Environmental Impact Assessment Report - Volume 2B Addendum

Appendix 10-4: Updated Subsea Noise Modelling Report

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Environmental Impact Assessment Report – Addendum
Appendix 10-4: Updated Subsea Noise Modelling Report

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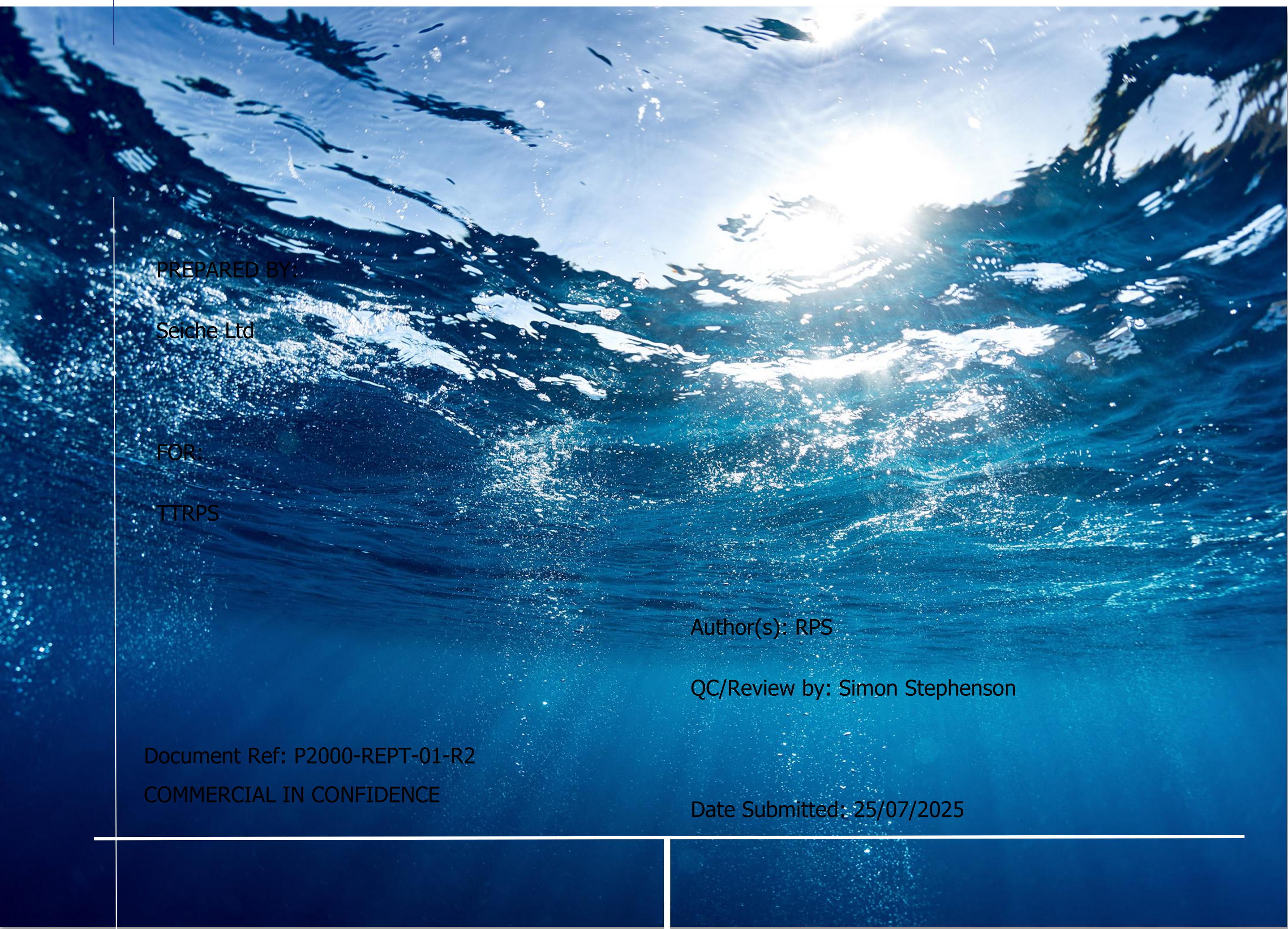
10-4 - Updated Subsea Noise Modelling Report

Updated Subsea Noise Modelling Report



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1 Introduction

This report has also been prepared in response to a Request for Further Information (RFI) from An Coimisiún Pleanála (formally An Bord Pleanála) regarding the planning application (case reference 319799) for the Oriel Wind Farm Project (hereafter referred to as "the Project") and in particular the following request noted as 9.H.

> It is noted that recent research (Wood et al., 2023) suggests that the modelling method of Weston (1971) used in the application, has been found to be problematic and potentially underestimates the received levels from the noise sources. The 0.5% value used in the Subsea Noise Technical Report is within a reasonable range, however no justification for this value has been provided, therefore it cannot be assumed it has been chosen based on specific aspects of the operations. Options for this value vary, and may reach up to 1.56%, which would give a difference of 4.9dB from the 0.5% used in the assessment. The applicant is requested to address these concerns and, in particular, to provide a justification for the modelling methodology employed.

