9 POTENTIAL IMPACTS OF UNDERWATER NOISE AND VIBRATION

9.1 INTRODUCTION

This section presents:

- *a review of possible sources of underwater noise from the Demonstrator Project, and a summary of the planned duration of each activity causing noise*
- *a description of the method used to assess potential effects of noise on marine animals*
- *a quantitative assessment, using standard models and equations, of the noise levels to which marine organisms might be exposed during the installation and operation of the Demonstrator WTGs*
- *a summary of the mitigation measures that Talisman will employ to reduce further the potential effects of noise from different operations.*

Talisman recognise that there are uncertainties in the modelling of noise propagation underwater, and the precise way in which different species may react to various noises under different conditions (for example, ambient level and types of background noise, behaviour or activity of the individual immediately before exposure to the noise, and any level of conditioning that may have taken place in respect of an existing or previous noise). However, where there are uncertainties, Talisman has taken a precautionary approach in using conservative published data on, for example, peak hearing frequencies and threshold values. Talisman believes that the results presented in this section provide the necessary data to assess the potential effects of underwater noise from the project and how these effects might be mitigated.

9.2 SOURCES OF UNDERWATER NOISE FROM THE DEMONSTRATOR PROJECT AND KEY RECEPTORS

9.2.1 SOURCES OF UNDERWATER NOISE

Results from the scoping report and from the consultation programme indicate that underwater noise could arise from the following sources:

Noise generated by vessels during construction, installation and maintenance

During construction, varying levels of vessel noise would be present in and around the site for the months of June and July.

Noise generated by piling operations to fix the structures to the seabed

Pile-driving is expected to take less than two hours to drive each 1.8m diameter pile to the required depth. It is planned that two piles would be fixed each day, and that piling operations would last a maximum of four days. This results in a maximum total pile-driving time of 16 hours for both WTGs.

Noise generated by trenching operations to bury subsea cables

The umbilicals would be buried in late May or early June, in an operation that is planned to take about 12 hours total for both WTGs.

Noise and vibration generated by the turbines themselves when in use

The turbines would operate throughout the lifetime of the project, whenever meteorological conditions were suitable.

9.2.2 KEY RECEPTORS

From a consideration of the environmental sensitivities of the Demonstrator site (Section 4), the key marine species that would be exposed to underwater noise are bottlenose dolphins, harbour porpoise, the grey seal, the common (or harbour) seal, minke whale and salmon. This section, therefore, focuses on potential effects on these species. Bottlenose dolphin may be present around the Demonstrator site (Section 4.6) and a precautionary approach has been used by modelling noise effects for dolphins using the audiogram for bottlenose dolphin.

9.3 METHOD USED TO ASSESS NOISE EFFECTS

9.3.1 HEARING IN MARINE MAMMALS AND FISH

Marine mammals and fish use underwater noise in a wide variety of ways, to gather information about their environment, and to communicate with other individuals of their own species (for a review see Richardson *et al.,* 1995). Many species of both groups are able both to detect underwater noises and to produce underwater noise of their own.

The hearing ability of marine organisms is commonly expressed by means of an audiogram. This is a plot of the species' threshold hearing level for different frequencies, and indicates (a) the range of frequencies that a species can detect; and (b) the frequency range over which the species' hearing is most acute. Audiograms have been obtained for a number of species (Vella *et al.,* 2001; Popper *et al.,* 1998; Richardson *et al.,* 1995), and work is going on to obtain more detailed information (Nedwell and Howell, 2004). Table 9.1 shows the audible frequency ranges for some of the marine mammals and fish that may be present at the Demonstrator site, and indicates the threshold value at the peak frequency (i.e. the frequency at which their hearing is most acute).

Table 9.1 Hearing characteristics of some species of fish and mammals likely to be present at the Demonstrator site. (Data from Nedwell et al., 2004b; Nedwell and Howell, 2004; Richardson et al., 1995; Ketten, 1998).

Species	Hearing range (Hz)	Approximate peak frequency (Hz)	Threshold at peak frequency dB re 1μPa*
Bottlenose dolphin	100–300,000	50,000–80,000	40–50
Harbour porpoise	200–200,000	100,000–200,000	30–60
Grey seal	200–200,000	20,000–30,000	61–70
Common seal	100–200,000	7,000–30,000	63–67
Killer whale	500–200,000	10,000–30,000	30–45
Mysticetes (baleen whales)	15–30,000	400	–
Risso's dolphin	2,000–110,000	8,000–30,000	64–67
Cod	10–800	20–100	63–95
Dab	20–300	110	89
Haddock	30–500	100–300	80–85
Herring	20–4,000	50–200	75
Ling	40–600	200	81
Pollack	40–500	200–300	92–93
Atlantic salmon	30–400	160	95
Little skate	100–1000	200	123

* *Values rounded*

9.3.2 APPLICATION OF THE dB_{ht}*(species)* CONCEPT

Each species' sensitivity to a noise depends on its frequency, and the minimum noise level they are able to hear (the threshold) varies with the frequency of the noise. Nedwell and Turnpenny (1998) have therefore proposed the use of a weighted measure dB_{ht}*(species)* which models the noise level that a species would experience. The dB_{ht}*(species)* value for each species is a function of its sensitivity to noise, as derived from its audiogram; ht refers to the "hearing threshold" of the species which reflects a particular species' ability to detect sounds at different frequencies. It is argued that the application of this measure permits proper examination of the true likely effect of external noises on marine mammals and fish.

The noise level that may be perceived by a particular species can be calculated by applying the dB_{ht} "filter" – a correction factor – to the source noise level at different frequencies. The correction factors can be derived from the species' audiogram.

9.3.3 EFFECTS OF UNDERWATER NOISE

There is a considerable body of literature studying the different threshold levels for different species (for a review see Richardson *et al.,* 1995; Nedwell and Howell, 2004). The effects of underwater noise on marine mammals and fish vary depending on the received noise level, and the literature typically quotes five different levels of response (Vella *et al.,* 2001; WDCS, 2004):

- *a detection level – the noise level that the species would normally be able to detect in a quiet sea state*
- *an avoidance level – the noise level at which the species would start to exhibit active avoidance behaviour, such as swimming away, in order to avoid the noise level that it was experiencing*

- *a temporary hearing damage level – the noise level that would cause a temporary but reversible shift in the individual's hearing sensitivity*
- *a permanent hearing shift level – the noise level that would cause a permanent shift in the individual's hearing sensitivity*
- *a physical damage level – the noise level or pressure level that would result in gross physical damage to the organism's auditory system, other organs or tissues.*

9.3.4 SELECTION OF THRESHOLD LEVELS FOR ASSESSING POTENTIAL EFFECTS AT THE DEMONSTRATOR SITE

For the purposes of managing the potential effects of underwater noise as a result of the proposed Beatrice Demonstrator Project, Talisman focused on determining which activities might produce noises loud enough either to result in an animal displaying a "strong avoidance reaction", or to cause a temporary change in hearing ability (or "temporary threshold shift" (TTS)).

The threshold for strong avoidance reaction was selected because it is the lowest level at which overt behavioural changes occur in the animals which might be exposed to underwater noise, and there are data in the literature for this threshold level for different species. The threshold of temporary change in hearing ability was selected because it is the least damaging physical effect, and would be found over the largest area. It is therefore the most precautionary physical threshold and, again, there are data in the literature for this threshold level for different species.

