Hywind Scotland Pilot Park Project

Marine Noise Desk Study

Statoil ASA

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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. This 2.3 MW turbine, which has been tested and operated successfully for the last four years, has been verified as a technically viable concept. In order to continue towards achieving the long term vision for developing floating wind on a commercial scale, Statoil is planning to develop a number of Pilot Parks which will be used to demonstrate technological improvements, operation of multiple units, and cost reductions in a park configuration. Hywind Scotland is the first of the pilot parks to be taken forward for development.

The Hywind Scotland pilot park will consist of up to five turbines with a maximum installed capacity of 30 MW. The turbines will be located between 720 and 1,500 m apart and will be attached to the seabed by a three-point mooring spread. Depending on seabed conditions, the moorings will be secured with the most suitable type of anchor. The anchor types currently under consideration include torpedo anchors, suction anchors or weight anchors. The mooring lines are likely to be composed of chains with a diameter extending out from the Hywind turbines to approximately 800 to 1,000 m.

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 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 a high level overview of the potential impacts due to underwater noise from Hywind on the surrounding environment. In particular, this report reviews the underwater noise measurements and analysis previously undertaken by Statoil on the Hywind I demonstrator installed offshore Norway, to assess operational noise from the turbines. The report also makes recommendations for the types of impacts identified should be addressed in the EIA in terms of marine noise.

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. 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.

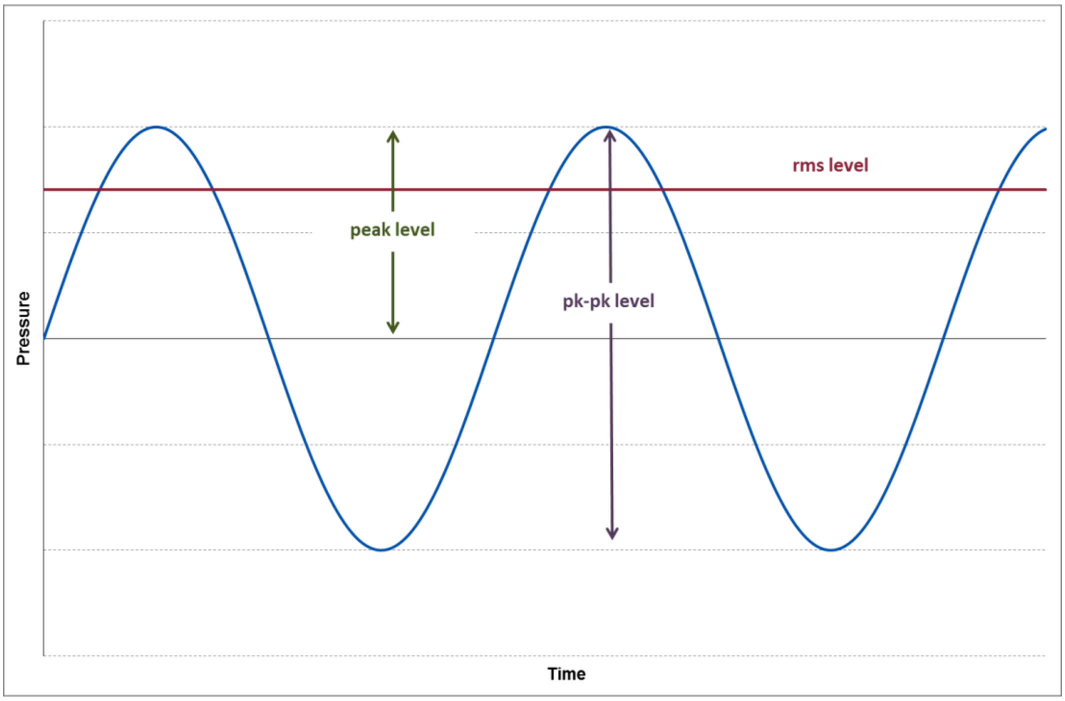

Figure 2.1 Graphical representation of acoustic wave descriptors

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[1].

The frequency, or pitch, of the sound is the rate at which these 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 faculty of marine mammals is not the same as humans, with marine mammals hearing over a wider range of frequencies and with a different sensitivity. It is therefore important to understand how an animal's hearing varies over the entire frequency range in order to assess the effects of sound on marine mammals. 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.)

