



Assessment of Effects of Offshore Wind Energy Facilities on the Marine Environment

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

**Technical Report
Monitoring and assessment of the effectiveness of noise mitigation
measures to reduce impact by percussive pile driving
in German waters**

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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 technical mitigation applied to reduce impact fro percussive pile driving on the marine environment. Information on the license procedures for offshore wind farms and data from the monitoring at offshore construction sites considered in the R&D Project and in the technical report has been available by BSH.

Authors are responsible for the contributions in the technical report.

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R&D Project “Assessment approaches for underwater sound monitoring associated with offshore approval procedures, maritime spatial planning and the marine strategy framework directive” on behalf of the Federal Maritime and Hydrographic Agency

Technical Report

Monitoring and assessment of the effectiveness of noise mitigation measures to reduce impact by percussive pile driving in German waters

Part one

Noise abatement strategy, thresholds, standards, legislative and administrative actions

1. Introduction

The strategy followed by BSH in regard with pile driving activities is the reduction of unwanted noise at the source. The strategy is in line with the precautionary principle and aims to prevent impacts to the marine environment and the key species harbour porpoise. The monitoring and assessment of BSH in regard to pile driving follows a holistic approach.

Since 2008 all licences given by BSH for offshore construction in German waters include mandatory threshold values for underwater pile driving sound in the incidental clauses: 160 dB Sound Event Level and 190 dB Sound Pressure Level at 750 m distance to piling location. A thorough application of technical mitigation systems is necessary to meet the threshold.

For addressing potential impacts regarding underwater noise with appropriate regulations, national research projects were initiated. These projects support the formation of a solid and effective regulatory framework, which is demonstrably beneficial for the marine environment, albeit a definition of a “good” environmental status is yet to be established and agreed among researchers and policy representatives.

The research project “Assessment approaches for underwater sound monitoring associated with offshore approval procedures, maritime spatial planning and the marine strategy framework directive” on behalf of the Federal Maritime and Hydrographic Agency was initiated for specifically focusing on these tasks.

This document provides underlying background information and definition of the thematic setting (chapter 2), a comprehensive description of the currently implemented regulatory

framework (chapter 3) and of the accompanying environmental monitoring (chapter 4), and outlines the consecutive steps by which the framework was developed and introduced in Germany (chapter 5).

2. Definition of thresholds and effect ranges

Effect ranges can be defined by means of either permanent hearing loss (PTS), or temporary hearing loss (TTS), or displacement due to sound events and are dependent on sound type and species specific hearing ability. In [NOAA of 2018] different hearing groups have been subdivided, including Low-Frequency (LF), Mid-Frequency (MF) High-Frequency (HF) Cetaceans. However, thresholds for species-specific TTS can be determined by physical methods, like auditory evoked potentials (AEP) described in Popov et al. 2005, Lucke et al., 2009, Ruser et al., 2016. By using physical methods, as AEP, uncertainties in the measurement can be well defined and straight-forward evidence of cause-impact relation is given. This causality is not given when considering displacement based on observations of behavioral changes, since these may depend on multiple naturally or man-made induced factors.

While depending on species specific hearing abilities in detail, the effect ranges for mitigated pile-driving sound for instance correspond to a few kilometers in radius in general. The extend of the effect ranges further depends on the site and project specific characteristics and on the effectiveness of technical mitigation measures applied. For non-mitigated pile driving events, effect-ranges (in terms of displacement) for Harbour Porpoises of 18-25 km were obtained by means of passive acoustic monitoring, see [Dähne et al. 2013, Tougaard, Sep 28, 2017]. Investigations on mitigated pile driving events, falling under German regulations (SEL05 160 dB re 1 Pa²s at 750 m), reported effect ranges of up to 12 km, see [Faulkner 2017, Dähne et al., 2017].

Uncertainties and variation in results of effect ranges are mostly given due to other noise sources like deterrent devices (pinger, seal scarer), shipping, construction vessels at site and the sensitivity to sound of different Harbour porpoise individuals.

Hence, when regulation is to manage noise impact on marine environment, a reliable reproducible and feasible approach and metric is necessary. Sind other definitions of effect ranges are affected by multi-causality and by other sound components that are beyond regulatory control, the effect range due to the sound pressure level threshold is the practically and realistically manageable one, and can further be validated directly by means of sound monitoring. This is he approach persued by BSH.

2.1. Setting thresholds, reduction of pressure level

Underwater sound propagation is known to be largely dependent on e.g. frequency, bathymetry and physical properties in the water column. Nevertheless, an applicable metric is required for regulatory purposes, allowing a quantification of the noise emission and corresponding abatement while maintaining feasible efforts of monitoring and analysis. These criteria justify the choice of a single value metric.

