ACOUSTIC IMPACT ASSESSMENT

Öresundskablarna FL25 Øresundskablet FL25

Assessing the impact of an ultra-short baseline sonar (USBL) on seals and harbor porpoises in the Sound

2024-11-20

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1 INTRODUCTION

WSP Denmark and WSP Sweden have carried out an acoustic impact assessment of ultra-short baseline sonars (USBL) operating in the Sound between Denmark and Sweden while exchanging power cables on the seabed. Ultra-short baseline sonars are used as acoustic positioning systems in water. They are needed to track remotely operated vehicles (ROVs) when removing large boulders, removing existing power cables and installing new cables between Denmark and Sweden.

The impact assessment is concerned with harbor porpoises and seals and investigates the risk for permanent threshold shift (PTS), temporary threshold shift (TTS) and behavioral response regarding the noise created by the sonar.

During the work at sea, other sonars than USBL sonars are needed. Multi-beam echo-sounders (MBES) have not been assessed since they operate at a frequency range which is beyond the hearing range of harbor porpoises and seals (≥ 200 kHz).

To further limit the scope of the impact assessment, it is based on simplified transmission loss calculations using the sonar equation. The transmission loss calculations are not time and place specific in the sense that neither bathymetry nor the schedule of the planned activities have been considered. The transmission loss models are, however, tuned to be representative of a worst-case scenario in the Sound.

2 ULTRA-SHORT BASELINE SONAR (USBL)

2.1 CHARACTERISTICS

A USBL system consists of two transponders both transmitting and receiving - one placed on the ROV and one on the hull of the surface vessel. The two transponders talk to each other using short pings to calculate the position of the ROV. The impact assessment is based on the assumptions that the transponders:

1. Radiate sound equally in all directions and behave as acoustic point sources,
2. Emits intermittent high-frequency signals, pings, of short duration,
3. Pings are narrowband, meaning that the transmitted energy is localized in a compact frequency region.

A JASCO report of a sea trial in the North Sea found that the tested USBL sonar was almost omnidirectional, intermittent and showed a spectrogram in which it is seen that the signal is narrowband but with harmonics (Pace, Robinson, Lumsden, & Martin, 2021). This supports the above-mentioned assumptions.

USBL sonars typically operate at a narrowband frequency between 19 and 50 kHz and have a source level of up to 192 dB RMS and 200 dB peak (Walker, 2019).

It is noted here that the narrowband assumption is important for the interpretation of the Danish guidelines for underwater noise.

2.2 PROGRAM

Energinet has provided WSP with a list of equipment used on the work vessels, MBES and USBL sonars, during the work at sea. Energinet has also provided the technical data of the USBL sonars including source level (SL), pulse length and pulse repetition frequency. Energinet has furthermore specified the program where the use of a USBL sonar is planned as presented in Table 1.

Table 1. Planned activities with corresponding USBL equipment and specifications.

Activity	Schedule (Preliminary)	USBL sonar	Transponders	Source level (dB RMS 125 ms re. 1 µPa at 1 m)	Pulse length (ms)
Removal of boulders	**July**	**SONARDYNE Ranger 2**	**Transceiver 8142**	**169 or 177**	**8**
			Transponder 8190	**169 or 181**	**8**
Removal of existing cables	**August**	**SONARDYNE Ranger 2**	**See above**	**See above**	**See above**
Installation of new cables	**September**	**ORE BATS (Depths >6 m) and SONARDYNE Scout (Depths <6 m)**	**BATS Transponder**	**192**	**6**
			BATS Transponder 4370A	**188**	**10**
			Scout Transceiver 8024	**180**	**6**
			Scout Transponder Coastal	**186**	**2**
			Scout Transponder 8071	**185**	**4**

2.3 CASE STUDIES

The best-case and worst-case were selected for the acoustic impact assessment. The best-case, Low SL, corresponds to the lowest reported source level in Table 1 and is representative for the USBL that will be used when removing large boulders and removing the existing power cables from the seabed. The worst-case, High SL, corresponds to the highest reported source level in Table 1 and is representative for the USBL that will be used to install the new power cables on the seabed. The two cases are summarized in Table 2.

