Omø South Nearshore A/S

Underwater noise

DECEMBER 2016

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1. INTRODUCTION

Underwater noise modelling has been undertaken by **Subacoustech** with respect to impact piling for installation of foundations for offshore wind turbines at the Omø South Offshore Wind Farm. The underwater noise modelling considered the installation of 3 MW and 8 MW turbine foundations.

1.1. The INSPIRE model

The INSPIRE model (currently version 3.4.3) is a semi-empirical underwater noise propagation model based around a combination of numerical modelling and actual measured data. The model provides estimates of the unweighted peak, peak-to-peak and RMS level of noise as well as various other metrics along 180 equally spaced radial transects (one every 2 degrees).

For each scenario, a criterion level can be specified allowing a contour to be drawn, within which a given effect may occur. These results are then plotted over the bathymetry data so that impact ranges can be clearly visualised and assessed as necessary.

1.2. Turbine details

A 3 MW and an 8 MW turbine are being considered and no further details regarding the turbine foundations or installation techniques are currently available. For the purposes of noise modelling, appropriate engineering parameters have been selected based on those used or proposed either previously on Danish projects or at other wind farms on a similar scale, and scaled from these parameters.

1.3. Modelling parameters

A soft start of 20 minutes has been included, with a gentle ramp-up in blow energy over the entire installation period; this is summarised in Table 1-1. Although large impact hammers, such as the Menck 1900S and Menck 3000S, are capable of delivering 32 blows per minute at maximum energy, the strike rate will tend to be much slower initially and so 3 seconds per blow over the whole piling period is expected to provide a reasonable average. It should be noted that all the modelling results assumed that only one piling operation will occur at any one time; i.e. there will be no simultaneous piling operations.

The following parameters are used for the underwater noise assessment, and assume a monopile installation:

3 MW turbine

Foundation diameter	3 metres
Maximum installation energy	1200 kJ (250 kJ at soft start)
Average strike rate	1 strike every 3 seconds
Total installation time	2 hours

8 MW turbine

Foundation diameter	8 metres
Maximum installation energy	2700 kJ (450 kJ at soft start)
Average strike rate	1 strike every 3 seconds
Total installation time	6 hours

Underwater noise levels from piling were modelled for locations at the north and south of the Omø South offshore wind farm boundary; these locations are summarised in Table 1-2 and Figure 1-1. It should be noted that the positions for 3 MW and 8 MW vary due to the differing layouts of the two turbine sizes.

Table 1-1 Summary of the soft start and ramp up procedure assumed for the modelling

3 MW turbine		8 MW turbine	
Energy (kJ)	Time (minutes)	Energy (kJ)	Time (minutes)
250 (soft start)	20	450 (soft start)	20
400	20	750	40
600	20	1100	60
800	20	1500	60
1000	20	1900	60
1200	20	2300	60
		2700	60

Table 1-2 Co-ordinates of the four modelling locations (UTM (north)-WGS84, Zone 32)

	T01 (3 MW)	T01 (8 MW)	T24 (3 MW)	T14 (8 MW)
Easting	633.355	633.242	632.300	632.313
Northing	6.110.770	6.109.520	6.095.857	6.096.252

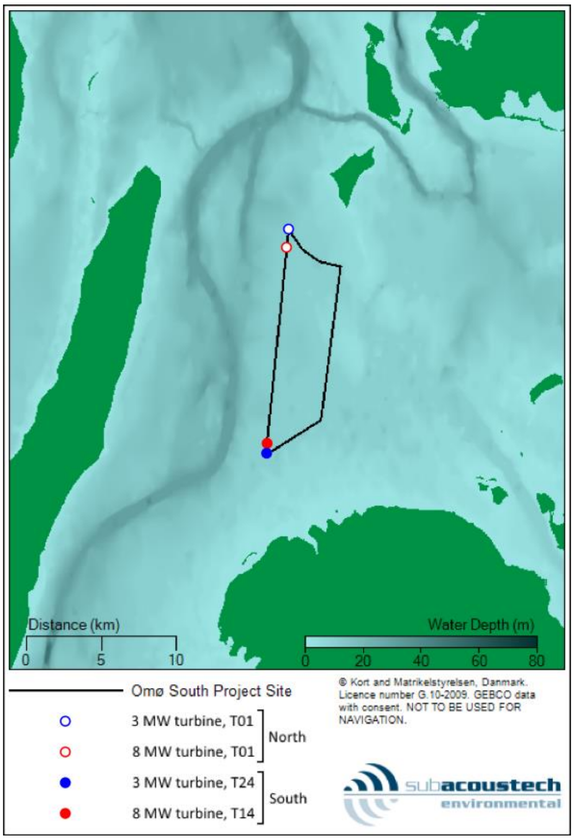

Figure 1-1 Map showing the boundary of the Omø South site along with the four modelling locations

2. ASSESMENT METRICS AND CRITERIA

2.1. Lethal and physical injury

Two criteria have been identified to assess lethal effect and physical injury, unrelated to hearing, to all receptors using unweighted peak-to-peak sound pressure levels (SPLs) (Parvin et al, 2007). These are:

- 240 dB re 1 µPa single strike unweighted peak SPL for lethal effect; and
- 220 dB re 1 µPa single strike unweighted peak SPL for physical traumatic injury, in excess of hearing damage.

