	Radius of potential injury zone (assuming continuous exposure within that radius over 24 hour period)				Radius of potential disturbance zone
	Low-frequency	Mid-frequency	High-frequency	Pinnipeds	All marine mammals
Anchor handling vessel	< 5 m	< 5 m	< 5 m	15 m	750 m
Ploughing vessel	25 m	15 m	12 m	50 m	5 km
Survey vessel	< 5 m	< 5 m	< 5 m	15 m	750 m
Rock placement vessel	25 m	15 m	12 m	50 m	5 km
Cable lay vessel	25 m	15 m	12 m	50 m	5 km

Table 6.2 Calculated effects of continuous vessel / construction noise

Studies by Hermannsen *et al* (2014), Palka & Hammond (2001) and Barlow (1988) have reported avoidance ranges of 800 to 1,200 m for propeller driven ships. Some of the vessels included in the Hywind Scotland project may utilise dynamic positioning (DP) thrusters and consequently noise from these vessels could be higher than for propeller driven ships. The values for the radius of potential disturbance for the anchor handling vessel and survey vessel (which are unlikely to use thrusters) are similar to the lower range of those reported in the above referenced studies. However, the potential range of effect for vessels using thrusters is predicted to be significantly greater. Due to the worst case assumptions made in the modelling (very precautionary 120 dB re 1 Pa criteria combined with worst case source noise assumptions), it is possible that the 5 km range will be overly pessimistic. Consequently, it is considered that the true range of the behavioural disturbance zone will be somewhere between 1 km to 5 km, depending on environmental variables (e.g. background noise), uncertainty in the criteria and calculations and the noise source levels of the actual vessels used.

The potential for injury and disturbance to fish is shown in the following tables. Table 6.3 shows the qualitative risk of injury and disturbance to different fish types depending on range, in accordance with ASA guidance.

Range:	Qualitative risk due to exposure to all vessels		
	Near *(10s of meters)*	**Intermediate** *(100s of meters)*	**Far** *(1000s of meters)*
ASA qualitative risk of potential injury:			
Fish: no swim bladder	Low	Low	Low
Fish: swim bladder not involved in hearing	Low	Low	Low
Fish: swim bladder involved in hearing	*N/A – see Table 6.4*		
Eggs and larvae	Low	Low	Low
ASA qualitative risk of potential disturbance:			
Fish: no swim bladder	Moderate	Moderate	Low
Fish: swim bladder not involved in hearing	Moderate	Low	Low
Fish: swim bladder involved in hearing	High	Moderate	Low
Eggs and larvae	Moderate	Moderate	Low

Table 6.3 Effects of continuous vessel / construction noise based on ASA qualitative criteria

Table 6.4 shows the calculated ranges of injury to fish with swim bladders in line with ASA guidelines, based on exceedance of 170 dB re 1 μPa (rms) over 48 hours continuous exposure, and the potential disturbance radius to fish based on the WSDOT criterion of 170 dB re 1 μPa (rms).

Activity / vessel	**ASA Radius of potential recoverable injury zone** (assuming continuous exposure within that radius over 48 hour period)	**Radius of potential disturbance zone (based on WSDOT criteria)**
	Fish: swim bladder involved in hearing	**All fish**
Anchor handling vessel	<5 m	25 m
Ploughing vessel	15 m	160 m
Survey vessel	<5 m	25 m
Rock placement vessel	15 m	160 m
Cable lay vessel	15 m	160 m

Table 6.4 Calculated effects of continuous vessel / construction noise

The potential ranges presented for injury and disturbance are not a hard and fast 'line' where an impact will occur on one side of the line and not on the other side. Potential impact is more probabilistic than that; dose dependency in PTS onset, individual variations and uncertainties regarding behavioural response and swim speed/direction all mean that in reality it is much more complex than drawing a contour around a location. These ranges are designed to provide a way in which a wider audience can understand the potential maximum spatial extent of the impact.