The choice of a worst- and best-case scenario is also based on the possibilities in choice of equipment for any given activity. When removing large boulders and existing power cables, the employed USBL sonar has high and low SL settings. The high SL setting is usually only used in deeper water, so a low SL setting is expected during these activities.

During the installation of new cables, the work is limited to using the ORE BATS USBL when operating at depths >6 meters. Therefore, we use this as a conservative estimate for shallow waters as well, even though the SONARDYNE Scout that will be used in shallow waters (<6 meters depth) has a lower SL.

We assume that the USBL sonars in Table 2 operates narrowband in the 25 kHz one-third octave band, which is a worst-case scenario for the transmission loss.

Table 2. Description of the worst-case and best-case USBL sonars used in the acoustic impact assessment.

Case studies of ultra-short baseline sonar Assumed to operate at 25 kHz			
	Source level (dB RMS 125 ms re. 1 µPa at 1 m)	Pulse length (ms)	Pulse repetition frequency (Hz)
Low SL	**169**	**8**	**1**
High SL	**192**	**6**	**1**

3 GUIDELINES FOR UNDERWATER NOISE

3.1 HEARING THRESHOLDS

Harbor porpoises (swe. tumlare, dan. marsvin), *Phocoena phocoena*, are shy animals that avoid loud noises; this has been shown in several studies of reactions to impulse sounds from, for example, piling and sonars (Tougaard J. , 2014; Andersson & Johansson, 2013). Harbor porpoises have good hearing and can hear sounds from about 1 kHz to above 150 kHz and can detect sounds as low as 40-50 dB re. 1 µPa (Andersson & Johansson, 2013). Harbor porpoises' reaction to an active sonar depends on, in addition to the sound source and sound propagation, several factors such as age, sex and activity at the moment they detect a sonar ping (Andersson & Johansson, 2013). A reaction can mean anything from something that is barely noticeable to escape behavior in the form of a change of course or swimming speed to females abandoning their calves (Andersson & Johansson, 2013; Tougaard J. , 2014; Tougaard J. , 2021a; Tougaard J. , 2021b).

Seals are less sensitive to underwater noise but is considered sensitive during the mating and breeding season (Andersson & Johansson, 2013). There are several species of seals in the Sound between Denmark and Sweden. There is a population of harbor seals (swe. knubbsäl, dan. spættet sæl), *Phoca vitulina*, and gray seals (swe. gråsäl, dan. gråsæl), *Halichoerus grypus.* Harbor seals and gray seals have good hearing and can hear sound from about 100 Hz to around 80 kHz and can detect sounds as low as 55-65 dB re. 1 µPa (Andersson & Johansson, 2013; Tougaard J. , 2021a).

To assess risk distances, guidelines are needed for when different forms of reactions occur. Our assessment is based on guidelines for underwater noise in Denmark (Danish Energy Agency, 2023). The guidelines require the application of a filter, an auditory frequency weight, that compensates for the animals' hearing. For this purpose, marine mammals are classified into hearing groups. Harbor porpoises belong to the hearing group VHF in Southall et al. (2019). Harbor seals and gray seals belong to the hearing group PCW in Southall et al. (2019).

USBL sonars overlap in frequency with the hearing range of harbor porpoises and seals (harbor seals and grey seals), and an illustration of the VHF and PCW group audiogram is seen in Figure 1. The corresponding filters, known as auditory weighting functions, are shown in Figure 2. The general frequency range 19 – 50 kHz for USBL sonars (Walker, 2019) are shown as well as the selected frequency of 25 kHz which is used in our impact assessment. The VHF filter weight is -0,5 dB at 25 kHz and PCW weight is -4 dB at 25 kHz. The corrections were not applied; in practice, a USBL sonar is operating at a frequency within a frequency range for which the VHF-filter is approximately 0 dB. For seals, a correction would lower the assessed impact and thus, by not applying auditory weighting functions, the estimated impact on seals is conservative. The equations with parameters for the group audiograms and the auditory weighting functions are published in Southall et al. (2019).

