Addendum to the
Environmental Impact
Assessment Report

NISA
North Irish Sea Array

Volume 9 - Offshore Appendices

Appendix A14.4

Temporary Threshold Shift Position Statement

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Appendix A14.4: Temporary Threshold Shift Position Statement

North Irish Sea Array Windfarm Ltd (NISA, hereafter referred to as 'the Developer') has been considering the Request for Further Information (RFI) issued by An Bord Pleanála (now An Coimisiún Pleanála) as well as the third-party submissions received following public consultation. At An Coimisiún Pleanála's behest, the Developer has also continued to consult with stakeholders in respect of the 2024 planning application throughout 2024-2026. The Developer has refined elements of the design to respond to the third-party submissions, the continued public and stakeholder consultation and the RFI. Full details of consultation undertaken can be found in Appendix A1.2 Consultation Report.

The RFI sections relevant to A14.4: Temporary Threshold Shift Position Statement in the RFI are included below.

RFI Section	RFI	Relevance to Chapter
1 (b)	The scientific information provided as part of the planning application documentation should be based on up-to-date survey reports and data. Accordingly, the applicant is requested to confirm/provide justification/verification that the information submitted in support of the planning application remains relevant and appropriate at the point of submitting further information or to update same as required.	The timeframes associated with the RFI have necessitated a review of the datasets previously used in the 2024 EIAR to ensure any necessary updates to the baseline environment are captured. Therefore, a review of the baseline environment has been undertaken to comply with RFI 1 (b).
10 (a)	The details that have been submitted in relation to underwater noise arising from the proposed development acknowledges the potential for impacts to arise on marine fauna from both Permanent Threshold Shift (PTS) and Temporary Threshold Shift (TTS) over significant areas. The Wildlife Act 1976, as amended, lists marine mammals, including all dolphin, porpoise, seal and whale species as protected, (with subsequent regulations also applying protections to all species of marine turtles and basking sharks) stating that it is an offence to hunt, injure, or wilfully interfere with/destroy the resting or breeding place of such species. The January 2014 'Guidance to Manage the Risk to Marine Mammals from Man-Made Sound Sources' published by the Department of Arts, Heritage and the Gaeltacht (NPWS (2014)), notes that sound sources with the potential to induce TTS in a receiving marine mammal has the potential to cause both disturbance and injury. This guidance has a statutory basis under Regulation 71 of SI No. 477 of 2011, and refers to the "offence to injure" under the Wildlife Act, 1976, noting that TTS "may constitute such an injury"…	In response to the point on TTS having the potential to cause both disturbance and injury, the Developer does not consider TTS to be auditory injury as stated in Section 14.2.10 Auditory Injury of Chapter 14, and further detail justifying this position is provided in this document.

RFI Section	RFI	Relevance to Chapter
10 (o)	The applicant is requested to update the Marine Mammal Mitigation Protocol (MMMP) (Appendix 14.4 of EIAR and Appendix 10 of NIS) to include reference to TTS, as this may constitute injury under Irish legislation and guidance.	The Developer has consulted with SMRU Consulting regarding TTS and effects on marine mammals. It is noted that the DAGH 2014 Guidance suggests that TTS may constitute injury, and that injury under the Wildlife Act 1976 it is an offence to injure. The DAGH guidance is ambiguous and cautious due to the limited science available to definitively state that TTS itself is an injury at the time of publishing. Based on the available science now it was assessed that impacts at the TTS-onset level does not constitute injury and that predicted TT-onset ranges should not require mitigation. This position is fully detailed in this document.

SMRU Consulting
understand ♦ assess ♦ mitigate

SMRU Consulting Temporary Threshold Shift (TTS) Position Statement (November 2025)

Purpose

The purpose of this document is to outline the position held by SMRU Consulting on the topic of the assessment and mitigation of Temporary Threshold Shift (TTS) in environmental impact assessments for marine mammals.

Hearing threshold shift

Marine mammals can experience a shift in their hearing thresholds induced by noise exposure, resulting in a reduction in their hearing abilities. This reduced hearing sensitivity can recover over time back to their normal hearing abilities (a temporary threshold shift, TTS) or may lead to a permanent change in hearing sensitivity, becoming a permanent threshold shift (PTS)[1].

What is TTS?

