Morlais Project

Marine Mammals
Underwater Noise Modelling Note

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1 Morlais Underwater Noise Modelling for Marine Mammals

1.1 Approach to Underwater Noise Modelling

Underwater noise modelling was undertaken to predict the propagation of the noise levels at the Morlais Demonstration Zone (MDZ) for:

- Drilling during installation of tidal devices;
- Operation of small and large tidal energy converter (TEC) for individual devices and as part of an array; and
- Acoustic deterrent devices (ADDs).

Drilling

As outlined in the Environmental Statement (ES) Chapter 4, Project Description and Section 12.6.1.1.1, due to the hard substrate (bedrock) in the MDZ, drilling will most likely be required to install foundations for the tidal devices and hubs. Of the potential installation methods that could be used, this has been considered as the worst-case scenario for underwater noise during the installation of the foundations for the tidal devices and hubs, compared to gravity base structures (GBS) or weighted anchors.

There are various methods and drill powers that can be used depending on the size of foundation being used, as well as the ground type. As this information has not been finalised, a likely worst-case assumption for the drilling has been made for the underwater noise modelling, based on similar operations and foundation installations.

Percussive drilling was modelled as a worst-case scenario. Percussive drilling is different from rotary drilling as it adds a rapid hammer action to the rotating head. The noise is characterised by very rapid transient peaks associated with the hammer action of the drilling rig being used. Compared to rotary drilling, percussive drilling is a louder process overall. Percussive drilling could be used over rotary drilling where harder substrate exists as the hammer action of the drill head would enable penetration into the harder material.

The modelling is based on percussive drilling using an approximate power of 300kW, which can install foundations of up to approximately 3m in diameter.

Operational turbines

Several options are being considered for the deployment of tidal turbine devices at the MDZ. Two scenarios have been modelled to cover either the largest number of turbines or the largest sized turbines. The first option is based on 620 ‘small tidal turbines’ with a rotor diameter of 16.13m; and the second option is based on 120 ‘large tidal turbines’, with dual turbines and rotor diameters of 24.6m.

These two options cover the possible worst-case scenarios for small and large turbines and will show whether more sound is created overall by a greater number of turbines or by a larger rotor diameter.

ADDs

ADDs are being considered as part of the mitigation plan to deter marine mammals from the operational rotors. As a worst-case option, i.e. one of the loudest ADDs that measurements are available for, modelling has been conducted for the Lofitech Seal Scarer.

1.1.1 Measurements of underwater noise

Sound measurements underwater are usually expressed using the decibel (dB) scale, which is a logarithmic measure of sound.

The Sound Pressure Level (SPL) is normally used to characterise noise and vibration of a continuous nature. The variation in sound pressure can be measured over a specific time period to determine the root mean square (RMS) level of the time varying acoustic pressure, therefore SPL (i.e. SPL_{RMS}) can be considered as a measure of the average unweighted level of the sound over the measurement period.

Peak SPLs (SPL_{peak}) are often used to characterise sound transients from impulsive sources, such as percussive impact piling. A peak SPL is calculated using the maximum variation of the pressure from positive to zero within the wave. This represents the maximum change in positive pressure (differential pressure from positive to zero) as the transient pressure wave propagates.

The sound exposure level (SEL) sums the acoustic energy over a measurement period, and effectively takes account of both the SPL of the sound source and the duration the sound is present in the acoustic environment. SEL_{cum} is the cumulative sound exposure level during the duration of drilling, operational turbines or ADDs.

Weighted metrics for marine mammals have been proposed by Southall *et al.* (2019), which assign a frequency response to groups of marine mammals (see **Section 1.1.4**).

1.1.2 Modelling methodology

The underwater noise modelling has been undertaken by Subacoustech using a numerical approach that is based on two different solvers:

- A parabolic equation (PE) method for lower frequencies (12.5 Hz to 200 Hz); and
- A ray tracing method for higher frequencies (250 Hz to 100 kHz).

The PE method is widely used within the underwater acoustics community but has computational limitations at high frequencies. Ray tracing is more computationally efficient at higher frequencies but is not suited to low frequencies (Etter, 1991).

This study utilised the dBSea software implementation of these numerical solutions.

These solvers account for a wide array of input parameters, including bathymetry, sediment data, sound speed and source frequency content to ensure as detailed results as possible.

Location and environmental conditions

The modelling takes full account of the environmental parameters within the study area. The bathymetry data used in the modelling was extracted from the 2018 EMODnet (European Marine Observation and Data Network) mean depth bathymetry dataset. The seabed at the MDZ is a mixture of sand and gravel, data for this sediment type, using geo-acoustic properties based on Jensen *et al*. (2011), has been used for modelling.

Different locations within the MDZ were chosen for the modelling to represent the worst-case for the different noise sources. The modelling locations for the single source investigations are shown in **Figure 1-1** (Plot A), with a worst-case location for small tidal turbines in the north west of the MDZ used for percussive drilling and ADD modelling. This position was chosen due to its location near to the deep water to the west of the site, which tends to maximise noise propagation. The modelling location chosen for the single large tidal turbine (the southernmost point in Plot A) is different as there are fewer turbine locations.

Figure 1-1 also shows the modelling locations used for the multiple location modelling, including 620 individual locations (Plot B) for the small tidal turbines with a minimum spacing of approximately 100m; and 120 locations (Plot C) for the dual-rotor large tidal turbines, with a minimum spacing of approximately 230m.

As modelling is undertaken at various depths, the ranges and calculations for the modelling are based on the worst-case, that the receptor is present in the loudest part of the water column at any location.

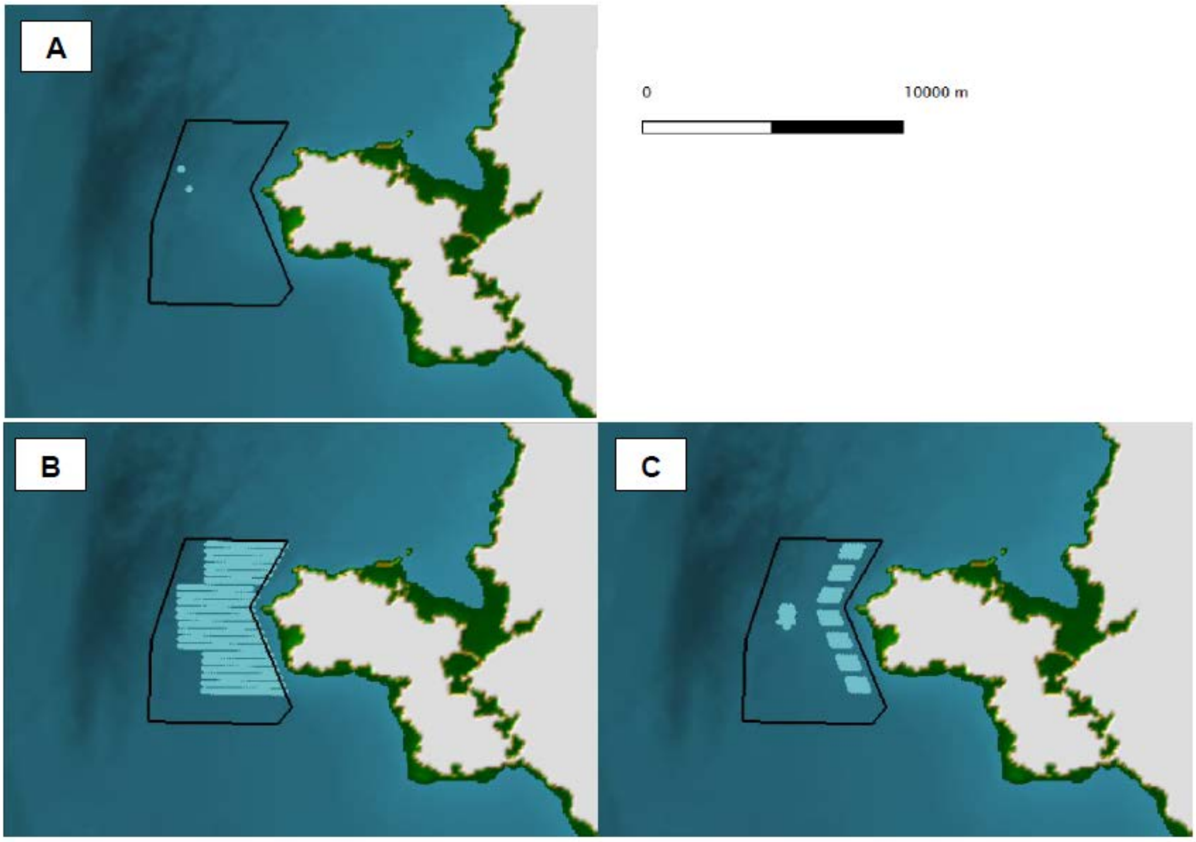

Figure 1-1: Locations used for modelling: Plot A shows locations for percussive drilling, single small tidal turbine, and ADDs (northernmost point) and single large tidal turbine (southernmost point); Plot B shows the 620 locations for small tidal turbines; and Plot C shows the 120 locations for large tidal turbines.

Background noise levels

A series of underwater noise monitoring stations were installed by SEACAMS (University of Bangor) to sample the background noise levels in and around the MDZ over periods of between 15 and 30 days in 2016, 2017 and 2018. Four of these datasets from different time periods and locations have been analysed by Subacoustech (Appendix 12.4, Appendix III of the ES) to provide a range of noise levels to define a baseline over a daily (high-low) and fortnightly (springs-neaps) tidal cycle. All measurements analysed were taken with a 48 kHz sample rate and with contiguous 10-minute samples, except the June 2017 sample period which used a finer 1-minute sample period throughout.

The results of the background noise monitoring in these locations in and around the MDZ show a remarkable degree of consistency in all locations and time periods, and noise levels varying with position of the tide. There were occasional, rare outliers expected to be associated with passing vessel traffic. All locations show a range of noise levels of 89 dB to 107 dB SPLRMS re 1 µPa (as either 1-minute or 10-minute samples).

An overview of the noise levels sampled at each location is given in **Table 1-1** (excluding outliers).

Table 1-1: **Summary of background noise levels in and around the MDZ**

Period	Overall average noise level	Tide cycle: Springs		Tide cycle: Neaps	
		Max SPL_{RMS}	Min SPL_{RMS}	Max SPL_{RMS}	Min SPL_{RMS}
April 2017	98.3 dB SPL_{RMS}	103.0 dB	91.9 dB	99.7 dB	90.7 dB
June 2017	96.9 dB SPL_{RMS}	104.1 dB	89.1 dB	97.5 dB	89.7 dB
July 2017	98.9 dB SPL_{RMS}	106.4 dB	92.7 dB	100.2 dB	95.2 dB
July 2018	98.0 dB SPL_{RMS}	106.6 dB	89.9 dB	99.8 dB	92.6 dB

1.1.3 Source levels

Percussive drilling

Measured data of percussive drilling has been used from Subacoustech's noise database and scaled to approximate the type of drilling that could take place at the MDZ.

For a percussive drill, with a power output of 300kW to install foundation piles of up to 3m in diameter, a SPL_{RMS} source level of 175.9 dB re 1 µPa @ 1m has been used of the modelling.

The frequency spectra used as an input for modelling is given in Figure 3-3 of Subacoustech (2020), with the majority of the energy concentrated in the lower frequency bands.

Operational turbines

Input parameters for operational tidal turbines has been derived from data from Subacoustech's measurement database with the source level scaled based on the rotor diameter of the proposed tidal turbine.

For a small turbine with a rotor diameter of 16.13m the source levels used in the modelling were 155.7 dB re 1 µPa @ 1m (SPL_{RMS}).