2.2. Modelling of PTS in marine mammals

Two criteria for assessing permanent threshold shift (PTS) in marine mammals have been used. The two criteria are:

- 186 dB re 1 µPa2s (Mpw) cumulative M-Weighted SEL for PTS in pinnipeds (Southall et al, 2007); and
- 180 dB re 1 µPa2s cumulative unweighted SEL for PTS in harbour porpoise (Lucke et al, 2009).
-

Both of these criteria take into account the cumulative received Sound Exposure Level (SEL) for a marine mammal over the entire piling operation. For this modelling it is assumed that the receptor is fleeing from the noise at a rate of 1.5 m/s (Otani et al, 2000).

The noise propagation model handles fleeing animals and cumulative noise impacts over time by calculating “starting range” for receptor. The contour output defines the noise exposure an animal would receive if it was at that point when the piling began and swam radially away. Thus, if an animal was inside the contour at the start of piling, it would receive a cumulative exposure in excess of the respective criterion. The noise model assumes that if the fleeing animal meets the coast it will stop in the shallow water for the remainder of the piling.

2.3. Modelling of TTS in marine mammals

Two criteria for assessing temporary threshold shift (TTS) in marine mammals have been used. These criteria are as follows:

- 171 dB re 1 µPa2s (Mpw) single strike M-Weighted SEL for TTS in pinnipeds (Southall et al, 2007); and
- 165 dB re 1 µPa2s single strike unweighted SEL for TTS in harbour porpoise (Lucke et al, 2009).

2.4. Modelling of injury in fish

Three criteria for assessing injury in fish have been identified (FHWG, 2008). These criteria are:

- 206 dB re 1 µPa single strike unweighted SPL (peak) for injury in all sizes of fish;
- 187 dB re 1 µPa2s cumulative unweighted SEL for injury in all sizes of fish; and
- 183 dB re 1 µPa2s cumulative unweighted SEL for injury for fish under 2 g in mass.
-

The second and third of these criteria take into account the cumulative received SEL for a receptor over the entire piling operation. For this modelling it is assumed that the receptor is stationary throughout the piling operation.

A recent publication by Popper et al (2014) has identified a noise level of 207 dB SPLpeak and 203 dB re 1 µPa2s cumulative unweighted SEL as could potentially lead to an injury in fish. These are both greater than the levels identified above, and with respect to the cumulative level, substantially greater. Therefore, the criteria bulleted above will continue to be used as conservative values.

2.5. Modelling of behavioural effect in marine mammals using unweighted SELs

Two criteria have been identified for assessing the behavioural effect in marine mammals, both using the level from a single strike in terms of unweighted SEL. The two criteria are:

- 150 dB re 1 µPa2s single strike unweighted SEL for behavioural effect in harbour porpoise and pinnipeds (Brandt et al, 2009); and
- 145 dB re 1 µPa2s single strike unweighted SEL for minor behavioural effect in harbour porpoise and pinnipeds (Lucke et al, 2009).

2.6. Modelling of behavioural effect using the dB_{ht}(*Species*)

The dBht(Species) value represents the number of decibels above the hearing threshold of a species, so in effect a perceived noise level by that species. 0 dBht(Species) is therefore, in effect, the minimum perceptible noise level by that species, based on its audiogram where available. A criterion of 90 dBht with reference to a species' audiogram is a noise level perceived as sufficiently loud that the majority of individuals will try to avoid a region insonified to that extent (Nedwell et al, 2007).

2.7. Summary of criteria

Table 2-1 collates all the criteria used in this assessment from the previous sections.

Effect	Criteria	Weighting	Species covered
Lethal	240 dB re 1 µPa	Unweighted SPL_{peak}	All
Physical injury	220 dB re 1 µPa	Unweighted SPL_{peak}	All
PTS	186 dB re 1 $\mu Pa^2 s(M_{pw})$	Cumulative M-Weighted SEL (pinni-peds in water)	Pinniped (seal)
PTS	180 dB re 1 $\mu Pa^2 s$	Cumulative unweighted SEL	Harbour porpoise
TTS	171 dB re 1 $\mu Pa^2 s(M_{pw})$	Single strike M-Weighted SEL (pinni-peds in water)	Pinniped (seal)
TTS	165 dB re 1 $\mu Pa^2 s$	Single strike unweighted SEL	Harbour porpoise
Injury	206 dB re 1 µPa	Unweighted SPL_{peak}	All fish
Injury	187 dB re 1 $\mu Pa^2 s$	Cumulative unweighted SEL	All fish
Injury	183 dB re 1 $\mu Pa^2 s$	Cumulative unweighted SEL	Fish with mass < 2 g
Behavioural effect	150 dB re 1 $\mu Pa^2 s$	Single strike unweighted SEL	Harbour porpoise and pinniped (seal)
Behavioural effect	90 dB_{ht}(*Species*)	dB_{ht}(*Species*)	Various (species specific)
Minor behavioural effect	145 dB re 1 $\mu Pa^2 s$	Single strike unweighted SEL	Harbour porpoise and pinniped (seal)