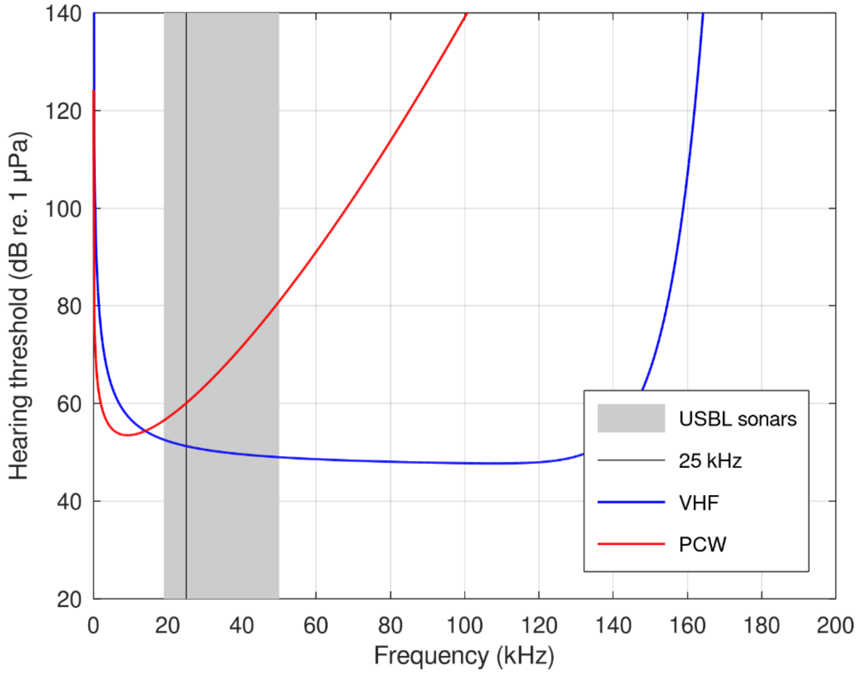

Figure 1. Group audiogram for the VHF and PCW marine mammals hearing groups and the frequency range in which a USBL sonar operates. The hearing range of the marine mammals and the frequency range of the sonar overlaps and thus the animals can be disturbed by the sonar or even risk hearing damage. We assess the impact at 25 kHz (marked by a vertical black line).