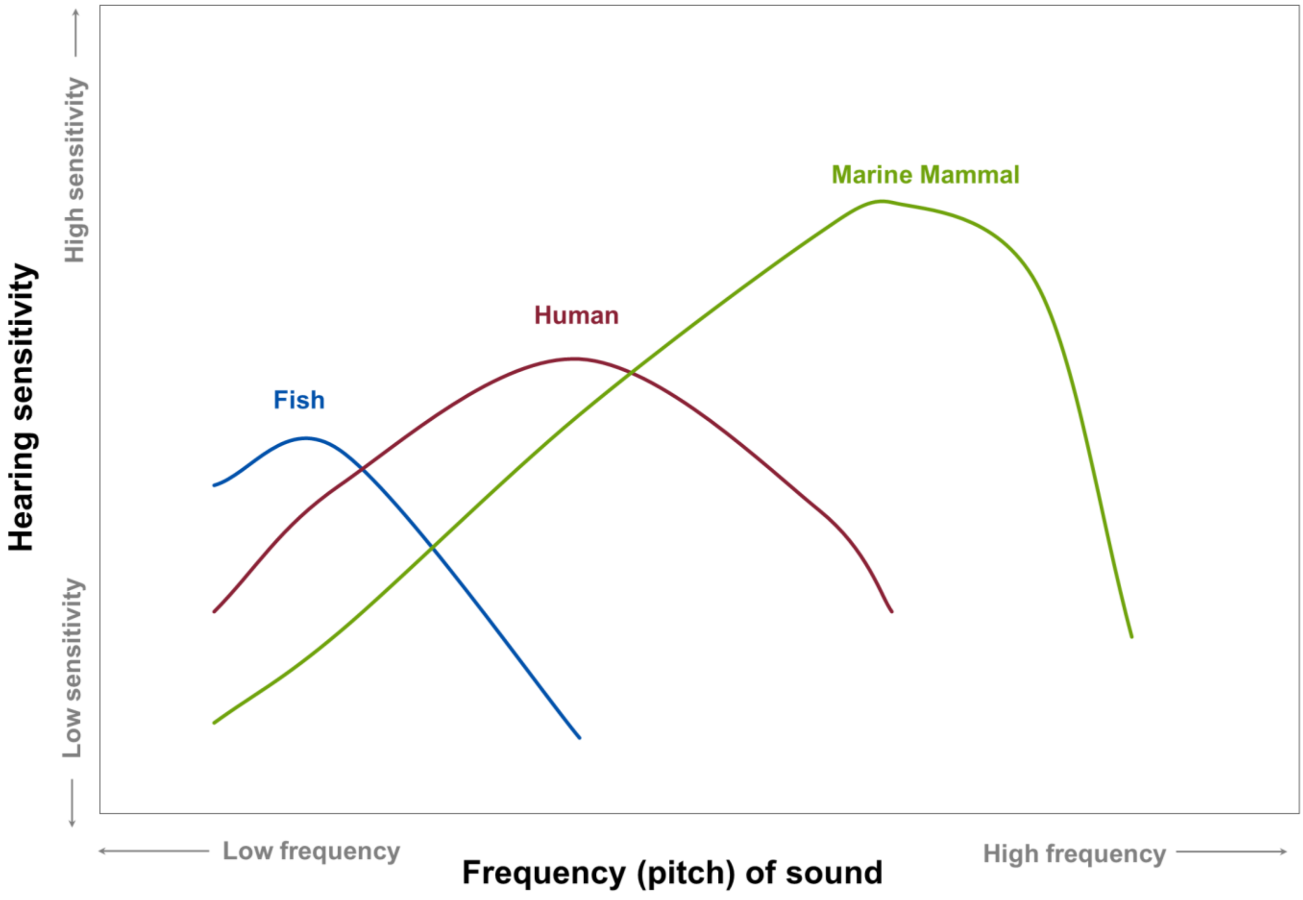

Figure 2.2 Comparison between hearing thresholds of different animals

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

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

3.1 Injury

A number of thresholds or methods for determining thresholds exist (e.g. the dB_{ht} method described by Nedwell et al. 2007) and each has advantages and disadvantages. For marine mammals, JNCC guidance recommends 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 where acoustic exposures can have auditory effects and is shown graphically in Figure 3.1.

