Rampion 2 Wind Farm

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Executive summary

This Appendix has been produced to provide the quantitative underwater noise impact assessment for marine mammals from pile driving at Rampion 2. The following marine mammal species were included in the quantitative assessment: harbour porpoise, bottlenose dolphins, common dolphins, minke whales, harbour seals and grey seals. For each of these species, the impacts of Permanent Threshold Shift (PTS)-onset, Temporary Threshold Shift (TTS)-onset and behavioural disturbance from pile driving activities at Rampion 2 are assessed. The assessment includes three model locations within the array area to demonstrate differing water depths and propagation conditions, both monopiles and pin-piles and both a worst-case and most likely piling profile. The quantitative underwater noise impact assessment concludes that there is **no significant impact** predicted to marine mammals from the pile driving activities, and that therefore no additional mitigation is considered to be required.

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1. Introduction

1.1.1 Rampion Extension Development Limited (RED) (the Applicant) is proposing to develop the Rampion 2 Offshore Wind Farm Project (Rampion 2) located adjacent to the existing Rampion Offshore Wind Farm (Rampion 1) located in the English Channel in the south of England.

1.1.2 SMRU Consulting was commissioned by the Applicant to undertake a quantitative assessment for the impact of pile driving noise during construction of Rampion 2 on marine mammals. This Appendix focuses only on the pile driving activities during construction, all other impact pathways are presented in the Environmental Statement (ES) **Chapter 11: Marine mammals, Volume 2** of the ES (Document Reference: 6.2.11).

1.1.3 This Appendix should be read in conjunction with:

- **Chapter 11: Marine mammals, Volume 2** of the ES (Document Reference: 6.2.11);
- **Appendix 11.1: Marine mammal baseline technical report, Volume 4** of the ES (Document Reference: 6.4.11.1); and
- **Appendix 11.3: Underwater noise assessment technical report, Volume 4** the ES (Document Reference: 6.4.11.3).

1.2 Purpose

1.2.1 The purpose of this Appendix is to provide the full quantitative noise impact assessment for pile driving, which will be used to inform the marine mammal chapter of the Development Consent Order (DCO) Application for Rampion 2 under the Planning Act 2008 (the 2008 Act).

1.2.2 This Appendix presents:

- a summary of the results of the baseline characterisation for marine mammals;
- the methodology used to assess the impact of underwater noise from pile driving activities during the construction of Rampion 2 on marine mammals;
- details on the assumptions and limitations of the assessment methodologies; and
- the results for the impact of Permanent Threshold Shift (PTS)-onset, Temporary Threshold Shift (TTS)-onset and behavioural disturbance from pile driving on harbour porpoise, bottlenose dolphins, common dolphins, minke whales, harbour seals and grey seals.

1.3 Baseline summary

1.3.1 The marine mammal baseline characterisation is presented in **Appendix 11.1: Marine mammal baseline technical report, Volume 4** of the ES (Document

Reference: 6.4.11.1). The baseline characterisation details the occurrence of marine mammal species present in the Rampion 2 Study Area (as stated in **Section 11.4** of **Chapter 11: Marine mammals, Volume 2** of the ES (Document Reference: 6.2.11)), compiled through a combination of a literature review and data obtained from site-specific surveys. The conclusion of the baseline characterisation is a set of recommended density estimates and Management Units (MUs) for each species to be used in this quantitative noise impact assessment (**Table 1-1**).

Table 1-1 Marine mammal MUs and density estimates used in the quantitative impact assessment

	MU	MU size	Density	Density source
Harbour porpoise	North Sea	346,601	0.213	SCANS III (Hammond et al., 2021)
Bottlenose dolphin	Offshore Channel and South West England	10,947	0.037	SAMMS surveys (Laran et al., 2017)
Common dolphin	Celtic and Greater North Seas	102,656	0.171	SAMMS surveys (Laran et al., 2017)
Minke whale	Celtic and Greater North Seas	20,118	0.0023	SCANS III (Hammond et al., 2021)
Harbour seal	50% South & South-east England MUs combined	2,633	Grid cell specific	Habitat preference map (Carter et al., 2020)
Grey seal	South and Southeast England MUs combined	36,368	Grid cell specific	Habitat preference map (Carter et al., 2020)

2. Assessment methodology

2.1 Context

2.1.1 This section outlines the marine mammal piling noise impact assessment methodology. This includes definitions of magnitude and sensitivity, pile driving parameters, modelling locations, description of the thresholds used for the PTS-onset, TTS-onset and behavioural disturbance assessment and an assessment of the sensitivity of the different species to PTS-onset and behavioural disturbance from pile driving. In addition to this, the assumptions and limitations associated with the assessment methodology is detailed.

2.2 Impact Criteria

2.2.1 The criteria for determining the significance of effects is a two-stage process that involves defining the sensitivity of the receptors and then predicting the magnitude of the impact. This section describes the criteria applied in this chapter to assign values to the sensitivity of receptors and the magnitude of potential impacts. The criteria for defining marine mammal sensitivity are outlined in **Table 2-1** and the criteria for defining magnitude are outlined in **Table 2-2**. The significance of the impact on marine mammals is determined by a matrix combining the magnitude of the impact and the sensitivity of the receptor. The impact significance matrix is presented in **Table 2-3**.

Table 2-1 Definition of terms relating to marine mammal sensitivity.

Sensitivity	Definition
High	No ability to adapt behaviour so that individual vital rates (survival and reproduction) are highly likely to be significantly affected. No tolerance – effect will cause a significant change in individual vital rates (survival and reproduction). No ability for the animal to recover from any impact on vital rates (reproduction and survival rates).
Medium	Limited ability to adapt behaviour so that individual vital rates (survival and reproduction) may be significantly affected. Limited tolerance – effect may cause a significant change in individual vital rates (survival and reproduction). Limited ability for the animal to recover from any impact on vital rates (reproduction and survival rates).
Low	Ability to adapt behaviour so that individual vital rates (survival and reproduction) may be affected, but not at a significant level. Some tolerance – no significant change in individual vital rates (survival and reproduction).

Sensitivity	Definition
	Ability for the animal to recover from any impact on vital rates (reproduction and survival rates).
Very Low	Receptor is able to adapt behaviour so that individual vital rates (survival and reproduction) are not affected. Receptor is able to tolerate the effect without any impact on individual vital rates (survival and reproduction). Receptor is able to return to previous behavioural states/activities once the impact has ceased.

Table 2-2 Definition of terms relating to magnitude of impact.

Magnitude	Definition
High	The impact would affect the behaviour and distribution of sufficient numbers of individuals, with sufficient severity, to affect the favourable conservation status and/or the long-term viability of the population at a generational scale (Adverse).
Medium	Temporary changes in behaviour and/or distribution of individuals at a scale that would result in potential reductions to lifetime reproductive success to some individuals although not enough to affect the population trajectory over a generational scale. Permanent effects on individuals that may influence individual survival but not at a level that would alter population trajectory over a generational scale (Adverse).
Low	Short-term and/or intermittent and temporary behavioural effects in a small proportion of the population. Reproductive rates of individuals may be impacted in the short term (over a limited number of breeding cycles). Survival and reproductive rates very unlikely to be impacted to the extent that the population trajectory would be altered (Adverse).
Very Low	Very short term, recoverable effect on the behaviour and/or distribution in a very small proportion of the population. No potential for any changes in the individual reproductive success or survival therefore no changes to the population size or trajectory (Adverse).

Table 2-3 Level of significance of an impact.

		Magnitude			
		High	**Medium**	**Low**	**Very Low**
Sensitivity	**High**	Major (significant)	Major (significant)	Moderate (potentially significant)	Minor (not significant)
	Medium	Major (significant)	Moderate (potentially significant)	Minor (not significant)	Minor (not significant)
	Low	Moderate (potentially significant)	Minor (not significant)	Minor (not significant)	Negligible (not significant)
	Very Low	Moderate (not significant)	Minor (not significant)	Negligible (not significant)	Negligible (not significant)

2.3 Piling parameters

2.3.1 The noise levels likely to occur as a result of the construction of Rampion 2 were predicted by Subacoustech Environmental Limited using the INSPIRE (Impulse Noise Sound Propagation and Impact Range Estimator) model. A detailed description of the modelling approach is presented in **Appendix 11.3: Underwater noise assessment technical report, Volume 4** of the ES (Document Reference: 6.4.11.3).

2.3.2 Recent industry operational experience when installing offshore wind farms has shown that the actual hammer energies used during construction have been much lower than the maximum design scenario (MDS) parameters defined during the ES assessments. In recognition of this, both a worst-case scenario (WCS) and an most likely scenario (MLS) for both monopiles (**Table 2-4** and **Table 2-5**) and pin-piles (**Table 2-6** and **Table 2-7**) are presented to cover the absolute maximum piling parameters that would ever be required to install a foundation (in terms of maximal hammer energies and longest piling durations) alongside the piling parameters that are considered to be more representative of the majority of the piling activity across the site.

2.3.3 For the calculation of cumulative PTS and TTS-onset from monopiles, the assumption has been made that two monopiles can be installed sequentially (one after the other) in a 24 hour period. Given that the capacity of Rampion 2 is for up to 116 turbines (10 megawatt (MW) capacity per turbine), this results in a total of 58 piling days. In addition to this, a concurrent scenario is considered, where piling occurs concurrently (simultaneously) at two locations (E and W). It is assumed that two monopiles will be installed per 24 hours at each of the two locations, resulting in a total of four monopiles installed in 24 hours. If all piling is concurrent then this results in 29 piling days.

2.3.4 For the calculation of cumulative PTS and TTS-onset from pin-piles, the assumption has been made that four pin-piles can be installed sequentially (one after the other) at one location in a 24 hour period. Given that the capacity of Rampion 2 is for up to 116 turbines with 4 pins per jacket (10 MW capacity per turbine), this results in a total number of 116 piling days assuming 4 pin-piles are installed in one 24 hour period. In addition to this, a concurrent scenario is considered, where piling occurs concurrently (simultaneously) at two locations (E and W). It is assumed that four pin-piles will be installed per 24 hours at each of the two locations, resulting in a total of eight pin-piles installed in 24 hours. If all piling is concurrent, then this results in 58 piling days.

Table 2-4 WCS piling parameters for 13.5 m diameter monopiles

Stage	Soft-start	Ramp-up			Full	Total single pile	Total per 24 hrs
% Energy	20	40	60	80	100	-	-
Hammer energy (kJ)	880	1,760	2,640	3,520	4,400	-	-
# strikes	75	75	113	113	8,400	**8,776**	**17,552**
Duration (min)	7.5	7.5	7.5	7.5	240	**270**	**540 (9 hrs)**

Table 2-5 MLS piling parameters for 13.5 m diameter monopiles

Stage	Soft-start	Ramp-up			Full	Total single pile	Total per 24 hrs
% Energy	20	40	60	80	100	-	-
Hammer energy (kJ)	800	1,600	2,400	3,200	4,000	-	-
# strikes	75	75	113	113	5,075	**5,451**	**10,902**
Duration (min)	7.5	7.5	7.5	7.5	145	**175**	**350 (5.8 hr)**

Table 2-6 WCS piling parameters for 4.5 m diameter pin-piles

Stage	Soft-start	Ramp-up			Full	Total single pile	Total per 24 hrs
% Energy	20	40	60	80	100	-	-
Hammer energy (kJ)	500	1,000	1,500	2,000	2,500	-	-
# strikes	75	75	113	113	8,400	**8,776**	**35,104**
Duration (min)	7.5	7.5	7.5	7.5	240	**270**	**1,080 (18 hr)**

Table 2-7 MLS piling parameters for 4.5 m diameter pin-piles

Stage	Soft-start	Ramp-up			Full	Total single pile	Total per 24 hrs
% Energy	20	40	60	80	100	-	-
Hammer energy (kJ)	400	800	1,200	1,600	2,000	-	-
# strikes	75	75	113	113	5,075	**5,451**	**21,804**
Duration (min)	7.5	7.5	7.5	7.5	145	**175**	**700 (11.7 hrs)**

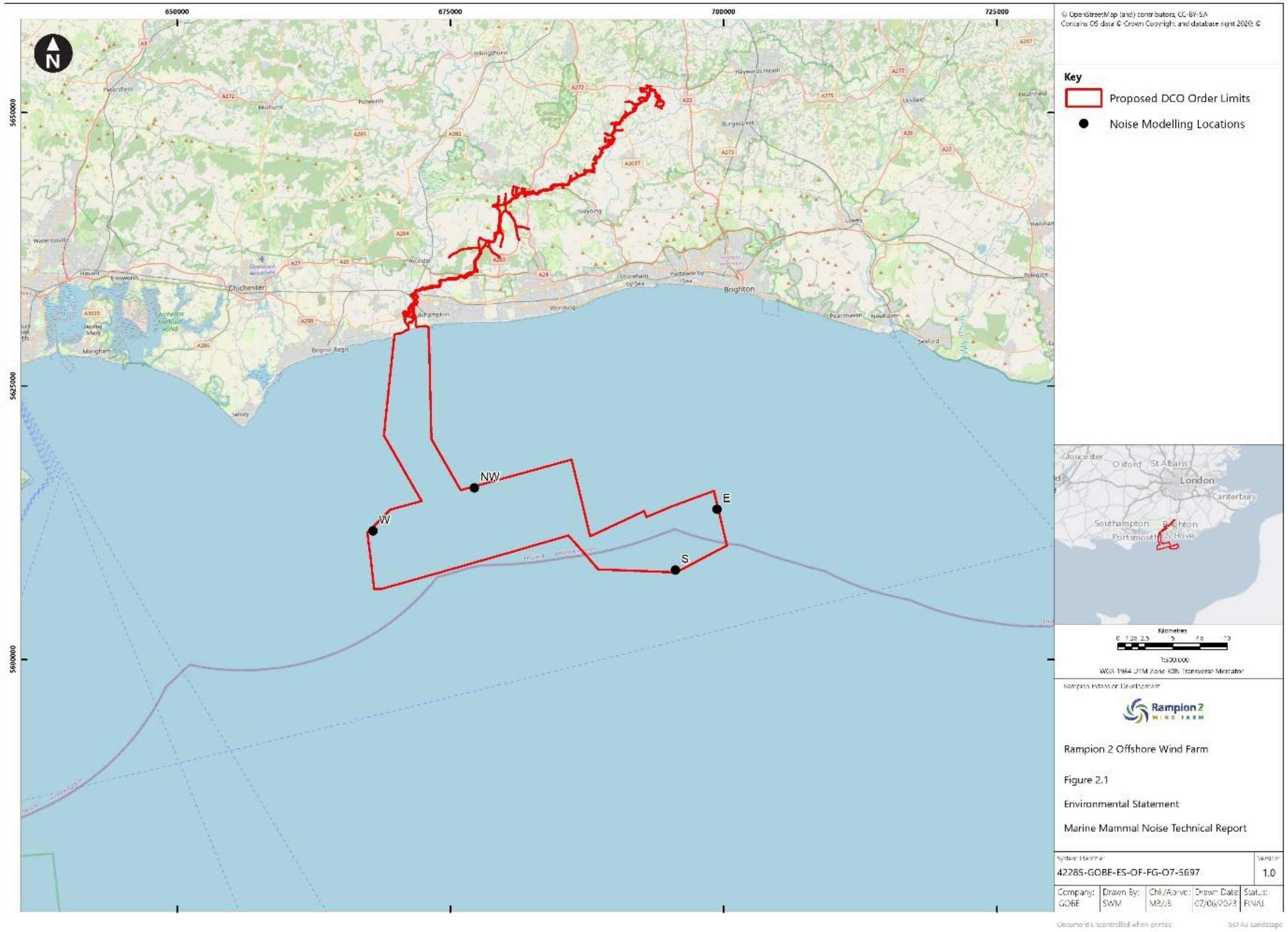
2.4 Piling locations

2.4.1 A total of four piling locations have been considered: Northwest (NW), West (W), South (S) and East (E) (**Table 2-8**). Both monopiles and pin-piles are considered at each modelling location. Details of the four piling locations are provided in **Table 2-8**.

Table 2-8 Piling locations included in the underwater noise modelling

Location	Latitude	Longitude	Depth (m)	Pile type
Northwest (NW)	50.6659	-0.4924	17.4	Monopiles and pin-piles
West (W)	50.6333	-0.625	26.4	Monopile and pin-piles
South (S)	50.5926	-0.2365	53.4	Monopile and pin-piles
East (E)	50.6412	-0.1796	43.8	Monopiles and pin-piles

Figure 2-1 Underwater noise modelling locations used for the quantitative impact assessment for pile driving



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2.5 Thresholds

PTS Assessment

2.5.1 For marine mammals, the main impact from Rampion 2 will be as a result of underwater noise produced during construction. Therefore, a detailed assessment has been provided for this impact pathway. Exposure to loud sounds can lead to a reduction in hearing sensitivity (a shift in hearing threshold), which is generally restricted to particular frequencies. This threshold shift results from physical injury to the auditory system and may be temporary (TTS) or permanent (PTS). The PTS and TTS onset thresholds used in this assessment are those presented in Southall et al. (2019). The method used to calculate PTS-onset impact ranges for both 'instantaneous' PTS (SPL_{peak}), and 'cumulative' PTS (SEL_{cum}, over 24 hours) are detailed in Appendix 11.3: Underwater Noise Assessment Technical Report.

Table 2-9 PTS-onset thresholds for impulsive noise (from Southall et al 2019).

Hearing group	Species	Cumulative PTS (SEL_{cum} dB re 1 μPa^2s weighted)	Instantaneous PTS (SPL_{peak} dB re 1 μPa unweighted)
Low Frequency (LF) cetacean	Minke whale	183	219
High Frequency (HF) cetacean	Bottlenose dolphin Common dolphin	185	230
Very High Frequency (VHF) cetacean	Harbour porpoise	155	202
Phocid	Harbour seal Grey seal	185	218

2.5.2 In calculating the received noise level that animals are likely to receive during the whole piling sequence, all animals were assumed to start moving away at a swim speed of 1.5 m/s once the piling has started (based on reported sustained swimming speeds for harbour porpoises) (Otani et al., 2000), except for minke whales which are assumed to swim at a speed of 3.25 m/s (Blix and Folkow, 1995). The calculated PTS and TTS-onset impact ranges therefore represent the minimum starting distances from the piling location for animals to escape and prevent them from receiving a dose higher than the threshold.

Table 2-10 Marine mammal swimming speed used in the cumulative PTS-onset assessment.

Hearing group	Species	Speed (m/s)
LF cetacean	Minke whale	3.25
HF cetacean	Bottlenose dolphin & Common dolphin	1.5
VHF cetacean	Harbour porpoise	1.5
Phocid	Harbour seal & Grey seal	1.5

TTS Assessment

2.5.3 SMRU Consulting appreciate that TTS is a temporary impairment of an animal's hearing ability with potential consequences for the animal's ability to escape predation, forage and/or communicate, supporting the statement of Kastelein et al. (2012c) that "*the magnitude of the consequence is likely to be related to the duration and magnitude of the TTS*". We would, however, like to point out that an assessment of the impact based on the TTS thresholds as currently given in Southall et al. (2019) (or the former NMFS (2016) guidelines and Southall et al. (2007) guidance) would lead to a substantial overestimate of the potential impact of TTS. Furthermore, SMRU Consulting believe that the prediction of TTS impact ranges, based on the sound exposure level (SEL) thresholds, are subject to the same inherent uncertainties as those for PTS, and in fact the uncertainties may be considered to have a proportionately larger effect on the prediction of TTS. We will explain these points in detail below based on the thresholds detailed by Southall et al. (2019), as these are based upon the most up-to-date scientific knowledge.

2.5.4 SMRU Consulting believe that basing any impact assessment on the impact ranges for TTS using current TTS thresholds would overestimate the potential for an ecologically significant effect. This is because the species-specific TTS-thresholds in Southall et al. (2019) describe those thresholds at which the **onset of TTS** is observed, which is, per their definition, a 6 dB shift in the hearing threshold, usually measured four minutes after sound exposure, which is considered as "*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*." The time hearing recovers back to normal (the recovery time) for such small threshold shifts is expected to be less than an hour, and therefore unlikely to cause any major consequences for an animal. A large shift in the hearing threshold near to values that may cause PTS may however require multiple days to recover (Finneran, 2015).

2.5.5 For TTS induced by steady-state tones or narrowband noise, Finneran (2015) describes a logarithmic relationship between recovery rate and recovery time, expressed in dB/decade (with a decade corresponding to a ratio of 10 between two time intervals, resulting in steps of 10, 100, 1000 minutes and so forth). For an initial shift of 5 to 15 dB above hearing threshold, TTS reduced by 4 to 6 dB per decade for dolphins, and 4 to 13 dB per decade for harbour porpoise and harbour seals. Larger initial TTSs tend to result in faster recovery rates, although the total time it takes to recover is usually longer for larger initial shifts (summarised in Finneran, 2015). While the rather simple logarithmic function fits well for exposure to steady-state tones, the relationship between recovery rate and recovery time might be more complex for more complex broadband sound, such as that produced by pile driving noise. For small threshold shifts of 4 to 5 dB caused by pulsed noise, Kastelein et al. (2016) demonstrated that porpoises recovered within one hour from TTS. While the onset of TTS has been experimentally validated, the determination of a threshold shift that would cause a longer term recovery time and is therefore potentially ecologically significant, is complex and associated with much uncertainty. The degree of TTS and the duration of recovery time that may be considered severe enough to lead to any kind of energetic or fitness consequences for an individual, is currently undetermined, as is how many individuals of a population can suffer this level of TTS before it may lead to population consequences. There is currently no set threshold for the onset of a biologically meaningful TTS, and this threshold is likely to be well above the TTS-onset threshold, leading to smaller impact ranges (and consequently much smaller impact areas, considering a squared relationship between area and range) than those obtained for the TTS-onset threshold. One has to bear in mind that the TTS-onset thresholds, as recommended first by Southall et al. (2007) and further revised by Southall et al. (2019) were determined as a means to be able to determine the PTS-onset thresholds and represent *the smallest measurable degree of TTS above normal day to day variation*. A direct determination of PTS-onset thresholds would lead to an injury of the experimental animal and is therefore considered as unethical. Guidelines such as National Academies of Sciences Engineering and Medicine (2016) and Southall et al. (2007) therefore rely on available data from humans and other terrestrial mammals that indicate that a shift in the hearing threshold of 40 dB may lead to the onset of PTS.

2.5.6 For pile driving for offshore wind farm foundations, the TTS and PTS-onset thresholds for impulsive sound are the appropriate thresholds to consider. These consist of a dual metric, a threshold for the peak sound pressure associated with each individual hammer strike, and one for the cumulative sound exposure level (SEL_{cum}), for which the sound energy over successive strikes is summated. The SEL_{cum} is based on the assumption that each unit of sound energy an animal is exposed to leads to a certain amount of threshold shift once the cumulated energy rises above the TTS-onset threshold. For impulsive sound, the threshold shift that is predicted to occur is 2.3 dB per dB noise received; for non-impulsive sound this rate is smaller (1.6 dB per dB noise) (Southall et al., 2007). The SEL_{cum} thresholds were determined with the assumption that a) the amount of sound energy an animal is exposed to within 24 hours will have the same effect on its auditory system, regardless of whether it is received all at once or in several smaller units spread over a longer period (called the equal-energy hypothesis), and b) the sound keeps its impulsive character regardless of the distance to the sound source. Both assumptions lead to a conservative determination of the impact ranges, as a) the magnitude of TTS induced might be influenced by the time interval between successive pulses, with some time for TTS recovery in-between pulses (e.g., Kastelein et al., 2014, Finneran et al., 2010b), therefore recovery may be possible in the gaps between individual pile strikes and in any short breaks in piling activity, and b) an impulsive sound will eventually lose its impulsive character while propagating through the water column, therefore becoming non-impulsive (as described in NMFS, 2016, Southall et al., 2019, Hastie et al., 2019), and then causing a smaller rate of threshold shift (see above). Modelling the SEL_{cum} impact ranges of PTS with a 'fleeing animal' model (as is typical during noise impact assessments) are subject to both of these precautions. Modelling the SEL_{cum} TTS impact ranges will inherit the same uncertainties, however, over a longer period of time, and over greater ranges as the TTS impact ranges are expected to be larger than those of PTS. Therefore these uncertainties and conservativisms will have a relatively larger effect on predictions of TTS ranges.

2.5.7 It is also important to bear in mind that the quantification of any impact ranges in the environmental assessment process, is done to inform an assessment of the potential magnitude and significance of an impact. Because the TTS thresholds are not universally used to indicate a level of biologically meaningful impact of concern *per se* but are used to enable the prediction of where PTS might occur, it would be very challenging to use them as the basis of any assessment of impact significance. While SMRU Consulting agree with the conclusion that because all of the data that exists on auditory injury in marine mammals is from studies of TTS, and not PTS, we may be more confident in our prediction of the range at which any TTS may occur, this is not necessarily very useful for the impact assessment process. We accept that scientific understanding of the degree of exposure required to elicit TTS may be more empirically based than our ability to predict the degree of sound required to elicit PTS. However, it does not automatically follow that our ability to determine the consequences of a stated level of TTS for individuals is any more certain than our ability to determine the consequences of a stated level of PTS for individuals. It could even be argued that we are more confident in our ability to predict the consequences of a permanent effect than we are to predict the consequences of a temporary effect of variable severity and uncertain duration.

2.5.8 It is important to consider that predictions of PTS and TTS are linked to potential changes in hearing sensitivity at particular hearing frequencies, which for piling noise are generally thought to occur in the 2-10 kHz range, and are not considered to occur across the whole frequency spectrum. Studies have shown that exposure to impulsive pile driving noise induces TTS in a relatively narrow frequency band in harbour porpoise and harbour seals (reviewed in Finneran, 2015), with statistically significant TTS occurring at 4 and 8 kHz (Kastelein et al., 2016) and centred at 4 kHz (Kastelein et al., 2012a, Kastelein et al., 2012b, Kastelein et al., 2013b, Kastelein et al., 2017). Our understanding of the consequences of PTS within this frequency range to an individual's survival and fecundity is limited, and therefore our ability to predict and assess the consequences of TTS of variable severity and duration is even more restricted.