Table 2-1 Summary of noise criteria used for the assessment of potential impact on marine mammals and fish

3. MODELLING RESULTS

3.1. Source levels

In order to establish likely levels of noise arising from impact piling operations, source levels of the piling activities at Omø South have been modelling using the INSPIRE model based on measurements undertaken by Subacoustech. The estimated source levels, in terms of unweighted peak SPLs and unweighted, single strike, SELs are summarised in Table 3-1 below.

	Unweighted SPL_{peak}	Unweighted SEL
3 MW turbine (3 m diameter pile, 1200 kJ maximum blow energy)	240.4 dB re 1 µPa @ 1 m	214.8 dB re 1 µPa^{2}s @ 1 m
8 MW turbine (8 m diameter pile, 2700 kJ maximum blow energy)	244.6 dB re 1 µPa @ 1 m	221.1 dB re 1 µPa^{2}s @ 1 m

Table 3-1 Summary of the modelled source levels for the two piling scenarios

3.2. Level with range

For each modelling scenario the transect with minimum attenuation (i.e. the longest predicted range) has been selected and an appropriate fit to the data has been made using an equation in the form $L_r=SL-N \log_{10} r-\alpha_r$, where L_r is the level at any range. For the north location, this was the 206° transect; for the south location this was the 346° or 356° transect. This has been carried out for both unweighted peak SPLs and unweighted, single strike, SELs.

3.2.1 Unweighted peak SPL

- For the 3 MW turbine modelling at the north location (T01), the predicted unweighted peak SPLs along the 206° transect can be approximated as $L_r = 240.4 - 16.5 \log_{10} r - 0.00085r$.
- For the 8 MW turbine modelling at the north location (T01), the predicted unweighted peak SPLs along the 206° transect can be approximated as $L_r = 244.6 - 16.5 \log_{10} r - 0.0009r$.
- For the 3 MW turbine modelling at the south location (T24), the predicted unweighted peak SPLs along the 346° transect can be approximated as $L_r = 240.4 - 16.9 \log_{10} r - 0.00086r$.
- For the 8 MW turbine modelling at the south location (T14), the predicted unweighted peak SPLs along the 346° transect can be approximated as $L_r = 244.6 - 16.9 \log_{10} r - 0.00084r$.

These fits are provided as level versus range plots in Figure 3-1 to Figure 3-4, below.

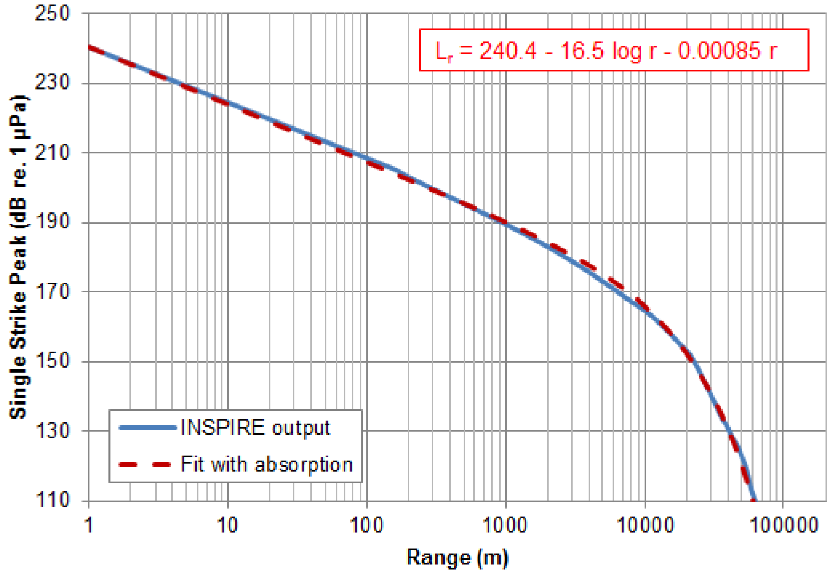

Figure 3-1 Level versus range plot showing the predicted unweighted peak SPL values along the 206° transect from the north location for the 3 MW turbine (T01), and the attenuation approximated as an N log R curve

