Underwater noise and marine mammals

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Underwater noise and marine mammals
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The attached report provides the results from a combined effort with Ramboll and NIRAS being responsible for the acoustic modelling, and NIRAS responsible for the calculations applying the new methodology following the recommendations of the Danish expert group. DHI and NIRAS compiled the impact assessment based on the numbers produced by the NIRAS team.

Indhold

1. Danish summary - dansk resumé

I forbindelse med udbud af Horns Rev 3 Havmøllepark i den danske del af Nordsøen har Energinet.dk nedsat en arbejdsgruppe for havpattedyr og undervandsstøj.

Denne gruppe har i et notat udarbejdet anbefalinger til støjregulering i forbindelse med opførelsen af Horns Rev 3 Havmøllepark. Gruppen har desuden på foranledning af Energistyrelsen, Naturstyrelsen og Energinet.dk haft til opdrag at udarbejde anbefalinger for beregning af kumulative støjpåvirkninger på havpattedyr, fastsættelse af tålegrænser for støjpåvirkning af havpattedyr og metode for fastlæggelse af eventuel behov for støjreduktion for overholdelse af de anbefalede tålegrænser i forbindelse med ramning af monopæle for etablering af havmøller. Beregningsmodellen medfører, at koncessionsholder skal beregne hvilken, om nogen, dæmpning af kildestyrken der er nødvendig for at sikre, at det marine miljø ikke lider unødig overlast.

Energistyrelsen har som myndighed meddelt at arbejdsgruppens anbefalinger skal anvendes i forbindelse med udarbejdelse af VVM-redegørelser for de 6 kystnære havmølleprojekter ved Sæby, Vesterhav Syd, Vesterhav Nord, Sejerø Bugt, Smålandsfarvandet og Bornholm.

Nærværende notat præsenterer beregninger af for de 6 kystnære havmølleprojekter baseret på Arbejdsgruppens anbefalinger. Da effekten af bortskræmning med pinger og sælskræmmer ikke er endeligt fastlagt i Arbejdsgruppens anbefalinger er der udført beregninger for marsvin og sæler baseret på en bortskræmningsafstand på 1 og 2 km. Desuden er der gennemført beregninger uden indledende bortskræmning som fastlagt i Arbejdsgruppens anbefalinger. Disse beregninger er grundlag for VVM-redegørelsernes vurderinger af mulige virkninger på havpattedyr i forbindelse med ramning af monopæle til kystnære havmølleparker.

Vurderinger for de seks havmølleparker er baseret på et worst case scenarie, hvor der planlægges opstilling af 10 MW havmøller med nedramning af monopælfundamenter.

Beregningsmodellen er lavet med henblik på at sikre, at støjreducerende foranstaltninger implementeres så ingen marsvin (og sæler) får permanent høretab (PTS).

Anvendelse af beregningerne udført i dette notat afhænger af myndighedernes afgørelse om grundlaget for vurderinger af effekten på marsvin og sæler ved anvendelse af indledende bortskræmning med pinger og sælskræmmer. Endvidere indgår der i grundlaget for anvendelse af beregningerne myndighedernes afklaringer vedrørende rammerne for vurderinger af virkninger i form af midlertidige høreskader og påvirkninger af havpattedyres adfærd i forhold til overholdelse af bevaringsmålsætninger for Natura 2000 områder.

2. Introduction and background

In recent years, Environmental Impact Assessments (EIAs) for offshore wind farms have included the option to install ever-larger wind turbines and thereby ever-larger foundations. In connection with the Horns Rev 3 offshore wind farm, the EIA calculated the noise propagation for monopile foundations with a diameter of up to 10 m.

As the foundation size increases, so does the required impact force to install the pile, and thereby also the noise level per strike. This leads to an increased risk of negatively affecting the marine wildlife. The negative effects on harbour porpoises especially have been of considerable concern, as this species carries out its entire life cycle in the inner Danish waters and is a strictly protected species under several international conventions and EU directives. Effects on other marine mammals, like harbour seals and grey seals, are also given particular focus, as they are designated species for Natura 2000 sites (due to their status in the EU habitat directive).

In previous EIAs for offshore wind farms the focus on underwater noise has been limited and varied. Underwater noise propagation modelling has not always been carried out. In some cases the effects of underwater noise has instead been estimated loosely based on common physical principles of sound propagation. With ever-increasing foundation sizes and the resulting increase in noise exposure, tighter regulation in countries such as Germany and Great Britain has been introduced. The Danish Energy Agency (Energistyrelsen) has decided that Denmark will increase focus on construction noise associated with wind farms in Danish waters.

In connection with the tender of Horns Rev 3 Offshore Wind Farm in the Danish part of the North Sea, Energinet.dk on behalf of the Danish Energy Agency and the Danish Nature Agency, established a working group for marine mammals and underwater noise. This working group has given recommendations on how to regulate underwater noise associated with the construction of Horns Rev 3 Offshore Wind Farm and future offshore wind farms at Kriegers Flak and six nearshore wind farms. The group has also provided recommendations for what the concession holder must fulfil and deliver in terms of prognosis and documentation of underwater noise emissions during construction.

