Sofia Offshore Wind Farm

Environmental Appraisal of Increased Hammer Energy: Appendix B: Auditory Injury Assessment: cumulative exposure to piling noise

2020

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1 Background

This Appendix has been prepared in support of the Environmental Appraisal of Increased Hammer Energy (Doc Ref: 003230484-02) which provides an assessment of a proposed increase in hammer energy for monopole foundations to 4,000kJ. As part of Environmental Appraisal process, underwater noise modelling predictions that informed the original Sofia impact assessment (as referred to within the application for consent) [1] were compared with those derived from new modelling (using a comparable approach) to establish the validity of the existing ES conclusions in relation to underwater noise effects. As detailed within the Environmental Appraisal report a like for like assessment (as far as reasonably practicable) was undertaken.

This Appendix has been updated directly from the version that was submitted (at Appendix B) in response to comments raised by Natural England (5th March 2018) on the original 5,500kJ Environmental Appraisal of Increased Hammer Energy report, and specifically considers the cumulative noise exposure from increased hammer energy on marine mammal receptors. Cumulative noise exposure was not considered within the original ES and therefore cannot be compared to the increased hammer energy proposals. Therefore, this Appendix forms a stand-alone assessment.

The original underwater noise modelling undertaken to inform the Sofia impact assessment that supported the application for consent was undertaken by the National Physical Laboratory (NPL) and completed in 2013. The updated noise modelling for the non-material change (NMC) DCO application has been undertaken by Subacoustech Environmental Ltd in 2018 (noting that whilst this modelling considered 5,500kJ maximum hammer energy scenario, outputs for 4,000kJ were also generated and are therefore, applicable to this latest appraisal work).

1.1 Document Structure

This document is set out as follows:

- Section 1: Background to the assessment of cumulative noise exposure on marine mammals;
- Section 2: Methodology of Assessment;
- Section 3: Results: Impact ranges for SEL_{cum} PTS and TTS, number of animals potentially affected by SEL_{cum} PTS and the significance of the effect;
- Section 4: Conclusions – A brief summary of the relevant findings and conclusions.

2 Methodology of Assessment

This environmental assessment has been undertaken to assess the risk of permanent threshold shift (PTS) occurring on key marine mammal receptors as a result of cumulative exposure over a 24 hour period during piling activity for the installation of offshore infrastructure at Sofia (SEL_{cum} PTS). The impact is then assessed taking account of the likelihood of the impact occurring, the sensitivity of the receptor and the magnitude of the potential effect.

Impact ranges are also presented to indicate the range that SEL_{cum} temporary threshold shift (TTS) may occur, however, the magnitude and significance of the effect of TTS has not been assessed (see Section 2.3 for more discussion of TTS).

2.1 Design Envelope to be assessed

The Sofia Environmental Statement (ES) (Dogger Bank Teesside A & B Offshore Wind Farms Environmental Statement, Forewind, 2014) submitted with the DCO application considered a worst case maximum hammer energy of 3,000 kJ for the installation of monopole foundations. However, as discussed above, Sofia Offshore Wind Farm Ltd (SOWFL) has

[1] https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010051/EN010051-000250-6.5.1%20ES%20Chapter%205%20Appendix%20A.pdf

identified that there may be a technical requirement to increase this maximum hammer energy to 4,000kJ for monopole installation only.

The ES included a worst case design envelope (its 'Rochdale Envelope'), as summarised in Table 3.1 of the Environmental Appraisal of Increased Hammer Energy (Doc Ref: 003230484-02). It is important to note that the increased maximum hammer energy is only applicable to monopole foundation locations. As a result of the increased hammer energy from 3,000kJ to 4,000kJ, the associated ramp up parameters have also changed.

As defined in Table 5.2 of Chapter 14 of the original ES, and in Table 3.1 of the Environmental Appraisal of Increased Hammer Energy; the worst case scenario for spatial extent effects was based on maximum hammer energy for monopole foundations as this produces the largest impact risk footprint for marine mammals.

However, when modelling the SEL_{cum} over 24 hours and using updated species specific thresholds and weighting functions as a result of new guidance on noise assessments from the US National Marine Fisheries Service and National Oceanic and Atmospheric Administration (National Marine Fisheries Service 2016), monopole installation no longer represents the worst case for all species. As a result, the risk of PTS from cumulative exposure from both monopole and pin pile installation was considered in this assessment. Table 2.1 presents the piling parameters assessed.