For a larger turbine consisting of two rotors, each measuring 24.6m in diameter the source levels used in the modelling were 161.2 dB re 1 µPa @ 1m (SPL_{RMS}).

The operational tidal turbine frequency spectra used as inputs for modelling are given in Figure 3-4 of Subacoustech (2020) and show a relatively flat response across the ⅓ octave bands.

ADDs

The Lofitech *Seal Scarer* has been used to model the effect of ADDs at the MDZ as it is one of the loudest ADDs currently available. Modelling used measurements of the device by Subacoustech Environmental

(Nedwell *et al*., 2010) and additional information from Brandt *et al*. (2013), which investigated the device's effectiveness on harbour porpoises.

A source level of 182.7 dB re 1 µPa @ 1m (SPL_{RMS}) has been used in the noise modelling, along with the ⅓ octave frequency spectra, as shown in Figure 3-5 of Subacoustech (2020). The main output of the Lofitech ADD is high-level pulses at 14.5kHz, as shown by the spike in Figure 3-5 of Subacoustech (2020).

Weighted source levels

To undertake the modelling with the weighted criteria, the source levels and frequencies were first adjusted using the auditory weighting functions (shown in Figure 3-6 of Subacoustech (2020)). This significantly alters the source level for each functional group, as shown in Figure 3-7 of Subacoustech (2020) for the large tidal turbine ⅓ octave frequency spectra. The equivalent source levels used for modelling are summarised in **Table 1-2**, showing, for example, how the high frequencies (above 10kHz) are reduced using the low frequency (LF) filter, and the low frequencies (below 1kHz) are removed for the high frequency (HF) and very high frequency (VHF) filters.

Table 1-2: Summary of the Southall et al. (2019) weighted source levels at 1m used for modelling

RMS Source Level (dB re 1 µPa @ 1 m)	**Percussive drilling**	**Small tidal turbine**	**Large tidal turbine**	**ADD**
Unweighted	175.9	155.7	161.2	182.7
Low Frequency (LF) Cetaceans	168.6	152.6	158.1	178.2
High Frequency (HF) Cetaceans	153.0	151.1	156.6	181.9
Very High Frequency (VHF) Cetaceans	149.3	150.3	155.8	180.5
Phocid Carnivores in Water (PCW)	162.5	151.7	157.2	181.2

1.1.4 Thresholds and criteria

The metrics and criteria that have been used in the modelling to assess the potential impacts of underwater noise on marine mammals are from Southall *et al*. (2019).

The Southall *et al*. (2019) guidance groups marine mammals into functional hearing groups and applies filters to the unweighted noise to approximate the hearing response of the receptor. These hearing groups are:

- Very High Frequency (VHF) Cetaceans, such as harbour porpoise *Phocoena phocoena* (High Frequency (HF) Cetacean category in National Marine Fisheries Service (NMFS) (2018) guidance);
- High Frequency (HF) Cetaceans, includes dolphin species, such as bottlenose dolphin *Tursiops truncatus*, Risso's dolphin *Grampus griseus* and common dolphin *Delphinus delphis* (Mid Frequency (MF) Cetaceans category in NMFS (2018) guidance);
- Low Frequency (LF) Cetaceans, such as minke whale *Balaenoptera acutorostrata*; and
- Phocid Pinnipeds Underwater (PW), such as grey seal *Halichoerus grypus* and harbour seal *Phoca vitulina*.

Southall *et al*. (2019) presents unweighted peak criteria (SPL_{peak}) and cumulative, weighted sound exposure criteria (SEL_{cum}) for both permanent threshold shift (PTS), where unrecoverable hearing damage may occur, and temporary threshold shift (TTS), where a temporary reduction in hearing sensitivity may occur in individual receptors.

In addition, Southall *et al*. (2019) also gives individual criteria based on whether the noise source is considered impulsive or non-impulsive. Southall *et al*. (2019) categorises impulsive noises as having high peak sound pressure, short duration, fast rise-time and broad frequency content at source, and non-impulsive sources as steady-state noise (a non-impulsive sound does not necessarily have to have a long duration). The noise sources in this modelling for drilling, operational turbines and ADDs are all considered non-pulses. **Table 1-3** summarise the Southall *et al*. (2019) criteria for onset of risk of PTS and TTS for each of the key marine mammal hearing groups for non-impulsive noise.

Table 1-3: **Southall *et al*. (2019) non-impulsive noise exposure criteria for PTS and TTS**

Functional group	**PTS criteria** (Weighted SEL_{cum} dB re 1 µPa^{2}s)	**TTS criteria** (Weighted SEL_{cum} dB re 1 µPa^{2}s)
Very High Frequency (VHF) Cetaceans	173	153
High Frequency (HF) Cetaceans	198	178
Low Frequency (LF) Cetaceans	199	179
Phocid Carnivores in Water (PCW)	201	181

To determine SEL_{cum} ranges, a fleeing animal model has been used. This assumes that the animal exposed to high noise levels will swim away from the noise source. For this, a constant speed of 3.25m/s has been assumed for the low frequency (LF) cetacean group (Blix and Folkow, 1995), based on data for minke whale. For all other receptors (harbour porpoise, dolphin species and seals) a constant swimming speed of 1.5 m/s has been used, which is based on the average swimming speed for a harbour porpoise (Otani *et al*., 2000). This is considered a 'worst-case' scenario as marine mammals are expected to be able to swim faster. For example, the swimming speed of a harbour porpoise during playbacks of pile driving sounds (SPL of 154 dB re 1 µPa) was 1.97m/s (7.1km/h) and during quiet baseline periods the mean swimming speed was 1.2m/s (4.3km/h; Kastelein *et al*., 2018).

In all the above scenarios, where cumulative SEL criteria are used, a 24-hour continuous noise has been assumed as a worst case.

Disturbance

A key part of the assessment for Morlais is the potential disturbance of marine mammals, but there are very few specific criteria as there is a lot of conflicting information on the subject. Disturbance is a broader and less measurable response, when compared to hearing injury (PTS and TTS). The Southall *et al*. (2019) criteria only covers PTS and TTS in marine mammals, and as such additional criteria have been used. These are:

- Southall *et al*. (2007) which recommends a low-end threshold of 120 dB (SPL_{RMS}) for continuous noise disturbance for marine mammals. This threshold has been used on a large amount of data where various investigations have reported behavioural disturbance with regards to sound, with louder levels causing disturbance, with 120 dB (RMS) being the quietest. It should be noted that 120 dB SPL_{RMS} is approaching the order of background noise in some areas (Nedwell *et al.* 2003, 2007).
- Hastie *et al*. (2018) identified a significant reduction in harbour seal from operational tidal turbine noise at an unweighted median received level of 142 dB (SPL_{RMS}). This is the most specific and relevant disturbance threshold available for this type of assessment.

1.2 Results of Underwater Noise Modelling

1.2.1 Percussive drilling

The maximum predicted impact ranges for the risk of PTS and TTS using the non-impulsive Southall *et al*. (2019) criteria for the proposed drilling operations at Morlais are presented in **Table 1-4**. Cumulative exposure (SEL_{cum}) is based on 24-hour continuous exposure and fleeing response model, with swimming speeds as outlined in **Section 1.1.4**.

Table 1-4 Maximum predicted PTS and TTS impact ranges for marine mammal species during drilling operations at Morlais, based on Southall *et al*. (2019) criteria for non-impulsive sounds

Species	Potential Impact	Criteria	Percussive drilling
Very High Frequency Cetaceans (harbour porpoise)	**PTS**	Weighted SEL_{cum} 173 dB re 1 µPa²s	<10m
	TTS	Weighted SEL_{cum} 153 dB re 1 µPa²s	<10m
High Frequency Cetaceans (dolphin species)	**PTS**	Weighted SEL_{cum} 198 dB re 1 µPa²s	<10m
	TTS	Weighted SEL_{cum} 178 dB re 1 µPa²s	<10m
Low Frequency Cetaceans (minke whale)	**PTS**	Weighted SEL_{cum} 199 dB re 1 µPa²s	<10m
	TTS	Weighted SEL_{cum} 179 dB re 1 µPa²s	<10m
Pinnipeds in water (grey and harbour seals)	**PTS**	Weighted SEL_{cum} 201 dB re 1 µPa²s	<10m
	TTS	Weighted SEL_{cum} 181 dB re 1 µPa²s	<10m

The maximum, mean and minimum predicted disturbance ranges for the proposed drilling operations at Morlais are presented in **Table 1-5**, based on the low-end threshold of 120 dB (SPL_{RMS}) for continuous noise disturbance for marine mammals from Southall *et al*. (2007) and the unweighted median received level of 142 dB (SPL_{RMS}) associated with a significant reduction in harbour seal from operational tidal turbine noise.

Table 1-5: Modelled SPL_{RMS} disturbance impact ranges for percussive drilling using the criteria from Southall *et al*. (2007) and Hastie *et al*. (2018)

Potential SPL_{RMS} disturbance threshold	Percussive drilling		
	Maximum range	**Mean range**	**Minimum range**
142 dB re 1 µPa (RMS)	300m	280m	260m
120 dB re 1 µPa (RMS)	6.9km	5.0km	3.2km

1.2.2 Small tidal turbine

The maximum predicted impact ranges for the risk of PTS and TTS using the non-impulsive Southall *et al*. (2019) criteria for small tidal turbine (16.13m diameter rotor) at Morlais are presented in **Table 1-6**.

Cumulative exposure (SEL_{cum}) is based on 24-hour continuous exposure and fleeing response modelled, with swimming speeds as outlined in **Section 1.1.4**.

Table 1-6 Maximum predicted PTS and TTS impact ranges for marine mammal species during operation of small turbine at Morlais, based on Southall *et al*. (2019) criteria for non-impulsive sounds

Species	Potential Impact	Criteria	Operational small turbine
Very High Frequency Cetaceans (harbour porpoise)	**PTS**	Weighted SEL_{cum} 173 dB re 1 µPa²s	<10m
	TTS	Weighted SEL_{cum} 153 dB re 1 µPa²s	50m
High Frequency Cetaceans (dolphin species)	**PTS**	Weighted SEL_{cum} 198 dB re 1 µPa²s	<10m
	TTS	Weighted SEL_{cum} 178 dB re 1 µPa²s	<10m
Low Frequency Cetaceans (minke whale)	**PTS**	Weighted SEL_{cum} 199 dB re 1 µPa²s	<10m
	TTS	Weighted SEL_{cum} 179 dB re 1 µPa²s	<10m
Pinnipeds in water (grey and harbour seals)	**PTS**	Weighted SEL_{cum} 201 dB re 1 µPa²s	<10m
	TTS	Weighted SEL_{cum} 181 dB re 1 µPa²s	<10m

The maximum, mean and minimum predicted disturbance ranges for a single small operational tidal turbine at Morlais are presented in **Table 1-7**, based on the low-end threshold of 120 dB (SPL_{RMS}) for continuous noise disturbance for marine mammals from Southall *et al*. (2007) and the unweighted median received level of 142 dB (SPL_{RMS}) associated with a significant reduction in harbour seal from operational tidal turbine noise.

Table 1-7: Modelled SPL_{RMS} disturbance impact ranges for operational single small tidal turbine using the criteria from Southall *et al*. (2007) and Hastie *et al*. (2018)

Potential SPL_{RMS} disturbance threshold	Small tidal turbine (single location)		
	Maximum range	**Mean range**	**Minimum range**
142 dB re 1 µPa (RMS)	20m	20m	20m
120 dB re 1 µPa (RMS)	620m	560m	510m

1.2.3 Large tidal turbine

The maximum predicted impact ranges for the risk of PTS and TTS using the non-impulsive Southall *et al*. (2019) criteria for large tidal turbine (with dual 24.6m diameter rotors) at Morlais are presented in **Table 1-8**. Cumulative exposure (SEL_{cum}) is based on 24-hour continuous exposure and fleeing response modelled, with swimming speeds as outlined in **Section 1.1.4**.