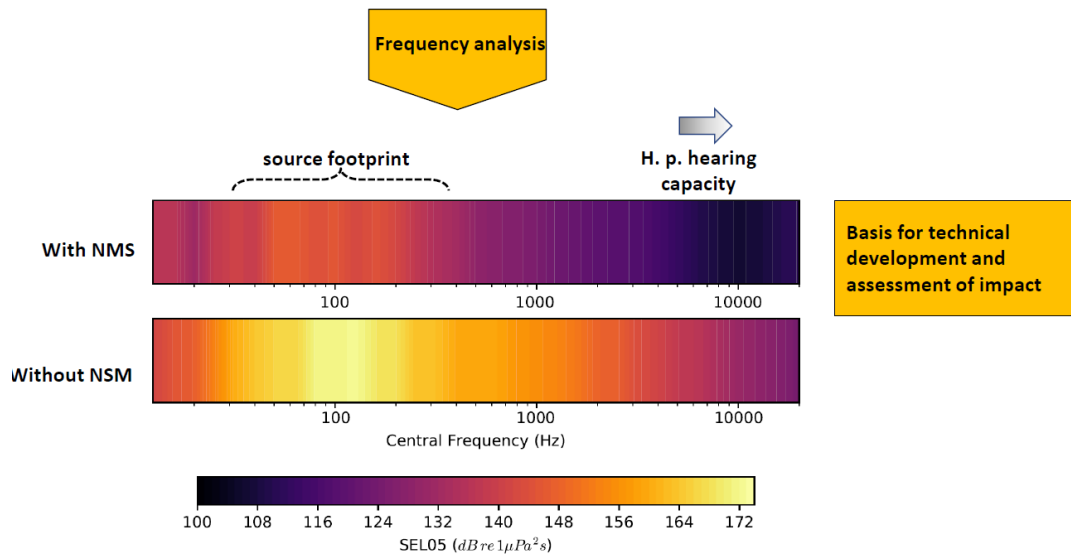


Figure 1. Frequency analysis for mitigated and unmitigated pile driving noise (BSH 2018)

The specification of single-number values as thresholds is occasionally discussed, since the audiogram of Marine Mammals, for example, is frequency-dependent and extends over a wide frequency range. However, they are effective for the regulation of sound inputs, since sound reduction measures typically reach the entire frequency range, see e.g. Figure 1. and 2.

Technical mitigation measures are known to be able to significantly reduce the sound energy radiated to water and to change the spectral composition of the sound event, see Figure 3.

This allows to achieve level reduction up to 40 dB in the kHz frequency range. For sound immission in particular, however, this must be taken into account when evaluating single-number values.

