Energistyrelsen

Guideline for underwater noise measurements for geophysical, geotechnical and seismic survey activities

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Summary and overview

This Guideline pertains to underwater noise measurements for geophysical, geotechnical and seismic surveys in Danish waters.

Depending on the permit conditions, either Noise level (Type 1) measurements or Sound source verification (Type 2) measurements must be conducted during the activity, adhering to the definitions and requirements outlined in this document.

The applicant is required to prepare a measurement program, as specified in this document, and submit it for approval to the Danish Energy Agency

The measurement program must demonstrate the capability to conduct the measurements accordance with all requirements. Any deviations from the requirements must be listed and justified for approval by the Danish Energy Agency.

Following the measurements, the results must be documented according to the specifications in these guidelines and submitted to the Danish Energy Agency.

Document overview

- **Section 1** defines acoustic metrics and terms used in the guideline.
- **Section 2** outlines acoustic criteria for survey activities.
- **Section 3** details measurement requirements per permit conditions for Noise Level (Type 1) measurements.
- **Section 4** details measurement requirements per permit conditions for Sound source verification (Type 2) measurements.
- **Section 5** specifies system self-noise requirements.
- **Section 6** specifies system calibration requirements.

1. Definitions

Acoustic metrics in the guidelines align with Energistyrelsen (2023), DS/ISO 18405 (2017) and DS/ISO 18406 (2017).

Notably, source level definitions are briefly summarized, with detailed ones available in ISO 18405.

For impulsive and intermittent sound sources sound exposure source level ($L_{S,E}$ [dB re 1 µPa^{2}m^{2}s]) reflects the time-integrated squared sound pressure level at 1 m from a hypothetical point source, in an infinite uniform lossless medium, with the same sound exposure source level as the true source.

For continuous noise sources, the source level (L_S [dB re 1 µPa^{2}m^2]) represents the time-integrated squared sound pressure level at 1 m from a hypothetical point source, placed in an infinite uniform lossless medium, with the same sound pressure source level as the true source.

2. Acoustic criteria

The measurements must include calculation of underwater noise impact on all relevant marine mammal species (see Tougaard et al. (2020)). In this regard, best-available knowledge on species-specific hearing thresholds and impact levels must be used. At the time of writing, this is considered to be represented by auditory group thresholds outlined in (Tougaard, 2021) and National Marine Fisheries Service (NMFS) (2024) as summarized in Table 1. For each equipment type measured, an evaluation of the sources' impulsivity (impulsive/non-impulsive, sensu NMFS (2024)) must be provided. If it is unclear whether a source should be classified as impulsive or not, it should be assumed to be impulsive as a precautionary measure.

Table 1 shows threshold criteria for species of marine mammals commonly occurring in Danish waters with corresponding auditory groups. Acoustic thresholds stated as SEL_{cum} in dB re 1 μPa^2s and SPL in dB re 1 µPa. Source: (Tougaard, (2021), NMFS (2024)).

Species (English)	Species (Danish)	Weighting (NMFS 2024)	Threshold type				
			TTS (SEL_{cum} ; $L_{E,p,xx,24h}$)		AUD INJ (SEL_{cum} ; $L_{E,p,xx,24h}$)		Behavioural Disturbance (SPL $L_{p,125ms}$)
			Non-impulsive	Impulsive	Non-impulsive	Impulsive	-
Harbour porpoise	Marsvin	VHF	161	144	181	159	103
White-beaked dolphin	Hvidnæse	HF	181	178	201	193	-
Pilot whale[1]	Grindehval	HF	181	178	201	193	-
Minke whale	Vågehval	LF	177	168	197	183	-
Harbour seal	Spættet sæl	PCW	175	168	195	183	-
Grey seal	Gråsæl	PCW	175	168	195	183	-

Note 1: And other deep diving odontocetes.

Behaviour disturbance thresholds are currently available only for harbour porpoise (see Tougaard (2021) and (2025)). If using behavioural disturbance thresholds for other species, thorough substantiation is required. Generic cetacean thresholds of 160/180 dB rms are not considered applicable.

3. Requirements for Noise Level (Type 1) measurements

If the investigation permit specifies a requirement for Noise Level (Type 1) measurements, follow this section's guidance. The applicant must prepare and submit a detailed measurement program to the Danish Energy Agency, that meets the following specifications.