This report has also been prepared in response to comments received from the Irish Whale and Dolphin Group (IWDG) submission on the Project application. The IWDG comments in relation to underwater acoustic modelling are as follows:

In section 1.5.2 Construction phase in the Subsea Noise Technical Report the modelled assessment of the amount of sound energy input into the marine environment during a piling operation with 9.6m piles using a maximum of 3500kJ of energy is based on the assumption that 1% of hammer energy is converted into sound to derive the SEL. This is based on a review of literature from Robinson et al., 2009, Robinson et al., 2013, Lepper et al., 2012 and Bailey et al., 2010 and is calculated according to De Jong & Ainslie (2008):

$$SEL = 120 + 10\log_{10}\left(\frac{\beta E c_0 \rho}{4\pi}\right)$$

Where β is the acoustic energy conversion efficiency, which is taken to be 0.5%[1]*, c_0 is the speed of sound in seawater in m/s, and ρ is the density of seawater in kg/m^3.*

This energy conversion factor (ECF) method to model the sound outputs from piling has been reviewed by Wood et al. (2023) for Marine Scotland who recommended that the method should not be accepted in EIAs due to the evident errors in its predictions, based as it is on point source assumptions which so not apply in the case of piling. In addition, the choice of 0.5% for β is arbitrary, reliable estimates ranging from 0.17% to 1.56% which are equivalent to a 9.6dB range.

[1] Note that as above, a conversion factor of 1% was used in appendix 10-2: Subsea Noise Technical Report (EIAR volume 2B). 0.5% was incorrectly stated in the definitions for the equation (page 19 of appendix 10-2) and it is assumed this is why it was taken forward to the IWDG submission. However, the correct value of 1%, was also referenced (on page 19 of appendix 10-2). For clarity, 1% was used in the subsea noise modelling (in appendix 10-2) and in preparing the updated subsea noise model to inform this report.

Section 1.7 Sound propagation modelling methodology describes how the propagation model chosen is based on Weston (1971), which is relatively simplistic. Wood et al. (2023) found this choice to be inappropriate, potentially underestimating the received levels: "Combining the effect of predicting the source level using a point-source equivalent ECF of 0.5 % and using point-source propagation for one presented example yielded underestimate of the per-pulse sound exposure levels between 100 and 1000 m from the pile of between 9.5 and 12.1 dB. Using the point-source equivalent ECF method for a benchmark case scenario similarly showed underestimates between 6.3 and 10.2 dB for receivers at 250, 750, and 1500 m from the pile". The IWDG also understands that the new Australian regulations for underwater noise, currently in final review, will explicitly preclude the modelling approach taken in this EIAR as being inadequate and overly simplistic.

Based on the queries raised, the two key issues raised can be summarised as:

- Is the method of determining the source sound level for piling appropriate?
- Is the method of determining the sound propagation appropriate?

Whilst the assessment undertaken as part of the EIAR considered the best available advice at the time, advances have been made in the field of underwater sound modelling since the assessment was carried out, particularly in the field of noise generated by piling activities. Therefore, Seiche has undertaken an updated noise modelling exercise to remodel the injury ranges associated with piling to present the most scientifically rigorous and up to date results. The results of the remodelling exercise and comparison to the EIAR (2024) noise modelling results are presented in this report.

2 Background

2.1 EIAR Methodology

Noise modelling for the Oriel Wind Farm Project (hereafter referred to as 'the Project) is presented in appendix 10-2: Subsea Noise Technical Report (volume 2B) of the EIAR. The modelling was undertaken using peer reviewed and commonly applied methodologies that represented standard practice at the time.

The source modelling used in the EIAR used the equivalent monopole Energy Conversion Factor (ECF) (De Jong and Ainslie, 2008). The assumption used for the modelling was that approximately 1% of the hammer energy is converted into sound, based on a review of literature from Robinson *et al.*, 2009, Robinson *et al.*, 2013, Lepper, 2007, Lepper *et al.*, 2012 and Bailey *et al.*, 2010).

Propagation modelling for the EIAR used the Weston Energy Flux model. This model had been widely used in other noise modelling studies for piling and was also based on the assumption of a point source. This was acknowledged in the EIAR (appendix 10-2: Subsea Noise Technical Report (volume 2B)), section 1.5, which stated that:

"Underwater sound sources are usually quantified in dB scale with values generally referenced to 1 µPa pressure amplitude as if measured at a hypothetical distance of 1 m from the source (called the Source Level, (SL)). In practice, it is not usually possible to measure at 1 m from a source, but the metric allows comparison and reporting of different source levels on a like-for-like basis. In reality, for a large sound source this imagined point at 1 m from the acoustic centre does not exist. Furthermore, the energy is distributed across the source and does not all emanate from this imagined acoustic centre point. Therefore, the stated sound pressure level at 1 m does not occur for large sources. In the acoustic near field (i.e. close to the source), the sound pressure level will be significantly lower than the value predicted by the SL."

2.2 Marine Scotland Energy Conversion Factor Report

Marine Scotland commissioned a study to look at the accuracy of ECFs (Wood *et al.*, 2023) which was published in October 2023, after the noise modelling for the Project had been completed. The report concluded that there were benefits and shortcomings of the ECF method, as summarised in Table 2-1.

Table 2-1: Summary of the Benefits and Shortcomings of the ECF method as Identified by Wood et al. (2023)

Benefits	Shortcomings
Its simplicity in that it requires only the hammer energy and a value for β to generate a source function.	The ratio of hammer input energy to radiated acoustic energy in the water column is not a fixed universal value. Recorded values range from 0.17 % to 1.56 %, which equates to a range of 9.6 dB.
The speed at which one can generate source inputs and modelling outputs.	The dependence of this ratio on input parameters based on the pile, the hammer, the environment, and the geometry is not well understood.
Its exploitation of a powerful physical principle, i.e., conservation of energy.	