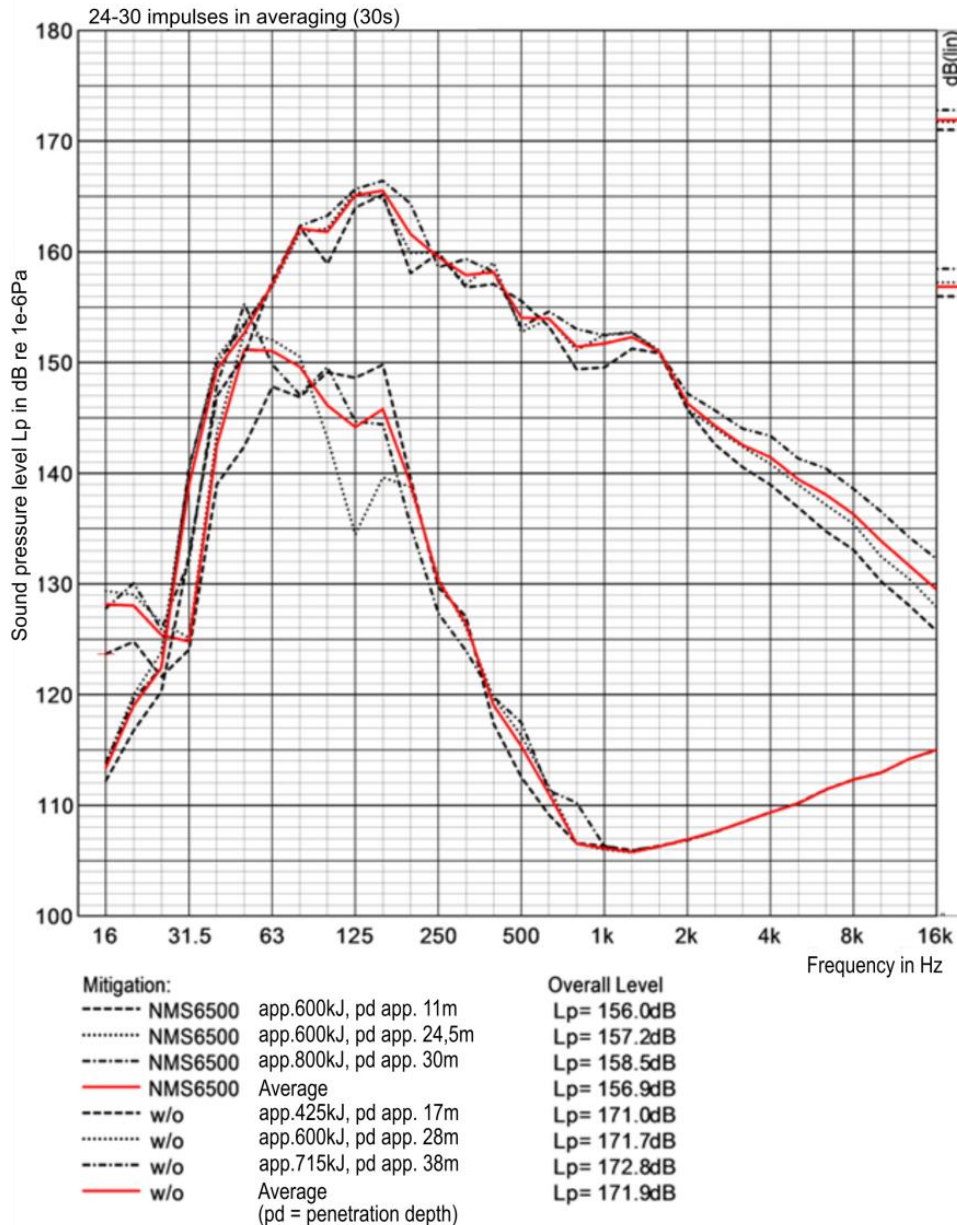


Figure 2: Pile-driving noise: Comparison with / without mitigation (Müller-BBM, 2015).

2.2. Reduction of emitted sound and impact area

The noise generated by pile-driving can be significantly reduced by acoustic measures. Depending on the measures used, level reductions (insertion loss) compared to unmitigated pile-driving of up to 24 dB can be achieved. Figure 3 shows the reduction of the emitted sound energy as a percentage depending on the effectiveness of the sound insulation measure,

At 10 dB level reduction, the emitted sound energy is reduced by 90 %, at 20 dB even by 99 %.

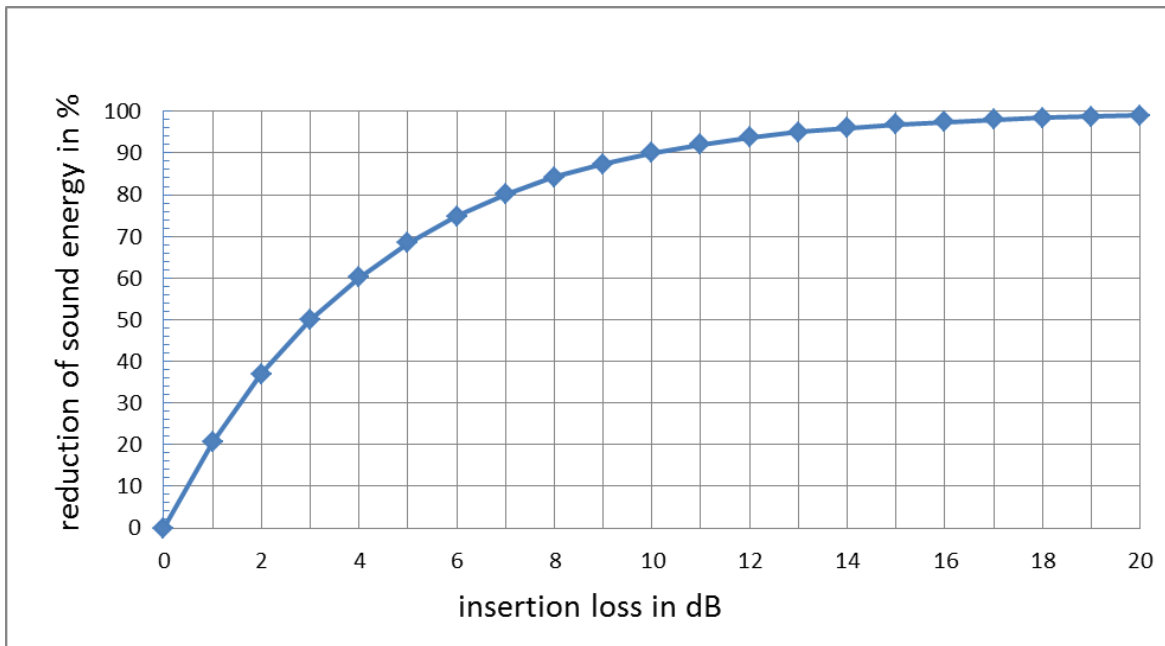


Figure 3: Reduction of emitted sound energy as a function of the insertion loss of the sound insulation measure, e.g. bubble curtain.

Typical unmitigated pile-driving (pile diameter 6-8m) achieve sound exposure levels at 750 m in the order of 180 dB. If the impact area is considered to be the range in which the sound exposure level is above 160 dB, the impact area is reduced by more than 99 % if the sound mitigation measure achieves 20 dB level reduction.cf. Figure 4.