Table 2.1: Sofia offshore wind farm maximum design parameters[3].

Hammer maximum blow energy	Percent of maximum blow energy						
	10%	25%	40%	55%	70%	85%	100%
2,300kJ (pin pile)	230	575	920	1,265	1,600	1,955	2,300
3,000kJ (monopole)	300	750	1,200	1,650	2,100	2,550	3,000
4,000kJ (monopole)	400	1,000	1,600	2,200	2,800	3,400	4,000
Strike Rate	3 s per strike						1.5 s per strike
Duration (minutes)	5	5	5	5	5	5	300 (sequence 3[2])
Total strikes	100	100	100	100	100	100	12,000 (sequence 3)

2.2 Underwater Noise Modelling

Modelling undertaken by Subacoustech, using the INSPIRE model was based on piling undertaken at a single location at the northernmost boundary of the Sofia site (see Figure 1.1 in Appendix A of Doc Ref: 003230547-01). This site is in some of the deepest water (32m) at the Sofia array site. The ranges calculated are considered to represent the worst case for the purposes of this assessment as the deepest water location typically results in the greatest underwater noise propagation. This assessment incorporates the new criteria (which have been published since the Sofia ES) for impacts on marine mammals (National Marine Fisheries Service (NMFS) 2016) into the INSPIRE model. This allows consideration of the potential for an effect on relevant receptors based on the most contemporary assessment methodologies. Further detail on the assessment process is presented, as relevant, in the sections below.

2.3 Criteria and assessment

The ES chapter assessed the impacts of noise from pile driving on grey seal (*Halichoerus grypus)*, harbour porpoise (*Phocoena phocoena*), minke whale *(Balaenoptera acutorostrata*) and white-beaked dolphin (*Agenorhynchus albirostris*).

Both cetaceans (harbour porpoise, minke whale and white-beaked dolphin) and pinnipeds (grey seals) are vulnerable to impacts of piling noise, with impacts including lethal or physical injury, hearing injury and disturbance, depending on the received noise levels. This updated assessment only covers PTS and TTS as a result of cumulative exposure to piling noise over 24 hours. Hearing injury in marine mammals depends on the sensitivity of the species and factors such as the duration, frequency and level of the noise. Hearing injury can manifest itself as a TTS, where the sensitivity of an

[2] Sequence 3 represents the "worst case" scenario of the piling ramp up profiles considered within the ES (Table 6.2 of Chapter 6: Marine Mammals)

individual's hearing at certain frequencies is reduced temporarily before fully recovering, and as a permanent threshold shift (PTS) where a permanent change occurs in the sensitivity of hearing at certain frequencies.

Since it was published, Southall et al. (2007) has been the source of the most widely used criteria to assess the effects of noise on marine mammals, and was the main criteria, along with Lucke et al. (2009) for harbour porpoises. National Marine Fisheries Service (2016) was co-authored by many of the same authors from the Southall et al. (2007) paper, and effectively updates its criteria for assessing the risk of auditory injury. The NMFS guidance is more explicit in the requirement to model cumulative exposure to multiple sound events over 24 hours. This has led to requests as standard, from SNCBs to include an assessment of the potential occurrence of auditory injury over longer periods than single strike (instantaneous) metrics.

Similar to Southall et al. (2007), the NMFS (2016) guidance groups marine mammals into hearing groups and applies filters to the unweighted noise to approximate the hearing sensitivity of the receiver. It should be noted that the filters used in Southall et al. (2007) differ from those used in NMFS (2016). Figure 2.1 presents the auditory weighting functions used in the modelling to predict PTS and TTS-onset ranges presented in this document.

A summary of the noise thresholds (SEL in dB re 1µPa^{2}s) modelled for marine mammal receptors in this assessment are provided in Table 2.2.

A 'fleeing' animal model was used to calculate PTS and TTS-onset ranges. Animals were assumed to start moving away from the source at the onset of piling, at a constant speed. The speed selected for each species was considered to be a precautionary long term responsive movement speed, although it is recognised that the immediate response may occur at a much more rapid rate than this. A constant speed of 3.25ms^{-1} has been assumed for the low frequency (LF) cetaceans group based on data for Minke whale (Blix and Folkow 1995). All other receptors are assumed to swim at a constant speed of 1.5ms^{-1} (Otani et al. 2000).