Wood *et al*. (2023) also reviewed use of point source propagation models for piling and concluded that *"the nature of propagation from point source models is substantially different from one suitable for piling noise. It is also noted that a source level does not exist for a pile, and that it is unhelpful to attempt to characterise it as such… Predictions of distances to sound level thresholds can often be out by orders of magnitude, with examples showing errors up to 10 dB within 5 km of the pile."*

Wood *et al*. (2023) also noted that the effects of using both ECF and point source modelling methodology can be compounded when used together. The report made the following recommendations:

- Point-source equivalent ECF should not be used, having been superseded by more modern approaches.
- Numerical modelling provides the greatest flexibility in terms of selection of hammer, pile, and environment and is considered the leading method:
- Genuine values of the ECF could be used provided they are used with a model that supports them.
- Where measurements exist of similar scenarios, these may be used with adjustments to apply to alternative scenarios with caution (e.g. von Pein et al., 2022).

3 Acoustic Modelling Methodology

3.1 Revised Source Modelling Method

Source levels were determined by scaling data measured during pile driving for similar operations to the Project in order to determine source levels. The subject of noise generation due to impact piling is an active area of research and the evidence base is constantly being updated by new measurements, research and published papers. A recent peer-reviewed paper (von Pein *et al.*, 2022) presents a methodology for the dependencies of the SEL on strike energy, diameter, ram weight, and water depth that can be used for scaling measured or computed SELs from one project to another. The method has been shown to be usable within practical ranges of accuracy, especially if the measurement uncertainties are taken into account. The paper suggests that scaling should be performed over either a small number of very similar piling situations or over a larger data set with according averaging. This is a recently published method for deriving the noise source level which provides a more scientifically robust method compared to using an energy conversion factor (the conversion factor method simply assumes that a percentage of the hammer energy is converted into noise irrespective of parameters such as pile size, water depth and hammer specifications).

Since the von Pein *et al*. (2022) methodology takes into account several site-specific and pile-specific factors, in addition to hammer energy, and because it is based on a scientifically rigorous and peer reviewed study, it is therefore considered to be a significant improvement on the use of ECFs.

Using the equation below (von Pein *et al.*, 2022), a broadband source level value is calculated for the noise emitted during impact pile driving operation in each operation window.

$$SEL_1 = SEL_0 + 10log_{10}\left(\frac{E_1}{E_0}\right) + 16.7log_{10}\left(\frac{d_1}{d_0}\right) - 10log_{10}\left(\frac{m_{r,1}}{m_{r,0}}\right) + 750\left[\frac{10log_{10}(|R_0|^2)}{2\,cot(\varphi)}\left(\frac{1}{h_1} - \frac{1}{h_0}\right)\right]$$

In this equation, *E* is the hammer energy employed in Joules, *d* is the pile diameter, m_r is the ram mass in kg, *h* is the water depth in m, $|R_0|$ is the reflection coefficient and φ is the propagation angle (approximately 17° for a Mach wave[2] generated by impact piling). The equation allows measured pile noise data from one site (denoted by subscript 0) to be scaled to another site (denoted by subscript 1).

The spectral distribution of the source SELs for impact piling were derived from the reference spectrum provided in the ORJIP ReCon report, reproduced in Figure 3.1.

[2] a Mach wave, also known as a weak discontinuity, is a pressure wave traveling with the speed of sound caused by a slight change of pressure added to a compressible flow

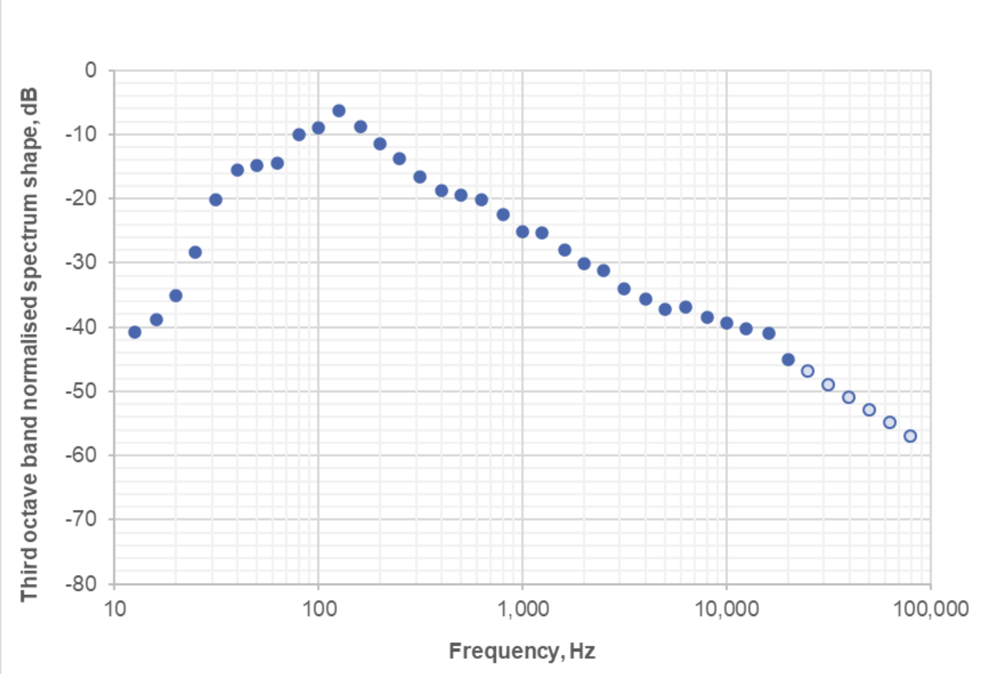

Figure 3.1: Normalised median 1/3 octave spectra for monopile installations used in the source level modelling.