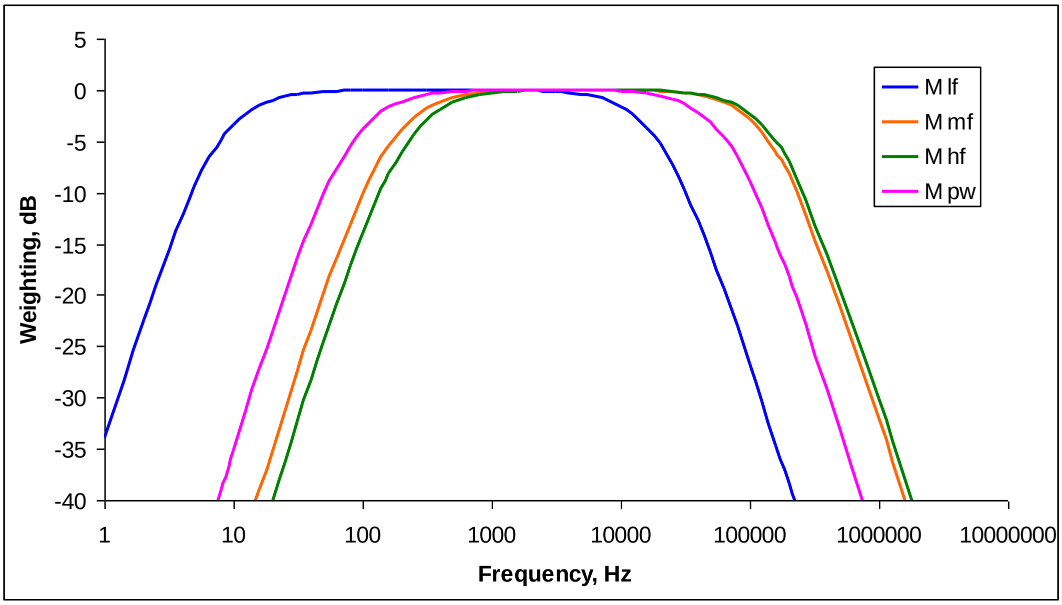

Figure 3.1 M-weighting functions for pinnipeds and cetaceans in water (lf = low-frequency, mf = mid-frequency, hf = high-frequency, pw = pinniped in water)

The proposed injury criteria for single and multiple pulses described by Southall *et al.* are a peak pressure level of 230 dB re 1 μPa and an M-weighted Sound Exposure Level (SEL) of 198 dB re 1 μPa^2s for all cetaceans. These injury criteria values are derived from values for onset of Temporary Threshold Shift (TTS) with an additional allowance of +6 dB for peak noise and + 15 dB for SEL to estimate the potential onset of Permanent Threshold Shift (PTS). The Southall document states that these thresholds represent suitable levels for a precautionary approach.

It has been reported by Lucke *et al.* 2009 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 dB re 1 μPa^2s (un-weighted). JNCC 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, 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). It is, however, difficult to derive equivalent SEL criteria using the Lucke study because the reported SELs are un-weighted, and not M-weighted as used in Southall. Nevertheless, assuming that the hf M-weighting correction is relatively small, this would result in a revised SEL criterion of 179 dB re 1 μPa^2s.

The proposed injury criteria relating to this project are summarised in Table 3.1.

Marine Mammal Group	Type of sound	Injury Criteria - underwater	
		Peak pressure, dB re 1 μPa	SEL, dB re 1 μPa^2.s (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	230	215
High-frequency cetaceans (other than harbour porpoise)	Single or multiple pulses	230	198
	Non-pulses	230	215
Harbour porpoise	Single or multiple pulses	200	179
	Non-pulses	200	196
Pinnipeds in water	Single or multiple pulses	218	186
	Non-pulses	218	203

Table 3.1 Suggested criteria for onset of injury criteria (per 24 hr period in water)

3.2 Mortality

Few data are available on the mortality of marine species, although there are generalised guidelines on the effects of transient pressure peaks (Parvin, Nedwell, and Harland 2007). These are classified as:

> Incident peak underwater sound levels > 260 dB re: 1 μPa (peak) - always lethal;

> Incident peak underwater sound levels > 240 dB re: 1 μPa (peak) - increased likelihood of death/ severe injury; and

> Incident peak underwater sound levels > 220 dB re: 1 μPa (peak) - direct physical injury may occur especially for repeated exposures.