Avoidance reaction

From a review of the available literature, Nedwell and Howell suggest that a behavioural response in a marine organism would be elicited if the dB_{ht}*(species)* noise level was greater than 90dB (Nedwell *et al.,* 2004a). At this noise level, individuals have been found to show an avoidance reaction, typically swimming away from the source of noise. Some individuals would express avoidance reaction beyond this range, but on the basis of available evidence this is the distance at which this species might be expected to exhibit avoidance. For the purposes of determining potential effects on marine organisms from the Demonstrator Project, therefore, the $90dB_{ht}$*(species)* value has been taken as a threshold.

Temporary change in hearing ability

When an animal is exposed to a loud noise for a period of time, the acuteness of its hearing may be temporarily diminished, i.e. it may be unable to detect noise levels that it would normally be expected to hear. This phenomenon is reversible (or disappears) some time after the animal is removed from the loud noise source. In a review of threshold levels, Ketten (1998) concluded that a noise level of 140dB, that is also 80-90dB above the species hearing threshold at each frequency, is necessary to produce a significant temporary change in hearing ability.

9.3.5 MODELLING UNDERWATER NOISE LEVELS AND THEIR EFFECTS

The noise levels that might be found in the water column at different distances from the Demonstrator site have been predicted by modelling the propagation of sound in water. The model used was the Source Level – Transmission Loss model described by Nedwell and Howell (2004). This method uses the following expression:

$$SPL = SL - TL$$

where SPL is the Sound Pressure Level, SL is the Source Level and TL is the Transmission Loss, all of which are measured in dB. The Source Level refers to the level of sound measured at one metre from the noise source, expressed in dB re 1 μPa @ 1m.

As an acoustic signal travels through the ocean, it becomes distorted as a result of multi-path effects, and weaker because of various loss mechanisms (Jensen *et al*, 1994). The standard measure of the change in signal strength in underwater acoustics is called Transmission Loss. This is calculated as the sum of a loss due to geometrical spreading and a loss due to attenuation, and can be expressed as follows:

$$TL = N \cdot \log(r) - \alpha \cdot r$$

where N is the coefficient relating to geometrical spreading, r is the range, i.e., the distance from the noise source, and α is the absorption coefficient.

The equations used also take into account the spreading loss, a measure of the way in which the signal weakens as it propagates outward from a source. There are two main geometrical spreading laws to be considered in underwater acoustic modelling – spherical spreading and cylindrical spreading – (Jensen *et al.,* 1994; Richardson *et al.,* 1995). It is generally considered that cylindrical spreading would occur in water depths of less than 200m (Jensen *et al.,* 1994) and in these circumstances it is appropriate to use a value of N=10 from transmission loss in the above equation.

The model was also used for assessing the propagation of noise caused by different noise sources, which could be situated at the same or different location. If the difference between the two noise levels is great, then the lower noise level will contribute very little

Table 9.2 Approximate values for determining the combined noise level from two noise sources (Norton, 1989).

Difference between two source pressure levels (dB)	Value to be added to the higher SPL (dB)
0–1	3
2–3	2
4–9	1
>10	0

The sound propagation modelling methodology used did not take into account the variations of the speed of sound in seawater with varying temperature, salinity and hydrodynamic pressure. Other factors affecting underwater sound propagation such as noise source depth, bathymetry, type of seabed or interactions with the seabed and the sea surface were not considered.

9.4 ASSESSMENT OF THE POTENTIAL NOISE EFFECTS OF UNDERWATER PILING

9.4.1 INTRODUCTION

Using the equations described in Section 9.3.5, modelling was carried out for source noise levels at several different frequencies, in order to assess the maximum size of the areas in which the different species might be exposed either to a noise level that resulted in an avoidance reaction, or to a level that caused a temporary change in hearing ability. Care was taken to ensure that both peak frequencies for the source noise level, and peak frequencies for the species hearing ability, were examined.

9.4.2 SOURCE AND CHARACTER OF NOISES FROM UNDERWATER PILING OPERATIONS

The piling operations for the two WTG substructures will require the use of a piston-type hammer (as opposed to a rotary-type), delivering repeated blows to a 1.8m diameter open-ended steel pile, being driven into sands and clays in a water depth of 45m. Piling operations at the Demonstrator site will therefore be more similar to the routine piling undertaken by the offshore oil and gas industry, rather than to the piling of large diameter monopile towers for nearshore wind farms. As described in Section 3.3.6, it is anticipated that it will take no more than two hours to drive each pile, and that two piles can be fixed each day. Piling noise might therefore be generated for a total of about four hours on four consecutive days.

Piling operations create underwater noises of a frequency and level that are audible to seals, toothed and baleen whales, and fish (Richardson *et al.,* 1995; Nedwell and Howell, 2004; Nedwell *et al.,* 2004a). Noise from piling can enter the marine environment by four pathways; the most significant pathway is thought to be by transmission of vibration through the pile itself directly into the water column. The noise produced during piling is dependent on several factors including the type of equipment used, the water depth, and the characteristics of the seabed (Nedwell *et al.,* 2001; Nedwell *et al.,* 2004a).

9.4.3 SOURCE NOISE LEVEL FOR PILING AT THE DEMONSTRATOR SITE

There are no specific measurements available for the noise that would be produced during operations to fix 1.8m diameter piles in a sand/clay seabed in a water depth of 45m. From noise measurements taken under different circumstances, however, there appears to be a correlation between the diameter of the pile or monopile being driven and the Source Noise Level (Nedwell, Workman and Parvin, 2005). The best fit line shows SL = 24.3D +179dB re 1μPa @1m, where D is pile diameter in metres, and this would suggest that the source noise level for a 1.8m diameter pile might be about 225dB re 1μPa @ 1m.

The frequency profile for piling noise is rather "flat" with no obvious peak, but maximum pressure levels are attained over the range 300^{-1},000Hz (Figure 9.6), which overlaps the hearing range of the key species under consideration.

During piling the noisiest vessel that is likely to be under way and in close proximity to the piling operations would be a supply vessel. The difference between the source level noise for piling (225dB) and source level noise for a supply vessel (164dB) is more than 10dB, so the presence of this additional noise source would make no contribution to the total source noise level at the site.

9.4.4 ESTIMATED RECEIVED NOISE LEVELS FROM PILING AT DEMONSTRATOR SITE

The potential effect of a piling noise of SL 225dB was examined by modelling the extent of the zone in which an avoidance reaction might be elicited, and the extent of the zone in which temporary change in hearing ability may be caused. Different frequencies were modelled to determine the largest extent of each zone, depending on the species' hearing ability.