Table 2.2: Summary of noise thresholds (SEL in dB re 1µPa^{2}s) modelled for marine mammal receptors, from NMFS (2016).

Potential Impacts	Harbour Porpoise (HF Cetaceans)	White-Beaked Dolphin (MF Cetaceans)	Minke Whale (LF Cetaceans)	Grey Seal (Phocid Pinnipeds)
PTS	155	185	183	185
TTS	140	170	168	170

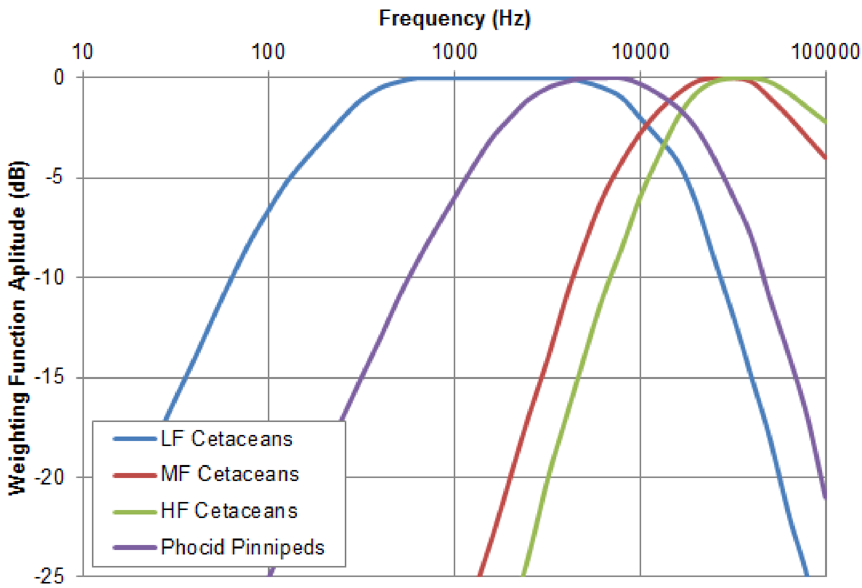

Figure 2.1: Auditory weighting functions for low frequency (LF) cetaceans, mid frequency (MF) cetaceans, high frequency (HF) cetaceans, and phocid pinnipeds (PW) (underwater) (from NMFS 2016)

The ranges for both PTS and TTS (at both 2,300 and 4,000 kJ maximum hammer energy outputs) have been modelled and are presented in this report, however only PTS has been quantified in terms of the number of animals potentially affected and assessed in terms of magnitude and significance. TTS is not quantified and assessed in this manner because basing any impact assessment on the impact ranges for TTS using current TTS-onset thresholds would greatly overestimate the potential for any ecologically significant effect. This is because the species specific TTS-thresholds developed by NMFS (2016), (and those presented by Southall et al., (2007) prior to that), describe those thresholds at which the onset of TTS is observed (a 6dB shift in the hearing threshold) 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." Because experiments inducing PTS in animals are considered unethical, our ability to predict where PTS might occur relies on available data from humans and other terrestrial mammals that indicate that a shift in the hearing threshold of 40dB may lead to the onset of PTS. It is therefore necessary to define TTS-onset thresholds, not to indicate any degree of significant loss of hearing sensitivity, but in order to be able to predict where PTS might occur.

TTS is by definition, temporary, and the duration of effect at the threshold for TTS-onset will be low; 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 nearer to values that may cause PTS may however may require multiple days to recover (Finneran 2015), and therefore may have more of an effect on life functions such as foraging and communication. An impact range which encompasses such a large variation in the predicted effect on individuals is extremely difficult to interpret in terms of the potential consequences for individuals, and therefore assessing the magnitude and significance of effect based on these TTS ranges is impossible to do reliably. It is important to bear in mind that the quantification of the spatial extent over which any impact is predicted to occur in the environmental assessment process, is done so in order to inform an assessment of the potential magnitude and significance of an impact. Because the TTS thresholds are not intended to indicate a level of impact of concern per se, but are used to enable the prediction of where PTS might occur, they should not be used for the basis of any assessment of impact significance.