3.1. Objectives

The goal of Noise Level (Type 1) measurements is to document the increase in underwater noise levels within the survey area due to survey activities.

Tasks to achieve this include:

- Measuring ambient underwater noise within the survey area.
- Measuring underwater noise levels during survey activities.
- Comparing survey-related noise with ambient noise, (where the ambient noise can include other anthropogenic sources unrelated to the survey).
- Estimating the degree to which underwater noise levels exceed harbour porpoise behaviour criterion (Table 1) during survey activities.

3.2. Methodology

The methodology for Noise Level (Type 1) measurements is based on the BIAS guidelines for underwater noise measurements (Verfuß, et al., 2015), JOMOPANS guidelines (Fischer, Kühnel, & Basan, 2021), the German guidelines for underwater noise measurements (BSH, 2011) and the specifications for underwater noise measurements in ISO 18406 (DS/ISO 18406, 2017).

3.2.1. Measurement locations

The applicant must propose measurement positions in the detailed measurement program, adhering to the following minimum specifications:

- Measurement systems must be positioned sufficiently within the project area to ensure statistical representativeness. The number of required positions depends on the size of the project area:
    - Less than 100 km²: A minimum of two (2) positions.
    - 100 km² – 200 km²: A minimum of three (3) positions.
    - 200 km² – 400 km²: A minimum of four (4) positions.
    - Greater than 400 km²: A minimum of five (5) positions.
- The measurement systems should be evenly distributed within the project area, maintaining a minimum distance of 1 km from the project area boundaries.
- The hydrophone depth at each measurement position should be located in the lower half of the water column.

- If the water depth within the project area varies significantly (> factor 2), the selection of positions should represent this range of water depths.
- In areas with significant stratification, additional hydrophones should be deployed in the upper half of the water column above the depth of sound speed minimum.
- Measurement stations can be advantageously placed alongside other types of measurement systems, provided they do not generate or contribute noise to the marine environment.

3.2.2. Measurement equipment

The measurement equipment must comply with the following specifications:

- All measurement systems must utilize hydrophones (i.e., measuring sound pressure).
- The frequency range must cover at least the 1/3-octave bands from 20 Hz to 50 kHz, requiring a sample rate of at least 128 kHz.
    - If survey activities involve equipment operating above 50 kHz, the frequency range must be extended accordingly up to a maximum limit of 150 kHz.
- Hydrophones must exhibit omnidirectional characteristics ($\pm 3\ dB$) in the horizontal plane.
- The dynamic range of each measurement system must be selected based on the expected noise levels and proximity to the survey vessel path. Systems close to the vessel path must capture high noise levels without extensive clipping, while those farther away should facilitate analysis of low noise levels against background/ambient noise.
- Raw measurement data must be recorded in .wav format for digital submission.
- The ADC (Analog to Digital Converter) must have a resolution of at least 16 bits.
- Calibration procedures for measurement systems must adhere to section 6 of these guidelines.
- Moorings, cables, acoustic triggers, and other physical components must be designed to minimize unwanted noise, such as rattling sounds.
- The measurement program must detail how flow noise is addressed or compensated.

3.2.3. Measurement timeframe and duration

Measurements must adhere to the following requirements:

- The measurement timeframe should align with the period when the relevant survey equipment is actively used.

- Measurements need to be continuous for at least 14 days of active survey activities (i.e. percentage of the active measurement period or duty cycle at 100% or as close as technically possible). Downtime (interruption to active survey activities, for whatever reason) does not count towards this.
- At least 24 hours (not necessarily consecutive) of ambient underwater noise measurements, taken before, during, or after survey activities, with weather conditions similar to those during the survey.