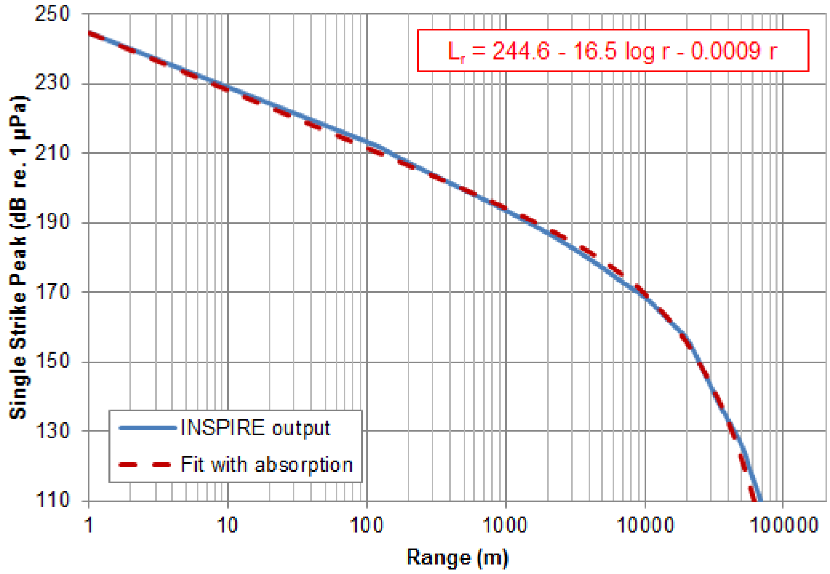

Figure 3-2 Level versus range plot showing the predicted unweighted peak SPL values along the 206° transect from the north location for the 8 MW turbine (T01), and the attenuation approximated as an N log R curve

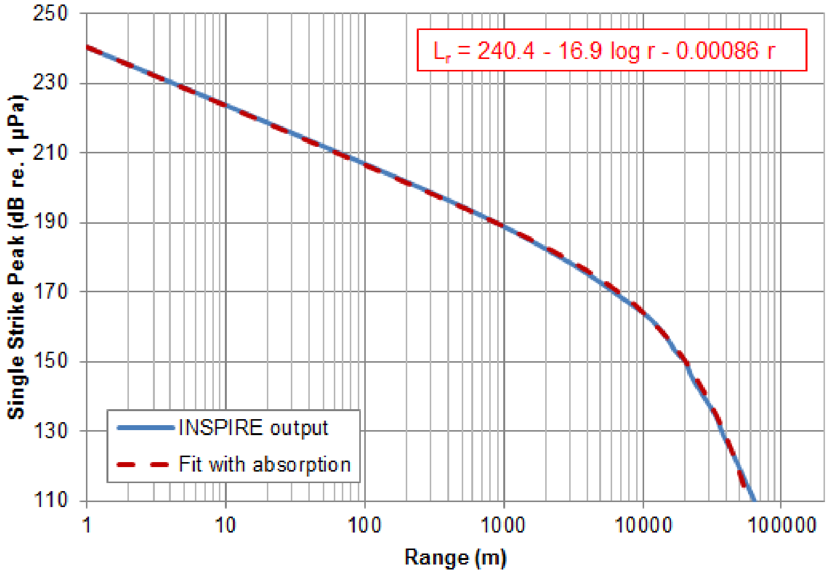

Figure 3-3 Level versus range plot showing the predicted unweighted peak SPL values along the 346° transect from the south location for the 3 MW turbine (T24), and the attenuation approximated as an N log R curve

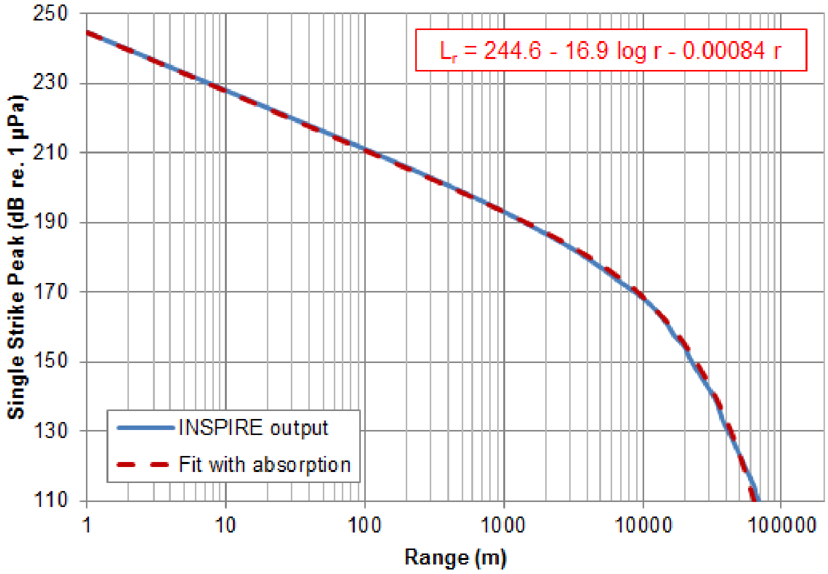

Figure 3-4 Level versus range plot showing the predicted unweighted peak SPL values along the 346° transect from the south location for the 3 MW turbine (T14), and the attenuation approximated as an N log R curve

3.2.2 Unweighted single strike SEL

- For the 3 MW turbine modelling at the north location (T01), the predicted unweighted single strike SELs along the 206° transect can be approximated as $L_r = 214.8 - 14.1 \log_{10} r - 0.00067r$.