Extent of zone for avoidance reaction

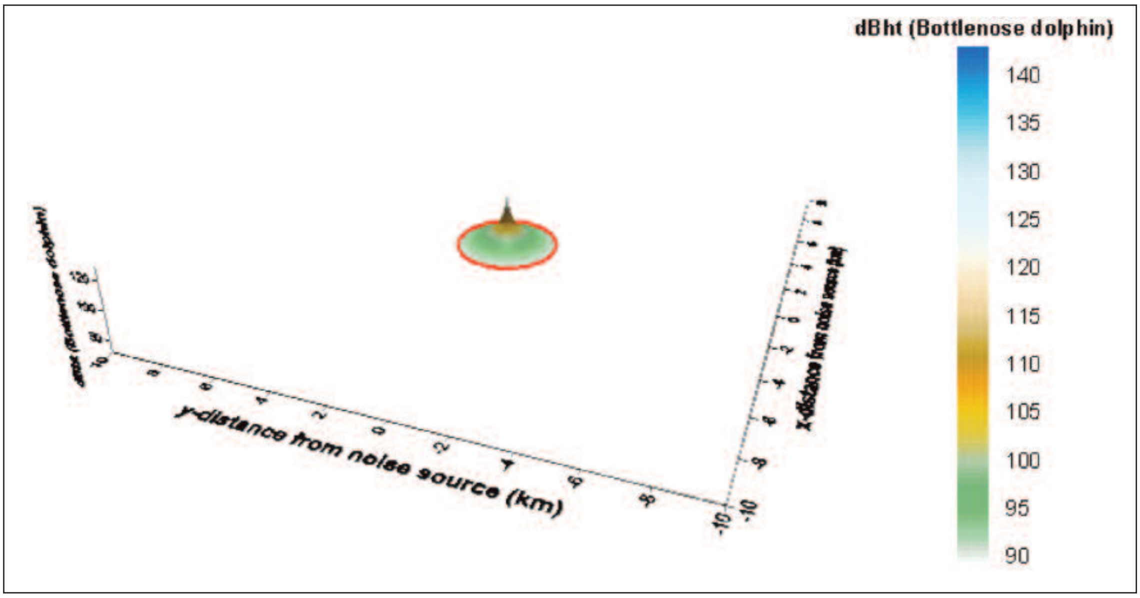
The extent of the avoidance zone was set at a perceived noise level of 90dB$_{(ht)}$ (Section 9.3.4). The significant frequencies, and the equivalent 90dB$_{(ht)}$ distances for the species examined are given in Table 9.3.

Table 9.3 Radius of maximum area for >90dB$_{(ht)}$ noise levels, and corresponding frequency, for selected species exposed to source noise level of 225dB from piling operations at Demonstrator site.

Species	Frequency (Hz)	Radius (km)
Bottlenose dolphin	1,000	2.0
Harbour porpoise	1,000	9.3
Common seal	1,000	7.5
Minke whale	400	33.0
Salmon	160	2.2

The model was also used for assessing the propagation of noise caused by different noise sources, which could be situated at the same or different location. If the difference between the two noise levels is great, then the lower noise level will contribute very little to the total noise level, as illustrated by the guide values given in Table 9.2.

Figure 9.1 The extent of the avoidance zone (>90dB$_{(ht)}$) for bottlenose dolphin exposed to a source noise of 225dB at 1,000Hz.



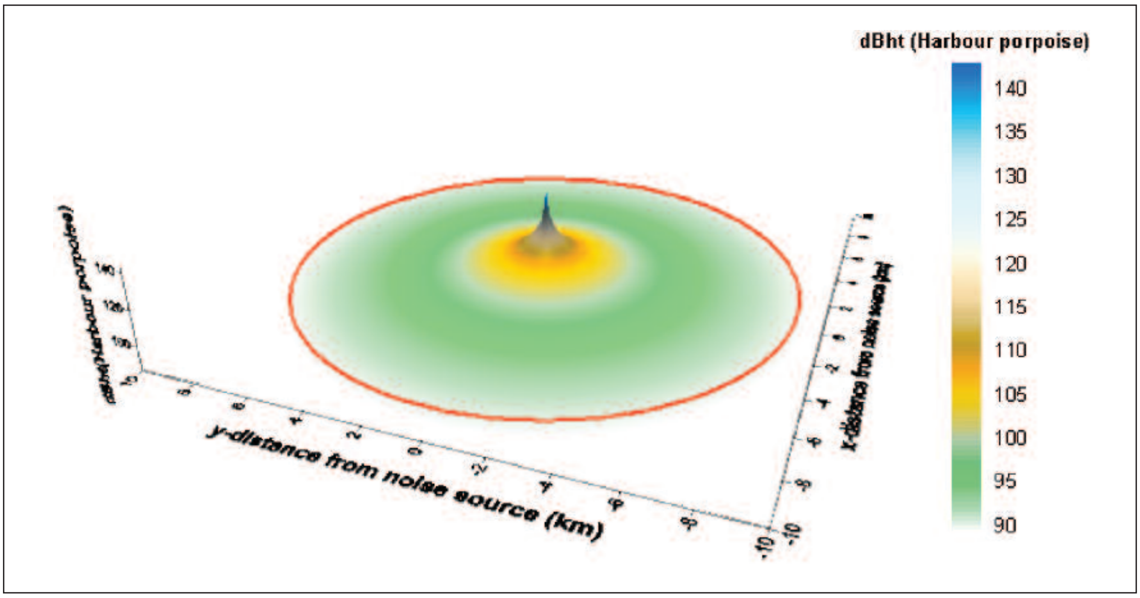


Figure 9.2 The extent of the avoidance zone (>90dB$_{(ht)}$) for harbour porpoise exposed to a source noise of 225dB at 1,000Hz.

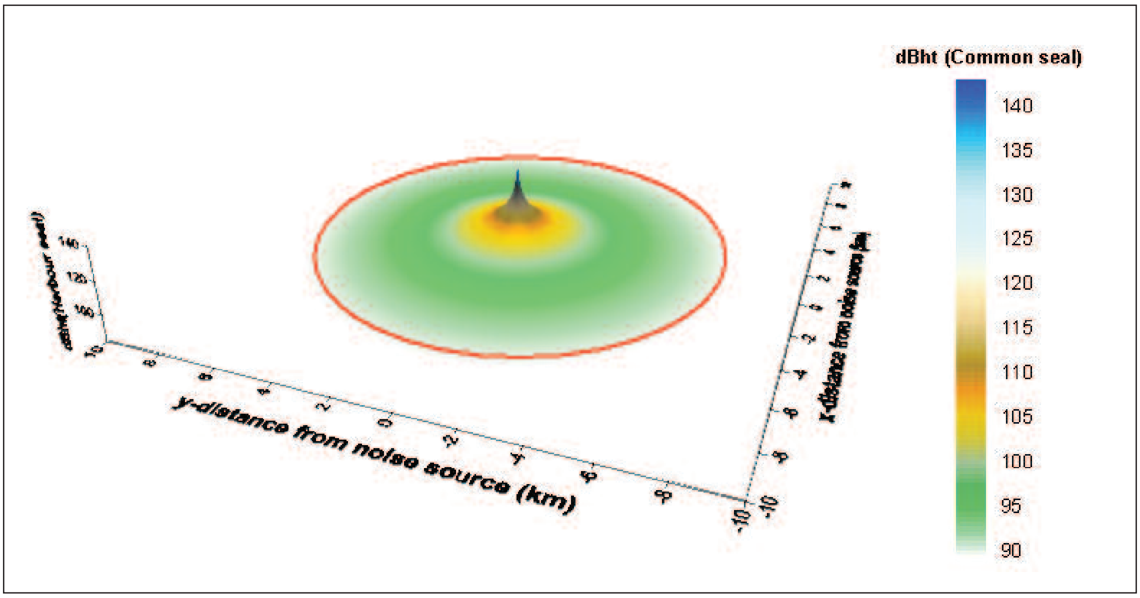


Figure 9.3 The extent of the avoidance zone (>90dB$_{(ht)}$) for common seal exposed to a source noise of 225dB at 1,000Hz.