6.2 Continuous Machinery Noise

The operation of the Hywind I turbine produced tonal noise at a frequency of 25 Hz and harmonics thereof. None of these components exhibited levels that exceeded a power spectral density (PSD) of 115 dB re 1 $\mu Pa^2 Hz^{-1}$. Xodus has performed some simple calculations to convert the PSD plots from the Jasco report into approximate sound pressure level data. PSD levels were converted to sound pressure by applying a frequency bandwidth related correction for the appropriate frequency bin (in this case third octave bands were used). This was then corrected for background noise using the data from the control monitoring point. This analysis shows that the broadband sound pressure level due to operational noise is approximately 119 dB re 1 μPa (rms) at the monitoring point, which was 150 m from the WTG Unit. If it is assumed that the WTG Units produce a similar level of noise over a 24 hour period then the daily cumulative sound exposure level (SEL) at 1 m from the source would be 168 dB re 1 μPa^2s.

Assuming spherical radiation of sound from the turbine this would result in a "source" sound pressure level of 162 dB re 1 μPa (rms) at 1 m and a "source" SEL of 212 dB re 1 μPa^2s at 1 m over a 24 hour period. The Hywind Scotland project will be larger in scale (up to five WTG Units with a maximum installed capacity of 30 MW). Assuming a simple scaling relationship exists between turbine power and underwater noise emission, this would mean that each Hywind Scotland WTG Unit (assuming a maximum power rating of 6 MW per turbine) could produce around 4 dB more noise than the Hywind I turbine, resulting in a sound pressure level at 1 m of 166 dB re 1 μPa (rms) and a SEL at 1 m of 216 dB re 1 μPa^2s over a 24 hour period.

The predicted M-weighted SELs as a result of each WTG Unit are presented in Figure 6.1 along with the injury onset criteria. It is important to note that these values assume an animal would stay within the stated range for 24 hours continuously, which is as unrealistic worst-case scenario. Based on the criteria from Southall *et al.* 2007, the figure shows that cetaceans are unlikely to experience injury as a result of operational noise from the Hywind project.