- For the 8 MW turbine modelling at the north location (T01), the predicted unweighted single strike SELs along the 206° transect can be approximated as $L_r = 221.1 - 14.2 \log_{10} r - 0.0007r$.
- For the 3 MW turbine modelling at the south location (T24), the predicted unweighted single strike SELs along the 356° transect can be approximated as $L_r = 214.8 - 14.7 \log_{10} r - 0.00059r$.
- For the 8 MW turbine modelling at the south location (T14), the predicted unweighted single strike SELs along the 346° transect can be approximated as $L_r = 221.1 - 14.5 \log_{10} r - 0.00065r$.

These fits are provided as level versus range plots in Figure 3-5 to Figure 3-8 below.

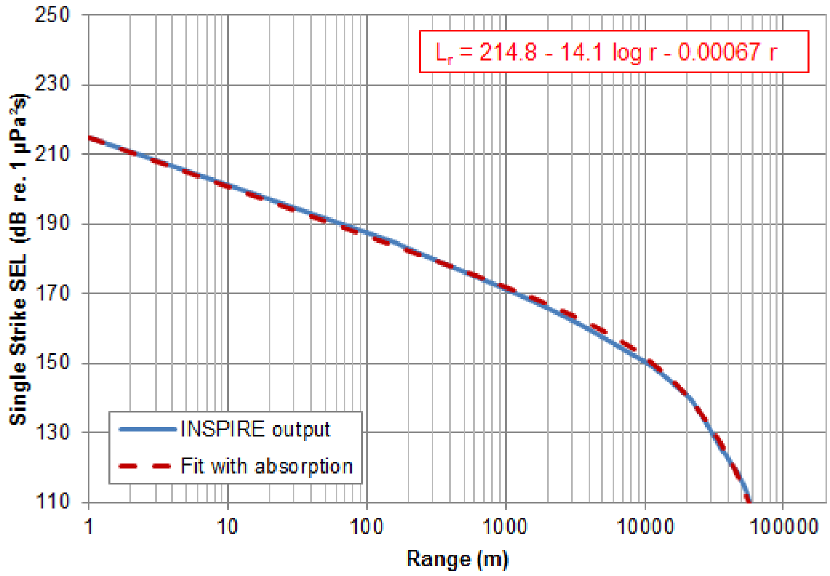

Figure 3-5 Level versus range plot showing the predicted unweighted single strike SEL values along the 206° transect from the north location for the 3 MW turbine (T01), and the attenuation approximated as an N log R curve

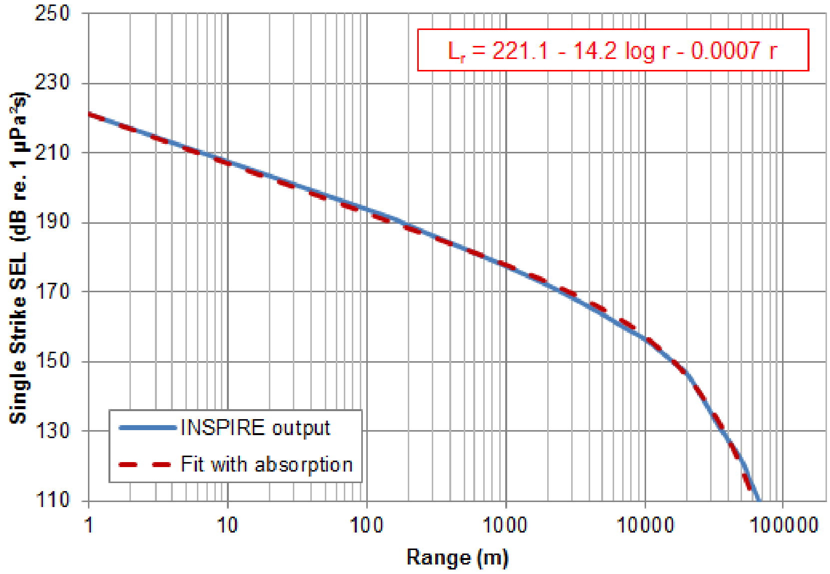

Figure 3-6 Level versus range plot showing the predicted unweighted single strike SEL values along the 206° transect from the north location for the 8 MW turbine (T01), and the attenuation approximated as an N log R curve