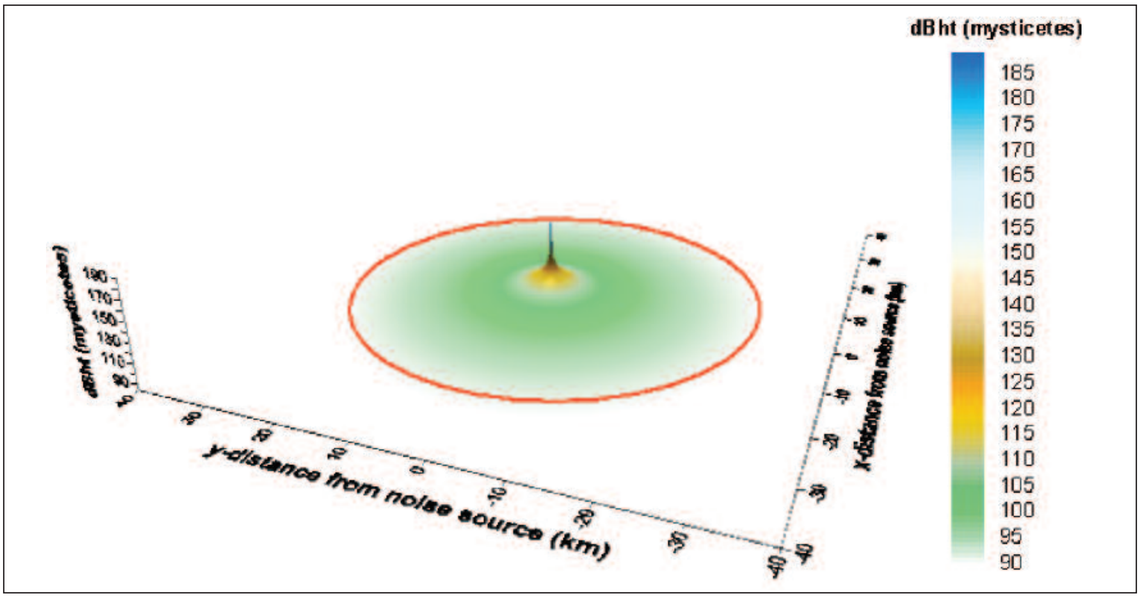


Figure 9.4 The extent of the avoidance zone (>90dB($_{ht}$)) for minke whale exposed to a source noise of 225dB at 400Hz.

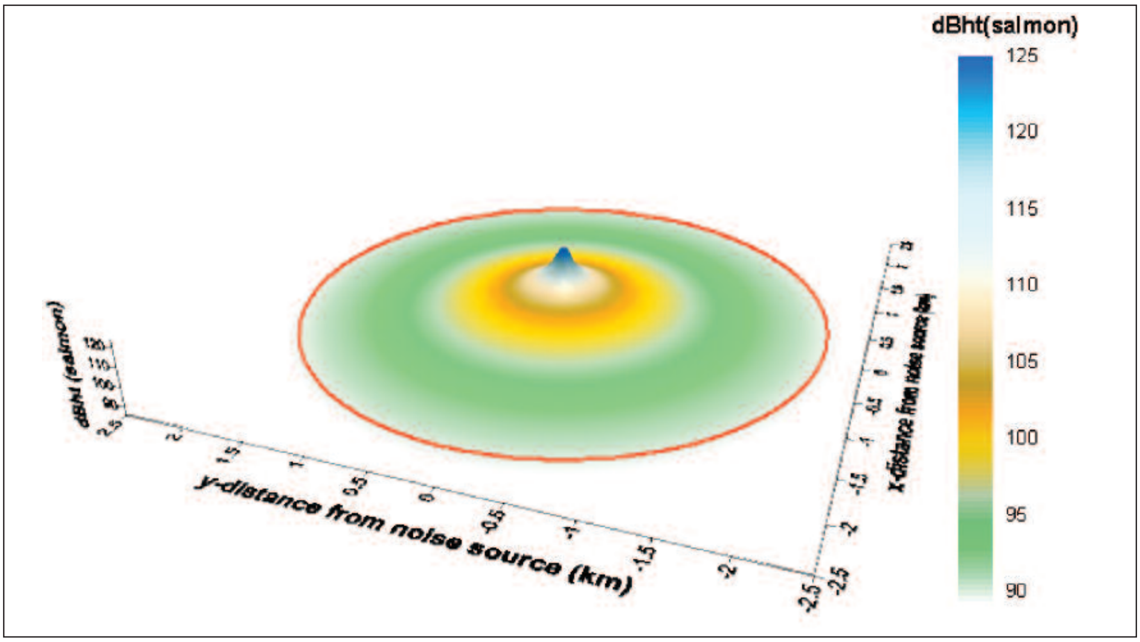


Figure 9.5 The extent of the avoidance zone (>90dB($_{ht}$)) for salmon exposed to a source noise of 225dB at 160Hz.

Extent of zone in which temporary change in hearing ability might occur

When examining noise propagation within 10km of a source, the noise attenuation due to absorption can be ignored (Nedwell *et al.,* 2003) so the equation for noise propagation can be simply expressed as:

$SPL(r) = SPL(source) – N \log(r)$, where r is the distance from the source and N is the transmission loss coefficient, in this case with a value of 22 (Nedwell *et al.,* 2003 for piling noise).

The propagation of the noise generated at several different frequencies was modelled for each species, using this equation, to estimate the maximum area of the zone in which temporary change in hearing ability might occur. The results of these assessments are shown in Figure 9.6 which shows:

- *the frequency profile for the pile source noise, peaking at 225dB around 300Hz*
- *the predicted profiles for temporary change in hearing ability (TTS) for bottlenose dolphin, harbour porpoise and common seal*
- *the predicted noise level from piling at a distance of 0.5km from source*
- *the predicted noise level from piling at a distance of 1km from source.*

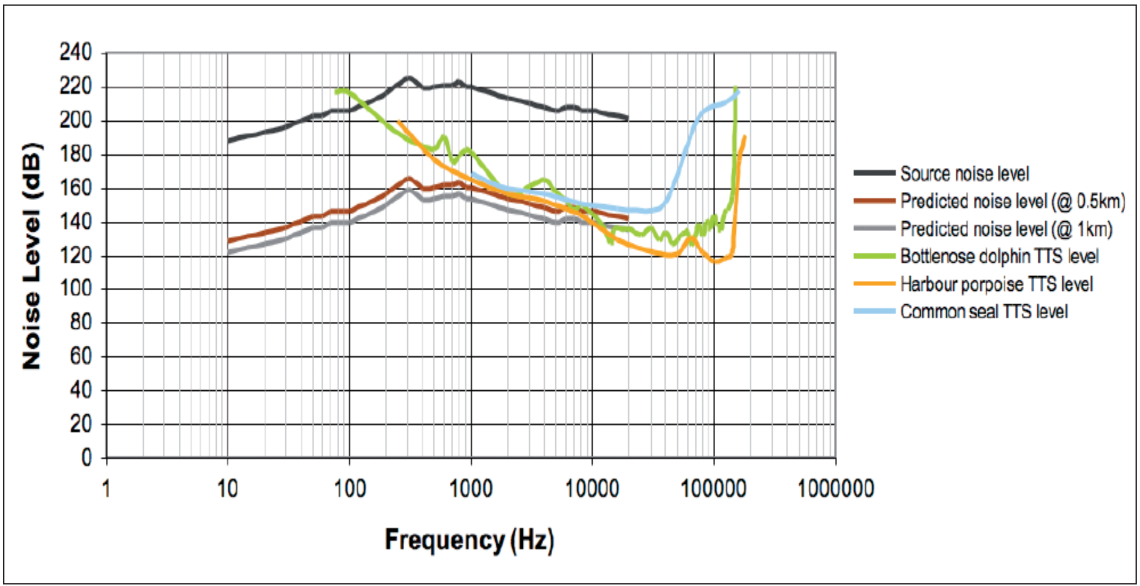


Figure 9.6 Piling noise and predicted noise level at two distances from source, in relation to predicted profiles for temporary change in hearing ability for selected species.