3.2.4. Analysis

Post-processing and analysis of the data must adhere to the following specifications:

- The most recent calibration levels must be used to convert recorded voltage levels to sound pressure levels, in accordance with manufacturer guidelines.
- The data should undergo quality assurance before any analysis of sound pressure levels, including identifying periods of extensive clipping to exclude them from the analysis. Statistics regarding omitted data and reasons must be provided for each measurement system.
- For the entire measurement period, the following calculations must be performed for each measurement system:
    - Sound pressure levels using time windows of 5 seconds ($L_{p,5s}$) and 125 ms ($L_{p,125ms}$). An appropriate windowing function such as Hann with 50% overlap should be utilized. Results should be expressed as broadband levels and in 1/3-octave bands (base 10) conforming to IEC 61260-1. For $L_{p,5s}$ frequency bands from 20 Hz up must be included, and for $L_{p,125ms}$ frequency bands from 400 Hz up must be included.
    - Daily averages and exceedance levels (5%, 10%, 25%, 50%, 75%, 90%, and 95%) must be reported numerically in table form.
    - A 10-minute aggregate plot of $L_{p,5s}$ must be shown (one plot per recording station) for all recording days, including exceedance levels (5%, 10%, 25%, 50%, 75%, 90%, and 95%).
    - A 1-minute aggregate plot of $L_{p,125ms}$ must be shown (one plot per recording station) for each recording day, including exceedance levels (5%, 10%, 25%, 50%, 75%, 90%, and 95%).
    - Statistical representation of measured sound pressure levels in 1/3-octave band levels should be presented using a box or violin plot, including exceedance levels (5%, 10%, 25%, 50%, 75%, 90%, and 95%).
    - Ambient noise levels as $L_{p,5s}$ must be shown in a plot, including exceedance levels (5%, 10%, 25%, 50%, 75%, 90%, and 95%).
    - A discussion of the results must be included.

- Calculate the percentage of recording time per measurement system where the harbour porpoise behaviour criterion (see Table 1) was exceeded based on VHF-weighted levels ($L_{p,125ms,VHF}$). This can be separated into parts attributed to the survey vessel and other unrelated sources.

3.2.5. Deliverables

A measurement report must be prepared containing the following:

- An executive summary that presents the primary findings at a non-technical level.
- A technical summary discussing the objectives and how they were achieved, along with detailed findings, conclusions and results.
- A description of the measurement program, including:
  - Deployment and recovery procedures.
  - Measurement locations in both coordinates and graphically on a map, with the EPSG clearly stated.
  - Deployment depth, including height of sensors (hydrophones) above the seabed.
  - Deployment and retrieval dates and times in UTC,
  - Survey activity visualization, with tracks/locations displayed temporally for the entire measurement duration in UTC.
- Measurement setup, including technical descriptions of measurement systems, hydrophones, mooring and deployment methodologies.
- Equipment calibration, including both laboratory and in-situ calibrations, with certificates attached in the appendix.
- Technical description of the survey activities conducted during the measurements, including all acoustic survey equipment and supporting equipment (such as Ultra short baseline (USBL), Dynamic Positioning (DP) systems). An activity time schedule must be provided graphically showing which equipment types were active during specific periods of the measurement duration. Relevant equipment-specific details must be provided, including but not limited to, source level, directivity, pulse rate, pulse length.
- Analysis methodology and metrics used, along with technical descriptions.
- Results, including all numerical table results (can be placed in appendix) and graphical results. The results section must also include a comparison between ambient noise levels (periods where no survey activities are within 10 km range of the respective measurement station) and active survey noise levels.
- A discussion on the findings, focused on how measured noise levels and estimated exposure to animals compare to predictions in the prognosis.
- A conclusion detailing the results and comparing them with the objectives for the measurements.

- Appendices including datasheet of measurement systems, hydrophones, probes, moorings, calibration certificates, and any results not presented within the report.

In addition to the measurement report, a digital delivery must be prepared and submitted to the Danish Energy Agency. The digital delivery must be provided in two physical copies (external hard drives with USB 3.2 connection or newer) and must include:

- All recorded data in .wav format
    - The files must be organized in a folder structure with one folder per measurement station.
    - If more than one deployment was conducted at one or more stations (with the same or different instruments), each deployment must be in a separate folder. The folder name should include the name of the station and deployment ID (date range or other unique means of identification).
    - The naming convention for each file must be consistent and be explained in a metafile including:
        - UTC date and time
        - Measurement station ID
        - Complete metadata for the instrument associated with each deployment, including serial number, hydrophone type for external hydrophones, and clipping level for the recorder (i.e., sound pressure level corresponding to full-scale detection of the wav file).
        - Metadata can be provided as text, XML, or HTF5 files.
- All relevant log files, including:
    - GPS log for survey vessel(s) and for measurement stations (to the extent GPS systems are used at measurement stations).
    - Deployment and retrieval log files
    - Measurement system log files
    - Operational log of the survey vessel
- Digital (.png or .jpeg) files of all result plots.
- Data files with numerical results (if not included in the appendix), either as CSV files or HTF5 files, in accordance with ICES Continuous Underwater Noise Reporting format (ICES, 2022).
- Calibration certificates (PDF).