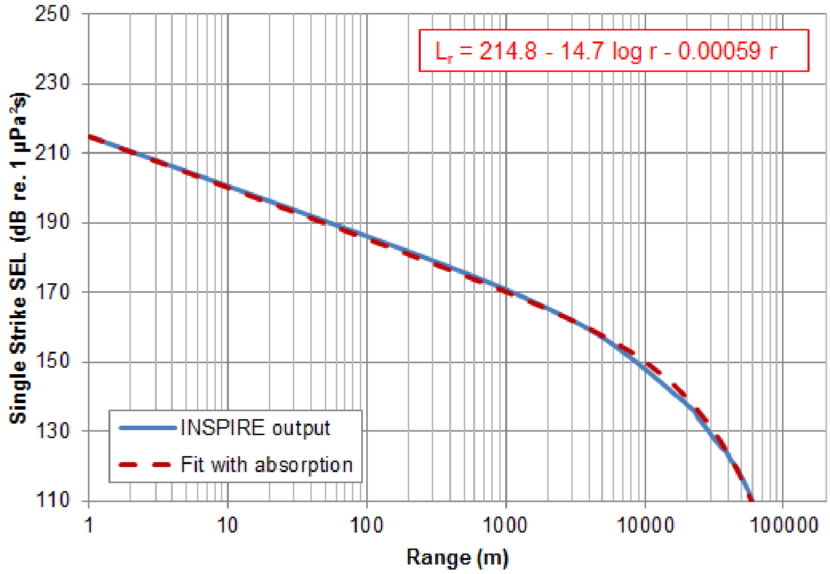

Figure 3-7 Level versus range plot showing the predicted unweighted single strike SEL values along the 356° transect from the south location for the 3 MW turbine (T24), and the attenuation approximated as an N log R curve

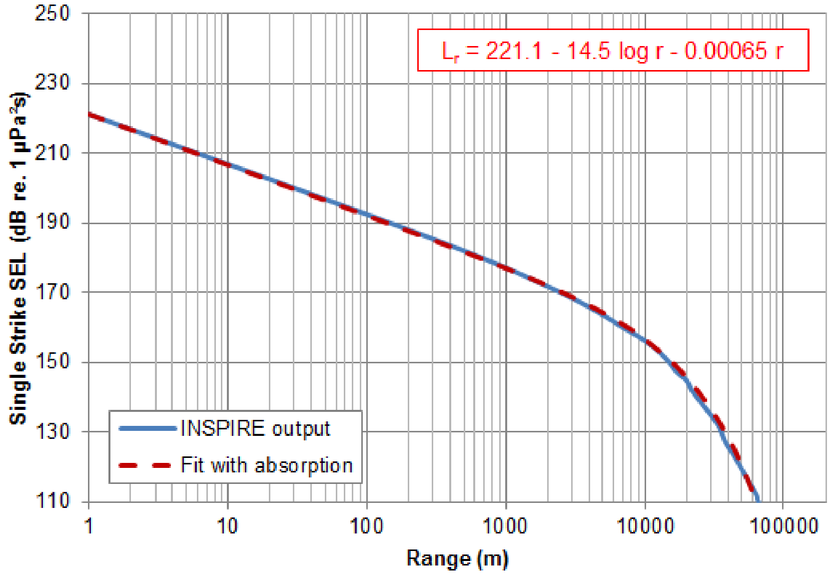

Figure 3-8 Level versus range plot showing the predicted unweighted single strike SEL values along the 346° transect from the south location for the 8 MW turbine (T14), and the attenuation approximated as an N log R curve

3.3. Lethal and physical injury

The results of modelling the 3 MW and 8 MW turbine foundation piles being installed with a maximum blow energy are summarised in Table 3-2 below.

	Lethal effect 240 dB re 1 µPa (SPL_{peak})		Physical traumatic injury 220 dB re 1 µPa (SPL_{peak})	
	3 MW turbine	**8 MW turbine**	**3 MW turbine**	**8 MW turbine**
North	1 m	2 m	17 m	31 m
South	1 m	2 m	17 m	30 m

Table 3-2 Maximum predicted impact ranges for lethal effect and physical traumatic injury

3.4. Modelling of PTS in marine mammal

It is assumed that at the start of piling, the noise level will be such that an animal will flee from the source. The ranges in Table 3-3 and Table 3-4 below define the modelled distance from the pile at which an animal would just receive the criterion dose for PTS if it was at that distance at the start of piling and fled. If an animal was closer than this distance to the pile at the start of piling and fled, it would receive a noise exposure greater than the criterion. If it was further from the pile, then it would receive a dose lower than the criterion.

For this modelling it is assumed that the receptor is fleeing from the noise at a rate of 1.5 m/s (Otani *et al*, 2000). As a comparison, modelling assuming a stationary animal has also been undertaken. The ranges below show the ranges where a receptor would need to be for the entire piling duration to receive a noise exposure greater than the criterion. This approach is briefly discussed in section 2.2.