Table 1-8 Maximum predicted PTS and TTS impact ranges for marine mammal species during operation of large turbine at Morlais, based on Southall *et al*. (2019) criteria for non-impulsive sounds

Species	Potential Impact	Criteria	Operational large turbine
Very High Frequency Cetaceans (harbour porpoise)	**PTS**	Weighted SEL_{cum} 173 dB re 1 µPa^{2}s	<10m
	TTS	Weighted SEL_{cum} 153 dB re 1 µPa^{2}s	230m
High Frequency Cetaceans (dolphin species)	**PTS**	Weighted SEL_{cum} 198 dB re 1 µPa^{2}s	<10m
	TTS	Weighted SEL_{cum} 178 dB re 1 µPa^{2}s	<10m
Low Frequency Cetaceans (minke whale)	**PTS**	Weighted SEL_{cum} 199 dB re 1 µPa^{2}s	<10m
	TTS	Weighted SEL_{cum} 179 dB re 1 µPa^{2}s	<10m
Pinnipeds in water (grey and harbour seals)	**PTS**	Weighted SEL_{cum} 201 dB re 1 µPa^{2}s	<10m
	TTS	Weighted SEL_{cum} 181 dB re 1 µPa^{2}s	<10m

The maximum, mean and minimum predicted disturbance ranges for a single large operational tidal turbine at Morlais are presented in **Table 1-9**, based on the low-end threshold of 120 dB (SPL_{RMS}) for continuous noise disturbance for marine mammals from Southall *et al*. (2007) and the unweighted median received level of 142 dB (SPL_{RMS}) associated with a significant reduction in harbour seal from operational tidal turbine noise.

Table 1-9: Modelled SPL_{RMS} disturbance impact ranges for operational single large tidal turbine (two rotors) using the criteria from Southall *et al*. (2007) and Hastie *et al*. (2018)

Potential SPL_{RMS} disturbance threshold	Large tidal turbine (single location)		
	Maximum range	**Mean range**	**Minimum range**
142 dB re 1 µPa (RMS)	70m	60m	60m
120 dB re 1 µPa (RMS)	1.3km	1.1km	1.0km

1.2.4 Tidal arrays

Subacoustech have produced noise plots for arrays of small operational tidal turbines (**Figure 1-2**) and arrays of large operational turbines (**Figure 1-3**), based on the locations in **Figure 1-1** Plot B and C. Both figures use the same spatial and colour scale so can be directly compared.

The results show that overall noise levels are louder for the small turbines at 620 locations than they are for large turbines at 120 locations. Although the large turbines are louder individually, the fact that there are 400 fewer locations, and the locations are more spaced out, results in a lower overall level.

It should be noted that tables of impact ranges have not been given for these cumulative impacts due to there being multiple source locations.

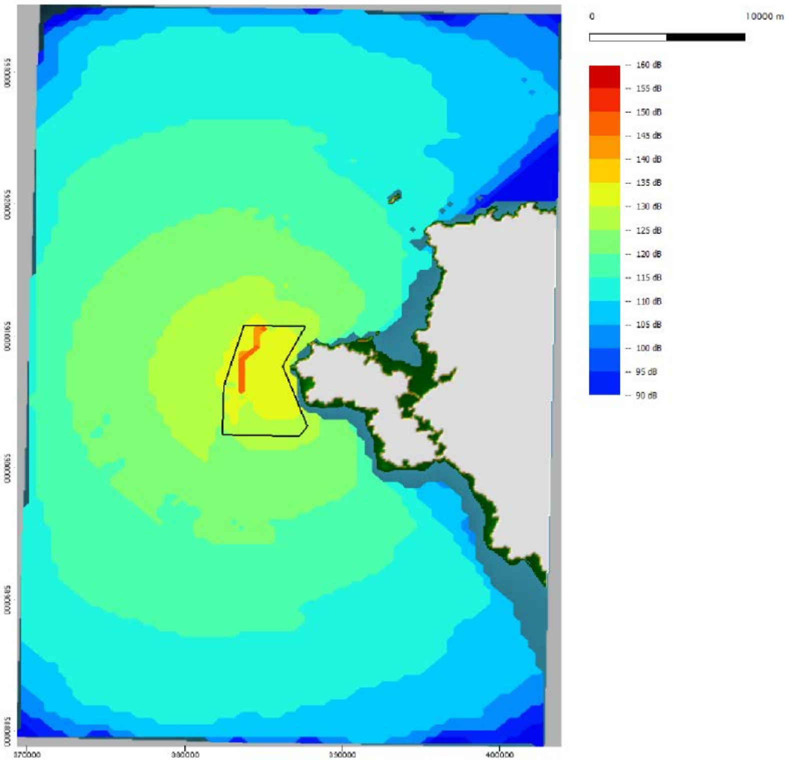

Figure 1-2: Underwater noise plot for small tidal turbine (16.13m diameter rotor) array with 620 locations unweighted SPL_{RMS}

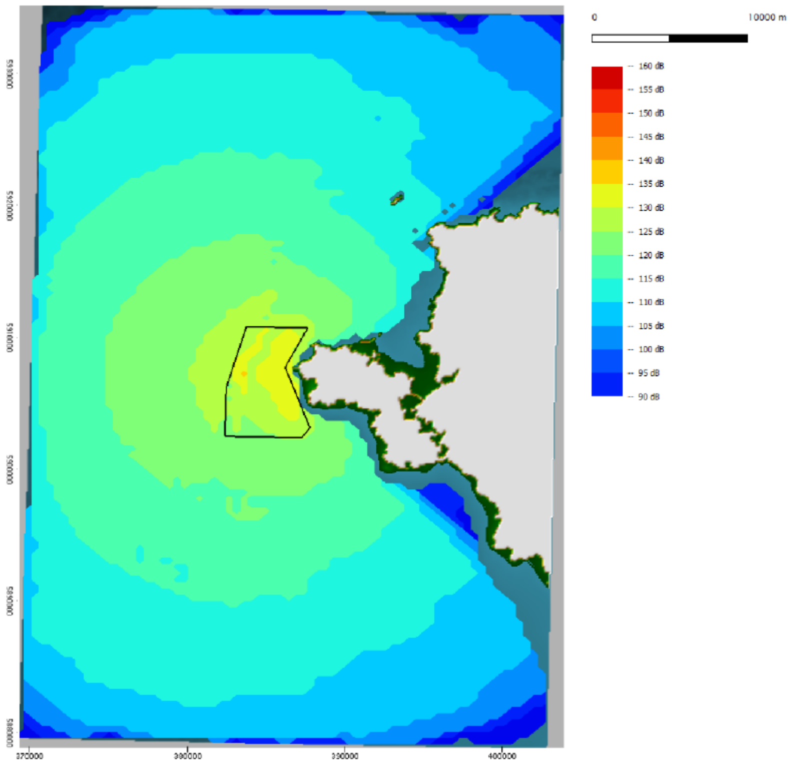

Figure 1-3: Underwater noise plot for large tidal turbine (dual 24.6m diameter rotors) array with 120 locations unweighted SPL_{RMS}

1.2.5 ADD

The maximum predicted impact ranges for the risk of PTS and TTS using the non-impulsive Southall *et al*. (2019) criteria for ADDs at Morlais are presented in **Table 1-10**. Cumulative exposure (SEL_{cum}) is based on 24-hour continuous exposure and fleeing response modelled, with swimming speeds as outlined in **Section 1.1.4**.

Table 1-10 Maximum predicted PTS and TTS impact ranges for marine mammal species during ADD activation at Morlais, based on Southall *et al*. (2019) criteria for non-impulsive sounds

Species	Potential Impact	Criteria	ADDs
Very High Frequency Cetaceans (harbour porpoise)	**PTS**	Weighted SEL_{cum} 173 dB re 1 µPa²s	220m
	TTS	Weighted SEL_{cum} 153 dB re 1 µPa²s	5.3km
High Frequency Cetaceans (dolphin species)	**PTS**	Weighted SEL_{cum} 198 dB re 1 µPa²s	<10m
	TTS	Weighted SEL_{cum} 178 dB re 1 µPa²s	50m
Low Frequency Cetaceans (minke whale)	**PTS**	Weighted SEL_{cum} 199 dB re 1 µPa²s	<10m
	TTS	Weighted SEL_{cum} 179 dB re 1 µPa²s	10m
Pinnipeds in water (grey and harbour seals)	**PTS**	Weighted SEL_{cum} 201 dB re 1 µPa²s	<10m
	TTS	Weighted SEL_{cum} 181 dB re 1 µPa²s	10m

The maximum, mean and minimum predicted disturbance ranges for a single ADD at Morlais are presented in **Table 1-11**, based on the low-end threshold of 120 dB (SPL_{RMS}) for continuous noise disturbance for marine mammals from Southall *et al*. (2007) and the unweighted median received level of 142 dB (SPL_{RMS}) associated with a significant reduction in harbour seal from operational tidal turbine noise.

Table 1-11: Modelled SPL_{RMS} disturbance impact ranges for operational ADD using the criteria from Southall *et al*. (2007) and Hastie *et al*. (2018)

Potential SPL_{RMS} disturbance threshold	Operational ADD		
	Maximum range	Mean range	Minimum range
142 dB re 1 µPa (RMS)	840m	640m	500m
120 dB re 1 µPa (RMS)	6.7km	5.7km	3. km

1.3 Comparison with assessments in ES

Underwater noise modelling was not conducted for the Morlais ES, as the types of devices and how they could be installed has still to finalised. Therefore, the assessment in the Morlais ES was based on underwater noise modelling that has been conducted for other projects with similar conditions, including the nearby Wylfa Newydd Development Area; the Perpetuus Tidal Energy Centre (PTEC) off the coast of the Isle of Wight; and MeyGen in the Inner Sound of the Pentland Firth.

The following sections compares the assessments in the Morlais ES with the underwater noise modelling that has been undertaken for the Morlais site.

1.3.1 Percussive drilling

Comparison with Wylfa

The maximum predicted impact ranges for the risk of PTS and TTS for the proposed drilling operations at Morlais are compared to the maximum predicted impact ranges for the risk of PTS and TTS presented in the ES based on modelling for drilling at Wylfa (**Table 1-12**).

The modelling for Morlais was based on the non-impulsive Southall *et al*. (2019) weighted criteria for SEL_{cum}, with 24-hour continuous exposure and fleeing response.

The modelling for the proposed drilling operations at the Wylfa Newydd Development Area was based the non-impulsive NMFS (2018) weighted criteria (same as Southall *et al*. (2019) weighted criteria, just different category names), assuming a stationary animal remaining in the vicinity over a 24-hour period.

The maximum predicted impact ranges for drilling at Wylfa as presented in the Morlais ES represent the worst-case, as the impact ranges are greater than those modelled for Morlais, with the exception of the maximum PTS range in dolphin species (**Table 1-12**).

It should be noted that the Morlais underwater noise modelling is taken to less than 10m as minimum range and could be less than 10m, e.g. 1m.

