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BUNDESAMT FÜR SEESCHIFFFAHRT UND HYDROGRAPHIE

„Assessment approaches for underwater sound monitoring associated with offshore approval procedures, maritime spatial planning and the marine strategy framework directive – BeMo“

Technical Report

Classification and assessment of impulsive noise with and without noise mitigation measures

Exposure Index based on a Habitat Approach

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The main objective of the R&D „ Assessment approaches for underwater sound monitoring associated with offshore approval procedures, maritime spatial planning and the marine strategy framework directive “ is to give insights in issues of mitigation applied to reduce impact from percussive pile driving on the marine environment. Information and data in the technical report have been available by the German National Noise Registry and the Informationsystem marinEARS of BSH.

Authors are responsible for the contributions in the technical report.

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1 Introduction

Noise pollution of the world's oceans has been of substantial public interest in recent years. Marine scientists continue to build our knowledge base by steadily/regularly recording underwater noise, attempting to assess the effects of anthropogenic noise input (such as ship noise and construction noise) in the marine environment. National legislators and international organisations are endeavouring to limit noise emission or immission by regulatory means where necessary. The EU Marine Strategy Directive classifies sound as impulsive and continuous sound events. A noise registry has been developed for impulsive noise sources at ICES, providing a basis for assessments in the OSPAR and HELCOM regions. Member states report their sound events annually. An active reduction of impulsive noise emissions can be mainly achieved by means of noise abatement systems. Current improvements in the noise quantification will consider the up to now non-mandatory information of the noise registry on noise mitigation measures. In the present work, actual data of the noise registry is used to perform an analysis on the effect of sound mitigation measures applying the proposed OSPAR ‘Indicator for the risk of impact from impulsive noise’. It depicts the consequences for the classification and the current assessment with and without application of noise abatement systems.

2 Relevant Documents

[1] Thiele, R & Schellenstede, G (1982): Standardwerte zur Ausbreitungsdämpfung in der Nordsee. FWG-Bericht 1980-7, Forschungsanstalt der Bundeswehr für Wasserschall und Geophysik

[2] Dekeling, R; Tasker, M; Van der Graaf, S; Ainslie, M; Andersson, M; André, M; Borsani, J; Brensing, K; Castellote, M; Cronin, D; Dalen, J; Ferreira, M; Folegot, T; Leaper, R; Pajala, J; Redman, P; Robinson, S; Sigray, P; Sutton, G; Thomsen, F; Werner, S; Wittekind, D; Young, J; Zampoukas, N; (2014): Monitoring Guidance for Underwater Noise in European Seas, Part II: Monitoring Guidance Specifications http://dx.doi.org/10.2788/27158

[3] Merchant, N; Faulkner, R & Martinez, R. (2018) Marine Noise Budgets in Practice. Conservation Letters., Volume 11, Issue 3 https://doi.org/10.1111/conl.12420

[4] de Jong, C; Heinis, F; von Benda-Beckmann, S & Binnerts, B. (2019-12) CEAF in SEANSE case studies, Impact of piling for wind farms on North Sea harbour porpoise population. TNO report, TNO 2019 R11563

[5] Tougaard, D & Dähne, J. (2017) Why is auditory frequency weighting so important in regulation of underwater noise? The Journal of the Acoustical Society of America 142, EL415 https://doi.org/10.1121/1.5008901

[6] DIN SPEC 45653:2017-04: Offshore wind farms –
In-situ determination of the insertion loss of control measures underwater

[7] ISO 18406:2017-04: Underwater acoustics –
Measurement of radiated underwater sound from percussive pile driving

[8] Bundesamt für Seeschiffahrt und Hydrographie (BSH) 20191002_DEsubmission_NoiseRegisterTemplate_NavalNoise_Explosion_Pile Driving, Events 2018

[9] Müller-BBM 2015: Report M100004/54 unpublished

[10] Alain Norro, Andreas Müller, Michael A. Ainslie, Nathan Merchant, Russell Leaper Müller-BBM Report No. M146361/06, Revision of the "TG Noise monitoring guidance" Sound exposure levels of pile-driving noise with/without noise protection measures, Background paper, Sep. 2019

[11] BMU Schallschutzkonzept, Konzept für den Schutz der Schweinswale vor Schallbelastungen bei der Errichtung von Offshore-Windparks in der deutschen Nordsee, 2013

3 Sound propagation under various scenarios in the German EEZ of the North Sea

In this study different scenarios were examined. Figure 1 and Figure 2 show the calculation of the different sound fields at three wind farms constructed in 2018, where the measured average sound levels regarding the metric SEL were below a value of 160 dB (Fig. 1) at 750 m distance and the virtual non-mitigated case with a SEL of 180 dB at 750 m distance (Fig. 2).

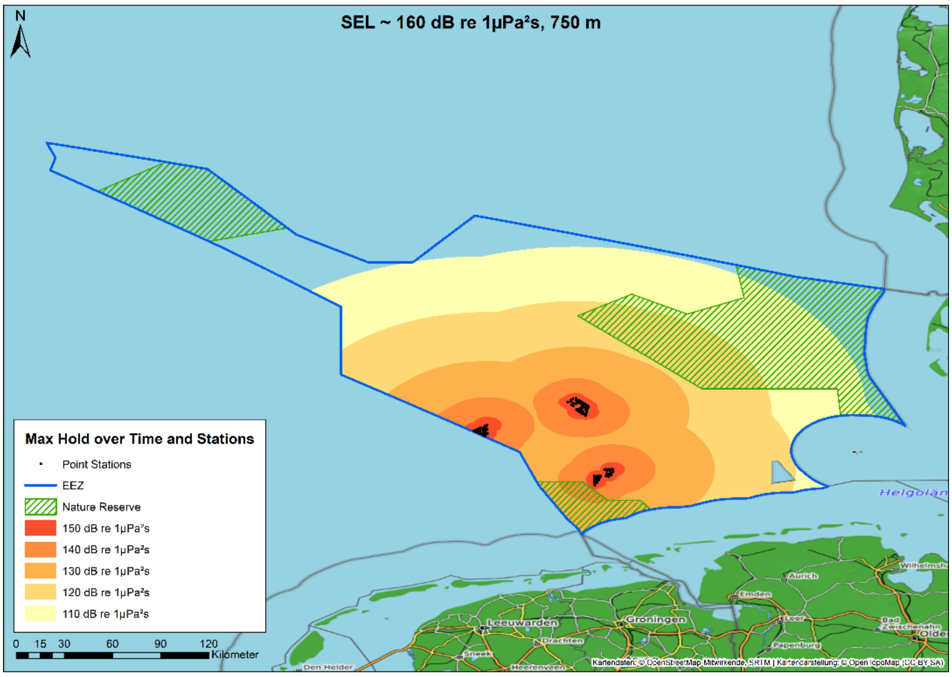


Figure 1: Maximum sound exposure level (Max Hold, 10 dB steps) of all pile driving activities in 2018 at an sound exposure level during pile driving of 160 dB re 1 µPa²s at 750 m

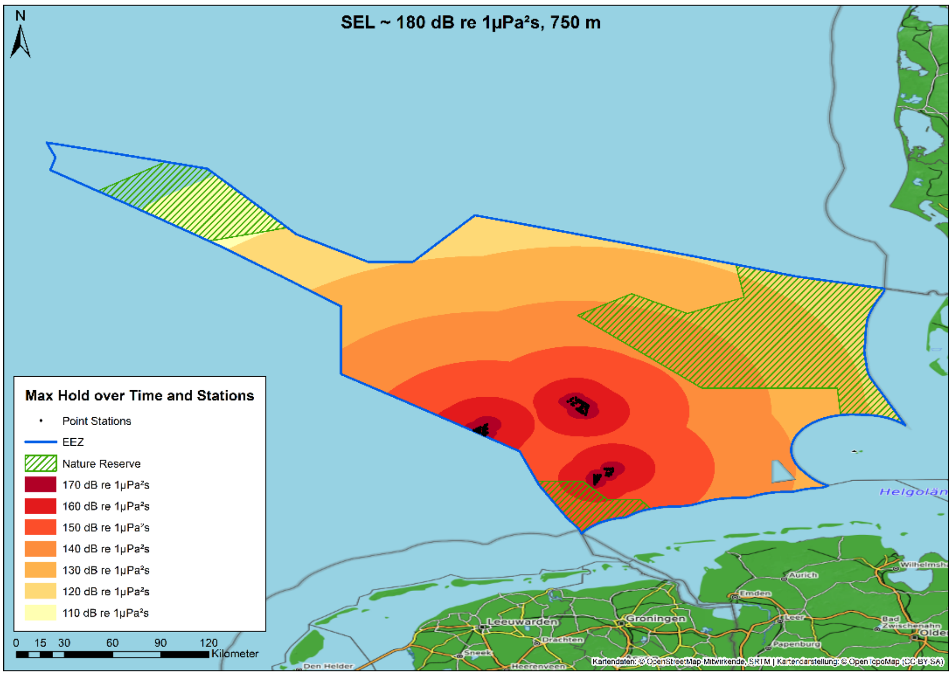


Figure 2: Maximum sound exposure level (Max Hold, 10 dB steps) of all pile driving activities in 2018 at a sound exposure level during pile driving of 180 dB re 1 µPa²s at 750 m

The sound insulation effect was assumed to be approx. 20 dB. Figure 1 and Figure 2 show how the area of the German EEZ (North Sea) is affected by impulsive noise in the period considered. Obviously, the noise abatement systems lead to a significantly reduction of the area impacted. These calculations were performed with a simple established empirical propagation model according to Thiele [1]. The propagation is conservative for long distances and may lead slightly reduced effective radii due to higher losses. For this study, these calculations are sufficiently accurate, as especially the relative comparisons and methodologies will be considered.