The TTS-onset threshold is *"the lowest level of noise exposure that has a measurable transient effect on hearing"* (Southall et al., 2007). It is important to note that this does not mean an animal with TTS is deaf. Instead, it means the animal has a temporary reduction in hearing sensitivity within a specific frequency range. This means that for a temporary period, a sound within that frequency range needs to be slightly louder (in that frequency range) for an animal to perceive it in the same manner as it would normally.

Impulsive sounds (such as explosions, pile driving strikes or airgun shots) stimulate the threshold shift faster than non-impulsive sounds (such as drilling or shipping) and are therefore more harmful to the mammalian ear. Impulsive sound can generate a threshold shift from a single exposure (through high peak sound pressure levels, $L_{p,0\text{-}pk}$ with high kurtosis) or a threshold shift caused by multiple exposures (cumulative sound exposure levels, SEL_{cum}).

There are different levels of TTS which are caused by different mechanisms and have differing biological consequences (see section: **Biologically meaningful TTS**).

Is TTS injury?

All cetaceans in Northern European waters are listed under Annex IV of the EU Directive 92/43/EEC of the Conservation of natural habitats and of wild fauna and flora (the Habitats Directive) as European Protected Species (EPS) of Community Interest and in need of strict protection. The Habitats Directive was transposed through the Conservation of Habitats and Species Regulations 2017 (in territorial waters out to 12 nautical miles (nm) and the Conservation of Offshore Marine Habitats and Species Regulations 2017 in offshore waters beyond 12 nm (together, the Habitats Regulations). The Habitats Regulations make it an offence to deliberately or recklessly injure an EPS.

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[1] It is assumed that 40 dB of threshold shift will cause PTS-onset in marine mammals (Southall et al., 2007).

Although the European Union (EU) Directive 92/43/EEC applies to all European waters, there is a lack of legal and regulatory consensus across countries regarding the definition of 'auditory injury' and thus, no consensus on whether TTS is considered auditory injury or not. This is demonstrated by the fact that countries have differing opinions as to whether auditory injury should be defined as PTS or TTS, and which threshold requires mitigation:

- **European countries:**
    - **UK (England, Scotland, Wales, Northern Ireland):** In the UK, auditory injury is deemed to have occurred when there is a permanent shift in the hearing threshold (e.g. JNCC et al., 2010; Marine Scotland, 2020; NRW, 2023). TTS is often referred to as the onset of fleeing response and treated as a proxy for disturbance and thus is not considered injury that would require mitigation.
    - **Denmark**: TTS does not constitute a significant injury and does not require mitigation (Skjellerup et al., 2015). PTS is the basis for assessment and regulation of impact on marine mammals (Tougaard, 2021). TTS is considered to be a temporary hearing loss that *"is unlikely to be significant and unlikely to affect survival or reproduction"* (Tougaard, 2021).
    - **France:** The guidance in France treats TTS primarily as a reversible, non-injurious effect, and PTS as the threshold for regulatory concern regarding injury (Persohn et al., 2020).
    - **Germany**: Under the German regulations, injury includes impairment of an animal's physical integrity and thus TTS is classified as injury and mitigation must apply once the TTS threshold has been exceeded (ASCOBANS, 2014).
    - **Ireland:** The current guidance (DAHG, 2014) states that *"TTS may constitute an injury"*, and that *"anthropogenic sound sources with the potential to induce TTS in a receiving marine mammal contain the potential for both (a) disturbance, and (b) injury to the animal"*. Thus, the current guidance is ambiguous.
- **Outside of the EU waters:**
    - **USA:** Under the Marine Mammal Protection Act, NMFS has defined auditory injury as *"damage to the inner ear that can result in destruction of tissue such as the loss of cochlear neuron synapses or auditory neuropathy"* (Houser, 2021; NMFS, 2024). The latest guidance clearly differentiates between *"temporary threshold shifts (TTS) and auditory injury (AUD INJ)"* (NMFS, 2024). Therefore, PTS constitutes an injury as it is permanent damage to tissue in the auditory system (e.g., disarticulation of the middle ear bones, loss of inner ear hair cells). TTS is a fully recoverable form of auditory fatigue and thus does not constitute injury. TTS is considered as a Level B harassment along with behavioural disturbance.
    - **Australia:** The regulator in Australia has recently released a document outlining their National Priorities in relation to offshore regulation. This refers to *"thresholds for the onset of auditory injury and temporary threshold shifts (TTS) in marine mammal hearing"*, which seems to differentiate between auditory injury and TTS, thus indicating that TTS does not constitute injury (NOPSEMA, 2025).

