



Energistyrelsen

Guideline for underwater noise prognosis for geophysical,  
geotechnical and seismic survey activities  
Energistyrelsen, November 2025

**Energistyrelsen**

Carsten Niebuhrs Gade 43  
1577 København V

T: +45 3392 6700  
E: [ens@ens.dk](mailto:ens@ens.dk)

[www.ens.dk](http://www.ens.dk)



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## Summary and overview

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This Guideline concerns underwater noise prognosis for geophysical, geotechnical and seismic surveys in Danish waters. Technical methods are presented for performing numerical prognosis. Acoustic criteria include Auditory Injury (AUD INJ) and behavioural impact. The acoustic criteria are based on auditory frequency weighting functions for relevant marine mammal species in Danish waters.

The applicant must carry out a prognosis for the proposed survey activities in line with this guideline, and must submit it to the Danish Energy Agency.

The prognosis must include relevant sound propagation models for the equipment included in the survey. Depending on the equipment types included, the individual equipment types could require either numerical modelling, semi-empirical modelling, or literature based evaluation. The latter is typically relevant for equipment types where modelling is not feasible, or where representative empirical data is available.

Through the prognosis results, harbour porpoise disturbance days must be calculated, as well as appropriate soft-start procedure, through definitions provided within this guideline. Both must be reported as part of the prognosis to the DEA.

### *Document overview*

- **Section 1** defines acoustic metrics and terms used throughout the Guideline.
- **Section 2** presents a set of acoustic criteria for which impact ranges must be documented for the proposed survey activities.
- **Section 3** specifies the criteria for numerical modelling vs. literature based evaluation for equipment.
- **Section 4** specifies the requirements of the prognosis, for equipment requiring either numerical or semi-empirical approaches.
- **Section 5** specifies the requirements for calculation of soft start procedure.
- **Section 7** specifies the requirements for calculation of harbour porpoise disturbance days.



## 1. Definitions

Acoustic metrics used throughout the guidelines generally follow (Energistyrelsen, 2023), ISO 18405 and ISO 18406.

## 2. Acoustic criteria

The prognosis 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 included in the prognosis, 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  $\mu Pa^2 s$  and SPL in dB re 1  $\mu Pa$ . 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 <sup>1</sup>	Grindhval	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.*

Note that behaviour disturbance thresholds are only available for harbour porpoise at the time of writing (see Tougaard (2021), Tougaard (2025)). If behavioural response thresholds are used for other species or species-groups, these must be thoroughly substantiated. The generic thresholds for behavioural responses of cetaceans of 160/180 dB rms are not considered applicable.



### 3. Criteria for modelling vs. literature based evaluation

Certain equipment types may not be suited for literature based evaluation, but instead requires numerical modelling or semi-empirical modelling, due to their source characteristics.

A screening of all proposed equipment is therefore required as part of the prognosis, where the source characteristics are evaluated with respect to the suitability for literature based evaluation, numerical modelling or semi-empirical modelling. The evaluation should as a minimum consider the equipment source level, frequency characteristics, directivity, and impulsivity. A non-exhaustive list of equipment typically characterized as impulsive include airguns, sparkers, boomers and explosives, while non-impulsive equipment includes sonars, pingers, USBL, echosounders, drilling, vibrocore and vessel noise. The evaluation should also consider environmental parameters for the survey area. Justification for exclusion from numerical or semi-empirical modelling must be provided for all equipment that the applicant would like to omit.

Examples of reasons for a literature based evaluation could be:

- Equipment with frequency content fully outside the audible range of relevant marine mammals, typically above ~180 kHz (e.g. a Multi-beam Echo Sounder (MBES) operating at 200 kHz).
- Equipment without acoustic emission, such as a magnetometer, unless an acoustic positioning system (USBL) is used to track the position of towed equipment.
- Equipment where empirical data shows less underwater noise emission than the survey vessel, such as a cone penetration test (CPT).

### 4. Procedure for numerical and semi-empirical modelling

A step-by-step procedure for carrying out the prognosis is provided, followed by individual sections specifying the detailed requirements for each step.

The procedure for the prognosis is that the applicant:

- 1) chooses an appropriate number of prognosis locations, in line with requirements in section 4.1.
- 2) performs a screening of all survey activities and supporting systems, such as USBL, and designs a detailed source model for those equipment types that require underwater sound propagation modelling. Source models must follow requirements in section 4.2.
- 3) uses source model from step 2 in a site specific underwater sound propagation model in line with requirements in section 4.3.1 for a semi-empirical model approach, or in section 4.3.2 for a numerical model approach.