2.4 Animal density and abundance

To estimate the number of individuals that would be expected to be at risk of PTS, contours based on thresholds outlined in Table 2.2 were generated and used to work out the area of potential PTS for each species. The underlying density estimates for each species were applied across these areas and used to calculate the number of individuals at risk. Reference population numbers are based on the latest available information (which for harbour porpoise and grey seal has resulted in updated numbers since the original ES). Densities for the Sofia site are based on the site specific surveys undertaken to support the original ES where available, or most appropriate information source (in the case of grey seal).

Table 2.3: Reference populations and density estimates used in this assessment of SEL_{cum} PTS-onset.

Species	Reference population extent and data source	Reference population size used in assessment (95% confidence intervals)	Density estimate (per km^2) used in assessment (95% confidence intervals) and data source
Harbour Porpoise	North Sea Management Unit based on SCANS III (Hammond et al. 2017)	345,373 (246,526 – 495,752)	0.7161 (0.5228-0.9733) Combined porpoise and potential porpoise from site specific surveys
Minke Whale	Celtic and Greater North Seas (IAMMWG 2015)	23,528 (13,989 – 39,572)	0.00866 (0-0.02391) Site specific surveys
White-Beaked Dolphin	Celtic and Greater North Seas (IAMMWG 2015)	15,895 (9,107 – 27,743)	0.01487 (0.00663-0.02813) Site specific surveys

Species	Reference population extent and data source	Reference population size used in assessment (95% confidence intervals)	Density estimate (per km^2) used in assessment (95% confidence intervals) and data source
Grey Seal	South-east England and North east England Management Unit ((SCOS 2017)	40,040	0.23 (SMRU seal usage maps)

2.5 Assessment of effect significance

The criteria for determining the significance of effects is a two stage process that involves defining the sensitivity of the receptors and the magnitude of the impacts. This section describes the criteria applied to assign values to the sensitivity of receptors and the magnitude of potential impacts. These definitions have been updated to reflect best practice since the original Sofia assessment was carried out.

The sensitivity of marine mammals is defined according to a five point scale which is based on an assessment of the combined vulnerability of the receptor to a given impact and the likely rate of recoverability to pre-impact conditions. Vulnerability is defined as the susceptibility of a species to disturbance, damage or death, from a specific external factor. Recoverability is the ability of the same species to return to a state close to that which existed before the activity or event which caused change. It is dependent on its ability to recover or reproduce depending on the extent of disturbance/damage incurred.

Information on these aspects of sensitivity of the marine mammals to given impacts has been informed by the best available evidence from published studies and evidence from analogous activities such as those associated with other offshore wind farms and oil and gas industries.

The criteria for defining sensitivity in this assessment are outlined in Table 2.4.

Table 2.4: Definition of terms relating to the sensitivity of the receptor.

Sensitivity	Definition used in this chapter
Very high	No ability to adapt behaviour so that survival and reproduction rates are affected. No tolerance – Effect will cause a change in both reproduction and survival rates. No ability for the animal to recover from the effect.
High	Limited ability to adapt behaviour so that survival and reproduction rates may be affected. Limited tolerance – Effect may cause a change in both reproduction and survival of individuals. Limited ability for the animal to recover from the effect.
Medium	Ability to adapt behaviour so that reproduction rates may be affected but survival rates not likely to be affected. Some tolerance – Effect unlikely to cause a change in both reproduction and survival rates. Ability for the animal to recover from the effect
Low	Receptor is able to adapt behaviour so that survival and reproduction rates are not affected. Receptor is able to tolerate the effect without any impact on reproduction and survival rates. Receptor is able to return to previous behavioural states/ activities once the impact has ceased.
Negligible	Very little or no effect on the behaviour of the Receptor.

The magnitude of the impact on a receptor was predicted by characterising the impact and the effect on the relevant marine mammal receptors. This was done by defining: a) the spatial extent of impact in relation to the natural range of the species which would determine the number of individuals potentially affected; b) duration of the impact in relation to the lifecycle of the species; c) frequency/timing of the impact in relation to seasonal variation, if known, and critical life stages and d) reversibility of the impact (i.e. whether the impact would lead to a reversible or irreversible change to the baseline conditions). These latter three factors in combination were used to inform an assessment of the likely severity of the effects resulting from the impact.

The magnitude was then assigned one of five levels based on the factors set out above. The criteria for defining magnitude in this assessment are outlined in Table 2.5.

Table 2.5: Definition of terms relating to the magnitude of an impact.