4 OSPAR: Indicator for the risk of impact from impulsive noise

4.1 Introduction and procedure

The OSPAR Committee EIHA is developing an indicator describing the impact of anthropogenic impulsive noise on the marine biota. The focus of the indicator is on the large scale, cumulative impact of impulsive noise exposure. The latest version of the indicator supplemented by an example of its application was presented to EIHA (Apri 2020). Applying the indicator roughly follows the steps described below.

A. Define assessment area (MA) and select indicator species.

B. Use the animal density or habitat area of the selected species within MA.

C. Determine the noise pressure map of assessment period.

D. Calculate a risk map using B and C.

E. Calculate the exposure curve using the risk map.

F. Compute the Exposure Index (EI).

Merchant et al. [3] published examples of the application of this indicator regarding disturbing effects both based on density data and on habitats.

However, the acoustic metrics are different for different sound events like explosion, seismic and pile-driving, see TSG Guidance [2], and cannot be easily compared. In the present study the area of the German EEZ (North Sea) was chosen as MA. As discussed in the methodology under development by TG-Noise and at the ongoing assessment of the indicator for OSPAR in the framework of the ICG-Noise population or habitat may be used alternatively under B.

Herewith an example based on the habitat approach is conducted. In the first step, the entire EEZ is taken as habitat of harbour porpoise, which is comparable to the population approach with an equal distribution of harbour porpoise density, which was e.g. considered in the TNO study. [4]. This approach automatically results in a direct comparability of the risk map and the noise pressure map. In the present study, exclusively pile-driving events of the year 2018 have been considered. Figure 3 schematically depicts the procedure used in the present work.

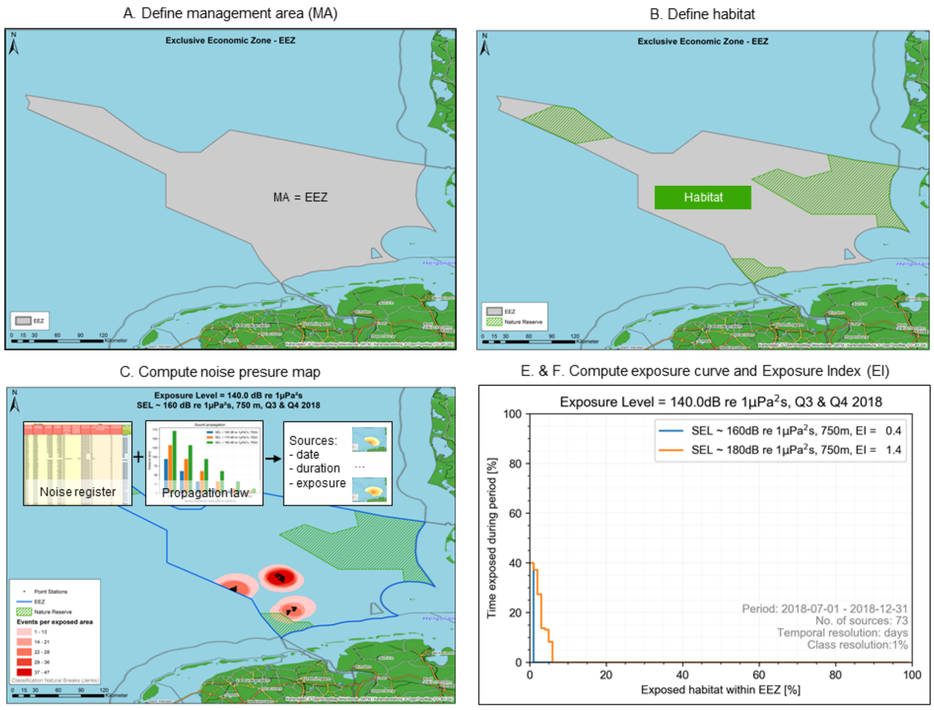


Figure 3: Schematic description of the procedure used in the present work.

Figure 4 and Figure 5 show the number of events (days with pile-driving) per area exposed to impulsive noise levels exceeding 140 dB re 1 µPa²s SEL in case of 160 dB re 1 µPa²s, at 750 m distance to the piling location, respectively 180 dB re 1 µPa²s, at 750 m distance (virtual non-mitigated case).

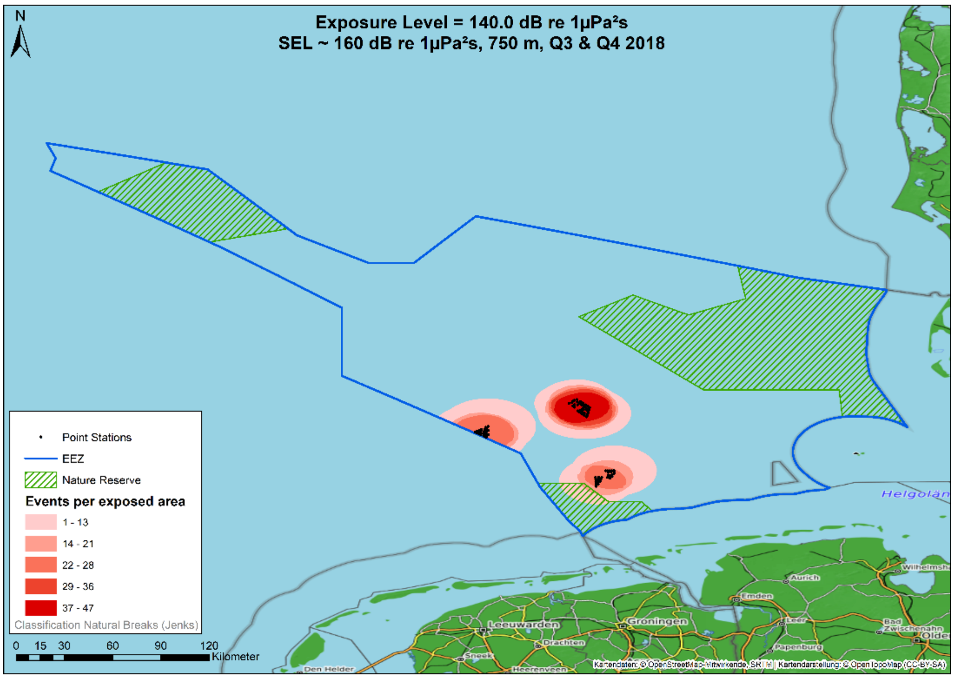


Figure 4: Number of events (days with pile-driving) per area (exposure level ≥ 140 dB re 1 µPa²s) for a period of half a year with a SEL of 160 dB re 1 µPa²s at 750 m distance to piling location.

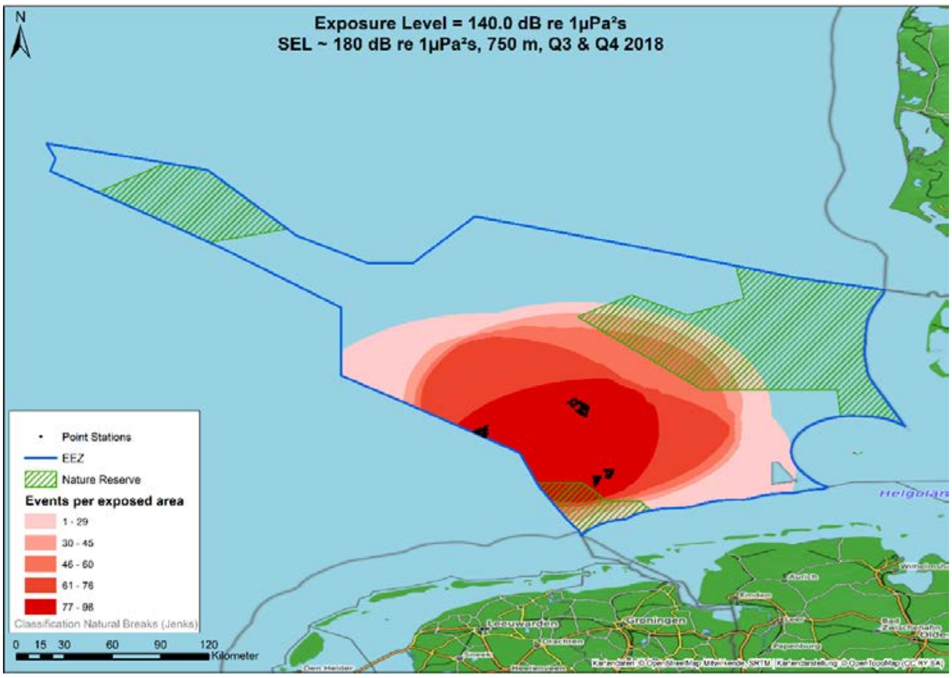


Figure 5: Number of events (pile driving) per area exposed ≥ 140 dB re 1 µPa2s for a period of half a year with a of 180 dB re 1 µPa2s at 750 m distance to piling location.