Table 1-12: Comparison of maximum predicted PTS and TTS impact ranges (and areas*) for marine mammal species during drilling operations at Morlais and drilling operations at Wylfa presented in the ES

Potential Impact	Criteria	Percussive drilling at Morlais based on Subacoustech modelling	Percussive drilling presented in the Morlais ES (based on Wylfa)	Two percussive drilling rigs as presented in the ES (based on Wylfa)
PTS in Very High Frequency Cetaceans (harbour porpoise)	Weighted SEL_{cum} 173 dB re 1 µPa²s	<10m (0.0003km²)	9m (0.00025km²)	10m (0.0003km²)
TTS in Very High Frequency Cetaceans (harbour porpoise)	Weighted SEL_{cum} 153 dB re 1 µPa²s	<10m (0.0003km²)	250m (0.2km²)	320m (0.32km²)
PTS in High Frequency Cetaceans (dolphin species)	Weighted SEL_{cum} 198 dB re 1 µPa²s	<10m (0.0003km²)	<1m (0.000314km²)	1m (0.000003km²)
TTS in High Frequency Cetaceans (dolphin species)	Weighted SEL_{cum} 178 dB re 1 µPa²s	<10m (0.0003km²)	10m (0.0003km²)	20m (0.0013km²)
PTS in Low Frequency Cetaceans (minke whale)	Weighted SEL_{cum} 199 dB re 1 µPa²s	<10m (0.0003km²)	100m (0.03km²)	210m (0.14km²)
TTS in Low Frequency Cetaceans (minke whale)	Weighted SEL_{cum} 179 dB re 1 µPa²s	<10m (0.0003km²)	1.5 km (7.07km²)	2.1 km (13.85km²)

Potential Impact	Criteria	Percussive drilling at Morlais based on Subacoustech modelling	Percussive drilling presented in the Morlais ES (based on Wylfa)	Two percussive drilling rigs as presented in the ES (based on Wylfa)
PTS in Pinnipeds in water (grey and harbour seals)	Weighted SEL_{cum} 201 dB re 1 µPa^2s	<10m (0.0003km^2)	9m (0.00025km^2)	10m (0.0003km^2)
TTS in Pinnipeds in water (grey and harbour seals)	Weighted SEL_{cum} 181 dB re 1 µPa^2s	<10m (0.0003km^2)	240m (0.18km^2)	320m (0.32km^2)

**based on area of a circle*

The maximum number of harbour porpoise, bottlenose dolphin, Risso's dolphin, common dolphin, minke whale, grey seal and harbour seal that could be at risk of PTS and TTS, based on the maximum area of impact for percussive drilling operations for Morlais compared to the maximum area of impact for two percussive drilling operations at Wylfa as presented in ES (**Table 1-13**). Density estimates and reference populations are based on Morlais site as used in the ES (as presented in the tables).

The magnitude of the potential risk of PTS and TTS for drilling is assessed as **negligible / very low** for all species based on the Morlais underwater noise modelling, this is the same as the assessment in the ES based on the Wyfla modelling (**Table 1-13**).

Taking into account the high sensitivity of all marine mammal species to any permanent auditory injury (i.e. receptor has very limited capacity to recover from the anticipated impact) and the potential magnitude of the effect (negligible/ very low for all species), the impact significance for any permanent auditory injury in harbour porpoise, bottlenose dolphin, Risso's dolphin, common dolphin, minke whale, grey seal and harbour seal from cumulative exposure during percussive drilling operations over 24 hours has been assessed as **minor (not significant)**. Therefore, this is the same as the assessment in the ES.

Taking into account the medium sensitivity of all marine mammal species to any temporary auditory injury (i.e. receptor has limited capacity to recover from the anticipated impact) and the potential magnitude of the effect (negligible/ very low for all species), the impact significance for any temporary auditory injury in harbour porpoise, bottlenose dolphin, Risso's dolphin, common dolphin, minke whale, grey seal and harbour seal from cumulative exposure during percussive drilling operations over 24 hours has been assessed as **minor (not significant)** for TTS. Therefore, this is the same as the assessment in the ES.

Table 1-13: Maximum number of individuals (and % of reference population) that could be at risk of permanent auditory injury (PTS) during percussive drilling operations at Morlais compared to two percussive drilling operations at Wylfa as presented in ES

Potential Impact	Maximum number of individuals and (% of reference population) and magnitude based on modelling of percussive drilling operations at Morlais	Maximum number of individuals and (% of reference population) and magnitude based on modelling of two percussive drilling operations at Wylfa
PTS in harbour porpoise	0.00023 individuals (based on density estimate of 0.783/km^2)	0.00024 individuals (based on density estimate of 0.783/km^2)

Potential Impact	Maximum number of individuals and (% of reference population) and magnitude based on modelling of percussive drilling operations at Morlais	Maximum number of individuals and (% of reference population) and magnitude based on modelling of two percussive drilling operations at Wylfa
	(0.00000023% of the 104,695 reference population). Potential permanent effect with **negligible / very low magnitude** (less than 0.001% of the reference population anticipated to be exposed to effect).	(0.00000023% of the 104,695 reference population). Potential permanent effect with **negligible / very low magnitude** (less than 0.001% of the reference population anticipated to be exposed to effect).
TTS in harbour porpoise	0.00023 individuals (based on density estimate of 0.783/km^2) (0.00000023% of the 104,695 reference population). Temporary effect with **negligible / very low magnitude** (less than 1% of the reference population anticipated to be exposed to effect).	0.25 individuals (based on density estimate of 0.783/km^2) (0.00024% of the 104,695 reference population). Temporary effect with **negligible / very low magnitude** (less than 1% of the reference population anticipated to be exposed to effect).
PTS in bottlenose dolphin	0.000006 individuals (based on density estimate of 0.02/km^2) (0.0000015% of the reference population of 397 bottlenose dolphin). Potential permanent effect with **negligible / very low magnitude** (less than 0.001% of the reference population anticipated to be exposed to effect).	0.00000006 individuals (based on density estimate of 0.02/km^2) (0.000000015% of the reference population of 397 bottlenose dolphin). Potential permanent effect with **negligible / very low magnitude** (less than 0.001% of the reference population anticipated to be exposed to effect).
TTS in bottlenose dolphin	0.000006 individuals (based on density estimate of 0.02/km^2) (0.0000015% of the reference population of 397 bottlenose dolphin). Temporary effect with **negligible / very low magnitude** (less than 1% of the reference population anticipated to be exposed to effect).	0.000026 individuals (based on density estimate of 0.02/km^2) (0.0000065% of the reference population of 397 bottlenose dolphin). Temporary effect with **negligible / very low magnitude** (less than 1% of the reference population anticipated to be exposed to effect).
PTS in Risso's dolphin	0.0000009 individuals (based on density estimate of 0.031/km^2) (0.0000001% of the reference population of 8,794 Risso's dolphin). Potential permanent effect with **negligible / very low magnitude** (less than 0.001% of the reference population anticipated to be exposed to effect).	0.00000009 individuals (based on density estimate of 0.031/km^2) (0.000000001% of the reference population of 8,794 Risso's dolphin). Potential permanent effect with **negligible / very low magnitude** (less than 0.001% of the reference population anticipated to be exposed to effect).
TTS in Risso's dolphin	0.0000009 individuals (based on density estimate of 0.031/km^2) (0.0000001% of the reference population of 8,794 Risso's dolphin). Temporary effect with **negligible / very low magnitude** (less than 1% of the	0.00004 individuals (based on density estimate of 0.031/km^2) (0.0000005% of the reference population of 8,794 Risso's dolphin). Temporary effect with **negligible / very low magnitude** (less than 1% of the reference

Potential Impact	Maximum number of individuals and (% of reference population) and magnitude based on modelling of percussive drilling operations at Morlais	Maximum number of individuals and (% of reference population) and magnitude based on modelling of two percussive drilling operations at Wylfa
	reference population anticipated to be exposed to effect).	population anticipated to be exposed to effect).
PTS in common dolphin	0.000066 individuals (based on density estimate of 0.22/km^2) (0.0000001% of the reference population of 56,556 common dolphin). Potential permanent effect with **negligible / very low magnitude** (less than 0.001% of the reference population anticipated to be exposed to effect).	0.00000066 individuals (based on density estimate of 0.22/km^2) (0.000000001% of the reference population of 56,556 common dolphin). Potential permanent effect with **negligible / very low magnitude** (less than 0.001% of the reference population anticipated to be exposed to effect).
TTS in common dolphin	0.000066 individuals (based on density estimate of 0.22/km^2) (0.0000001% of the reference population of 56,556 common dolphin). Temporary effect with **negligible / very low magnitude** (less than 1% of the reference population anticipated to be exposed to effect).	0.0003 individuals (based on density estimate of 0.22/km^2) (0.0000005% of the reference population of 56,556 common dolphin). Temporary effect with **negligible / very low magnitude** (less than 1% of the reference population anticipated to be exposed to effect).
PTS in minke whale	0.000005 individuals (based on density estimate of 0.017/km^2) (0.00000002% of the reference population of 23,528 minke whale). Potential permanent effect with **negligible / very low magnitude** (less than 0.001% of the reference population anticipated to be exposed to effect).	0.0024 individuals (based on density estimate of 0.017/km^2) (0.00001% of the reference population of 23,528 minke whale). Potential permanent effect with **negligible / very low magnitude** (less than 0.001% of the reference population anticipated to be exposed to effect).
TTS in minke whale	0.000005 individuals (based on density estimate of 0.017/km^2) (0.00000002% of the reference population of 23,528 minke whale). Temporary effect with **negligible / very low magnitude** (less than 1% of the reference population anticipated to be exposed to effect).	0.24 individuals (based on density estimate of 0.017/km^2) (0.001% of the reference population of 23,528 minke whale). Temporary effect with **negligible / very low magnitude** (less than 1% of the reference population anticipated to be exposed to effect).
PTS in grey seal	0.000047 individuals (based on density estimate of 0.155/km^2) (0.0000008% of the reference population of 6,000 grey seal). Potential permanent effect with **negligible / very low magnitude** (less than 0.001% of the reference population anticipated to be exposed to effect).	0.000047 individuals (based on density estimate of 0.155/km^2) (0.0000008% of the reference population of 6,000 grey seal). Potential permanent effect with **negligible / very low magnitude** (less than 0.001% of the reference population anticipated to be exposed to effect).
TTS in grey seal	0.000047 individuals (based on density estimate of 0.155/km^2)	0.05 individuals (based on density estimate of 0.155/km^2)

Potential Impact	Maximum number of individuals and (% of reference population) and magnitude based on modelling of percussive drilling operations at Morlais	Maximum number of individuals and (% of reference population) and magnitude based on modelling of two percussive drilling operations at Wylfa
	(0.0000008% of the reference population of 6,000 grey seal). Temporary effect with **negligible / very low magnitude** (less than 1% of the reference population anticipated to be exposed to effect).	(0.0008% of the reference population of 6,000 grey seal). Temporary effect with **negligible / very low magnitude** (less than 1% of the reference population anticipated to be exposed to effect).
PTS in harbour seal	0.00000015 individuals (based on density estimate of 0.0005/km^2) (0.0000003% of the reference population of 50 harbour seal). Potential permanent effect with **negligible / very low magnitude** (less than 0.001% of the reference population anticipated to be exposed to effect).	0.00000015 individuals (based on density estimate of 0.0005/km^2) (0.0000003% of the reference population of 50 harbour seal). Potential permanent effect with **negligible / very low magnitude** (less than 0.001% of the reference population anticipated to be exposed to effect).
TTS in harbour seal	0.00000015 individuals (based on density estimate of 0.0005/km^2) (0.0000003% of the reference population of 50 harbour seal). Temporary effect with **negligible / very low magnitude** (less than 1% of the reference population anticipated to be exposed to effect).	0.00016 individuals (based on density estimate of 0.0005/km^2) (0.0003% of the reference population of 50 harbour seal). Temporary effect with **negligible / very low magnitude** (less than 1% of the reference population anticipated to be exposed to effect).