- 4) calculates impact ranges for the AUD INJ and behaviour impact criteria provided in section 4.4 for all relevant species.
- 5) calculates and documents soft start procedure according to the procedure outlined in section 5.
- 6) calculates and documents harbour porpoise disturbance days for the survey according to the procedure outlined in section 7.

#### 4.1. Prognosis extent

The following requirements must be fulfilled and documented through the prognosis:

- A suitable number of locations within the project area must be selected for the prognosis. For project areas covering less than 10 km<sup>2</sup>, a minimum of 3 source positions are required. For project areas covering more than 10 km<sup>2</sup>, a minimum of 5 source positions are required. For projects in geographical regions with large variations in bathymetry, sediment or hydrography, a higher number of positions should be considered, so that the variations are represented. The number of survey positions must, regardless of the minimum number, always be sufficient to cover the survey activities and the environmental variation. Number of positions selected must be justified.
- Source positions should be selected based on:
  - o Positions within the site likely to have the lowest sound propagation loss.
  - o Positions in close proximity to protected areas for marine species, such as relevant Natura 2000 appointed to protect marine mammals, to determine the extent of noise overlapping the area.
- Documentation of chosen source positions must include georeferenced maps, as well as coordinates for each position in an appropriate Coordinate Reference System (CRS) such as EPSG: 4326 or EPSG: 2583X [X=1/2/3].

#### 4.2. Source model

The following requirements must be fulfilled and documented:

- Source level and spectrum for the proposed activities.
  - o Source Level for a transient source is defined as  $L_{S,E}$  [dB re 1  $\mu Pa^2 m^2 s$ ], as defined in ISO 18405 (DS/ISO 18405, 2017). Abbreviation is SEL



- Source Level for a continuous source is defined as  $L_S$  [dB re 1  $\mu Pa^2 m^2$ ], as defined in ISO 18405 (DS/ISO 18405, 2017). Abbreviation is SPL
- Source Level is presented as both broadband level and in decidecade bands. Broadband values must include species specific frequency weighted broadband values of each relevant marine mammal species, as per hearing group specifications in (Southall, et al., 2019). Source levels must correspond to the maximum equipment source level to be used during the activity.
- Frequency range for individual source models should cover the extent relevant for the individual noise sources, however not beyond the range 12.5 Hz to 160 kHz (decidecade center frequencies).
- A justification for the source level and frequency spectrum along with assumptions and uncertainties must be provided, based on best-available knowledge.
- Each survey activity must be described.
  - For moving survey activities, such as geophysical and seismic surveys, this includes vessel speed (in knots) and active survey duration over a 24 hour period (i.e. hours, where the ship is testing equipment, performing soft start or collecting data) for each relevant equipment type. To the extent it is available, the survey line plan should also be described.
  - For stationary survey activities, such as certain geotechnical survey activities, the active duration of each activity at each location, as well as number of samples during a 24 hour period must be specified.

### 4.3. Site specific propagation model

The prognosis must be based on a site-specific sound propagation model to determine sound emission from the survey.

The sound propagation model can be based on either:

- A semi-empirical approach, where previous measurements form the base of the assumed sound propagation loss, or



- A numerical model approach, where appropriate sound propagation models (e.g. Finite element, Parabolic Equation, Ray/Beam tracing, Normal modes,...) are used.

Separate requirements for the two approaches apply as detailed in the following subsections.

### 4.3.1. Semi-Empirical model

A semi-empirical model may be used if all the criteria below are fulfilled:

- The oceanographic conditions during the measurements, on which the semi-empirical prognosis will be based, must be comparable to those for the area to be investigated as minimum on the parameters:
  - o Bathymetry
  - o Sediment soil acoustic properties of uppermost layers
  - o Water temperature and salinity profiles
- An assessment of the local influence of seasonality must be added, relating the conditions during measurement to those of the intended survey timeframe. E.g. the influence of measurement results obtained during summer months, relative to an intended survey in winter months for the project area. This assessment must be supported by best-available knowledge on local salinity and temperature changes over the year.
  - o If measurements are performed during significantly different sound speed conditions than the assessment finds to be likely conditions during installation, the measurements are not considered valid as a basis for the prognosis.
- The characteristics of the sound source used to obtain measurements must comply with the following:
  - o The frequency content of the source must cover the frequency range of the source model.
  - o The frequency content must be measurable above ambient noise level within each frequency band in the entire frequency range.
- A sound propagation curve fit for the measurements in the form  $\Delta L = X \cdot \log_{10}(r) + A \cdot r \text{ dB}$ , where  $X$  [-] is a positive and  $A$  [m-1] a positive or negative constant, and  $r$  the distance [m].
  - o The transect bathymetry for which the curve fit is supplied, must be illustrated graphically.