The images are comparable to the risk maps proposed by Merchant et al. [3], since the habitat approach relies on a uniform distribution, and can directly be converted to exposure curves. The exposure curve and the exposure index are exemplary as shown in Figure 6 for the second half of the year 2018.

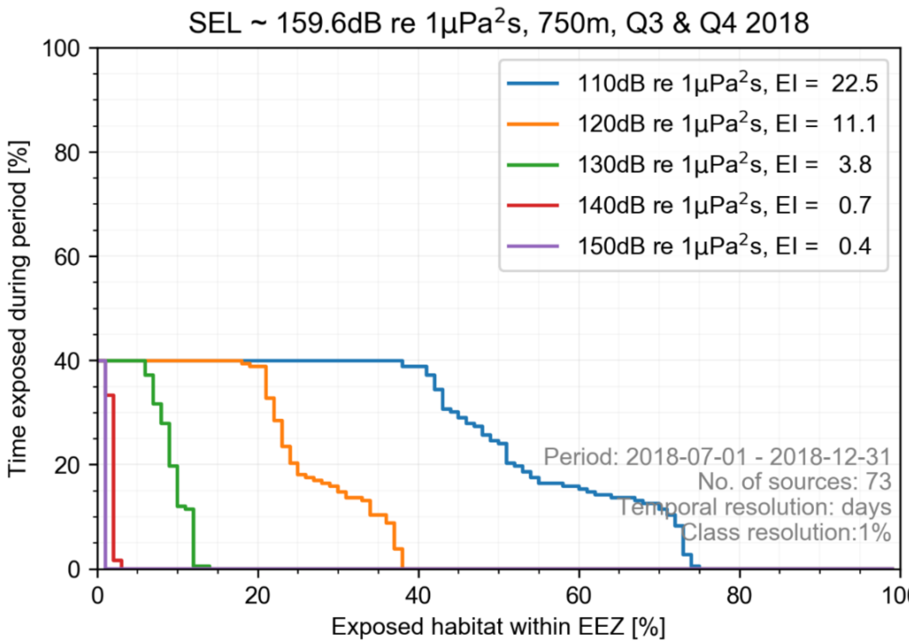


Figure 6: Exposure curve and Exposure Index for the second half of the year 2018 at an average SEL of 160 dB re 1 µPa²s at 750 m distance to piling location, at 73 pile-driving events per day for sound radii >110 dB to >150 dB. The class resolution of 1 % means that one hundredth of an area step is considered, see section 4.3.

Notes on Figure 6:
Short note on the interpretation of the Figure 6:

The following information can be inferred from the exposure curves. At 40 percent of the total days (73 days out of 183 days) piling events took place. Up to 40 % of the habitat has been exposed to a noise level above 110 dB SEL during the whole piling period (73 days) and the sound never reached this level in 25 % of the area.

Assuming an equal spatial distribution of the population in the area considered, in the same way up to 40 % of the population has been exposed to a noise level above 110 dB SEL for the whole piling period and 25 % of the population has never been exposed to impulsive noise above this level.

Exemplary acoustic threshold values were included in the analysis. By decreasing the threshold, the Exposure Index (since the exposed area is increasing) increases.

The following chapters analyse the influence of individual parameters such as time, space, but also sound mitigation measures (insertion loss) on the Exposure Index. We further examine how the noise registry content may be exploited in a best possible way. This applies in particular for categories of sources.

4.2 Influence of the temporal resolution and investigation time on the Exposure Index

4.2.1 Temporal resolution

With the previous representations, the effect of one event per day was examined. The temporal sound exposure may significantly differ for the type of impulsive noise event: while explosions are very short-time, pile-driving may last for up to three hours a day[1], seismic surveys possibly for the whole day. Figure 7 illustrates the influence of the temporal resolution on the time exposed for a 5 days period.

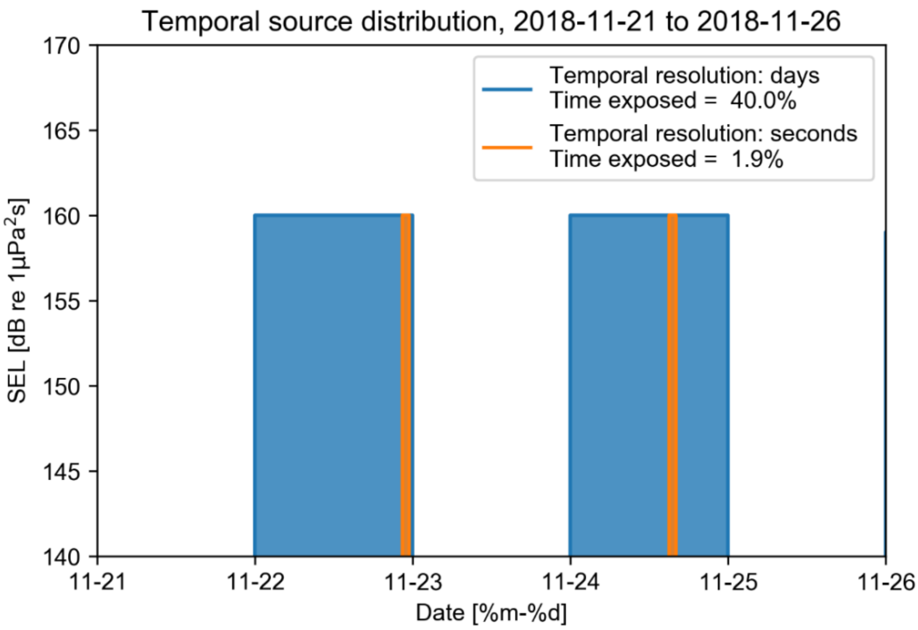


Figure 7: Demonstration of temporal resolution influence on time exposed during period, period is limited to 5 days with two pile-driving.

Figure 8 shows an example of the Exposure Index for a classification per day compared to a classification per second. In the present case the overall time period is half year (third and fourth quarter of 2018).

[1] Following the clauses in the German approvals the duration of driving a single pile may not last for more than three hours.

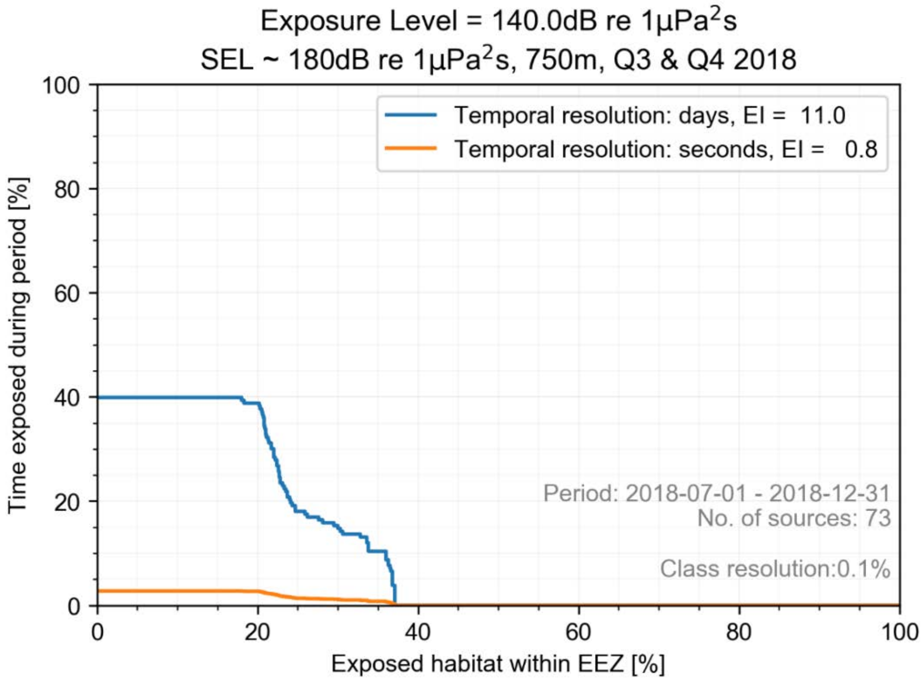


Figure 8: An example of the Exposure Index for a classification per day compared to one per second.

The analysis shows that the Exposure Index is highly dependent on the temporal resolution chosen.

Remark:

A further question arises if several events occur on one day. In this case, cumulative considerations must be made.