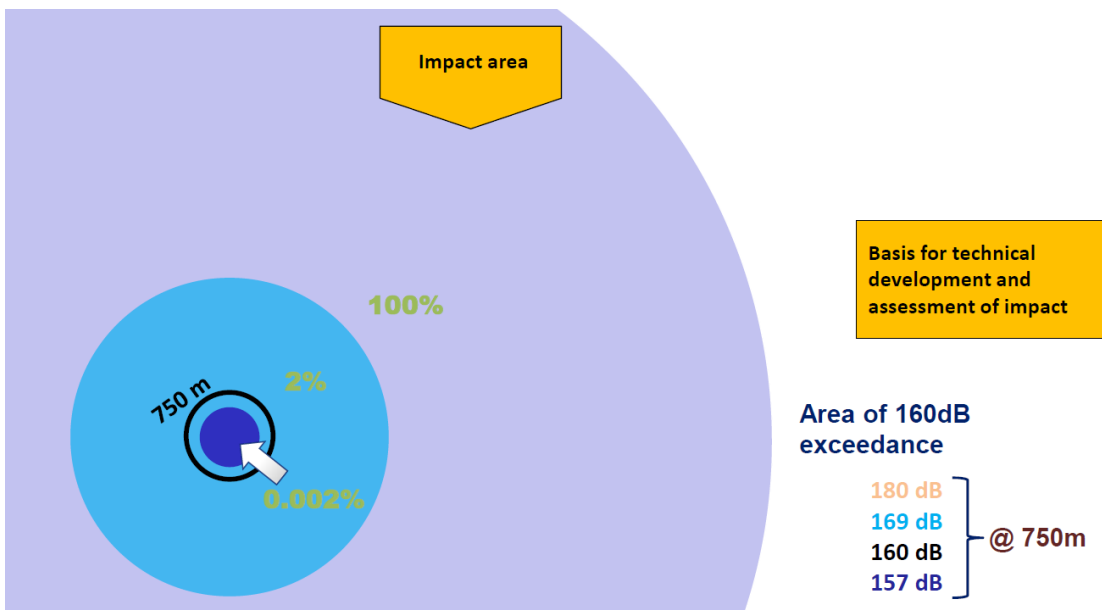


Figure 4. Comparison of impact area for mitigated and unmitigated pile driving noise (BSH,2018).

Numerous member states of the European Union use a distance of approx. 750 m as standard for their acoustic measurements during pile driving activities. National and international standards 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 introduced this information as non-mandatory entries in the template for reporting to the noise register.

The implementation of technical noise mitigation measures have been a standard requirement at offshore construction sites in the German EEZ since 2011. As of 2018, 18 offshore wind farms (OWPs) are operated in the German Exclusive Economic Zone (EEZ), four OWPs are under construction. The Federal Maritime and Hydrographic Agency (BSH) holds numerous measurements of underwater sound of pile driving activities collected in accordance with the licensing requirements. The data is integrated in the German national noise registry and provides a substantial basis for assessing influencing factors of the generation and transmission of sound, but also of the effectiveness of noise reduction measures.

3. Current procedure of Implementation of noise mitigation

Licenses given by BSH for offshore construction include incidental clauses with thresholds for noise reduction that will be mandatory implemented by all projects.

The major steps include EIA and modelling of noise emissions in the framework of the approval procedure, development of a noise abatement concept together with the final pile design two years prior and specification of the implementation plan for noise abatement measures three months prior to start of construction work.

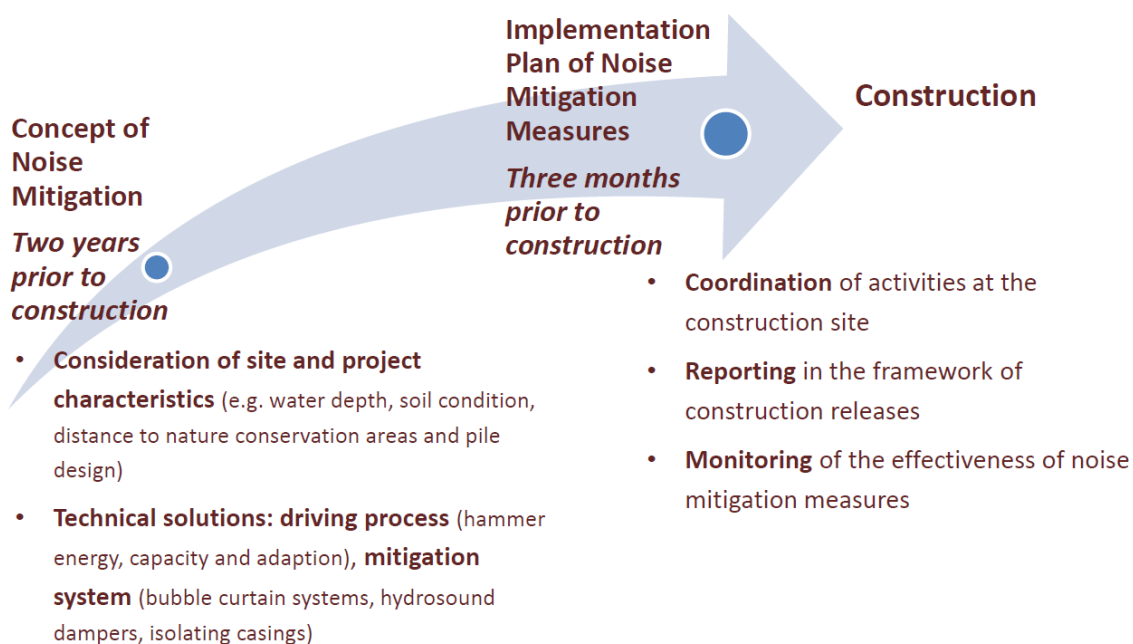


Figure 5. Schematic representation of the process from concept to implementation plan for noise mitigation measures.