Magnitude of impact	Definition used in this chapter
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).
	Long term, large scale increase in the population trajectory at a generational scale (Beneficial)
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).
	Benefit to the habitat influencing foraging efficiency resulting in increased reproductive potential and increased population health and size (Beneficial)
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).
	Short term (over a limited number of breeding cycles) benefit to the habitat influencing foraging efficiency resulting in increased reproductive potential (Beneficial).
Negligible	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).
	Very minor benefit to the habitat influencing foraging efficiency of a limited number of individuals (Beneficial)
No change	No predicted effect

The significance of the effect upon marine mammals is determined by correlating the magnitude of the impact and the sensitivity of the receptor. The particular method employed for this assessment is presented in Table 2.6. Where a range of significance of effect is presented in Table 2.6, the final assessment for each effect is based upon expert judgement. For the purposes of this assessment, any effects with a significance level of minor or less have been concluded to be not significant in terms of the EIA Regulations.

Table 2.6: Matrix used for the assessment of the significance of the effect.

	Magnitude of impact					
Sensitivity of receptor		No change	Negligible	Low	Medium	High
	Negligible	Negligible	Negligible	Negligible or minor	Negligible or minor	Minor
	Low	Negligible	Negligible or minor	Negligible or minor	Minor	Minor or moderate
	Medium	Negligible	Negligible or minor	Minor	Moderate	Moderate or major
	High	Negligible	Minor	Minor or moderate	Moderate or major	Major or substantial
	Very high	Negligible	Minor	Moderate or major	Major or substantial	Substantial

3 Impact Assessment Results

3.1 Modelling Results

This section considers the potential risk of cumulative PTS to marine mammals in relation to the proposed increased hammer energy. As discussed above TTS ranges are presented for information and comparative purposes only.

The results presented in this section summarise the assessment of the predicted noise impact risk ranges based on the updated noise modelling undertaken.

Within the assessment a soft-start procedure was considered as built in mitigation to avoid auditory injury to marine mammals. As described in the ES, a soft-start would be conducted for 30 minutes where the starting hammer energy applied would be around 10% of maximum hammer energy (in the ES a starting hammer energy of 300kJ was assessed for maximum hammer energy of 3,000kJ) for all piling locations. During the soft-start, there would be a gradual increase in hammer energy, until after a period of 30 minutes hammer energy would be at 85% of maximum. After this 30 minute ramp up, hammer energy would be expected to ramp up further to a maximum of full hammer energy needed to install monopoles to full design penetration at the site. The hammer energies considered within this report are based on the piling sequence as set out in Table 2.1.

3.1.1 High-frequency Cetaceans – Harbour Porpoise

For the installation of monopoles a maximum PTS-onset range of 250m, and a mean range of 220m is predicted. For the installation of pin piles maximum PTS-onset range of 6,500m, and a mean range of 6,000m is predicted. The impact ranges for PTS and TTS-onset are shown in Table 3.1 below.

Table 3.1: PTS-onset and TTS-onset ranges for harbour porpoise

Piling scenario	PTS range in metres (min, mean, max)	TTS range in metres (min, mean, max)
Monopole 4,000kJ	190 **220** 250	14,400 **16,600** 18,900
Pin pile 2,300kJ	5,600 **6,000** 6,500	23,400 **29,500** 37,500

Table 3.2: presents the number of individuals within each impact risk range. The individuals predicted to be at risk of

PTS represent ≤0.001% of the reference population for the monopole scenario.

For pin piles, 0.025% and 0.035% of the reference population is predicted to be at risk of PTS.

These values are the predicted level of impact without any additional mitigation in place, the implementation of a Marine Mammal Mitigation Protocol (MMMP) with a standard 500m mitigation zone would reduce this impact risk range for harbour porpoise. A further mitigation radii can be provided for through the use of acoustic deterrent devices (ADDs) as part of the MMMP, affording complete protection to 1.1km or greater, dependent upon the time over which such equipment is deployed. ADDs have been shown to substantially reduce the number of harbour porpoise up to 5km to 10km from the ADD, with a complete deterrence range of at least 1.1km and a deterrence efficiency of 88% out to 15km (Brandt et al. 2012, Brandt et al. 2013, Dähne et al. 2017, Mikkelsen et al. 2017). Applying these measures of mitigation, assuming complete deterrence to 1km and 88% deterrence over the remaining range to 15km, reduces these levels of impact to zero for the monopole ramp ups and to 0.002% and 0.003% for pin pile ramp up sequences 2 and 3 respectively (Table 3.2).