Comparison with PTEC

For PTEC, the source levels for the noise from percussive drilling operations was estimated to be 179.1 dB re 1 µPa@1 m (RMS) for the installation of 3m diameter piles. These levels are below the 240 and 220 dB re 1 µPa (SPL_{peak}) criteria for lethal effect and physical injury (Subacoustech, 2014). Therefore, no injury was anticipated.

Modelling undertaken for drilling at PTEC, based on the dB_{ht}(*Species*) criteria also indicates that for drilling noise the highest predicted source level was for harbour porpoise, for percussive drilling to install a 4m diameter pile, was 118.8 dB_{ht}(*Phocoena phocoena*)@1m. This is below 130 dB_{ht}(*Species*) perceived level used to indicate traumatic hearing damage (Subacoustech, 2014).

The modelling for PTEC, based on the M-weighted SEL Southall *et al*. (2007) thresholds is summarised in **Table 1-14**. The largest impact ranges are for the pinniped due to the more conservative criterion and shows a maximum range of 29m for installing the 3m pile through percussive drilling and 34m for a 4m pile. This means if a pinniped was positioned closer than 29m or 34m, respectively, from the drilling operation for 24 hours it would receive an exposure to sound that could be injurious using the Southall *et al*. (2007) criteria for non-pulses. However, the chance of a receptor staying this close to a noise source for such a long period of time is extremely unlikely (Subacoustech, 2014).

For harbour porpoise, dolphin species and minke whale the maximum predicted impact ranges for PTS presented in the ES based on the PTEC underwater noise modelling are within the predicted impact ranges of less than 10m for these species based on the noise modelling for Morlais.

The predicted impact ranges for seals based on the modelling for PTEC using the previous Southall *et al*. (2007) criteria were greater than the predicted impact ranges for the Morlais site based on the latest Southall *et al*. (2019) criteria, which reflects the updated weighting for pinnipeds in the latest Southall *et al*. (2019) criteria.

Table 1-14: Summary of the ranges out to which the injury criteria for non-pulses (Southall *et al*, 2007) is reached for percussive drilling noise over a 24 hour period modelled for PTEC (Subacoustech, 2014)

Percussive drilling	**Range (m)**			
	High Freq. Cetaceans (harbour porpoise) Range to 215 dB re 1 μPa²s	**Mid Freq. Cetaceans (dolphin species) Range to 215 dB re 1 μPa²s**	**Low Freq. Cetaceans (minke whale) Range to 215 dB re 1 μPa²s**	**Pinnipeds (in water) (grey and harbour seal) Range to 203 dB re 1 μPa²s**
1m diameter pile	2m	3m	4m	18m
2m diameter pile	3m	4m	5m	25m
3m diameter pile	4m	5m	6m	29m
4m diameter pile	6m	7m	8m	34m

Comparison with MeyGen

For MeyGen, the source levels for drilling were considerably below the levels at which lethal injury to species of marine mammal might occur (240 dB re. 1 μPa). It was therefore considered unlikely that any marine animals would be killed as a consequence of the underwater noise from drilling activities at the Inner Sound development area.

The noise modelling for MeyGen also indicated that the peak source levels associated with drilling were also below the levels at which hearing damage from the underwater noise might occur (230 dB re. 1μPa and 224 dB re. 1μPa for the onset of Permanent Threshold Shift (PTS) and Temporary Threshold Shift (TTS) for cetaceans and 218 dB re. 1μPa and 212 dB re. 1μPa for the onset of PTS and TTS for pinnipeds). Even taking into account the more conservative criteria proposed by Lucke *et al*. (2009) for harbour porpoises (193.7 dB re 1 μPa) and those put forward by the NMFS (1995), whereby auditory injury may occur to pinnipeds and cetaceans following prolonged exposure to underwater sound at levels at or above 190 dB re. 1 μPa and 180 dB re. 1 μPa respectively, the source levels were sufficiently low such that the NMFS impact criteria were not exceeded (Kongsberg, 2012).

This is consistent with noise modelling for Morlais, as the risk of PTS is negligible.

1.3.2 Operational tidal turbines

PTS

The underwater noise modelling for the maximum predicted range for PTS is less than 10m for small tidal turbine (**Table 1-6**) and large tidal turbine (**Table 1-8**) at Morlais, based on the non-impulsive Southall *et* *al*. (2019) criteria for cumulative exposure (SEL_{cum}). The magnitude of the potential risk of PTS from operational turbines is assessed as **negligible / very low** for all species based on the Morlais underwater noise modelling (**Table 1-15**).

This is consistent with assessment for PTS in the ES, which found that the noise levels would not be sufficient to result in any auditory injury, based on the noise measurements and modelling for a range of different operational tidal devices.

For PTEC, the source levels for the operational tidal device noise were estimated to be 155.8, 162.2, and 165.4 dB re 1 µPa@1 m (RMS) for the 10m, 15m, and 20m rotor diameters respectively, were below the 240 and 220 dB re 1 µPa (SPL_{peak}) criteria for lethal effect and physical injury (Subacoustech, 2014).

The modelling for MeyGen indicated that the source levels for operational noise from either the 1MW turbine or the 2.4MW turbine were below the levels at which lethal injury to species of marine mammal might occur (240 dB re. 1 µPa) (Konsberg, 2012).

The modelling for MeyGen also indicated that peak source levels associated with operational noise from either the 1MW or 2.4MW turbines were below the levels at which hearing damage from the underwater noise might occur (230 dB re. 1µPa and 224 dB re. 1µPa for the onset of PTS and TTS in cetaceans and 218 dB re. 1µPa and 212 dB re. 1µPa for the onset of PTS and TTS in pinnipeds). Even taking into account the more conservative criteria proposed by Lucke *et al*. (2009) for harbour porpoises (193.7 dB re 1 µPa) and NMFS (1995), whereby auditory injury may occur to pinnipeds and cetaceans following prolonged exposure to underwater sound at levels at or above 190 dB re. 1 µPa and 180 dB re. 1 µPa respectively, the source levels for operational noise for each turbine were sufficiently low such that the NMFS impact criteria were not exceeded (Konsberg, 2012).

TTS

The underwater noise modelling for the maximum predicted range for TTS from small tidal turbine (**Table 1-6**) or large tidal turbine (**Table 1-8**) at Morlais, based on the non-impulsive Southall *et al*. (2019) criteria for cumulative exposure (SEL_{cum}), is less than 10m for all species, with the exception of harbour porpoise.

For harbour porpoise the maximum predicted TTS range is 50m for small tidal turbine (**Table 1-6**) and 230m for large tidal turbine (**Table 1-8**) at Morlais, based on the non-impulsive Southall *et al*. (2019) criteria for cumulative exposure (SEL_{cum}).

The magnitude of the potential risk of TTS from operational turbines is assessed as **negligible / very low** for all species based on the Morlais underwater noise modelling (**Table 1-15**).

Taking into account the medium sensitivity of all marine mammal species to any temporary auditory injury (i.e. receptor has limited capacity to recover from the anticipated impact) and the potential magnitude of the effect (negligible/very low for all species), the impact significance for any permanent auditory injury in harbour porpoise, bottlenose dolphin, Risso's dolphin, common dolphin, minke whale, grey seal and harbour seal from cumulative exposure from operational turbines has been assessed as **minor (not significant)**.

TTS was not assessed for operational turbines in the ES.

Table 1-15: Maximum number of individuals (and % of reference population) that could be at risk of PTS and TTS from operational turbines at Morlais

Potential Impact	Maximum number of individuals and (% of reference population) and magnitude based on modelling for small operational turbine at Morlais	Maximum number of individuals and (% of reference population) and magnitude based on modelling for large operational turbine at Morlais
PTS in harbour porpoise	0.00024 individuals (based on density estimate of 0.783/km^2) (0.00000023% of the 104,695 reference population). Potential permanent effect with **negligible / very low magnitude** (less than 0.001% of the reference population anticipated to be exposed to effect).	0.00024 individuals (based on density estimate of 0.783/km^2) (0.00000023% of the 104,695 reference population). Potential permanent effect with **negligible / very low magnitude** (less than 0.001% of the reference population anticipated to be exposed to effect).
TTS in harbour porpoise	0.006 individuals (based on density estimate of 0.783/km^2) (0.000006% of the 104,695 reference population). Temporary effect with **negligible / very low magnitude** (less than 1% of the reference population anticipated to be exposed to effect).	0.2 individuals (based on density estimate of 0.783/km^2) (0.0002% of the 104,695 reference population). Temporary effect with **negligible / very low magnitude** (less than 1% of the reference population anticipated to be exposed to effect).
PTS in bottlenose dolphin	0.000006 individuals (based on density estimate of 0.02/km^2) (0.0000015% of the reference population of 397 bottlenose dolphin). Potential permanent effect with **negligible / very low magnitude** (less than 0.001% of the reference population anticipated to be exposed to effect).	0.000006 individuals (based on density estimate of 0.02/km^2) (0.0000015% of the reference population of 397 bottlenose dolphin). Potential permanent effect with **negligible / very low magnitude** (less than 0.001% of the reference population anticipated to be exposed to effect).
TTS in bottlenose dolphin	0.000006 individuals (based on density estimate of 0.02/km^2) (0.0000015% of the reference population of 397 bottlenose dolphin). Temporary effect with **negligible / very low magnitude** (less than 1% of the reference population anticipated to be exposed to effect).	0.000006 individuals (based on density estimate of 0.02/km^2) (0.0000015% of the reference population of 397 bottlenose dolphin). Temporary effect with **negligible / very low magnitude** (less than 1% of the reference population anticipated to be exposed to effect).
PTS in Risso's dolphin	0.000009 individuals (based on density estimate of 0.031/km^2) (0.0000001% of the reference population of 8,794 Risso's dolphin). Potential permanent effect with **negligible / very low magnitude** (less than 0.001% of the reference population anticipated to be exposed to effect).	0.000009 individuals (based on density estimate of 0.031/km^2) (0.0000001% of the reference population of 8,794 Risso's dolphin). Potential permanent effect with **negligible / very low magnitude** (less than 0.001% of the reference population anticipated to be exposed to effect).