4.2.2 Investigation time

Usually annual and seasonal temporal analyses are performed. Figure 9 and Figure 10 show the entire second half of 2018 and the third and fourth quarters separately. As there were more events in the third quarter than in the fourth quarter, the Exposure Index of the third quarter shows the highest value.

Remark:
In order to enable an absolute evaluation for effects yet to be defined, a reference period (e.q. monthly, quarterly or annually) for the Exposure Index is required; for comparative studies, this Exposure index should already be used now. Suitable threshold values must be specified in future.

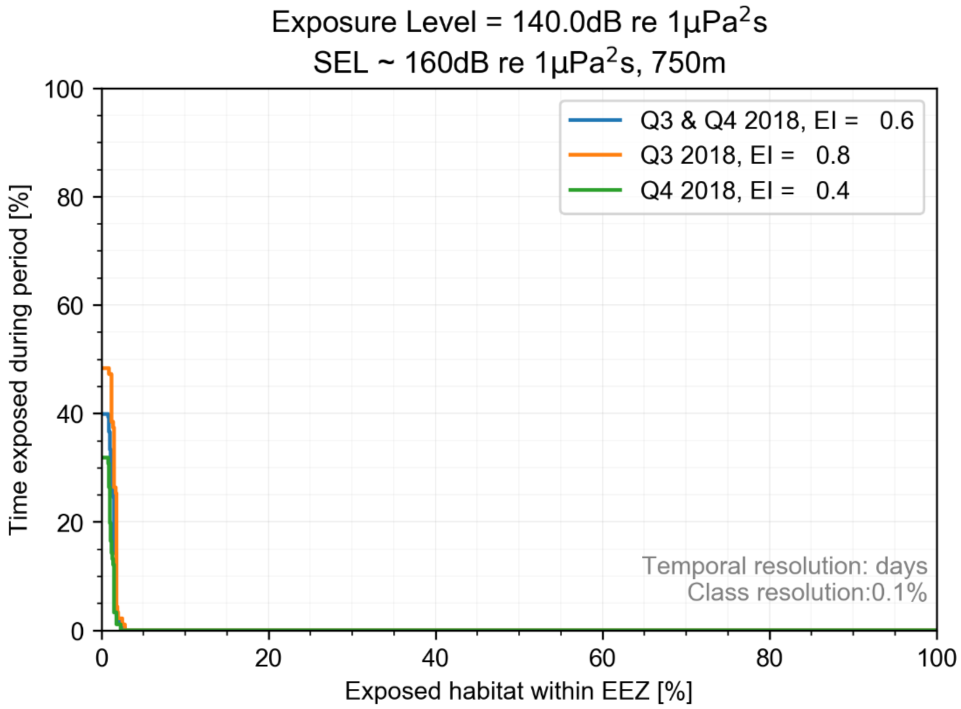


Figure 9: Comparison of the second half of the year 2018 with the 3rd and 4th quarters at an SEL of 160 dB re 1 µPa²s in 750m and a maximum permissible received SEL of 140 dB re 1 µPa²s.

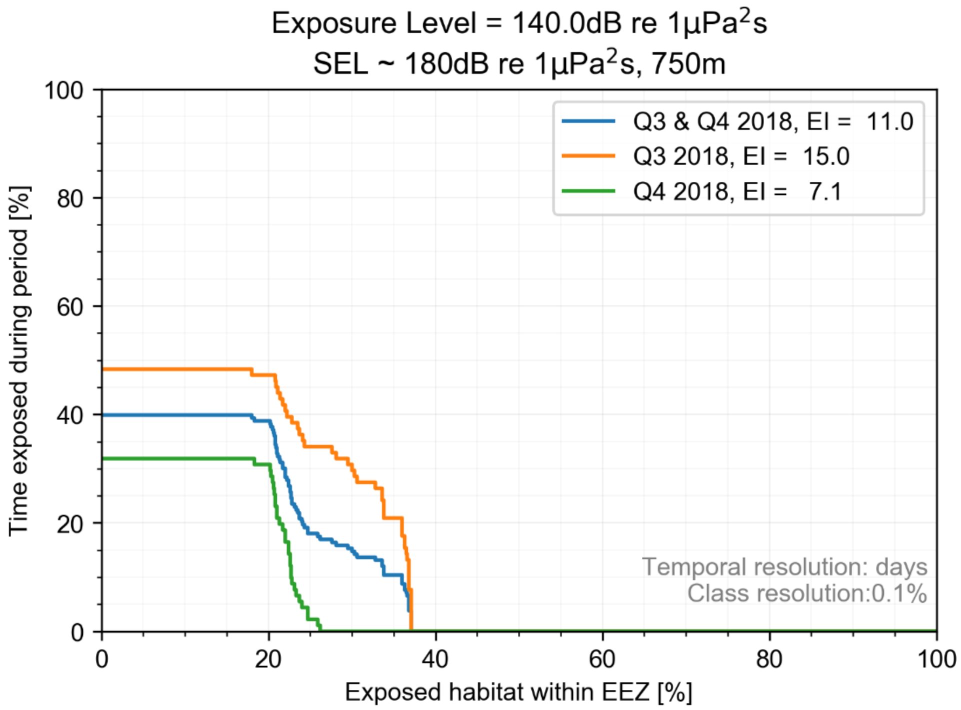


Figure 10: Comparison of the second half of the year 2018 with the 3rd and 4th quarters at an SEL of 180 dB re 1 µPa²s in 750m and a maximum permissible received SEL of 140 dB re 1 µPa²s.

The analysis shows that the Exposure Index is dependent on the analysed period. However, with reservations shorter periods can be joined to a longer one.

Another effect, not shown in the present work, is that analysing the same sources with periods having different percentage of exposed time leads to a difference in Exposure Indexes. E.g. 15 pile-driving events which occurred during the first 15 days of a month will lead to a peak value of the exposure curve of up to 50 % time exposed when considering a period of a total month. However, if instead only the first half of the month is considered in an assessment, the exposure curve would show a peak value of up to 100 % and thus result in another, higher, Exposure Index.

4.3 Influence of the grid size on the Exposure Index

For a long time, the spatial resolution of the investigations has been controversially discussed. To illustrate this, the ICES rectangles of the German EEZ and the sound prediction for the pile-driving events in 2018 are presented jointly, see Figure 11.

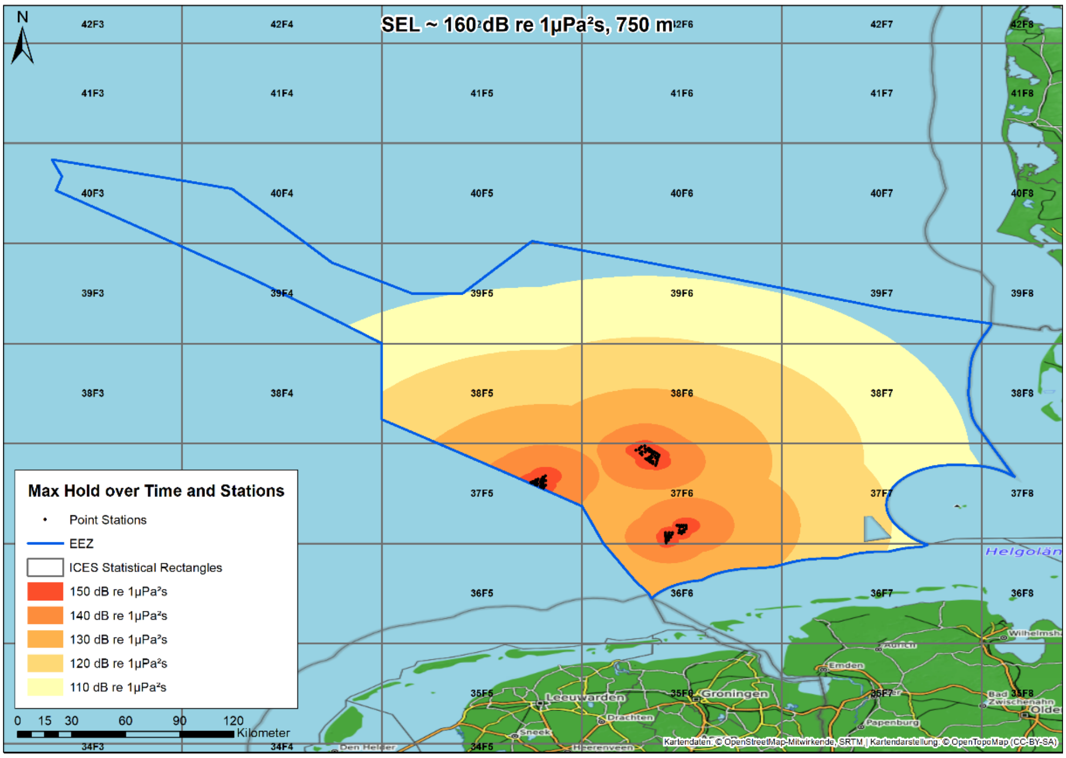


Figure 11: Sound prediction over the year 2018 displayed in German EEZ (North sea) together with ICES rectangles.