3.3 Disturbance

Beyond the area in which injury may occur, the effect on marine mammal behaviour is the most important measure of impact. The JNCC guidance 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.

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 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 (2010) 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. operational noise, 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). This relates to a study involving migrating Gray whales. The only study for Minke wales 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). For White-beaked dolphin and Atlantic white-sided dolphin, 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, there are a number of individual response score 6 rankings ranging from 80 dB re 1 μPa (rms) and upwards, but there is a significant increase in the number of mammals responding once the received sound pressure level is greater than 140 dB re 1 μPa (rms).

The Southall *et al.* (2007) document presents a summary of observed behavioural responses due to multiple pulsed sound, although the data is primarily based on responses to seismic exploration activities. Although these datasets contain much relevant data for low-frequency cetaceans, there is 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 that is available for mid-frequency cetaceans indicates that some significant response was observed at an 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).

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 sound on marine mammals (HESS, 1997) concluded that behavioural disturbance would most likely occur at sound levels greater than 140 dB re 1 μPa (rms). This workshop drew on studies by Richardson *et al.* 1995 but recognised that there was some degree of variability in reactions between different studies and mammal groups. Although the workshop was concerned with the effects of seismic surveys, it is considered that the findings could be extended to include other types of sound, in the absence of any other strong evidence.

For assessing the likelihood of behavioural effects in fish, use can be made of the dB_{ht}(*species*) scale. This is simply a decibel scale reflecting the level above the hearing threshold (i.e. quietest perceptible sound) of that species. A typical scale for predicting the likelihood of disturbance is presented in Table 3.2.

Noise Level	Likelihood of disturbance
0 – 50 dB_{ht} (*Species*)	Low likelihood of disturbance
75 dB_{ht} (*Species*)	Mild avoidance reaction occurs in a majority of individuals
90 dB_{ht} (*Species*)	Strong avoidance reaction by most individuals

Table 3.2 Quantitative assessment of likelihood of disturbance

3.4 Summary of Suggested Criteria

The suggested criteria for assessing the effects of sound on marine mammals and fish are summarised in Table 3.3. The physiological damage criteria for marine mammals refer to those contained in Table 3.1.

Species	No effect	Mild behavioural disturbance	Strong behavioural disturbance	Physiological damage
Marine Mammals	No detectable change in ambient noise level	rms sound pressure level more than 140 dB re 1 μPa	rms sound pressure level more than 160 dB re 1 μPa	Exceeds Southall criteria for PTS
Fish	No detectable change in ambient noise level	75 dB_{ht} above species specific threshold of hearing	90 dB_{ht} above species specific threshold of hearing	Peak to peak sound pressure level more than 240 dB re 1 μPa

Table 3.3 Suggested criteria for assessing effects of sound on marine mammals and fish

4 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 the 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 4.1.