Table 3.2: The estimated number of harbour porpoises within the PTS-onset range based on average density estimate, with and without mitigation (ADD assuming complete deterrence within 1km, 88% deterrence over 15km range, based on data collected by Brandt et al.).

Piling scenario	Detail	Impact without mitigation	Impact with mitigation
Monopole 4,000kJ	Area (km^2)	0.2	0
	Individuals	0.14	0
	% of ref population	<0.001	0
Pin pile 2,300kJ	Area (km^2)	111	107.9
	Individuals	80	10
	% of ref population	0.023	0.003

Based on these very low percentages affected, the magnitude of impact is considered to be negligible. The sensitivity of all cetaceans to PTS is assessed as high (a precautionary measure given uncertainty about the effect of PTS on individual survival and reproduction in species which use hearing as a primary sensory modality). Therefore, the impact significance is minor, and not considered significant in EIA terms.

3.1.2 Mid-frequency Cetaceans – White-beaked Dolphin

All ranges were less than 50m for mid frequency cetaceans. This is illustrated in Table 3.3 below.

Table 3.3: PTS-onset and TTS-onset ranges for white-beaked dolphins.

Piling scenario	PTS range in metres (min, mean, max)	TTS range in metres (min, mean, max)
Monopole 4,000kJ	<50	<50
	<50	**<50**
	<50	<50
Pin pile 2,300kJ	<50	<50
	<50	**<50**
	<50	<50

Table 3.4: The estimated number of white-beaked dolphins within the PTS-onset range for each sequence based on average density estimate.

Piling scenario	Detail	Impact without mitigation
Monopole 4,000kJ	Area (km^2)	<0.1
	Individuals	<0.1
	% of ref population	<0.001
Pin pile 2,300 kJ	Area (km^2)	<0.1
	Individuals	<0.1
	% of ref population	<0.001

As a result, the risk to white-beaked dolphins from PTS as a result of cumulative exposure, even in the absence of mitigation is negligible. Therefore, the impact significance is minor, and not considered significant in EIA terms.

3.1.3 Low-frequency Cetaceans – Minke Whale

For the installation of monopoles, a maximum PTS-onset range of 7,300m, and a mean range of 6,300m is predicted. For the installation of pin piles a maximum PTS-onset range of 5,700m, and a mean range of 4,900m is predicted.
The impact ranges for PTS and TTS-onset are shown in Table 3.5 below.

Table 3.5: PTS-onset and TTS-onset ranges for minke whales.

Piling scenario	PTS range in metres (min, mean, max)	TTS range in metres (min, mean, max)
Monopole 4,000kJ	5,500 **6,300** 7,300	23,900 **32,700** 47,200
Pin pile 2,300kJ	4,200 **4,900** 5,700	22,300 **30,100** 42,600

Table 3.6 presents the number of individuals within each impact risk range. The individuals predicted to be at risk of PTS represent ≤0.01% of the reference population for all ramp up sequences.

This is the predicted level of impact without any additional mitigation in place, the implementation of a Marine Mammal Mitigation Protocol (MMMP) with a standard 500m mitigation zone would reduce this impact risk range for minke whale. A further mitigation radii can be provided for through the use of acoustic deterrent devices (ADDs) as part of the MMMP, affording protection to 1.1km or greater, dependent upon the time over which such equipment is deployed. ADDs have been shown to successfully deter minke whales at ranges of at least up to 1.5km (and possibly larger ranges as whales were not tracked beyond this range) (McGarry *et al*. 2017). Applying this additional mitigation will reduce the area affected by approximately 7km^2, reducing impact by a further 10% for the pin pile scenario and 5% to 6 % for the monopole scenario.

Table 3.6: The estimated number of minke whales within the PTS-onset range for each sequence based on average density estimate.

Piling scenario	Detail	Impact without mitigation
Monopole 4,000kJ	Area (km^2)	125
	Individuals	1.3
	% of ref population	0.005
Pin pile 2,300 kJ	Area (km^2)	74.7
	Individuals	0.65
	% of ref population	0.003

Based on these very low percentages affected, the magnitude of impact is considered to be negligible. The sensitivity of all cetaceans to PTS is assessed as high (a precautionary measure given uncertainty about the effect of PTS on individual survival and reproduction in species which use hearing as a primary sensory modality). Therefore, the impact significance is minor, and not considered significant in EIA terms.