- The curve fit must be supplied as a broadband curve fit, provided unweighted and for each of the frequency weightings as per requirement - o, section 4.2.
  - o The curve fit can optionally also be provided as individual unweighted curve fits for each 1/3 octave band.
- The curve fit documentation must include all measurement data points supporting the curve fit. The metric used must be  $SEL_{SS}$  or SPL over the pulse duration, as defined in ISO 18406 (DS/ISO 18406, 2017).
- The precision and uncertainty of the prognosis must be discussed.
- Technical documentation of the measurements used in this approach must be attached as an appendix to the prognosis in order to be considered a valid method.

### 4.3.2. Numerical model

A numerical model approach may be used if all the criteria below are fulfilled:

- An appropriate numerical model, or a combination of multiple models, is used. Argumentation for model choice must be reported, with reference to the site and source specific conditions.
- A non-exclusive list of exemplary model types is Finite Element (FE), Parabolic Equation (PE), Normal Modes (NM), Wavenumber Integration (WI), Ray/Beam Tracing (RT/BT).
- The used propagation software must be stated, including program version and date.
- Site specific acoustic environmental inputs must be used and reported, including:
  - o Bathymetry
  - o Sediment soil acoustic properties of uppermost layers, including absorption, density and sound speed.
  - o Air-water interface conditions: Calm water or surface roughness
  - o Water temperature and salinity profiles for the entire water depth
  - o Sound speed profile(s) for the entire water depth
- Sound propagation curve fit(s) resulting from the model must be documented.



- Curve fit(s) must be based on a Max-Over-Depth (MOD) approach, where sound propagation model output at each range step is the maximum level at that range over all water depths.
- The curve fit of at least the worst-case transect must be supplied.
- The curve fit must be documented both unweighted and for each relevant marine mammal auditory group frequency weightings.
- Curve fit documentation is recommended to include a distance vs. level plot with all data points as well as the used curve fit.
- The curve fit must be documented in either:
  - The form  $\Delta L = X \cdot \log_{10}(r) + A \cdot r$  dB, where  $X$  [-] is a positive and  $A$  [ $m^{-1}$ ] a positive or negative constant, and  $r$  the distance [m], or
  - Using a more accurate curve fit model. In this case, the approach must be justified, and extrapolation methodology explained.
- The metric used must be  $SEL_{SS}$  for impulsive sources and  $SPL$  for continuous sources, as defined in ISO 18406 (DS/ISO 18406, 2017).
- Number of transects modelled must be at least:
$$N_{transects} \geq \begin{cases} \frac{180}{r_{land}} & \text{if } r_{land} \leq 10 \\ 18 & \text{otherwise} \end{cases}$$
  - Where;  $N_{transects}$  is the minimum number of transects required, and  $r_{land}$  is the minimum distance in km in any direction from the source to a land mass.
- The horizontal resolution of the model should reflect the site specific conditions and choice of sound propagation model. Recommended spacing is 25 m or shorter. Justification for choice must be provided.
- The vertical resolution of the model should be 1 m or finer. Justification for choice must be provided.
- Sound propagation model must cover at least 10 km radius, however may be reduced if land is reached in all directions before 10 km distance. For seismic surveys, however, a minimum of 20 km radius is required. It is the responsibility of applicant to choose a sufficiently large calculation range to document the distance to relevant impact ranges.
- The uncertainty of the prognosis must be discussed, based on environmental parameters and sound propagation model choice.



#### 4.4. Acoustic criteria

The following process for calculating impact ranges for the relevant species must be followed.