3.2 Updated Sound Propagation Modelling Method

In the case of offshore pile installation using an impact hammer, the sound source can be thought of as a "line source" extending through the water column (or in the case of installations using a submersible hammer, a line source through a lower portion of the water column). The hammer strike at the top of the pile produces a compression wave in the pile resulting in radial displacement of the pile walls which is transmitted into the surround media (water and sediments) as sound waves. These compressional waves travel through the pile at circa 5,000 m/s, resulting in a conically shaped wavefront.

The updated underwater acoustic propagation modelling for this Project has been undertaken using a line-source energy flux model, based on an implementation of the energy flux model for a directional source set out in de Jong *et al.* (2019).

The line-source energy flux model (de Jong *et al.* 2019) includes the effect of directionality of the cone shaped wavefront associated with piling noise (circa. 17 degrees). This results in damped cylindrical spreading at shorter ranges and mode stripping behaviour at more distant ranges. At even more distant ranges, once the 'mode stripping' has eliminated the contribution of all waveguide modes except the lowest mode, propagation is evaluated according to a single mode regime.

For estimation of propagation loss of acoustic energy at different distances away from the sound source location (in different directions), the following steps were undertaken:

- The bathymetry information around this chosen source points will be extracted from the GEBCO database in 72 different transects.
- A geoacoustic model of the different seafloor layers in the survey region will be calculated based on the BGS borehole database and EMODnet sediment database.
- A calibrated line-source propagation model will be employed to estimate the transmission loss matrices for different frequencies of interest (from 25 Hz to 80 kHz) along the 72 different transects.
- Source levels for the line-source array will be determined based on a back-calculation from the received sound level and spectrum shape at 750 m (based on the scaling laws set out in von Pein et al. (2022)).
- The calculated source level values will be combined with the transmission loss results to achieve a frequency and range dependant RL of acoustic energy around the chosen source position.
- The TTS and PTS potential impact distances for different marine mammal groups will be calculated using relevant metrics and weighting functions (from Southall et al., 2019) and by employing a simplistic animal movement model (directly away from the sound source) where appropriate and compared with the results from the EIAR 2024.

3.3 Geo-acoustic and Sound-speed Input Parameters

Based on British Geological Society core data in the vicinity of the Project offshore wind farm area, the geo-acoustic model is based on the following parameters (Table 3-1):

Table 3-1: Geo-acoustic model parameters

Layer	V_p, m/s	V_s, m/s	α_p, dB/λ_p	α_s, dB/λ_s	density, kg/m^3
Sandy Mud	1,652	80	0.89	2.5	1,771

3.4 Sound Exposure Modelling

In the Subsea Noise Technical Report (see appendix 10-2, volume 2B), both unweighted SPLs and weighted cumulative SEL for different marine mammal groups were used to assess potential impact ranges. To calculate these for a swimming mammal the assumption is made that a mammal will swim away from the noise source at the onset of activities for the duration. As a marine mammal swims away from the sound source, the noise it experiences will become progressively more attenuated; the cumulative SEL is derived by logarithmically adding the SEL to which the mammal is exposed as it travels away from the source. This calculation was used to estimate the approximate minimum start distance for a marine mammal in order for it to be exposed to sufficient sound energy to result in the onset of potential injury. It should be noted that the sound exposure calculations are based on the simplistic assumption that the animal will continue to swim away at a fairly constant relative speed. The real-world situation is more complex, and the animal is likely to move in a more complex manner.

These were calculated with swim speeds listed below in Table 3-2. The same method and swim speeds were applied to calculate the revised injury ranges. Note that in the case of fish, the case of a static receptor has also been included as a sensitivity check.

Table 3-2: Swim speeds assumed for exposure modelling.

Species	Hearing Group	Swim Speed (m/s)	Source Reference
Harbour porpoise	VHF	1.5	Otani *et al.,* 2000
Harbour seal	PCW	1.8	Thompson, 2015
Grey seal	PCW	1.8	Thompson, 2015
Minke whale	LF	2.3	Boisseau *et al.,* 2021
Bottlenose dolphin	HF	1.52	Bailey and Thompson, 2010
White-beaked dolphin	HF	1.52	Bailey and Thompson, 2010
Basking shark	Group 1 fish	1.0	Sims, 2000
All other fish groups	All fish groups	0.5 and static	Popper *et al.,* 2014

4 Results

4.1 Comparison of Source and Propagation Models

The updated source model and line array model has been compared against the following scenarios:

- Use of 1% ECF combined with the Weston point source Energy Flux propagation modelling (as reported in the EIAR Subsea Noise Technical Report)
- Use of 1% ECF combined with the Directive Line Source Energy Flux propagation modelling
- Use of scaled source level (using von Pein et al., 2022) combined with the Directive Line Source Energy Flux propagation modelling

The results of this comparison are shown Figure 4.1.