2.5.9 The ranges that indicate TTS-onset were modelled and are presented alongside an estimate of the potential number of animals within these impact ranges. However, 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; therefore, it was not possible to carry out a quantitative assessment of the magnitude or significance of the impact of TTS on marine mammals. This approach was agreed with the Centre for Environment, Fisheries and Aquaculture Science (Cefas) at the Expert Topic Group meeting on 18th September 2020.

Table 2-11 TTS-onset thresholds for impulsive noise (from Southall et al 2019).

Hearing group	Species	Cumulative TTS (SEL_{cum} dB re 1 μPa^2s weighted)	Instantaneous TTS (SPL_{peak} dB re 1 µPa unweighted)
LF cetacean	Minke whale	168	213
HF cetacean	Bottlenose dolphin Common dolphin	170	224
VHF cetacean	Harbour porpoise	140	196
Phocid	Harbour seal Grey seal	170	212

Disturbance assessment

2.5.10 The assessment of disturbance was based on the current best practice methodology, making use of the best available scientific evidence. This incorporated the application of a species-specific dose-response approach rather than a fixed behavioural threshold approach. Noise contours at 5 dB intervals were generated by noise modelling and were overlain on species density surfaces to predict the number of animals potentially disturbed. This allowed for the quantification of the number of animals that will potentially respond.

2.5.11 The dose-response curve adopted in this assessment for all harbour porpoise (**Figure 2-2**) was developed by Graham et al. (2017a) and was generated from data on harbour porpoises collected during the first six weeks of piling during Phase 1 of the Beatrice Offshore Wind Farm monitoring program. There is no corresponding data for any other cetacean species, and as such, the same curve was applied to the disturbance assessment for all cetacean species.

2.5.12 For both species of seal, the dose-response curve (**Figure 2-3**) adopted was based on the data presented in Whyte et al. (2020), where the percentage change in harbour seal density was predicted at the Linc offshore windfarm. It has been assumed that all seals are displaced at sound exposure levels above 180 dB re 1 μPa^2s, this is a conservative assumption since there was no data presented in the study for harbour seal responses at this level. It is also important to note that the percentage decrease in response in the categories 170≤175 and 175≤180 dB re 1 μPa^2s are slightly anomalous (higher response at a lower sound exposure level) due to the small number of spatial cells included in the analysis for these categories (n= 2 and 3 respectively). There is no corresponding data for grey seals, and as such, the same curve was applied to the grey seal disturbance assessment.

Figure 2-2 Relationship between the proportion of porpoise responding and the received single strike SEL (SEL_{SS}) (Graham et al. 2017a).

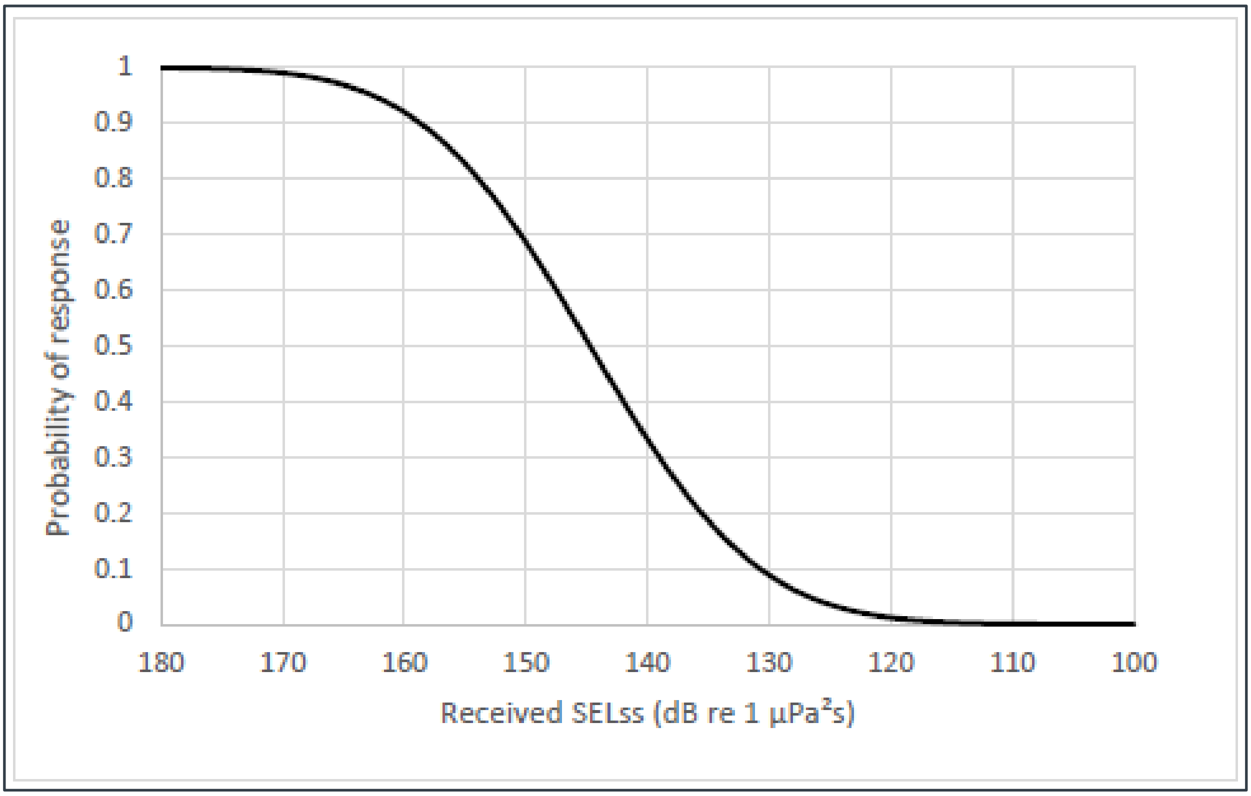
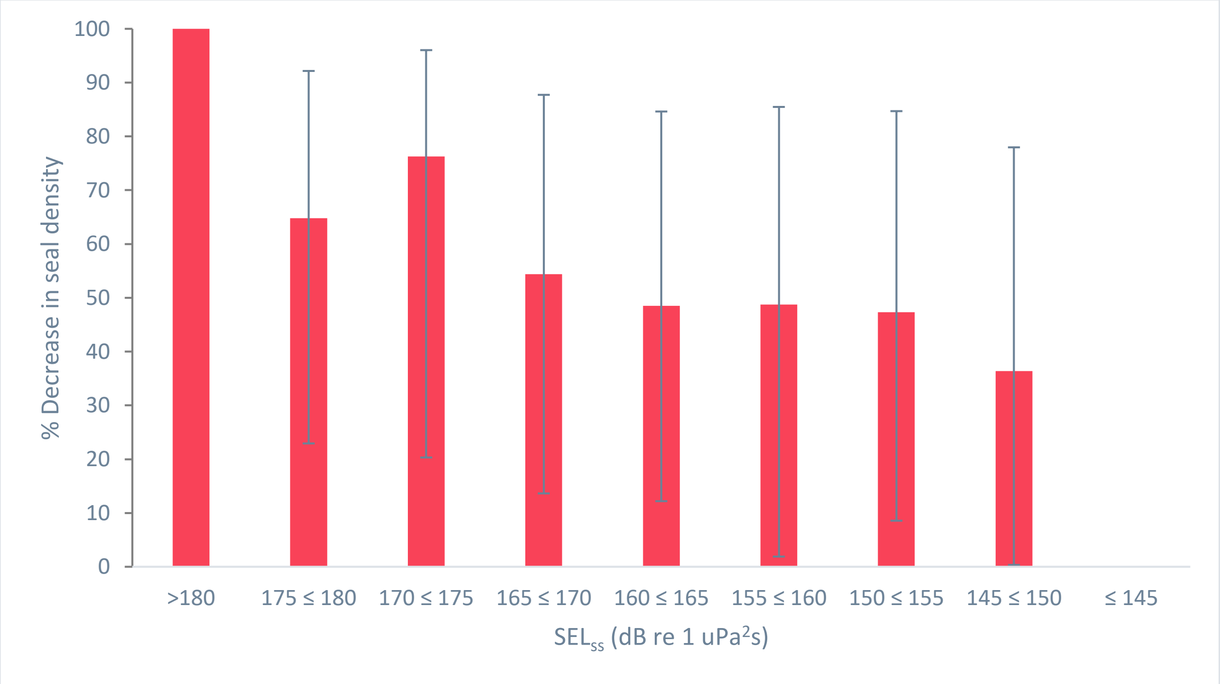


Figure 2-3 Predicted decrease in seal density as a function of estimated sound exposure level, error bars show 95% CI (from Whyte et al 2020).



2.6 Assumptions and limitations

2.6.1 There are uncertainties relating to the underwater noise modelling and impact assessment for Rampion 2. Broadly, these relate to predicting exposure of animals to underwater noise, predicting the response of animals to underwater noise and predicting potential population consequences of disturbance from underwater noise. Further detail of such uncertainty is set out below.

Exposure to noise

2.6.2 There are uncertainties relating to the ability to predict the exposure of animals to underwater noise, as well as in predicting the response to that exposure. These uncertainties relate to a number of factors: the ability to predict the level of noise that animals are exposed to, particularly over long periods of time; the ability to predict the numbers of animals affected, and the ability to predict the individual and ultimately population consequences of exposure to noise. These are explored in further detail in the paragraphs below.

2.6.3 The propagation of underwater noise is relatively well understood and modelled using standard methods. However, there are uncertainties regarding the amount of noise actually produced by each pulse at source and how the pulse characteristics change with range from the source. There are also uncertainties regarding the position of receptors in relation to received levels of noise, particularly over time, and understanding how position in the water column may affect received level. Noise monitoring is not always carried out at distances relevant to the ranges predicted for effects on marine mammals, so effects at greater distances remain un-validated in terms of actual received levels. The extent to which ambient noise and other anthropogenic sources of noise may mask signals from the offshore wind farm construction are not specifically addressed. The dose-response curves for porpoise include behavioural responses at noise levels down to 120 dB SEL_{ss} which may be indistinguishable from ambient noise at the ranges these levels are predicted.

PTS-onset

2.6.4 There are no empirical data on the threshold for auditory injury in the form of PTS-onset for marine mammals, as to test this would be inhumane. Therefore, PTS-onset thresholds are estimated based on extrapolating from TTS-onset thresholds. For pulsed noise, such as piling, National Oceanic Atmospheric Administration (NOAA) have set the onset of TTS at the lowest level that exceeds natural recorded variation in hearing sensitivity (6 dB), and assumes that PTS occurs from exposures resulting in 40 dB or more of TTS measured approximately four minutes after exposure.

Cumulative PTS

2.6.5 The cumulative sound exposure level (SEL_{cum}) is energy-based and is a measure of the accumulated sound energy an animal is exposed to over an exposure period. An animal is considered to be at risk of experiencing “cumulative PTS” if the SEL_{cum} exceeds the energy-based threshold. The calculation of SEL_{cum} is done with frequency-weighted sound levels, using species group-specific weighting functions to reflect the hearing sensitivity of each functional hearing group. To assess the risk of cumulative PTS, it is necessary to make assumptions on how animals may respond to noise exposure, since any displacement of the animal relative to the noise source will affect the sound levels received. For this assessment, it was assumed that animals would flee from the pile foundation at the onset of piling. A fleeing animal model was therefore used to determine the cumulative PTS impact ranges to determine the minimum distance to the pile site at which an animal can start to flee without the risk of experiencing cumulative PTS.

2.6.6 There is much more uncertainty associated with the prediction of the cumulative PTS impact ranges than with those for the instantaneous PTS. One reason is that the sound levels an animal receives, and which are accumulated over a whole piling sequence are difficult to predict over such long periods of time as a result of uncertainties about the animal's (responsive) movement in terms of its changing distance to the sound source and the related speed, and its position in the water column.

2.6.7 Another reason is that the prediction of the onset of PTS (which is assumed to be at the SEL_{cum} threshold values provided by Southall et al. 2019) is determined with the assumptions that:

- a) the amount of sound energy an animal is exposed to within 24 hours will have the same effect on its auditory system, regardless of whether it is received all at once (i.e., with a single bout of sound) or in several smaller doses spread over a longer period (called the equal-energy hypothesis); and,
- b) the sound keeps its impulsive character, regardless of the distance to the sound source.

2.6.8 In practice:

- a) there is some recovery of a threshold shift caused by the sound energy if the dose is applied in several smaller doses (e.g., between pulses during pile driving or in piling breaks) leading to an onset of PTS at a higher energy level than assumed with the given SEL_{cum} threshold; and,
- b) pulsed sound loses its impulsive characteristics while propagating away from the sound source, resulting in a slower shift of an animal's hearing threshold than would be predicted for an impulsive sound.

2.6.9 Both assumptions therefore lead to a conservative determination of the impact ranges and are discussed in further detail in the sections below.

2.6.10 Modelling the SEL_{cum} impact ranges of PTS with a 'fleeing animal' model, as is typical in noise impact assessments, are subject to both above-mentioned uncertainties and the result is a highly precautionary prediction of impact ranges. As a result of these and the uncertainties on animal movement, model parameters chosen, such as swim speed, are generally highly conservative and, when considered across multiple parameters, this precaution is compounded. Therefore, the resulting predictions are highly precautionary and very unlikely to be realised.

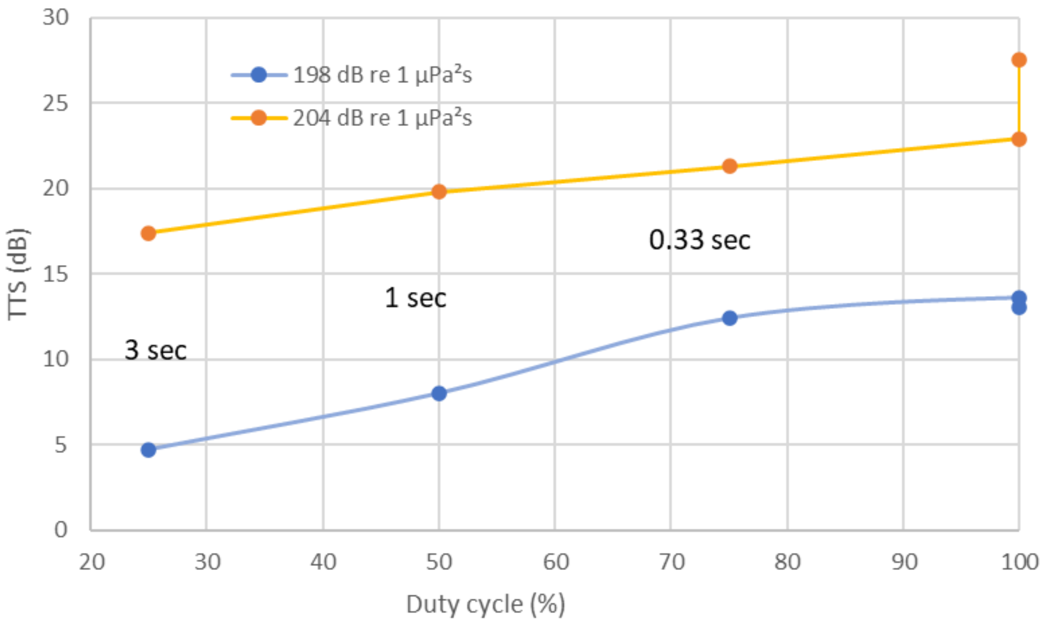
Equal-energy hypothesis

2.6.11 The equal-energy hypothesis states that "*exposures of equal-energy are assumed to produce equal amounts of noise-induced threshold shift, regardless of how the energy is distributed over time*" (Ward, 1997). However, a continuous and an intermittent noise exposure of the same SEL will produce different levels of TTS (Ward, 1997). Ward (1997) highlights that the same is true for impulsive noise, giving the example of humans exposed to simulated gunfire of the same SEL_{cum}, where 30 impulses with an SPL_{peak} of 150 dB re 1 m Pa result in a TTS of 20 dB, while 300 impulses of a respectively lower SPL_{peak} did not result in any TTS.

2.6.12 Finneran (2015) showed that several marine mammal studies have demonstrated that the temporal pattern of the exposure does in fact affect the resulting threshold shift (Finneran et al., 2010a, e.g., Kastak et al., 2005, Mooney et al., 2009, Kastelein et al., 2013a). Intermittent noise allows for some recovery of the threshold shift in between exposures, and therefore recovery can occur in the gaps between individual pile strikes and in the breaks in piling activity, resulting in a lower overall threshold shift compared to continuous exposure at the same SEL. Kastelein et al. (2013a) showed that, for seals, the threshold shifts observed did not follow the assumptions made in the guidance regarding the equal-energy hypothesis; instead, the threshold shifts observed were more similar to the hypothesis presented in Henderson et al. (1991) that hearing loss induced due to noise does not solely depend upon the total amount of energy, but on the interaction of several factors such as the level and duration of the exposure, the rate of repetition, and the susceptibility of the animal. Therefore, the equal-energy hypothesis assumption behind the -SEL_{cum} threshold is not valid, and as such, models will overestimate the level of threshold shift experienced from intermittent noise exposures.

2.6.13 Another detailed example to give is the study of Kastelein et al. (2014), where a harbour porpoise was exposed to a series of 1-2 kHz sonar down-sweep pulses of 1 second duration of various combinations with regard to received sound pressure level, exposure duration and duty cycle (% of time with sound during a broadcast) to quantify the related threshold shift. The porpoise experienced a 6 to 8 dB lower TTS when exposed to sound with a duty cycle of 25% compared to a continuous sound (**Figure 2-4**). A 1 sec silent period in-between pulses resulted in a 3 to 5 dB lower TTS compared to a continuous sound (**Figure 2-4**).

Figure 2-4 Temporary threshold shift (TTS) elicited in a harbour porpoise by a series of 1-2 kHz sonar down-sweeps of 1 second duration with varying duty cycle and a constant SELcum of 198 and 204 dB re1 µPa²s, respectively. Also labelled is the corresponding 'silent period' in-between pulses. Data from Kastelein et al. (2014)



2.6.14 Kastelein et al. (2015) showed that the 40 dB hearing threshold shift (the PTS-onset threshold) for harbour porpoise, is expected to be reached at different SELcum levels depending on the duty cycle: for a 100% duty cycle, the 40 dB hearing threshold shift is predicted to be reached at a SELcum of 196 dB re 1 µPa^{2}s, but for a 10% duty cycle, the 40 dB hearing threshold shift is predicted to be reached at a SELcum of 206 dB re 1 µPa^{2}s (thus resulting in a 10 dB re 1 µPa^{2}s difference in the threshold).

2.6.15 Pile strikes are relatively short signals; the signal duration of monopile pile strikes may range between 0.1 sec (De Jong and Ainslie, 2008) and approximately 0.3 sec (Dähne et al., 2017) measured at a distance of 3.3 to 3.6 km. Duration will however increase with increasing distance from the pile site.

2.6.16 For the pile driving at Rampion 2, the soft start and start of the ramp-up is 10 blows per minute for monopile worst case. Assuming a signal duration of around 0.5 sec for a pile strike, the soft start ramp-up will be a- 8.3% duty cycle (0.5 sec pulse followed by 5.5 sec silence). In the study of Kastelein et al. (2014), a silent period of 3 sec corresponds to a duty cycle of 25%. The reduction in TTS at a duty cycle of 25% is 8.3 dB. Assuming similar effects to the hearing system, the PTS-onset threshold would be expected to be around 2.4 dB higher than that proposed by Southall et al. (2019) and used in the current assessment, as reasoned in the following section.

2.6.17 Southall et al. (2019) calculates the PTS-onset thresholds based on the assumption that a TTS of 40 dB will lead to PTS, and that an animal's hearing threshold will shift by 2.3 dB per dB SEL received from an impulsive sound. This means, if the same SEL elicits a ≥5.5 dB lower TTS at 25% duty cycle compared to 100% duty cycle, to elicit the same TTS as a sound of 100% duty cycle, a ≥2.4 dB (≥5.5 dB / 2.3) higher SEL is needed with a 25% duty cycle than with a 100% duty cycle. The threshold at which PTS-onset is likely is therefore at least 2.4 dB higher than the PTS-onset threshold proposed by Southall et al. (2019). If a 2 or 3 dB increase in the PTS-threshold is assumed, then this can make a significant difference to the maximum predicted impact range for cumulative PTS (see **Table 2-12**).

2.6.18 While more research needs to be conducted to understand the exact magnitude of this effect in relation to pile driving sound, this study reveals a significant reduction in the risk of PTS even through short silent periods between piling pulses.

Table 2-12 Cumulative PTS onset impact ranges if duty cycle is accounted for.

Species	Scenario	Threshold	Max impact range	% reduction
Minke whale	Monopile Northwest WCS 2 piles	183	3.15 km	-
		185 (+2 dB)	1.50 km	52%
		186 (+3 dB)	0.95 km	70%
Minke whale	Monopile South WCS 2 piles	183	15.4 km	-
		185 (+2 dB)	11.9 km	23%
		186 (+3 dB)	10.2 km	34%
Harbour porpoise	Monopile Northwest WCS 2 piles	155	2.2 km	-
		157 (+2 dB)	1.15 km	48%
		158 (+3 dB)	0.75 km	66%
Harbour porpoise	Monopile South WCS 2 piles	155	7.35 km	-
		157 (+2 dB)	5.10 km	31%
		158 (+3 dB)	4.05 km	45%

Impulsive characteristics

2.6.19 Southall et al. (2019) acknowledges that as a result of propagation effects, the sound signal of certain sound sources (e.g., pile-driving) loses its impulsive characteristics and could potentially be characterised as non-impulsive beyond a certain distance. The changes in noise characteristics with distance generally result in exposures becoming less physiologically damaging with increasing distance as sharp transient peaks become less prominent (Southall et al., 2007). The Southall et al. (2019) updated criteria proposed that, while keeping the same source categories, the exposure criteria for impulsive and non-impulsive sound should be applied based on the signal features likely to be perceived by the animal rather than those emitted by the source. Methods to estimate the distance at which the transition from impulsive to non-impulsive noise are currently being developed (Southall et al., 2019).

2.6.20 Using the criteria of signal duration, rise time, crest factor and peak pressure divided by signal duration, Hastie et al. (2019) estimated the transition from impulsive to non-impulsive characteristics of piledriving noise during the installation of offshore wind turbine foundations at the Wash and in the Moray Firth. Hastie et al. (2019) showed that the noise signal experienced a high degree of change in its impulsive characteristics with increasing distance. Southall et al. (2019) state that mammalian hearing is most readily damaged by transient sounds with rapid rise-time, high peak pressures, and sustained duration relative to risetime. Therefore, of the four criteria used by Hastie et al. (2019), the rise-time and peak pressure may be the most appropriate indicators to determine the impulsive/non-impulsive transition. Based on this data it is expected that the probability of a signal being defined as “impulsive” (using the criteria of rise time being less than 25 ms) reduces to only 20% between ~2 and 5 km from the source. Predicted PTS impact ranges based on the impulsive noise thresholds may therefore be overestimates in cases where the impact ranges lie beyond this. Any animal present beyond that distance when piling starts will only be exposed to non-impulsive noise, and therefore impact ranges should be based on the non-impulsive thresholds.

2.6.21 It is acknowledged that the Hastie et al. (2019) study is an initial investigation into this topic, and that further data are required to set limits to the range at which impulsive criteria for PTS are applied.

2.6.22 Since the Hastie et al. (2019) study, Martin et al. (2020) investigated the sound emission of different sound sources to test techniques for distinguishing between the sound being impulsive or non-impulsive. For impulsive sound sources, they included impact pile driving of four-legged jacket foundations, installed at around 20 m water depth (at the Block Island Wind Farm in the USA). For the pile-driving sound they recorded sound at four distances between ~500 m and 9 km, recording the sound of 24 piling events. To investigate the impulsiveness of the sound, they used three different parameters: kurtosis[1], crest factor and Harris factor[2], which they computed over 1-minute time windows, i.e., integrated over multiple transients (please see Martin et al. (2020) for definitions). As their data showed a strong correlation between the three different factors, the authors argued for the use of kurtosis to further investigate the impulsiveness of sound. Hamernik et al. (2007) showed a positive correlation between the magnitude of PTS and the kurtosis value in chinchillas, with an increase in PTS for a kurtosis value from 3 up to 40. Therefore, Martin et al. (2020) argued that:

- Kurtosis of 0-3 = continuous sinusoidal signal (non-impulsive);
- Kurtosis of 3-40 = transition from non-impulsive to impulsive sound; and

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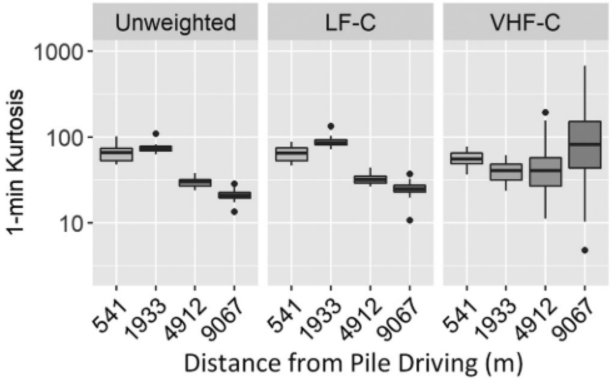
[1] Kurtosis is a measure of the asymmetry of a probability distribution of a real-valued variable.

[2] The Harris (1998) impulse factor is the maximum value for each minute of the impulse time-weighted SPL minus the slow time-weighted SPL.

- Kurtosis of 40 = fully impulsive.

2.6.23 For the evaluation of their data, Martin et al. (2020) used unweighted as well as LF-Cetacean (C) and VHF-C weighted sound based on the species-specific weighting curves in Southall et al. (2019) to investigate the impulsiveness of sound. Their results for pile driving are shown in **Figure 2-5**. For the unweighted and LFC weighted sound, the kurtosis value was >40 within a km from the piling site. Beyond 2 km, the kurtosis value decreased with increasing distance. For the VHFC weighted sound, kurtosis factor is more inconclusive with the median value >40 for the 500 m and 9 km measuring stations, and at 40 for the stations between. However, the variability of the kurtosis value for the VHFC weighted sound increased with distance.