Figure 11 clearly shows that such a coarse resolution is not suitable for an accurate assessment of the situation regarding the pressure or risk from impulsive noise events. The German EEZ (North Sea) covers an area of 28,539 km². Figure 12 and Figure 13 show the influence of the grid size on the Exposure Index, exemplified by 0.1 % of the MA, 1 % of the MA and 10 % of the MA. It can be seen that the resolution for the question presented here is in principle accurate at a resolution of one percent. With coarser grids, the area is incorrectly weighted, i.e. an overestimated weight is assumed. This point will be further discussed in Section 4.6.

Remark:
Please note that the computation of the exposed area in this study follows the scheme of Thiele [8] and thus does not depend on a grid size. The degrading into classes with a specific grid size only applies while calculating the exposure curve and the Exposure Index (step E. and F. of the computation procedure).

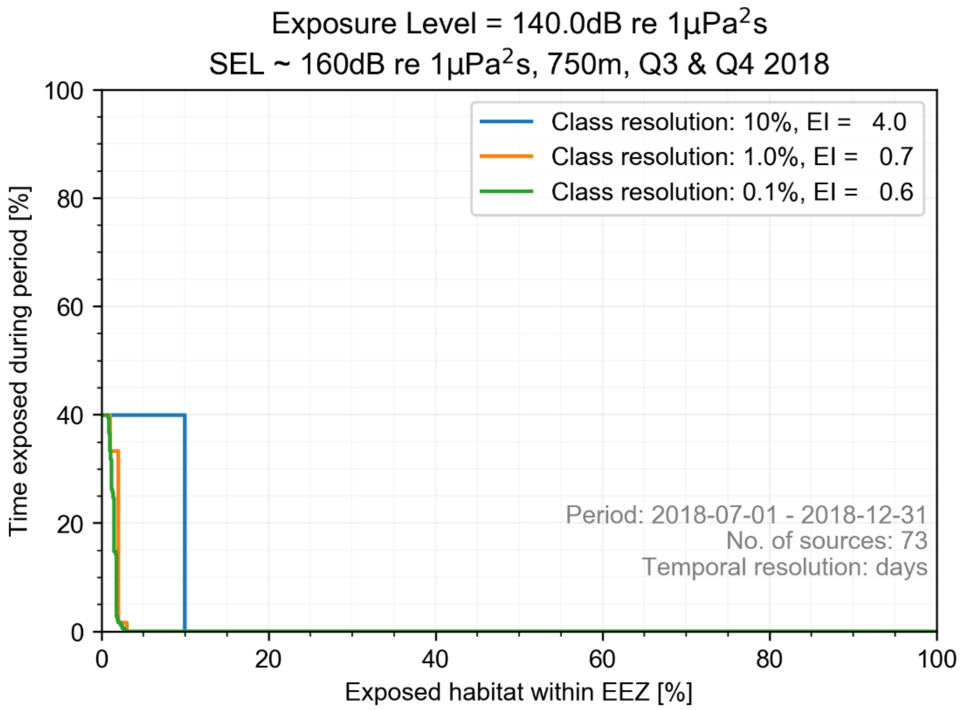


Figure 12: Influence of the grid size (Class resolution) on the Exposure Index, exemplified by 0.1% of the MA, 1% of the MA and 10% of the MA, SEL of 160 dB re 1 µPa²s at 750 m distance and a maximum permissible received SEL of 140 dB re 1 µPa²s.

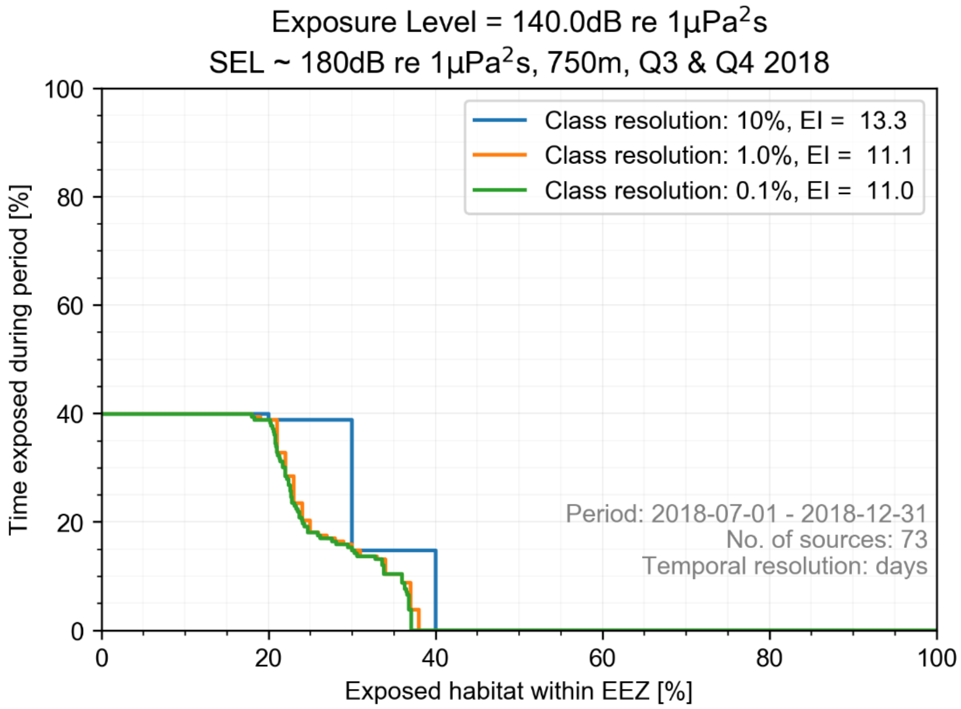


Figure 13: Influence of the grid size (Class resolution) on the Exposure Index, exemplified by 0.1 % of the MA, 1 % of the MA and 10 % of the MA, SEL of 180 dB re 1 µPa²s at 750 m distance and a maximum permissible received SEL of 140 dB re 1 µPa²s.

4.4 Influence of sound mitigation measures on the exposure Index

In order to perform an exemplary test regarding the influence of sound mitigation measures on the Exposure Index, it was assumed that the pile-driving was carried out in the second half of the year 2018 without sound mitigation measures, see Figure 14. It can be seen that this situation leads to a significant change in the Exposure Index, and thus the source strength in itself can be a first indicator for the assessment. We will discuss this again in Section 4.7.