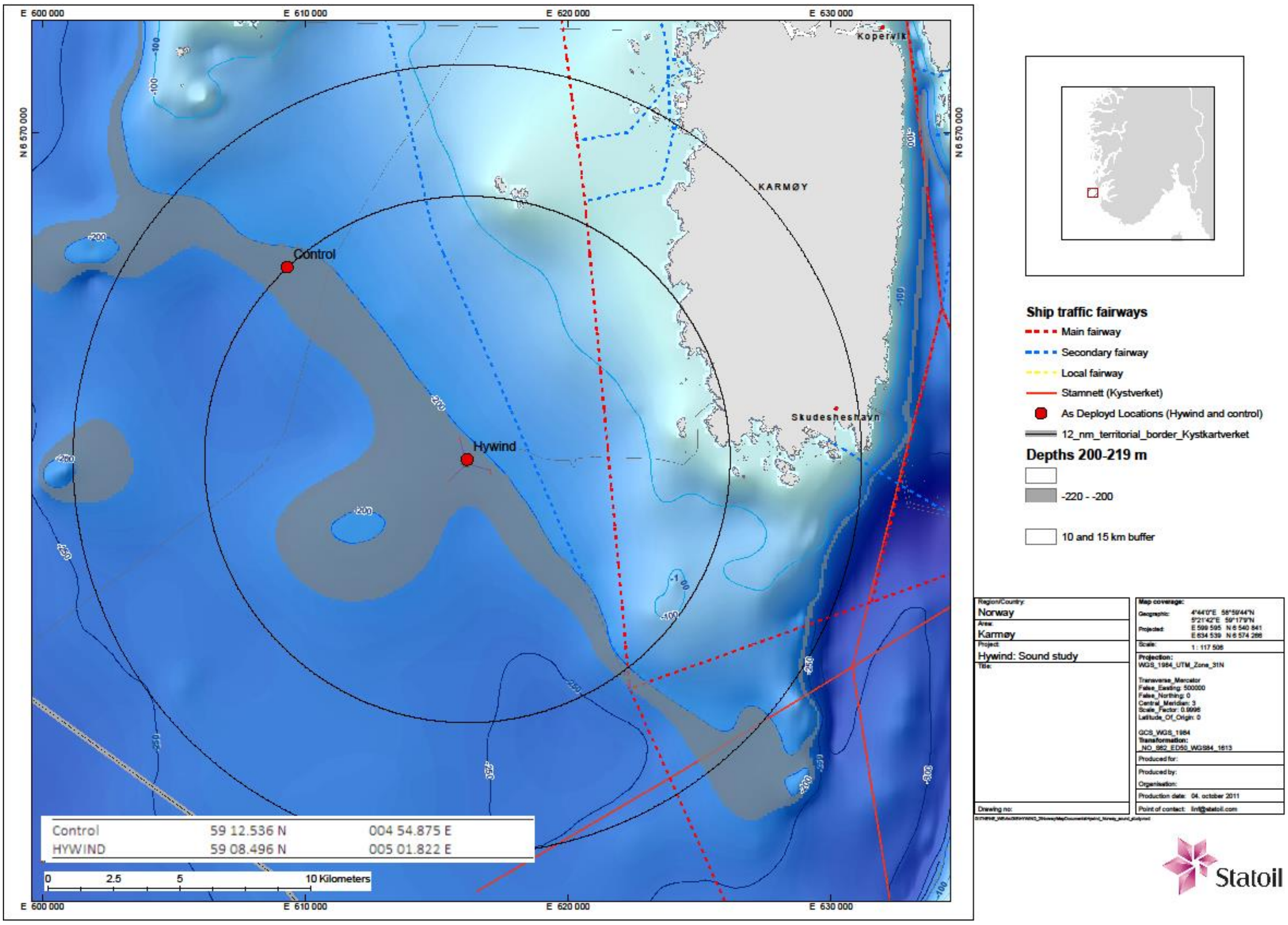

Figure 4.1 Location of the recording hydrophones for Hywind and Control.

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.

5 FURTHER ANALYSIS RELATING TO HYWIND SCOTLAND

5.1 Tonal Sound from Operation

The operation of the 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 turbine. If it is assumed that the turbines produce a similar level of noise over a 24 hour period then the daily cumulative sound exposure level (SEL) would be 168 dB re 1 $\mu Pa^2 s$ at 1 m

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 $\mu Pa^2 s$ at 1 m.

This would imply a potential zone of disturbance for marine mammals of approximately 10 – 15 m radius around each turbine, which is unlikely to be significant. It is extremely unlikely that injury would occur, even for harbour porpoise (which would need to remain in a radius of a few metres of the turbine for an entire day in order for it to be exposed to a sound exposure level in excess of the injury criterion).

It should be noted that the above analysis is approximate at this time and is based on the Hywind I turbine (i.e. a single 2.3 MW turbine). The Hywind Scotland project is likely to be larger in scale (up to five turbines with a maximum installed capacity of 30 MW) and this will need to be taken into account as part of the EIA.

5.2 Snapping Sound

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).

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.

The snapping sounds are impulsive in nature and it can therefore been assumed that the relationship between the various parameters will be similar to piling noise, which is also impulsive in nature and for which there is a good range of data available. Assuming a T90 time (i.e. the interval which contains 90% of the sound energy) of approximately 0.1 s, it is considered likely that the rms sound pressure level will be approximately 15 dB less than the peak sound pressure level. This would mean that the rms sound pressure level at 150 m would be 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 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 turbine. Assuming that multiple turbines could cause snapping sounds at the same rate under similar conditions, this could mean up to 140 snapping events per day (assuming 6 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 would be around 157 dB re 1 $\mu Pa^2 s$ at 150 m from the turbine. This is well below the onset criteria for injury to marine mammals. It is possible that the peak pressure level could exceed the injury criteria for harbour porpoise at very close range, although further analysis will be required to determine how likely this is to occur.