4. Requirements for Sound Source Verification (Type 2) measurements

If the investigation permit specifies a requirement for Sound Source Verification (Type 2) measurements, follow this section's guidance. The applicant must prepare and submit a detailed measurement program to the Danish Energy Agency, that meets the specifications.

4.1. Objectives

The primary goal of Sound Source Verification (Type 2) measurements is to describe and document the underwater source levels and noise emission characteristics of survey equipment, as well as estimate their impact on the marine environment.

The tasks involved in achieving this objective are to:

- Measuring and documenting the ambient underwater noise level within the survey area.
- Measuring and documenting the equipment-specific underwater noise emission resulting from survey activities and/or supporting systems.
- Calculating equipment-specific source levels (defined in section 1) in the horizontal plane based on back-propagation of measured levels to 1m.
- Calculating impact ranges for threshold criteria relevant to marine life resulting from survey activities.

4.2. Methodology

The methodology for Sound Source Verification (Type 2) measurements is based on the BIAS guidelines for underwater noise measurements (Verfuß, et al., 2015), JOMOPANS guidelines (Fischer, Kühnel, & Basan, 2021), the Danish guidelines for underwater noise from pile driving (Energistyrelsen, 2023), shallow water noise measurement concepts for vessels (MacGillivray, et al., 2023), the German guidelines for underwater noise measurements (BSH, 2011) and the specifications for underwater noise measurements in ISO 18406 (DS/ISO 18406, 2017).

4.2.1. Measurement locations

Measurement locations must be proposed by the applicant in the detailed measurement program, fulfilling the following specifications:

- Fixed measurement systems are to be deployed along a straight line (transect) away from the survey ship , for accurate back-calculation of underwater noise emission from each individual equipment type of interest.
- A measurement transect must have at least five (5) measurement systems, exponentially spaced, with the first system positioned under the planned vessel path, representing vertical noise emission, and the furthest

positioned at a distance where the prognosis predicts noise levels of $L_{p,125ms,VHF} = 97\ dB\ re.\ 1\mu Pa$, (6 dB below the harbour porpoise behaviour criterion).
    - For example, if the predicted maximum impact range is 3 km, measurement systems could be positioned at 0 m (underneath the vessel path), 50 m, 250 m, 1000 m, 3000 m from the vessel path.
- The survey vessel path should be perpendicular to the measurement transect, passing over the measurement system at 0 m or as close thereto as operationally possible. The vessel path begins at 1 km before the closest point of approach (CPA) and ends 1 km after the CPA. The CPA refers to the position of the equipment currently being measured.
    - For measurements with all equipment active, the CPA may vary for different pieces of equipment, depending on whether they are vessel-mounted or towed behind the survey vessel. This variation must be considered during analysis.
- A minimum of three vessel passes must be completed for each piece of equipment, to ensure sufficient data for analysis.
- If any survey or supporting equipment is horizontally directional (e.g. a USBL system with a directional transducer), measurements of that system must include an additional vessel path to measure noise emission in the main lobe. The following applies:
    - An additional vessel path should begin at the location of the 0 m measurement system and extend to a distance corresponding to the predicted maximum harbour porpoise behaviour impact range in the direction directly opposite of the measurement transect.
    - A minimum of three vessel passes away from the measurement transect, and a minimum of three vessel passes toward the measurement transect must be conducted.
- Measurement lines and systems should, to the extent possible, be deployed in a part of the survey area with homogenous seabed conditions (sediment and bathymetry), to minimize the risk of seabed features influencing the transmission loss.
- All hydrophones must be placed in the lower half of the water column at each measurement location, ensuring that all measurement locations on a straight line are at the same depth relative to the seabed.
    - In areas with strong stratification, additional hydrophones should be positioned in the upper part of the water column above the depth of sound speed minimum.