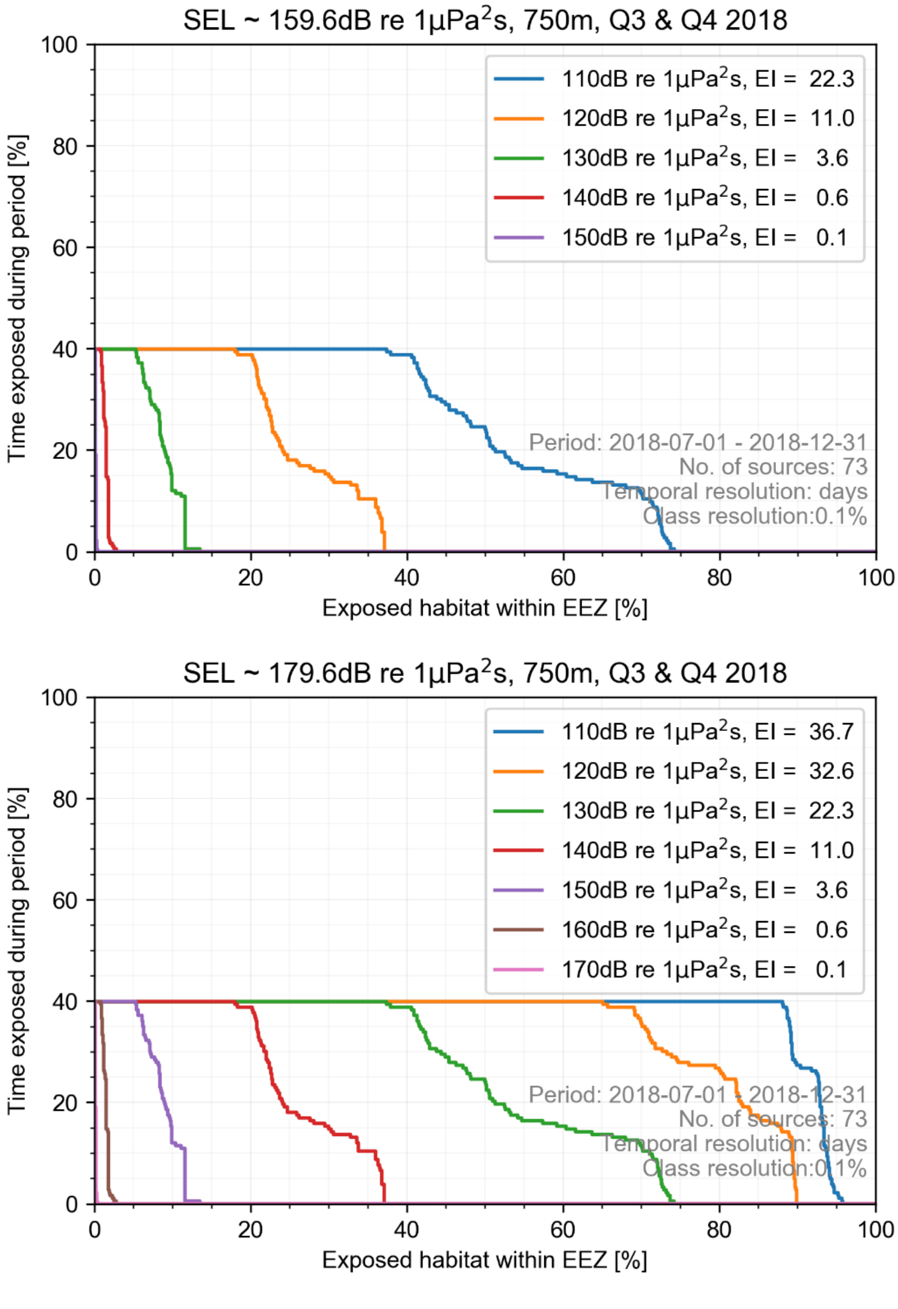


Figure 14: Exposed habitat depending on received level. The upper graph illustrates a source strength of SEL 159.6 dB re 1 µPa²s, 750m, the lower graph the non-mitigated case with a source strength of SEL 179.6 dB re 1 µPa²s, 750m.

4.5 Consideration of nature conservation areas

There are different possibilities to include nature conservation areas, esp. Natura2000-areas in the approach. In the previous sections we have considered the entire EEZ as MA and habitat. If nature conservation areas are included in the overall analysis, they should be evaluated separately or given special weight in the overall assessment.

The concept for the protection of harbour porpoises in the German EEZ of the North Sea was established 2013 by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety and follows a habitat approach in regard with disturbance as a cumulative impact of sound emissions due to percussive pile driving [11].

The concept addresses the reduction of sound emissions during installation of piles for wind farms by means of technical noise abatement and cumulative effects on habitats due to simultaneous activities at several construction sites.

The main rules of the concept regarding avoidance and reduction of disturbance on habitats for harbour porpoise are as follows:

a) The proportion of area affected by disturbing impulsive noise shall not exceed 10% of the entire area of the German EEZ in the North Sea in the case of parallel pile-driving operations,

b) The proportion of the area affected by disturbing impulsive noise shall not exceed 10% of the area of one of the nature conservation areas (Natura 2000 sites),

c) In the time from 01.05. to 31.08. the proportion of the area affected by disturbing impulsive noise shall not exceed 1% of the area of the nature conservation site "Sylter Außenriff - Östliche Deutsche Bucht", which is identified as calving ground for harbour porpoises.

The rules presume compliance with thresholds at activity level (SEL < 160 dB re 1 $\mu Pa^2 s$, Lpeak < 190 dB re 1µPa) and onset of significant disturbance at 140 dB re 1 $\mu Pa^2 s$.

Figure 15 shows that criterion a) was safely met for a SEL of 160 dB re 1$\mu Pa^2 s$ at 750 m. The rate was well below 5% for the entire half year. A temporally parallel pile driving activity would have been possible. However, Figure 15 also shows that for a SEL of 180 dB re 1$\mu Pa^2 s$ at 750 m (non-mitigated case), criterion a) was not met. It should however be noted that according to [11] a propagation model was used, which rather overestimates occurring sound pressure values at long distances.

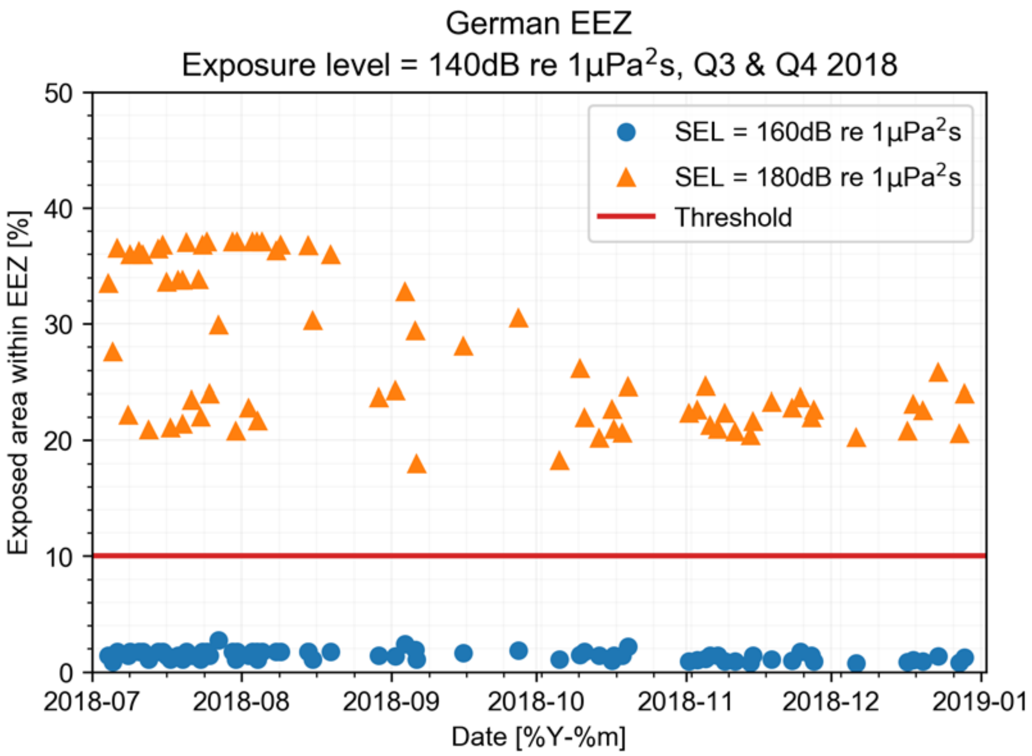


Figure 15: Percentage of area exposed per day within the German EEZ for a source strength of SEL 160 dB re 1 µPa²s, 750m, and SEL 180 dB re 1 µPa²s, 750m with 10% criteria.

If criterion b) is considered for the example of the nature conservation area “Borkum Riffgrund”, the resulting situation is shown in Figure 16. Again, the criterion is fulfilled in most cases for a compliance with a SEL of 160 dB re 1µPa²s at 750 m. Without noise abatement measures, the threshold would always be exceeded.

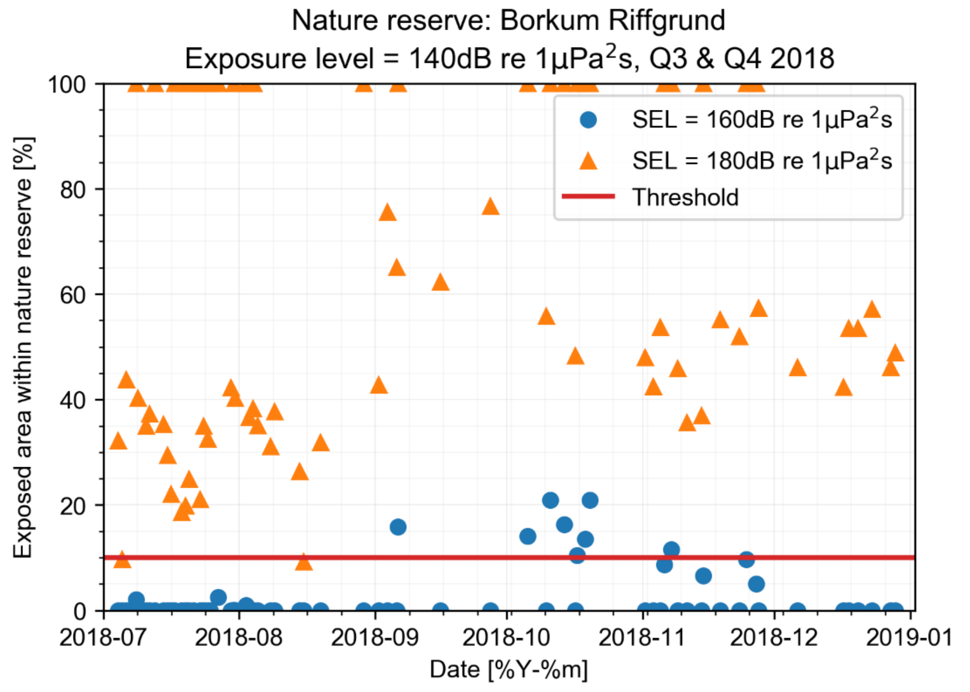


Figure 16: Exposed area over time (daily resolved) within nature conservation area (Borkum Riffgrund) for a source strength of SEL 160 dB re 1µPa²s, 750m, and SEL 180 dB re 1µPa²s, 750m with 10% criteria.