3.1.4 Phocid (in water) – Grey Seal

All PTS ranges were less than 50m for seals. The impact ranges for PTS and TTS-onset are shown in Table 3.7 below.

Table 3.7: PTS-onset and TTS-onset ranges for grey seals.

Piling scenario	PTS range in metres (min, mean, max)	TTS range in metres (min, mean, max)
Monopole 4,000kJ	<50 <50 <50	13.300 **12,600** 16.200
Pin pile 2,300kJ	<50 <50 <50	10,100 **11,300** 12,600

Table 3.8 presents the number of individuals within each impact risk range. The individuals predicted to be at risk of PTS represent ≤0.001% of the reference population for both ramp up sequences for both pin piles and monopoles.

Table 3.8: The estimated number of grey seals within the PTS-onset range for each sequence based on average density estimate.

Piling scenario	Detail	Impact without mitigation
Monopole 4,000kJ	Area (km^2)	<0.1
	Individuals	<0.02
	% of ref population	<0.001
Pin pile 2,300 kJ	Area (km^2)	<0.1
	Individuals	<0.02
	% of ref population	<0.001

Based on these very low percentages affected, the magnitude of impact is considered to be negligible. The sensitivity of grey seals to PTS is assessed as medium (a precautionary measure given uncertainty about the effect of PTS on individual survival and reproduction in species which does not use hearing as a primary sensory modality for foraging and navigation). Therefore, the impact significance is minor, and not considered significant in EIA terms.

4 Summary and discussion

This report provides an assessment of the impact of PTS resulting from cumulative exposure to piling noise over 24 hours as a result of an updated project design envelope at Sofia. This impact was not previously quantified or assessed explicitly in EIA terms for all receptors in the ES for Sofia and is required here due to an increase in hammer energy for the installation for monopoles and updated best practice for marine mammal noise impact assessment. Whilst this hammer energy increase only applied to monopoles, the re-modelling using revised species specific weightings revealed that monopole installation no longer provided the worst case effect for all species. As a result pin piles were also assessed in this report even though no change in maximum hammer energy is proposed for pin piles. Because this is a new assessment, the appropriate reference populations used in the quantitative assessment, and the impact assessment methodology, were updated to reflect current best practice in marine mammal noise impact assessments.

The assessment results demonstrate that the updates to the maximum design envelope for pile driving activity at Sofia (including a hammer energy increase for the installation of monopoles) will not result in cumulative exposure to piling noise that would result in any significant impacts to marine mammal species. It can therefore be concluded that despite changes to the project design envelope, and changes in assessment methodology, the predicted worst-case impacts are not greater than those presented and assessed in the original ES for the project.

There are a number of uncertainties in the assessment, and as a result, several elements of the assessment involve considerable precaution. These areas are explained further below.

The assessment is based on assuming that 100% of individuals within the PTS-onset ranges will be impacted, although this is unlikely as these contours represent PTS-onset ranges beyond which we can be sure that there is zero risk of PTS (a gradient effect out to this range is more likely in reality). It is expected that the risk of PTS to any individuals will increase from low at the edge of these areas, to high towards the source of the sound. Therefore, the quantification of numbers of animals will be an overestimate of those that would potentially be affected.

There is also uncertainty about the relationship between noise exposure and the risk of auditory injury. There is no empirical support for the levels of PTS onset predicted here, rather the probability of auditory injury is extrapolated from a very small number of empirical studies of exposure to noise over much shorter periods. These calculations are based on the assumption that 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). It is also based on the assumption that 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:

a) It is well known that the equal energy hypothesis over-estimates the effect of intermittent noise since the quiet periods between exposures will allow some recovery compared to noise that is continuously present with the same total SEL (Ward, 1997). A number of studies have demonstrated that the resulting auditory impairment in marine mammals from pulsed sound is less than that from continuous exposure with the same total SEL (Mooney et al. 2009, Finneran et al. 2010, Kastelein et al. 2014). However, NMFS (2016), adopt the equal-energy-hypothesis for multiple pulse sound types, as there is currently no supported alternative method to accumulated exposure.
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), and then causing a smaller rate of threshold shift.

Modelling the SEL_{cum} impact ranges of PTS with a 'fleeing animal' model as employed here is subject to both of these uncertainties. Not accounting for these uncertainties in this assessment will have lead to a more precautionary assessment in the impacts set out in this report.