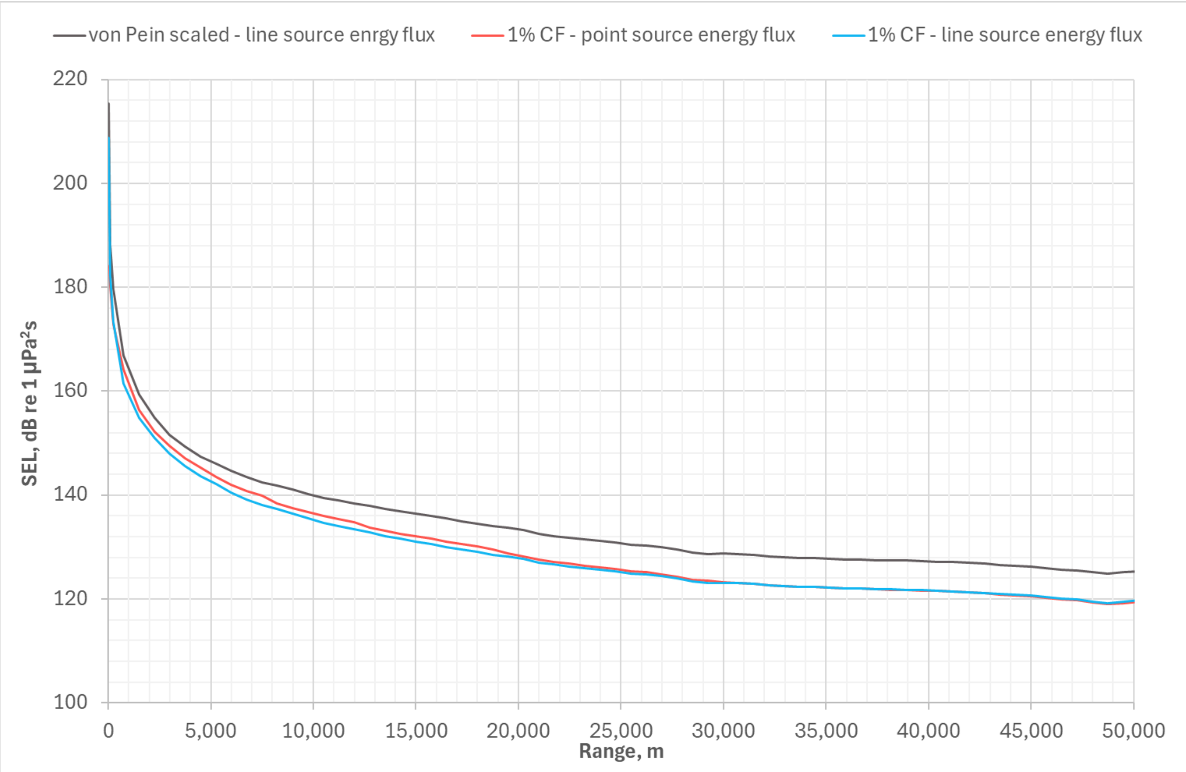

Figure 4.1: Comparison of models considered for the assessment: use of 1% ECF combined with the Weston point source Energy Flux propagation modelling (as reported in the EIAR Subsea Noise Technical Report); use of 1% ECF combined with the Directive Line Source Energy Flux propagation modelling; use of scaled source level (using von Pein *et al.*, 2022) combined with the Directive Line Source Energy Flux propagation modelling

As can be seen from Figure 4.1, the two models (point source and line source) using the ECF method result in similar received sound levels at ranges greater than 20 km, and inside of those ranges the point source energy flux model reported in the EIAR is more conservative (i.e. the point source model results in higher levels nearer to the pile compared to the line source method). The line source model using the von Pein *et al.* (2022) scaled source level resulted in consistently higher sound levels at all ranges. Consequently, it is concluded that the ECF source model used in the EIAR (2024) underestimated sound from piling compared to the more recent scaling method set out by von Pein et al. (2022).

4.2 Revised Injury Ranges

Impact ranges were modelled for both locations, however only the most adverse case injury ranges have been reported, taken for a monopile installation at the east of the Offshore Wind Farm Area. Cumulative SEL impact ranges for marine mammals are summarised in Table 4-1, for fleeing fish, sea turtles and basking sharks in

Table 4-2, and for static fish, sea turtles and basking sharks in Table 4-3, for single piling events (i.e. installation of one pile). Cumulative SELs are assessed in terms of two scenarios, a mitigated scenario in which all soft start and low energy phases of piling are applied, and a mitigated plus Acoustic Deterrent Device (ADD) scenario, which include the same mitigations but with the addition of a 15 minute period of ADD, to match what was reported in the EIAR subsea noise technical report (appendix 10.2, volume 2B).

It should be noted that at the residual ranges reported with the addition of the ADD, increasing the duration of the ADD would not be sufficient to reduce the residual TTS levels to a non-exceedance. However, it should be further noted that despite an increase in injury ranges, the addition of 15 minutes of ADD is sufficient to reduce all PTS ranges to a non-exceedance.

During impact piling the interaction with the seabed and the water column is complex. In these cases, a combination of dispersion (i.e. where the waveform shape elongates), and multiple reflections from the sea surface and bottom and molecular absorption of high frequency energy, the sound will lose its impulsive shape after some distance (generally in order of several kilometres).

An article by Southall (2021) discusses this aspect in detail, and notes that "*…when onset criteria levels were applied to relatively high-intensity impulsive sources (e.g. pile driving), TTS onset was predicted in some instances at ranges of tens of kilometers from the sources. In reality, acoustic propagation over such ranges transforms impulsive characteristics in time and frequency (see Hastie et al., 2019; Amaral et al., 2020; Martin et al., 2020). Changes to received signals include less rapid signal onset, longer total duration, reduced crest factor, reduced kurtosis, and narrower bandwidth (reduced high-frequency content). A better means of accounting for these changes can avoid overly precautionary conclusions, although how to do so is proving vexing*". The point is reenforced later in the discussion which points out that "*…it should be recognized that the use of impulsive exposure criteria for receivers at greater ranges (tens of kilometers) is almost certainly an overly precautionary interpretation of existing criteria*".