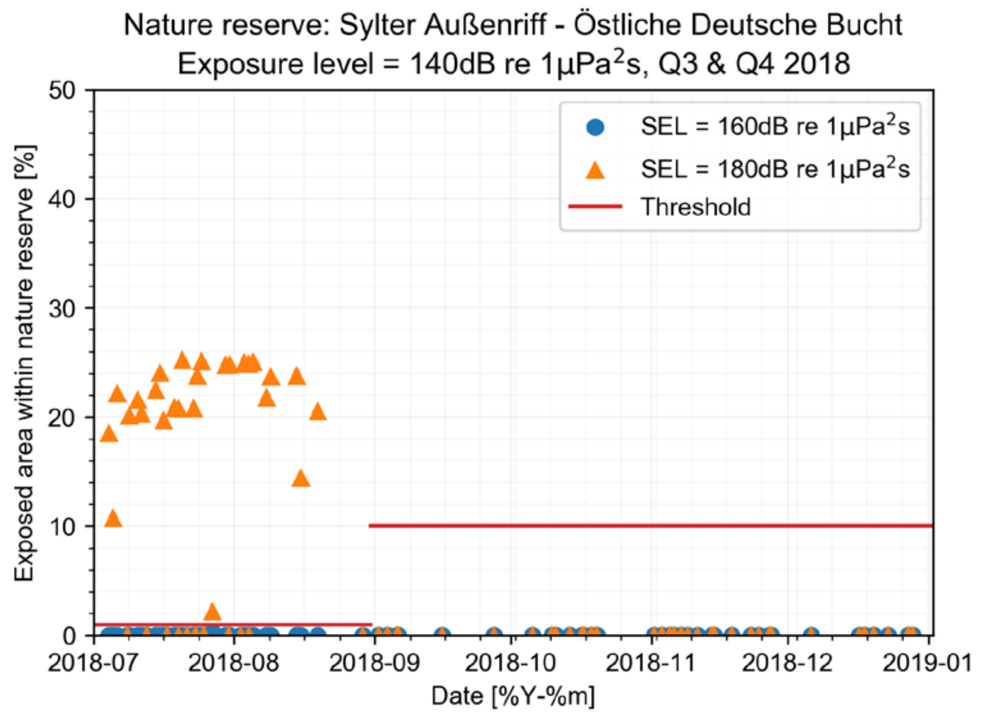
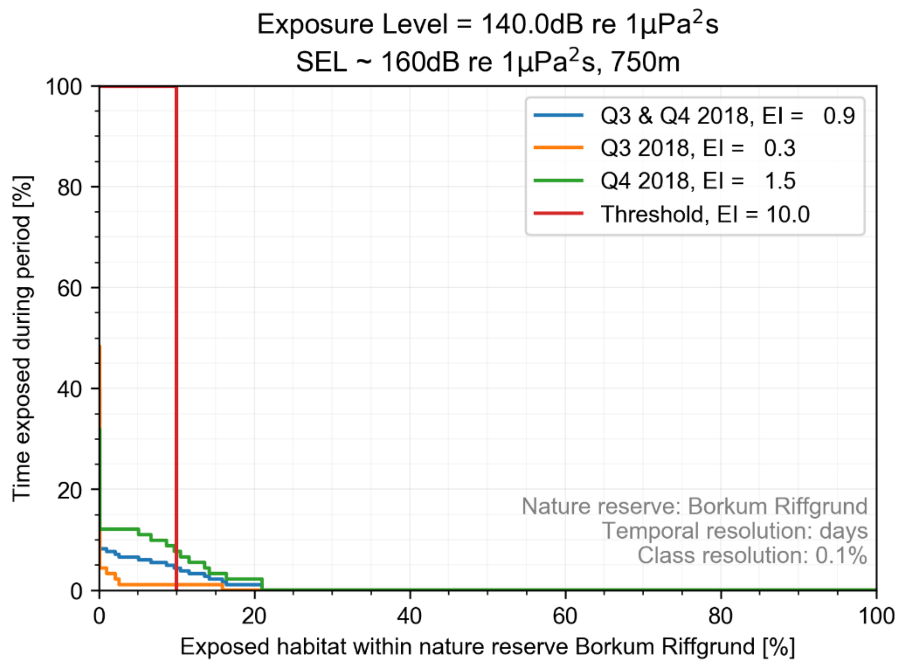


Figure 17: Exposed area over time (daily resolved) within nature conservation area (Sylter Außenriff) for a source strength of SEL 160 dB re 1µPa²s, 750m, and SEL 180 dB re 1µPa²s, 750m with 1% and 10% criteria.

The last case c) is displayed in Figure 17 for the Nature conservation area “Sylter-Aussenriff”. For the period considered, the target was met during the construction phase in 2018. If no noise abatement measures had been used, it would not have been possible to meet the target.

Finally, let us briefly consider the exposure curve and Exposure Index (EI) proposed by OSPAR. Figure 18 shows the test case for the nature conservation area “Borkum Riffgrund”. In addition, the 10% area criterion is considered. This criterion leads to a corresponding single value EI of 10. The EI remained below this value during the period under consideration in the construction phase, however at individual times the 10% rule was exceeded. Hence, the consideration of the EI alone is therefore not suitable for assessing the specific situation and might be complemented by additional spatial and temporal criteria.



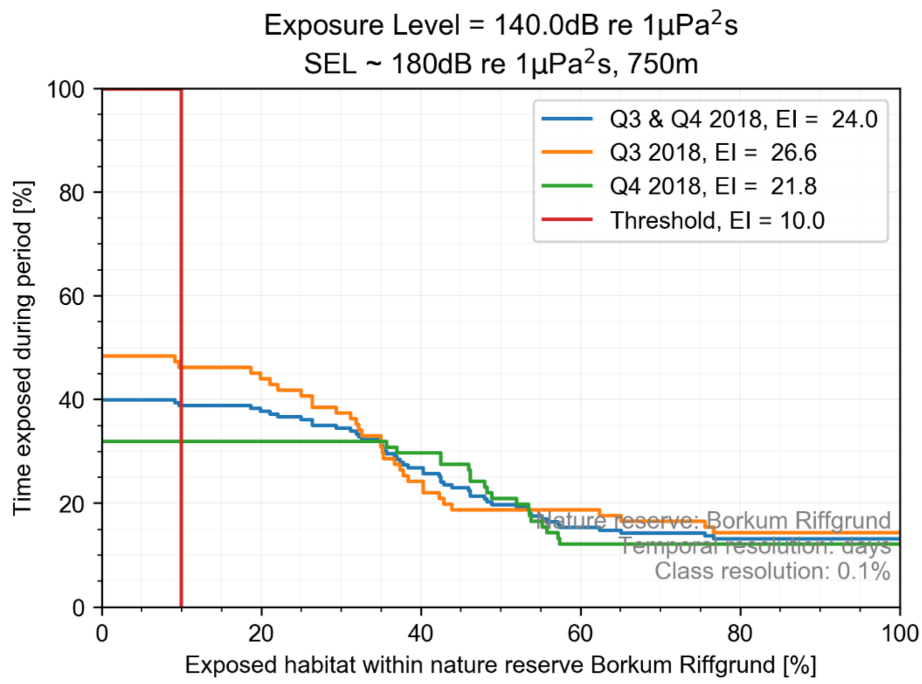


Figure 18: Exposure curves and Exposure Index: Comparison of the second half of the year 2018 with the 3rd and 4th quarters at an SEL of 160 dB and 180 dB re 1 µPa²s at 750m and a maximum permissible received exposure level of 140 dB re 1 µPa²s.

4.6 Discussion of the different assessment methods in relation to the Exposure Index

In principle, there are two different evaluation options, one based on habitats (e.g. Natura 2000 sites) and one based on population. For the population option, one can assume mean distributions and "exact" distributions (snap shots) determined for a particular time span. Both will result in an additional uncertainty in the prediction. However, independently of the approach taken, a comparability of the indicator and assessment result should be guaranteed.

In the OSPAR-approach, observed radii of action are assumed for mitigated (12 km) and non-mitigated sound events (20 km). However, these radii do not correlate with the radii that would be determined according to the application of sound mitigation measures based on sound propagation. An example on this is given in Figure 19.