Description of the implementation steps as applied in the German EEZ: included in incidental clauses of licenses given by BSH for offshore construction and mandatory implemented by all projects.

- Use of a foundation method with low noise emissions,
- Prediction of noise emissions due to pile driving (mostly through empirical models under consideration of all available data from underwater sound measurements or alternatively by numerical models),

- Thresholds for Pile Driving: SEL05 of 160 dB re 1 μ Pa²s and SPL of 190 dB re 1 μ Pa at 750 m, mandatory since 2008,
- Limitation of piling duration (180 min for monopiles, 140 min for jacket piles),
- Application of deterrence for marine mammals prior to piling to prevent physical injury,
- Ramp up piling procedure,
- Constraints on hammer energy (up to max. 2000 kJ) assumed that target penetration depth is achieved,
- Control technique requirements for hammer (high frequency - low energy procedure),
- Application of technical mitigation systems for noise reduction applied at far distance to piling site (bubble curtains) and depending on site and project characteristics simultaneously at near distance (hydro sound dampers, noise mitigation tube),
- Extensive monitoring of the effectivity of noise mitigation measures including real-time monitoring of SEL for the purpose of guiding the hammer operation at site to meet the threshold, surveys of underwater sound at each pile site and in the next nature conservation area to evaluate the effectivity of noise mitigation and surveys to detect the activity of harbour porpoise in the vicinity of piling sites,
- Tight reporting procedure of the monitoring results to the responsible agencies,
- Construction releases given by BSH are based on a step-by-step procedure: Each release applies for a limited number of locations (piles),
- Extension of release after evaluation of the effectivity of noise mitigation measures applied as revealed by the results of the monitoring.

4. Overview to the established Environmental Impact Assessment in Germany

The most direct option to evaluate potential impacts of noise emissions is the assessment of measureable and observable impacts, by monitoring the sound on one hand and the animal distribution on the other. This direct assessment is the method of choice of BSH. This approach can and should be supported by modelling approaches but can not be replaced by them under the premiss of retaining a comparable quality and information gain.

Monitoring adverse impacts such as effects from underwater noise is mandatory prior to construction, during construction and during operation of the wind farm. The monitoring consists of visual observations and acoustic observations. The guidance 'Standard Investigation of the impacts of offshore wind turbines on the Marine environment (StUK 4, BSH, 2013) is provided on the BSH website. The StUK describes the scope of investigations (predictions / modelling, measurements and observations) that are required for the planning and approval of an offshore wind farm and detailed information about the required monitoring. It covers the four phases (pre-pollution and feasibility investigation phase, construction phase, operation phase, decommissioning phase) of licensing and enforcement procedures of offshore installations in the German EEZ. The aim of this guidance is to standardize the monitoring methods and metrics to be used as well as the presentation of the results.

The baseline survey monitoring data is used as input for the EIA. Since the implementation of the new Offshore Wind Energy Act in 2017, BSH is now responsible for the baseline monitoring and the developer is responsible for monitoring during the construction and during operation.

The monitoring and assessment of marine mammals according to StUK4 is mainly based on three methods: digital aerial surveys, ship-based surveys and static acoustic monitoring. For the purpose of monitoring and assessment of abundance and distribution patterns so called cluster investigations by means of digital surveys covering areas of more than 4.000 km² each are carried out.