Figure 9.6 shows that at a distance of 500m from the source, for all three species, the predicted noise for frequencies below 5,000Hz falls below the level at which temporary change in hearing ability might occur. At frequencies above 5,000Hz, the predicted noise level exceeds the level at which temporary change in hearing ability might occur for bottlenose dolphin and harbour porpoise.

At a distance of 1km from the source, for all three species, the predicted noise for all frequencies below 10,000Hz falls below the level at which temporary change in hearing ability may occur. At this distance, noises at frequencies above 10,000Hz are predicted to reach a level that would cause temporary change in hearing ability for bottlenose dolphin and harbour porpoise.

A similar assessment for minke whales shows that the level that might result in temporary change in hearing ability is just reached, at a distance of about 0.4km from the source, at a frequency of about 400Hz.

9.4.5 PUBLISHED DATA IN RESPONSES TO UNDERWATER NOISE FROM PILING

The perceived noise levels from piling operations exceed ambient noise levels and are inevitably detectable by marine mammals. The responses of marine mammals to sounds of different noise levels are summarised in Section 9.3.3. Loud noises are potentially physically damaging to marine mammals if individuals are in close proximity to the source when piling operations begin.

Few marine mammals are exposed to the full force of underwater piling noise because of the range of mitigation measures enacted by piling operations associated with wind farms. Attention has focused on displacement and behavioural responses, and most studies have shown that with regard to noise from installation operations, these effects are likely to be temporary and localised, even though evidence suggests that marine mammals would be able to hear piling noise over a large area (Laidre *et al.,* 2001). Monitoring studies conducted for the Horns Rev offshore wind farm found that harbour porpoises returned to the area quickly after cessation of the noise (Tougaard *et al.,* 2003). This temporary displacement of marine mammals, however, may have been exacerbated by the displacement of their food source. At the Horns Rev project, it was found that more seals entered the water during piling than during periods without piling, but this may have been because the seals were taking advantage of local fish mortality caused by the piling. A Danish summary paper (Gastrup *et al.,* 2000) on the first four offshore wind farms in Denmark speculates that the effect of piling noise on marine life is short-term avoidance, and that there are no long-term effects directly linked to the construction phase.

Noise levels from underwater piling have been shown to induce avoidance reactions, injuries and even mortality in fish (Nedwell *et al.,* 2004). Further research undertaken indicated a lack of reaction to piling noise and it was demonstrated that piling activities only affected fish behaviour within a radius of 600m (Nedwell *et al.,* 2003; Feist *et al.,* 1996). Anderson (1992) reports similar results, and also observed that habituation to piling occurred almost immediately.

9.4.6 PROJECT MITIGATION MEASURES FOR PILING NOISE

Table 9.4 summarises the predicted extent of areas in which an avoidance reaction, and a temporary change in hearing ability, might be expected, for each of the species exposed to the predicted piling noise.

Table 9.4 Estimated maximum radius for zones of avoidance reaction, and temporary change in hearing ability, for selected species exposed to 225dB source noise from piling operations at the Beatrice wind farm Demonstrator site.

Species or group	Estimated maximum radius (km)	
	Avoidance reaction	TTS
Bottlenose dolphin	2.0	1
Harbour porpoise	9.3	1
Common seal	7.5	<1
Minke whale	33.0	0.4
Salmon	2.2	<0.1

Talisman will develop a project-specific environmental protection plan outlining the mitigation measures to be used during piling. This will include a series of mitigation measures based on the principles in the JNCC 'Guidelines for Minimising Accoustic Disturbance from Seismic Surveys', specifically:

- *reduce the source level of piling noise, if possible, using physical barriers*
- *use marine mammal observers and passive acoustic monitoring to ensure as far as possible that no marine mammal is within 1km of the site before piling starts*
- *use a "soft start" technique to alert marine mammals in the immediate vicinity (for example within 10km) to the commencement of the piling operations.*

It may be possible to use various physical devices to reduce the level of noise from piling. Such systems can reduce the source noise level in the water column; and reductions of 3dB to 10dB are claimed (Nedwell *et al.,* 2003). Talisman is currently exploring opportunities for physical noise mitigation, and how to overcome the technical and logistical problems of deploying such arrangements in 45m of water offshore. Clearly, even a reduction of a few dB at source reduces the radius of the zones of effect estimated in the modelling.

The focus of the project's mitigation measures will be firstly, to ensure that no marine mammal is present within 1km of piling operations, and secondly, that individuals present in the zone where perceived noise levels might be expected to cause strong avoidance reactions are encouraged to move further away.

Talisman will follow the principles of the JNCC guidelines for minimising the acoustic effects of seismic operations on marine mammals. Independent marine mammal observers will be present offshore throughout the piling programme. Before operations begin, the area within 1km of the site will be carefully surveyed to ensure that there are no marine mammals present. Piling will not be started during darkness. The environmental protection plan will be based on similar plans produced and operated by Talisman (Talisman, 2000) and will identify clear actions to be taken if marine mammals are detected before and during all operations.

Before full piling operations begin, a "soft start" will be implemented, whereby the force of piling is gradually increased, steadily raising the underwater noise level over a period of time. This will alert animals located more than 1km from the site to the piling activities, without exposing them to more intense levels of noise, and provide an opportunity for them to move away from the noise source.

9.4.7 CONCLUSIONS FOR EFFECTS OF PILING NOISE AT DEMONSTRATOR SITE

Marine mammals located within the Moray Firth SAC are not likely to experience noise levels above 90dB($_{ht}$) from pilling that would elicit an avoidance reaction. The boundary of the SAC is about 25km from the Demonstrator site, and a source noise of 225dB will have fallen to about 160db at this distance, giving dB$_{ht}$*(species)* levels of approximately 60-80dB at 300Hz for both bottlenose dolphin and harbour porpoise.

It is therefore concluded that, with the mitigation measures in place, some cetaceans and pinnipeds at distances of 1km to 9km from the site might be exposed to non-damaging noise levels above the 90dB($_{ht}$) threshold. These individuals are likely to display varying degrees of avoidance behaviour, and are likely to swim away from the source of the noise. Marine mammals exposed to noises of less than 90dB$_{ht}$*(species)* would be expected to stay away from the source of noise, and not swim closer to it. All species of marine mammal that may be displaced during piling operations would be expected to return to the area very soon after piling ceased, and to resume their normal pattern of visits to the Beatrice area.

Therefore, given the relatively short duration of pile driving operations (16 hours in total) and hence the short exposure time for marine mammals, we consider that the worst effects of the likely underwater noise (a temporary change in hearing ability that would be confined to an area within 1km of the site), can be avoided through the application of the proposed mitigation measures outlined in this section.

It is likely that some fish will be exposed to high levels of noise, and those within about 60-80m of the site may be injured or killed (Nedwell and Howell, 2004). However, at distances of more than about 100m, physical injury is less likely and most species would display an avoidance reaction.

9.4.8 POTENTIAL COMBINED EFFECTS OF NOISE FROM OTHER OFFSHORE ACTIVITIES IN THE MORAY FIRTH

The Moray Firth is an active area for oil and gas exploration and development. Underwater noise may be generated by other projects using vessels, drilling, or piling structures to the seabed. It is possible that seismic surveys may be conducted in parts of the Moray Firth in 2006 as a result of new licence awards made in the 23rd licensing round. Such surveys are subject to licensing, and strict controls are put in place to minimise effects of marine life.

Seismic surveys use short pulses of high-energy, low frequency sound which are emitted by a towed array of air-guns. Large areas of sea may be covered during seismic surveys, which typically last 30-90 days. Firing normally occurs at intervals of 10-15 seconds, continuously day and night, with breaks only for bad weather and making line turns.