Limitations of TTS in impact assessment calculation

There are three key considerations in impact assessments, which lead to highly precautionary estimates: 1) the use of the TTS-onset level as the threshold assessed, 2) the conservatisms in the calculation of cumulative TTS, and 3) the lack of information on what constitutes biologically meaningful TTS. Each of these is described below.

TTS-onset threshold

The marine mammal hearing group-specific TTS-onset thresholds (first defined in Southall et al. (2007) which derived from Schlundt et al. (2000) who defined onset of TTS as being a temporary elevation of hearing threshold by 6 dB) describe those thresholds at which the **onset of TTS** is observed. TTS onset (6 dB shift in the hearing threshold in a specific frequency range) is 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.”* Therefore, current TTS-onset thresholds are based on the **smallest measurable** changes in hearing, rather than on levels likely to cause functional impairment. Note that these values were originally developed to support estimation of PTS-onset[2], rather than to serve as regulatory thresholds for ecologically signficant impact. The time taken for hearing to recover back to normal (the recovery time) for such small threshold shifts is expected to be less than an hour, and therefore highly unlikely to cause any major consequences for an animal.

For auditory threshold shifts of 4 - 5 dB caused by pulsed noise, Kastelein et al. (2016) demonstrated that TTS in porpoises recovered within one hour. A review by Finneran (2015) showed that a larger initial TTS tends to result in a faster recovery rate, 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 is more complex for more complex broadband sound, such as that produced by pile driving noise.

It is important to consider that predictions of TTS are linked to potential changes in hearing sensitivity at particular hearing frequencies. For low frequency, broadband pulsed signals like those generated during pile driving threshold shifts are considered to occur between 2-10 kHz (critically, despite the signal being broadband, the shift is not observed to occur across the whole frequency hearing spectrum, rather a narrower band). Studies have shown that exposure to impulsive pile driving noise induces TTS in a relatively narrow frequency band (e.g. 4-8 kHz) in harbour porpoise and harbour seals (Kastelein et al., 2012a; Kastelein et al., 2012b; Kastelein et al., 2013b; Finneran, 2015; Kastelein et al., 2016; Kastelein et al., 2017).

The current understanding of the consequences of PTS within this very narrow frequency range to an individual’s survival and fecundity is limited (please see **Appendix 3**), and therefore our ability to predict and assess the consequences of TTS of variable severity and duration is even more difficult to do. It is also important to note that the vast majority of pile driving signals are broadband, meaning

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[2] Note: there are no experimental/deliberate experiments showing that 40 dB TTS equates to PTS onset in any marine mammal as it would be unethical to do so.

that even where hearing sensitivity is reduced within a very narrow frequency range, there is still information received within the frequencies in which the animal can still hear as normal.

Cumulative TTS (SEL_{cum})

The calculation of the growth (accumulation) of threshold shift (using the SEL_{cum} metric) 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 rate of threshold shift that is predicted to occur is 2.3 dB per dB of noise received; for non-impulsive sound, this rate is smaller (1.6 dB per dB of noise) (Southall et al., 2007).

The SEL_{cum} thresholds are determined with the assumption that:

> a) the amount of sound energy an animal is exposed to within the time period being cumulatively evaluated (e.g. 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
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> 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 is influenced by the time interval between successive pulses, with some time for TTS recovery between pulses (e.g., Finneran et al., 2010b; Kastelein et al., 2014), 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 lose some of its impulsive characteristics (e.g. kurtosis, rise time, crest factor, etc.) while acoustically propagating, therefore becoming less-impulsive (as described in NMFS, 2016; Hastie et al., 2019a; Southall et al., 2019; Matei et al., 2024), and then causing a smaller shift in the auditory threshold (see above).

Modelling the SEL_{cum} impact ranges of TTS with a ‘fleeing animal’ model (as is typical in noise impact assessments) are subject to both of these precautions (for further detail, see **Appendix 1** and **Appendix 2**). Modelling the SEL_{cum} PTS-onset impact ranges will inherit the same uncertainties. However, as TTS-onset thresholds are lower than those of PTS-onset, and the TTS-onset impact ranges are therefore larger, the potential influence of these conservatisms is greater (i.e. predicted ranges have greater propensity to be inaccurate, for example, via recovery between exposures and/or greater loss of impulsive characteristics of sound given greater range from the sound source).