Figure 2-5: The range of kurtosis weighted by LF-C and VHF-C Southall et al. (2019) auditory frequency weighting functions for 30 min of impact pile driving data measured in 25 m of water at the Block Island Wind Farm



	Median value (1-min kurtosis)		
Distance (km)	Unweighted	LF-C	VHF-C
0.541	65	65	60
1.933	70	85	40
4.912	30	30	40
9.067	20	25	80

Notes: Unweighted data are 10 Hz and above high pass filtered. For each range and auditory frequency weighting function, the boxes show the interquartile range. The horizontal line in the box is the median value. The vertical lines show the range of values for the 25% of the data above or below the middle half. The dots above or below the line indicate outlier values (From: Martin et al. (2020): Figure 7). Table shows approximate median values extracted from the graph

2.6.24 Martin et al. (2020) used this data to conclude that the change to non-impulsiveness "*is not relevant for assessing hearing injury because sounds retain impulsive character when SPLs are above EQT (effective quiet threshold[3])*" (i.e., the sounds they recorded retain their impulsive character while being at sound levels that can contribute to auditory injury). The Applicant interprets their results differently. **Figure 2-5** clearly shows (for unweighted and LF-C weighted sound)

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[3] From MARTIN, B., LUCKE, K. & BARCLAY, D. 2020. Techniques for distinguishing between impulsive and non-impulsive sound in the context of regulating sound exposure for marine mammals. *The Journal of the Acoustical Society of America,* 147**,** 2159-2176.: The proposed effective quiet threshold (EQT) is the 1-min auditory frequency weighted SPL that accumulates to this 1-min SEL, which numerically is 18 dB below the 1-min SEL [because $10\cdot\log_{10}(1\ \text{min}/1\ \text{s})$ dB¼17.7 dB]. Thus, the proposed level for effective quiet is equivalently a 1-min SPL that is 50 dB below the numeric value of the auditory frequency-weighted Southall et al. (2019) daily SEL TTS threshold for non-impulsive sources.

that piling sound loses its impulsiveness with increasing distance from the piling site - the kurtosis value decreases with increasing distance and therefore the sound loses its harmful impulsive characteristics.

2.6.25 There are some points that need to be considered before adopting kurtosis as a measure of impulsiveness, with the recommended threshold value of 40. Firstly, this value was experimentally obtained for chinchillas that were exposed to noise for a 5day period. Caution may need to be taken to directly adopt this threshold-value (and the related dose-response of increasing PTS with increasing kurtosis between 3 and 40) to marine mammals, especially given that the PTS guidance considers time periods of up to 24 hours. Secondly, kurtosis is recommended to be computed over at least 30 seconds, which means that it is not a specific measure that can be used for single blows of a piling sequence. Instead, kurtosis has been recommended to evaluate steady-state noise in order to include the risk from embedded impulsive noise (Goley et al., 2011). Metrics used by Hastie et al. (2019) computed for each pile strike (e.g., risetime) may be more suitable to be included in piling impact assessments, as, for each single pile strike, the sound exposure levels received by an animal are considered. Which metric is the most useful and how they correlate with the magnitude of auditory injury in (marine) mammals is still to be investigated.

2.6.26 Southall (2021) points out that “*at present there are no properly designed, comparative studies evaluating TTS for any marine mammal species with various noise types, using a range of impulsive metrics to determine either the best metric or to define an explicit threshold with which to delineate impulsiveness*”. He proposes that the presence of high-frequency noise energy could be used as a proxy for impulsiveness, as all currently used metrics have in common is that a high frequency spectral content results in high values for those metrics. His suggestion is an interim approach: “*the range at which noise from an impulsive source lacks discernible energy (relative to ambient noise at the same location) at frequencies ≥ 10 kHz could be used to distinguish when the relevant hearing effect criteria transitions from impulsive to non-impulsive*”. Southall (2021), however, notes that “*it should be recognized that the use of impulsive exposure criteria for receivers at greater ranges (tens of kilometers) is almost certainly an overly precautionary interpretation of existing criteria*”.

2.6.27 Considering that an increasing proportion of the sound emitted during a piling sequence will become less impulsive (and thereby less harmful) while propagating away from the sound source, and this effect starts at ranges below 5 km in all above mentioned examples, the cumulative PTS-onset threshold for animals starting to flee at 5 km should be higher than the Southall (2021) threshold adopted for this assessment (i.e., the risk of experiencing PTS becomes lower), and any impact range estimated beyond this distance should be considered as an unrealistic over-estimate, especially when they result in very large distances.

2.6.28 For the purpose of presenting a precautionary assessment, the quantitative impact assessment for Rampion 2 is based on fully impulsive thresholds, but the potential for overestimation should be noted.

Proportion impacted

2.6.29 It is important to note that it is expected that only 18-19% of animals are predicted to actually experience PTS at the PTS-onset threshold level. This was the approach adopted by Donovan et al. (2017) to develop their dose response curve implemented into the Statistical Algorithms For Estimating the Sonar Influence on Marine Megafauna (SAFESIMM) model, based on the data presented in Finneran et al. (2005). Therefore, where PTS-onset ranges are provided, it is not expected that all individuals within that range will experience PTS. Therefore, the number of animals predicted to be within PTS-onset ranges are precautionary.

Density

2.6.30 There are uncertainties relating to the ability to predict the responses of animals to underwater noise and the prediction of the numbers of animals potentially exposed to levels of noise that may cause an impact is uncertain. Given the high spatial and temporal variation in marine mammal abundance and distribution in any particular area of the sea, it is difficult to confidently predict how many animals may be present within the range of noise impacts. All methods for determining at sea abundance and distribution suffer from a range of biases and uncertainties and no single method or data source will provide a complete prediction of future conditions.

Predicting response

2.6.31 In addition, there is limited empirical data available to confidently predict the extent to which animals may experience auditory damage or display responses to noise. The current methods for prediction of behavioural responses are based on received sound levels, but it is likely that factors other than noise levels alone will also influence the probability of response and the strength of response (e.g. previous experience, behavioural and physiological context, proximity to activities, characteristics of the sound other than level, such as duty cycle and pulse characteristics). However, at present, it is impossible to adequately take these factors into account in a predictive sense. This assessment makes use of the monitoring work that has been carried out during the construction of the Beatrice Offshore Wind Farm and therefore uses the most recent and site-specific information on disturbance to harbour porpoise as a result of pile driving noise.

2.6.32 There is also a lack of information on how observed effects (e.g. short-term displacement around pile-driving activities) manifest themselves in terms of effects on individual fitness, and ultimately population dynamics in order to attempt to quantify the amount of disturbance required before vital rates are impacted.

Duration of impact

2.6.33 The duration of disturbance is another uncertainty. Studies at Horns Rev 2 demonstrated that porpoises returned to the area between 1 and 3 days (Brandt et al., 2011) and monitoring at the Dan Tysk Wind Farm as part of the Disturbance Effects on the Harbour Porpoise Population in the North Sea (DEPONS) project found return times of around 12 hours (van Beest et al., 2015). Two studies at Alpha Ventus demonstrated, using aerial surveys, that the return of porpoises was about 18 hours after piling (Dähne et al., 2013). A recent study of porpoise response at the Gemini wind farm in the Netherlands, also part of the DEPONS project, found that local population densities recovered between two and six hours after piling (Nabe-Nielsen et al., 2018). An analysis of data collected at the first seven offshore wind farms in Germany has shown that harbour porpoise detections were reduced between one and two days after piling (Brandt et al., 2018). Analysis of data from monitoring of marine mammal activity during piling of jacket pile foundations at Beatrice Offshore Wind Farm (Graham et al., 2017a, Graham et al., 2019) provides evidence that harbour porpoise were displaced during pile driving but return after cessation of piling, with a reduced extent of disturbance over the duration of the construction period. This suggests that the assumptions adopted in the current assessment are precautionary as animals are predicted to remain disturbed at the same level for the entire duration of the pile driving phase of construction.

3. PTS-onset results

3.1 Context

3.1.1 This section outlines the marine mammal PTS-onset impact ranges, number of animals potentially within these ranges and the proportion of the MU that may be impacted. This, in combination with the sensitivity assessment, provides the magnitude, sensitivity and overall impact significance scores for unmitigated pile driving of both monopiles and pin-piles under both the WCS and MLS.

3.2 VHF Cetacean - Harbour porpoise

Sensitivity to PTS from pile driving

3.2.1 The ecological consequence of PTS for marine mammals is uncertain. At a Department for Business, Energy & Industrial Strategy (BEIS) funded expert elicitation workshop held at the University of St Andrews (March 2018), experts in marine mammal hearing discussed the nature, extent and potential consequence of PTS to UK marine mammal species (Booth and Heinis, 2018). This workshop outlined and collated the best and most recent empirical data available on the effects of PTS on marine mammals. A number of general points came out in discussions as part of the elicitation. These included that PTS did not mean animals were deaf, that the limitations of the ambient noise environment should be considered and that the magnitude and frequency band in which PTS occurs are critical to assessing the effect on vital rates.

3.2.2 Southall et al. (2007) defined the onset of TTS as “*being a temporary elevation of a hearing threshold by 6 dB*” (in which the reference pressure for the dB is 1µPa). Although 6 dB of TTS is a somewhat arbitrary definition of onset, it has been adopted largely because 6 dB is a measurable quantity that is typically outside the variability of repeated thresholds measurements. The onset of PTS was defined as a non-recoverable elevation of the hearing threshold of 6 dB, for similar reasons. Based upon TTS growth rates obtained from the scientific literature, it has been assumed that the onset of PTS occurs after TTS has grown to 40 dB. The growth rate of TTS is dependent on the frequency of exposure, but is nevertheless assumed to occur as a function of an exposure that results in 40 dB of TTS, i.e. 40 dB of TTS is assumed to equate to 6 dB of PTS.

3.2.3 For piling noise, most energy is between ~30 - 500 Hz, with a peak usually between 100 – 300 Hz and energy extending above 2 kHz (Kastelein et al., 2015, Kastelein et al., 2016). Studies have shown that exposure to impulsive pile driving noise induces TTS in a relatively narrow frequency band in harbour porpoise and harbour seals (reviewed in Finneran, 2015), with statistically significant TTS occurring at 4 and 8 kHz (Kastelein et al., 2016) and centred at 4 kHz (Kastelein et al., 2012a, Kastelein et al., 2012b, Kastelein et al., 2013b, Kastelein et al., 2017). Therefore, during the expert elicitation, the experts agreed that any threshold shifts as a result of pile driving would manifest themselves in the 2 - 10 kHz range (Kastelein et al., 2017) and that a PTS ‘notch’ of 6 – 18 dB in a narrow frequency band in the 2 - 10 kHz region is unlikely to significantly affect the fitness of individuals (ability to survive and reproduce). The expert elicitation concluded that:

- the effects of a 6 dB PTS in the 2-10 kHz band was unlikely to have a large effect on survival or fertility of the species of interest;
- for all species, experts indicated that the most likely predicted effect on survival or fertility as a result of 6 dB PTS was likely to be very small (i.e. <5 % reduction in survival or fertility); and
- the defined PTS was likely to have a slightly larger effect on calves/pups and juveniles than on mature females survival or fertility.

3.2.4 For harbour porpoise, the predicted decline in vital rates from the impact of a 6 dB PTS in the 2-10 kHz band for different percentiles of the elicited probability distribution are provided in **Table 3-1**. The data provided in **Table 3-1** should be interpreted as:

- Experts estimated that the median decline in an individual mature female harbour porpoise’s fertility was 0.09% (due to a 6 dB PTS (a notch a few kHz wide and 6 dB high) occurring somewhere in the hearing between 2-10 kHz).
- Experts estimated that the median decline in an individual mature female harbour porpoise’s survival was 0.01% (due to a 6 dB PTS (a notch a few kHz wide and 6 dB high) occurring somewhere in the hearing between 2-10 kHz).
- Experts estimated that the median decline in an individual harbour porpoise juvenile or dependent calf survival was 0.18% (due to a 6 dB PTS (a notch a few kHz wide and 6 dB high) occurring somewhere in the hearing between 2-10 kHz).

Table 3-1 Predicted decline in harbour porpoise vital rates for different percentiles of the elicited probability distribution

	Percentiles of the elicited probability distribution								
	10%	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**
Adult survival	0	0	0	0.01	0.01	0.03	0.05	0.1	0.23
Fertility	0	0	0.02	0.05	0.09	0.16	0.3	0.7	1.35
Calf/Juvenile survival	0	0	0.02	0.09	0.18	0.31	0.49	0.8	1.46

Figure 3-1 Probability distribution showing the consensus distribution for the effects on fertility of a mature female harbour porpoise as a consequence of a maximum 6 dB of PTS within a 2-10 kHz band (figure from Booth and Heinis (2018))

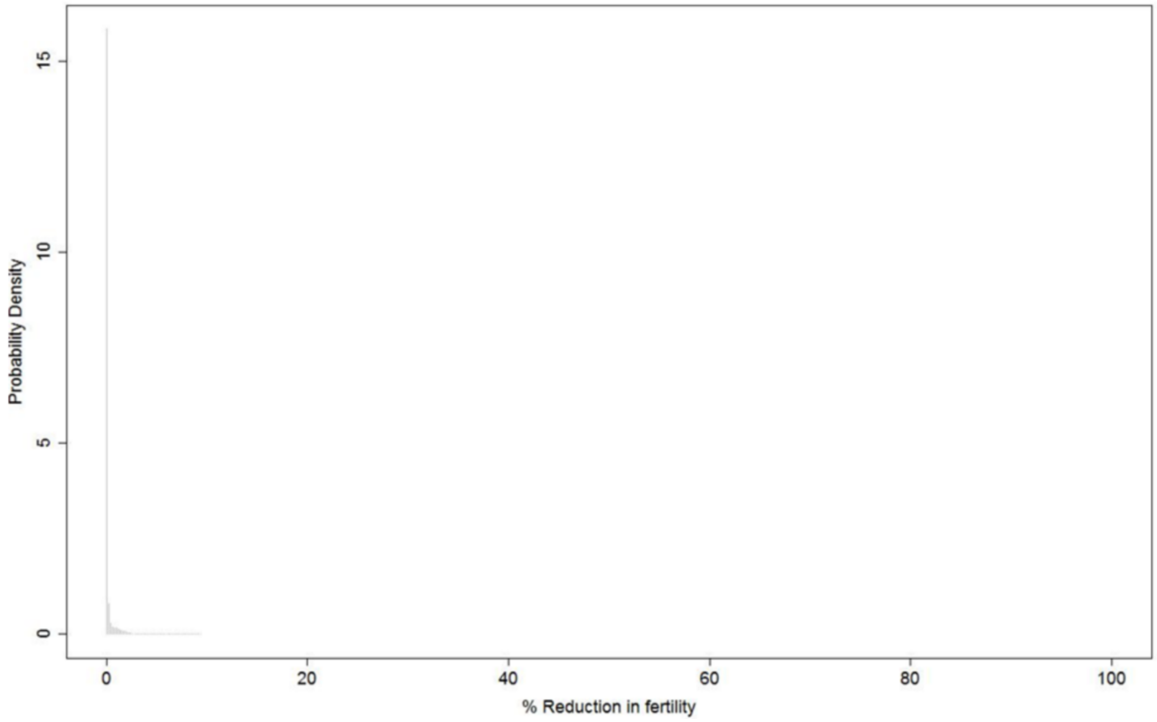


Figure 3-2 Probability distribution showing the consensus distribution for the effects on survival of a mature female harbour porpoise as a consequence of a maximum 6 dB of PTS within a 2-10 kHz band (figure from Booth and Heinis (2018))

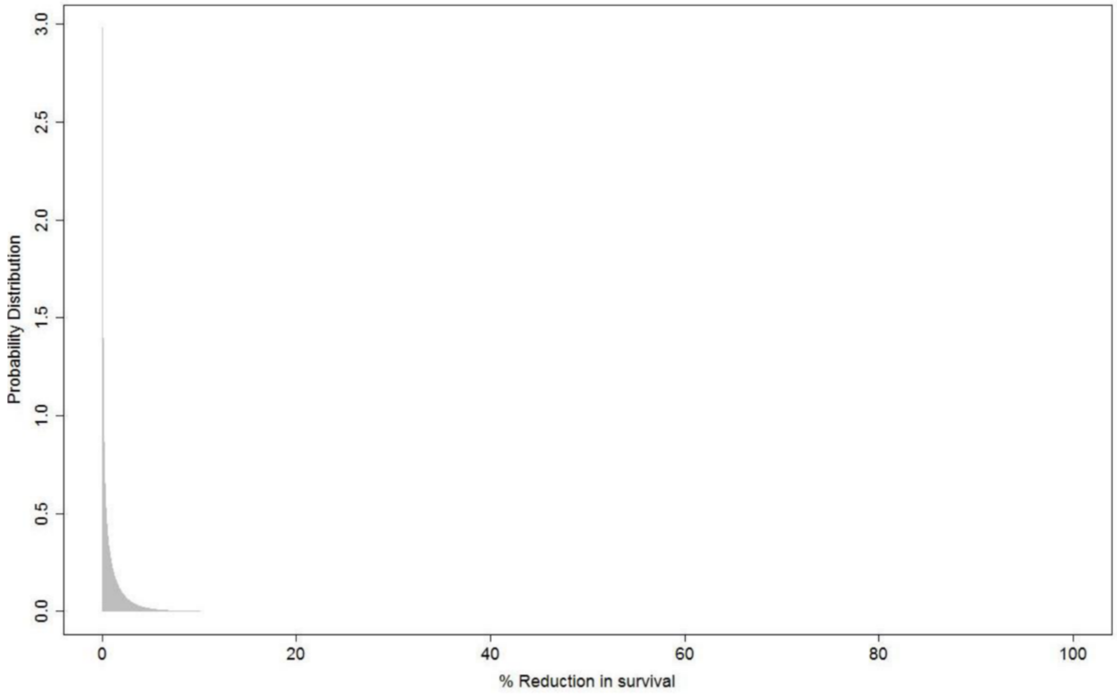
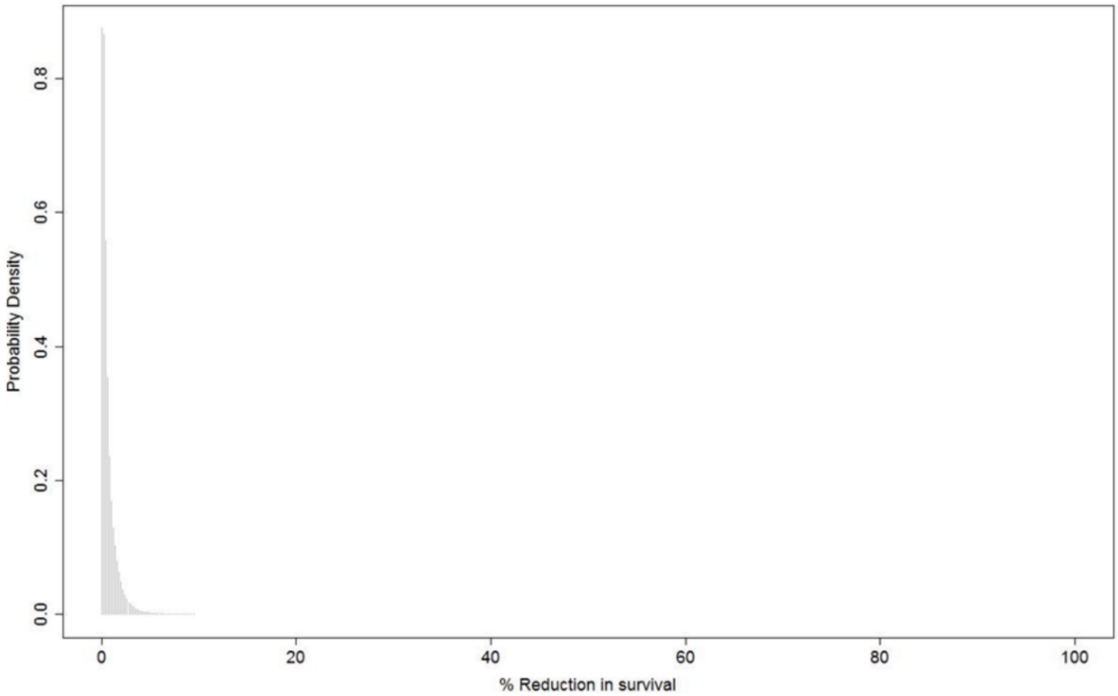


Figure 3-3 Probability distribution showing the consensus distribution for the effects on survival of juvenile or dependent calf harbour porpoise as a consequence of a maximum 6 dB of PTS within a 2-10 kHz band (figure from Booth and Heinis (2018))



3.2.5 Data collected during wind farm construction have demonstrated that porpoise detections around the pile driving site decline several hours prior to the start of pile driving, and it is assumed that this is due to the increase in other construction related activities and vessel presence in advance of the actual pile driving (Brandt et al., 2018, Graham et al., 2019, Benhemma-Le Gall et al., 2020). Therefore, the presence of construction related vessels prior to the start of piling can act as a local scale deterrent for harbour porpoise and therefore reduce the risk of auditory injury. Assumptions that harbour porpoise are present in the vicinity of the pile driving at the start of the soft start are therefore likely to be overly conservative.

3.2.6 In conclusion, given the results of the expert elicitation, which combined our best knowledge on the effects of PTS-onset on marine mammals, the sensitivity of harbour porpoise to PTS-onset from pile driving activities is considered to be **Low**, whereby individual vital rates (survival and reproduction) may be affected, but not at a significant level.

Magnitude

3.2.7 **Table 3-2** outlines the potential for PTS-onset for harbour porpoise under the WCS for both monopiles and pin-piles. The largest predicted cumulative PTS-onset impact range is 7.4 km for the installation of two sequential monopiles at the South location, resulting in a potential PTS-onset impact to 26 harbour porpoise per piling day which represents 0.007% of the North Sea MU.

3.2.8 **Table 3-3** outlines the potential for PTS-onset for harbour porpoise under the MLS for both monopiles and pin-piles. The largest predicted cumulative PTS-onset impact range is 6.9 km for the installation of two sequential monopiles at the South location, resulting in a potential PTS-onset impact to 23 harbour porpoise per piling day which represents 0.007% of the North Sea MU.

3.2.9 **Table 3-4** outlines the potential for PTS-onset for harbour porpoise for both monopiles and pin-piles under the concurrent piling scenario. The largest predicted cumulative PTS-onset impact area is for the concurrent installation of two sequential monopiles at both the East and West locations simultaneously, resulting in a potential PTS-onset impact to 113 harbour porpoise per piling day which represents 0.033% of the North Sea MU.

3.2.10 Although the numbers of individuals predicted to be at risk per piling day are low and would not be considered significant in Environmental Impact Assessment (EIA) terms, harbour porpoise are an European Protected Species (EPS) and under EPS legislation (Habitats Directive) it is an offence to injure a single individual (this includes PTS auditory injury). Therefore, Rampion 2 has committed to a piling Marine Mammal Mitigation Protocol (MMMP) (Commitment C-52 in **Commitment Register** (Document Reference: 7.22)) to reduce the risk of PTS-onset to **Negligible** levels. In addition to this embedded mitigation, it is also likely that the presence of novel vessels and associated construction activity will ensure that the vicinity of the pile is free of harbour porpoise by the time that piling begins.

Table 3-2 Impact area, maximum range, number of harbour porpoise and percentage of MU predicted to experience PTS-onset for the WCS

	Monopile (4,400 kJ)				**Pin-pile (2,500 kJ)**			
	NW	**W**	**S**	**E**	**NW**	**W**	**S**	**E**
Instantaneous PTS: 202 dB unweighted SPL$_{peak}$								
Area (km^2)	0.57	0.91	1.4	1.4	0.38	0.63	0.99	0.93
Max range (km)	0.43	0.55	0.68	0.66	0.36	0.46	0.56	0.55
# Porpoise	<1	<1	<1	<1	<1	<1	<1	<1
% MU	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cumulative PTS: 155 dB VHF Weighted SEL$_{cum}$ (single pile)								
Area (km^2)	6.8	19	120	85	2.7	20	75	53
Max range (km)	2.2	3.8	7.3	6.7	1.4	3.8	5.8	5.3
# Porpoise	1	2	26	18	<1	4	16	11
% MU	0.000	0.000	0.007	0.005	0.000	0.001	0.004	0.003
Cumulative PTS: 155 dB VHF Weighted SEL$_{cum}$ (multiple piles in 24 hrs)								
Area (km^2)	6.9	20	120	87	2.8	10	77	54
Max range (km)	2.2	3.8	7.4	6.9	1.5	2.8	5.9	5.4

	Monopile (4,400 kJ)				Pin-pile (2,500 kJ)			
	NW	**W**	**S**	**E**	**NW**	**W**	**S**	**E**
# Porpoise	1	2	26	19	<1	2	16	12
% MU	0.000	0.000	0.007	0.005	0.000	0.000	0.004	0.003

Table 3-3 Impact area, maximum range, number of harbour porpoise and percentage of MU predicted to experience PTS-onset for the MLS.

	Monopile (4,000 kJ)				Pin-pile (2,000 kJ)			
	NW	**W**	**S**	**E**	**NW**	**W**	**S**	**E**
Instantaneous PTS: 202 dB unweighted SPL_{peak}								
Area (km^2)	0.54	0.87	1.4	1.3	0.33	0.53	0.82	0.77
Max range (km)	0.42	0.54	0.67	0.65	0.33	0.42	0.51	0.5
# Porpoise	<1	<1	<1	<1	<1	<1	<1	<1
% MU	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cumulative PTS: 155 dB VHF Weighted SEL_{cum} (single pile)								
Area (km^2)	5.7	17	100	73	1.4	6.1	53	36
Max range (km)	2.0	3.4	6.6	6.1	1.0	2.1	4.7	4.3
# Porpoise	1	4	21	16	<1	1	11	8
% MU	0.000	0.001	0.006	0.004	0.000	0.000	0.003	0.002
Cumulative PTS: 155 dB VHF Weighted SEL_{cum} (multiple piles in 24 hrs)								
Area (km^2)	6	17	110	78	1.5	6.5	57	40
Max range (km)	2.1	3.4	6.9	6.5	1.1	2.2	5.0	4.6
# Porpoise	1	4	23	17	<1	1	12	9
% MU	0.000	0.001	0.007	0.004	0.000	0.000	0.003	0.002

Table 3-4 Impact area, number of harbour porpoise and percentage of MU predicted to experience PTS-onset for the WCS concurrent piling

	Monopile (4,400 kJ)	Pin-pile (2,500 kJ)
Cumulative PTS: 155 dB VHF Weighted SEL_{cum} (single pile)		
E Area (km^2)	85	53
W Area (km^2)	19	9.8
Combined E&W area (km^2)	510	420
# porpoise	109	89
% MU	0.03	0.025
Cumulative PTS: 155 dB VHF Weighted SEL_{cum} (multiple piles in 24 hrs)		
E Area (km^2)	87	54
W Area (km^2)	20	10
Combined E&W area (km^2)	530	450
# porpoise	113	96
% MU	0.03	0.027

Significance

3.2.11 The PTS impact is predicted to be of local spatial extent, short term duration and intermittent, however since PTS is a permanent change in the hearing threshold, it is not recoverable. With the use of embedded environmental measures (**Commitments Register** (Document Reference: 7.22)), it is expected that the risk of PTS will be **Very Low/Negligible**. Harbour porpoise have been assessed as having a **Low** sensitivity to PTS-onset from pile driving. Therefore, the resulting impact significance for the onset of PTS in harbour porpoise from both the WCS and MLS for both monopiles and pin-piles is **Negligible (not significant)**.