- The auditory group cumulative sound exposure level,  $L_{E,cum,xx}$  is calculated through Equation 1 (stationary sources) or Equation 2 (moving sources) for each of the relevant marine mammal auditory groups (xx) for each relevant equipment type. Calculations can be omitted for equipment types without acoustic emission in the 10 Hz – 160 kHz frequency range.
  - o The calculation must at least be carried out for the transect with the lowest sound transmission loss for each respective marine mammal auditory group. It is encouraged to carry out calculations for additional transects.
  - o A fleeing speed  $v_f$  of 1.5 m/s should be used. Any use of an alternative fleeing speed can be used if supported by best-available knowledge, in which case this must be documented and justified.
  - o The calculation is carried out for one auditory group's specific frequency weighting at a time. This implies the use of auditory group specific transmission loss coefficients and source level.

For stationary sources, using an iterative process for each frequency weighting, Equation 1 is used to calculate the safe starting distance " $r_0$ " for AUD INJ threshold criteria.

*Equation 1: Stationary source cumulative impact level*

$$L_{E,p,xx,24h} = 10 \cdot \log_{10} \sum_{i=1}^N 10^{\frac{L_{S,E,xx} - X_{xx} \cdot \log_{10}(r_0 + v_{receiver} \cdot t_i) - A_{xx}(r_0 + v_{receiver} \cdot t_i)}{10}}$$

Where

- $L_{E,p,xx,24h}$  [dB] is the auditory group frequency weighted threshold criteria for AUD INJ over a 24 hour time frame,
- $xx$  is the auditory group frequency weighting, LF, HF, VHF or PCW.
- $i$  [-] is the current pulse number where the first emitted pulse is at  $i = 1$ .
- $N$  [-] is the total number of pulses the equipment emits within any 24 hour period,
- $L_{S,E,xx}$  [dB re 1  $\mu\text{Pa}^2\text{m}^2\text{s}$ ] is the auditory group frequency weighted source level at 100% source level, as defined in ISO 18405,



- $X_{xx}$  [-] is the auditory group frequency weighted curve fit coefficient obtained through sound propagation modelling.
- $A_{xx}$  [ $m^{-1}$ ] is the auditory group frequency weighted curve fit coefficient obtained through sound propagation modelling.
- $r_0$  [m] is the start distance of the marine mammal at the survey activity onset,
- $v_{receiver}$  [m/s] is the fleeing speed of the marine mammal, typically 1,5 m/s
- $t_i$  [s] is the total time elapsed at pulse “ $i$ ” since the onset of the survey, which occurs at  $t_1 = 0$ .

For moving sources, using an iterative process for each frequency weighting, Equation 2 is used to calculate the safe starting distance “ $r_0$ ” as the safe starting distance for the marine mammal for the AUD INJ thresholds.

*Equation 2: Moving source cumulative impact level*

$$L_{E,p,xx,24h} = 10 \cdot \log_{10} \left( \sum_{i=1}^N 10^{\left( \frac{L_{S,E,xx} - X_{xx} \cdot \log_{10}(r_i) - A_{xx}(r_i)}{10} \right)} \right)$$

Where:

- $L_{E,p,xx,24h}$  [dB] is the auditory group frequency weighted threshold criteria for AUD INJ over a 24 hour time frame,
- $i$  [-] is the current pulse number where the first emitted pulse is at  $i = 1$ .
- $N$  [-] is the total number of pulses the equipment emits within any 24 hour period,
- $L_{S,E,xx}$  [dB re 1  $\mu Pa^2 m^2 s$ ] is the auditory group frequency weighted source level at 100% source level, as defined in ISO 18405,
- $X_{xx}$  [-] is the auditory group frequency weighted curve fit coefficient obtained through sound propagation modelling.
- $A_{xx}$  [ $m^{-1}$ ] is the auditory group frequency weighted curve fit coefficient obtained through sound propagation modelling.
- $r_i$  [m] is the distance between survey equipment and receptor (marine mammal) at time of pulse “ $i$ ” defined through Equation 3.

*Equation 3: Distance calculation for moving sources and moving receivers*

$$r_i = \sqrt{(r_0 - ((i - 1) \cdot t_i) \cdot v_{ship})^2 + (((i - 1) \cdot t_i) \cdot v_{receiver})^2}$$

Where:

- $r_0$  [m] is the on-axis distance between vessel and receptor (marine mammal)
- $t_i$  [s] is the total time elapsed at pulse “ $i$ ” since the onset of the survey, which occurs at  $t_1 = 0$ .
- $v_{ship}$  [m/s] is the vessel speed,
- $v_{receiver}$  [m/s] is the receptor (marine mammal) swim speed.