At the moment EIAs are being carried out for six Danish offshore wind farms (Vesterhav Nord, Vesterhav Syd, Sæby, Sejerø Bugt, Smålandsfarvandet and Bornholm).

This memo has been prepared to ensure that the recommendations and guidelines establish by the working group is incorporated into the EIA studies for six Danish offshore wind farms.

This memo provides results based on the Working Group guidelines. Since deterrence distance is not given in the guidelines calculations are based on deterrence distances of 1 and 2 km for porpoise and seals. And according to guidelines effects without deterrence (1 m distance) is also included. These calculations will be the background for assessment of underwater noise effects on marine mammals in the EIA for the six Danish nearshore projects. The specific conditions concerning deterrence distance will be defined by the Authorities at a later stage.

3. Presentation of working group recommendations and model

The working group has written a memo describing how regulation of underwater noise should be handled for Horns Rev 3 Offshore Wind Farm and guidelines for how these methods are implemented on other Danish offshore wind farm projects under preparation. (Working Group 2014. Memorandum prepared for Energinet.dk. 2015).

The guidelines do not set specific values for deterrence distance using Pinger and seal scarer. This is primarily due to the risks of changes to regulation and recommendations as a result of the ever-increasing knowledge of underwater noise propagation and its adverse effects on marine mammals.

The working group describes a model for calculating the cumulative underwater noise impact from construction of offshore wind farms. This model utilizes the project specific sound attenuation over distance, the piling procedure (the progress of a single piling event) and the bio-acoustic thresholds for adverse effects on marine mammals. The model enables the concession holder to document the expected impact on the marine environment during the construction phase of any offshore wind farm.

Comparing the expected noise impact with the bio-acoustic thresholds for adverse effects on marine mammals, the concession holder is able to calculate if any attenuation of the source strength is necessary in order to avoid causing hearing damage to the marine mammals.

For the documentation of these calculations the concession holder shall provide a detailed description of how the prognosis has been prepared. As a minimum, the description shall comprise of:

- Description of which method had been used for estimating noise source strength,
- Description of which method has been used for estimation of sound propagation loss,
- Discussion of assumptions and simplifications inherent to the chosen model/method,

- Noise source strength as single strike 'broad-band' (12.5 Hz to 2 kHz) SEL and as single strike SEL spectrum in 1/3 octave bands at 100% hammer energy and full pile tip penetration at 750 m distance and at a depth of 1/3 and 2/3 of the water depth as well as back-propagated to 1 m distance,
- Depth chart of the bathymetry used for modelling,
- Tables of acoustic properties used for sea bed soils,
- Sound speed profiles used,
- 'Noise maps' showing spatial variation of single strike SEL. It is recommended that at least 18 radials are calculated. The spatial extent of noise maps shall be at least as large as the maximum fleeing distance of harbour porpoise given the expected duration of piling. If the concession holder includes the variation of noise source strength then noise maps shall be provided for each relevant noise source strength level, e.g. beginning of piling, end of piling, 'best location', 'worst location' etc.,
- Tables with best fit $X \cdot \log10(r) + \alpha \cdot r$ curves approximating the propagation loss in the direction where it is smallest,
- Proposed piling 'history', i.e. no. of blows, starting hammer energy level, end hammer energy level and incremental curve. To be provided as curves and as tables,
- Estimated 'efficiency spectrum' of proposed noise mitigation method (third-octave spectrum of insertion loss in dB SEL),
- Cumulative SEL for the driving of the pile(s), calculated with a fleeing animal as described later in this document,
- In the case noise mitigation in the form of damping has to be employed:
  - Single strike broadband SEL, and SEL spectrum in 1/3 octave band in 750 m distance with the noise mitigation fully employed,
  - Description of how the calculation has been performed.
- Mitigated single strike SEL at 750 m distance has to be calculated at the same hammer energy and at the same depth(s) as the unmitigated SEL.

To demonstrate the validity of the prognosis the concession holder is required to perform control measurements. Measurements shall be performed with the purpose of accurately and rapidly determining the cumulated SEL of the pile installation, and shall thus:

- Allow determination of SEL for each hammer strike,
- Employ calibrated omnidirectional hydrophones with a sensitivity deviation of less than ±2 dB up to 40 kHz in the horizontal plane and less than ±3 dB up to 40 kHz in the vertical plane,
- It is recommended that a calibration signal is recorded,
- Be conducted for the entire pile installation duration,
- Be performed in 750 m distance ±5% and shall be distance-corrected to 750 m using the approximated $X \cdot \log_{10}(r) + \alpha \cdot r$ propagation loss function,
- Be performed at two different depths, at 66% and 33% water depth (but in no case less than 2 m below the sea surface),
- Be recorded in a frequency range at least ranging from 12.5 Hz to 20 kHz,
- Be recorded in .wav-format at 44.1 kHz sampling rate and 16 bit resolution or better or in similar lossless format.