3.3 HF Cetacean – Bottlenose and common dolphins

Sensitivity to PTS from pile driving

Bottlenose dolphin

3.3.1 The expert elicitation on the potential effects of PTS-onset from pile driving on vital rates also included bottlenose dolphins. The predicted decline in bottlenose dolphin vital rates from the impact of a 6 dB PTS in the 2-10 kHz band for different percentiles of the elicited probability distribution are provided in **Table 3-5**. The data provided in **Table 3-5** should be interpreted as:

- Experts estimated that the median decline in an individual mature female bottlenose dolphin's fertility was 0.43% (due to a 6 dB PTS (a notch a few kHz wide and 6 dB high) occurring somewhere in the hearing between 2-10 kHz).
- Experts estimated that the median decline in an individual mature female bottlenose dolphin's survival was 1.6% (due to a 6 dB PTS (a notch a few kHz wide and 6 dB high) occurring somewhere in the hearing between 2-10 kHz).
- Experts estimated that the median decline in an individual bottlenose dolphin juvenile survival was 1.32% (due to a 6 dB PTS (a notch a few kHz wide and 6dB high) occurring somewhere in the hearing between 2-10 kHz).
- Experts estimated that the median decline in an individual bottlenose dolphin dependent calf survival was 2.96% (due to a 6 dB PTS (a notch a few kHz wide and 6 dB high) occurring somewhere in the hearing between 2-10 kHz).

Table 3-5 Predicted decline in bottlenose dolphin vital rates for different percentiles of the elicited probability distribution

	Percentiles of the elicited probability distribution								
	10%	**20%**	**30%**	**40%**	**50%**	**60%**	**70%**	**80%**	**90%**
Adult survival	0	0.18	0.57	1.04	1.6	2.34	3.39	5.18	10.99
Fertility	0	0.04	0.13	0.26	0.43	0.85	1.66	3.49	6.22
Juvenile survival	0.01	0.11	0.35	0.75	1.32	2.14	3.3	5.19	11.24
Calf survival	0	0.29	0.93	1.77	2.96	4.96	7.81	10.69	14.79

Figure 3-4 Probability distribution showing the consensus distribution for the effects on fertility of mature female bottlenose dolphin as a consequence of a maximum 6 dB of PTS within a 2-10 kHz band (figure from Booth and Heinis (2018))

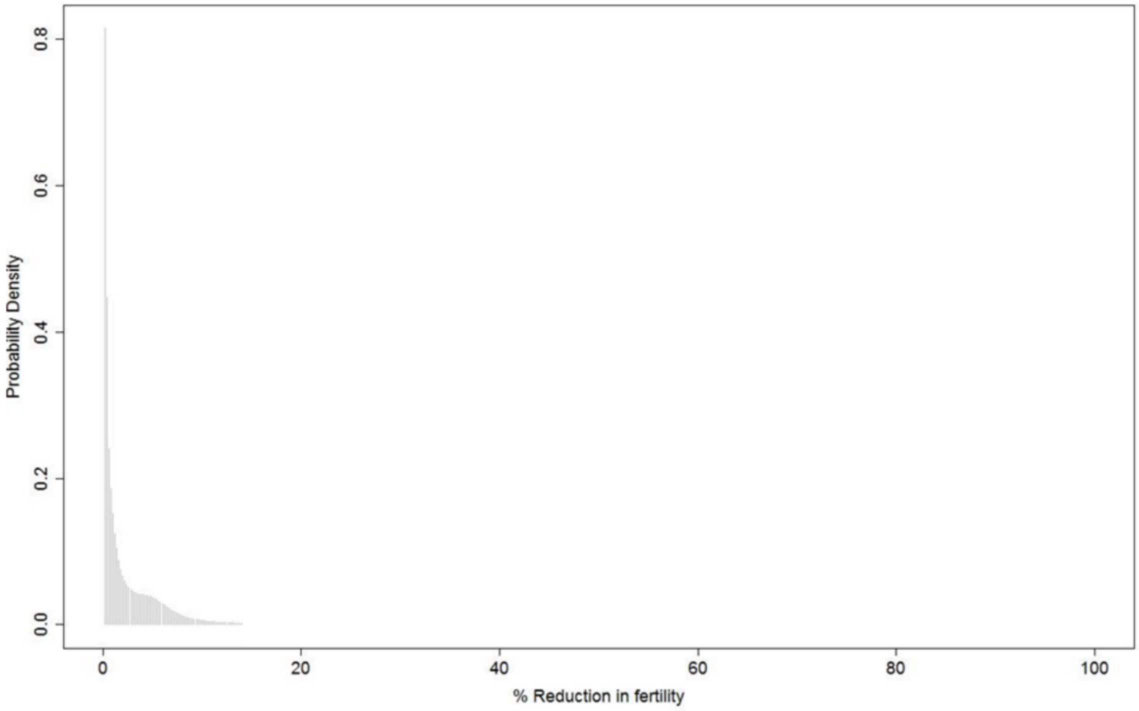


Figure 3-5 Probability distribution showing the consensus distribution for the effects on survival of mature female bottlenose dolphin as a consequence of a maximum 6 dB of PTS within a 2-10 kHz band (figure from Booth and Heinis (2018))

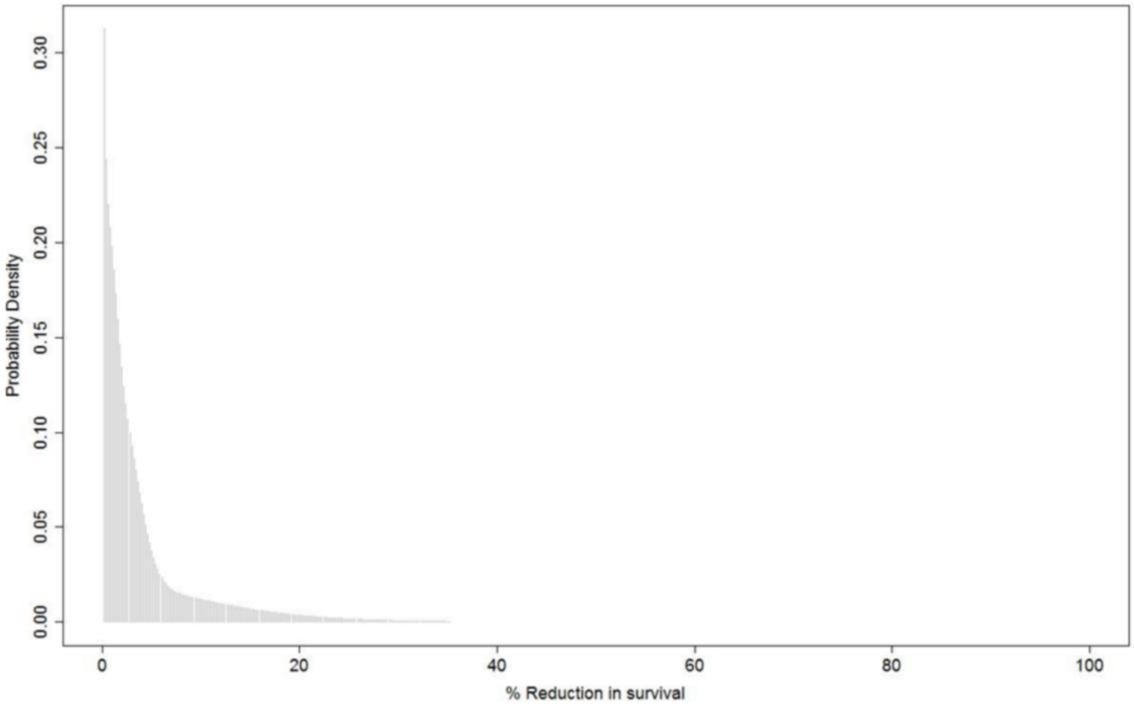
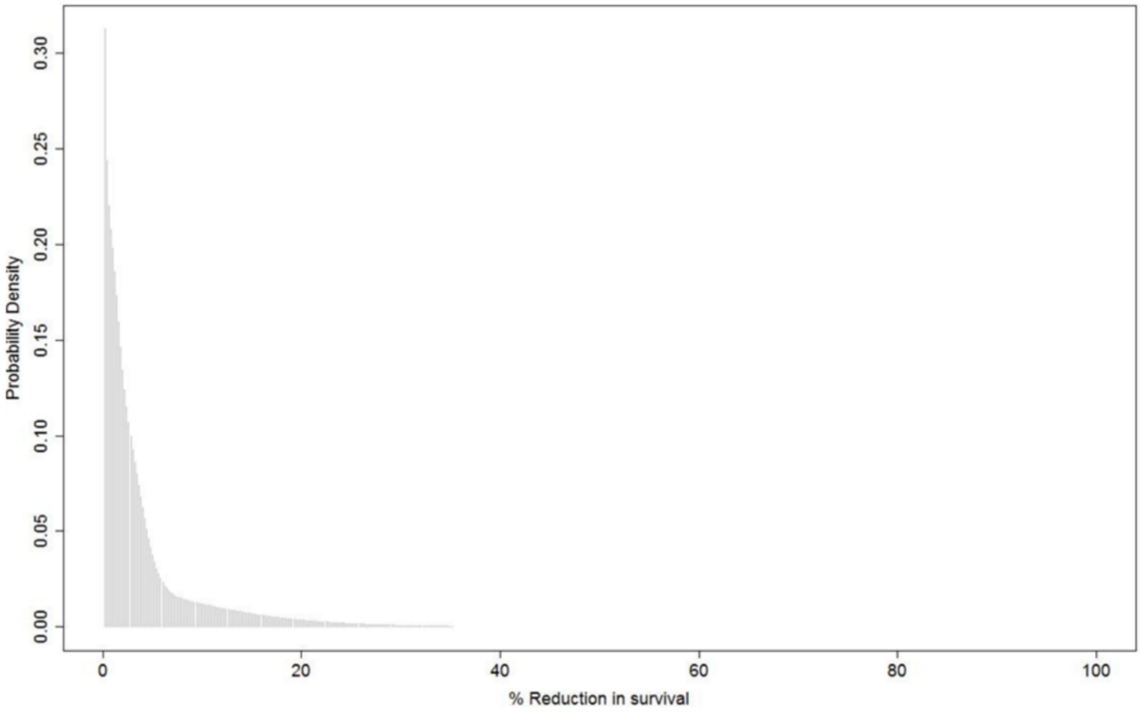


Figure 3-6 Probability distribution showing the consensus distribution for the effects on survival of juvenile or dependent calf bottlenose dolphin as a consequence of a maximum 6 dB of PTS within a 2-10 kHz band (figure from Booth and Heinis (2018))



3.3.2 In conclusion, given the results of the expert elicitation, which combined our best knowledge on the effects of PTS-onset on marine mammals, the sensitivity of dolphin species to PTS-onset from pile driving activities is considered to be **Low**, whereby individual vital rates (survival and reproduction) may be affected, but not at a significant level.

Common dolphin

3.3.3 The hearing range of common dolphins is currently estimated from their sound production, and has been labelled medium-high frequency, spanning between 150 Hz to 160 kHz (Finneran, 2016, Houser et al., 2017). There are few studies investigating the effects of pile driving on common dolphins, which could relate to their occupation of deeper waters, contrasting the shallower habitat in which offshore construction frequently occurs. However, an analysis of pile driving activity in Broadhaven bay, Ireland, found construction activity to be associated with a reduction in the presence of minke whales and harbour porpoise, but not with common dolphins (Culloch et al., 2016). Conversely, increased vessel presence during the construction period was associated with a decrease of common dolphins in the surrounding area. While there is little information on the impacts of pile driving on common dolphins, there are a few studies documenting the impacts of seismic activity. Although the noise produced by airguns differs in its duration and cumulative acoustic energy levels, it may be similar in its frequency range to the low-frequency noise produced by pile driving. In general, there is contrasting evidence for the response of common dolphins to seismic surveys. While some research indicates no change in the occurrence or sighing density of common dolphins when exposed to seismic activity (Kavanagh et al., 2019, Stone et al., 2017), Goold (1996) found a reduction in common dolphin presence within 1 km of ongoing seismic surveys near Pembrokeshire.

Magnitude

3.3.4 **Table 3-6** outlines the potential for PTS-onset for bottlenose and common dolphins under the WCS for both monopiles and pin-piles. The largest predicted cumulative PTS-onset impact range is <0.1 km, resulting in a potential PTS-onset impact to <1 individual dolphin per piling day which represents 0.000% of the MU for each species. Given the low numbers predicted for the WCS, the MLS numbers were not presented here since they would be lower than those predicted for the WCS.

3.3.5 Although the numbers of individuals predicted to be at risk per piling day are minimal and would not be considered significant in EIA terms, bottlenose dolphins and common dolphins are both an EPS and under EPS legislation it is an offence to injure a single individual (this includes PTS auditory injury). Therefore, Rampion 2 has committed to a piling MMMP (Commitment C-52 of the **Commitments Register** (Document Reference: 7.22)) to reduce the risk of PTS-onset to **Negligible** levels.

Table 3-6 Impact area, maximum range and number of bottlenose and common dolphins predicted to experience PTS-onset for the WCS

	Monopile (4,400 kJ)				**Pin-pile (2,500 kJ)**			
	NW	**W**	**S**	**E**	**NW**	**W**	**S**	**E**
Instantaneous PTS: 230 dB unweighted SPL$_{peak}$								
Area (km^2)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Max range (km)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
# bottlenose	<1	<1	<1	<1	<1	<1	<1	<1
# common	<1	<1	<1	<1	<1	<1	<1	<1
Cumulative PTS: 185 dB HF Weighted SEL$_{cum}$ (single pile)								
Area (km^2)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Max range (km)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
# bottlenose	<1	<1	<1	<1	<1	<1	<1	<1
# common	<1	<1	<1	<1	<1	<1	<1	<1
Cumulative PTS: 185 dB HF Weighted SEL$_{cum}$ (multiple piles in 24 hrs)								
Area (km^2)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

	Monopile (4,400 kJ)				Pin-pile (2,500 kJ)			
	NW	**W**	**S**	**E**	**NW**	**W**	**S**	**E**
Max range (km)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
# bottlenose	<1	<1	<1	<1	<1	<1	<1	<1
# common	<1	<1	<1	<1	<1	<1	<1	<1

Table 3-7 Impact areas for dolphin species for PTS-onset for the WCS concurrent piling

	Monopile (4,400 kJ)	Pin-pile (2,500 kJ)
Cumulative PTS: 185 dB VHF Weighted SEL_{cum} (single pile)		
E Area (km^2)	<0.1	<0.1
W Area (km^2)	<0.1	<0.1
Combined E&W area (km^2)	No cumulative effect	No cumulative effect
Cumulative PTS: 185 dB VHF Weighted SEL_{cum} (multiple piles in 24 hrs)		
E Area (km^2)	<0.1	<0.1
W Area (km^2)	<0.1	<0.1
Combined E&W area (km^2)	No cumulative effect	No cumulative effect

Significance

3.3.6 The PTS-onset impact is predicted to be of local spatial extent, short term duration and intermittent, however since PTS is a permanent change in the hearing threshold, it is not recoverable. With the use of embedded environmental measures (**Commitments Register** (Document Reference: 7.22)), it is expected that the risk of PTS will be **Very Low/Negligible**. Both bottlenose and common dolphins have been assessed as having a **Low** sensitivity to PTS-onset from pile driving. Therefore, the resulting impact significance for the onset of PTS in bottlenose dolphins and common dolphins from both the WCS and MLS for both monopiles and pin-piles is **Negligible (not significant)**.

3.4 LF Cetacean – Minke whale

Sensitivity to PTS from pile driving

3.4.1 There is significantly less information available on baleen whale hearing and the potential impacts of PTS on vital rates. Thus minke whales were not included in the previous expert elicitation on this subject. The low frequency noise produced during piling may be more likely to overlap with the hearing range of low frequency cetacean species such as minke whales. For minke whales, Tubelli et al. (2012) estimated the most sensitive hearing range as the region with thresholds within 40 dB of best sensitivity, to extend from 30 to 100 Hz up to 7.5 to 25 kHz, depending on the specific model used. Therefore a 2-10 kHz notch of 6 dB will only affect a small region of minke whale hearing. In addition, minke whale communication signals have been demonstrated to be below 2 kHz (Edds-Walton, 2000, Mellinger et al., 2000, Gedamke et al., 2001, Risch et al., 2013, Risch et al., 2014). Like other mysticete whales, minke whales are also thought to be capable of hearing sounds through their skull bones (Cranford and Krysl, 2015).

3.4.2 While it is acknowledged that the data available on minke whale sensitivity to PTS from pile driving is lacking, it is expected that PTS-onset in a small region of their hearing is likely to result in **Low** sensitivity, whereby individual vital rates (survival and reproduction) may be affected, but not at a significant level.

Magnitude

3.4.3 **Table 3-8** outlines the potential for PTS-onset for minke whales under the WCS for both monopiles and pin-piles. The largest predicted cumulative PTS-onset impact range is 15 km under the WCS. Despite these larger PTS-onset impact ranges, the density of minke whales predicted to be in the area is so low (0.0023 whales/km^2, SCANS III) that even with impact ranges of this size, this results in a potential PTS-onset impact to a maximum of 1 individual whale per piling day which represents 0.004% of the MU.

3.4.4 **Table 3-9** outlines the potential for PTS-onset for minke whales for both monopiles and pin-piles under the concurrent piling scenario. The largest predicted cumulative PTS-onset impact area is for the concurrent installation of two sequential monopiles at both the East and West locations simultaneously, resulting in a potential PTS-onset impact to 2 individual minke whales per piling day which represents 0.01% of the MU.

3.4.5 Although the numbers of individuals predicted to be at risk per piling day are minimal and would not be considered significant in EIA terms, minke whales are an EPS and under EPS legislation it is an offence to injure a single individual (this includes PTS auditory injury). Therefore, Rampion 2 has committed to a piling MMMP (Commitment C-52 in the **Commitments Register** (Document Reference: 7.22) to reduce the risk of PTS-onset to **Negligible** levels.

Table 3-8 Impact area, maximum range, number of minke whales predicted to experience PTS-onset for the WCS

	Monopile (4,400 kJ)				Pin-pile (2,500 kJ)			
	NW	**W**	**S**	**E**	**NW**	**W**	**S**	**E**
Instantaneous PTS: 219 dB unweighted SPL_{peak}								
Area (km^2)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Max range (km)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
# whales	<1	<1	<1	<1	<1	<1	<1	<1
% MU	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004	<0.004
Cumulative PTS: 183 dB LF Weighted SEL_{cum} (single pile)								
Area (km^2)	8.6	43	380	280	2.2	21	280	190
Max range (km)	3.2	7.2	15.0	14.0	1.7	5.3	13.0	12.0
# whales	<1	<1	1	1	<1	<1	1	<1
% MU	<0.004	<0.004	0.004	0.004	<0.004	<0.004	0.004	<0.004
Cumulative PTS: 183 dB LF Weighted SEL_{cum} (multiple piles in 24 hrs)								
Area (km^2)	8.6	43	380	280	2.2	21	280	190
Max range (km)	3.2	7.2	15.0	14.0	1.8	5.3	13.0	12.0
# whales	<1	<1	1	1	<1	<1	1	<1
% MU	<0.004	<0.004	0.004	0.004	<0.004	<0.004	0.004	<0.004

Table 3-9 Impact area, number of minke whales and percentage of MU predicted to experience PTS-onset for the WCS concurrent piling

	Monopile (4,400 kJ)	Pin-pile (2,500 kJ)
Cumulative PTS: 183 dB VHF Weighted SEL_{cum} (single pile)		
E Area (km^2)	280	190
W Area (km^2)	43	21
Combined E&W area (km^2)	890	760
# whales	2	2
% MU	0.01%	0.01%
Cumulative PTS: 183 dB VHF Weighted SEL_{cum} (multiple piles in 24 hrs)		
E Area (km^2)	280	190
W Area (km^2)	43	21
Combined E&W area (km^2)	890	760
# whales	2	2
% MU	0.01%	0.01%

Significance

3.4.6 The PTS-onset impact is predicted to be of local spatial extent, short term duration and intermittent, however since PTS is a permanent change in the hearing threshold, it is not recoverable. With the use of embedded environmental measures (**Commitments Register** (Document Reference: 7.22)), it is expected that the risk of PTS will be negligible. Minke whales have been assessed as having a **Low** sensitivity to PTS-onset. Therefore, the resulting impact significance for the onset of PTS in minke whales from both the WCS and MLS for both monopiles and pin-piles is **Negligible (not significant)**.

3.5 Phocids - Harbour and grey seals

Sensitivity to PTS from pile driving

3.5.1 The expert elicitation on the potential effects of PTS-onset from pile driving on vital rates also included harbour and grey seals. The predicted decline in harbour and grey seals vital rates from the impact of a 6 dB PTS in the 2-10 kHz band for different percentiles of the elicited probability distribution are provided in **Table 3-10**. The data provided in **Table 3-10** should be interpreted as:

- Experts estimated that the median decline in an individual mature female seal’s fertility was 0.27% (due to a 6 dB PTS (a notch a few kHz wide and 6 dB high) occurring somewhere in the hearing between 2-10 kHz).
- Experts estimated that the median decline in an individual mature female seal’s survival was 0.39% (due to a 6 dB PTS (a notch a few kHz wide and 6 dB high) occurring somewhere in the hearing between 2-10 kHz).
- Experts estimated that the median decline in an individual seal pup/juvenile survival was 0.52% (due to a 6 dB PTS (a notch a few kHz wide and 6 dB high) occurring somewhere in the hearing between 2-10 kHz).