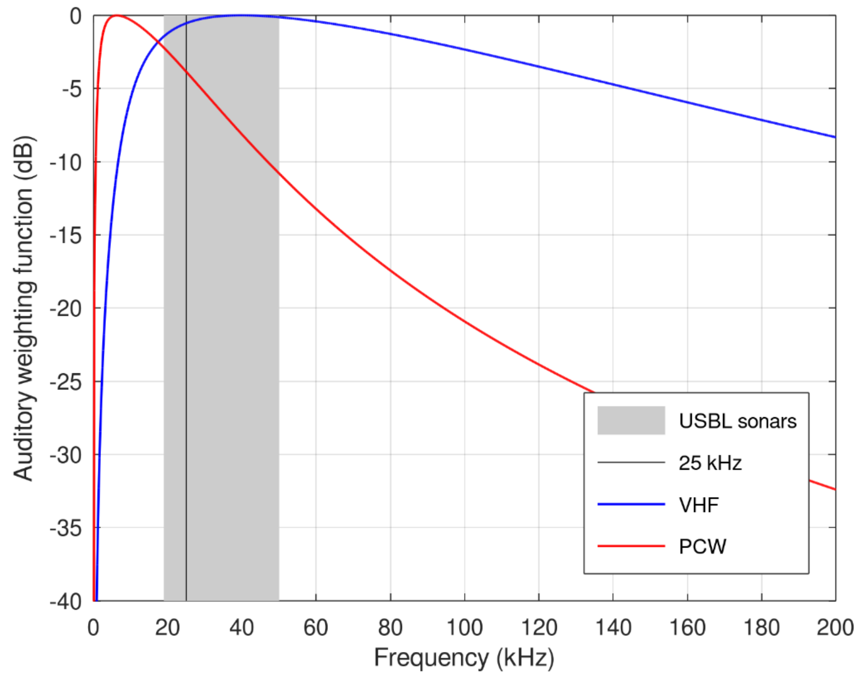

Figure 2. Auditory weighting function for the VHF and PCW marine mammals hearing groups and the frequency range in which a USBL sonar operates. We assess the impact at 25 kHz (marked by a vertical black line).

3.2 IMPULSE SOUNDS

There are many sources of anthropogenic sound in water that overlap in frequency with the hearing of fish and marine mammals. This means that marine life can be disturbed or injured by underwater noise. Anthropogenic sound is divided into impulse sound and continuous sound for assessment of effects on marine life (Tougaard J. , 2021a; Popper & Hawkins, 2019).

It can be hard to characterize sound signals into impulse or non-impulse sounds. Tougaard (2021a) has defined four characteristics that define an impulse sound:

1. Sharp onset with very short rise-time from start to peak pressure, on the scale of milliseconds,
2. Short duration, often not more than a second,
3. Large bandwidth,
4. Low time bandwidth product.

Only sounds that fulfills all four criteria are considered as an impulse sound (Tougaard J. , 2021a). Examples are sounds produced by underwater explosions, seismic air guns and pile driving (Tougaard J. , 2021a). Those impulse sounds are distinct from other sounds that fulfill some but not all the listed criteria. Examples of such sounds are produced by seal scarers and sonars (Tougaard J. , 2021a). They often violate the criteria of large bandwidth and are instead narrowband although often with strong harmonics (Tougaard J. , 2021a).

The above is consistent with the view of Andersson and Johansson (2013) that sonar signals may be seen either as a continuous sound, when the signal is longer than 100 ms, or as an impulse sound when short. It has been found that the behavioral response of harbor porpoises to a sonar signal depends on the signal characteristics (tonal, frequency modulated, et cetera) (Andersson & Johansson, 2013). It is therefore possible to argue for a behavioral threshold for harbor porpoise to sonar signals that is higher than that for impulse sounds that meets all four criteria; for example, 120 dB is used as a behavioral threshold by the US Navy (Andersson & Johansson, 2013). However, the Danish guidelines are conservative, and 103 dB given by Tougaard (2021b) and the Danish Energy Agency (2023) will be used to assess the acoustical impact.

In Pace et al. (2021) there is a spectrogram of a USBL sonar and it is seen that the received signal is both narrowband and with harmonics. Therefore, at least in Denmark, from a legal point of view, the USBL sonars does not produce impulse sounds and emitted pings belong to the category of P-Type impulse sounds in the Danish guidelines for underwater noise (Danish Energy Agency, 2023).

3.3 HARBOR PORPOISES

3.3.1 Denmark

The thresholds related to harbor porpoises in the Danish guidelines for underwater noise (Danish Energy Agency, 2023) are stated in Table 3 and Table 4. USBL sonars belong to the category of P-type impulse sound, which is regulated as non-impulse sound, because emitted pings violate the large bandwidth criterium. Thus, the TTS threshold is a cumulative sound exposure level (SEL cum) of 153 dB and the PTS threshold corresponds to a SEL cum of 173 dB. The behavioral threshold of 103 dB RMS 125 ms re. 1 µPa is based on impulse sound sources but used for other types of sound until better data is available for regulators (Tougaard J. , 2021b; Danish Energy Agency, 2023).

Table 3. Threshold values for TTS and PTS for harbor porpoise.

Cumulative sound exposure level thresholds for temporary and permanent threshold shift		
	Non-impulse sound (dB 24h VHF re. 1 µPa^{2}s)	Impulse sound (dB 24h VHF re. 1 µPa^{2}s)
TTS	**153**	**140**
PTS	**173**	**155**

Table 4. Threshold values for behavioral response.