Subsequent reporting shall:

- Report calculated and measured SEL for each blow in tables and as curves as well as the cumulative SEL for the whole driving period,
- Include used hammer force for each hammer strike in tables and curves,
- Include hydrophone data and calibration,
- Be conducted for the entire pile installation duration,
- Provide position of measurement station, and hydrophone depths,
- Report results from different depths both separately and as the average dB-level of the two,
- Report details of calculation of distance correction,
- Be calculated for the frequency range between 12.5 Hz and 20 kHz,
- Report measurement data in .wav-format at 44.1 kHz sampling rate and 16 bit resolution or better or in similar lossless format.

For more information on noise prognosis, control measurements and reporting see (Working Group 2014. Memorandum prepared for Energinet.dk. 2015).

Using the model in accordance with the description above the concession holder is able to make decisions on how to construct a given offshore wind farm under the given environmental requirements stated by the authorities.

The model can also be used as a supportive tool when predicting environmental effects. In Chapter 5 and 6 the model is used to describe effects of constructing six different offshore wind farms on marine mammals.

4. Thresholds for noise impact on marine mammals

The working group for marine mammals and underwater noise have recommended thresholds for permanent hearing loss/ threshold shift (PTS), temporary hearing loss/ threshold shift (TTS) as well as thresholds for behavioural changes in marine mammals in Danish waters (Working Group 2014. Memorandum prepared for Energinet.dk. 2015).

Threshold values for inflicting impact have been determined by the group based on an assessment on available values from the most recent scientific literature.

Table 1 Threshold values for PTS, TTS and behavioural effects as recommended by the working group (Working Group 2014. Memorandum prepared for Energinet.dk. 2015). All levels are unweighted SEL.

Species	Behavioural response (dB re 1 µPa SEL)	TTS (dB re 1 µPa SEL cum)	PTS (dB re 1 µPa SEL cum)
Grey seal and harbour seal	-	176	200
Harbour porpoise	140 (single strike)	≥164	≥183

The threshold values recommended by the working group differ from the historic values used in the background reports in the EIAs for the six offshore wind farms.

Table 2 Threshold values used in the background reports in the EIAs for the six offshore wind farms. All levels are M-weighted SEL (* unweighted SEL).

Species	Behavioural response (dB re 1 µPa SEL)	TTS (dB re 1 µPa SEL cum)	PTS (dB re 1 µPa SEL cum)
Grey seal and harbour seal	171	171	186
Harbour porpoise	145 (single strike)	164*	179

By comparing Table 1 and Table 2 it is seen that the work has resulted in increased threshold values for TTS and PTS in seals and harbour porpoise. For an explanation of the different thresholds see (Working Group 2014. Memorandum prepared for Energinet.dk. 2015)

The working group was not able to recommend a threshold value for behavioural effects on seals. The main reason for this is that there is very limited evidence on how and when seals react to underwater noise.

Attention is drawn to the fact that the threshold values used in the background reports are updated according to the working group guidelines based on the newest scientific knowledge.
Attention is also drawn to the fact that the threshold values recommended by the working group might by subject to further adjustment in the near future, as new information emerges.

5. Noise impacts of offshore wind farms

As explained in Chapter 3, the new model allows calculation of the noise impacts to be expected if the sound source is not attenuated, but also the attenuation required to avoid hearing damage (PTS) on marine mammals. In this chapter the new model is used to calculate the noise impact and required attenuation for the six offshore wind farms based on the description of the projects in the respective EIA studies.

Section 5.1 below describes the input for the model for each of the six offshore wind farms, while the results are presented in section 5.2.

5.1 Model parameters

In order to ensure the possibility of comparison between the six offshore wind farms, it was decided to use the same source strength and piling procedure (progress of a single piling event) for the six offshore wind farms. Maximum source strength of 221.6 dB re 1 μPa SEL was chosen, along with a piling procedure of 6 hours with gradually increasing source strength.

Sound propagation is site-specific, and can vary significantly from project to project. The density of harbour porpoises and seals is also site-specific.

The sound propagation and animal densities in the different EIA studies are given in Table 3.

Regarding seals, the paucity of data (i.e. low number of detections) in aerial surveys conducted in the area would preclude a credible density estimate for seals as the standard errors on the estimates would be too large for the estimates to be useful. Estimates for harbour porpoises from SCANS surveys (or an even better example, common seabirds where you have hundreds or thousands of observations e.g. Petersen et al 2012) are based on a larger number of detections, sufficiently large enough to develop credible models of animal abundance and density. In general, there are not enough observations of seals from line transect surveys in these parts of the Danish waters to calculate valid density estimates.