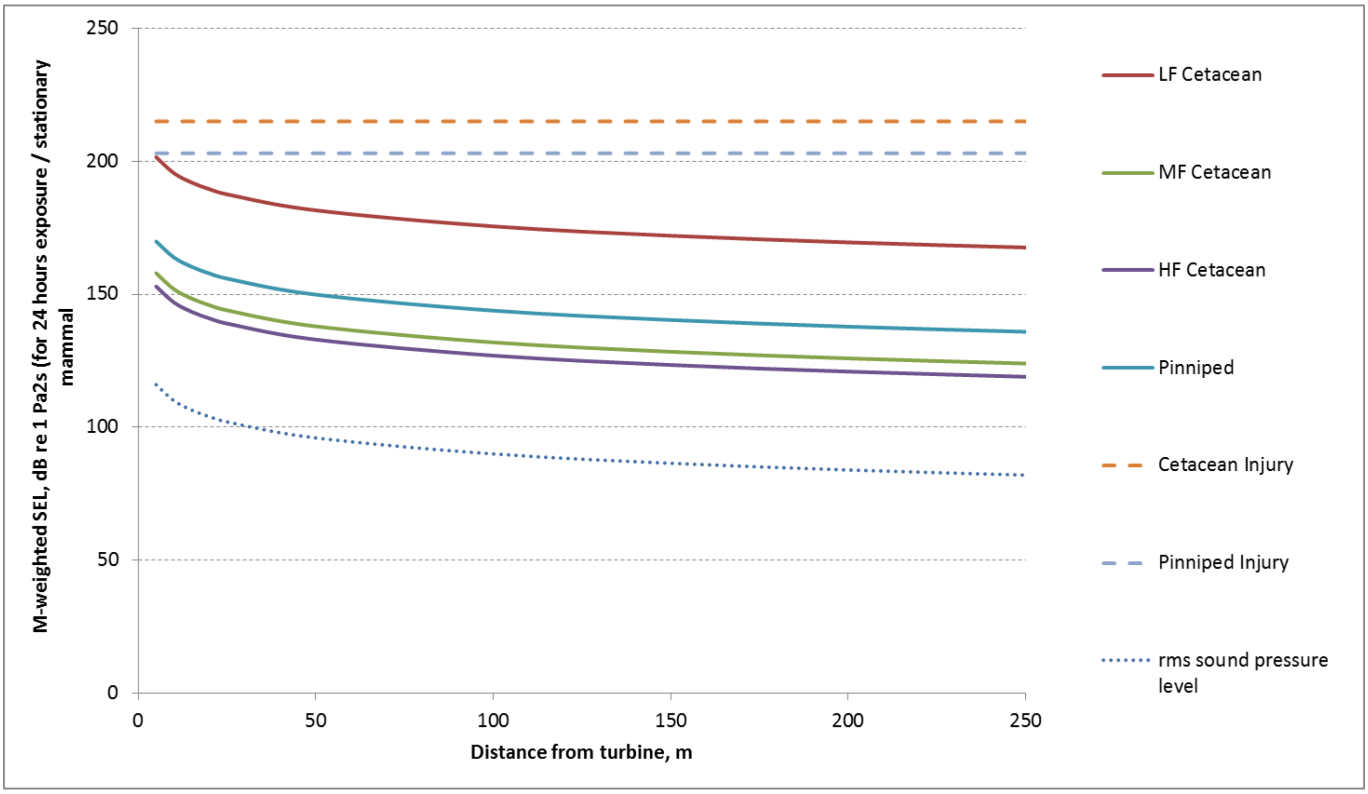

Figure 6.1 Relationship between cumulative SEL and range for 24 hour exposure of a stationary mammal to operational noise and comparison to Southall *et al.* 2007 criteria for injury

The range of potential disturbance for marine mammals is 450 m based on exceeding the 120 dB re 1 μPa (rms) criterion for continuous noise.

Based on the ASA guideline criterion for potential injury to fish with swim bladders involved in hearing of 170 dB re 1 μPa (for 48 hours exposure), it is not expected that any fish will experience injury as a result of exposure to noise from the turbines. The potential range of behavioural effects for fish is expected to be a maximum of 15 m from each WTG Unit based on exceeding the 150 dB re 1 μPa (rms) criterion (WSDOT, 2011).

Vessels will be utilised for some activities during the operations and maintenance phase of the project. However, the impact associated with use of vessels is unlikely to be significant since the area is already busy with various fishing and commercial traffic so the character of the acoustic environment is unlikely to change. Any impacts due to vessel noise will be similar to those outlined for construction and installation.

6.3 Cable 'Snapping' Noise

The snapping sound, which was attributed to the cables, produced a broadband peak sound pressure level of 160 dB re 1 μPa (peak) at 150 m. Associated 1 minute rms sound pressure levels at the time of these recordings were generally in the range 120 – 125 dB re 1 μPa (rms). A graphical representation of one of the snapping sound events is shown in Figure 6.2.