Sound pressure level thresholds for behavioral response		
	Non-impulse sound (dB RMS 125 ms re. 1 µPa)	Impulse sound (dB RMS 125 ms re. 1 µPa)
Behavioral	**103**	**103**

3.3.2 Sweden

There is no established regulation of underwater noise in Sweden. The Swedish Agency for Marine and Water Management (2023) and the Swedish Environmental Protection Agency (2021) recommends, however, the use of the same threshold values for TTS, PTS and behavioral response as in Denmark.

The authors have not found, in Swedish texts on underwater noise, a clear discussion on criteria for impulse sound similar to the one in Tougaard (2021a). It is reasoned that the interpretation of the thresholds should be identical in both countries, so that the USBL can be regarded as a non-impulse sound source in Sweden.

There are, however, other thresholds in Swedish literature on underwater noise. A discussion on thresholds specifically for acoustic impact assessment of sonar systems can be found in Andersson and Johansson (2013). Other thresholds that could have been considered in Sweden for impact assessment are not used here since they do not exist in the Danish regulation.

3.4 SEALS

Both harbor seals and grey seals can possibly be present in or in the vicinity of the project area.

3.4.1 Denmark

The thresholds related to seals in the Danish guidelines for underwater noise (Danish Energy Agency, 2023) are stated in Table 5. Note that there is no threshold for behavioral response in seals.

Table 5. Threshold values for TTS and PTS for seals.

Cumulative sound exposure level thresholds for temporary and permanent threshold shift		
	Non-impulse sound (dB 24h PCW re. 1 µPa^{2}s)	Impulse sound (dB 24h PCW re. 1 µPa^{2}s)
TTS	**181**	**170**
PTS	**201**	**185**

3.4.2 Sweden

The Swedish Environmental Protection Agency (2021) recommends the use of the same threshold values for TTS and PTS as in Denmark.

4 APPROACH

The calculation of risk distances is made with the sonar equation (Lurton, 2015; Andersson & Johansson, 2013; Urick, 2013; Swedish Environmental Protection Agency, 2016). According to the sonar equation, the received sound pressure level SPL at a slant range r from a sound source is

$$SPL = SL - TL(r)$$

Here, $TL(r)$ is a transmission loss model. The model is either determined from measurements or numerical computation. The slant range is the distance between the sound source and the receiver. To evaluate risk distances where the received noise level is equal to or higher than a detection threshold value DT, one can write the signal excess SE (Urick, 2013) as

$$SE = SL - TL - DT$$

The risk distance is the largest slant range where $SE \geq 0$. The sound exposure level SEL can be calculated from the SPL using the following relationship (Lurton, 2015)

$$SEL = SPL + ED$$

where ED is the exposure duration. The exposure duration for a single ping is $10 \log_{10}(T_p)$ with T_p being the pulse length.

The correction for pulse length gives for a single 8 ms ping –21 dB and for a single 6 ms ping -22 dB. It is noted that the actual pulse length on a received sonar ping depends on the slant range because of multipath propagation and reverberation. Our calculations are simplified and based on the nominal pulse length. In Pace el al. (2021) the measured difference for SPL and SEL for a USBL was around -17 dB so the assumed numbers are realistic.

The cumulative sound exposure level can then be calculated in accordance with the Danish guidelines (Danish Energy Agency, 2023) for a fleeing animal. The calculation is based on a fleeing speed of 1,5 m/s for both harbor porpoises and seals.

5 TRANSMISSION LOSS

Transmission loss describes the attenuation of sound as it propagates away from the source in water. Our reasoning is that actual transmission loss in a surrounding can be bounded by two models, "high" and "low". Here, surrounding refers to the ambient water volume, seabed and surface. The high transmission loss model is the upper bound and means that sound wave is attenuated by the surroundings faster than in the case of a low transmission loss model, the lower bound. Hence, the low transmission loss model, if the model is properly calibrated, is a conservative estimate of sound propagation in a surrounding and suitable for acoustic impact assessment.

