Annex S Underwater Noise Assessment Approach

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Annex S.1 Approach to PTS and TTS-onset

The modelling of impact piling has been undertaken using the INSPIRE underwater noise model, developed by Subacoustech Environmental Ltd. The INSPIRE model (currently version 5.2) is a semi-empirical underwater noise propagation model based around a combination of numerical modelling (a combined geometric and energy flow/hysteresis loss method) and actual measured data. It is designed to calculate the propagation of noise in shallow (i.e., less than 100 m), mixed water; typical of the conditions around Ireland and the UK and well suited for use in the Irish Sea. The model has been tuned for accuracy using over 80 datasets of underwater noise propagation from monitoring around offshore piling activities. Full details of the INSPIRE model are presented in EIAR Volume III, Appendix 11.1: Underwater Noise Assessment (Revised March 2026).

The PTS-onset thresholds used to assess the potential for auditory injury to marine mammals during pile driving are those presented in Southall *et al.* (2019) for impulsive noise (Annex Table H). The TTS-onset thresholds are also presented (Annex Table H), whereby TTS is not regarded as injury given its temporary nature and any impacts relating to the effects of TTS are considered to be captured in the quantitative assessment of disturbance.

Impulsive sound sources, such as pile driving, have high peak sound pressure, short duration, fast rise-time, and broad frequency content at source.

Both instantaneous Sound Pressure Level (SPL_{peak}) and cumulative Sound Exposure Level (SEL_{cum}) PTS and TTS-onset thresholds have been presented by Southall *et al.* (2019) (Annex Table H) and are used within this assessment.

Southall *et al.* (2019) propose the SPL_{peak} being either unweighted or flat weighted across the entire frequency band of a Functional Hearing Group (FHG) because the direct mechanical damage to the auditory system that is associated with high peak sound pressures is not frequency dependent and is therefore restricted to the audible frequency range of a species. Unweighted SPLpeak values are therefore included in this assessment for instantaneous PTS and TTS (Annex Table H).

The SEL_{cum} thresholds considers the SEL received by an animal and the duration of exposure, accounting for the accumulated exposure over a 24-hour period. Southall *et al.* (2019) recommends the application of SEL_{cum} for the individual activity alone (i.e., not for multiple activities occurring within the same area or over the same time). To inform this impact assessment, sound modelling has considered the SEL_{cum} over a piling event. It is important to note that the physiological damage that sound energy can cause is mainly restricted to energy occurring in the frequency range of a species' hearing range. Therefore, for the SEL_{cum}, sound has been weighted based on species group specific weighting curves presented in Southall *et al.* (2019).

Annex Table E: PTS and TTS-onset thresholds for impulsive noise (Southall *et al.*, 2019)

Species	FHG	Cumulative PTS (SEL_{cum} dB re 1 μPa^2s weighted)	Instantaneous PTS (SPL_{peak} dB re 1 µPa unweighted)	Cumulative TTS (SEL_{cum} dB re 1 μPa^2s weighted)	Instantaneous TTS (SPL_{peak} dB re 1 µPa unweighted)
Harbour porpoise	VHF cetacean	155	202	140	196
Dolphin species (bottlenose dolphin, Risso's dolphin, common dolphin	HF cetacean	185	230	170	224
Minke whale	LF cetacean	183	219	168	213

To quantify the impact of underwater noise on marine mammals with regard to PTS and TTS, the instantaneous (SPL_{peak}) and cumulative (SEL_{cum}, over 24 hours) PTS and TTS-onset impact ranges (the area around the piling location within which the noise levels exceed the PTS or TTS-onset thresholds for the relevant FHG) are determined using the recent thresholds presented by Southall *et al.* (2019). Further information on the modelling approach and the methods used the calculate PTS and TTS-onset impact ranges is provided in Volume III, Appendix 11.1: Underwater Noise Assessment (Revised March 2026).

The noise modelling assessment by Subacoustech Environmental Ltd in EIAR Volume III, Appendix 11.1: Underwater Noise Assessment (Revised March 2026) assumed that when exposed to high levels of noise, minke whale will swim away from the noise source at a constant swim speed of 3.25 ms^{-1} (Blix and Folkow, 1995) and for all other species, animals were assumed to flee at a constant speed of 1.5 ms^{-1}, based on reported sustainable long-term swimming speeds for harbour porpoise (Otani *et al.*, 2000).

The ranges that indicate TTS-onset were modelled and are presented in this impact assessment for both Project Design Options. The current set of TTS-onset thresholds presented by Southall *et al.* (2019) (Annex Table H) define a TTS-onset as the exposure required to produce a 6 dB shift in the hearing threshold. However, data upon which these thresholds are based for TTS-onset in marine mammals from impulsive noise, such as pile driving, is extremely limited. It has been necessary to determine exposure functions for TTS in order to estimate the levels at which the onset of PTS could occur, as experiments inducing PTS in animals is considered unethical. Predicted exposures of 40 dB of TTS are considered to result in PTS onset (Southall *et al.*, 2007). For the purposes of developing these thresholds, TTS was considered to be "the minimum threshold shift clearly larger than any day-to-day or session-to-session variation in a subject's normal hearing ability", and which "is typically the minimum amount of threshold shift that can be differentiated in most experimental conditions" (Southall *et al.*, 2007). Thus, using a threshold for the onset of TTS would typically result in overestimates of potential ranges at which ecologically significant effects could occur. Furthermore, as TTS-onset is defined primarily as a means of predicting PTS-onset, there is currently no threshold for TTS-onset that would indicate a biologically significant amount of TTS.