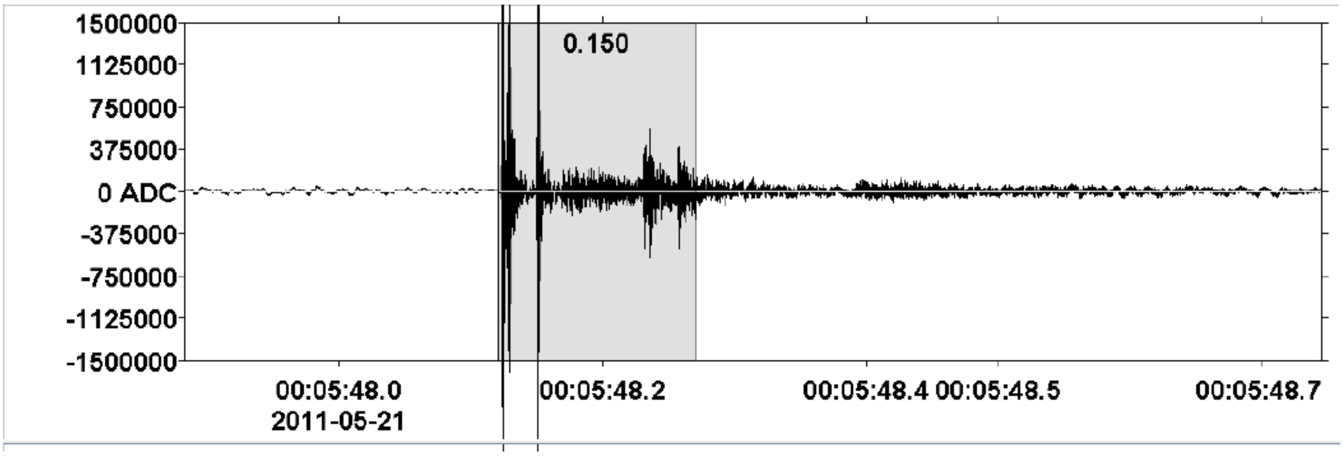

Figure 6.2 Sample snapping sound event (4096 point FFT, 500 real data points, 250 point overlap, Reisz window)

The Jasco report does not provide sufficient detail about the snapping sound to covert from peak sound pressure to rms sound pressure and SEL. For transient impulsive sounds, the rule of thumb of a 6 dB difference between peak pressure and rms sound pressure level (which applies to continuous sound) does not hold true. It is therefore necessary (in absence of more detailed data) to make some assumptions about the sound in order to derive estimates of these parameters, for comparison to the various criteria for injury and disturbance.

Based on the time history graph (and extrapolating beyond the "cut-off" y-axis) it is estimated that the T90 time (i.e. the interval which contains 90% of the sound energy) is approximately 25 ms. (This is the estimated T90 time for a single snapping event, i.e. only one of the transient peaks shown in the graph.) Taking a one minute rms sound pressure level of 120 dB re 1 μPa, this would result in a rms sound pressure level at 150 m of around 145 dB re 1 μPa (rms) and the SEL per "snap" would be around 135 dB re 1 $\mu Pa^2 s$.

It is not known whether the proposed larger turbines used for Hywind Scotland will produce the same level of noise and it is not possible to apply scaling to the measured sound pressure levels since the noise generating mechanism is unlikely to be related to the turbine's power rating. It is also difficult to estimate the sound source level at 1 m due to the physical size of the ropes and chains. The large spread of the chain footprint means that the range from the source to the hydrophone is unknown and it is unlikely that the propagation can be treated as simply spherical spreading of sound.

The snapping events were found to occur up to 23 times per day for a single WTG Unit. Assuming that multiple WTG Units could cause snapping sounds at the same rate under similar conditions, this could mean up to 115 snapping events per day (assuming five turbines). It is not possible at this time to predict the regularity and temporal spacing of such events. Nevertheless, a simple calculation shows that the potential cumulative SEL over a 24 hour period could be around 156 dB re 1 $\mu Pa^2 s$ at 150 m from the turbine. This SEL is well below the onset criteria for injury to marine mammals, and the rms sound pressure level is well below the threshold for onset of injury to fish.

It is also important to note that it is not known whether the snapping sound will be a characteristic of the Hywind Scotland Project because only one set of noise measurements has been conducted at Hywind I. The mooring arrangement will be different for the Hywind Scotland Project and there is therefore a significant level of uncertainty as to whether the snapping sound encountered at the Hywind I demo site will occur.