However, at Vesterhav Nord and Syd OWF maximum density have been estimated using a reference for seal density in the German part of the North Sea and the few observations of seals in the park areas (Herr, et al. 2009). At Bornholm OWF the assessment of noise impact on seals is instead based on how big a part of the home range of the species is affected. This and the size of the populations of seals is used to estimate a conservative density of seals in the area. Because of the low number of detections it has not been possible to use similar procedures to quantify the number of seals affected at Sejerø Bugt, Smålandsfarvandet and Sæby OWF.

Table 3 Site-specific inputs for the model for each of the six offshore wind farms. Sound propagation is given for the direction where the sound is attenuated the least over distance, along with an average across all directions.

Offshore wind farm	Porpoise density	Seal density	Sound propagation scenario	Sound propagation parameters	
	N/km²	N/km² (harbour seal/grey seal)		X	α
Bornholm	0.01	0.10/0.08	Worst-case	13.8	0.0012
			Average	14.4	0.00135
Sejerø Bugt	0.28-0.61	–	Worst-case	18.7	0.000343
			Average	20	0.0008
Smålandsfarvandet	0.28-0.61	–	Worst-case	20	0.0028
			Average	20	0.0038
Sæby	0.28-0.61	–	Worst-case	14.5	0.00035
			Average	17.8	0.0004
Vesterhav Nord	0.45	0.05/0.05	Worst-case	14.2	0.0008
			Average	14.6	0.00095
Vesterhav Syd	0.67	0.08/0.08	Worst-case	13.9	0.00075
			Average	14.5	0.00075

5.2 Model results

The cumulative noise dose for animals in flight is calculated using the thresholds, as well as the piling procedure and noise propagation model.

The model also needs to include a minimum starting distance from the source for the animals. Experiments have shown that most porpoises react with strong aversive behaviour to seal scarers. The effective deterring range of seal scarers with regard to harbour porpoises is still largely unclear. However, several studies indicate an effective range of ~1-2 km from the active seal scarer, where the majority of animals have fled and avoid getting closer while the scarer is in use (M. J. Brandt, et al. 2013a, M. J. Brandt, et al. 2013b, Olesuik, et al. 2002, Coram, et al. 2014). As there are substantial differences between the studies in terms of the methodology as well as site specific differences, the results cannot be directly transferred to other areas. As a result of this, different starting distances are used in the calculations below.

Based on the above, the cumulative noise dose for animals in flight is calculated for a starting distance from the source of 1 m, 1 km and 2 km at the onset of piling. Additionally, the source strength attenuation necessary to prevent permanent hearing damage on marine mammals (PTS) is calculated. The calculated source strength attenuation should in combination with seal scarers theoretically reduce the number of marine mammals at risk of PTS to zero, however as there is no guarantee for 100 % deterrence or that animals will flee in the manner assumed by the model there will always be a risk of exceptions. The results of these calculations are shown in Table 4.

All results are given for the following two scenarios:

1. A worst-case scenario – noise exposure in the direction from the source, where the sound is attenuated the least, and thereby gives the worst-case noise exposure over distance.
2. An average scenario – noise exposure averaged over all calculated directions from the source.

Table 4 Calculation of the cumulative sound exposure level (SEL) experienced by fleeing animals and the matching reduction needed to avoid PTS in any animals. Note that the figures for seals are based on distances which are not scientifically founded, see text.

Offshore wind farm /species	Sound propagation scenario	Cumulative SEL at 1 m experienced by a fleeing animal (dB re 1µPa)	Cumulative SEL at 1 km experienced by a fleeing animal (dB re 1µPa)	Cumulative SEL at 2 km experienced by a fleeing animal (dB re 1µPa)	Reduction of source level with starting distance at 1 m to avoid PTS in any animals (dB)	Reduction of source level with starting distance at 1 km to avoid PTS in any animals (dB)	Reduction of source level with starting distance at 2 km to avoid PTS in any animals (dB)
Harbour porpoise							
Bornholm	Worst-case	214.6	194.5	190.9	31.6	11.5	7.9
	Average	214.4	192.1	188.2	31.4	9.1	5.2
Vesterhav Nord	Worst-case	214.5	194.3	191.4	31.5	11.3	8.4
	Average	214.3	192.5	189.2	31.3	9.5	6.2
Vesterhav Syd	Worst-case	214.6	195.5	192.7	31.6	12.5	9.7
	Average	214.4	193.5	190.5	31.4	10.5	7.5
Sejerø	Worst-case	213.7	180.7	177.5	30.7	-2.3	-5.5
	Average	213.6	174.9	170.5	30.6	-8.1	-12.5
Smålandsfarvandet	Worst-case	213.6	171	163.9.9	30.6	-12	-19.1
	Average	213.6	169.4	161.1	30.6	-13.6	-21.9
Sæby	Worst-case	214.4	195.3	193.7	31.4	12.3	10.1
	Average	213.8	183.5	181.1	30.8	0.5	-2.5