Table 3-10 Predicted decline in harbour and grey seal vital rates for different percentiles of the elicited probability distribution

	Percentiles of the elicited probability distribution								
	10%	20%	30%	40%	50%	60%	70%	80%	90%
Adult survival	0.02	0.1	0.18	0.27	0.39	0.55	0.78	1.14	1.89
Fertility	0.01	0.02	0.05	0.14	0.27	0.48	0.88	1.48	4.34
Calf survival	0	0.04	0.15	0.32	0.52	0.8	1.21	1.88	3

Figure 3-7 Probability distribution showing the consensus distribution for the effects on fertility of a mature female (harbour or grey) seal as a consequence of a maximum 6 dB of PTS within a 2-10 kHz band (figure from Booth and Heinis (2018))

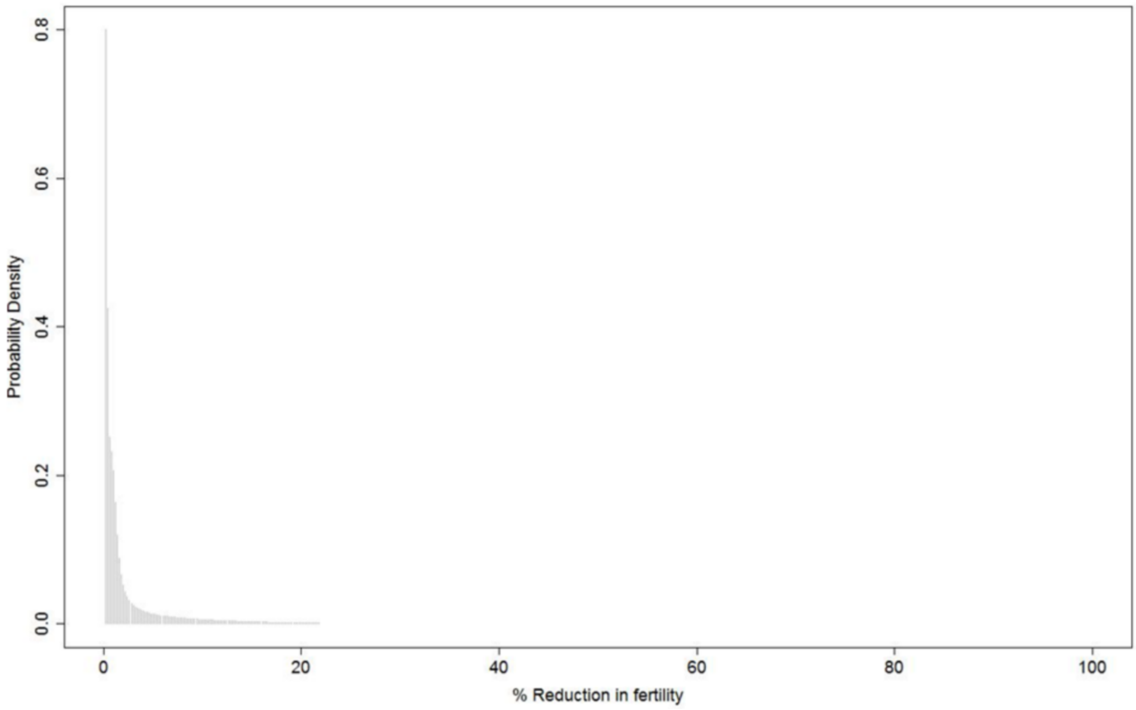


Figure 3-8 Probability distribution showing the consensus distribution for the effects on survival of a mature female (harbour or grey) seal as a consequence of a maximum 6 dB of PTS within a 2-10 kHz band (figure from Booth and Heinis (2018))

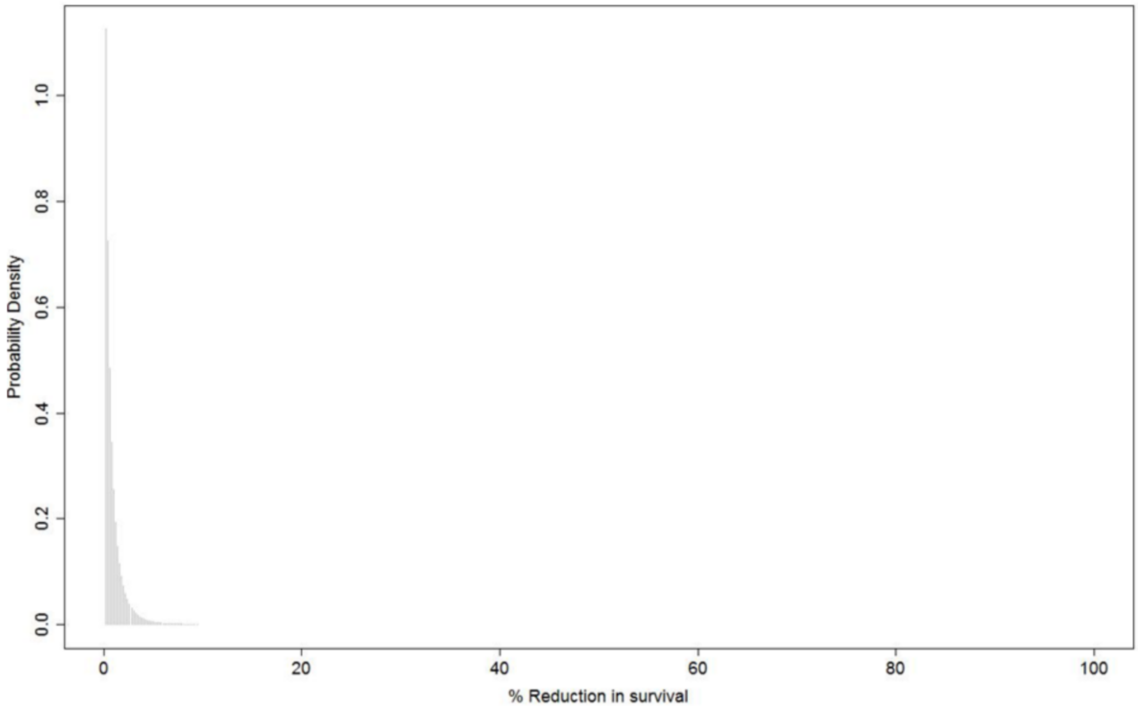
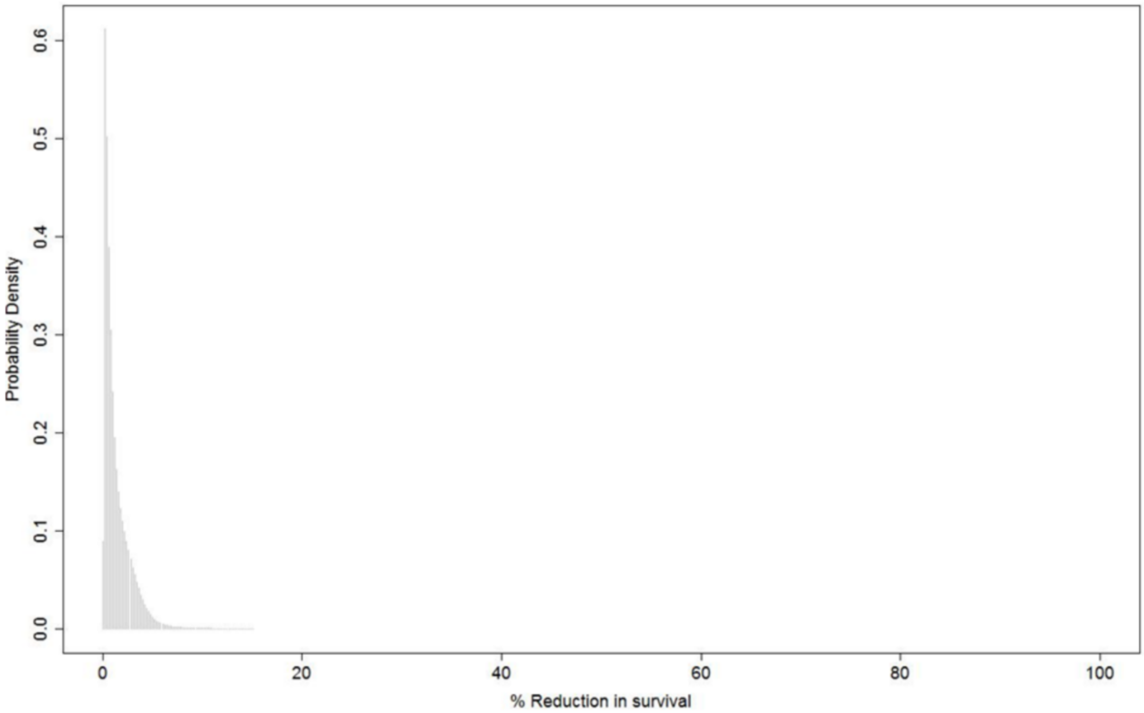


Figure 3-9 Probability distribution showing the consensus distribution for the effects on survival of juvenile or dependent pup (harbour or grey) seal as a consequence of a maximum 6 dB of PTS within a 2-10 kHz band (figure from Booth and Heinis (2018))



3.5.2 Seals are less dependent on hearing for foraging than cetaceans, but rely on sound for communication and predator avoidance (Deecke et al., 2002). Seals have very well developed tactile sensory systems that are used for foraging (Dehnhardt et al., 2001) and Hastie et al. (2015) reported that, based on calculations of SEL of tagged seals during the Lincs Offshore Windfarm construction, at least half of the tagged seals would have received a dose of sound greater than published thresholds for PTS. A recent update of this analysis using the revised Southall et al. (2019) thresholds and weighting reduced this proportion to 25% of the seals (Russell and Hastie, 2017). Based on the extent of the offshore wind farm construction in the Wash over the last ten years and the degree of overlap with the foraging ranges of harbour seals in the region (Russell et al., 2016), it would not be unreasonable to suggest that a large number of individuals of the Wash population may have experienced levels of sound with the potential to cause hearing loss.

3.5.3 The Wash harbour seal population has been increasing over this period which may provide an indication that either: a) seals are not developing PTS despite predictions of exposure that would indicate that they should; or b) that the survival and fitness of individual seals are not affected by PTS. Point a) would indicate that methods for predicting PTS are perhaps unreliable and/or over precautionary, and b) would suggest a lack of sensitivity to the effects of PTS.

3.5.4 In conclusion, given the results of the expert elicitation, which combined our best knowledge on the effects of PTS-onset on marine mammals, the sensitivity of both seal species to PTS-onset from pile driving activities is considered to be **Low**, whereby individual vital rates (survival and reproduction) may be affected, but not at a significant level.

Magnitude

3.5.5 **Table 3-11** outlines the potential for PTS-onset for harbour and grey seals under the WCS for both monopiles and pin-piles. The predicted cumulative PTS-onset impact range across all scenarios is <0.1 km which represents <1 individual harbour or grey seal. Given the low numbers predicted for the WCS, the MLS numbers were not presented here since they would be lower than those predicted for the WCS.

3.5.6 The PTS-onset impact is predicted to be of local spatial extent, short term duration and intermittent, however since PTS is a permanent change in the hearing threshold, it is not recoverable. Given that <1 individual is predicted to experience PTS-onset under any scenario, pile type or location, the magnitude is assessed as **Very Low**. Additionally, Rampion 2 has committed to a piling MMMP (Commitment C-52 in the **Commitments Register** (Document Reference: 7.22)) to reduce the risk of PTS-onset to **Negligible** levels.

Table 3-11 Impact area, maximum range, number of harbour and grey seals predicted to experience PTS-onset for the WCS

	Monopile (4,400 kJ)				**Pin-pile (2,500 kJ)**			
	NW	**W**	**S**	**E**	**NW**	**W**	**S**	**E**
Instantaneous PTS: 218 dB unweighted SPL_{peak}								
Area (km^2)	<0.01	<0.01	0.01	0.01	<0.01	<0.01	<0.01	<0.01
Max range (km)	<0.05	<0.05	0.06	0.05	<0.05	<0.05	<0.05	<0.05
# harbour	<1	<1	<1	<1	<1	<1	<1	<1
# grey	<1	<1	<1	<1	<1	<1	<1	<1
Cumulative PTS: 185 dB PCW Weighted SEL_{cum} (single pile)								
Area (km^2)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Max range (km)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
# harbour	<1	<1	<1	<1	<1	<1	<1	<1
# grey	<1	<1	<1	<1	<1	<1	<1	<1
Cumulative PTS: 185 dB PCW Weighted SEL_{cum} (multiple piles in 24 hrs)								
Area (km^2)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Max range (km)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

	Monopile (4,400 kJ)				Pin-pile (2,500 kJ)			
	NW	**W**	**S**	**E**	**NW**	**W**	**S**	**E**
# harbour	<1	<1	<1	<1	<1	<1	<1	<1
# grey	<1	<1	<1	<1	<1	<1	<1	<1

Table 3-12 Impact areas for seal species for PTS-onset for the WCS concurrent piling

	Monopile (4,400 kJ)	Pin-pile (2,500 kJ)
Cumulative PTS: 185 dB PCW Weighted SEL_{cum} (single pile)		
E Area (km^2)	<0.1	<0.1
W Area (km^2)	<0.1	<0.1
Combined E&W area (km^2)	No cumulative effect	No cumulative effect
Cumulative PTS: 185 dB PCW Weighted SEL_{cum} (multiple piles in 24 hrs)		
E Area (km^2)	<0.1	<0.1
W Area (km^2)	<0.1	<0.1
Combined E&W area (km^2)	No cumulative effect	No cumulative effect

Significance

3.5.7 The PTS-onset impact is predicted to be of local spatial extent, short term duration and intermittent, however since PTS is a permanent change in the hearing threshold, it is not recoverable. With the use of embedded mitigation methods (**Commitments Register** (Document Reference: 7.22)), it is expected that the risk of PTS will be **Very Low/Negligible**. Both harbour and grey seals have been assessed as having a **Low** sensitivity to PTS. Therefore, the resulting impact significance for the onset of PTS in both harbour and grey seals from both the WCS and MLS for both monopiles and pin-piles is **Negligible (not significant)**.

3.6 PTS-onset summary

3.6.1 Given the embedded mitigation of an MMMP to reduce the risk of PTS-onset to negligible levels, the impact of PTS-onset from piling noise under both the WCS and the MLS is not considered to have a significant effect on any marine mammal species considered in this assessment (**Table 3-13**).

Table 3-13 Impact significance for all marine mammals to the impact of PTS-onset from impact piling

	Monopiles & Pin-piles WCS & MLS		
	Magnitude	**Sensitivity**	**Impact**
Harbour porpoise	Low/Negligible	Low	Negligible (not significant)
Bottlenose dolphin	Very Low/Negligible	Low	Negligible (not significant)
Common dolphin	Very Low/Negligible	Low	Negligible (not significant)
Minke whale	Very Low/Negligible	Low	Negligible (not significant)
Harbour seal	Very Low/Negligible	Low	Negligible (not significant)
Grey seal	Very Low/Negligible	Low	Negligible (not significant)

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4. TTS-onset results

4.1 Context

4.1.1 This section outlines the marine mammal TTS-onset impact ranges and number of animals potentially within these ranges that may be impacted by pile driving of both monopiles and pin-piles under the WCS.

4.1.2 The ranges that indicate TTS-onset were modelled and are presented alongside an estimate of the potential number of animals within these impact ranges. However, 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; therefore, it was not possible to carry out a quantitative assessment of the magnitude or significance of the impact of TTS on marine mammals. The current set of TTS-onset thresholds would result in a significant overestimate of the impact due to the extremely large resulting impact ranges representing the smallest measurable amount of TTS. This approach was agreed with Cefas at the Expert Topic Group meeting on 18 September 2020.

4.2 VHF Cetacean - Harbour porpoise

4.2.1 **Table 4-1** outlines the potential for TTS-onset for harbour porpoise for both monopiles and pin-piles under the WCS. The largest predicted cumulative TTS-onset impact range is 34 km, resulting in a potential TTS-onset impact to 383 harbour porpoise per piling day which represents 0.11% of the North Sea MU.

4.2.2 **Table 4-2** outlines the potential for TTS-onset for harbour porpoise for both monopiles and pin-piles under the WCS for concurrent piling at the East and West locations simultaneously. The largest predicted cumulative TTS-onset impact is to 533 porpoise per piling day which represents 0.15% of the relevant MU.

Table 4-1 Impact area, maximum range, number of harbour porpoise and percentage of MU predicted to experience TTS-onset for the WCS

	Monopile (4,400 kJ)				Pin-pile (2,500 kJ)			
	NW	**W**	**S**	**E**	**NW**	**W**	**S**	**E**
Instantaneous TTS: 196 dB unweighted SPL_{peak}								
Area (km^2)	2.8	4.6	8.7	8.1	2	3.3	6.1	5.6
Max range (km)	0.97	1.3	1.7	1.6	0.81	1.1	1.7	1.4

	Monopile (4,400 kJ)				**Pin-pile (2,500 kJ)**			
	NW	**W**	**S**	**E**	**NW**	**W**	**S**	**E**
# Porpoise	<1	1	2	2	<1	<1	1	1
% MU	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cumulative TTS: 140 dB VHF Weighted SEL$_{cum}$ (single pile)								
Area (km^2)	530	700	1800	1500	430	580	1500	1300
Max range (km)	21.0	24.0	33.0	32.0	18.0	22.0	30.0	29.0
# Porpoise	113	149	383	320	92	123	920	277
% MU	0.03	0.04	0.11	0.09	0.03	0.04	0.09	0.08
Cumulative TTS: 140 dB VHF Weighted SEL$_{cum}$ (multiple piles in 24 hrs)								
Area (km^2)	550	720	1800	1500	440	600	1600	1300
Max range (km)	21.0	24.0	34.0	33.0	19.0	22.0	31.0	30.0
# Porpoise	117	153	383	320	94	138	341	277
% MU	0.03	0.04	0.11	0.09	0.03	0.04	0.10	0.08

Table 4-2 Impact areas for harbour porpoise for TTS-onset for the WCS concurrent piling

	Monopile (4,400 kJ)	**Pin-pile (2,500 kJ)**
Cumulative TTS: 140 dB VHF Weighted SEL$_{cum}$ (single pile)		
E Area (km^2)	1500	1300
W Area (km^2)	700	580
Combined E&W area (km^2)	2400	2200
# porpoise	511	469

	Monopile (4,400 kJ)	Pin-pile (2,500 kJ)
% MU	0.14%	0.13%
Cumulative TTS: 140 dB VHF Weighted SEL$_{cum}$ (multiple piles in 24 hrs)		
E Area (km^2)	1500	1300
W Area (km^2)	720	600
Combined E&W area (km^2)	2500	2200
# porpoise	533	469
% MU	0.15%	0.13%

4.3 HF Cetacean – Bottlenose and common dolphins

4.3.1 **Table 4-3** outlines the potential for TTS-onset for bottlenose and common dolphins for both monopiles and pin-piles under the WCS. The largest predicted cumulative TTS-onset impact range is <0.1 km, resulting in a potential TTS-onset impact to <1 individual dolphin of each species per piling day which represents 0.000% of the relevant MU for each species. Given the low numbers predicted for the WCS, the MLS numbers were not presented here since they would be lower than those predicted for the WCS.

4.3.2 **Table 4-4** outlines the potential for TTS-onset for dolphins for both monopiles and pin-piles under the WCS for concurrent piling at the East and West locations simultaneously. There is no overlap in the contours for the two locations, and thus there is no potential for a cumulative effect.

Table 4-3 Impact area, maximum range, number of bottlenose and common dolphins and predicted to experience TTS-onset for the WCS

	Monopile (4,400 kJ)				Pin-pile (2,500 kJ)			
	NW	W	S	E	NW	W	S	E
Instantaneous TTS: 224 dB unweighted SPL$_{peak}$								
Area (km^2)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Max range (km)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
# bnd	<1	<1	<1	<1	<1	<1	<1	<1
# cd	<1	<1	<1	<1	<1	<1	<1	<1
Cumulative TTS: 170 dB HF Weighted SEL$_{cum}$ (single pile)								
Area (km^2)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

	Monopile (4,400 kJ)				Pin-pile (2,500 kJ)			
	NW	**W**	**S**	**E**	**NW**	**W**	**S**	**E**
Max range (km)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
# bottlenose	<1	<1	<1	<1	<1	<1	<1	<1
# common	<1	<1	<1	<1	<1	<1	<1	<1
Cumulative TTS: 170 dB HF Weighted SEL$_{cum}$ (multiple piles in 24 hrs)								
Area (km^2)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Max range (km)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
# bottlenose	<1	<1	<1	<1	<1	<1	<1	<1
# common	<1	<1	<1	<1	<1	<1	<1	<1

Table 4-4 Impact areas for dolphin species for TTS-onset for the WCS concurrent piling

	Monopile (4,400 kJ)	Pin-pile (2,500 kJ)
Cumulative TTS: 170 dB HF Weighted SEL$_{cum}$ (single pile)		
E Area (km^2)	<0.1	<0.1
W Area (km^2)	<0.1	<0.1
Combined E&W area (km^2)	No cumulative effect	No cumulative effect
Cumulative TTS: 170 dB HF Weighted SEL$_{cum}$ (multiple piles in 24 hrs)		
E Area (km^2)	<0.1	<0.1
W Area (km^2)	<0.1	<0.1
Combined E&W area (km^2)	No cumulative effect	No cumulative effect

4.4 LF Cetacean – Minke whale

4.4.1 **Table 4-5** outlines the potential for TTS-onset for minke whales for both monopiles and pin-piles under the WCS. The largest predicted cumulative TTS-onset impact range is 46 km, resulting in a potential TTS-onset impact to 6 whales per piling day which represents 0.03% of the relevant MU.

4.4.2 **Table 4-6** outlines the potential for TTS-onset for minke whales for both monopiles and pin-piles under the WCS for concurrent piling at the East and West locations simultaneously. The largest predicted cumulative TTS-onset impact is to 8 whales per piling day which represents 0.04% of the relevant MU.

Table 4-5 Impact area, maximum range, number of minke whales and percentage of MU predicted to experience TTS-onset for the WCS

	Monopile (4,400 kJ)				**Pin-pile (2,500 kJ)**			
	NW	**W**	**S**	**E**	**NW**	**W**	**S**	**E**
Instantaneous TTS: 213 dB unweighted SPL_{peak}								
Area (km^2)	0.02	0.03	0.05	0.04	0.02	0.02	0.03	0.03
Max range (km)	0.09	0.11	0.12	0.12	0.07	0.08	0.10	0.10
# whales	<1	<1	<1	<1	<1	<1	<1	<1
% MU	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cumulative TTS: 168 dB LF Weighted SEL_{cum} (single pile)								
Area (km^2)	730	1100	2700	2300	580	880	2400	2000
Max range (km)	26	31	46	44	23	29	43	41
# whales	2	3	6	5	1	2	6	5
% MU	0.01	0.01	0.03	0.02	0.00	0.01	0.03	0.02
Cumulative TTS: 168 dB LF Weighted SEL_{cum} (multiple piles in 24 hrs)								
Area (km^2)	730	1100	2700	2300	580	880	2400	2000
Max range (km)	26	31	46	44	23	28	43	41
# whales	2	3	6	5	1	2	6	5
% MU	0.01	0.01	0.03	0.02	0.00	0.01	0.03	0.02

Table 4-6 Impact areas for minke whale for TTS-onset for the WCS concurrent piling

	Monopile (4,400 kJ)	Pin-pile (2,500 kJ)
Cumulative TTS: 168 dB LF Weighted SEL_{cum} (single pile)		
E Area (km^2)	2300	2000
W Area (km^2)	1100	880
Combined E&W area (km^2)	3300	3000
# whales	8	7
% MU	0.04%	0.034%
Cumulative TTS: 168 dB LF Weighted SEL_{cum} (multiple piles in 24 hrs)		
E Area (km^2)	2300	2000
W Area (km^2)	1100	880
Combined E&W area (km^2)	3300	3000
# whales	8	7
% MU	0.04%	0.034%

4.5 Phocids - Harbour and grey seals

4.5.1 **Table 4-7** outlines the potential for TTS-onset for harbour and grey seals for both monopiles and pin-piles under the WCS. The largest predicted cumulative TTS-onset impact range is 16 km, resulting in a potential TTS-onset impact to <1 seal of each species per piling day.

4.5.2 **Table 4-8** outlines the potential for TTS-onset for seals for both monopiles and pin-piles under the WCS for concurrent piling at the East and West locations simultaneously. The largest predicted cumulative TTS-onset impact is to <1 individual of each species per piling day.

Table 4-7 Impact area, maximum range, number of harbour and grey seals predicted to experience TTS-onset for the WCS

	Monopile (4,400 kJ)				Pin-pile (2,500 kJ)			
	NW	W	S	E	NW	W	S	E
Instantaneous TTS: 218 dB unweighted SPL_{peak}								
Area (km^2)	0.03	0.05	0.06	0.06	0.02	0.03	0.04	0.04

	Monopile (4,400 kJ)				Pin-pile (2,500 kJ)			
	NW	**W**	**S**	**E**	**NW**	**W**	**S**	**E**
Max range (km)	0.1	0.12	0.14	0.14	0.08	0.1	0.12	0.11
# harbour	<1	<1	<1	<1	<1	<1	<1	<1
# grey	<1	<1	<1	<1	<1	<1	<1	<1
Cumulative TTS: 170 dB PCW Weighted SEL$_{cum}$ (single pile)								
Area (km^2)	35	89	460	350	25	72	400	300
Max range (km)	5.2	8.7	15.0	14.00	4.5	7.8	14.0	13.0
# harbour	<1	<1	<1	<1	<1	<1	<1	<1
# grey	<1	<1	<1	<1	<1	<1	<1	<1
Cumulative TTS: 170 dB PCW Weighted SEL$_{cum}$ (multiple piles in 24 hrs)								
Area (km^2)	36	92	470	360	26	75	410	310
Max range (km)	5.3	8.9	16.0	15.0	4.6	8.0	15.0	14.0
# harbour	<1	<1	<1	<1	<1	<1	<1	<1
# grey	<1	<1	<1	<1	<1	<1	<1	<1

Table 4-8 Impact areas for seal species for TTS-onset for the WCS concurrent piling

	Monopile (4,400 kJ)	Pin-pile (2,500 kJ)
Cumulative TTS: 170 dB PCW Weighted SEL$_{cum}$ (single pile)		
E Area (km^2)	350	300
W Area (km^2)	89	72
Combined E&W area (km^2)	970	900
# harbour	<1	<1
# grey	<1	<1
Cumulative TTS: 170 dB PCW Weighted SEL$_{cum}$ (multiple piles in 24 hrs)		
E Area (km^2)	360	310
W Area (km^2)	92	75

	Monopile (4,400 kJ)	**Pin-pile (2,500 kJ)**
Combined E&W area (km^2)	1000	930
# harbour	<1	<1
# grey	<1	<1

5. Disturbance results

5.1 Context

5.1.1 This section outlines the marine mammal behavioural disturbance impact ranges, number of animals potentially within these ranges and the proportion of the MU that may be impacted. This, in combination with the sensitivity assessment, provides the magnitude, sensitivity and overall impact significance scores for unmitigated pile driving of both monopiles and pin-piles under both the WCS and MLS.

5.2 Harbour porpoise

Sensitivity to pile driving disturbance

5.2.1 Previous studies have shown that harbour porpoises are displaced from the vicinity of piling events. For example, studies at wind farms in the German North Sea have recorded large declines in porpoise detections close to the piling (>90% decline at noise levels above 170 dB) with decreasing effect with increasing distance from the pile (25% decline at noise levels between 145 and 150 dB) (Brandt *et al.* 2016). The detection rates revealed that porpoise were only displaced from the piling area in the short term (1 to 3 days) (Brandt et al., 2011, Brandt et al., 2016, Brandt et al., 2018, Dähne et al., 2013). Harbour porpoise are small cetaceans which makes them vulnerable to heat loss and requires them to maintain a high metabolic rate with little energy remaining for fat storage (e.g. Rojano-Doñate et al., 2018). This makes them vulnerable to starvation if they are unable to obtain sufficient levels of prey intake.

5.2.2 Studies using Digital Acoustic Recording Tags (DTAGs) have shown that porpoise tagged after capture in pound nets foraged on small prey nearly continuously during both the day and the night on their release (Wisniewska et al., 2016). However, Hoekendijk et al. (2018) point out that this could be an extreme short-term response to capture in nets, and may not reflect natural harbour porpoise behaviour. Nevertheless, if the foraging efficiency of harbour porpoise is disturbed or if they are displaced from a high-quality foraging ground, and are unable to find suitable alternative feeding grounds, they could potentially be at risk of changes to their overall fitness if they are not able to compensate and obtain sufficient food intake in order to meet their metabolic demands.

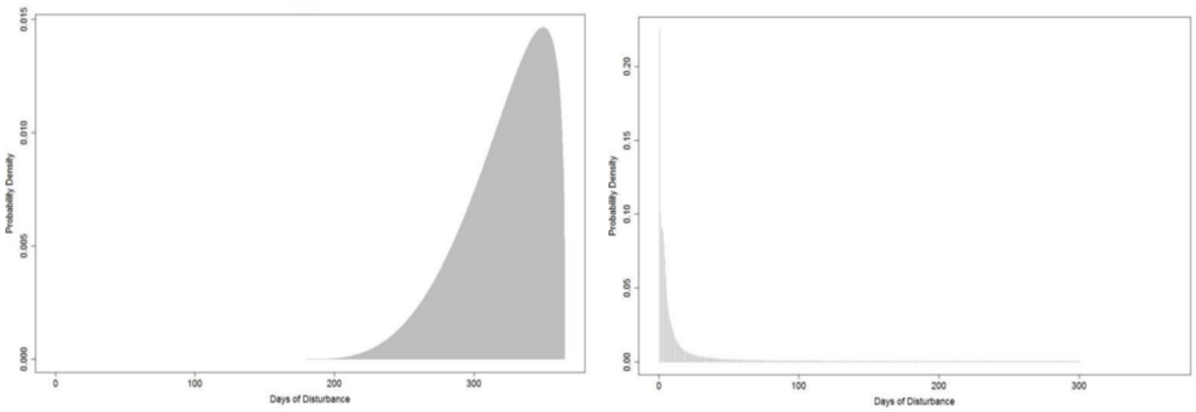
5.2.3 The results from Wisniewska et al. (2016) could also suggest that porpoises have an ability to respond to short term reductions in food intake, implying a resilience to disturbance. As Hoekendijk et al. (2018) argue, this could help explain why porpoises are such an abundant and successful species. It is important to note that the studies providing evidence for the responsiveness of harbour porpoises to piling noise have not provided any evidence for subsequent individual consequences. In this way, responsiveness to disturbance cannot reliably be equated to sensitivity to disturbance and porpoises may well be able to compensate by moving quickly to alternative areas to feed, while at the same time increasing their feeding rates.