A recent investigation undertaken by Offshore Renewables Joint Industry Programme (ORJIP) and published in May 2024 (ORJIP, 2024) further investigated the metrics used to evaluate impulsiveness in order to the transition point. The report states that "*… we predict such a transition would happen within the first 0.6 km to 3.3 km depending on the pile diameter and hammer energy. If values of kurtosis ≥ 3 indicate full non-impulsiveness of the soundscape, the distance at which sounds would become fully non-impulsive ranges between 13.5 and > 55 km depending on the pile diameter and hammer energy... Species from the HF cetaceans hearing group would most likely not experience sounds from impact pile driving as impulsive if the pile diameter was ≥ 5m. For larger pile diameters, animals from the remaining* *three functional hearing groups would be exposed to sounds characterised as impulsive within the first 3.5 km from the piling site."*

Consequently, great caution should be used when interpreting any results with predicted injury ranges in the order of tens of kilometres.

Table 4-1: Summary of SEL injury ranges for marine mammals due to installation of one 9.6 m diameter monopile (N/E = threshold not exceeded).

Species/Group	Response	Threshold, SEL (dB re 1 µPa²s)	Range (m)	
			No ADD	15 min ADD
LF	PTS	183	1,135	N/E
	TTS	168	21,500	19,500
HF	PTS	185	N/E	N/E
	TTS	170	21	N/E
VHF	PTS	155	815	N/E
	TTS	140	14,500	13,000
PCW	PTS	185	11	N/E
	TTS	170	5,520	3,890
OCW	PTS	203	N/E	N/E
	TTS	188	N/E	N/E

Table 4-2: Summary of SEL injury ranges for moving fish due to installation of one 9.6 m diameter monopile (N/E = threshold not exceeded).

Hearing Group	Response	Threshold, SEL (dB re 1 µPa²s)	Range (m)
Group 1 Fish: No swim bladder (particle motion detection)	Mortality	219	N/E
	Recoverable injury	216	N/E
	TTS	186	5,520
Basking shark	Mortality	219	N/E
	Recoverable injury	216	N/E
	TTS	186	3,200
Group 2 Fish: Swim bladder not involved in hearing (particle motion detection)	Mortality	210	21
	Recoverable injury	203	147
	TTS	186	5,520
Group 3 and 4 Fish: Swim bladder involved in hearing (primarily pressure detection)	Mortality	207	51
	Recoverable injury	203	147
	TTS	186	5,520
Sea Turtles	Mortality	210	21
Fish eggs and larvae	Mortality	210	935

Table 4-3: Summary of SEL injury ranges for static fish due to installation of one 9.6 m diameter monopile (N/E = threshold not exceeded).

Hearing Group	Response	Threshold, SEL (dB re 1 µPa²s)	Range (m)
Group 1 Fish: No swim bladder (particle motion detection)	Mortality	219	385
	Recoverable injury	216	516
	TTS	186	9,620
Basking shark	Mortality	219	385
	Recoverable injury	216	516
	TTS	186	9,620
Group 2 Fish: Swim bladder not involved in hearing (particle motion detection)	Mortality	210	935
	Recoverable injury	203	1,860
	TTS	186	9,620
Group 3 and 4 Fish: Swim bladder involved in hearing (primarily pressure detection)	Mortality	207	1,250
	Recoverable injury	203	1,860
	TTS	186	9,620
Sea Turtles	Mortality	210	935
Fish eggs and larvae	Mortality	210	935

The injury ranges for marine mammals based on peak pressure are summarised in Table 4-4, and for fish, sea turtles and basking sharks in Table 4-5. These ranges represent the potential zone for instantaneous injury. The injury ranges for peak sound pressure are based on both the first strike the animal experiences at the closest point during each phase of the pile installation, as well as for the maximum hammer energy over the entire installation.

Table 4-4: Summary of peak pressure injury ranges for marine mammals due to impact piling of 9.6 m diameter monopiles (N/E = threshold not exceeded).

Species/Group	Response	Threshold, L_{0-pk}, dB re 1 µPa	Range (m)	
			First Strike	Highest Energy
LF	PTS	219	169	425
	TTS	213	273	684
HF	PTS	230	71	177
	TTS	224	114	286
VHF	PTS	202	653	1,638
	TTS	196	1,051	2,638
PCW	PTS	218	183	460
	TTS	212	295	741
OCW	PTS	232	60	151

	TTS	262	97	244

Table 4-5: Summary of peak pressure injury ranges for fish due to impact piling of 9.6 m diameter monopiles (N/E = threshold not exceeded).

Hearing Group	Response	Threshold, $L_{0\text{-}pk}$ (dB re 1 µPa)	Range (m)	
			First Strike	Highest Energy
Group 1 Fish: No swim bladder (particle motion detection)	Mortality	213	273	684
	Recoverable injury	213	273	684
Basking shark	Mortality	213	273	684
	Recoverable injury	213	273	684
Group 2 Fish: Swim bladder not involved in hearing (particle motion detection)	Mortality	207	439	1,101
	Recoverable injury	207	439	1,101
Group 3 and 4 Fish: Swim bladder involved in hearing (primarily pressure detection)	Mortality	207	439	1,101
	Recoverable injury	207	439	1,101
Sea Turtles	Mortality	207	439	1,101
Fish eggs and larvae	Mortality	207	439	1,101

The disturbance range for fish based on the SPL_{rms} metric is shown in Table 4-6.