Offshore wind farm /species	Sound propagation scenario	Cumulative SEL at 1 m experienced by a fleeing animal (dB re 1µPa)	Cumulative SEL at 1 km experienced by a fleeing animal (dB re 1µPa)	Cumulative SEL at 2 km experienced by a fleeing animal (dB re 1µPa)	Reduction of source level with starting distance at 1 m to avoid PTS in any animals (dB)	Reduction of source level with starting distance at 1 km to avoid PTS in any animals (dB)	Reduction of source level with starting distance at 2 km to avoid PTS in any animals (dB)
Seals							
Bornholm	Worst-case	214,6	194,5	190,9	14,6	-5,5	-9,1
	Average	214,4	192,1	188,2	14,4	-7,9	-11,8
Vesterhav Nord	Worst-case	214,5	194,3	191,4	14,5	-5,7	-8,6
	Average	214,3	192,5	189,2	14,3	-7,5	-10,8
Vesterhav Syd	Worst-case	214,6	195,5	192,7	14,6	-4,5	-7,3
	Average	214,4	193,5	190,5	14,4	-6,5	-9,5
Sejerø	Worst-case	213.7	180.7	177.5	13.7	-19.3	-22.5
	Average	213.6	174.9	170.5	13.6	-25.1	-29.5
Smålandsfarvandet	Worst-case	213.6	171	163.9	13.6	-29	-36.1
	Average	213.6	169.4	161.1	13.6	-30.6	-38.9
Sæby	Worst-case	214.4	195.3	193.1	14.4	-4.7	-6.9
	Average	213.8	183.5	180.5	13.8	-16.5	-19.5

As can be seen, there is generally similar reduction of source level in the worst case and average scenario – except for Sæby. The large difference between the average and the maximum is because of the fact that for Sæby, there is basically only deeper water in one general direction (northwest). Thus the average in all directions is quite a bit less than the maximum. Calculations have been performed in 8 directions representing all the representative bathymetry transects. Based on the 8 different propagation types the contour plots were generated in more than 20 directions.

In the individual assessments in Section 6, it is calculated how many marine mammals are at risk of PTS, TTS and behavioural change, if no seal scarers are used prior to the pile installation. This is indicated by the number of animals exposed to noise doses above the PTS, TTS and behavioural change thresholds. To be able to calculate the number of animals affected, areas on land or protected from the noise source by islands have been deducted.

6. Site specific assessments of impacts on marine mammals

6.1 Bornholm Offshore Wind Farm

In the background report for marine mammals at Bornholm Offshore Wind Farm the number of seals and porpoise affected by the piling of one foundation has been evaluated. In the table below the number of animals affected as predicted by the new model using different scenarios is presented.

Table 5 Number of animals affected in the background report and based on the new model. Numbers refers to piling of one foundation.

Effect	Background report (n)	New model – worst case - no deterrence and no reduction of source level (n)	New model – 1 m deterrence and 31,6 dB reduction of source level (n)	New model – 1 km deterrence and 11,6 dB reduction of source level (n)	New model – 2 km deterrence and 7,9 dB reduction of source level (n)
PTS (porpoise)	4	1	0	0	0
TTS (porpoise)	13	9	0	3	4
Behavioural effect (porpoise) - (single strike)	6	11	0	4	6
PTS (harbour seal)	8	0	0	0	0
TTS (harbour seal)	58	27	0	4	8
PTS (grey seal)	10	0	0	0	0
TTS (grey seal)	67	21	0	3	6

In the background report it is concluded that there is no need for actively reducing the noise as long as seal scarers and pingers are used. It is concluded that the noise from piling will not have an effect on marine mammals at population level, and that seal scarers and pingers will prevent PTS.

However, in the new model it is a requirement that not a single animal risks being subjected to PTS. As Table 5 shows this is not the case at Bornholm in the worst case scenario. This means that the maximum allowed noise level at Bornholm should be reduced.

For instance, if the starting distance of a fleeing porpoise is 2 km the cumulative SEL experienced by the animal can be calculated as 190.9 dB (Table 4). If the PTS threshold for porpoise is 183 dB then the source level, SEL_{Max} (221.6 dB SEL, Section 5.1) will have to be reduced by 7.9 dB to avoid any porpoise being subjected to PTS.

If the PTS threshold for porpoise is 183 dB, the source level, SEL_{Max} is 221.6 dB SEL (Section 5.1) and the starting point of porpoises is very close to the pile-driving site (1 m), the result of the model is that the source level will have to be reduced by 31,6 dB to avoid any porpoise being subjected to PTS. If harbour porpoises are deterred to a distance of 1 or 2 km (using pingers and seal scares) the source level will have to be reduced by 11,6 or 7,9 dB respectively to avoid any porpoise being subjected to PTS.

The reduction can be achieved by using smaller foundations, fewer strikes, active noise reduction measures etc.