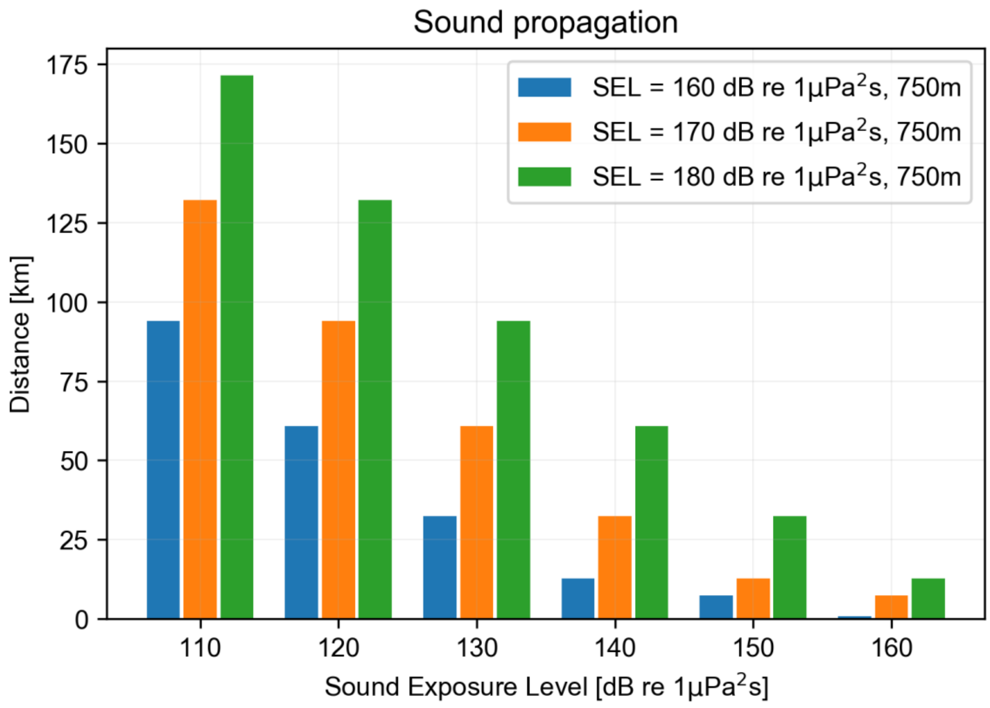


Figure 19: Distance to Received Sound Exposure Level for different source strength (computed according to [1]).

If the assessment were to be based on the hearing threshold (curve), in this case for harbour porpoise, an even more profound analysis would be required, as most sound abatement systems provide better insulation in the medium and high frequency spectrum, see Figure 20.

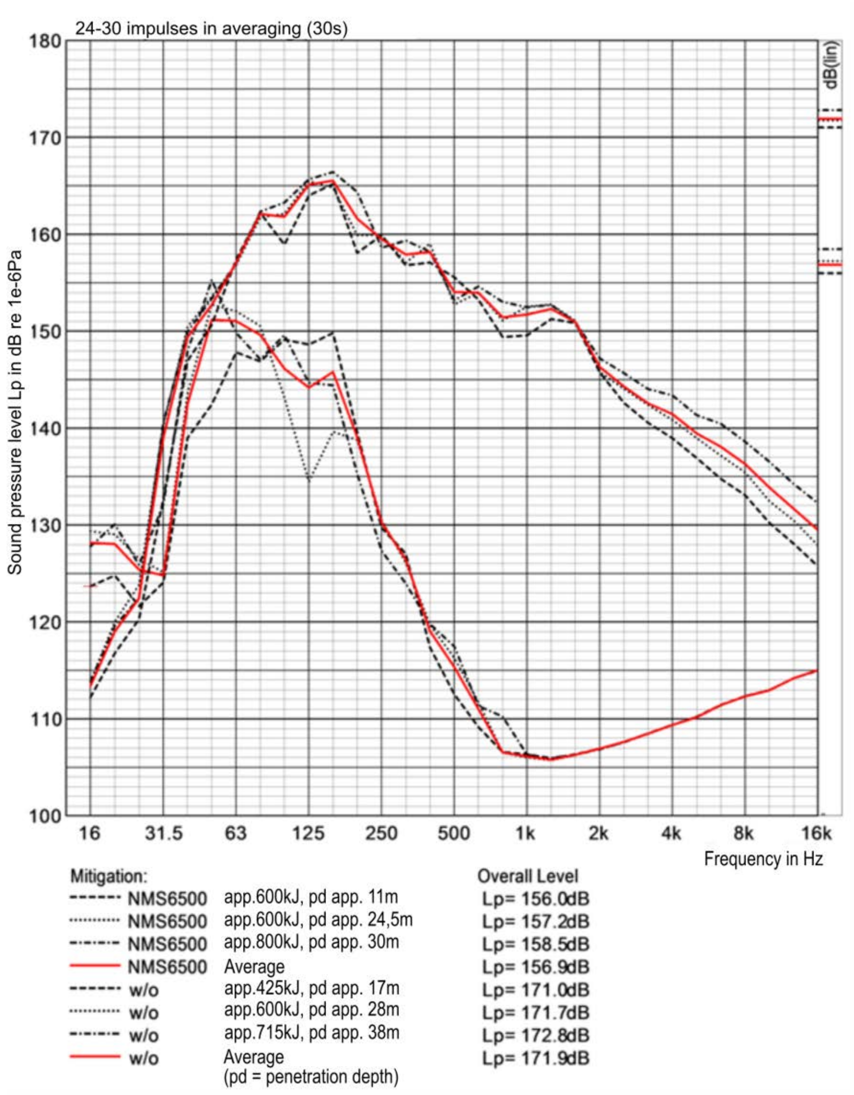


Figure 20: Sound Pressure Level with and without mitigation measures [9].

Auditory frequency weighting is regularly discussed, see [5]. A frequency weighting would emphasize the positive influence of noise abatement measures even more clearly. However, suitable threshold values should be further evaluated and proposed by bioacoustic experts.

4.7 Significance of the classification in the noise registry

Some member states of the European Union (e.g. Belgium, the Netherlands, Germany and Denmark) have initiated acoustic measurements to determine the actual noise impact during pile driving activities. Often, the measurements were (or are being) carried out in a distance of approx. 750 m to the piling location. National [6] and international standards [6] have adopted this measuring distance and recommend it, which has helped to build up a large data base that is likely to further increase. OSPAR has already introduced this information as non-mandatory entries for the template of the noise register.

The following task will be to integrate noise abatement systems and results of the measurements when it comes to formulate source levels for pile-driving noise (status Sep. 2019) [10]. A categorisation of sound events (pile-driving) is now under discussion in TG Noise as shown in Table 1.

Table 1: Current state of discussion of the categorisation of sources.

Categories	SEL (750 m) dB re 1µPa²s	L_{peak} (750 m) dB re 1µPa
A	141 – 161	163 – 183
B	162 – 171	184 – 193
C	172 – 181	194 – 203
D	182 – 191	204 – 213
E	192 –	214 –

The sound events considered in the present study were in the categories A to C.

It is very well possible to classify the source strength objectively. If this is to be achieved for the sound impact, i.e. the Exposure Index, clear procedures must be defined in order to ensure objective statements. Uncertainties enter the approach, for example, due to the selection of habitats and the weighting of habitats. This also applies for the case when population models are used, as each approach is based on assumptions that are certainly only a limited representation of the ground truth, e.g. since not all individuals were actually monitored during the observation period.

As a conclusion drawn from this study, a direct correlation between the source category and the sound exposure index would be most reasonable. The EI naturally varies with the change in source strength. However, the sound concept that has been put into practice in Germany, see Section 4.5, adds a further component, namely the permissible spatial acoustic radiation at a threshold value of the EEZ and nature conservation area. In Table 2 an example is given which considers the approach to habitat protection in Germany. The entries of EI and a spatial criterion in the form of a percentage of exposed area (EA) are to be seen as a proposal of the concept which motivate further analysis and discussion. A first example of this concept is presented in the following table. However, further details should be examined in a deeper consideration.

Table 2: Example for a possible combination of source categories with the Exposure Index (EI) and the spatial criterion of the percentage of exposed area per day (EA) during the observation period based on received level SEL140 dB re 1µPa²s for nature conservation areas.

Categories	SEL (750 m) dB re 1µPa²s Categories	Allowed EI and EA for EEZ *		Allowed EI and EA for nature conservation area *	
		EI	EA	EI	EA
1	A	<5	<1%	<5	<1%
2	A	<5	<10%	<5	<10%
3	B	…	…	…	…
4	…	…	…	…	…

*during the observation period based on received level SEL140 dB re 1µPa²s

The assessment criteria should be clarified. Under this premise, a categorisation can be successful. From the German point of view, the undercutting of the SEL 160 dB in 750 m is a suitable measure that should also be reflected and depicted in a module for the evaluation of the behavioural disturbance.

5 Conclusion

In this study, some aspects of the assessment of an Exposure Index have been addressed. Further comparative studies are necessary to enable an objective assessment. For the consideration of sound, for example, the frequency weighting must certainly be pursued further.

The study shows that the Exposure Index can in principle describe the profit of using sound abatement systems. The methodology also allows to compare different time periods (e.g. compare different quarter of a year) and to analysis different exposure thresholds.

However, the study displays the dependency of the Exposure Index on several parameters. Assuming that the noise pressure map and the habitat follow the state-of-the-art, the most important parameters to consider are the spatial and temporal resolution. The consequences are that specifications for the spatial and temporal resolution must be made when using the Exposure Index. Otherwise, a global classification will not be possible and the comparability and interpretability of assessment results remains a challenge.

A follow up to the present study will be the analysis of the Exposure Index when different types of sound source activities occur during a given period.

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