Table 4-6: Summary of the disturbance ranges for fish due to the installation of 9.6 m diameter monopiles

Hearing Group	Response	Threshold, SPL_{rms} (dB re 1 µPa)	Range (m)
All Fish Groups	Disturbance	150	19,580

4.3 Comparison of Injury Ranges to EIAR 2024 Results

The above listed injury ranges found using the revised methodology are presented alongside the ranges presented in the EIAR (appendix 10-2, volume 2B), below in Figure 4.2 to Figure 4.4. For marine mammals, there is slight disparity between the peak injury ranges for PTS, with the new peak ranges all being greater (Figure 4.2). Similar is seen in the Fish, Sea turtles and Basking shark peak ranges (Figure 4.3). There is a larger difference for the SEL_{cum} ranges for marine mammals (Figure 4.2). With the new ranges markedly increased, over double the range for LF (minke whale), and over four times the range for VHF (harbour porpoise). However, for PCW (seals) the new SEL_{cum} range is decreased from the original EIA. For Sea turtles and Group 2 Fish the SEL_{cum} ranges are similar between the original EIA and revised results.

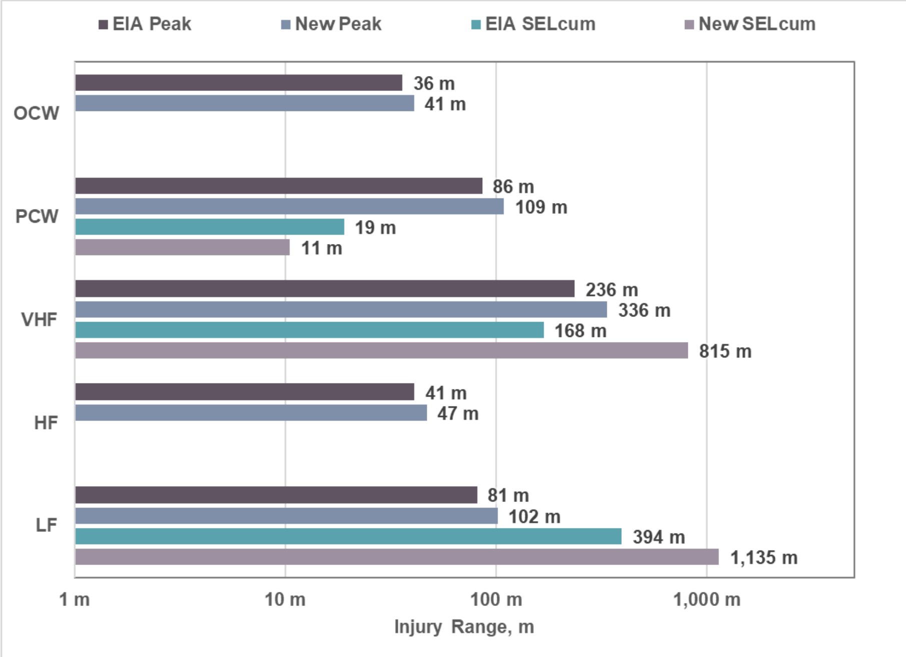

Figure 4.2: Comparison of PTS injury ranges for marine mammals, including peak ranges from first strike and SEL_{cum}

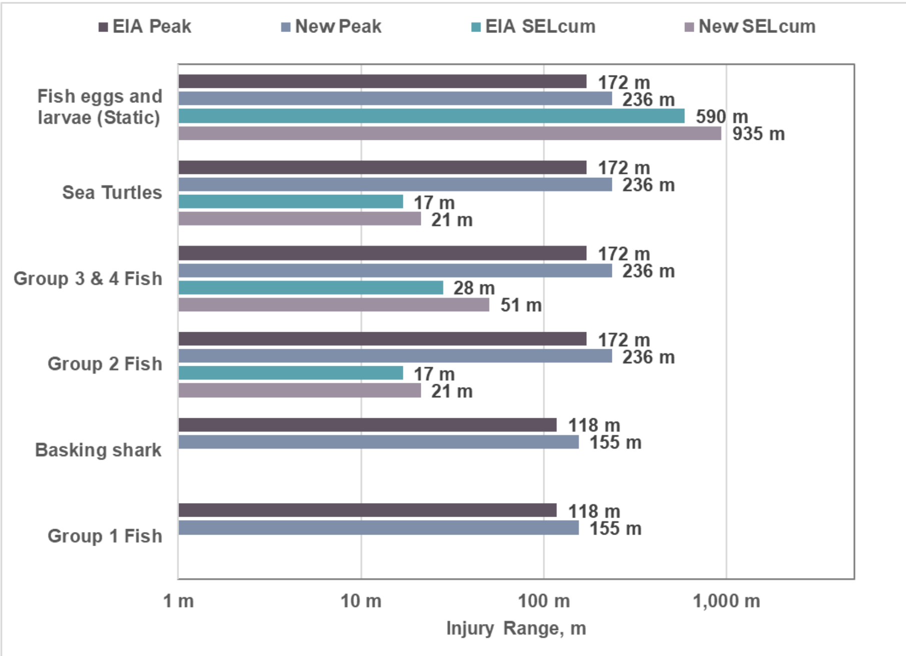

Figure 4.3: Comparison of mortality injury ranges for fish, sea turtles, and basking shark, including peak ranges from first strike and SEL_{cum}. In the case of SEL_{cum}, both ranges represent the moving fish scenario.