As the waters around Bornholm OWF are not thought to be part of a kernel area for porpoise, and because there are no important haul-outs in the vicinity of the farm the background report does not suggest more stringent noise thresholds as a measure to reduce behavioural effects.

6.2 Vesterhav Nord Offshore Wind Farm

In the background report for marine mammals at Vesterhav Nord Offshore Wind Farm the number of seals and porpoise affected by the piling of one foundation has been evaluated. In the table below the number of animals affected as predicted by the new model using different scenarios is presented.

Table 6 Number of animals affected in the background report and based on the new model. Numbers refers to piling of one foundation.

Effect	Background report (n) (for seals numbers are from EIA)	New model – worst case - no deterrence and no reduction of source level (n)	New model – 1 m deterrence and 31,5 dB reduction of source level (n)	New model – 1 km deterrence and 11,3 dB reduction of source level (n)	New model – 2 km deterrence and 8,4 dB reduction of source level (n)
PTS (porpoise)	326	65	0	0	0
TTS (porpoise)	1,552	584	1	212	286
Behavioural effect (porpoise) - (single strike)	418	614	8	250	321
PTS (seals)	4	0	0	0	0
TTS (seals)	96	22	0	3	5

In the background report it is concluded that there is a need for reducing the noise in addition to using seal scarers and pingers. It is concluded that the noise from piling in the worst case scenario will have a moderate effect on marine mammals.

The use of the new model also results in a requirement of the use of seal scares and pingers as well as noise reduction to ensure that no animals are at risk of being subjected to PTS.

If the PTS threshold for porpoise is 183 dB, the source level, SELMax is 221.6 dB SEL (Section 5.1) and the starting point of porpoises is very close to the pile-driving site (1 m), the result of the model is that the source level will have to be reduced by 31,5 dB to avoid any porpoise being subjected to PTS. If harbour porpoises are deterred to a distance of 1 or 2 km (using pingers and seal scares) the source level will have to be reduced by 11,3 or 8,4 dB respectively to avoid any porpoise being subjected to PTS.

The reduction can be achieved by using smaller foundations, fewer strikes, active noise reduction measures etc.

As the waters around Vesterhav Nord OWF are not thought to be part of a kernel area for porpoise, and because there are no important haul-outs in the vicinity of the farm it is suggested that it is not necessary to use more stringent noise thresholds as a measure to reduce behavioural effects beyond the reduction achieved by the described reduction in source level.

6.3 Vesterhav Syd Offshore Wind Farm

In the background report for marine mammals at Vesterhav Syd Offshore Wind Farm the number of seals and porpoise affected by the piling of one foundation has been evaluated. In the table below the number of animals affected as predicted by the new model using different scenarios is presented.

Table 7 Number of animals affected in the background report and based on the new model. Numbers refers to piling of one foundation.

Effect	Background report (n) (for seals numbers are from EIA)	New model – worst case - no deterrence and no reduction of source level (n)	New model – 1 m deterrence and 31,6 dB reduction of source level (n)	New model – 1 km deterrence and 12,5 dB reduction of source level (n)	New model – 2 km deterrence and 9,7 dB reduction of source level (n)
PTS (porpoise)	691	140	0	0	0
TTS (porpoise)	2,818	1,106	2	371	489
Behavioural effect (porpoise) - (single strike)	814	1,121	16	412	530
PTS (seals)	13	0	0	0	0
TTS (seals)	140	47	0	5	9

In the background report it is concluded that there is a need for reducing the noise in addition to using seal scarers and pingers. It is concluded that the noise from piling in the worst case scenario will have a moderate effect on marine mammals.

The use of the new model also results in a requirement of the use of seal scares and pingers as well as noise reduction to ensure that no animals are at risk of being subjected to PTS.

If the PTS threshold for porpoise is 183 dB, the source level, SELMax is 221.6 dB SEL (Section 5.1) and the starting point of porpoises is very close to the pile-driving site (1 m), the result of the model is that the source level will have to be reduced by 31,6 dB to avoid any porpoise being subjected to PTS. If harbour porpoises are deterred to a distance of 1 or 2 km (using pingers and seal scares) the source level will have to be reduced by 12,5 or 9,7 dB respectively to avoid any porpoise being subjected to PTS.

The reduction can be achieved by using smaller foundations, fewer strikes, active noise reduction measures etc.

As the waters around Vesterhav Syd OWF are not thought to be part of a kernel area for porpoise, and because there are no important haul-outs in the vicinity of the farm it is suggested that it is not necessary to use more stringent noise thresholds as a measure to reduce behavioural effects beyond the reduction achieved by the described reduction in source level.