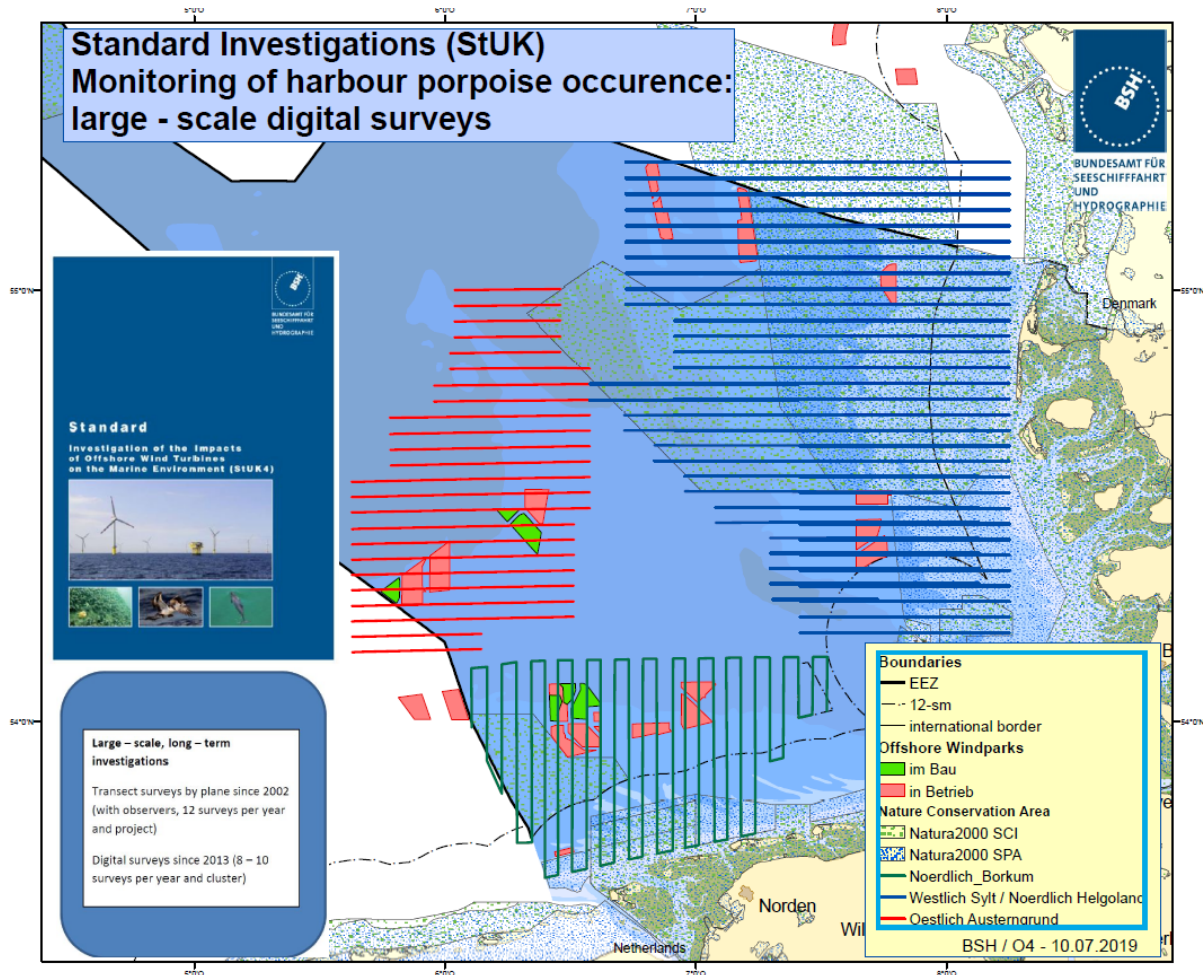


Figure 6. Monitoring design for digital surveys of offshore wind farms.

Since 2009 a net of CPOD-stations has been operated by offshore wind farm developers for assessing seasonal and interannual changes in habitat use by harbor porpoises (Brandt et al., 2016). During the construction phase CPOD stations are deployed in the immediate vicinity of the site as well as along a gradient from the site to look for direct effects of the pile driving activity on the habitat use by harbor porpoise. Some results have already been published (Dähne et al. 2013, Dähne et al., 2017, Brandt et al., 2018).