Another uncertainty is the rate at which animals are predicted to swim away from the piling noise. Relatively low swim speeds have been used in the modelling of cumulative exposure. This is likely to be precautionary as several marine mammal species have been observed to increase their swimming speeds in relation to exposure to underwater noise (e.g. Dyndo et al. 2015, McGarry et al. 2017). This would have the effect of moving animals away faster from the most intense noise, thus reducing their overall exposure and therefore reducing the modelled impact ranges presented here.

The modelled piling durations are also considered to be highly precautionary. Typically, installation of piles is expected to last between one and two hours and only a small percentage (likely 5% or less) of piling operations will take longer.

As a result of these uncertainties, and the resulting precaution applied to the assessment, as well as the application of mitigation to reduce impacts to negligible, it can be concluded with confidence that there is no significant risk of PTS resulting from cumulative exposure to any marine mammals as a result of piling activity during construction of Sofia.

5 References

Blix, A., and L. Folkow. 1995. Daily energy expenditure in free living minke whales. Acta Physiologica

153:61-66. Brandt, M. J., C. Hoeschle, A. Diederichs, K. Betke, R. Matuschek, and G. Nehls. 2013. Seal

scarers as a tool to deter harbour porpoises from offshore construction sites. Marine Ecology Progress Series **475**:291-302.

Brandt, M. J., C. Höschle, A. Diederichs, K. Betke, R. Matuschek, S. Witte, and G. Nehls. 2012. Effectiveness of a sealscarer in deterring harbour porpoises (Phocoena phocoena).

Dähne, M., J. Tougaard, J. Carstensen, A. Rose, and J. Nabe-Nielsen. 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.

Dyndo, M., D. M. Wiśniewska, L. Rojano-Doñate, and P. T. Madsen. 2015. Harbour porpoises react to low levels of high frequency vessel noise. Scientific Reports **5**:11083.

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., D. A. Carder, C. E. Schlundt, and R. L. Dear. 2010. Temporary threshold shift in a bottlenose dolphin (*Tursiops truncatus*) exposed to intermittent tones. Journal of the Acoustical Society of America **127**:3267-3272.

Forewind. 2014 Dogger Bank Teesside A and B Offshore Wind Farm: Environmental Statement

Hammond, P., C. Lacey, A. Gilles, S. Viquerat, P. Börjesson, H. Herr, K. Macleod, V. Ridoux, M. Santos, M. Scheidat, J. Teilmann, J. Vingada, and N. Øien. 2017. Estimates of cetacean abundance in European Atlantic waters in summer 2016 from the SCANS-III aerial and shipboard surveys.

IAMMWG. 2015. Management Units for cetaceans in UK waters. JNCC Report 547, ISSN 0963-8091.

Kastelein, R. A., L. Hoek, R. Gransier, M. Rambags, and N. Claeys. 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.

Lucke, K., U. Siebert, P. A. Lepper, and M. Blanchet. 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.

McGarry, T., O. Boisseau, S. Stephenson, and R. Compton. 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. .

Mikkelsen, L., L. Hermannsen, K. Beedholm, P. T. Madsen, and J. Tougaard. 2017. Simulated seal scarer sounds scare porpoises, but not seals: species-specific responses to 12 kHz deterrence sounds. Royal Society Open Science **4**:170286.

Mooney, T. A., P. E. Nachtigall, and S. Vlachos. 2009. Sonar-induced temporary hearing loss in dolphins. Biology Letters:rsbl-2009.

National Marine Fisheries Service. 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. Page 189. U.S. Department of Commerce, Silver Spring.

Otani, S., Y. Naito, A. Kato, and A. Kawamura. 2000. Diving behavior and swimming speed of a free-ranging harbor porpoise, Phocoena phocoena. Marine Mammal Science **16**:811-814.

SCOS. 2017. Scientific Advice on Matters Related to the Management of Seal Populations: 2017.

Southall, B. L., A. E. Bowles, W. T. Ellison, J. J. Finneran, R. L. Gentry, C. R. J. Greene, D. Kastak, D. R. Ketten, J. H. Miller, P. E. Nachtigall, W. J. Richardson, J. A. Thomas, and P. L. Tyack. 2007. Marine mammal noise exposure criteria: initial scientific recommendations. Aquatic Mammals **33**:411-414