6.4 Sejerø Bugt Offshore Wind Farm

Sejerø Bugt is characterized as a high density area for harbour porpoises, but as there are no site specific densities available, the 2005 density estimate of 0.28 N/km^2 in Kattegat from Hammond (2013) and the 2012 density estimate of 0.61 N/km^2 in the eastern Kattegat, Inner Danish waters and Western Baltic from Sveegaard et al. (2013) will serve to represent two different densities throughout the Kattegat. It is therefore important to evaluate potential differences between the background report and the results of the new model. There are considerable differences when looking at the estimated number of harbour porpoises affected by pile driving at Sejerø Bugt OWF (Table 8). The background report estimates that the number of individuals potentially exposed to PTS inducing noise levels would likely be several hundred if no mitigation is used. Using the new model this estimate has falls to 0. A similar trend can be seen for the number of harbour porpoises experiencing behavioural effects, but for TTS depending on the density the number is largely unaffected.

Table 8 Number of animals affected in the background report and based on the new model using the worst-case sound propagation model. Numbers refer to piling of one foundation.

Effect	Background report (n)	New model – worst case - no deterrence and no reduction of source level (n)	New model – 1 m deterrence and 30.7 dB reduction of source level (n)	New model – 1 km deterrence and 0 dB reduction of source level (n)	New model – 2 km deterrence and 0 dB reduction of source level (n)
PTS (porpoise)	290	0-1*	0	0	0
TTS (porpoise)	335	165-360*	0	165-358*	162-353*
Behavioural effect (porpoise) - (single strike)	1,660	141-306*	0-1*	140-305*	137-299*

*The range of animals affected is due to two different densities reported for harbour porpoises in the inner Danish waters (see chapter 5).

There are four known factors that can contribute to this change; 1) The impact thresholds have been modified according to new evidence (see chapter 4), 2) Animal fleeing has been included in the model whereas the background report assumed 1 hour of sound accumulation to accommodate this, 3) the new method includes soft start/ramp-up, and 4) The sound propagation has been remodelled. Overall a higher sound transmission loss in the propagation model would result in a decrease in the number of animals affected. The inclusion of animal fleeing and soft start would also likely result in a smaller number of animals being affected especially by PTS. The changes in thresholds between the background report and the new model, should also lead to less animals experiencing PTS, as the threshold has been increased. However, as required according to the new guidelines measuring sound propagation in the area would be needed to fully validate the sound propagation model, and thus the predictions made above.

The new model also provides an estimate of how much the noise needs to be mitigated to comply with the new thresholds. If no deterring devices are used porpoises could in theory be present very close to the pile driving site (close to 1 m) though it is very unlikely the noise source level would have to be attenuated by >30 dB in order to insure that no porpoises would experience PTS inducing noise levels.

The new model also includes a scenario where the majority of harbour porpoises are assumed to be deterred to a distance using pingers and seal scarers. Regardless of whether the starting distance used in the model is either 1 or 2 km (Table 8) there is very little difference in the number of affected animals. The initial background report suggests that the use of mitigation measures is necessary to alleviate the risks posed to marine mammals from pile driving. The new model predicts that if porpoises are displaced to a distance of 1 km or more, no further mitigation should be necessary in terms of reducing the risk of PTS (Table 8). However, there is still substantial risk of TTS and behavioural effects.

Due to insufficient data on harbour seals and grey seals, estimating of the number of animals affected has not been possible in neither the background report nor using the new model. However, as they can be found in the area, and their responsiveness to seal scarers is unknown, they could potentially be close enough to the pile to be exposed to PTS inducing noise levels. Seals can thus theoretically be very close to the pile. If seals are very close to the pile (~1 m) noise source levels would have to be attenuated by 14 dB. However, based on the sound propagation models calculations the transmission loss in the wind farm construction area is very high. Therefore at a distance of 10 m the noise level has fallen to the PTS threshold for seals, and they should not be at risk of PTS beyond this distance.

6.5 Smålandsfarvandet Offshore Wind Farm

Smålandsfarvandet is also an important area for harbour porpoises according to the background report, but as there is no site specific densities, the densities from Hammond (2013) and Sveegaard et al. (2013) are used. The substantial difference between the background report and the new model when estimating the number of harbour porpoises affected by pile driving (Table 9) is therefore very important to note. More than one hundred harbour porpoises are estimated to suffer from PTS in the background report, while 0 individuals are estimated to be affected at these noise levels in the new model. The number of harbour porpoises experiencing TTS and behavioural effects is also reduced significantly.

Table 9 Number of animals affected in the background report and based on the new model using the worst-case sound propagation model. Numbers refer to piling of one foundation.

Effect	Background report (n)	New model – worst case - no deterrence and no reduction of source level (n)	New model – 1 m deterrence and 30.6 dB reduction of source level (n)	New model – 1 km deterrence and 0 dB reduction of source level (n)	New model – 2 km deterrence and 0 dB reduction of source level (n)
PTS (porpoise)	108	0	0	0	0
TTS (porpoise)	120	4-8*	0	3-6*	0**
Behavioural effect (porpoise) - (single strike)	209	12-26*	0	11-24*	8-18*

*The range of animals affected is due to two different densities reported for harbour porpoises in the inner Danish waters (see chapter 5).