5.2.4 Monitoring of harbour porpoise activity at the Beatrice Offshore Wind Farm during pile driving activity has indicated that porpoises were displaced from the immediate vicinity of the pile driving activity – with a 50% probability of response occurring at approximately 7 km (Graham et al., 2019). This monitoring also indicated that the response diminished over the construction period, so that eight months into the construction phase, the range at which there was a 50% probability of response was only 1.3 km. In addition, the study indicated that porpoise activity recovered between pile driving events.

5.2.5 A study of tagged harbour porpoises has shown large variability between individual responses to an airgun stimulus (van Beest et al., 2018). Of the five porpoises tagged and exposed to airgun pulses at ranges of 420–690 m (SEL 135–147 dB re 1 µPa^{2}s), one individual showed rapid and directed movements away from the source. Two individuals displayed shorter and shallower dives immediately after exposure and the remaining two animals did not show any quantifiable response. Therefore, there is expected to be a high level of variability in responses from individual harbour porpoises exposed to low frequency broadband pulsed noise (including both airguns and pile-driving).

5.2.6 At a BEIS funded expert elicitation workshop held in Amsterdam in June 2018, experts in marine mammal physiology, behaviour and energetics discussed the nature, extent and potential consequences of disturbance to harbour porpoise from exposure to low frequency broadband pulsed noise (e.g. pile-driving, airgun pulses) (Booth et al., 2019). Experts were asked to estimate the potential consequences of a six hour period of zero energy intake, assuming that disturbance from a pile driving event resulted in missed foraging opportunities for this duration. A Dynamic Energy Budget model for harbour porpoise (based on the DEB model in Hin et al., 2019) was used to aid discussions regarding the potential effects of missed foraging opportunities on survival and reproduction. The model described the way in which the life history processes (growth, reproduction and survival) of a female and her calf depend on the way in which assimilated energy is allocated between different processes, and was used during the elicitation to model the effects of energy intake and reserves following simulated disturbance. The experts agreed that first year calf survival (post-weaning) and fertility were the most likely vital rates to be affected by disturbance, but that juvenile and adult survival were unlikely to be significantly affected as these life-stages were considered to be more robust. Experts agreed that the final third of the year was the most critical for harbour porpoises as they reach the end of the current lactation period and the start of new pregnancies, therefore it was thought that significant impacts on fertility would only occur when animals received repeated exposure throughout the whole year. Experts agreed it would likely take high levels of repeated disturbance to an individual before there was any effect on that individual's fertility (**Figure 5-1 left**), and that it was very unlikely an animal would terminate a pregnancy early. The experts agreed that calf survival could be reduced by only a few days of repeated disturbance to a mother/calf pair during early lactation (**Figure 5-1 right**); however it is highly unlikely that the same mother-calf pair would repeatedly return to the area in order to receive these levels of repeated disturbance.

Figure 5-1 Probability distributions showing the consensus of the expert elicitation for harbour porpoise disturbance from piling (Booth et al., 2019)

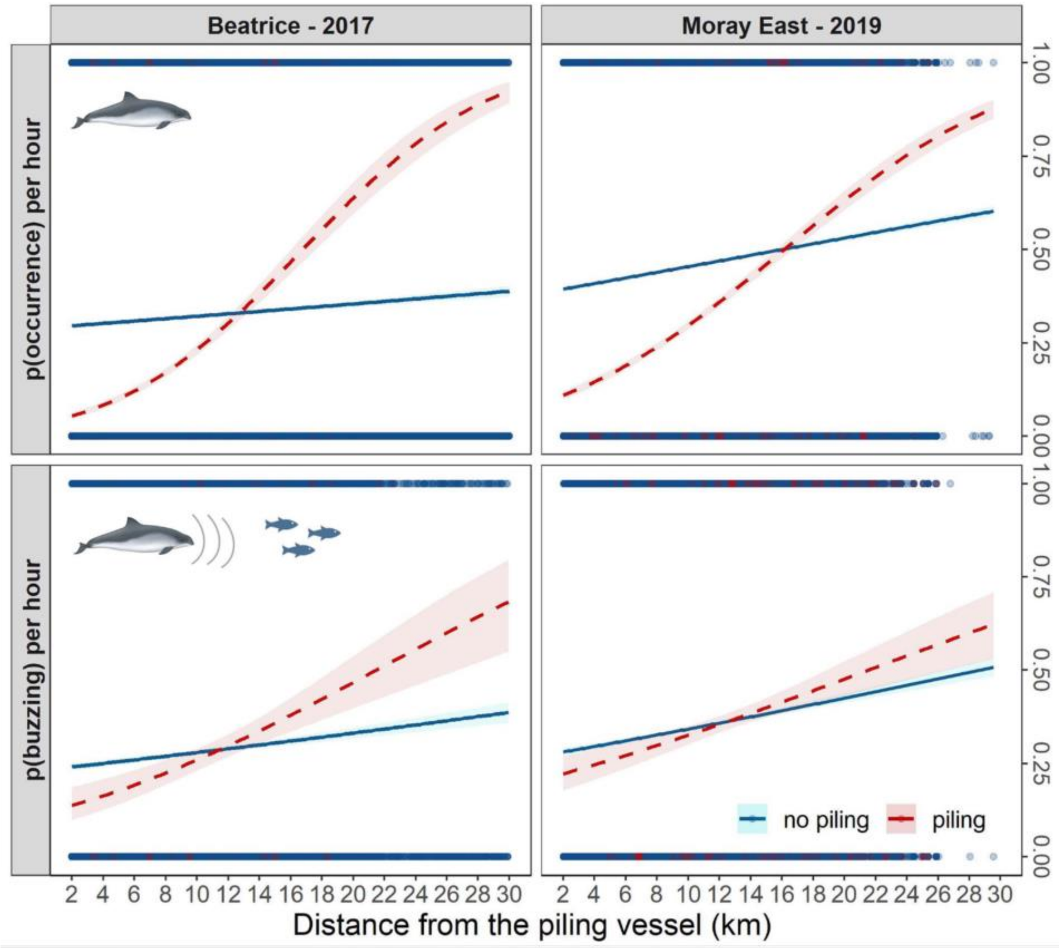


Left: the number of days of disturbance (i.e. days on which an animal does not feed for six hours) a pregnant female could ‘tolerate’ before it has any effect on fertility. Right: the number of days of disturbance (of six hours zero energy intake) a mother/calf pair could ‘tolerate’ before it has any effect on survival.

5.2.7 A recent study by Benhemma-Le Gall et al. (2021) provided two key findings in relation to harbour porpoise response to pile driving. Porpoise were not completely displaced from the piling site: detections of clicks (echolocation) and buzzing (associated with prey capture) in the short-range (2 km) did not cease in response to pile driving, and porpoise appeared to compensate: detections of both clicks (echolocation) and buzzing (associated with prey capture) increased above baseline levels with increasing distance from the pile, which suggests that those porpoise that are displaced from the near-field, compensate by increasing foraging activities beyond the impact range (**Figure 5-2**). Therefore, porpoise that experience displacement are expected to be able to compensate for the lost foraging opportunities and increased energy expenditure of fleeing.

5.2.8 Due to observed responsiveness to piling, their income breeder life history, and the low numbers of days of disturbance expected to effect calf survival, harbour porpoises have been assessed here as having a **Low** sensitivity to disturbance and resulting displacement from foraging grounds.

Figure 5-2 The probability of harbour porpoise occurrence and buzzing activity per hour during (dashed red line) and outwith (blue line) pile-driving hours, in relation to distance from the pile-driving vessel at Beatrice (left) and Moray East (right). Obtained from Benhemma-Le Gall et al. (2021)



Magnitude

Table 5-1 outlines the number of harbour porpoise potentially disturbed by pile driving at each modelling location for both monopiles and pin piles under both the WCS and MLS. The highest level of disturbance from a single location is predicted at the south location which is the deepest location and where noise propagates furthest (an example of the noise contours are shown in **Figure 5-3**[4]).

- For monopiles, the WCS is for the south location, where (using the SCANS III density estimate, 0.213 porpoise/km^2) a total of 725 porpoise are predicted to be potentially disturbed once hammer energy reaches its maximum, which represents 0.21% of the MU.

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[4] Note: all modelled noise impact contours for both monopiles and pin-piles, for both the worst case scenario and the most likely scenario and all three modelling locations can be found in Appendix 11.3: Underwater Noise Assessment Technical Report.

- For the concurrent piling of monopiles at the west and east locations, a total of 743 porpoise are predicted to be potentially disturbed once hammer energy reaches its maximum, which represents 0.21% of the MU.
- For pin-piles, the WCS is for the south location, where 652 porpoise are predicted to be potentially disturbed once hammer energy reaches its maximum (0.19% of the MU).
- For the concurrent piling of pin-piles at the west and east locations simultaneously, a total of 670 porpoise are predicted to be potentially disturbed once hammer energy reaches its maximum, which represents 0.19% of the MU.

5.2.9 Given the results of the expert elicitation on the likely effects of behavioural disturbance on vital rates (Booth et al. 2019), a total of 58 days piling for monopiles (assuming 2 monopiles are installed concurrently) and 116 days piling for pin-piles is unlikely to cause any effect on fertility rates, although there is the potential for calf survival to be affected. However, it is highly unlikely that the same mother-calf pair would repeatedly return to the area in order to receive these levels of repeated disturbance over this many days. Any potential impact on calf survival rates is likely to be temporary and is not expected to result in any changes in the population trajectory or overall size.

5.2.10 The impact is predicted to be of local spatial extent, short term duration, intermittent and is reversible. The extent of the impact in terms of the number of animals affected, the proportion of the MU affected, and the duration of impact is low. The magnitude is therefore considered to be **Low**, where short-term and/or intermittent and temporary behavioural effects are expected in a small proportion of the population, and any impact to vital rates of individuals occur only in the short term (over a limited number of breeding cycles, <1 in this case) and where any changes to individual vital rates are very unlikely to occur to the extent that the population trajectory would be altered.

Table 5-1 Number of harbour porpoise and percentage of the MU predicted to experience potential behavioural disturbance for the WCS and MLS

	NW	W	E	S	E&W	NW	W	E	S	E&W
WCS	**Monopile (4,400 kJ)**					**Pin-pile (2,500 kJ)**				
# porpoise	285	360	626	725	743	243	313	561	652	670
% MU	0.08	0.10	0.18	0.21	0.21	0.07	0.09	0.16	0.19	0.19
MLS	**Monopile (4,000 kJ)**					**Pin-pile (2,000 kJ)**				
# porpoise	280	354	618	716	734	229	296	534	622	641
% MU	0.08	0.10	0.18	0.21	0.21	0.07	0.09	0.15	0.18	0.19

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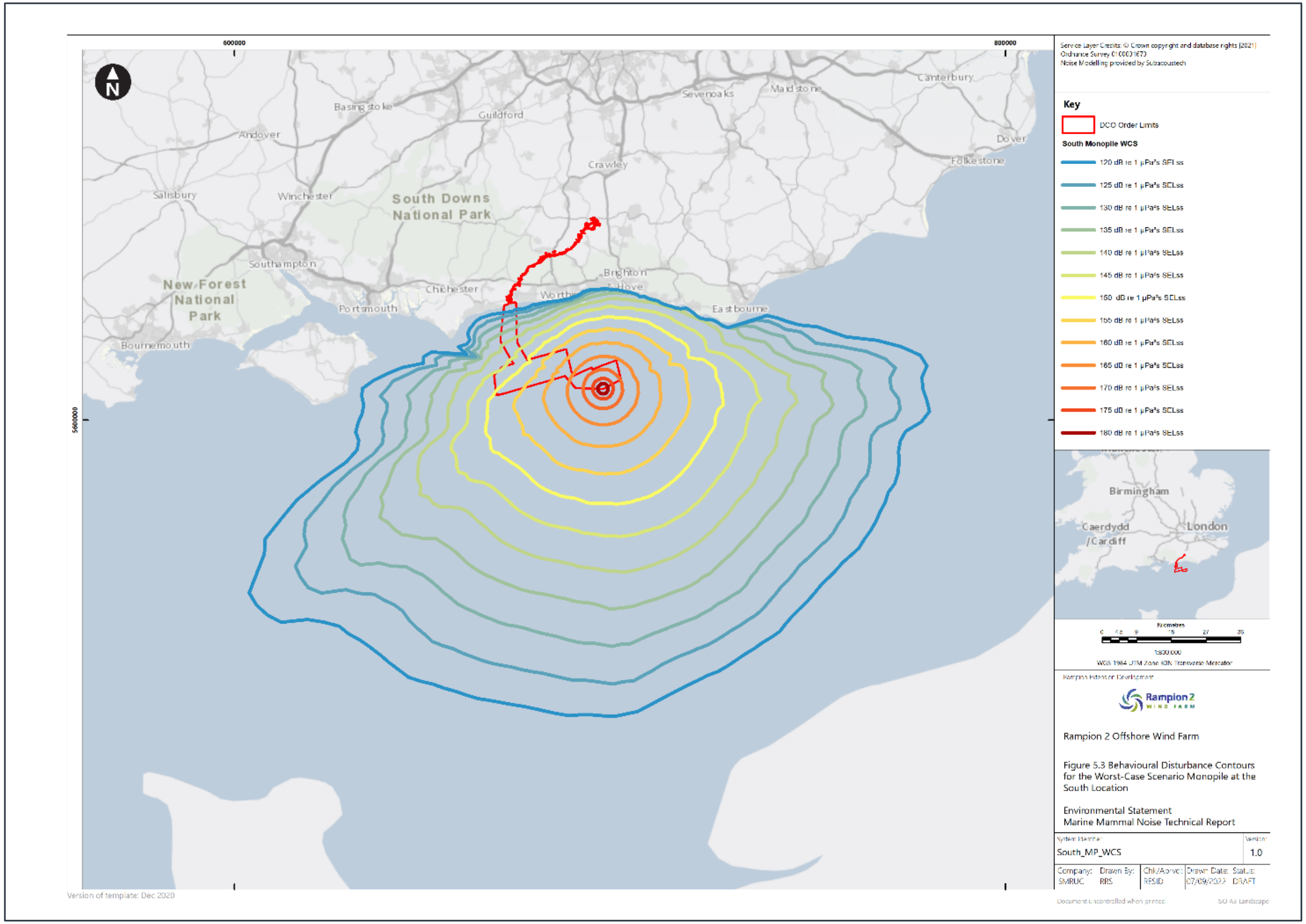
Figure 5-3 Behavioural disturbance noise contours for the Worst Case Scenario for monopiles at the south location



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Significance

5.2.11 Overall, the sensitivity of harbour porpoise to disturbance has been assessed as **Low** and the magnitude is predicted to be **Low**. Therefore, the resulting impact significance for behavioural disturbance in harbour porpoise from both the WCS and MLS for both monopiles and pin-piles is **Minor (not significant)**.

5.3 Bottlenose dolphin

Sensitivity to pile driving disturbance

5.3.1 Bottlenose dolphins have been shown to be displaced from an area as a result of the noise produced by offshore construction activities; for example, avoidance behaviour in bottlenose dolphins has been shown in relation to dredging activities (Pirotta et al., 2013). In a recent study on bottlenose dolphins in the Moray Firth (in relation to the construction of the Nigg Energy Park in the Cromarty Firth), small effects of pile driving on dolphin presence have been observed, however, dolphins were not excluded from the vicinity of the piling activities (Graham et al., 2017b). In this study the median peak-to-peak source levels recorded during impact piling were estimated to be 240 dB re 1μPa (range 8 dB) with a single pulse source level of 198 dB re 1 $\mu Pa^2 s$. The pile driving resulted in a slight reduction of the presence, detection positive hours and the encounter duration for dolphins within the Cromarty Firth, however, this response was only significant for the encounter durations. Encounter durations decreased within the Cromarty Firth (though only by a few minutes) and increased outside of the Cromarty Firth on days of piling activity. These data highlight a small spatial and temporal scale disturbance to bottlenose dolphins as a result of impact piling activities.

5.3.2 According to the opinions of the experts involved in the expert elicitation for Interim Population Consequences of Disturbance framework (iPCoD), which forms our best available knowledge on the topic, disturbance would be most likely to affect bottlenose dolphin calf survival, where: "*Experts felt that disturbance could affect calf survival if it exceeded 30-50 days, because it could result in mothers becoming separated from their calves and this could affect the amount of milk transferred from the mother to her calf*"(Harwood et al., 2014). There is the potential for behavioural disturbance and displacement to result in disruption in foraging and resting activities and an increase in travel and energetic costs. However, it has been previously shown that bottlenose dolphins have the ability to compensate for behavioural responses as a result of increased commercial vessel activity (New et al., 2013). Therefore, while there remains the potential for disturbance and displacement to affect individual behaviour and therefore vital rates and population level changes, bottlenose dolphins do have some capability to adapt their behaviour and tolerate certain levels of temporary disturbance. Therefore, since bottlenose dolphins are expected to be able to adapt their behaviour, with the impact most likely to result in potential changes in calf survival (but not expected to affect adult survival or future reproductive rates) they are categorised as having a **Low** sensitivity score to behavioural disturbance from piling.

Magnitude

5.3.3 **Table 5-2** outlines the number of bottlenose dolphins potentially disturbed by pile driving at each modelling location for both monopiles and pin piles under both the WCS and MLS. The highest level of disturbance from a single location is predicted at the south location which is the deepest location and where noise propagates furthest.

- For monopiles, the WCS is the south location, where (using the SAMMS density estimate, 0.037 dolphins/km^2) a total of 126 bottlenose dolphins are predicted to be potentially disturbed once hammer energy reaches its maximum, which represents 1.15% of the MU.
- For the concurrent piling of monopiles at the west and east locations simultaneously, a total of 129 dolphins are predicted to be potentially disturbed once hammer energy reaches its maximum, which represents 1.18% of the MU.
- For pin-piles, the WCS is the south location, where 113 bottlenose dolphins are predicted to be potentially disturbed once hammer energy reaches its maximum (1.03% of the MU).
- For the concurrent piling of pin-piles at the west and east locations simultaneously, a total of 116 dolphins are predicted to be potentially disturbed once hammer energy reaches its maximum, which represents 1.06% of the MU.

5.3.4 The number of bottlenose dolphins predicted to experience behavioural disturbance as a result of pile-driving is considered to be conservative. This is due to the fact that the density estimate used (0.037 dolphin/km^2) is the summer density estimate for the English Channel, however densities are expected to be much lower in the winter (0.010 dolphins/km^2) and therefore the numbers presented in **Table 5-2** are highly precautionary for the predicted level of impact in winter months.

5.3.5 Another conservatism in these results is the fact that the harbour porpoise dose-response curve has been used as a proxy for bottlenose dolphin response in the absence of similar empirical data. However, this makes the assumption that the same disturbance relationship is observed in bottlenose dolphins. It is anticipated that this approach will be overly precautionary as evidence suggests that bottlenose dolphins are less sensitive to disturbance compared to harbour porpoise. A literature review of recent (post Southall et al. (2007)) behavioural responses by harbour porpoises and bottlenose dolphins to noise was conducted by Moray Offshore Renewables Limited (2012). Several studies have reported a moderate to high level of behavioural response at a wide range of received SPLs (100 and 180 dB re 1µPa) (Lucke et al., 2009, Tougaard et al., 2009, Brandt et al., 2011). Conversely, a study by Niu et al. (2012) reported moderate level responses to non-pulsed noise by bottlenose dolphins at received SPLs of 140 dB re 1µPa. Another high frequency cetacean, Risso’s dolphin, reported no behavioural response at received SPLs of 135 dB re 1µPa (Southall et al., 2010). Whilst both species showed a high degree of variability in responses and a general positive trend with higher responses at higher received levels, moderate level responses were observed above 80 dB re 1µPa in harbour porpoise and above

140 dB re 1µPa in bottlenose dolphins (Moray Offshore Renewables Limited, 2012), indicating that moderate level responses by bottlenose dolphins will be exhibited at a higher received SPL and, therefore, they are likely to show a lesser response to disturbance. Furthermore, the relatively dynamic social structure of bottlenose dolphins (Connor et al., 2001) and the fact that they have no significant predation threats and do not appear to face excessive competition for food with other marine mammal species, have potentially resulted in a higher tolerance to perceived threats or disturbances in their environment, which may make them less sensitive to disturbance.

5.3.6 Previous iPCoD modelling for bottlenose dolphins has shown that disturbance from piling at the Moray West offshore windfarm to ~5% of the population did not result in any significant effect on the long term population size (Moray Offshore Windfarm (West) Limited, 2018). A cumulative impact assessment of Scottish east coast offshore windfarm construction on the east coast bottlenose dolphin population showed that increasing the number of days of consecutive piling and increasing the proportion of the population disturbed per day resulted in an increased risk of population decline (**Figure 5-4**) (Smith et al., 2019). However, the proportion of the population predicted to be impacted by Rampion 2 (up to 1.18% of the MU per day) and the number of days of piling expected to occur (116 piling days assuming 4 pin-piles are installed in one 24 hour period) is highly unlikely to result in any decline in the bottlenose dolphin population.

5.3.7 The impact is predicted to be of local spatial extent, short term duration, intermittent and is reversible. Given the number of dolphins predicted to be impacted and the proportion of the population this represents, the magnitude is considered to be **Low,** whereby survival and reproductive rates very unlikely to be impacted to the extent that the population trajectory would be altered.

Figure 5-4 Contour plot showing the effect of increasing the number of days of disturbance and increasing the number of individuals disturbed per day for a population of 195 bottlenose dolphins (residual days of disturbance set to 1) (Smith et al., 2019)

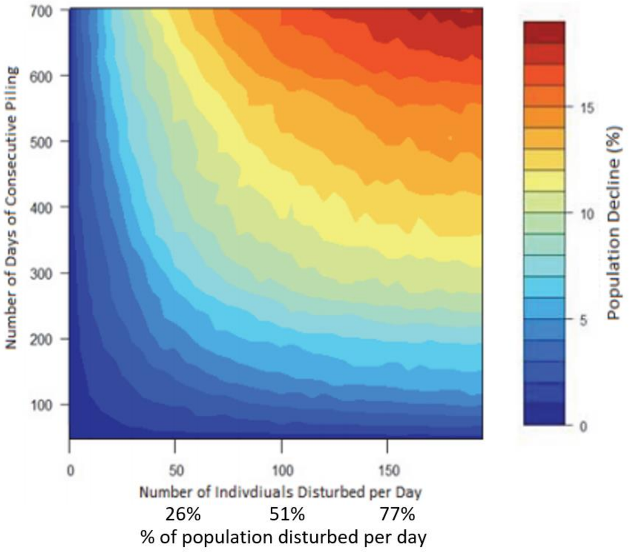


Table 5-2 Number of bottlenose dolphins and percentage of the MU predicted to experience potential behavioural disturbance for the WCS and MLS

	NW	W	E	S	E&W	NW	W	E	S	E&W
WCS			**Monopile (4,400 kJ)**					**Pin-pile (2,500 kJ)**		
# dolphins	50	62	109	126	129	42	54	97	113	116
% MU	0.46	0.57	1.00	1.15	1.18	0.38	0.49	0.89	1.03	1.06
MLS			**Monopile (4,000 kJ)**					**Pin-pile (2,000 kJ)**		
# dolphins	49	61	107	124	128	40	51	93	108	111
% MU	0.45	0.56	0.98	1.13	1.17	0.37	0.47	0.85	0.99	1.01

Significance

5.3.8 Disturbance as a result of pile driving may be small in spatial and temporal scale, however direct evidence for this species is generally lacking. There is evidence that pile driving can result in temporary displacement of bottlenose dolphins, but that this displacement may be limited to small temporal and spatial scales. While there remains the potential for disturbance and displacement to affect individual behaviour and in particular calf survival rates, bottlenose dolphins do have some capability to adapt their behaviour and tolerate certain levels of temporary disturbance. Therefore, the sensitivity of bottlenose dolphins to disturbance from pile driving is considered to be **Low**, where short-term and/or intermittent and temporary behavioural effects are expected in a small proportion of the population, and any impact to vital rates of individuals occur only in the short term (over a limited number of breeding cycles, <1 in this case) and where any changes to individual vital rates are very unlikely to occur to the extent that the population trajectory would be altered.

5.3.9 Overall, the sensitivity of bottlenose dolphins to disturbance has been assessed as **Low** and the magnitude is predicted to be **Low**. Therefore, the resulting impact significance for behavioural disturbance in bottlenose dolphins from both the WCS and MLS for both monopiles and pin-piles is **Minor (not significant)**.

5.4 Common dolphin

Sensitivity to pile driving disturbance

5.4.1 Relatively few studies document the impacts of marine construction or investigation on common dolphins, but there is some evidence of the impacts of vessel traffic and boat noise on common dolphins. While the direct impacts of vessel noise on common dolphins are rather under-researched, the presence of vessel activity has been found to alter their behavioural states and has been linked to disturbance. In New Zealand, Markov chain models were used to assess the impacts of tourism on the behaviour of common dolphins. Foraging and resting bouts were significantly disrupted by boat interactions, with less time spent in these states. In addition, post-disturbance activity indicated a shift from foraging states to milling and socialising and returns to foraging took significantly longer (Stockin et al., 2008, Meissner et al., 2015). While the aforementioned studies relate to short term impacts, a long-term study of common dolphins in the waters around Ischia Island found declines that could have resulted from a combination of habitat degradation and disturbance from increasing traffic. The surrounding area has been listed as one of the noisiest in the Mediterranean due to a range of marine traffic, commercial and seismic surveys, and drilling activity (Mussi et al., 2019). Conversely, some research suggests that common dolphins may be altering their communication to compensate for high levels of anthropogenic noise. It has been suggested that a difference in the frequency of whistles between two populations of common dolphins, one in the Celtic Sea, and one in the English Channel, may reflect a shift in acoustic characteristics to counter masking caused by high levels of vessel traffic in the latter location (Ansmann et al., 2007). Additionally, for both Atlantic spotted dolphins and short-beaked common dolphins, the presence of high noise levels has been associated with an increase in the maximum whistle frequency, indicating vocal compensation for potential masking in a noisy environment (Papale et al., 2015).