Talisman understands that while other operators may be planning such surveys in the Moray Firth for 2006 it is unlikely that they would take place at the same time as the proposed piling operations, because of possible interference with seismic signals. Piling noise from the Demonstrator site would, therefore, not be additive to possible seismic noise. The proposed operations at the Demonstrator site would be of very short duration in comparison to a seismic programme, and so it is unlikely that the piling noise would result in a cumulative effect on marine life.

9.5 ASSESSMENT OF THE POTENTIAL NOISE EFFECTS OF VESSELS DURING INSTALLATION

9.5.1 SOURCE AND CHARACTER OF NOISES FROM VESSELS

Several different types of vessel will be used at the Demonstrator site during the installation programme (Section 3). All would be typical of the vessels routinely used in the UK North Sea for oil and gas operations and other activities.

The underwater noise that is produced by vessels arises from two sources – propeller cavitation and the propulsion machinery inside the vessel. Vessel noise may be considered to be a continuous, rather than transient noise source, which is a combination of broadband noise and tonal sounds at specific frequencies. Table 9.5 summarises published data on the sound source levels and frequencies for the types of vessels that would be used during the installation programme. Where no data exist for a specific type of vessel, data from a vessel of similar size and power to that proposed for the Demonstrator Project are given.

Table 9.5 Sound frequencies and source levels produced by the types of vessel that will be used for installing the WTGs. (Richardson et al., 1995; Heathershaw et al., 2002; Hildebrand, 2004; WDCS, 2004).

Vessel Type	Frequency (kHz)	Source Level (dB re 1μPa @ 1m)
Fishing boat for seabed sweep	0.25 –1.0	151
Tug (pulling empty barge)	0.037–5.0	145–166
Tug (pulling loaded barge)	1.0–5.0	161–170
Pipelaying vessel using dynamic positioning (DP)	0.05->1	177
34m twin diesel work boat	0.63	159
Supply vessel supplying the platform or HLV	0.1	164

9.5.2 PREDICTED NOISE LEVELS FROM THE VESSEL SPREAD AT THE DEMONSTRATOR SITE

The noise that will be generated by the vessel spread will be determined by the types and numbers of vessels that are present at the site at any one time. Because the decibel scale used to measure sound is a logarithmic scale, the presence of several sources of noise at any location at any one time leads to only a small increase in the total source level of noise at that site. For example, a tug creating 170dB and a supply vessel creating 164dB, if operating in close proximity to each other could be viewed a constituting a single noise source with a level of 170 + 1 = 171dB.

For the Demonstrator Project, examination of the proposed installation schedule shows that there would be a maximum of two vessels that would be likely to be working (under way) in close proximity to each other at any one time. The potentially noisiest realistic combination of vessels would be the pipelaying vessel on dynamic positioning (DP) and an attendant supply vessel. Noise from both vessels has a similar frequency spectrum, and the total noise created would be some 177+0=177dB. This scenario was therefore used to model potential noise impacts from vessels at the site. Other scenarios involving different combinations of vessels would give rise to lower source noise levels, and their potential effects would therefore be smaller than those predicted below. Table 9.6 expresses the source noise level of 177dB in terms of dB_{ht}*(species)* for the four species of principal concern at the site.

Table 9.6 Source noise level of 177dB at 500Hz and 1,000Hz expressed as dB_{ht}(species) for bottlenose dolphin, harbour porpoise, common seal and salmon.

Source Noise Level, dB_{ht} *(species)*	Species			
	Bottlenose dolphin	**Harbour porpoise**	**Common seal**	**Salmon**
At 500Hz	79	85	96	–
At 1,000Hz	82	96	94	–

No information is available in the audiograms for salmon at 500Hz.

The 90dB_{ht}*(species)* threshold value is exceeded at 500Hz for common seal, out to a distance of about 50m from the source. This same threshold level is exceeded at 1,000Hz for harbour porpoise and common seal (to a distance of about 10m in both species). The threshold levels for bottlenose dolphin, salmon and minke whale are not exceeded by this noise.

9.5.3 PUBLISHED DATA ON RESPONSES TO VESSEL NOISE

Literature on the response of marine mammals to vessel noise has been reviewed by Richardson *et al.,* (1995) and Vella *et al.,* (2001). Many marine mammals are tolerant of vessel noise and are regularly observed in areas where there is continuous heavy traffic (WDCS, 2003). However, at times, a species that used to show tolerance may show avoidance. For example, resting dolphins tend to avoid boats, feeding dolphins ignore them, and socialising dolphins may approach boats (Richardson *et al.,* 1995). It is not clear if such observations are related to production of noise or disturbance caused by the presence of boats.

Generally, fish only respond to very low or very high frequency sounds and studies have shown that vessel noise can either cause avoidance or attraction (Vella *et al.,* 2001). Experimental studies of fish reactions to vessel noise show that avoidance occurs at 118dB within the frequency range of 60-3,000Hz, whereas sounds in the range of 20-60Hz have no effect (Engas *et al.,* 1995). Changes in schooling behaviour have also been noted, such as forming tighter formations, increased swimming speeds and turning away from the noise source (McCauley, 1994).

9.5.4 PROJECT MITIGATION MEASURES FOR VESSEL NOISE

Vessel noise in the Beatrice field is not a new phenomenon, and no project-specific measures for the Demonstrator Project are planned. Importantly, vessel noise associated with the installation of the Demonstrator

WTGs would not start suddenly, but would vary gradually throughout the course of the installation programme, as vessels came and went from the field, and undertook a variety of tasks while both under way and “on station” close to the Demonstrator site. Marine mammals and fish that frequent or visit the general area of the Beatrice field might therefore be expected to be accustomed to some level of vessel noise in the area. In addition, the variable nature of the noise created by the relatively short-term installation operations at the Demonstrator site would provide some opportunity for individuals to move away from, or not approach, sources of noise that would elicit strong avoidance reactions in them.

9.5.5 CONCLUSIONS FOR EFFECTS OF VESSEL NOISE AT DEMONSTRATOR SITE

It is unlikely that individual marine mammals or fish at the Demonstrator site would be suddenly and without warning exposed to a high level of noise created by vessel operations. Marine mammals and fish may move away from the area in which numbers of vessels are routinely operating, and in which higher levels of vessel noise (>90dB_{ht}*(species)*, maximum radius of about 50m) may be experienced. This is a small area given the known ranges of these species. Dolphins, harbour porpoise and common seal roam widely in search of food, and if they avoid a small area in the immediate vicinity of the Demonstrator for short periods of time during installation, this is unlikely to lead to any significant or long-term detrimental effect.

It is therefore concluded that the noise from vessels, at the frequencies considered, would result in some degree of avoidance only for any individuals located in very close proximity (<100m) to vessels, and for short periods of time.

9.6 ASSESSMENT OF THE POTENTIAL NOISE EFFECTS FROM OPERATIONS TO BURY THE UMBILICALS

9.6.1 SOURCE AND CHARACTER OF NOISES FROM BURIAL OPERATIONS

The umbilicals will be buried by deploying a self-propelled underwater tool to traverse the seabed and fluidise the surface sediment using a directed jet of high-pressure water (Section 3.3.3). Burial operations are expected to take about 12 hours total for both WTGs. There are no measurements for the character or source sound level produced by such equipment.