4.2.2. Survey trial program

The measurement program must detail the survey vessel's movement and the operation of the equipment during measurements.

- Each survey activity of interest must be measured individually, without any other active source types, and in combination, reflecting how the survey activities are conducted.
    - For example, a survey could involve a sparker, sub-bottom profiler (SBP), multi beam echosounder (MBES), side scan sonar (SSS) and supporting system USBL all active simultaneously. If the equipment types of interest are identified as the sparker and the USBL system, these two systems must be measured individually, as well as in conjunction with all equipment types active at the same time.
- The GPS location of the vessel must be logged continuously, along with the location of towed equipment.

4.2.3. Measurement equipment

The measurement equipment must comply with the following specifications:

- All measurement systems must utilize hydrophones (i.e., measuring sound pressure).
- The frequency range must cover at least the 1/3-octave bands from 20 Hz to 50 kHz, requiring a sample rate of at least 128 kHz.
    - If survey activities involve equipment operating above 50 kHz, the frequency range must be extended accordingly up to a maximum limit of 150 kHz.
- Hydrophones must exhibit omnidirectional characteristics ($\pm 3\ dB$) in the horizontal plane.
- The dynamic range of each measurement system must be selected based on the expected noise levels and proximity to the survey vessel path. Systems close to the vessel path must capture high noise levels without extensive clipping, while those farther away should facilitate analysis of low noise levels against background/ambient noise.
- Raw measurement data must be recorded in .wav format for digital submission.
- The ADC (Analog to Digital Converter) must have a resolution of at least 16 bits.
- Calibration procedures for measurement systems must adhere to section 6 of these guidelines.
- Moorings, cables, acoustic triggers, and other physical components must be designed to minimize unwanted noise, such as rattling sounds.
- The measurement program must detail how flow noise is addressed or compensated.

4.2.4. Measurement timeframe and duration

Measurements must be conducted within an appropriate time period, adhering to the following requirements:

- The period for the measurements must correspond with the survey trial duration.
- The duty cycle, or the percentage of the active measurement period, must be 100% during the survey trial.

4.2.5. Analysis

Data post-processing and analysis must follow these specifications:

- The most recent calibration levels must be used to convert recorded voltage levels to sound pressure levels, in accordance with manufacturer guidelines.
- The data should undergo quality assurance before any analysis of sound pressure levels, including identifying periods of extensive clipping to exclude them from the analysis. Statistics regarding omitted data and reasons must be provided for each measurement system.
- If additional measurement systems are used in the upper half of the water column due to strong stratification (see last item in section 4.2.1), analysis must separately consider results from the upper and lower halves of the water column. Present the data sets separately.
- When measuring horizontally directional equipment, the analysis should separately consider vessel passes that are perpendicular to the measurement transect, and those that are at other aspect angles.
- For the analysis, at least 10 pulses around CPA per vessel pass must be included. The absolute distance between source and the measurement system must be calculated for each individual pulse.
- The following must be calculated for each measurement system for the individual trials:
    - Spectrograms for each source type and each distance (measurement station). Color bars must clearly indicate sound levels in the plot.
    - Numerical tables, showing maximum and average CPA levels in:
        - Peak sound pressure level ($L_{p,peak}$)
        - unweighted, PCW, LF, HF and VHF Per pulse SEL (SEL_{ss})
        - unweighted, PCW, LF, HF and VHF SPL ($L_{p,125ms}$)
    - Time plot of a single representative pulse near CPA and a sequence of pulses showing repetition rate. Mark the pulse closest to CPA clearly in sequence plots.
    - Frequency plots: Power spectrum density (PSD) unweighted; and 1/3-octave unweighted and with PCW, LF, HF and VHF frequency weighting for a representative pulse near CPA.
    - Background/ambient/self-noise must be presented alongside pulse frequency spectrums. The background/ambient/self-noise for these