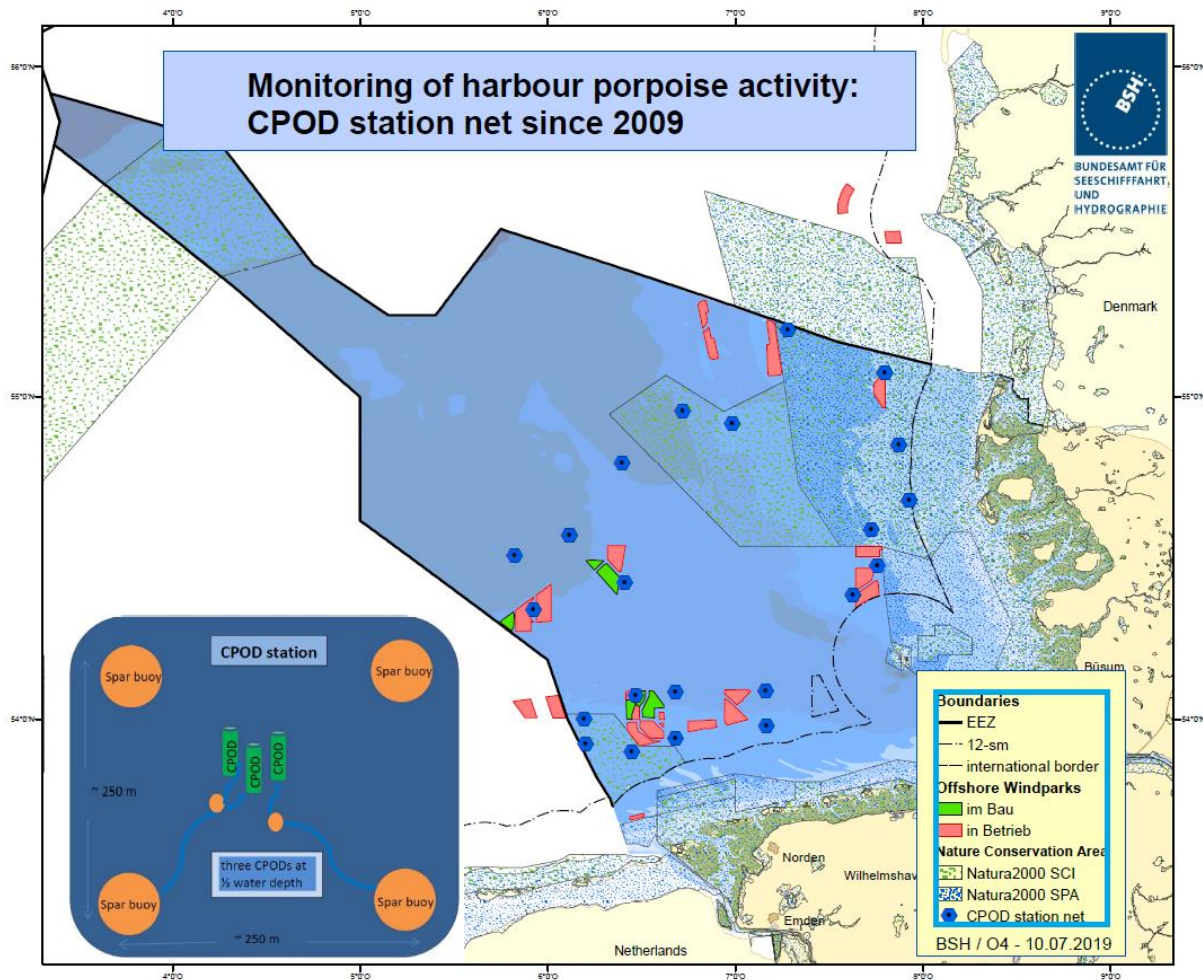


Figure 7. Acoustical investigation of habitat use of harbor porpoise by means of a C-POD station network

For monitoring compliance with the threshold underwater noise, measurements are carried out during pile driving. Both for underwater noise measurements and for determination of the effectivity of technical noise mitigation systems guidance given by BSH as well as national and international standards have to be followed. The metrics used comply with BSH guidance and international standards (ISO 18405:2017, ISO 18406:2017).

The guidance given by BSH includes the instructions from 2011 and 2013). Since 2008, all underwater noise measurements have to be carried out following the ISO 18406:2017 and the determination of the effectivity of technical mitigation has to follow DIN SPEC45653:2017. The measuring institutes have to be qualified through accreditation according to DIN EN ISO/IEC 17025 and in regard with ISO18406:2017 and DIN SPEC 45653:2017.

The major metric used to prove for compliance with the threshold is the Sound Exposure Level SEL defined as the level of the sound exposure, for a specified reference value (ISO 18406:2017). A detailed description of the application is found in the guidance of BSH (2011).

5. Roadmap towards the German regulation: necessary steps to set a regulatory procedure for mitigation measures for the reduction of underwater sound from percussive pile driving

Since 2008 all licences given for offshore construction in German waters include threshold value for underwater pile driving noise in the incidental clauses. Nowadays, the threshold value for impulsive sound radiated from percussive pile driving is based on a dual criterion: 160 dB SEL05 re $1\mu\text{Pa}^2\text{ s}$ and 190 dB zero-to-peak re $1\mu\text{Pa}$ at 750 m distance to piling location

Following steps describe the development of threshold values set by the German Government for pile driving noise.

Step one: Research on underwater sound characteristics and on impacts to marine life

Threshold values were first proved and discussed in the years 2002 to 2007 in the framework of national research projects (Elmer et al., 2007). The harbour porpoise was proved to be the target/indicator species in German waters in the North Sea and in the Baltic Sea. Extensive research projects and monitoring of the distribution and abundance of harbour porpoise and other marine mammals have been running since 2002 (Gilles et al., 2006).

Step two: Determination of a target value for impulsive sound radiated from percussive pile driving

Following the results of the research projects and in accordance with the precautionary principle a threshold value of 160 dB re $1\mu\text{Pa}^2\text{s}$ at 750 m distance to the piling location was derived and considered reasonable for preventing impacts to marine life and esp. to the harbour porpoise in German waters. Since direct evidence on the effect of impulsive noise on harbour porpoise was missing and a state-of-the-art on technical solutions to reduce pile driving noise was not achieved, the threshold value (160 dB SEL re $1\mu\text{Pa}^2\text{s}$ at 750 m) in incidental clauses included in licenses issued from 2004 to 2007 was set as a target value, that should be achieved by technical abatement systems.