PTS (Pinniped/Seal) 186 dB SEL re 1 µPa²s (M_{pw}) (cumulative SEL)		3 MW turbine (fleeing 1.5 ms⁻¹)	8 MW turbine (fleeing 1.5 ms⁻¹)	3 MW turbine (stationary)	8 MW turbine (stationary)
North	Maximum	0.2 km	0.5 km	2.8 km	8.1 km
	Minimum	0.1 km	0.4 km	2.3 km	4.8 km
	Mean	0.2 km	0.5 km	2.5 km	6.4 km
South	Maximum	0.2 km	0.5 km	2.4 km	7.8 km
	Minimum	0.1 km	0.4 km	2.1 km	4.4 km
	Mean	0.2 km	0.4 km	2.3 km	5.9 km

Table 3-3 Predicted impact ranges using the PTS criteria for pinnipeds, an animal closer than this distance at the start of piling will receive an exposure in excess of the criterion

PTS (Harbour Porpoise) 180 dB SEL re 1 µPa²s (cumulative SEL)		3 MW turbine (fleeing 1.5 ms⁻¹)	8 MW turbine (fleeing 1.5 ms⁻¹)	3 MW turbine (stationary)	8 MW turbine (stationary)
North	Maximum	3.5 km	6.9 km	8.8 km	18.2 km
	Minimum	1.4 km	2.7 km	4.0 km	4.8 km
	Mean	2.4 km	4.6 km	6.9 km	12.1 km
South	Maximum	3.3 km	6.9 km	8.7 km	19.1 km
	Minimum	1.4 km	2.6 km	4.5 km	6.0 km
	Mean	2.1 km	4.2 km	6.4 km	11.2 km

Table 3-4 Predicted impact ranges using the PTS criteria for harbour porpoises, an animal closer than this distance at the start of piling will receive an exposure in excess of the criterion

Thus, an animal inside the ranges above at the start of piling is at risk of PTS according to the defined criterion.

3.5. Modelling of TTS in marine mammals

The range within which a marine mammal must be at the start of piling to elicit TTS to the criteria discussed in Section 2.3 is summarised in Table 3-5 and Table 3-6.

TTS pinniped (seal) 171 dB re 1 µPa²s (M_{pw}) (single strike SEL)		3 MW turbine	8 MW turbine
North	Maximum	570 m	1110 m
	Minimum	540 m	1020 m
	Mean	560 m	1060 m
South	Maximum	540 m	1050 m
	Minimum	510 m	990 m
	Mean	530 m	1010 m

Table 3-5 Predicted impact ranges using the TTS criteria for pinnipeds using single strike M-Weighted SELs

TTS harbour porpoise 165 dB re 1 µPa²s (single strike SEL)		3 MW turbine	8 MW turbine
North	Maximum	2.4 km	4.9 km
	Minimum	2.1 km	3.8 km
	Mean	2.2 km	4.4 km
South	Maximum	2.2 km	4.8 km
	Minimum	2.0 km	3.5 km
	Mean	2.1 km	4.1 km

Table 3-6 Predicted impact ranges using the TTS criteria for harbour porpoise using unweighted single strike SELs

3.6. Modelling of injury in fish

The range within which a fish must be at the start of piling to elicit TTS are summarised in Table 3-7 and Table 3-8. As stated in section 2.4, it is assumed for this modelling that the receptor is stationary throughout the piling operation.

All fish 206 dB re 1 µPa (SPL_{peak})		3 MW turbine	8 MW turbine
North	Maximum	116 m	203 m
	Minimum	115 m	202 m
	Mean	116 m	203 m
South	Maximum	113 m	199 m
	Minimum	112 m	198 m
	Mean	113 m	199 m

Table 3-7 Predicted impact ranges using the SPL_{peak} injury criteria for fish

All fish 187 dB re 1 µPa²s (cumulative SEL)		3 MW turbine	8 MW turbine
North	Maximum	4.4 km	11.9 km
	Minimum	3.3 km	4.8 km
	Mean	3.8 km	8.8 km
South	Maximum	4.1 km	12.8 km
	Minimum	3.0 km	5.3 km
	Mean	3.5 km	8.5 km

Table 3-8 Predicted impact ranges using the SEL injury criteria for all sizes of fish (assuming stationary animal)

Where the fish are less than 2 grams in mass, the stricter criterion of 183 dB re 1 µPa²s is relevant and shown in Table 3-9.

Fish with mass < 2 g 183 dB re 1 µPa^{2}s (cumulative SEL)		3 MW turbine	8 MW turbine
North	Maximum	6.8 km	15.6 km
	Minimum	4.0 km	4.8 km
	Mean	5.4 km	10.6 km
South	Maximum	6.3 km	17.0 km
	Minimum	3.9 km	5.8 km
	Mean	5.1 km	10.2 km

Table 3-9 Predicted impact ranges using the SEL injury criteria for fish with mass less than 2 grams in weight (assuming stationary animal)

3.7. Modelling of behavioural effect in marine mammals using unweighted SELs

Table 3-10 summarises the levels at which a behavioural effect and a minor behavioural effect may be experienced by harbour porpoise and pinnipeds using the unweighted SEL criteria discussed in Section 2.5.