plots should be taken from intervals between pulses, where feasible.
- All results must clearly indicate the aspect angle of the vessel relative to the measurement transect.
- Measurement plots with all pulses should be provided, showing broadband received levels as a function of distance, along with curve fits for:
  - peak sound pressure level ($L_{p,peak}$)
  - unweighted, PCW, LF, HF and VHF Per pulse SEL (SEL_{ss})
  - unweighted, PCW, LF, HF and VHF SPL ($L_{p,125ms}$)
  - Equivalent source levels should be reported for each equipment type for each measurement line through propagation loss curve fits, unweighted and with PCW, LF, HF and VHF weighting:
    $\Delta L_w = L_{S,E,w} - X_w \cdot log_{10}(r) - A_w \cdot r$, where $L_{S,E,w}$ is the equivalent frequency weighted (w) source level (see section 1), r is the distance between source and receiver in m, and X_w, A_w are the frequency weighted propagation coefficients.
- A comparison of the results at different measurement distances, including an analysis of differences.
  - If upper half water depth measurement systems were used, the discussion must include the differences between upper and lower half measurement systems.

4.2.6. Deliverables

A measurement report must be prepared containing the following:

- An executive summary presenting the primary findings at a non-technical level.
- A technical summary discussing the objectives and how they were achieved. Detailed findings, conclusions and results must be presented.
- A detailed description of the measurement program, including:
  - Deployment and recovery procedures.
  - Measurement locations in both coordinates and graphically on a map, with the EPSG clearly stated.
  - Deployment depth and height of sensor (hydrophone) above seabed.
  - Deployment and retrieval dates and times in UTC,
  - Survey activity visualization, with tracks/locations visualized temporally for the duration of the measurement period in UTC.
- Measurement setup, including technical description of measurement systems, hydrophones, mooring and deployment methodologies.

- Equipment calibration, including both laboratory and in-situ calibrations. Certificates must be attached in appendix.
- Technical description of the survey activities conducted during the measurements, including all acoustic survey equipment and supporting equipment (such as Ultra short baseline (USBL), Dynamic Positioning (DP) systems). An activity time schedule must be provided graphically showing which equipment types were active during specific periods of the measurement duration. Relevant equipment-specific details must be provided, including but not limited to, source level, directivity, pulse rate, pulse length.
- Analysis methodology and metrics used, along with technical descriptions.
- Results, including all numerical table results (can be placed in appendix) and graphical results. The results section must also include a comparison between ambient noise levels (periods where no survey activities are within 10 km range of the respective measurement station) and active survey noise levels.
- A discussion on the findings, focused on how measured noise levels and estimated exposure to animals compare to predictions in the prognosis.
- A conclusion detailing the results and comparing them with the objectives for the measurements.
- Appendices including datasheet of measurement systems, hydrophones, probes, moorings, calibration certificates, and any results not presented within the report.

In addition to the measurement report, a digital delivery must be prepared and submitted to the Danish Energy Agency. The digital delivery must be provided in two physical copies (external hard drives with USB 3.2 connection or newer) and must include:

- All recorded data in .wav format
    - The files must be organized in a folder structure with one folder per measurement station.
    - If more than one deployment was conducted at one or more stations (with the same or different instruments), each deployment must be in a separate folder.
    - The naming convention for each file must be consistent and be explained in a metafile including:
        - UTC date and time
        - Measurement station ID
        - Complete metadata for the instrument associated with each deployment, including serial number, hydrophone type for external hydrophones, and clipping level for the recorder (i.e., sound pressure level corresponding to full-scale detection of the wav file).
        - Metadata can be provided as text, XML, or HTF5 files.

- All relevant log files, including:
    - GPS log for survey vessel(s) and for measurement stations (to the extent GPS systems are used at measurement stations).
    - Deployment and retrieval log files
    - Measurement system log files
    - Operational log of the survey vessel
- Digital (.png or .jpeg) files of all result plots.
- Data files with numerical results (if not included in the appendix), either as CSV files or HTF5 files, in accordance with ICES Continuous underwater noise reporting format (ICES, 2022).
- Calibration certificates (PDF).

5. System self-noise

The system self-noise of any measurement setup should be documented and comply with recommendations in ISO 18406, section 4.2.5.

6. Requirements for calibration

To ensure the quality of measurements, periodic laboratory calibration across the full frequency range is required, as well as calibration checks before and after the deployment of equipment for specific projects. The calibration guidelines outlined in ISO 18406, section 4.3, should be adhered to.