It is noted here that for large slant ranges between the sound source, the USBL sonar, and the receiver, the marine mammal, the most important parameter for transmission loss is volume attenuation and surface and seabed attenuation.

5.1 MODEL

Danish guidelines (Danish Energy Agency, 2023) admit simplified calculations with a transmission loss model on the form:

$$TL(r) = X \log_{10}(r) + A \frac{r}{1000}$$

where X and A are positive constants and r is the slant range in meters. The slant range is the distance between the source, a USBL, and the receiver, a marine mammal. The above is a classic model of transmission loss in water (Andersson & Johansson, 2013; Swedish Environmental Protection Agency, 2016) and X is known as the spreading factor and A as the attenuation factor and is expressed in dB/km. The attenuation may be due to volume attenuation and seabed attenuation (Andersson & Johansson, 2013).

The transmission loss model should be curve fitted to measurements (Danish Energy Agency, 2023). We do not have access to measured data of a USBL sonar operating in the Sound. Due to the lack of data, we have calibrated our model from remarks and transmission loss models in the Swedish literature for the Baltic sea (Andersson & Johansson, 2013; Swedish Environmental Protection Agency, 2016) and the Skagerrak strait (Andersson & Johansson, 2013).

We argue that a reasonable worst-case scenario of transmission loss in the Sound is expected to be similar to the transmission loss in the Baltic Sea due to the low salinity leading to low attenuation. The Skagerrak strait has higher salinity and thus the attenuation is expected to be higher than in the Sound.

5.2 SPREADING FACTOR

The spreading factor X is expected to be a positive number between 10, cylindrical spreading, and 20, spherical spreading (Urick, 2013). In the Baltic Sea, the spreading factor lies between 15 and 18 at large slant ranges (Swedish Environmental Protection Agency, 2016).

5.3 ATTENUATION FACTOR

The attenuation factor depends on depth, salinity and temperature (Urick, 2013). In Andersson and Johansson (2013) it is stated that the volume attenuation at 25 kHz in the Baltic Sea (salinity 7 PSU, 10 °C, 100 m) is around 1.12 dB/km and in the Skagerrak strait (30 PSU, 10 °C, 100 m) around 4.22 dB/km according to the Francois-Garrison model for absorption. In addition to volume attenuation, the seabed and surface attenuation will add up to those numbers.

5.4 REFERENCE MODELS

Andersson and Johansson (2013) attempted to simplify transmission loss in the Baltic Sea and the Skagerrak strait and to put transmission loss on a compact form. They used a model on the form

$$TL(r) = C + 10 \log_{10}(r) + (A + B) \frac{r}{1000}$$

Here, A is the volume attenuation, B is the attenuation from seabed and surface and C is a constant. The term $10 \log_{10}(r)$ represents cylindrical spreading. The coefficients B and C are curve fitted. We have used their models for low and high transmission loss at an optimal depth to calibrate our model. The reference models from Andersson and Johansson (2013) are used to bound our model of the Sound at large slant ranges and have the parameters in Table 6.

Table 6. Reference models for transmission loss at optimal depth from Andersson and Johansson (2013).

Simplified models for transmission loss in the Baltic Sea and the Skagerrak strait at optimal depth

$$TL(r) = C + 10\log_{10}(r) + (A + B)\frac{r}{1000}$$

Attenuation coefficients at 25 kHz

	Constant, $\boldsymbol{C}$	Volume attenuation, $\boldsymbol{A}$	Other attenuation, $\boldsymbol{B}$
The Baltic Sea			
Low TL	**19**	**1.12**	**0.6**
High TL	**30**	**1.12**	**2.8**
The Skagerrak strait			
Low TL	**19**	**4.22**	**1.5**
High TL	**30**	**4.22**	**2.8**