5.4.2 Disturbance as a result of pile driving may be small in spatial and temporal scale, however direct evidence for this species is lacking. It is therefore expected that their sensitivity will be similar to bottlenose dolphins, as both species are grouped together as high-frequency cetaceans with similar hearing abilities. While there is the potential for disturbance to affect individual behaviour and therefore vital rates and population level changes, it is expected that like bottlenose dolphins, common dolphins will have some capability to adapt their behaviour and tolerate certain levels of temporary disturbance. Therefore, the sensitivity of common dolphins is considered to be **Low**, where short-term and/or intermittent and temporary behavioural effects are expected in a small proportion of the population, and any impact to vital rates of individuals occur only in the short term (over a limited number of breeding cycles, <1 in this case) and where any changes to individual vital rates are very unlikely to occur to the extent that the population trajectory would be altered. The sparse information available for the impacts of construction, seismic activity and vessel noise on common dolphins make it difficult to assess the risk for this species. While there is some evidence of disturbance of animals by seismic activity, and reduced presence in increasingly noisy habitat, this species may adjust its whistle characteristics to account for masking, suggesting some flexibility or tolerance. However, given the high SPL and cumulative energy levels produced by pile driving, and our lack of understanding of the sensitivity of this species, it is considered to be more precautionary to assign a **Low** sensitivity score.

Magnitude

5.4.3 **Table 5-3** outlines the number of common dolphins potentially disturbed by pile driving at each modelling location for both monopiles and pin-piles under both the WCS and MLS. The highest level of disturbance in spatial terms is predicted to be from the installation of a monopile at the south location which is the deepest location and where noise propagates furthest.

- For monopiles, the WCS is the south location, where (using the SAMMS density estimate, 0.171 dolphins/km^2) a total of 582 common dolphins are predicted to be potentially disturbed once hammer energy reaches its maximum, which represents 0.57% of the MU.
- For the concurrent piling of monopiles at the west and east locations simultaneously, a total of 597 dolphins are predicted to be potentially disturbed once hammer energy reaches its maximum, which represents 0.58% of the MU.
- For pin-piles, the WCS is the south location, where 524 common dolphins are predicted to be potentially disturbed once hammer energy reaches its maximum (0.51% of the MU).
- For the concurrent piling of pin-piles at the west and east locations simultaneously, a total of 538 dolphins are predicted to be potentially disturbed once hammer energy reaches its maximum, which represents 0.52% of the MU.

5.4.4 Similar to the situation with bottlenose dolphins, the number of common dolphins predicted to experience behavioural disturbance as a result of pile-driving is considered to be conservative. This is due to the fact that the density estimate used (0.171 dolphin/km^2) is the winter density estimate for the English Channel, however the same study predicted densities to be much lower in the summer (0.011 dolphins/km^2) (Laran et al., 2017) and therefore the numbers presented in **Table 5-3** are highly precautionary for the predicted level of impact in summer months. In addition to this, the density estimate used is for “small-sized delphinids” (common and striped dolphins combined) so is likely to be an over-estimate for common dolphins alone.

5.4.5 Likewise, another conservatism in these results is the fact that the harbour porpoise dose-response curve has been used as a proxy for common dolphin response in the absence of similar empirical data. However, this makes the assumption that the same disturbance relationship is observed in common dolphins. It is anticipated that this approach will be overly precautionary as evidence suggests that dolphin species are less sensitive to disturbance compared to harbour porpoise.

5.4.6 The impact is predicted to be of local spatial extent, short term duration, intermittent and is reversible. Given the number of dolphins predicted to be impacted and the proportion of the population this represents, the magnitude is considered to be **Low**, whereby survival and reproductive rates are very unlikely to be impacted to the extent that the population trajectory would be altered.

Table 5-3 Number of common dolphins and percentage of the MU predicted to experience potential behavioural disturbance for the WCS and MLS

	NW	W	E	S	E&W	NW	W	E	S	E&W
WCS			**Monopile (4,400 kJ)**					**Pin-pile (2,500 kJ)**		
# dolphins	229	289	503	582	597	195	251	450	524	538
% MU	0.22	0.28	0.49	0.57	0.58	0.19	0.24	0.44	0.51	0.52
MLS			**Monopile (4,000 kJ)**					**Pin-pile (2,000 kJ)**		
# dolphins	225	284	496	574	589	184	238	429	499	515
% MU	0.22	0.28	0.48	0.56	0.57	0.18	0.23	0.42	0.49	0.50

Significance

5.4.7 Overall, the sensitivity of common dolphins to disturbance has been assessed as **Low** and the magnitude is predicted to be **Low**. Therefore, the resulting impact significance for behavioural disturbance in common dolphins from both the WCS and MLS for both monopiles and pin-piles is **Minor (not significant)**.

5.5 Minke whale

Sensitivity to pile driving disturbance

5.5.1 There is little information available on the behavioural responses of minke whales to underwater noise. Minke whales have been shown to change their diving patterns and behavioural state in response to disturbance from whale watching vessels; and it was suggested that a reduction in foraging activity at feeding grounds could result in reduced reproductive success in this capital breeding species (Christiansen et al., 2013). There is only one study showing minke whale reactions to sonar signals (Sivle et al., 2015) with severity scores above 4 for a received SPL of 146 dB re 1 µPa (score 7) and a received SPL of 158 dB re 1 µPa (score 8). There is a study detailing minke whale responses to the Lofitech device which has a source level of 204 dB re re 1 µPa @1m, which showed minke whales within 500 m and 1,000 m of the source exhibiting a behavioural response. Estimated received level at 1,000 m was 136.1 dB re 1 µPa (McGarry et al., 2017).

5.5.2 Since minke whales are known to forage in UK waters in the summer months, there is the potential for displacement to impact reproductive rates. Therefore, minke whales have been assessed as having a medium sensitivity to disturbance and resulting displacement from foraging grounds. Due to their large size and capacity for energy storage, it is expected that minke whales will be able to tolerate temporary displacement from foraging areas much better than harbour porpoise. Disturbance as a result of pile driving may be small in spatial and temporal scale, however direct evidence for this species is lacking. While there is the potential for disturbance to affect individual behaviour and therefore vital rates and population level changes, it is expected that minke whales will be able to tolerate temporary displacement from foraging areas due to their large size and capacity for energy storage. Therefore, the sensitivity of minke whales is considered to be **Low**, where short-term and/or intermittent and temporary behavioural effects are expected in a small proportion of the population, and any impact to vital rates of individuals occur only in the short term (over a limited number of breeding cycles, <1 in this case) and where any changes to individual vital rates are very unlikely to occur to the extent that the population trajectory would be altered.

Magnitude

5.5.3 **Table 5-4** outlines the number of minke whales potentially disturbed by pile driving at each modelling location for both monopiles and pin-piles under both the WCS and MLS. The highest level of disturbance in spatial terms is predicted to be from the installation of a monopile at the south location which is the deepest location and where noise propagates furthest.

- For monopiles, the WCS is the south location, where (using the SCANS III density estimate, 0.002 whales/km^2) a total of 8 minke whales are predicted to be potentially disturbed once hammer energy reaches its maximum, which represents 0.04% of the MU.
- For the concurrent piling of monopiles at the west and east locations simultaneously, a total of 8 whales are predicted to be potentially disturbed once hammer energy reaches its maximum, which represents 0.04% of the MU.
- For pin-piles, the WCS is the south location, where 7 minke whales are predicted to be potentially disturbed once hammer energy reaches its maximum (0.03% of the MU).
- For the concurrent piling of pin-piles at the west and east locations simultaneously, a total of 7 whales are predicted to be potentially disturbed once hammer energy reaches its maximum, which represents 0.03% of the MU.

5.5.4 The impact is predicted to be of local spatial extent, short term duration, intermittent and is reversible. Given the low density of minke whales predicted to be in the area, the resulting number of animals and proportion of the population potentially disturbed by pile driving results in a magnitude score of **Low,** whereby survival and reproductive rates are very unlikely to be impacted to the extent that the population trajectory would be altered.

Table 5-4 Number of minke whales and percentage of the MU predicted to experience potential behavioural disturbance for the WCS and MLS

	NW	W	E	S	E&W	NW	W	E	S	E&W
WCS	**Monopile (4,400 kJ)**					**Pin-pile (2,500 kJ)**				
# whales	3	4	7	8	8	3	3	6	7	7
% MU	0.01	0.02	0.03	0.04	0.04	0.01	0.01	0.03	0.03	0.03
MLS	**Monopile (4,000 kJ)**					**Pin-pile (2,000 kJ)**				
# whales	3	4	7	8	8	2	3	6	7	7
% MU	0.01	0.02	0.03	0.04	0.04	0.01	0.01	0.03	0.03	0.03

Significance

5.5.5 Overall, the sensitivity of minke whales to disturbance has been assessed as **Low** and the magnitude is predicted to be **Low**. Therefore, the resulting impact significance for behavioural disturbance in minke whales from both the WCS and MLS for both monopiles and pin-piles is **Minor (not significant)**.

5.6 Harbour seal

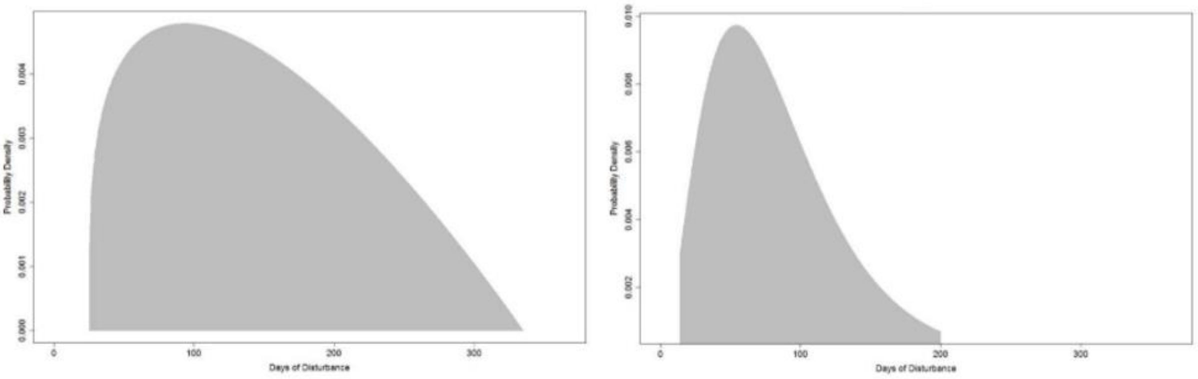
Sensitivity to pile driving disturbance

5.6.1 A study of tagged harbour seals in the Wash has shown that they are displaced from the vicinity of piles during pile-driving activities. Russell et al. (2016) showed that seal abundance was significantly reduced within an area with a radius of 25 km from a pile, during piling activities, with a 19 to 83% decline in abundance during pile-driving compared to during breaks in piling. The duration of the displacement was only in the short-term as seals returned to non-piling distributions within two hours after the end of a pile-driving event. Unlike harbour porpoise, both harbour and grey seals store energy in a thick layer of blubber, which means that they are more tolerant of periods of fasting when hauled out and resting between foraging trips, and when hauled out during the breeding and moulting periods. Therefore, they are unlikely to be particularly sensitive to short-term displacement from foraging grounds during periods of active piling.

5.6.2 At the expert elicitation workshop in Amsterdam in 2018, (Booth et al., 2019), experts agreed the most likely potential consequences of a six hour period of zero energy intake, assuming that disturbance (from exposure to low frequency broadband pulsed noise (e.g. pile-driving, airgun pulses)) resulted in missed foraging opportunities. In general, it was agreed that harbour seals were considered to have a reasonable ability to compensate for lost foraging opportunities due to their generalist diet, mobility, life history and adequate fat stores. The survival of ‘weaned of the year’ animals and fertility were determined to be the most sensitive life history parameters to disturbance (i.e. leading to reduced energy intake). Juvenile harbour seals are typically considered to be coastal foragers (Booth et al., 2019) and so less likely to be exposed to disturbances and similarly pups were thought to be unlikely to be exposed to disturbance due to their proximity to land. Unlike for harbour porpoise, there was no DEB model available to simulate the effects of disturbance on seal energy intake and reserves, therefore the opinions of the experts were less certain. Experts considered that the location of the disturbance would influence the effect of the disturbance, with a greater effect if animals were disturbed at a foraging ground as opposed to when animals were transiting through an area. It was thought that for an animal in bad condition, moderate levels of repeated disturbance might be sufficient to reduce fertility (**Figure 5-5 left**), however there was a large amount of uncertainty in this estimate, with opinions ranging between <50 days and >300 days. The ‘weaned of the year’ were considered to be most vulnerable following the post-weaning fast, and that during this time, experts felt it might take ~60 days of repeated disturbance before there was expected to be any effect on the probability of survival (**Figure 5-5 right**), however again, there was a lot of uncertainty surrounding this estimate with estimates ranging between <50 days and >200 days. Similar to above, it is considered unlikely that individual harbour seals would repeatedly return to a site where they’d been previously displaced from to experience this number of days of repeated disturbance.

5.6.3 Disturbance as result of pile driving may temporarily affect harbour seal fertility and survival of “weaned of the year”. Due to observed responsiveness to piling, their generalist diet, their life history and their ability to store fat, the sensitivity of harbour seals is therefore considered to be **Low**, where short-term and/or intermittent and temporary behavioural effects are expected in a small proportion of the population, and any impact to vital rates of individuals occur only in the short term (over a limited number of breeding cycles, <1 in this case) and where any changes to individual vital rates are very unlikely to occur to the extent that the population trajectory would be altered.

Figure 5-5 Probability distributions showing the consensus of the expert elicitation for harbour seal disturbance from piling (Booth et al., 2019)



Left: the number of days of disturbance (i.e. days on which an animal does not feed for six hours) a pregnant female could ‘tolerate’ before it has any effect on fertility. Right: the number of days of disturbance (of six hours zero energy intake) a ‘weaned of the year’ harbour seal could ‘tolerate’ before it has any effect on survival.

Magnitude

5.6.4 **Table 5-5** outlines the number of harbour seals potentially disturbed by pile driving at each modelling location for both monopiles and pin-piles under the WCS.

- For both monopiles and pin-piles, all locations (including concurrent piling at East and West) result in disturbance predicted to impact <1 harbour seal once hammer energy reaches its maximum (<0.002% of the population).

5.6.5 Given the low numbers predicted for the WCS, the MLS numbers were not calculated since they would be lower than those predicted for the WCS (as the maximum hammer energy is lower).

5.6.6 The impact is predicted to be of local spatial extent, short term duration, intermittent and is reversible. The extent of the impact in terms of the number of animals affected, the proportion of the MU affected, and the duration of impact is very low. The magnitude is therefore considered to be **Very Low**, whereby there is considered to be no potential for any changes in individual reproductive success or survival therefore no changes to the population size or trajectory.

Table 5-5 Number of harbour seals predicted to experience potential behavioural disturbance for the WCS

	NW	W	E	S	E&W	NW	W	E	S	E&W
WCS	**Monopile (4,400 kJ)**					**Pin-pile (2,500 kJ)**				
# seals	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1

Significance

5.6.7 Overall, the sensitivity of harbour seals to disturbance has been assessed as **Low** and the magnitude is predicted to be **Very Low**. Therefore, the resulting impact significance for behavioural disturbance in harbour seals from both the WCS and MLS for both monopiles and pin-piles is **Negligible (not significant)**.

5.7 Grey seal

Sensitivity to pile driving disturbance

5.7.1 There are limited data on grey seal behavioural responses to pile driving. The key dataset on this topic is presented in Aarts et al. (2018) where 20 grey seals were tagged in the Wadden Sea to record their responses to pile driving at two offshore wind farms: Luchterduinen in 2014 and Gemini in 2015. The grey seals showed varying responses to the pile driving, including no response, altered surfacing and diving behaviour, and changes in swimming direction. The most common reaction was a decline in descent speed and a reduction in bottom time, which suggests a change in behaviour from foraging to horizontal movement. The distances at which seals responded varied significantly; in one instance a grey seal showed responses at 45 km from the pile location, while other grey seals showed no response when within 12 km. Differences in responses could be attributed to differences in hearing sensitivity between individuals, differences in sound transmission with environmental conditions or the behaviour and motivation for the seal to be in the area. The telemetry data also showed that seals returned to the pile driving area after pile driving ceased.

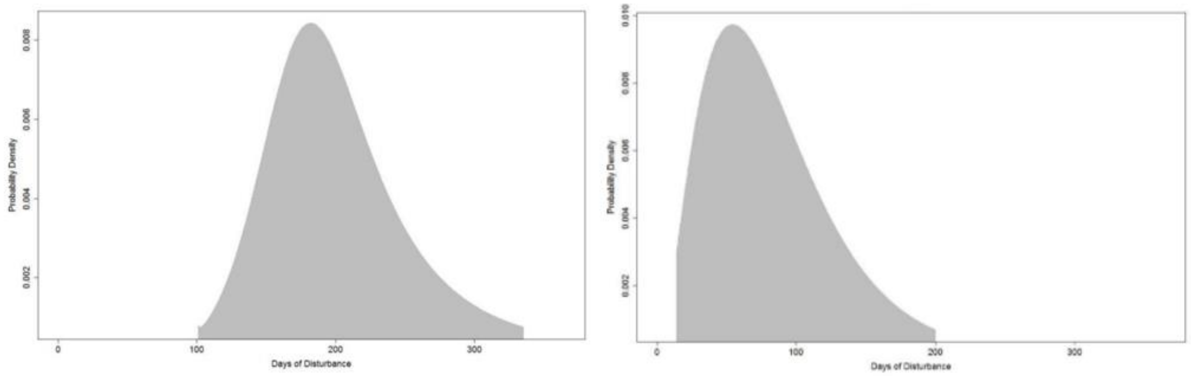
5.7.2 As with harbour seals, the expert elicitation workshop in Amsterdam in 2018, (Booth et al., 2019) concluded that grey seals were considered to have a reasonable ability to compensate for lost foraging opportunities due to their generalist diet, mobility, life history and adequate fat stores and that the survival of ‘weaned of the year’ animals and fertility were determined to be the most sensitive parameters to disturbance (i.e. reduced energy intake). However, in general, experts agreed that grey seals would be much more robust than harbour seals to the effects of disturbance due to their larger energy stores and more generalist and adaptable foraging strategies. It was agreed that grey seals would require moderate-high levels of repeated disturbance before there was any effect on fertility rates to reduce fertility (**Figure 5-6 left**). As with harbour seals, the ‘weaned of the year’ were considered to be most vulnerable following the post-weaning fast, and that during this time it might take ~60 days of repeated disturbance before there was expected to be any effect on weaned-of-the-year survival (**Figure 5-6 right**), however there was a lot of uncertainty surrounding this estimate.

5.7.3 Grey seals are capital breeders and store energy in a thick layer of blubber, which means that, in combination with their large body size, they are tolerant of periods of fasting as part of their normal life history. Grey seals are also highly adaptable to a changing environment and are capable of adjusting their metabolic rate and foraging tactics, to compensate for different periods of energy demand and supply (Beck et al., 2003, Sparling et al., 2006). Grey seals are also very wide ranging and are capable of moving large distances between different haul out and foraging regions (Russell et al., 2013). Therefore, they are unlikely to be particularly sensitive to displacement from foraging grounds during periods of active piling.

5.7.4 Hastie et al. (2021) found that grey seal avoidance rates in response to pile driving sounds were dependent on the quality of the prey patch, with grey seals continuing to forage at high density prey patches when exposed to pile driving sounds, but showing reduced foraging success at low density prey patches when exposed to pile driving sounds. Additionally, the seals showed an initial aversive response to the pile driving playbacks (lower proportion of dives spent foraging) but this diminished during each trial. Therefore, the likelihood of grey seal response is expected to be linked to the quality of the prey patch.

5.7.5 Disturbance as result of pile driving may temporarily affect grey seal fertility and survival of “weaned of the year”. Due to observed responsiveness to piling, their capital breeder life history and their tolerance of periods of fasting, the sensitivity of grey seals is therefore considered to be **Very Low**.

Figure 5-6 Probability distributions showing the consensus of the expert elicitation for grey seal disturbance from piling (Booth et al., 2019)



Left: the number of days of disturbance (i.e. days on which an animal does not feed for six hours) a pregnant female could ‘tolerate’ before it has any effect on fertility. Right: the number of days of disturbance (of six hours zero energy intake) a ‘weaned of the year’ grey seal could ‘tolerate’ before it has any effect on survival.

Magnitude

5.7.6 The impact is predicted to be of local spatial extent, short term duration, intermittent and is reversible. The extent of the impact in terms of the number of animals affected, the proportion of the MU affected, and the duration of impact is very low. The magnitude is therefore considered to be **Very Low**, whereby there is considered to be no potential for any changes in individual reproductive success or survival therefore no changes to the population size or trajectory.

5.7.7 **Table 5-6** outlines the number of grey seals potentially disturbed by pile driving at each modelling location for both monopiles and pin-piles under the WCS.

- For monopiles, the WCS is the concurrent east and west locations, where (using the habitat preference maps) a total of 2 grey seals are predicted to be potentially disturbed once hammer energy reaches its maximum (0.004% of the population).

5.7.8 Given the low numbers predicted for the WCS, the MLS numbers were not calculated since they would be lower than those predicted for the WCS (as the maximum hammer energy is lower).

5.7.9 The impact is predicted to be of local spatial extent, short term duration, intermittent and is reversible. The extent of the impact in terms of the number of animals affected, the proportion of the MU affected, and the duration of impact is very low. The magnitude is therefore considered to be **Very Low**, whereby there is considered to be no potential for any changes in individual reproductive success or survival therefore no changes to the population size or trajectory.

Table 5-6 Number of grey seals (mean & 95% CI) predicted to experience potential behavioural disturbance for the WCS

	NW	W	E	S	E&W	NW	W	E	S	E&W
WCS			**Monopile (4,400 kJ)**					**Pin pile (2,500 kJ)**		
# seals	<1 (0-1)	<1 (0-1)	1 (0-2)	1 (0-2)	2 (0-3)	<1 (0<1)	<1 (0-1)	1 (0-2)	<1 (0-2)	1 (0-2)
% MU	<0.001	<0.001	0.003	0.003	0.004	<0.001	<0.001	0.003	<0.001	0.003

Significance

5.7.10 Overall, the sensitivity of grey seals to disturbance has been assessed as **Very Low** and the magnitude is predicted to be **Very Low**. Therefore, the resulting impact significance for behavioural disturbance in grey seals from both the WCS and MLS for both monopiles and pin-piles is **Negligible (not significant)**.

5.8 Disturbance summary

5.8.1 The impact of behavioural disturbance from piling noise under both the WCS and the MLS is not considered to have a significant effect on any marine mammal species considered in this assessment (**Table 5-7**).

Table 5-7 Impact significance for all marine mammals to the impact of behavioural disturbance from piling

	Monopiles & Pin-piles (WCS & MLS)		
	Magnitude	**Sensitivity**	**Impact**
Harbour porpoise	Low	Low	Minor (not significant)
Bottlenose dolphin	Low	Low	Minor (not significant)
Common dolphin	Low	Low	Minor (not significant)
Minke whale	Low	Low	Minor (not significant)
Harbour seal	Very Low	Low	Negligible (not significant)
Grey seal	Very Low	Very Low	Negligible (not significant)

6. Conclusion

6.1.1 This quantitative underwater noise impact assessment has found that no significant impacts are predicted from construction related pile driving at Rampion 2 on marine mammals. The embedded environmental measure of an MMMP (C-52 in the **Commitments Register** (Document Reference: 7.22)) to reduce the risk of PTS-onset to negligible levels is considered to be sufficient, and no other mitigation measures are required to reduce impacts to marine mammals.

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7. Glossary of terms and abbreviations

Table 7-1 Glossary of terms and abbreviations

Term (acronym)	Definition
BEIS	Department for Business, Energy and Industrial Strategy
dB	Decibel
DEPONS	Disturbance Effects on the Harbour Porpoise Population in the North Sea
Development Consent Order (DCO)	An order made under the Planning Act 2008 granting development consent for one or more Nationally Significant Infrastructure Projects (NSIP).
E	East
HF	High frequency
kHz	Kilo Hertz
km	Kilometres
LF	Low frequency
MDS	Maximum design scenario
MLS	Most likely scenario
MMMP	Marine Mammal Mitigation Protocol
ms	Millisecond
MU	Management Units
MW	Megawatt
NOAA	National Oceanic Atmospheric Administration
NW	Northwest
PTS	Permanent threshold shift
RED	Rampion Extension Development Limited (the Applicant)
S	South
SAFESIMM	Statistical Algorithms For Estimating the Sonar Influence on Marine Megafauna

Term (acronym)	Definition
SEL	Sound Exposure Level
SPL	Sound Pressure Level
TTS	Temporary threshold shift
VHF	Very high frequency
W	West
WCS	Worst-case scenario

8. References

AARTS, G., BRASSEUR, S. & KIRKWOOD, R. 2018. Behavioural response of grey seals to pile-driving. Wageningen Marine Research report C006/18.

ANSMANN, I. C., GOOLD, J. C., EVANS, P. G., SIMMONDS, M. & KEITH, S. G. 2007. Variation in the whistle characteristics of short-beaked common dolphins, Delphinus delphis, at two locations around the British Isles. *Journal of the Marine Biological Association of the United Kingdom,* 87**,** 19-26.

BECK, C. A., BOWEN, W. D. & IVERSON, S. J. 2003. Sex differences in the seasonal patterns of energy storage and expenditure in a phocid seal. *Journal of Animal Ecology,* 72**,** 280-291.

BENHEMMA-LE GALL, A., THOMPSON, P., GRAHAM, I. & MERCHANT, N. Lessons learned: harbour porpoises respond to vessel activities during offshore windfarm construction. Environmental Interactions of Marine Renewables 2020, 2020 Online.