- All measurement systems must undergo calibration traceable to national or international standards. It is recommended that hydrophones be fully calibrated at intervals of two years.
    - The most recent laboratory calibration certificates must be included in the measurement documentation.
    - If a hydrophone has experienced physical damage or improper handling, such as being caught in a trawl, full laboratory calibration is necessary before redeployment.
- All measurement systems must undergo calibration checks immediately before and after deployment, as well as between any repeated deployments.
    - Calibration checks can be performed using a hydrophone calibrator (pistonphone) or, if feasible and suitable for the chosen measurement system, through an electrical signal injection (insert voltage, where a known signal is applied via a resistor directly to the input of the preamplifier with the hydrophone element connected in the normal configuration).

- Calibration values for all measurement systems must be documented in the final report. This documentation should include details on the dynamic range, gain settings, and the sound pressure level corresponding to full-scale recording (clip level).

Bibliography

BSH. (2011). *Measuring instruction for underwater sound monitoring; Offshore wind farms.* Hamburg: Bundesamt für Seeschifffahrt und Hydrographie.

DS/ISO 18405. (2017). DS/ISO 18405 - Underwater acoustics - Terminology.

DS/ISO 18406. (2017). DS/ISO 18406 - Underwater acoustics - Measurement of radiated underwater sound from percussive pile driving.

Energistyrelsen. (2023). *Guideline for underwater noise - Installation of impact or vibratory driven piles.* March.

Fischer, J.-G., Kühnel, D., & Basan, F. (2021). *JOMOPANS measurement guidelines. Report of the EU INTERREG Joint Monitoring Programme for Ambient Noise North Sea (JOMOPANS).*

ICES. (2022). *Continuous Underwater Noise Reporting Format.* Copenhagen.

MacGillivray, A. O., Martin, B., Ainslie, M. A., Dolman, J. N., Li, Z., & Warner, G. A. (2023). Measuring vessel underwater radiated noise in shallow water. *JASA*, 1506-1524; https://doi.org/10.1121/10.0017433.

National Marine Fisheries Service. (2024). *Update of Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 3.0) - Underwater and In-Air Criteria for Onset of Auditory Injury and Temporary Threshold Shifts.* p. 182: NOAA Technical Memorandum NMFS-OPR-71.

NOAA. (April 2018). *Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2.0), NOAA Technical Memorandum NMFS-OPR-59.* Silver Spring, MD 20910, USA: National Marine Fisheries Service.

Southall, B. L., Finneran, J. J., Reichmuth, C., Nachtigall, P. E., Ketten, D. R., Bowles, A. E., . . . Tyack, P. L. (2019). Marine Mammal Noise Exposure Criteria: Updated Scientific Recommendations for Residual Hearing Effects. *Aquatic Mammals 45(2)*, 125-232, DOI 10.1578/AM.45.2.2019.125.

Tougaard, J. (2021). *Thresholds for behavioural responses to noise in marine mammals. Background note to revision of guidelines from the Danish Energy.* Aarhus: Aarhus University DCE – Danish Centre for Environment and Energy, 32 pp. Technical Report No. 225 http://dce2.au.dk/pub/TR225.pdf.

Tougaard, J. (2021). *Thresholds for noise induced hearing loss in marine mammals. Background note to revision of guidelines from the Danish Energy Agency.* https://dce.au.dk/fileadmin/dce.au.dk/Udgivelser/Notater_2021/N2021%7C28.pdf: DCE - Danish Centre for Environmnet and Energy, 34s. - Scientific note no. 2021|28.

Tougaard, J. (2025). Behavioural reactions of harbour porpoises to impact pile driving noise are predicted by the auditory frequency weighted sound pressure level. *J. Acoust Soc Am 157*, 1368-1377, doi.org/10.1121/10.0035916.

Tougaard, J., Sveegaard, S., & Galatius, A. (2020). *Marine mammal species of relevance for assessment of impact from pile driving in Danish waters. Background note to revision of guidelines from the Danish Energy Agency.* Roskilde.

Verfuß, U., Andersson, M., Folegot, T., Laanearu, J., Matuschek, R., Pajala, J., . . . Tougaard, J. (2015). *BIAS Standards for noise measurements. Background information,Guidelines and Quality Assurance. Amended version.*