Potential Impact	Maximum number of individuals and (% of reference population) and magnitude based on modelling for small operational turbine at Morlais	Maximum number of individuals and (% of reference population) and magnitude based on modelling for large operational turbine at Morlais
TTS in Risso's dolphin	0.000009 individuals (based on density estimate of 0.031/km^2) (0.0000001% of the reference population of 8,794 Risso's dolphin). Temporary effect with **negligible / very low magnitude** (less than 1% of the reference population anticipated to be exposed to effect).	0.000009 individuals (based on density estimate of 0.031/km^2) (0.0000001% of the reference population of 8,794 Risso's dolphin). Temporary effect with **negligible / very low magnitude** (less than 1% of the reference population anticipated to be exposed to effect).
PTS in common dolphin	0.000066 individuals (based on density estimate of 0.22/km^2) (0.0000001% of the reference population of 56,556 common dolphin). Potential permanent effect with **negligible / very low magnitude** (less than 0.001% of the reference population anticipated to be exposed to effect).	0.000066 individuals (based on density estimate of 0.22/km^2) (0.0000001% of the reference population of 56,556 common dolphin). Potential permanent effect with **negligible / very low magnitude** (less than 0.001% of the reference population anticipated to be exposed to effect).
TTS in common dolphin	0.000066 individuals (based on density estimate of 0.22/km^2) (0.0000001% of the reference population of 56,556 common dolphin). Temporary effect with **negligible / very low magnitude** (less than 1% of the reference population anticipated to be exposed to effect).	0.000066 individuals (based on density estimate of 0.22/km^2) (0.0000001% of the reference population of 56,556 common dolphin). Temporary effect with **negligible / very low magnitude** (less than 1% of the reference population anticipated to be exposed to effect).
PTS in minke whale	0.000005 individuals (based on density estimate of 0.017/km^2) (0.00000002% of the reference population of 23,528 minke whale). Potential permanent effect with **negligible / very low magnitude** (less than 0.001% of the reference population anticipated to be exposed to effect).	0.000005 individuals (based on density estimate of 0.017/km^2) (0.00000002% of the reference population of 23,528 minke whale). Potential permanent effect with **negligible / very low magnitude** (less than 0.001% of the reference population anticipated to be exposed to effect).
TTS in minke whale	0.000005 individuals (based on density estimate of 0.017/km^2) (0.00000002% of the reference population of 23,528 minke whale). Temporary effect with **negligible / very low magnitude** (less than 1% of the reference population anticipated to be exposed to effect).	0.000005 individuals (based on density estimate of 0.017/km^2) (0.00000002% of the reference population of 23,528 minke whale). Temporary effect with **negligible / very low magnitude** (less than 1% of the reference population anticipated to be exposed to effect).
PTS in grey seal	0.000047 individuals (based on density estimate of 0.155/km^2)	0.000047 individuals (based on density estimate of 0.155/km^2)

Potential Impact	Maximum number of individuals and (% of reference population) and magnitude based on modelling for small operational turbine at Morlais	Maximum number of individuals and (% of reference population) and magnitude based on modelling for large operational turbine at Morlais
	(0.0000008% of the reference population of 6,000 grey seal). Potential permanent effect with **negligible / very low magnitude** (less than 0.001% of the reference population anticipated to be exposed to effect).	(0.0000008% of the reference population of 6,000 grey seal). Potential permanent effect with **negligible / very low magnitude** (less than 0.001% of the reference population anticipated to be exposed to effect).
TTS in grey seal	0.000047 individuals (based on density estimate of 0.155/km^2) (0.0000008% of the reference population of 6,000 grey seal). Temporary effect with **negligible / very low magnitude** (less than 1% of the reference population anticipated to be exposed to effect).	0.000047 individuals (based on density estimate of 0.155/km^2) (0.0000008% of the reference population of 6,000 grey seal). Temporary effect with **negligible / very low magnitude** (less than 1% of the reference population anticipated to be exposed to effect).
PTS in harbour seal	0.00000015 individuals (based on density estimate of 0.0005/km^2) (0.0000003% of the reference population of 50 harbour seal). Potential permanent effect with **negligible / very low magnitude** (less than 0.001% of the reference population anticipated to be exposed to effect).	0.00000015 individuals (based on density estimate of 0.0005/km^2) (0.0000003% of the reference population of 50 harbour seal). Potential permanent effect with **negligible / very low magnitude** (less than 0.001% of the reference population anticipated to be exposed to effect).
TTS in harbour seal	0.00000015 individuals (based on density estimate of 0.0005/km^2) (0.0000003% of the reference population of 50 harbour seal). Temporary effect with **negligible / very low magnitude** (less than 1% of the reference population anticipated to be exposed to effect).	0.00000015 individuals (based on density estimate of 0.0005/km^2) (0.0000003% of the reference population of 50 harbour seal). Temporary effect with **negligible / very low magnitude** (less than 1% of the reference population anticipated to be exposed to effect).

Disturbance

The assessment of potential disturbance, as assessed in the ES is presented in **Table 1-16**.

The assessment in the ES was based on the worst-case scenario for the PTEC noise modelling, the number of marine mammals that could be disturbed from the underwater of operational turbines at Morlais was estimated for one device based on the possible mild avoidance range for 75 dB_{ht}(*Species*) and 90 dB_{ht}(*Species*) (**Table 1-16**).

Table 1-16: Summary of the modelled ranges for 90 and 75 dB_{ht}(Species) levels from an operational tidal device with a rotor diameter of 24m at PTEC, as assessed in the ES

Potential Impact	**90 dB_{ht}(*Species*) maximum range (m)**	**75 dB_{ht}(*Species*) maximum range (m)**
Disturbance of harbour porpoise	**610m**	9.1km
Disturbance of bottlenose dolphin (dolphin species)	**95m**	2.2km
Disturbance of minke whale	**400m**	4.7km
Disturbance of grey and harbour seal	**75m**	2.0km

The underwater noise modelling results for single small tidal turbines with 16.13m diameter rotor and large tidal turbine with dual 24.6m diameter rotors, indicate that the maximum predicted disturbance range for the large tidal turbine is 70m (**Table 1-17**) based on the unweighted median received level of 142 dB (SPL_{RMS}) associated with a significant reduction in harbour seal from operational tidal turbine noise (Hastie *et al*. (2018). This is the most specific and relevant disturbance threshold available for this type of assessment. As the low-end threshold of 120 dB (SPL_{RMS}) for continuous noise disturbance for marine mammals from Southall *et al*. (2007) is approaching the order of background noise in some areas (Nedwell *et al*. 2003, 2007).

Therefore, the predicted maximum disturbance range of 70m is within the disturbance ranges assessed in the ES, based on strong avoidance at 90 dB_{ht}(*Species*) range.

Table 1-17: Modelled SPL_{RMS} disturbance impact ranges for operational single small and large tidal turbines using the criteria from Southall *et al*. (2007) and Hastie *et al*. (2018)

Potential SPL_{RMS} disturbance threshold	**Small tidal turbine (single location)**	**Large tidal turbine (2 rotors) (single location)**
142 dB re 1 µPa (RMS)	20m	**70m**

For the assessment in the Morlais ES, the full deployment assessment was based on the possible strong avoidance at 90 dB_{ht}(*Species*) range from the PTEC modelling, as a worst-case scenario.

The assessment in the Morlais ES for the full deployment was based on arrays rather than individual tidal devices, as individual marine mammals would be more likely to be disturbed by the closest turbine they approach rather than all individual turbines within the array. As an indicative precautionary worst-case, the assessment has been based on up to 10 arrays, however the maximum number of arrays at the Morlais is likely to be eight. The areas are based on an area of a circle and assessment also assumes no overlap in disturbance areas between arrays / groups of turbines (**Table 1-18**).

Based on the underwater noise modelling for a large tidal turbine at Morlais with predicted disturbance range of 70m, the area of potential disturbance around each device was estimated to be $0.15km^2$, based on the area of a circle. As assessed in the ES and as an indicative precautionary worst-case, the assessment has been based on up to 10 arrays for full deployment (**Table 1-18**).

Taking into account the low sensitivity to any disturbance (i.e. has some tolerance to avoid, adapt to, accommodate or recover from the anticipated impact) and the potential magnitude of the effect of very low / negligible for all marine mammal species, the impact significance for any possible long-term disturbance in harbour porpoise, bottlenose dolphin, Risso's dolphin, common dolphin, minke whale, grey seal and harbour seal was assessed as **negligible** in the ES and there is no change based on the assessment of the underwater noise modelling.

Table 1-18: Maximum number of individuals (% of reference population) and magnitude for disturbance of marine mammals as a result of underwater from operational tidal devices at Morlais, based on assessment in the ES and underwater noise modelling at Morlais

Potential Impact	**Assessment in ES**			**Updated assessment**		
	One device (90dB$_{ht}$)	**Full deployment (x10 arrays)**	**Magnitude**	**One large device (142 dB re 1 µPa (RMS))**	**Full deployment (x10 arrays)**	**Magnitude**
Disturbance of harbour porpoise	0.92 individuals in 1.17km^2 (based on density estimate of 0.783/km^2) (0.0009% of the 104,695 reference population).	9.2 individuals in 11.7km^2 (0.009% of MU)	Long term effect with **very low / negligible magnitude** (less than 0.01% of the reference population anticipated to be exposed to effect).	0.012 individuals in 0.015km^2 (based on density estimate of 0.783/km^2) (0.00001% of the 104,695 reference population).	0.12 individuals in 0.15km^2 (0.0001% of MU).	Long term effect with **very low / negligible magnitude** (less than 0.01% of the reference population anticipated to be exposed to effect).
Disturbance of bottlenose dolphin	0.0006 individuals in 0.028km^2 (based on density estimate of 0.02/km^2) (0.00015% of the reference population of 397 bottlenose dolphin).	0.006 individuals in 0.28km^2 (0.0015% for MU)	Long-term effect with **very low / negligible magnitude** (less than 0.01% of the reference population anticipated to be exposed to effect).	0.0003 individuals in 0.015km^2 (based on density estimate of 0.02/km^2) (0.00008% of the reference population of 397 bottlenose dolphin).	0.003 individuals in 0.15km^2 (0.0008% for MU).	Long-term effect with **very low / negligible magnitude** (less than 0.01% of the reference population anticipated to be exposed to effect).
Disturbance of Risso's dolphin	0.0009 individuals in 0.028km^2 (based on density estimate of 0.031/km^2) (0.00001% of the reference	0.009 individuals in 0.28km^2 (0.0001% for MU)	Long-term effect with **very low / negligible magnitude** (less than 0.01% of the reference population	0.0005 individuals in 0.015km^2 (based on density estimate of 0.031/km^2) (0.000006% of the reference	0.005 individuals in 0.15km^2 (0.00006% for MU)	Long-term effect with **very low / negligible magnitude** (less than 0.01% of the reference population

Potential Impact	Assessment in ES			Updated assessment		
	One device (90dB$_{ht}$)	**Full deployment (x10 arrays)**	**Magnitude**	**One large device (142 dB re 1 µPa (RMS))**	**Full deployment (x10 arrays)**	**Magnitude**
	population of 8,794 Risso's dolphin).		anticipated to be exposed to effect).	population of 8,794 Risso's dolphin).		anticipated to be exposed to effect).
Disturbance of common dolphin	0.006 individuals in 0.028km^2 (based on density estimate of 0.22/km^2) (0.00001% of the reference population of 56,556 common dolphin).	0.06 individuals in 0.28km^2 (0.0001% of MU).	Long-term effect with **very low / negligible magnitude** (less than 0.01% of the reference population anticipated to be exposed to effect).	0.003 individuals in 0.015km^2 (based on density estimate of 0.22/km^2) (0.000006% of the reference population of 56,556 common dolphin).	0.03 individuals in 0.15km^2 (0.00006% of MU).	Long-term effect with **very low / negligible magnitude** (less than 0.01% of the reference population anticipated to be exposed to effect).
Disturbance of minke whale	0.0085 individuals (0.5km^2; based on density estimate of 0.017/km^2) (0.00004% of the reference population of 23,528 minke whale).	0.085 individuals in 5km^2 (0.0004% of MU)	Long-term effect with **very low / negligible magnitude** (less than 0.01% of the reference population anticipated to be exposed to effect).	0.0003 individuals (0.015km^2; based on density estimate of 0.017/km^2) (0.000001% of the reference population of 23,528 minke whale).	0.003 individuals in 0.15km^2 (0.00001% of MU)	Long-term effect with **very low / negligible magnitude** (less than 0.01% of the reference population anticipated to be exposed to effect).
Disturbance of grey seal	0.012 individuals in 0.018km^2 (based on density estimate of 0.155/km^2) (0.0002% of the reference population	0.03 individuals in 0.18km^2 (0.0005% of MU)	Long-term effect with **very low / negligible magnitude** (less than 0.01% of the reference population anticipated to be	0.002 individuals in 0.015km^2 (based on density estimate of 0.155/km^2) (0.00003% of the reference population	0.02 individuals in 0.15km^2 (0.0003% of MU)	Long-term effect with **very low / negligible magnitude** (less than 0.01% of the reference population anticipated to be

Potential Impact	Assessment in ES			Updated assessment		
	One device (90dB$_{ht}$)	Full deployment (x10 arrays)	Magnitude	One large device (142 dB re 1 µPa (RMS))	Full deployment (x10 arrays)	Magnitude
	of 6,000 grey seal).		exposed to effect).	of 6,000 grey seal).		exposed to effect).
Disturbance of harbour seal	0.000009 individuals in 0.018km^2 (based on density estimate of 0.0005/km^2) (0.000018% of the reference population of 50 harbour seal).	0.00009 individuals in 0.18km^2 (0.00018% of MU)	Long-term effect with **very low / negligible magnitude** (less than 0.01% of the reference population anticipated to be exposed to effect).	0.000008 individuals in 0.015km^2 (based on density estimate of 0.0005/km^2) (0.000016% of the reference population of 50 harbour seal).	0.00008 individuals in 0.15km^2 (0.00016% of MU)	Long-term effect with **very low / negligible magnitude** (less than 0.01% of the reference population anticipated to be exposed to effect).