5.5 CASE STUDIES

Since we have access to four reference models of low and high transmission loss in neighboring waters, the Baltic Sea and the Skagerrak strait (Andersson & Johansson, 2013), we reason that the transmission loss in the Sound lie between the two. Because the Danish guidelines (Danish Energy Agency, 2023) admit a classic model of transmission loss in water, WSP calibrated the parameter A so that our models of low and high transmission loss lie between the reference models from Andersson and Johansson (2013) at large slant ranges where attenuation is important. WSP selected the parameter X from the Swedish Environmental Protection Agency (2016) and this corresponds to the Baltic Sea. We reason that the Baltic Sea is a worst case for the Sound. The selected parameters are summarized in Table 7. The two transmission loss models are illustrated in Figure 3 and Figure 4.

Table 7. Low and high transmission loss models for the Sound.

Simplified models for transmission loss in the Sound

$$TL(r) = X\log_{10}(r) + A\frac{r}{1000}$$

Attenuation coefficients at 25 kHz

	Spreading factor, $\boldsymbol{X}$	Attenuation factor, $\boldsymbol{A}$
Low TL	**15**	**2**
High TL	**18**	**5**

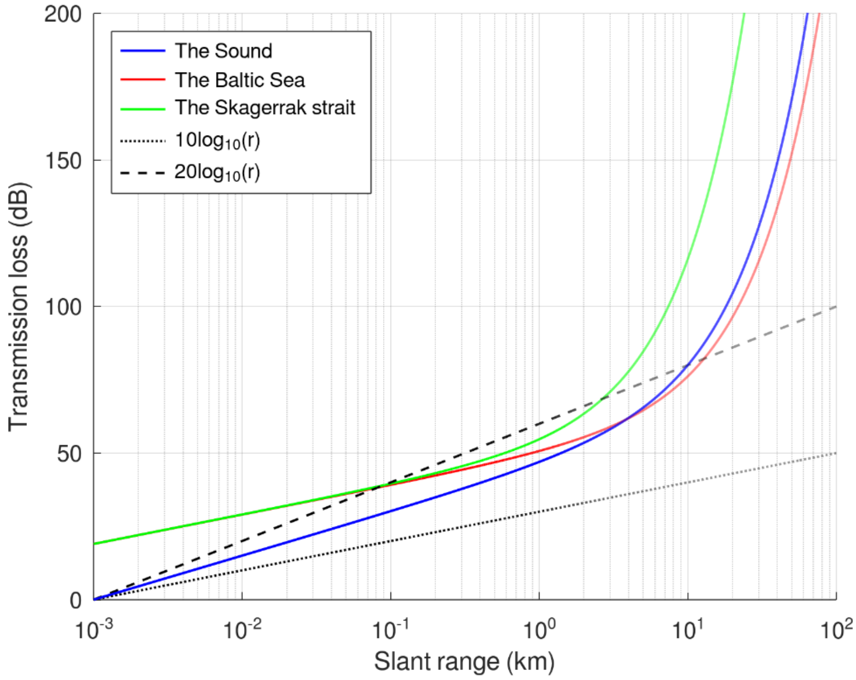

Figure 3. The simplified model of low transmission loss in the Sound, Low TL, compared to reference models for the Baltic Sea and the Skagerrak strait as well as cylindrical, $10\log_{10}(r)$, and spherical spreading, $20\log_{10}(r)$.