Biologically meaningful TTS

While the TTS-onset has been experimentally validated in several marine mammal species, larger thresholds shifts that would be associated with longer recovery times have not. 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 widely accepted threshold for the onset of a biologically meaningful TTS in marine mammals; however, it is reasonable to assume that such a threshold would be well above those currently adopted for TTS onset. As such, a biologically meaningful TTS threshold would be associated with smaller impact ranges (and substantially smaller impact areas) than those associated with TTS-onset thresholds. It is acknowledged that there is the potential for a biologically meaningful level of TTS to occur, and that a large shift in the hearing threshold near to values that may cause PTS-onset may require multiple days to recover (Finneran, 2015). However, this nuance is not included in how TTS-onset thresholds are currently assessed.

It is important to note that there are different levels of TTS (Melnick, 1991; Ryan et al., 2016; Kurabi et al., 2017; Saunders and Dooling, 2018). Low-level TTS and higher-level TTS likely differ mechanistically and could result in different consequences for the individual. These are described below. N.B. These groupings are putative and illustrative, not empirical or regulatory classifications, and should not be used as the basis for legal or management decisions since the evidence base is insufficient to define any threshold between them.

- **Low-level TTS (≤15 dB threshold shift[3]):** responses are primarily chemical, involving changes at the molecular and cellular level. Chemical triggers cause temporary changes in hair cell function which reduce the cellular response to sound. This is thought to be an adaptive process, protecting the cochlea from overstimulation or metabolic stress.
- **Higher-level TTS (15<40 dB threshold shift):** responses involve physiological and observable effects in tissues. This can involve physical changes in cochlear structures, swelling at nerve endings underneath inner hair cells, excitotoxicity which causes temporary damage to cochlear neurons, metabolic overload and effects on synaptic contacts between hair cells and spiral ganglion neurons. It is noted that where TTS results in physical damage, it may potentially be considered as auditory injury due to the fact that, even if the hearing thresholds recover, the cellular injury may not be fully reversible (e.g. Tougaard et al., 2009).

Therefore, the current state of knowledge means that TTS of >15 dB have sometimes been discussed as potentially involving more pronounced physiological responses than the onset criterion of 6 dB; however, given the limited and variable evidence base, this distinction should be considered illustrative rather than indicative of biological significance. This certainly warrants further research to strengthen the evidence base and support improved management decisions.

A recent study considered auditory fatigue in poorly studied Antarctic marine mammal species in a ‘pristine environment’ as part of a case study of noise-producing activities occurring under German jurisdiction within Antarctic waters (Booth et al., 2024; Verfuss et al., 2024). This was carried out under consideration of the Antarctic Environmental Protocol in which conservatively considers any *“less than minor or transitory”* impact as requiring an EIA. In this context, an expert elicitation process involving acousticians, mammal hearing experts, physiologists and marine mammal ecologists, estimated the level of threshold shift that could potentially significantly and negatively affect biological and/or life history functions of a marine mammal (in the unique context of the Antarctic environment and German regulatory environment (as described in the **Is TTS injury?** section above). The definition for this case study was: *“injury as ‘significant (=non-negligible) damage to the physical integrity or health of each individual animal such as a temporary/reversible impairment”*. Experts determined that for exposures to vessel noise and seismic airgun noise (a pulsed, low frequency, broadband noise source that is acoustically similar to noise generated from pile-driving) median threshold shifts of 20.5 dB for very high frequency cetaceans (including harbour porpoise) could be considered to meet the above definition (Verfuss et al., 2024).

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[3] Ryan et al., (2016): *“the initial 10–15 dB of TTS may serve as a mechanism to extend the dynamic range of hearing, rather than representing a damage mechanism”*.

Other similar exercises have attempted to assess the available evidence base to consider the extent to which a more severe PTS could have detrimental effects on the vital rates (survival or reproduction) of individual marine mammals. Experts assessed given that auditory injury at the PTS-onset level (40 dB threshold shift) is considered unlikely to be biologically significant in terms of effects on the vital rates of harbour porpoise, bottlenose dolphins and seals (Booth and Heinis, 2018), see detail in **Appendix 3**.