Harbour porpoise and pinniped (seal)		Behavioural effect 150 dB re 1 µPa^{2}s (single strike SEL)		Minor behavioural effect 145 dB re 1 µPa^{2}s (single strike SEL)	
		3 MW	8 MW	3 MW	8 MW
North	Maximum	11.1 km	16.8 km	15.9 km	22.3 km
	Minimum	4.0 km	4.8 km	4.0 km	4.8 km
	Mean	8.3 km	11.3 km	10.7 km	13.8 km
South	Maximum	11.8 km	18.2 km	16.9 km	20.5 km
	Minimum	5.0 km	5.9 km	5.6 km	6.0 km
	Mean	8.0 km	10.6 km	10.0 km	13.5 km

Table 3-10 Predicted impact ranges for behavioural effect using unweighted SEL criteria for marine mammals

3.8. Modelling of behavioural effect using the dB_{ht}(*Species*) metric

Table 3-11, below, summarises the 90 dB_{ht}(*Species*) impact ranges for various species of fish and marine mammal. As discussed in Section 2.6, the dB_{ht}(*Species*) metric is a species specific metric based on a receptors audiogram. A criterion of 90 dB_{ht}(*Species*) is a noise level where a strong avoidance reaction is likely to occur in virtually all individuals.

90 dB_{ht}(*Species*)		North		South	
		3 MW	8 MW	3 MW	8 MW
Cod	Maximum	8.8 km	14.9 km	8.2 km	16.1 km
	Minimum	4.0 km	4.8 km	4.2 km	5.5 km
	Mean	6.6 km	9.9 km	5.9 km	9.5 km
Dab	Maximum	2.2 km	4.7 km	2.0 km	4.5 km
	Minimum	2.0 km	3.7 km	1.9 km	3.4 km
	Mean	2.1 km	4.2 km	1.9 km	3.9 km
Herring	Maximum	11.6 km	16.5 km	12.4 km	18.1 km
	Minimum	4.0 km	4.8 km	5.0 km	5.8 km
	Mean	8.5 km	11.0 km	8.1 km	10.4 km
Sand lance	Maximum	0.2 km	0.3 km	0.2 km	0.3 km
	Minimum	0.1 km	0.3 km	0.1 km	0.2 km
	Mean	0.1 km	0.3 km	0.1 km	0.3 km
Harbour porpoise	Maximum	11.4 km	12.9 km	11.8 km	13.5 km
	Minimum	4.0 km	4.8 km	5.5 km	5.9 km
	Mean	8.9 km	9.8 km	8.6 km	9.5 km
Harbour seal	Maximum	8.6 km	9.0 km	8.3 km	9.1 km
	Minimum	4.0 km	4.8 km	4.5 km	4.8 km
	Mean	6.7 km	7.2 km	6.3 km	6.8 km

Table 3-11 Summary of the modelled ranges out to 90 dB_{ht}(Species)

4. SUMMARY AND CONCLUSIONS

Subacoustech Environmental has undertaken a study of the impact of underwater piling in the Great Belt in relation to the proposed construction of offshore wind turbine foundations as part of the Omø South project.

Modelling of underwater noise produced by the installation of foundations for 3 MW turbines and 8 MW turbines has been undertaken, using proposed parame-ters for the foundation piles. No direct noise control mitigation has been applied to the modelled noise levels.

Unweighted peak source levels of noise during installation are expected to be 240.4 dB re 1 µPa @ 1 m for the 3 MW turbine, and 244.6 dB re 1 µPa @ 1 m for the 8 MW turbine. Approximate N log R fits to the predicted noise attenuation have also been made.
Modelling shows that lethality and physical injury, using the Parvin et al (2007) criteria, may occur out to a maximum of 2 m and 31 m respectively for the instal-lation of the larger 8MW turbine.

The criteria for assessing PTS (permanent threshold shift) and TTS (temporary threshold shift) in marine mammals (Southall et al, 2007 and Lucke et al, 2009) show that species of pinniped are likely to experience PTS at a maximum range of 8.1 km and harbour porpoise are likely to experience PTS at a maximum range of 18.2 km, assuming the worst case ‘stationary animal’ model during installation of an 8 MW turbine. Using the single strike criteria, pinnipeds are likely to experi-ence TTS at a maximum range of 1.1 km and harbour porpoise would experience TTS at 4.9 km, for the 8 MW turbine.

Injury in species of fish has been assessed using the FHWG (2008) criteria. Pre-dicted maximum impact ranges for all fish assuming a stationary animal model is 11.9 km, or, using the stricter criteria for fish of < 2 g mass, up to 15.6 km.

Criteria for assessing behavioural effect for harbour porpoises and pinnipeds us-ing unweighted, single strike, SELs (Brandt et al, 2009 and Lucke et al, 2009) show that maximum ranges are predicted out to 16.8 km for a behavioural effect and 22.3 km for a minor behavioural effect when installing the foundations for the larger 8 MW turbine. Behavioural effect was also assessed using the dBht(Species) metric (Nedwell et al, 2007), using the 90 dBht criteria for strong avoidance behaviour. Maximum ranges were predicted out to 18.1 km for herring and 13.5 km for harbour por-poise during installation of the 8 MW turbine foundations.

It is also worth noting that these ranges are the greatest expected during piling and are only expected when the piling is undertaken at the maximum blow energy. This is not generally a common occurrence, with a pile typically being driven at much lower blow energies for the majority of time.

5. REFERENCES

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