BLIX, A. & FOLKOW, L. 1995. Daily energy expenditure in free living minke whales. *Acta Physiologica Scandinavica,* 153**,** 61-66.

BOOTH, C. & HEINIS, F. 2018. Updating the Interim PCoD Model: Workshop Report - New transfer functions for the effects of permanent threshold shifts on vital rates in marine mammal species. Report Code SMRUC-UOA-2018-006, submitted to the University of Aberdeen and Department for Business, Energy and Industrial Strategy (BEIS), June 2018 (unpublished).

BOOTH, C. G., HEINIS, F. & J., H. 2019. Updating the Interim PCoD Model: Workshop Report - New transfer functions for the effects of disturbance on vital rates in marine mammal species. Report Code SMRUC-BEI-2018-011, submitted to the Department for Business, Energy and Industrial Strategy (BEIS), February 2019 (unpublished.

BRANDT, M. J., DIEDERICHS, A., BETKE, K. & NEHLS, G. 2011. Responses of harbour porpoises to pile driving at the Horns Rev II offshore wind farm in the Danish North Sea. *Marine Ecology Progress Series,* 421**,** 205-216.

BRANDT, M. J., DRAGON, A.-C., DIEDERICHS, A., BELLMANN, M. A., WAHL, V., PIPER, W., NABE-NIELSEN, J. & NEHLS, G. 2018. Disturbance of harbour porpoises during construction of the first seven offshore wind farms in Germany. *Marine Ecology Progress Series,* 596**,** 213-232.

BRANDT, M. J., DRAGON, A., DIEDERICHS, A., SCHUBERT, A., KOSAREV, V., NEHLS, G., WAHL, V., MICHALIK, A., BRAASCH, A., HINZ, C., KATZER, C., TODESKINO, D., GAUGER, M., LACZNY, M. & PIPER, W. 2016. Effects of offshore pile driving on harbour porpoise abundance in the German Bight. Report prepared for Offshore Forum Windenergie. *Prepared for Offshore Forum Windenergie.*

CARTER, M., BOEHME, L., DUCK, C., GRECIAN, W., HASTIE, G., MCCONNELL, B., MILLER, D., MORRIS, C., MOSS, S., THOMPSON, D., THOMPSON, P. & RUSSELL, D. 2020. Habitat-based predictions of at-sea distribution for grey and harbour seals in the British Isles. Report to BEIS, OESEA-16-76/OESEA-17-78: Sea Mammal Research Unit, University of St Andrews.

CHRISTIANSEN, F., VIKINGSSON, G. A., RASMUSSEN, M. H. & LUSSEAU, D. 2013. Minke whales maximise energy storage on their feeding grounds. *Journal of Experimental Biology,* 216**,** 427-436.

CONNOR, R. C., HEITHAUS, M. R. & BARRE, L. M. 2001. Complex social structure, alliance stability and mating access in a bottlenose dolphin 'super-alliance'. *Proc Biol Sci,* 268**,** 263-7.

CRANFORD, T. W. & KRYSL, P. 2015. Fin whale sound reception mechanisms: skull vibration enables low-frequency hearing. *PloS one,* 10**,** e0116222.

CULLOCH, R. M., ANDERWALD, P., BRANDECKER, A., HABERLIN, D., MCGOVERN, B., PINFIELD, R., VISSER, F., JESSOPP, M. & CRONIN, M. 2016. Effect of construction-related activities and vessel traffic on marine mammals. *Marine Ecology Progress Series,* 549**,** 231-242.

DÄHNE, M., GILLES, A., LUCKE, K., PESCHKO, V., ADLER, S., KRUGEL, K., SUNDERMEYER, J. & SIEBERT, U. 2013. Effects of pile-driving on harbour porpoises (*Phocoena phocoena*) at the first offshore wind farm in Germany. *Environmental Research Letters,* 8**,** 025002.

DÄHNE, M., TOUGAARD, J., CARSTENSEN, J., ROSE, A. & NABE-NIELSEN, J. 2017. Bubble curtains attenuate noise from offshore wind farm construction and reduce temporary habitat loss for harbour porpoises. *Marine Ecology Progress Series,* 580**,** 221-237.

DE JONG, C. A. F. & AINSLIE, M. A. 2008. Underwater radiated noise due to the piling for the Q7 Offshore Wind Park. *Journal of the Acoustical Society of America,* 123**,** 2987.

DEECKE, V. B., SLATER, P. J. & FORD, J. K. 2002. Selective habituation shapes acoustic predator recognition in harbour seals. *Nature,* 420**,** 171-173.

DEHNHARDT, G., MAUCK, B., HANKE, W. & BLECKMANN, H. 2001. Hydrodynamic trail-following in harbor seals (Phoca vitulina). *Science,* 293**,** 102-104.

DONOVAN, C. R., HARRIS, C. M., MILAZZO, L., HARWOOD, J., MARSHALL, L. & WILLIAMS, R. 2017. A simulation approach to assessing environmental risk of sound exposure to marine mammals. *Ecology and Evolution*.

EDDS-WALTON, P. L. 2000. Vocalizations Of Minke Whales *Balaenoptera Acutorostrata* In The St. Lawrence Estuary. *Bioacoustics,* 11**,** 31-50.

FINNERAN, J. J. 2015. Noise-induced hearing loss in marine mammals: A review of temporary threshold shift studies from 1996 to 2015. *The Journal of the Acoustical Society of America,* 138**,** 1702-1726.

FINNERAN, J. J. 2016. Auditory weighting functions and TTS/PTS exposure functions for marine mammals exposed to underwater noise. San Diego, CA 92152-5001: SSC Pacific.

FINNERAN, J. J., CARDER, D. A., SCHLUNDT, C. E. & DEAR, R. L. 2010a. Growth and recovery of temporary threshold shift at 3 kHz in bottlenose dolphins: Experimental data and mathematical models. *The Journal of the Acoustical Society of America,* 127**,** 3256-3266.

FINNERAN, J. J., CARDER, D. A., SCHLUNDT, C. E. & DEAR, R. L. 2010b. Temporary threshold shift in a bottlenose dolphin (*Tursiops truncatus*) exposed to intermittent tones. *Journal of the Acoustical Society of America,* 127**,** 3267-3272.

FINNERAN, J. J., CARDER, D. A., SCHLUNDT, C. E. & RIDGWAY, S. H. 2005. Temporary threshold shift in bottlenose dolphins (Tursiops truncatus) exposed to mid-frequency tones. *The Journal of the Acoustical Society of America,* 118**,** 2696-2705.

GEDAMKE, J., COSTA, D. P. & DUNSTAN, A. 2001. Localization and visual verification of a complex minke whale vocalization. *The Journal of the Acoustical Society of America,* 109**,** 3038-3047.

GOLEY, G. S., SONG, W. J. & KIM, J. H. 2011. Kurtosis corrected sound pressure level as a noise metric for risk assessment of occupational noises. *The Journal of the Acoustical Society of America,* 129**,** 1475-1481.

GOOLD, J. C. 1996. Acoustic assessment of populations of common dolphin Delphinus delphis in conjunction with seismic surveying. *JOURNAL-MARINE BIOLOGICAL ASSOCIATION OF THE UNITED KINGDOM,* 76**,** 811-820.

GRAHAM, I. M., FARCAS, A., MERCHANT, N. D. & THOMPSON, P. 2017a. Beatrice Offshore Wind Farm: An interim estimate of the probability of porpoise displacement at different unweighted single-pulse sound exposure levels. Prepared by the University of Aberdeen for Beatrice Offshore Windfarm Ltd.

GRAHAM, I. M., MERCHANT, N. D., FARCAS, A., BARTON, T. R. C., CHENEY, B., BONO, S. & THOMPSON, P. M. 2019. Harbour porpoise responses to pile-driving diminish over time. *Royal Society Open Science,* 6**,** 190335.

GRAHAM, I. M., PIROTTA, E., MERCHANT, N. D., FARCAS, A., BARTON, T. R., CHENEY, B., HASTIE, G. D. & THOMPSON, P. M. 2017b. Responses of bottlenose dolphins and harbor porpoises to impact and vibration piling noise during harbor construction. *Ecosphere,* 8.

HAMERNIK, R. P., QIU, W. & DAVIS, B. 2007. Hearing loss from interrupted, intermittent, and time varying non-Gaussian noise exposure: The applicability of the equal energy hypothesis. *The Journal of the Acoustical Society of America,* 122**,** 2245-2254.

HAMMOND, P., LACEY, C., GILLES, A., VIQUERAT, S., BÖRJESSON, P., HERR, H., MACLEOD, K., RIDOUX, V., SANTOS, M., SCHEIDAT, M., TEILMANN, J., VINGADA, J. & ØIE, N. 2021. Estimates of cetacean abundance in European Atlantic waters in summer 2016 from the SCANS-III aerial and shipboard surveys - revised June 2021.

HARWOOD, J., KING, S., SCHICK, R., DONOVAN, C. & BOOTH, C. 2014. A protocol for Implementing the Interim Population Consequences of Disturbance (PCoD) approach: Quantifying and assessing the effects of UK offshore renewable energy developments on marine mammal populations. Report Number SMRUL-TCE-2013-014. Scottish Marine And Freshwater Science, 5(2).

HASTIE, G., MERCHANT, N. D., GÖTZ, T., RUSSELL, D. J., THOMPSON, P. & JANIK, V. M. 2019. Effects of impulsive noise on marine mammals: investigating range-dependent risk. *Ecological Applications,* 29**,** e01906.

HASTIE, G. D., RUSSELL, D. J. F., MCCONNELL, B., MOSS, S., THOMPSON, D. & JANIK, V. M. 2015. Sound exposure in harbour seals during the installation of an offshore wind farm: predictions of auditory damage. *Journal of Applied Ecology,* 52**,** 631-640.

HENDERSON, D., SUBRAMANIAM, M., GRATTON, M. A. & SAUNDERS, S. S. 1991. Impact noise: the importance of level, duration, and repetition rate. *The Journal of the Acoustical Society of America,* 89**,** 1350-1357.

HIN, V., HARWOOD, J. & DE ROOS, A. M. 2019. Bio-energetic modeling of medium-sized cetaceans shows high sensitivity to disturbance in seasons of low resource supply. *Ecological Applications,* 29(5).

HOEKENDIJK, J., SPITZ, J., READ, A. J., LEOPOLD, M. F. & FONTAINE, M. C. 2018. Resilience of harbor porpoises to anthropogenic disturbance: Must they really feed continuously? *Marine Mammal Science,* 34**,** 258-264.

HOUSER, D. S., YOST, W., BURKARD, R., FINNERAN, J. J., REICHMUTH, C. & MULSOW, J. 2017. A review of the history, development and application of auditory weighting functions in humans and marine mammals. *The Journal of the Acoustical Society of America,* 141**,** 1371-1413.

KASTAK, D., HOLT, M., KASTAK, C., SOUTHALL, B., MULSOW, J. & SCHUSTERMAN, R. A voluntary mechanism of protection from airborne noise in a harbor seal. 16th Biennial Conference on the Biology of Marine Mammals, 2005. San Diego CA, 148.

KASTELEIN, R. A., GRANSIER, R. & HOEK, L. 2013a. Comparative temporary threshold shifts in a harbor porpoise and harbor seal, and severe shift in a seal (L). *Journal of the Acoustical Society of America,* 134**,** 13-16.

KASTELEIN, R. A., GRANSIER, R., HOEK, L. & DE JONG, C. A. 2012a. The hearing threshold of a harbor porpoise (*Phocoena phocoena*) for impulsive sounds (L). *Journal of the Acoustical Society of America,* 132**,** 607-610.

KASTELEIN, R. A., GRANSIER, R., HOEK, L., MACLEOD, A. & TERHUNE, J. M. 2012b. Hearing threshold shifts and recovery in harbor seals (*Phoca vitulina*) after octave-band noise exposure at 4 kHz. *Journal of the Acoustical Society of America,* 132**,** 2745-2761.

KASTELEIN, R. A., GRANSIER, R., HOEK, L. & OLTHUIS, J. 2012c. Temporary threshold shifts and recovery in a harbor porpoise (*Phocoena phocoena*) after octave-band noise at 4kHz. *Journal of the Acoustical Society of America,* 132**,** 3525-3537.

KASTELEIN, R. A., GRANSIER, R., HOEK, L. & RAMBAGS, M. 2013b. Hearing frequency thresholds of a harbor porpoise (*Phocoena phocoena*) temporarily affected by a continuous 1.5 kHz tone. *Journal of the Acoustical Society of America,* 134**,** 2286-2292.

KASTELEIN, R. A., GRANSIER, R., MARIJT, M. A. T. & HOEK, L. 2015. Hearing frequency thresholds of harbor porpoises (*Phocoena phocoena*) temporarily affected by played back offshore pile driving sounds. *The Journal of the Acoustical Society of America,* 137**,** 556-564.

KASTELEIN, R. A., HELDER-HOEK, L., COVI, J. & GRANSIER, R. 2016. Pile driving playback sounds and temporary threshold shift in harbor porpoises (*Phocoena phocoena*): Effect of exposure duration. *The Journal of the Acoustical Society of America,* 139**,** 2842-2851.

KASTELEIN, R. A., HELDER-HOEK, L., VAN DE VOORDE, S., VON BENDA-BECKMANN, A. M., LAM, F.-P. A., JANSEN, E., DE JONG, C. A. & AINSLIE, M. A. 2017. Temporary hearing threshold shift in a harbor porpoise (*Phocoena phocoena*) after exposure to multiple airgun sounds. *The Journal of the Acoustical Society of America,* 142**,** 2430-2442.

KASTELEIN, R. A., HOEK, L., GRANSIER, R., RAMBAGS, M. & CLAEYS, N. 2014. Effect of level, duration, and inter-pulse interval of 1-2 kHz sonar signal exposures on harbor porpoise hearing. *The Journal of the Acoustical Society of America,* 136**,** 412-422.

KAVANAGH, A. S., NYKÄNEN, M., HUNT, W., RICHARDSON, N. & JESSOPP, M. J. 2019. Seismic surveys reduce cetacean sightings across a large marine ecosystem. *Scientific Reports,* 9**,** 19164.

LARAN, S., AUTHIER, M., BLANCK, A., DOREMUS, G., FALCHETTO, H., MONESTIEZ, P., PETTEX, E., STEPHAN, E., VAN CANNEYT, O. & RIDOUX, V. 2017. Seasonal distribution and abundance of cetaceans within French waters-Part II: The Bay of Biscay and the English Channel. *Deep Sea Research Part II: Topical Studies in Oceanography,* 141**,** 31-40.

LUCKE, K., SIEBERT, U., LEPPER, P. A. & BLANCHET, M. 2009. Temporary shift in masked hearing thresholds in a harbor porpoise (*Phocoena phocoena*) after exposure to siesmic airgun stimuli. *Journal of the Acoustical Society of America,* 125**,** 4060-4070.

MARTIN, B., LUCKE, K. & BARCLAY, D. 2020. Techniques for distinguishing between impulsive and non-impulsive sound in the context of regulating sound exposure for marine mammals. *The Journal of the Acoustical Society of America,* 147**,** 2159-2176.

MCGARRY, T., BOISSEAU, O., STEPHENSON, S. & COMPTON, R. 2017. Understanding the Effectiveness of Acoustic Deterrent Devices (ADDs) on Minke Whale (*Balaenoptera acutorostrata*), a Low Frequency Cetacean. Report for the Offshore Renewables Joint Industry Programme (ORJIP) Project 4, Phase 2. Prepared on behalf of the Carbon Trust.

MEISSNER, A. M., CHRISTIANSEN, F., MARTINEZ, E., PAWLEY, M. D., ORAMS, M. B. & STOCKIN, K. A. 2015. Behavioural effects of tourism on oceanic common dolphins, Delphinus sp., in New Zealand: the effects of Markov analysis variations and current tour operator compliance with regulations. *PloS one,* 10**,** e0116962.

MELLINGER, D. K., CARSON, C. D. & CLARK, C. W. 2000. Characteristics of minke whale (Balaenoptera acutorostrata) pulse trains recorded near Puerto Rico. *Marine Mammal Science,* 16**,** 739-756.

MOONEY, T. A., NACHTIGALL, P. E., BREESE, M., VLACHOS, S. & AU, W. W. 2009. Predicting temporary threshold shifts in a bottlenose dolphin (*Tursiops truncatus*): The effects of noise level and duration. *The Journal of the Acoustical Society of America,* 125**,** 1816-1826.

MORAY OFFSHORE RENEWABLES LIMITED 2012. Telford, Stevenson, MacColl Wind Farms and associated Transmission Infrastructure Environmental Statement: Technical Appendix 7.3 D - A comparison of behavioural responses by harbour porpoises and bottlenose dolphins to noise: Implications for wind farm risk assessments.

MORAY OFFSHORE WINDFARM (WEST) LIMITED 2018. Moray Offshore Windfarm (West) Limited, Environmental Impact Assessment Report, Chapter 9 Marine Mammal Ecology.

MUSSI, B., VIVALDI, C., ZUCCHINI, A., MIRAGLIUOLO, A. & PACE, D. S. 2019. The decline of short-beaked common dolphin (Delphinus delphis) in the waters off the island of Ischia (Gulf of Naples, Italy). *Aquatic Conservation: Marine and Freshwater Ecosystems,* n/a.

NABE-NIELSEN, J., VAN BEEST, F., GRIMM, V., SIBLY, R., TEILMANN, J. & THOMPSON, P. M. 2018. Predicting the impacts of anthropogenic disturbances on marine populations. *Conservation Letters,* e12563.

NATIONAL ACADEMIES OF SCIENCES ENGINEERING AND MEDICINE 2016. Approaches to Understanding the Cumulative Effects of Stressors on Marine Mammals. Washington, DC: The National Academies Press.

NEW, L. F., HARWOOD, J., THOMAS, L., DONOVAN, C., CLARK, J. S., HASTIE, G., THOMPSON, P. M., CHENEY, B., SCOTT-HAYWARD, L. & LUSSEAU, D. 2013. Modelling the biological significance of behavioural change in coastal bottlenose dolphins in response to disturbance. *Functional Ecology,* 27**,** 314-322.

NIU, F.-Q., LIU, Z.-W., WEN, H.-T., XU, D.-W. & YANG, Y.-M. 2012. Behavioral responses of two captive bottlenose dolphins (Tursiops truncatus) to a continuous 50 kHz tone. *The Journal of the Acoustical Society of America,* 131**,** 1643-1649.

NMFS 2016. Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing: Underwater Acoustic Thresholds for Onset of Permanent and Temporary Threshold Shifts. Silver Spring: U.S. Department of Commerce.

NMFS 2018. Revisions to: Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2.0): Underwater Thresholds for Onset of Permanent and Temporary Threshold Shifts. Silver Spring: U.S. Department of Commerce, NOAA.

OTANI, S., NAITO, Y., KATO, A. & KAWAMURA, A. 2000. Diving behavior and swimming speed of a free-ranging harbor porpoise, *Phocoena phocoena*. *Marine Mammal Science,* 16**,** 811-814.

PAPALE, E., GAMBA, M., PEREZ-GIL, M., MARTIN, V. M. & GIACOMA, C. 2015. Dolphins Adjust Species-Specific Frequency Parameters to Compensate for Increasing Background Noise. *PLOS ONE,* 10**,** e0121711.

PIROTTA, E., LAESSER, B. E., HARDAKER, A., RIDDOCH, N., MARCOUX, M. & LUSSEAU, D. 2013. Dredging displaces bottlenose dolphins from an urbanised foraging patch. *Marine Pollution Bulletin,* 74**,** 396-402.

RISCH, D., CLARK, C. W., DUGAN, P. J., POPESCU, M., SIEBERT, U. & VAN PARIJS, S. M. 2013. Minke whale acoustic behavior and multi-year seasonal and diel vocalization patterns in Massachusetts Bay, USA. *Marine Ecology Progress Series,* 489**,** 279-295.

RISCH, D., SIEBERT, U. & VAN PARIJS, S. M. 2014. Individual calling behaviour and movements of North Atlantic minke whales (*Balaenoptera acutorostrata*). *Behaviour,* 151**,** 1335-1360.

ROJANO-DOÑATE, L., MCDONALD, B. I., WISNIEWSKA, D. M., JOHNSON, M., TEILMANN, J., WAHLBERG, M., HØJER-KRISTENSEN, J. & MADSEN, P. T. 2018. High field metabolic rates of wild harbour porpoises. *Journal of Experimental Biology,* 221**,** jeb185827.

RUSSELL, D. & HASTIE, G. 2017. Associating predictions of change in distribution with predicted received levels during piling. Report produced for SMRU Consulting.

RUSSELL, D. J., HASTIE, G. D., THOMPSON, D., JANIK, V. M., HAMMOND, P. S., SCOTT-HAYWARD, L. A., MATTHIOPOULOS, J., JONES, E. L. & MCCONNELL, B. J. 2016. Avoidance of wind farms by harbour seals is limited to pile driving activities. *Journal of Applied Ecology,* 53**,** 1642-1652.

RUSSELL, D. J. F., MCCONNELL, B., THOMPSON, D., DUCK, C., MORRIS, C., HARWOOD, J. & MATTHIOPOULOS, J. 2013. Uncovering the links between foraging and breeding regions in a highly mobile mammal. *Journal of Applied Ecology,* 50**,** 499-509.

SIVLE, L. D., KVADSHEIM, P. H., CURÉ, C., ISOJUNNO, S., WENSVEEN, P. J., LAM, F.-P. A., VISSER, F., KLEIVANE, L., TYACK, P. L. & HARRIS, C. M. 2015. Severity of expert-identified behavioural responses of humpback whale, minke whale, and northern bottlenose whale to naval sonar. *Aquatic Mammals,* 41**,** 469.

SMITH, H., CARTER, C. & MANSON, F. 2019. Cumulative impact assessment of Scottish east coast offshore windfarm construction on key species of marine mammals using iPCoD. Scottish Natural Heritage Research Report No. 1081.

SOUTHALL, B. 2021. Evolutions in Marine Mammal Noise Exposure Criteria. *Acoustics Today,* 17.

SOUTHALL, B., CALAMBOKIDIS, J., TYACK, P., MORETTI, D., HILDEBRAND, J., KYBURG, C., CARLSON, CARLSON, R., FRIEDLAENDER, A., FALCONE, E., SCHORR, G., DOUGLAS, A., DERUITER, S., GOLDBOGEN, J. & BARLOW, J. 2010. Biological and Behavioral Response Studies of Marine Mammals in Southern California, 2010 (SOCAL-10) Final Project Report.

SOUTHALL, B., FINNERAN, J. J., REICHMUTH, C., NACHTIGALL, P. E., KETTEN, D. R., BOWLES, A. E., ELLISON, W. T., NOWACEK, D. & TYACK, P. 2019. Marine Mammal Noise Exposure Criteria: Updated Scientific Recommendations for Residual Hearing Effects. *Aquatic Mammals,* 45**,** 125-232.

SOUTHALL, B. L., BOWLES, A. E., ELLISON, W. T., FINNERAN, J. J., GENTRY, R. L., GREENE, C. R. J., KASTAK, D., KETTEN, D. R., MILLER, J. H., NACHTIGALL, P. E., RICHARDSON, W. J., THOMAS, J. A. & TYACK, P. L. 2007. Marine mammal noise exposure criteria: initial scientific recommendations. *Aquatic Mammals,* 33**,** 411-414.

SPARLING, C. E., SPEAKMAN, J. R. & FEDAK, M. A. 2006. Seasonal variation in the metabolic rate and body composition of female grey seals: fat conservation prior to high-cost reproduction in a capital breeder? *Journal of Comparative Physiology B,* 176**,** 505-512.

STOCKIN, K. A., LUSSEAU, D., BINEDELL, V., WISEMAN, N. & ORAMS, M. B. 2008. Tourism affects the behavioural budget of the common dolphin Delphinus sp. in the Hauraki Gulf, New Zealand. *Marine Ecology Progress Series,* 355**,** 287-295.

STONE, C. J., HALL, K., MENDES, S. & TASKER, M. L. 2017. The effects of seismic operations in UK waters: analysis of Marine Mammal Observer data. *Journal of Cetacean Research and Management,* 16**,** 71-85.

TOUGAARD, J., CARSTENSEN, J., TEILMANN, J., HENRIK, S. & RASMUSSEN, P. 2009. Pile driving zone of responsiveness extends beyond 20 km for harbor porpoises (*Phocoena phocoena* (L.)) (L). *Journal of the Acoustical Society of America,* 126**,** 11-14.

TUBELLI, A. A., ZOSULS, A., KETTEN, D. R., YAMATO, M. & MOUNTAIN, D. C. 2012. A prediction of the minke whale (*Balaenoptera acutorostrata*) middle-ear transfer function. *Journal of the Acoustical Society of America,* 132**,** 3263-3272.

VAN BEEST, F. M., NABE-NIELSEN, J., CARSTENSEN, J., TEILMANN, J. & TOUGAARD, J. 2015. Disturbance Effects on the Harbour Porpoise Population in the North Sea (DEPONS): Status report on model development.

VAN BEEST, F. M., TEILMANN, J., HERMANNSEN, L., GALATIUS, A., MIKKELSEN, L., SVEEGAARD, S., BALLE, J. D., DIETZ, R. & NABE-NIELSEN, J. 2018. Fine-scale movement responses of free-ranging harbour porpoises to capture, tagging and short-term noise pulses from a single airgun. *Royal Society Open Science,* 5**,** 170110.

WARD, W. D. 1997. Effects of high-intensity sound. *In:* CROCKER, M. J. (ed.) *Encyclopedia of acoustics.* New York: John Wiley & Sons.

WHYTE, K., RUSSELL, D., SPARLING, C., BINNERTS, B. & HASTIE, G. 2020. Estimating the effects of pile driving sounds on seals: Pitfalls and possibilities. *The Effects of Noise on Aquatic Life,* 14**,** 3948-3958.

WISNIEWSKA, D. M., JOHNSON, M., TEILMANN, J., ROJANO-DOÑATE, L., SHEARER, J., SVEEGAARD, S., MILLER, L. A., SIEBERT, U. & MADSEN, P. T. 2016. Ultra-high foraging rates of harbor porpoises make them vulnerable to anthropogenic disturbance. *Current Biology,* 26**,** 1441-1446.

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Rampion 2
WIND FARM