1.3.3 ADDs

PTS

The underwater noise modelling for the maximum predicted range for PTS is less than 10m for the Lofitech seal scarer ADD at Morlais for dolphin species, minke whale and seals (**Table 1-10**), based on the non-impulsive Southall *et al*. (2019) criteria for cumulative exposure (SEL_{cum}). For harbour porpoise the maximum predicted range for PTS is up to 220m for the Lofitech seal scarer ADD at Morlais (**Table 1-10**), based on the non-impulsive Southall *et al*. (2019) criteria for cumulative exposure (SEL_{cum}).

The magnitude of the potential risk of PTS is assessed as **negligible / very low** for all species based on the Morlais underwater noise modelling (**Table 1-19**).

This is consistent with the assessment in the ES, which indicated that the risk of marine mammals receiving a dose of sound sufficient to cause auditory injury from ADDs is very low. The Joint Nature Conservation Committee (JNCC) guide to selection of ADDs (McGarry *et al*., 2018) modelled the potential for auditory injury from ADDs, assuming a swim speed of 2.5m/s and 30 minutes of ADD activation. The results showed that the NOAA (NMFS, 2018) PTS threshold for all mammals was not exceeded beyond 100m for any of the devices modelled, with the exception of the SaveWave Orcasaver where PTS could potentially occur up to 130m from the device. It was therefore concluded that the risk of injury due to ADD deployment is low for all devices, including the Lofitech seal scarer ADD (McGarry *et al*., 2018).

TTS

The underwater noise modelling for the maximum predicted range for TTS for the Lofitech seal scarer ADD at Morlais, based on the non-impulsive Southall *et al*. (2019) criteria for cumulative exposure (SEL_{cum}), is 10m for minke whale, grey seal and harbour seal (**Table 1-10**).

For bottlenose dolphin the maximum predicted TTS range is 50m and for harbour porpoise it is up to 5.3km for the Lofitech seal scarer ADD at Morlais (**Table 1-10**), based on the non-impulsive Southall et al. (2019) criteria for cumulative exposure (SEL_{cum}).

The magnitude of the potential risk of TTS for the Lofitech seal scarer ADD is assessed as **negligible / very low** for all species based on the Morlais underwater noise modelling (**Table 1-19**).

Taking into account the medium sensitivity of all marine mammal species to any temporary auditory injury (i.e. receptor has limited capacity to recover from the anticipated impact) and the potential magnitude of the effect (negligible/very low for all species), the impact significance for any permanent auditory injury in harbour porpoise, bottlenose dolphin, Risso's dolphin, common dolphin, minke whale, grey seal and harbour seal for the Lofitech seal scarer ADD at Morlais has been assessed as **minor (not significant)**.

TTS was not assessed for ADDs in the ES.

Table 1-19: Maximum number of individuals (and % of reference population) that could be at risk of PTS and TTS from ADDs at Morlais

Potential Impact	Maximum number of individuals and (% of reference population) and Magnitude based on modelling for ADD at Morlais
PTS in harbour porpoise	0.12 individuals (based on density estimate of 0.783/km^2) (0.0001% of the 104,695 reference population). Potential permanent effect with **negligible / very low magnitude** (less than 0.001% of the reference population anticipated to be exposed to effect).
TTS in harbour porpoise	69 individuals (based on density estimate of 0.783/km^2) (0.07% of the 104,695 reference population). Temporary effect with **negligible / very low magnitude** (less than 1% of the reference population anticipated to be exposed to effect).
PTS in bottlenose dolphin	0.000006 individuals (based on density estimate of 0.02/km^2) (0.0000015% of the reference population of 397 bottlenose dolphin). Potential permanent effect with **negligible / very low magnitude** (less than 0.001% of the reference population anticipated to be exposed to effect).
TTS in bottlenose dolphin	0.00016 individuals (based on density estimate of 0.02/km^2) (0.00004% of the reference population of 397 bottlenose dolphin). Temporary effect with **negligible / very low magnitude** (less than 1% of the reference population anticipated to be exposed to effect).
PTS in Risso's dolphin	0.000009 individuals (based on density estimate of 0.031/km^2) (0.0000001% of the reference population of 8,794 Risso's dolphin). Potential permanent effect with **negligible / very low magnitude** (less than 0.001% of the reference population anticipated to be exposed to effect).
TTS in Risso's dolphin	0.000009 individuals (based on density estimate of 0.031/km^2) (0.0000001% of the reference population of 8,794 Risso's dolphin). Temporary effect with **negligible / very low magnitude** (less than 1% of the reference population anticipated to be exposed to effect).
PTS in common dolphin	0.000066 individuals (based on density estimate of 0.22/km^2) (0.0000001% of the reference population of 56,556 common dolphin). Potential permanent effect with **negligible / very low magnitude** (less than 0.001% of the reference population anticipated to be exposed to effect).

Potential Impact	Maximum number of individuals and (% of reference population) and Magnitude based on modelling for ADD at Morlais
TTS in common dolphin	0.000066 individuals (based on density estimate of 0.22/km^2) (0.0000001% of the reference population of 56,556 common dolphin). Temporary effect with **negligible / very low magnitude** (less than 1% of the reference population anticipated to be exposed to effect).
PTS in minke whale	0.000005 individuals (based on density estimate of 0.017/km^2) (0.00000002% of the reference population of 23,528 minke whale). Potential permanent effect with **negligible / very low magnitude** (less than 0.001% of the reference population anticipated to be exposed to effect).
TTS in minke whale	0.000005 individuals (based on density estimate of 0.017/km^2) (0.00000002% of the reference population of 23,528 minke whale). Temporary effect with **negligible / very low magnitude** (less than 1% of the reference population anticipated to be exposed to effect).
PTS in grey seal	0.000047 individuals (based on density estimate of 0.155/km^2) (0.0000008% of the reference population of 6,000 grey seal). Potential permanent effect with **negligible / very low magnitude** (less than 0.001% of the reference population anticipated to be exposed to effect).
TTS in grey seal	0.000047 individuals (based on density estimate of 0.155/km^2) (0.0000008% of the reference population of 6,000 grey seal). Temporary effect with **negligible / very low magnitude** (less than 1% of the reference population anticipated to be exposed to effect).
PTS in harbour seal	0.00000015 individuals (based on density estimate of 0.0005/km^2) (0.0000003% of the reference population of 50 harbour seal). Potential permanent effect with **negligible / very low magnitude** (less than 0.001% of the reference population anticipated to be exposed to effect).
TTS in harbour seal	0.00000015 individuals (based on density estimate of 0.0005/km^2) (0.0000003% of the reference population of 50 harbour seal). Temporary effect with **negligible / very low magnitude** (less than 1% of the reference population anticipated to be exposed to effect).

Disturbance

As outlined in the EMMP and the marine mammal monitoring note, the use of ADDs will be considered post consent in consultation with NRW and therefore this has been inlcuded as a precautionary assessment.

As outlined in the ES, the JNCC guide to selection of ADDs in industry, which describes the commercially available ADDs and their applications (McGarry *et al*., 2018), the Offshore Renewables Joint Industry Project (ORJIP) review on the effectiveness of ADD for mitigation purposes (Herschel *et al*., 2013; 2014) and a review of the effectiveness of ADDs on minke whale (McGarry *et al*., 2017), the Lofitech device has been shown to be the most consistent and effective device for deterring seals, harbour porpoise and minke whale. The Lofitech device has successfully been used in a number of projects for a range of industries, including for aquaculture projects and the offshore wind industry. Therefore, this device has been used, as an example, in this assessment (**Table 1-19**).

Studies have shown the Lofitech device to be effective for harbour porpoise with an immediate response on activation of the device (Brandt *et al*., 2012, 2013; McGarry *et al*., 2018). In tests of the effectiveness of the Lofitech device on harbour porpoise at a site in the German North Sea, a significant decline in harbour porpoise detection was observed even at the furthest CPOD at 7.5km from the source (Brandt *et al*., 2013). Therefore, 7.5km was used as a worst-case in the ES for the potential displacement of harbour porpoise during ADD activation (**Table 1-19**).

There is no information available on the effectiveness of the Lofitech device on dolphin species. However, studies on the effectiveness of ADDs in captive dolphins has shown startle responses in bottlenose dolphins at ADD source levels of 135 dB re 1µPa RMS (Janik and Götz, 2015). It could therefore be assumed that the deterrence range of bottlenose dolphins from an ADD emitting a sound source level of 190 dB re 1 µPa with a high frequency could be more than 4km (McGarry *et al*., 2017). There is very little information on the effect of ADDs on other dolphin species, such as Risso's dolphin and common dolphin. However, based on hearing range, they would be expected to have a similar response as bottlenose dolphins. Therefore, 4km was used as a worst-case in the ES for the potential displacement of dolphin species during ADD activation (**Table 1-19**).

The Lofitech device has been proven to effect minke whale behaviour up to 1km from the source, with a maximum deterrence range of 4.5 km detected (McGarry *et al*., 2017). Therefore, 4.5km was used as a worst-case in the ES for the potential displacement of minke whale during ADD activation (**Table 1-19**).

A number of different trials have shown that the Lofitech device is effective at deterring harbour and grey seals to a distance of 1km from the device location (Brandt *et al*., 2012; 2013; Gordon *et al*., 2015). Therefore, 1km was used as a worst-case in the ES for the potential displacement of grey and harbour seal during ADD activation (**Table 1-19**).

In addition, as a precautionary approach, the assessment in the ES was also based on a potential average disturbance range of approximately 1km (3.14km^2) for a range of ADD devices for all species (**Table 1-19**), based on the JNCC guide for the selection and deployment of acoustic deterrent devices (McGarry *et al*., 2018).

The underwater noise modelling results for single ADD, indicated a maximum predicted disturbance range of 840m (**Table 1-11**) based on the unweighted median received level of 142 dB (SPL_{RMS}) associated with a significant reduction in harbour seal from operational tidal turbine noise (Hastie *et al*. (2018). This is the most specific and relevant disturbance threshold available for this type of assessment. As the low-end threshold of 120 dB (SPL_{RMS}) for continuous noise disturbance for marine mammals from Southall *et al*. (2007) is approaching the order of background noise in some areas (Nedwell *et al*. 2003, 2007).

Therefore, the predicted maximum disturbance range of 840m (2.22km^2 based on area of a circle) is within the disturbance ranges and areas assessed in the ES.

The requirements for ADD use has still to be determined during the development of the EMMP. Therefore, for the ES assessment a precautionary indicative example was assumed, in that there could be four ADDs at each of the arrays with a worst-case scenario of up to ten arrays (**Table 1-20**), although a maximum of eight arrays are proposed for the Morlais. However, it is proposed that the ADDs would only be activated when marine mammals are in close proximity to the arrays and therefore not all 40 ADDs would ever be activated at the same time.