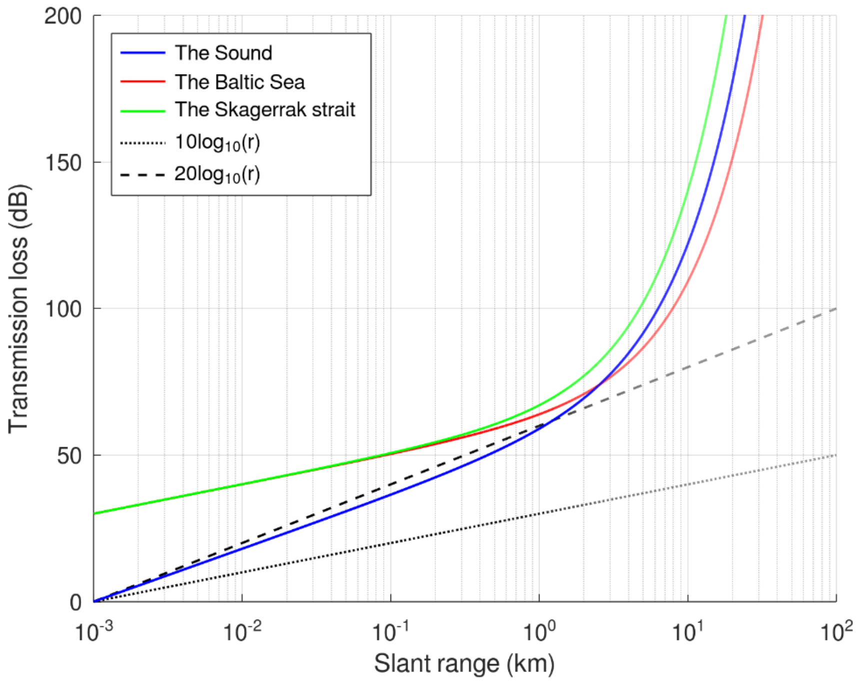

Figure 4. The simplified model of high transmission loss in the Sound, High TL, compared to reference models for the Baltic Sea and the Skagerrak strait as well as cylindrical, $10\log_{10}(r)$, and spherical spreading, $20\log_{10}(r)$.

6 RESULTS

6.1 HARBOR PORPOISES

The results are listed below in Table 8, Table 9 and Table 10.

Table 8. Risk distances for behavioral response of harbor porpoises.

Behavioral response 103 dB RMS		
	Low TL	High TL
Low SL	**5.2 km**	**1.7 km**
High SL	**13.6 km**	**4.7 km**

Table 9. Risk distances for temporary threshold shift of harbor porpoises.

Temporary threshold shift (TTS) SEL cum 153 dB		
	Low TL	High TL
Low SL	**No risk**	**No risk**
High SL	**600 m**	**100 m**

Table 10. Risk distances for permanent threshold shift of harbor porpoises.

Permanent threshold shift (PTS) SEL cum 173 dB		
	Low TL	High TL
Low SL	**No risk**	**No risk**
High SL	**No risk**[1]	**No risk**

6.2 SEALS

The results are listed below in Table 11 and Table 12.

Table 11. Risk distances for temporary threshold shift of seals.

Temporary threshold shift (TTS) SEL cum 181 dB		
	Low TL	High TL
Low SL	**No risk**	**No risk**
High SL	**No risk**	**No risk**

[1] The calculated value is 172.65 dB SEL cum.

Table 12. Risk distances for permanent threshold shift of seals.

Permanent threshold shift (PTS) SEL cum 201 dB		
	Low TL	High TL
Low SL	**No risk**	**No risk**
High SL	**No risk**	**No risk**

7 CONCLUDING REMARKS

- USBL sonars have a source level of up to 200 dB peak and 192 dB RMS. They operate at a narrowband frequency within the frequency range 19 - 50 kHz.
- USBL sonars emit pings that belong to the category of P-Type impulse sounds in the Danish guidelines for underwater noise. P-type impulse sounds are regulated as non-impulse sound. The reason that the pings are not belonging to I-type impulse sounds, which is regulated as impulse sound, is the pings being narrowband.
- USBL sonars operate within the frequency range in which harbor porpoises hear well. Our impact assessment of underwater noise from USBL sonars on harbor porpoises in the Sound, between Denmark and Sweden, indicates: (a) behavioral impact at distances up to 13.6 km, (b) temporary threshold shift for distances up to 0.6 km and (c) no risk of permanent threshold shift. The risk distances have been calculated for adverse acoustic conditions with low propagation loss and worst-case source level.
- There is no risk for seals.

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