The number of individuals that may be affected by PTS relative to the reference population was quantified by multiplying the onset impact ranges by the density estimates for each species and calculating the proportion of the reference population.

Annex S.2 Behavioural disturbance

Dose-response functions

A species-specific dose-response approach was used for the assessment of disturbance to marine mammals from underwater noise during pile driving. This approach was based on current best practice methodology to provide evidence-based estimates rather than the fixed behavioural threshold approach.

The application of a dose-response function is used to quantify the probability of a response from an animal to a stressor or stimulus, which will vary according to the dose of stressor or stimulus received by the animal (Dunlop *et al.*, 2017). Therefore, it is based on the assumption that not all animals in an impact zone will respond, unlike traditional methods of threshold assessment.

For the purpose of this assessment, the dose is the received single-strike SEL_{SS} which is considered to be best practice for this type of assessment (Southall *et al.*, 2021). SEL_{SS} contours at 5 dB intervals generated by noise modelling (see Volume III, Appendix 11.1: Underwater Noise Assessment (Revised March 2026)) were overlain on species density surfaces to quantify the number of animals receiving each SEL_{SS}, and subsequently the number of animals likely to be disturbed based on the dose-response curve.

This impact assessment for cetaceans uses the dose-response curve that was developed by Graham *et al.* (2017a) for harbour porpoise using data collected during the first six weeks of piling during Phase 1 of the Beatrice offshore windfarm.

Following the development of this dose-response curve, additional data from the remaining piling events have been processed and showed that the responses of harbour porpoises to piling noise diminishes over the construction period (Graham *et al.*, 2019). Therefore, the use of the dose-response curve from the initial piling event in this assessment can be considered conservative.

In the absence of species-specific dose-response data for dolphins or minke whales, this dose-response curve has been adopted for all cetaceans, however it is considered that the application of the porpoise dose-response curve to other cetacean species is highly over-precautionary. This is because harbour porpoises are highly responsive to anthropogenic disturbance, with multiple studies showing response via avoidance and/or reduced vocalisation to various anthropogenic noise sources (Benhemma-Le Gall *et al.*, 2021; Brandt *et al.*, 2013; Brandt *et al.*, 2018; Thompson *et al.*, 2013; Thompson *et al.*, 2020; Sarnocińska *et al.*, 2020). Other cetacean species, including bottlenose dolphin and common dolphin, have shown less of a response to underwater noise in comparison to harbour porpoise (Fernandez-Betelu *et al.*, 2021; Kastelein *et al.*, 2006; Stone *et al.*, 2017).

Level B harassment – Fixed noise thresholds

In the absence of specific-specific empirical data for dolphin species and minke whale and given that the application of the harbour porpoise dose-response curve (Graham *et al.,* 2017b) is highly over-precautionary, the numbers of animals predicted to experience behavioural disturbance using the United States (US) National Marine Fisheries Service (NMFS) Level B harassment thresholds for strong disturbance (NMFS, 2005) are presented alongside the dose-response assessment methodology to provide context on the potential extent of disturbance.

In the US, under the 1994 Amendments to the Marine Mammal Protection Act, Level B harassment is defined as having the potential to disturb a marine mammal or marine mammal stock in the wild, by causing disruption of behavioural patterns including, but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering, but which does not have the potential to injure a marine mammal or marine mammal stock in the wild (NMFS, 2005).

The threshold predicts that Level B harassment will occur when an animal is exposed to received sound levels above 160 dB re 1 µPa (rms) from non-explosive impulsive sounds sources, such as seismic airguns,

impact pile driving, or intermittent sound sources, such as non-tactical sonar or scientific (Guan and Brookens, 2021; NMFS, 2023). The threshold is based on studies of grey whale (also low-frequency cetaceans) responses to playbacks signals from air guns above 160 dB re 1µPa (rms), which showed that the animal's exhibited an avoidance response (Malme *et al.,* 1984). Beyond the 160 dB re 1 µPa (rms) threshold, the behavioural responses are likely to become less severe, for example, minor changes in speed, direction and/or dive profile, modification of vocal behaviour and minor changes in respiratory rate (Southall *et al.,* 2007). However, it is important to note that marine mammal responses to disturbance will, depend on the individual and the context. For example, previous experience and acclimatisation will affect whether an individual exhibits an aversive response to noise, particularly in a historically noisy area.

Further information on the assumptions surrounding underwater noise, including the subsea noise model, PTS-onset and TTS-onset are detailed within the EIAR Volume II, Chapter 11: Marine Mammals (Revised March 2026).

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