Taking into account the low sensitivity to any disturbance (i.e. has some tolerance to avoid, adapt to, accommodate or recover from the anticipated impact) and the potential magnitude of the effect (negligible / very low for all species), the impact significance for displacement as a result of ADDs has been assessed as **negligible** in the ES and there is no change based on the assessment of the underwater noise modelling.

Table 1-20 Number of individuals (and % of reference population) that could be disturbed during ADD activation based on Lofitech device, as assessed in the ES and underwater noise modelling at Morlais

Potential Impact	Assessment in ES					Updated assessment			
	One Lofitech device (maximum potential range)	One ADD ($3.14km^2$)	Full deployment for up to 10 ADDs ($31.4km^2$)	Full deployment for up to 40 ADDs ($125.6km^2$)	Magnitude	One ADD ($2.22km^2$)	Full deployment for up to 10 ADDs ($22.2km^2$)	Full deployment for up to 40 ADDs ($88.8km^2$)	Magnitude
Disturbance of harbour porpoise	Up to 7.5km ($177km^2$) 139 individuals (0.13% of MU)	2.46 individuals (based on density estimate of $0.783/km^2$) (0.002% of the 104,695 reference population).	24.6 individuals (based on density estimate of $0.783/km^2$) (0.02% of the 104,695 reference population).	98 individuals (based on density estimate of $0.783/km^2$) (0.09% of the 104,695 reference population).	Temporary effect with **negligible / very low magnitude** (less than 1% of the reference population anticipated to be exposed to effect).	1.74 individuals (based on density estimate of $0.783/km^2$) (0.002% of the 104,695 reference population).	17.4 individuals (based on density estimate of $0.783/km^2$) (0.02% of the 104,695 reference population).	60.5 individuals (based on density estimate of $0.783/km^2$) (0.07% of the 104,695 reference population).	Temporary effect with **negligible / very low magnitude** (less than 1% of the reference population anticipated to be exposed to effect).
Disturbance of bottlenose dolphin	Up to 4km ($50.3km^2$) 1 individual (0.25% of MU)	0.06 individuals (based on density estimate of $0.02/km^2$) (0.015% of the reference	0.6 individuals (based on density estimate of $0.02/km^2$) (0.15% of the reference	2.5 individuals (based on density estimate of $0.02/km^2$) (0.63% of the reference	Temporary effect with **negligible / very low magnitude** (less than 1% of the reference population	0.04 individuals (based on density estimate of $0.02/km^2$) (0.01% of the reference	0.4 individuals (based on density estimate of $0.02/km^2$) (0.1% of the reference population	1.8 individuals (based on density estimate of $0.02/km^2$) (0.45% of the reference	Temporary effect with **negligible / very low magnitude** (less than 1% of the reference population

Potential Impact	Assessment in ES					Updated assessment			
	One Lofitech device (maximum potential range)	**One ADD (3.14km²)**	**Full deployment for up to 10 ADDs (31.4km²)**	**Full deployment for up to 40 ADDs (125.6km²)**	**Magnitude**	**One ADD (2.22km²)**	**Full deployment for up to 10 ADDs (22.2km²)**	**Full deployment for up to 40 ADDs (88.8km²)**	**Magnitude**
		population of 397 bottlenose dolphin).	population of 397 bottlenose dolphin).	population of 397 bottlenose dolphin).	anticipated to be exposed to effect).	population of 397 bottlenose dolphin).	of 397 bottlenose dolphin).	population of 397 bottlenose dolphin).	anticipated to be exposed to effect).
Disturbance of Risso's dolphin	Up to 4 km (50.3km²) 1.6 individual (0.02% of MU)	0.1 individuals (based on density estimate of 0.031/km²) (0.001% of the reference population of 8,794 Risso's dolphin).	1 individual (based on density estimate of 0.031/km²) (0.01% of the reference population of 8,794 Risso's dolphin).	4 individuals (based on density estimate of 0.031/km²) (0.04% of the reference population of 8,794 Risso's dolphin).	Temporary effect with **negligible / very low magnitude** (less than 1% of the reference population anticipated to be exposed to effect).	0.07 individuals (based on density estimate of 0.031/km²) (0.0008% of the reference population of 8,794 Risso's dolphin).	0.7 individuals (based on density estimate of 0.031/km²) (0.008% of the reference population of 8,794 Risso's dolphin).	2.8 individuals (based on density estimate of 0.031/km²) (0.03% of the reference population of 8,794 Risso's dolphin).	Temporary effect with **negligible / very low magnitude** (less than 1% of the reference population anticipated to be exposed to effect).
Disturbance of common dolphin	Up to 4 km (50.3km²) 11 individual (0.02% of MU)	0.69 individuals (based on density estimate of 0.22/km²) (0.001% of the reference population of 56,556	7 individuals (based on density estimate of 0.22/km²) (0.01% of the reference population of 56,556	28 individuals (based on density estimate of 0.22/km²) (0.05% of the reference population of 56,556	Temporary effect with **negligible / very low magnitude** (less than 1% of the reference population anticipated to be	0.5 individuals (based on density estimate of 0.22/km²) (0.0009% of the reference population of 56,556	5 individuals (based on density estimate of 0.22/km²) (0.009% of the reference population of 56,556	20 individuals (based on density estimate of 0.22/km²) (0.04% of the reference population of 56,556	Temporary effect with **negligible / very low magnitude** (less than 1% of the reference population anticipated to be

Potential Impact	Assessment in ES					Updated assessment			
	One Lofitech device (maximum potential range)	One ADD ($3.14km^2$)	Full deployment for up to 10 ADDs ($31.4km^2$)	Full deployment for up to 40 ADDs ($125.6km^2$)	Magnitude	One ADD ($2.22km^2$)	Full deployment for up to 10 ADDs ($22.2km^2$)	Full deployment for up to 40 ADDs ($88.8km^2$)	Magnitude
		common dolphin).	common dolphin).	common dolphin).	exposed to effect).	common dolphin).	common dolphin).		exposed to effect).
Disturbance of minke whale	Up to 4.5km ($64km^2$) 1 individual (0.004 of MU)	0.05 individuals (based on density estimate of $0.017/km^2$) (0.0002% of the reference population of 23,528 minke whale).	0.5 individuals (based on density estimate of $0.017/km^2$) (0.002% of the reference population of 23,528 minke whale).	2 individuals (based on density estimate of $0.017/km^2$) (0.01% of the reference population of 23,528 minke whale).	Temporary effect with **negligible / very low magnitude** (less than 1% of the reference population anticipated to be exposed to effect).	0.04 individuals (based on density estimate of $0.017/km^2$) (0.0002% of the reference population of 23,528 minke whale).	0.4 individuals (based on density estimate of $0.017/km^2$) (0.002% of the reference population of 23,528 minke whale).	1.5 individuals (based on density estimate of $0.017/km^2$) (0.006% of the reference population of 23,528 minke whale).	Temporary effect with **negligible / very low magnitude** (less than 1% of the reference population anticipated to be exposed to effect).
Disturbance of grey seal	Up to 1km ($3.14km^2$) 0.49 individuals (0.008% of MU)	0.49 individuals (based on density estimate of $0.155/km^2$) (0.008% of the reference population of 6,000 grey seal).	5 individuals (based on density estimate of $0.155/km^2$) (0.08% of the reference population of 6,000 grey seal).	19.5 individuals (based on density estimate of $0.155/km^2$) (0.32% of the reference population of 6,000 grey seal).	Temporary effect with **negligible / very low magnitude** (less than 1% of the reference population anticipated to be exposed to effect).	0.3 individuals (based on density estimate of $0.155/km^2$) (0.005% of the reference population of 6,000 grey seal).	3.4 individuals (based on density estimate of $0.155/km^2$) (0.06% of the reference population of 6,000 grey seal).	13.8 individuals (based on density estimate of $0.155/km^2$) (0.23% of the reference population of 6,000 grey seal).	Temporary effect with **negligible / very low magnitude** (less than 1% of the reference population anticipated to be exposed to effect).

Potential Impact	Assessment in ES					Updated assessment			
	One Lofitech device (maximum potential range)	**One ADD (3.14km²)**	**Full deployment for up to 10 ADDs (31.4km²)**	**Full deployment for up to 40 ADDs (125.6km²)**	**Magnitude**	**One ADD (2.22km²)**	**Full deployment for up to 10 ADDs (22.2km²)**	**Full deployment for up to 40 ADDs (88.8km²)**	**Magnitude**
Disturbance of harbour seal	Up to 1km (3.14km²) 0.002 individuals (0.004% of MU)	0.002 individuals (based on density estimate of 0.0005/km²) (0.004% of the reference population of 50 harbour seal).	0.02 individuals (based on density estimate of 0.0005/km²) (0.04% of the reference population of 50 harbour seal).	0.06 individuals (based on density estimate of 0.0005/km²) (0.13% of the reference population of 50 harbour seal).	Temporary effect with **negligible / very low magnitude** (less than 1% of the reference population anticipated to be exposed to effect).	0.001 individuals (based on density estimate of 0.0005/km²) (0.002% of the reference population of 50 harbour seal).	0.01 individuals (based on density estimate of 0.0005/km²) (0.02% of the reference population of 50 harbour seal).	0.18 individuals (based on density estimate of 0.0005/km²) (0.4% of the reference population of 50 harbour seal).	Temporary effect with **negligible / very low magnitude** (less than 1% of the reference population anticipated to be exposed to effect).

1.3.4 Cumulative Impact Assessment

The assessment of the potential disturbance of marine mammals as a result of underwater noise from drilling, operational turbines and ADDs, based on the underwater noise modelling for Morlais is less than those assessed in the ES. Therefore, there would be no change or increase to the potential cumulative impacts as assessed in the ES.

1.4 Comparison with assessments in HRA

The assessment of the potential disturbance of marine mammals as a result of underwater noise from drilling, operational turbines and ADDs, based on the underwater noise modelling for Morlais is less than those assessed in the HRA. Therefore, there would be no change to the assessments in the HRA, including the in-combination assessments.

1.5 Summary and Conclusions

The level of underwater noise has been estimated using a parabolic equation (PE) method for lower frequencies and a ray tracing solution at higher frequencies. The modelling considers a variety of input parameters including source noise levels, frequency content, duty cycle, seabed properties and the sound speed profile in the water column. Full account is taken of the complex bathymetry in the area.

Worst case assumptions have been used for the modelling including the size, power and type of drilling apparatus, the model of ADD and using the maximum level in the water column. Two tidal turbine models and layouts have been modelled to cover the largest turbines and the greatest number of turbines.

Table 1-21gives a summary of the maximum Southall *et al*. (2019) injury criteria for TTS in VHF cetaceans (harbour porpoise) and the maximum Hastie *et al*. (2018) disturbance criteria for the different noise sources modelled, showing maximum injury ranges for ADDs and maximum disturbance ranges for drilling and ADDs.

Table 1-21: **Summary of the maximum predicted impact ranges for the modelling noise sources**

Potential Impact	VHF TTS (Weighted SEL_{cum}) (Southall *et al*. 2019)	142 dB re 1 μPa (Unweighted SPL_{RMS}) Disturbance (Hastie *et al.* 2018)
Percussive drilling	<10m	300m
Small tidal turbine	50m	20m
Large tidal turbine	230m	70m
ADDs	5.3km	840m

When considering operational turbines at all possible locations the results showed that overall noise levels are louder for the small turbines at 620 locations than they are for large turbines at 120 locations. Although the large turbines are louder individually, the fact that there are 400 less locations, and the locations are more spaced out, results in a lower overall level.

The assessments based on the underwater noise modelling are within the maximum ranges and worst-case scenarios assessed in the ES and HRA, including cumulative impacts and in-combination effects. Therefore there are no changes to the outcomes of the assessments.

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