In terms of disturbance, it is estimated that the 140 dB re 1 μPa (rms) criterion for mild behavioural disturbance in marine mammals (for impulsive sounds) would be exceeded at a range of up to approximately 250 m from each turbine and the extent of the zone of potential strong behavioural disturbance will extend approximately 30 m around each turbine. The potential behavioural reaction zone will be around 100 m for fish, based on the 150 dB re 1 μPa (rms) criterion. The potential disturbance zone for marine mammals and fish is therefore unlikely to overlap spatially between the turbines given the proposed turbine spacing of up to 1 km. It should be noted that the snapping sound will not occur (if indeed it does occur) with a known regularity and is unlikely to occur for all turbines at the same time.

It must be emphasised that the above analysis is very approximate at this time due to the various unknown quantities and potential errors involved (different moorings, unknown propagation correction, unknown rms to peak correction, unknown T90 time).

7 CONCLUSIONS

This report has presented a review of potential impacts due to underwater noise during the construction and operation of the Hywind Scotland Pilot Park. It is concluded that:

> There is potential for installation vessels and other equipment to produce noise during installation of the anchors, anchor lines, turbines and power cables. This includes use of vessels and seabed preparation equipment. HDD operations are unlikely to produce any significant underwater noise.

> Potential injury zones around installation vessels range between less than 5 m up to 50 m for marine mammals, although this is based on a number of conservative assumptions, including the assumption of an animal staying within range of the vessels for 24 hours at a time, which is considered unrealistic. A more realistic scenario is that marine mammals would only spend a short amount of time in the vicinity of vessels, in which case it is highly unlikely that any injury would occur.

> The potential injury zone for fish with swim bladders is up to 15 m for even the largest vessel, although this is based on based on a number of conservative assumptions, including continuous 48 hours exposure to vessel noise which is considered highly unlikely to occur. A more realistic scenario is that fish would only spend a short amount of time in the vicinity of vessels, in which case it is highly unlikely that any injury would occur.

> The potential zone for disturbance due to larger vessels could extend up to five kilometres for marine mammals and up to 160 m for fish, but these will be temporary noise sources. Furthermore, the criteria used for assessing behavioural disturbance to marine mammals are based on very precautionary assumptions and are likely to represent a significantly over-pessimistic assessment. It is possible that sound pressure levels in the local environment will already be as high as the behavioural disturbance threshold of 120 dB re 1 μPa (rms) for marine mammals much of the time.

> It is extremely unlikely that injury would occur for any marine mammals or fish as a result of the continuous sound from the turbines.

> The maximum potential zone of disturbance around each WTG Unit due to continuous operational noise is estimated to be approximately 450 m for marine mammals and 15 m for fish.

> The snapping sounds that were recorded during the monitoring of the Hywind Demo have been assessed, although it is currently uncertain if they will also be associated with the Hywind Scotland Project. These sounds are impulsive in nature and, assuming that multiple WTG Unit could cause snapping sounds at the same rate under similar conditions, this could mean up to 115 snapping events per day, based on extrapolations from data measured at Hywind Demo in Norway.

> There is limited data presented in the reports for the Hywind I noise surveys regarding the snapping sound, resulting in considerable uncertainty in assessing the potential for these sounds to affect marine wildlife. Based on the information available, it is considered unlikely that the SEL criteria for injury to marine mammals will be exceeded, although there is a possibility that the peak pressure level criteria could be exceeded at very close range.

> In terms of disturbance from the snapping sound, it is estimated that the criterion for mild behavioural disturbance would be exceeded at a range of up to approximately 250 m (but a much smaller zone of potential strong behavioural disturbance of 30 m) from each turbine for marine mammals and 100 m for fish, although these are ballpark figures.

> The potential disturbance zone is unlikely to overlap spatially between the turbines given the proposed turbine spacing of 800 m – 1 km and the snapping sound, if it occurs at all, is unlikely to occur for all WTG Units at the same time.

> The use of vessels during the operations and maintenance phase of the project is unlikely to result in a significant impact because this area of the North Sea is already utilised by fishing and commercial traffic.

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