The noises produced by subsea trenching operations depend on the equipment used and the nature of the seabed sediments. A trenching noise spectrum reported in Richardson *et al.* (1995) has peak levels of 178dB re 1µPa @ 1m at 160Hz, with an overall source level 185dB re 1µPa @1m; this agrees with data reported by Nedwell *et al.,* 2004. These levels are for mechanical dredging operations, and may be noisier than the fluidising equipment proposed for the Demonstrator.

9.6.2 PREDICTED NOISE LEVELS FROM BURIAL OPERATIONS AT THE DEMONSTRATOR SITE

For the purposes of modelling, a source noise level of 185dB re 1µPa @ 1m was assumed, with a frequency spectrum that paralleled that of the audiograms for the key species under consideration (i.e. a worst-case scenario in terms of frequency).

From the project schedule, the noisiest situation would be the deployment of the seabed fluidiser from a vessel operating under dynamic positioning. In such circumstances the combined source noise level might be about 185+1=186dB re 1µPa @ 1m. Figure 9.7 shows this source noise level expressed as dB_{ht}*(species)* for the key species.

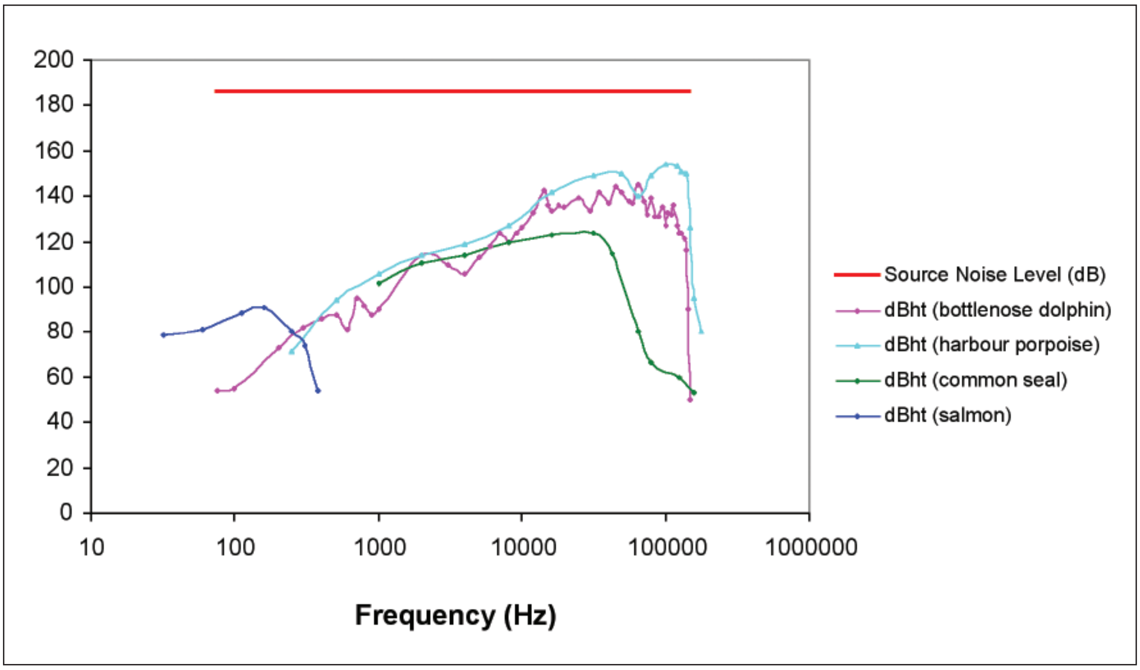


Figure 9.7 Source noise level of 186dB expressed as dB_{ht}(species) for bottlenose dolphin, harbour porpoise, common seal and salmon.

In the absence of a frequency spectrum for this noise source, the propagation of a 185dB noise was modelled several times, once for each of the key species under consideration. The selected frequencies corresponded to the frequency to which the species is most sensitive (i.e. this would be the worst scenario for each species).

Table 9.7 shows the frequency value used for each species, the corresponding received noise level at the source (dB_{ht}*(species)* at 1m) and the distance at which the received noise level falls below 90dB_{ht}*(species)*.

Table 9.7 Frequency values, perceived source noise level, and distance to 90dBht(species) threshold level for bottlenose dolphin, harbour porpoise, common seal and salmon exposed to 185dB noise from operations to bury umbilicals.

Data	Species			
	Bottlenose dolphin	**Harbour porpoise**	**Common seal**	**Salmon**
Frequency (Hz)	65,000	100,000	32,000	160
Source Noise Level, dB_{ht}*(species)*	145	154	124	90.8
Distance to *90*dB_{ht} *(species)* threshold (m)	*500*	*600*	*<50*	*<5*

It should be noted this assessment is a simplification, an attempt to capture the possible combined effects of two sources of noise vertically separated in the water column. One source is on the surface and is radiating noise downward and outwards, whereas the other is on the seabed radiating noise both into the sediment and upwards into the water column.

9.6.3 PUBLISHED DATA ON RESPONSES TO NOISE FROM BURIAL OPERATIONS

There is no published information about the effects of seabed fluidisers on marine mammals and fish. Noises from the burial operations are likely to be similar to those that very frequently arise offshore as a result of the use of vessels and equipment on the vessels or deployed by them.

9.6.4 PROJECT MITIGATION MEASURES FOR NOISE FROM BURIAL OPERATIONS

The areas in which noises >90dB_{ht}*(species)* would be experienced is very small, and therefore the numbers of animals that may be exposed to levels eliciting a behavioural or physical response when burial operations begin will be low. Operations to bury the umbilicals will start gradually (with the manoeuvring of vessels, the deployment of the fluidiser to the seabed and the beginning of jetting) so marine mammals in the immediate vicinity would be alerted to this activity and have the opportunity to move away. Individuals within the >90dB_{ht}*(species)* zone would be able to swim out of the area in a few minutes (a harbour porpoise swimming at 0.9$m.s^{-1}$ would take about 11 minutes to cover 600m).

9.6.5 CONCLUSIONS FOR EFFECTS OF BURIAL NOISE AT DEMONSTRATOR SITE

Trenching and burial operations will be preceded by general vessel activity, alerting animals in the vicinity to ongoing operations. The trenching and burial operations themselves, on the seabed, will last a relatively short period of time, about 12 hours in total for both WTGs. Although there is no published data on the noise produced by the fluidising equipment that would be used, estimates made using information from mechanical burying operations suggest that the area in which the selected species might be exposed to noise levels >90dB_{ht} would be less than 600m wide. It is therefore concluded that there will be not significant or long-term effects on any marine mammal or fish in the area.

9.7 ASSESSMENT OF THE POTENTIAL NOISE EFFECTS FROM THE OPERATION OF THE DEMONSTRATOR TURBINES

9.7.1 SOURCE AND CHARACTER OF OPERATIONAL NOISE

When the turbines are operational, the main source of underwater noise will be from the working of the gears in the nacelle at the top of the tower (Nedwell and Howell, 2004). This noise/vibration is transmitted into the sea by the structure of the tower itself, and manifests as low frequency noise. Other transmission pathways are via the tower and the seabed, or through the air and air/water interface, but these are unlikely to be as important as the pathway directly through the tower (Nedwell and Howell, 2004). The received level of sound from turbines depends on a number of factors including local wind speed, sound propagation profile, water column depth, sea surface roughness and seabed geology (Nedwell and Howell, 2004).