Step three: Determination of mandatory threshold value to reduce impulsive sound radiated from percussive pile driving

The determination of mandatory threshold values to be included in incidental clauses of licenses is finally based on following criteria:

1. Evidence of impact on individuals of the target / indicator species by means of a method based on physical principles,
2. Determination of a well-defined metric for the threshold value that can be monitored by means of standardized procedures,
3. Evaluation and adjustment of the threshold value to account for cumulative impacts due to multiple blows,
4. Standardization of the measuring instruction for proving the compliance with the threshold value,
5. Development of technical abatement systems to reduce sound to achieve a level of state-of-the art,
6. Development of methods to prove the effectivity of technical abatement systems,
7. Development of a concept to monitor the effects of mitigated pile driving on harbour porpoises.

In 2008 experimental studies based on auditory evoked potentials (AEP) methods could reveal the onset of temporary threshold shift (TTS) on a harbour porpoise. Based on research results by Lucke et al., (2009) who found a TTS caused at 164 dB SEL at 4 kHz, the reference value was then turned into a mandatory threshold in the incidental clauses of licenses for offshore construction following the dual criterion mentioned above. The evidence of effects on target/ indicator species based on the results of methods other than behavioral observations is of crucial importance when dealing with thresholds. The method applied by Lucke et al. (2009) is directly derived from the medical research and application and free from interferences due to individual motivation, as may be the case at behavioral studies.

The study of Lucke et al. (2009) based on auditory evoked potential (AEP) gave evidence of TTS at 164 dB at a high frequency of 4 kHz. However, in accordance with the precautionary principle it was decided to set the mandatory threshold value at 160 SEL₀₅ re 1 $\mu\text{Pa}^2\text{s}$ at 750m distance for low frequency sound radiated from percussive pile driving which is usually emitted at frequencies between 60 Hz to 250 Hz.

Moreover, the current implementation of the threshold is based on percentile statistics, SEL₀₅ percentile level, which is exceeded in 5 % of the time over the total piling period to account for cumulative effects due to multiple blows for driving piles to final penetration depth.

The issue of reliable and standardized evidence for compliance with the threshold value was also evaluated. The metric used for the threshold value (SEL₀₅ re 1 $\mu\text{Pa}^2\text{s}$) is considered reliable and can be monitored safely according to available measuring standards (Measuring Instruction by BSH, 2011 and ISO 18406:2017).

To comply with the threshold values technical noise abatement systems have to be applied during pile driving activities. The determination of effectivity of the technical noise follows guidance included in the standard DIN SPEC45653:2017 (available in English and German).

The strategy followed by setting threshold values is to prevent any significant impacts of pile driving on harbour porpoise. According to the German regulation the acceptable level of potential impacts on harbour porpoise is given, when the threshold value of 160 dB SEL₀₅ re 1 $\mu\text{Pa}^2\text{s}$ at 750m distance to the piling location has been met.

Step four: Legislative and administrative actions in regard with the threshold value for sound radiated from percussive pile driving:

Besides the scientific work described under steps one to three, a series of consecutive legislative and administrative actions were needed for the implementation of measures to meet the threshold in offshore construction sites.

1. Legislative actions:

- a) Maritime Spatial Planning Ordinance (Ro-V, 2009) does not allow licensing of offshore wind farms in nature conservation areas,
- b) Federal Nature Conservation Act (BNatSchG, 2009). Most relevant articles, § 34 sets rules for the protection of habitats for populations of species (e.g. harbour porpoise) within nature conservation areas, § 44 sets rules for the protection of species within nature conservation areas as well as in the entire administrative area,

- c) Offshore Wind Energy Act (WindSeeG, 2017) and Offshore Installation Ordinance (SeeAnIV), sets rules for selecting, planning and licensing of offshore wind farms in the German EEZ under consideration of the Environmental Impact Assessment Act (UVPG, last amended 2017) and BNatSchG (2009)
- d) Nature Conservation Area Ordinances (2017) set among others rules and criteria for the protection of habitats for protected species in nature conservation areas.

2. Administrative actions:

- a) Site Development Plan (FEP, 2019) includes rules and criteria for the specification of sites under consideration of the legislative basis mentioned above.
- b) Management Plans for the Nature Conservation Areas (under development) include rules and measures for the protection of habitats for harbour porpoise in Nature Conservation Areas.
- c) Licenses for Offshore Wind Farm Projects in the German EEZ given by BSH (2001 and ongoing) include noise mitigation measures for the protection of harbour porpoise from impacts due to pile driving. The noise mitigation measures included in incidental clauses of licenses given by BSH are based on the legislative actions (a – d) and on administrative actions (a, b) referred above. Moreover, the noise mitigation measures included in incidental clauses consider new research results, negotiated agreements and state-of-the-art in technical solutions.

3. Agreement and Recommendations:

- a) Recommendations on Noise Thresholds for Offshore Construction (UBA, 2011),
- b) Protection plan for the harbour porpoise in the German North Sea by BMU (2013).

6. Outlook

The following parts of the report will focus on the determination of the effectiveness of technical abatement systems applied in construction sites in the German EEZ.

The potential of noise reduction will be evaluated for applications of single abatement systems as well as for combination of noise abatement systems. The analysis will consider in particular frequency dependence of the reduction.

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