Summary

- Whilst there is a lack of legal and regulatory consensus regarding the definition of 'auditory injury', **most countries do not consider TTS to be auditory injury**.
- TTS represents a short-term reduction in hearing sensitivity, typically recovering within an hour for small shifts (4–5 dB). Not all TTS-inducing exposures lead to tissue damage (and thus lead to physical injury).
- TTS effects from pile driving have been shown to be frequency-specific (e.g. 4-8 kHz in harbour porpoises). As such, their impact on marine mammal biological functions (communication, predator/prey detection) is currently considered to be limited.
- Current TTS-onset thresholds (NMFS, 2024) are based on the *smallest measurable* changes in hearing, not on levels likely to cause functional impairment. These thresholds were originally developed to support estimations of PTS-onset, **not to serve as regulatory thresholds for ecologically significant impact**.
- What level of threshold shift might be considered biologically meaningful is currently unknown, and **no biologically meaningful TTS thresholds have been established**.
- TTS predictions based on $\mathrm{SEL}_{\mathrm{cum}}$ are **highly conservative** as they omit: (i) the potential for TTS recovery between pile strikes or during breaks in pile driving, and (ii) distance-related effects on the impulsive characteristics of the sound. These factors likely lead to overestimations of impact ranges.
- Until there is sufficient scientific evidence to indicate a level and duration of TTS that may have a biologically meaningful effect on individuals, it is more appropriate to focus environmental impact assessments on PTS (as true auditory injury) and behavioural disturbance (e.g. disruption to foraging or migration).

SMRU Consulting Position

For the reasons outlined in the sections above, SMRU Consulting consider that the most widely adopted definition of auditory injury, this being PTS-onset, is most supported by the evidence. Further, SMRU Consulting do not agree that quantifying the numbers of animals potentially at risk of TTS, **based on current TTS-onset thresholds**, will provide sufficient information on which to base an assessment of the likely significance of the effect of TTS on individual receptors or, ultimately, on receptor populations. Until there is a greater understanding of the level and duration of TTS that may have a meaningful biological effect, **impact assessments should focus on PTS for auditory injury.**

Appendix 1: Equal Energy Hypothesis

The equal-energy hypothesis assumes 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 however, a continuous and an intermittent noise exposure of the same SEL will produce different levels of TTS (Ward, 1997). However, 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 (e.g. Kastak et al., 2005; Mooney et al., 2009; Finneran et al., 2010a; 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. Therefore, the equal energy hypothesis assumption behind the $\mathrm{SEL}_{\mathrm{cum}}$ threshold is not valid, and as such, models will overestimate the level of threshold shift experienced from intermittent noise exposures.

Kastelein et al. (2014) showed that a porpoise experienced a 6-8 dB lower TTS when exposed to sound with a duty cycle of 25% compared to a continuous sound. Kastelein et al. (2015) also showed for a 100% duty cycle (continuous noise), PTS-onset is predicted to be reached at a $\mathrm{SEL}_{\mathrm{cum}}$ of 196 dB re 1 $\mu\mathrm{Pa}^2$s, but for a 10% duty cycle, the 40 dB hearing threshold shift is predicted to be reached at a $\mathrm{SEL}_{\mathrm{cum}}$ of 206 dB re 1 $\mu\mathrm{Pa}^2$s (thus resulting in a 10 dB re 1 $\mu\mathrm{Pa}^2$s difference in the threshold).

These findings can be used to highlight the potential conservatism in the current PTS/TTS assessments for pile driving, which typically have a duty cycle <25% during the soft start and initial ramp up. Southall et al. (2007) 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. Therefore, the threshold at which PTS-onset is likely is at least 2.4 dB higher than the PTS-onset threshold proposed by Southall et al. (2019) when considering a 25% duty cycle.

Appendix 2: Impulsiveness

Southall et al. (2019) assumed that an animal's hearing threshold will shift by 2.3 dB per dB SEL received from an impulsive sound, but only 1.6 dB per dB SEL when the sound received is non impulsive. The TTS/PTS onset thresholds for non-impulsive sound are, therefore, higher than for impulsive sound, as more energy is needed to cause TTS/PTS. Consequently, an animal subject to both types of sound will be at risk of PTS at an SEL_{cum} that lies somewhere between the PTS onset thresholds of impulsive and non-impulsive sound.

Southall et al. (2019) acknowledge that as a result of propagation effects, the sound signal of certain sound sources (e.g., impact piling) 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 (Southall et al., 2007).