**The TTS range was shorter than 2 km, and this scenario assumes that no porpoises are within 2 km of the pile.

As was the case for Sejerø Bugt the drastic changes in the number of affected porpoises in Table 9 is likely caused by the changes is thresholds, acoustic transmission loss model and the inclusion of animal fleeing into the model, still measuring sound propagation would be needed to fully validate the sound propagation model, and thereby the predictions made above.

Similarly if no deterring devices are used and porpoises theoretically could be present very close to the pile driving site (close to 1 m) the noise source level would have to be attenuated by >30 dB in order to insure that no porpoises would experience PTS inducing noise levels.

The new model for this area also shows very little difference on the number of animals affected regardless of the deterring distance assumed (1 or 2 km), and predicts that if porpoises are displaced to a distance of 1 km or more, no further mitigation should be necessary (Table 9).

As was the case for Sejerø Bugt insufficient data on harbour seals and grey seals, prevented estimating the number of animals affected in the background report as well as when using the new model. However, as they can be found in the area, they can theoretically be very close to the pile, and could again potentially be close enough to the pile to be exposed to PTS inducing noise levels, and noise source levels would have to be attenuated by 14 dB. Based on the sound propagation models calculations the transmission loss in this wind farm construction area is also very high, and the modelling results indicate that at a distance of 7 m the noise level has fallen to the PTS threshold for seals. Seals should thus not be at risk of PTS beyond this distance.

6.6 Sæby Offshore Wind Farm

Though the Sæby area is not a high density area, the background report characterizes it to be of moderate importance for harbour porpoises. As there is no site specific densities, the densities from Hammond (2013) and Sveegaard et al. (2013) are used. Changes in the impact thresholds and the sound propagation model and thus the impact ranges, can cause substantial changes in the number of harbour porpoises estimated to be affected negatively. Table 10 shows the difference between the background report and the results of the new model. The number of animals likely to experience PTS inducing noise levels has been reduced a little, but there is next to no change in the number of animals experiencing TTS and behavioural reactions. Measuring sound propagation as stated in the guidelines would still be needed to fully validate the sound propagation model.

If no deterring devices are used and porpoises thus theoretically could be very close to the pile-driving site (1 m) the noise source level should be attenuated by 31 dB in order to insure that no porpoises would be at risk of getting PTS, and even if harbour porpoises are deterred to a distance of 1or 2 km the noise source levels would have to be mitigated beyond the use of pingers and seal scarers. There are marked decreases in the number of animals affected if a 2 km deterring distance is assumed as opposed 1 km deterring distance (Table 10). However, the noise attenuation needed to accommodate the requirements of no porpoises being exposed to PTS risks differ by only 2 dB from12 to 10 dB for 1 and 2 km deterring distances respectively. This may partly be explained by the sound spreading in the propagation model reflecting the acoustic conditions in the construction area. At Sæby sound spreading is closer to the theoretical cylindrical spreading model, where a 3 dB increase in sound level causes a doubling of the impact range. At Sejerø Bugt and Smålandsfarvandet the sound spreading model is close to the theoretical spherical spreading where a 6 dB increase in sound level causes a doubling of the impact range.

Once again due to insufficient data on seal distribution, modelling of the number of seals affected was not undertaken in the background report or the new modelling, but as they can be found in the area, they could theoretically be very close to the pile, and could again potentially be close enough to the pile to be exposed to PTS inducing noise levels, and noise source levels would have to be attenuated by 14 dB, to accommodate this. However, the modelling results indicate that at a distance of 150 m the noise level has fallen to the PTS threshold for seals. Seals should thus not be at risk of PTS beyond this distance. If the mitigation measures required for porpoises are instigated it would reduce the risk of PTS in seals substantially as well, as they would have to be within 2-3 m of the pile, to be subjected to PTS inducing noise levels, which seems to be an unlikely situation.

Table 10 Number of animals affected in the background report and based on the new model using the worst-case sound propagation model. Number refers to piling of one foundation.

Effect	Background report (n)	New model – worst case - no deterrence and no reduction of source level (n)	New model – 1 m deterrence and 31.4 dB reduction of source level (n)	New model – 1 km deterrence and 12.3 dB reduction of source level (n)	New model – 2 km deterrence and 10.1 dB reduction of source level (n)
PTS (porpoise)	444	143-331*	0	0	6
TTS (porpoise)	1,637	1218-2653*	1-2*	338-845*	505-1,101*
Behavioural effect (porpoise) - (single strike)	1,038	909-1981*	6-12*	264-576*	340-741*

*The range of animals affected is due to two different densities reported for harbour porpoises in the inner Danish waters (see chapter 5).

7. Outlook and discussion

In the memo written by the working group describing how regulation of underwater noise should be handled for Horns Rev 3 Offshore Wind Farm, an outlook and discussion section was included (Working Group 2014. Memorandum prepared for Energinet.dk. 2015). This section is still considered valid, and should be consulted for further information.

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