Published data on the source noise levels from operating wind farms (reviewed by Nedwell and Howell, 2004), indicate that noise generated may have a peak frequency in the range 16 to 60Hz, and that the sound level may be up to 153 dB re µPa @ 1m (Nedwell and Howell, 2004). The available field data showed that although the absolute level of turbine noise increases with increasing wind speed, the noise level relative to background noise (i.e. from wave action, entrained bubbles) remains relatively constant. It should be noted, however, that these data are all for monopole or gravity structures located in relatively shallow water. The character and level of noise generated by operating turbines is dependent not only on the characteristics of the turbine itself, but also on the nature of the support structure and the way in which this may efficiently transmit noise and vibration into the water column.

9.7.2 PREDICTED UNDERWATER NOISE LEVELS FROM OPERATING TURBINES AT THE DEMONSTRATOR SITE

There are few data on the operational noise levels of the REpower 5M turbine, or on the way noise from such a turbine might be transmitted into the sea by a "jacket-like" substructure such as that proposed for the Demonstrator WTGs. For this reason, no assessment has been made of the possible effects of underwater vibration (as opposed to noise) from the proposed WTGs.

For the purposes of modelling underwater noise, however, it has been assumed that the Demonstrator WTGs would create a source level of 153dB re μPa @ 1m, and that the noise frequency spectrum would be similar to those reported in the literature (i.e. peaking at 16Hz).

If the underwater noise from the operating WTGs is of a low frequency range, it would essentially not detectable by bottlenose dolphin, harbour porpoise, common seal or salmon. The <90dB_{ht}*(species)* level is attained within 80–90m of the source for all the selected species.

Because the operating WTGs will be located adjacent to the operating Beatrice platforms, however, the possible combined effects of noise have been examined. Table 9.8 examines different combinations of WTG noise, Beatrice platform noise, and vessel noise, to estimate the maximum likely combined source noise level. Ignoring differences in frequency spectra, the total combined noise source under operating conditions is unlikely to exceed 188dB re μPa @ 1m if the source noise level of a WTG itself is about 153dB re μPa @ 1m. In cases where the noise from the operating platform is taken into consideration, the total source noise level is largely attributable to that noise rather than noise from the WTGs. Table 9.9 then expresses the estimated maximum source noise level as dB_{ht}*(species)* source noise for the selected species. The results show that the 90dB_{ht}*(species)* threshold is not exceeded for any of the selected species.

It should be stressed that there are very few data giving the underwater noise levels for operating oil and gas platforms. The data given in Table 9.8 is for the Douglas platform in Liverpool Bay. Unlike the Beatrice platforms, this installation has large gas turbines running all the time, to provide power to the platform. This is likely to be a significant source of underwater noise.

Table 9.8 Estimated combined source level noise for an operating WTG in combination with other sites or activities.

Scenario	**Combined source level (dB re μPa @ 1m)**
2 WTGs (at mid-point) (1)	113
1 WTG + working Beatrice Alpha platform (1, 2)	187
1 WTG with supply vessel + working Beatrice Alpha platform (1, 2)	188
1 WTG + supply vessel + Beatrice platform with supply vessel (1, 2)	188

(1) Assuming a peak frequency of 16Hz
(2) Combined noise calculated at the WTG location

Table 9.9 Source level noise of 188dB (300Hz) expressed as dB_{ht}(species) for bottlenose dolphin, harbour porpoise, common seal and salmon.

	Species			
	Bottlenose dolphin	**Harbour porpoise**	**Common seal**	**Salmon**
Source Noise Source Noise Level dB_{ht}*(species)*	84	77(*)	106 (**)	76 (*)

(*) The weighting value for harbour porpoise and salmon were obtained by an interpolation of the species audiogram.
(**) The weighting value for common seal was obtained by an extrapolation of the species audiogram.

9.7.3 PUBLISHED DATA ON RESPONSES TO NOISE FROM TURBINE OPERATIONS

The operational phase of offshore wind farms has been reported to produce broadband low frequency noise above ambient levels and at the lower end of the threshold frequency spectra of odontocetes (Richardson *et al.,* 1995). The zone of audibility and potential zone of exclusion around operational offshore wind farms has not been clearly defined. Different studies have reached different conclusions, perhaps affected by local conditions. By comparing auditory sensitivities of marine mammal species for different frequencies with wind turbine sound characteristics it was predicted by Henriksen *et al.,* (2001) that the maximum detection distance for harbour porpoises is likely to be 50m. Detection distances in relation to Vindeby (Denmark) and Gotland (Sweden) were predicted to be in the region of 20m (Bach *et al.,* 2000), but studies at the Vindeby site were not able to demonstrate any noticeable change in behaviour or numbers of animals present during its operation. Koschinski *et al.,* (2003) reported on the behavioural reactions of harbour porpoises and seals to the noise of a simulated 2MW wind turbine. Results indicated that porpoises and seals were able to detect the low-frequency sound generated and that they showed distinct reactions to the noise. In addition, the number of time intervals during which porpoise echolocation clicks were detected increased by a factor of 2 when the sound source was active (Booij, 2004).

Investigations conducted by Westerberg (1999) of the operational noise effects of the Svante wind farm (Sweden) on eels concluded there was no difference between migration speed or distance from the turbine or that no changes in behaviour could be related to the presence of the turbine.

Studies of the effects of noise on fish at the small wind farm site at Vindeby, Denmark, and oil and gas platforms in the UK sector, have also concluded that fish appear to be undisturbed by the background noise generated by wind turbines. Further, as noted elsewhere, fish may actually accumulate in the area of the turbines and foundations as occurs at other offshore structures. Fish have been noticed in close proximity to wind turbines at Blyth, Northumberland and sea birds have been observed diving within 20m of the turbines to catch fish (Vella *et al.,* 2001).

9.7.4 PROJECT MITIGATION MEASURES FOR OPERATIONAL NOISE FROM THE WIND TURBINE GENERATORS

The WTGs will be maintained and operated to a high standard, and this will help to minimise the amount of noise produced in the turbine nacelle and transmitted through the tower and substructure to the sea.

9.7.5 CONCLUSIONS FOR EFFECTS OF OPERATIONAL NOISE FROM THE WIND TURBINE GENERATORS

The degree to which turbine noise in the nacelle will be transmitted through the tower and substructure to the sea is not known for a WTG of the design proposed for the Demonstrator Project. It is likely that the construction and stiffness of the steel jacket will not transit sound as effectively into the water column as do free-standing monopiles. It is therefore not clear if the WTGs would create as much underwater noise as turbines reported in the literature.

The noise from wind turbines increases with increasing wind speed, but so does the background noise level of the sea. The relative noise of the turbines is, therefore, thought to remain fairly constant. Using published information from other types of turbine, it is estimated that the noise level from the WTG would fall to $<90dB_{ht}$*(species)* for all the selected species within 100m of the site. Using a single published estimate of underwater noise from a working platform, with different characteristics from the Beatrice platforms, it is estimated that at the midpoint between the Beatrice platform and WTG 1, the noise level would have fallen to $<90dB_{ht}$*(species)* for all the selected species.

The underwater noise from the working WTGs will vary depending on wind speed and sea state, and can be expected to vary during the day, from day to day, and from season to season. Changes in underwater noise levels are likely to be gradual, not sudden. Marine mammals will therefore be able to modify their local behaviour around the WTGs, in order to remove themselves from sources of noise that they find disturbing. Given the densities of marine mammals in the area of the Demonstrator Project, it is likely that only a very small number of marine mammals, if any, would be exposed to noise levels around a WTG at which avoidance reactions might be elicited.

It is therefore concluded that if the Beatrice Demonstrator turbines installed on top of the jacket-like substructures produce underwater sounds similar in level and frequency to those measured for smaller monopile turbines in shallower water, then very few marine mammals are likely to be exposed at any one time to noise levels that would be sufficiently high to elicit an avoidance reaction.