Hastie et al. (2019b) estimated the transition from impulsive to non-impulsive characteristics of impact piling noise during the installation of OWF turbine foundations at the Wash and in the Moray Firth. They showed that the noise signal experienced a high degree of change in its impulsive characteristics with increasing distance. 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 25ms) reduces to only 20% between ~2 and 5km from the source.

Martin et al. (2020) investigated the sound emission of different sound sources (including piling) to test techniques for distinguishing between the sound being impulsive or non-impulsive. They suggested the use of kurtosis (a measure of the asymmetry of a probability distribution of a real-valued variable) to further investigate the impulsiveness of sound. 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
- Kurtosis of 40 = fully impulsive (based on data from Hamernik *et al.,* 2007).

The results from Martin et al. (2020) shows (for unweighted and LF-C weighted sound) 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.

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"*. Southall (2021) also 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"*.

Most recently, as a part of the range dependent nature of impulsive noise (RaDIN) project, Matei et al. (2024) modelled four metrics of impulsiveness and found that impulsiveness of pile driving noise decreased as it travelled further away from the source. Although a decrease in impulsiveness was noted within the first five kilometres from the piling location for all metrics, the authors caveat that this is not equivalent to a range at which these sounds are no longer impulsive, and that the rate at which a signal becomes less impulsive will be dependent on the propagation conditions of that environment (Matei et al., 2024).

Appendix 3: Biological significance at the PTS-onset threshold

Booth and Heinis (2018) provides a summary of the most complete assessment of the evidence base on the topic of how PTS affects vital rates in marine mammals. This process involved convening seven world leading experts on marine mammal hearing and noise, a review of the available evidence collected to date (which has not markedly changed since 2018) and their best critical judgments given the evidence base. The experts worked together to collate and discuss the current state of knowledge of threshold shifts in response to low frequency broadband sound sources (later focusing on species-specific judgments as part of the elicitation process). The experts agreed that "*it was important to realise that reduced hearing ability does not necessarily mean a less fit animal (i.e. an animal of lower fitness)*."

Following a review and discussion of the current literature, experts determined: "*Following exposure to low frequency broadband pulsed noise, TTS was typically observed 1.5 octaves (see Appendix 1 - Glossary) higher than the centre frequency of the exposure sound for seals and porpoise (Kastelein et al. 2012a, Kastelein et al. 2012b, Kastelein et al. 2013a, Finneran 2015). For piling noise and airgun pulses, most energy is between ~30 Hz- 500 Hz, with a peak usually between 100 – 300 Hz and energy extending above 2 kHz (e.g. Kastelein et al. 2015a, Kastelein et al. 2016)*". Based on this, the experts concluded that if piling noise resulted in a threshold shift, that this would manifest in the mammalian ear as a notch in hearing sensitivity in a narrow frequency band between 2-10 kHz. They stressed this was not a loss of hearing across this entire band.

Furthermore, experts agreed (following an ad hoc analysis in the workshop – fully described in Appendix 3 of that report) it was unlikely that seals or bottlenose dolphins would experience more than 6 dB of PTS in the 2-10 kHz frequency band following exposure to LFBP due to low growth rates (under low duty cycle conditions). For porpoises, the elicitation considered both an 18 and a 24 dB PTS in the 2-10 kHz frequency band.

Overall, experts provided best estimates of the effect of PTS on vital rates of typically less than 0.5% reduction – which is significantly smaller than the natural year-to-year variation in vital rates expected to be caused by typical environmental conditions (estimated to be 25-30% (Harwood et al., 2014)).

Booth and Heinis (2018) also summarised the mechanisms experts considered as to whether PTS could significantly affect vital rates: *"In considering how any PTS could affect vital rates (i.e. probability of survival, probability of fertility), experts discussed the mechanisms by which this could occur. In general, experts noted that where communication has a significant social or reproductive function, that this might be a means by which survival and/or reproduction are affected. Experts noted however that PTS would likely occur over a small frequency range and that much of the energy of communication signals either fell outside the likely range affected by PTS or that the loss of part of the signal would likely not affect detection of the communication signals."*

Given the current understanding of how PTS from piling is expected to manifest in the mammalian ear – and the mechanisms that could lead to an effect on vital rates (sensu Booth and Heinis (2018)) – SMRU Consulting considers that it is highly unlikely that vital rates would be altered in a biologically meaningful way as a result of PTS from piling using the PTS-onset threshold.

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