Similar to what was seen in the mortality comparison, the TTS comparison shows more similar ranges for the peak metric (Figure 4.4). However for the SEL_{cum} injury ranges all results seen are over double those reported in the initial Oriel EIAR (Figure 4.4).

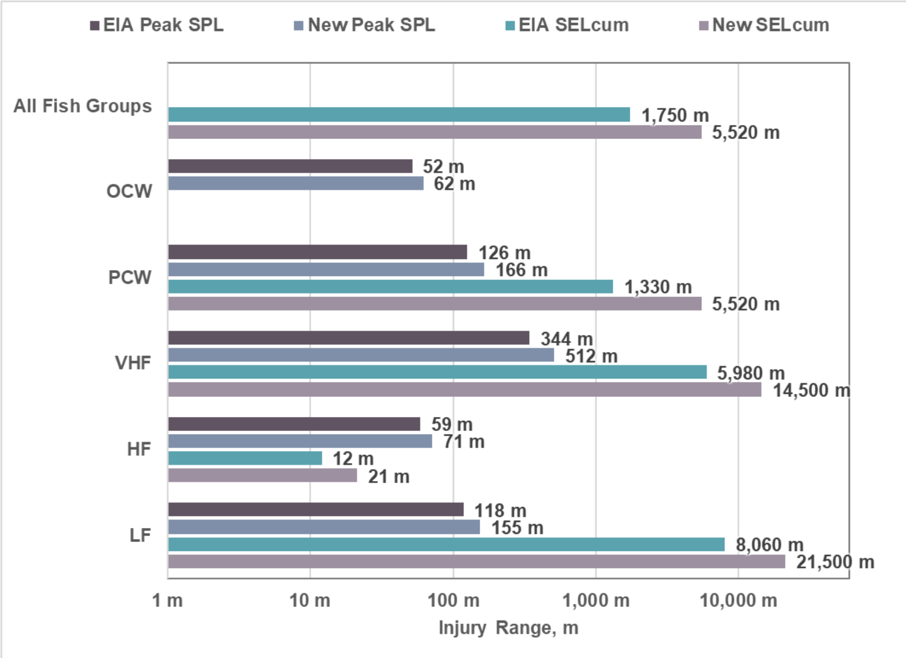

Figure 4.4: Comparison of TTS injury ranges for marine mammals and fish, for peak ranges from first strike and SEL_{cum}.

5 Summary and Conclusions

This report has sought to address the comments raised by the IWDG regarding the modelling of subsea noise and source level estimation due to piling as presented in the EIAR 2024. The revised underwater noise methodology uses a peer reviewed scaling model to derive source levels for piling, a directional line-source energy flux sound propagation model, in line with the methods suggested by Wood *et al.* (2024).

This revised methodology has been used to determine the range of potential effects on marine mammals, fish, sea turtles and basking sharks, for installation of monopiles due to noise from piling activities associated with the construction phase of the Project. The results are summarised in Table 5-1 for PTS and mortality and Table 5-2 for TTS, which shows the maximum injury ranges for each group of mammals, fish, turtles and basking sharks, for installation of monopiles, with and without mitigation, (the worst case of SEL or $L_{p,0\text{-}pk}$).

Table 5-1: Summary of maximum PTS injury ranges for marine mammals, and mortality for fish and turtles due to impact piling of single pile based on highest range of peak pressure or SEL (N/E = threshold not exceeded).

Species group	Injury range / m	
	No ADD	With 15 mins ADD
Low frequency cetacean	1,135*	425
High frequency cetacean	177	177
Very high frequency cetacean	1,638	1,638
Phocid carnivores	460	460
Other carnivores	151	151
Group 1 Fish: no swim bladder	684	684
Basking Sharks	684	684
Group 2 Fish: where swim bladder is not involved in hearing	1,101	1,101
Group 3 to 4 Fish: where swim bladder is involved in hearing	1,101	1,101
Sea turtles	684	684
Eggs and larvae	1,101	1,101

* – Cumulative SEL results in the greatest range of impact

Table 5-2: Summary of maximum TTS injury ranges for marine mammals and fish and turtles due to impact piling of single pile based on highest range of peak pressure or SEL (N/E = threshold not exceeded).

Species group	Injury range / m	
	No ADD	With 15 mins ADD
Low frequency cetacean	21,500*	19,500*
High frequency cetacean	286	286
Very high frequency cetacean	14,500*	13,000*
Phocid carnivores	5,520*	3,890*

Species group	Injury range / m	
	No ADD	With 15 mins ADD
Other carnivores	244	244
All fish groups	5,520*	5,520*

* – Cumulative SEL results in the greatest range of impact

Based on the results of this study it is concluded that:

- The Weston Energy Flux model and the directional line source variation of the Energy Flux model derived by de Jong *et al.* (2019) gave very similar results, with the point source Weston Energy Flux model in fact showing marginally more conservative results. However, the line source representation is a more scientifically rigorous approach which has now been adopted for this assessment and other recently submitted applications.
- It was found that the von Pein *et al.* (2022) method results in higher source sound levels than the ECF method.
- PTS and TTS ranges are generally (with some exceptions) higher using the revised modelling method compared to the noise modelling results presented in the EIAR.

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