In terms of disturbance, it is estimated that the 140 dB re 1 μPa (rms) criterion for mild behavioural disturbance would be exceeded at a range of up to approximately 250 m from each turbine, although this is a ballpark figure at this time. The potential disturbance zone is 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 with a known regularity and are unlikely to occur for all turbines at the same time. It is therefore difficult to estimate the cumulative effect of multiple turbines. These issues will need to be considered in more detail for the EIA.

It must be emphasised that the above analysis is very approximate at this time due to the various unknown quantities and potential errors involved (unknown propagation correction, unknown rms to peak correction, unknown T90 time). It is therefore recommend that additional data analysis is undertaken including inspection of the time series to derive rms(T90) and SEL levels for snapping events.

It is understood that there are potential mitigation measures being investigated to reduce or eliminate the chain snapping sounds. This includes investigating the use of rubber coatings over the chains and use of fibre ropes as an alternative.

5.3 Construction and Installation

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 (especially if DP is required), seabed survey (e.g. sub bottom surveys) and potentially seabed preparation equipment, including use of equipment such as long baseline transponders if required.

If DP vessels are used, there is potential that the zone for disturbance to marine mammals could extend over several kilometres, but these will be temporary noise sources. It should be noted that there is considerable variation in noise signature and levels between different vessels and even for different operating conditions. Whilst it is possible to try to utilise quieter vessels for installation, experience shows that underwater noise data is not available for many survey and installation vessels.

It will be important to ensure that all construction and installation noise sources are taken into account in the EIA.

6 DATA REQUEST

In order to inform further analysis that will be required for the EIA the following additional data will be required.

6.1 Operational Noise Data Request

It will be important to obtain additional information and analysis relating to the snapping sound. The following information is requested:

> Time history data for the snapping events (preferably in numerical text format);

> Estimates of T90 times for the snapping events;

> $Rms_{(T90)}$ sound pressure levels for the snapping events;

> SELs for the snapping events, preferably presented in third-octave bands.

6.2 Construction and Assembly Noise Data Request

The following information is requested for the construction noise assessment:

> Construction and installation methodology;

> Construction and installation schedule;

> Details of potential vessels to be used including requirements for DP/thrusters;

> Details for any other sources of marine sound, such as transponders, seabed preparation etc.

It may also be necessary to assess the effects of airborne sound on marine mammals (e.g. otters, pinnipeds) and birds, especially for any cable landfall / pull ashore operations, if required. Airborne noise data for any equipment operating onshore or near-shore should therefore also be provided.

7 CONCLUSIONS

This report has presented an initial high level overview of potential impacts due to underwater noise during the construction and operation of the Hywind Scotland pilot park. In particular, this report reviews the underwater noise measurements and analysis previously undertaken by Statoil on the Hywind I demonstration unit to assess operational noise from the turbines and makes recommendations for how these should be covered as part of the EIA in terms of marine noise. It is concluded that:

- The potential zone of disturbance for marine mammals due to continuous operational noise is estimated to be approximately 10 – 15 m radius around each turbine (assuming a 2.3 MW turbine), which is unlikely to be significant.
- It is extremely unlikely that injury would occur for any marine mammals as a result of the continuous sound.
- The snapping sounds are impulsive in nature and, assuming that multiple turbines could cause snapping sounds at the same rate under similar conditions, this could mean up to 140 snapping events per day (assuming 6 turbines).
- There is a lack of 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, it is estimated that the criterion for mild behavioural disturbance would be exceeded at a range of up to approximately 250 m from each turbine, although this is a ballpark figure at this time.
- The potential disturbance zone is unlikely to overlap spatially between the turbines given the proposed turbine spacing of up to 1 km and the snapping sound is unlikely to occur for all turbines at the same time.
- 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 (especially if DP is required), seabed survey (e.g. sub bottom surveys) and potentially seabed preparation equipment, including use of equipment such as long baseline transponders if required.
- If DP vessels are used, there is potential that the zone for disturbance to marine mammals could extend over several kilometres, but these will be temporary noise sources.
- A data request has been provided to allow analysis of the above issues as part of the EIA.

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