- behavioural disturbance distance for harbour porpoise ( $r_{behaviour}$ ) must be calculated as the distance, beyond which the rms sound pressure level,  $L_{p,125ms,VHF} \leq 103 \text{ dB}$ , where:  $L_{p,125ms,VHF} = L_{E,p} + 10 \log_{10}(0.125) = L_{E,p} + 9 \text{ dB}$ , where  $L_{E,p}$  is the VHF frequency weighted sound exposure level of pulses occurring within a 125 ms window.
  - o If a behavioural disturbance criteria is available for any other relevant species, the impact range must also be calculated for those.

## 5. Soft-start procedure

In addition to the calculation of AUD INJ and behaviour impact ranges, the soft start procedure to be followed prior to survey activities is defined as follows and must be calculated for each survey activity included in the prognosis. The calculated soft start procedure must be reported as part of the executive summary for the activity with the longest soft start duration, in table format in the following structure:

Soft start step	Source level $L_{S,E} [dB \text{ re } 1 \mu Pa^2 s]$	Duration T [minutes]	Pulse rate [pulses per second]
1			
2			
...			
N			

- If the AUD INJ impact ranges for all relevant marine mammals are below 50 m, and the harbour porpoise behavioural disturbance impact range is less than 1 km, for all equipment types, a soft start is not required.
- If the harbour porpoise behavioural disturbance impact range exceeds 1 km, but the AUD INJ does not exceed 50 m for any relevant marine mammals, a fixed 10 min soft start is required.
- If the AUD INJ distance for any marine mammal exceeds 50 m for any equipment according to the prognosis, a scaled soft start procedure must be used. The procedure is calculated through Equation 4, and must be calculated individually for each survey equipment with an AUD INJ impact range over 50 m.

Equation 4: Extended soft start duration

$$T_{SS} = 10 + \frac{r_{0,INJ}}{60 \times v_{receiver}} [min]$$

Where:



- $T_{SS}$  [min] is the soft start duration in minutes,
- $r_{0,INJ}$  [m] is the maximum AUD INJ impact range for the specific equipment type, over all relevant marine mammal species.
- $v_{receiver}$  [m/s] is the receptor (marine mammal) swim speed. 1.5 m/s can be assumed.
- The soft start must be carried out using appropriate equipment and can be either source types used for the intended activities, or separate equipment used only for the purpose of soft start. If separate equipment is used, it must have a comparable directionality to the survey equipment, or less directional. It is a condition that the equipment must have a deterring effect on the marine mammal species of relevance. If necessary to fulfil the procedure outlined below, multiple different pieces of equipment can also be used in combination. The soft start equipment is hereafter referred to as SSE.
- For the first 10 minutes of the soft start, the SSE must have a source level of  $L_{S,E} = 150 - 160 \text{ dB re } 1 \mu\text{Pa}^2\text{s}$ .
- Following the first 10 minutes, in steps of 10 minutes (or until  $T_{SS}$  is reached), the source level must be increased by up to 10 dB per step. The source level increase must take place without significant pause (< 60 seconds).

## 6. Overlap with Natura 2000 area

As part of the prognosis, the worst case overlap between AUD INJ, TTS and behaviour threshold criteria, with relevant Natura 2000 areas must be calculated. The calculations must be based on realistic worst case source positions, closest to the relevant Natura 2000 areas. The overlap must be reported in a table as both  $\text{km}^2$  and in percent of the total Natura 2000 area. The overlap table must be made available in both the results section of the report, as well as in the executive summary.

## 7. Harbour porpoise disturbance days

As part of the prognosis, a calculation of porpoise disturbance days (PDD) must be carried out. For a detailed explanation of PDD, see Tougaard (in press). A



simplified technical approach for calculation of PDD based on the sound propagation modelling results is provided in Equation 5.

*Equation 5: Calculation of porpoise disturbance days (PDD) using output from sound propagation modelling using a moving source.*

$$PDD = \rho_{porpoise} \cdot A_{behaviour,24h} \cdot N$$

Where:

- $PDD$  is the porpoise disturbance days in [*porpoise* · *days*].
- $\rho_{porpoise}$  is the density of harbour porpoise in  $\left[\frac{\text{porpoise}}{\text{km}^2}\right]$ .
- $A_{behaviour,24h}$  is the area affected over the harbour porpoise behaviour threshold criterion of  $L_{p,125ms,VHF} = 103 \text{ dB re. } 1\mu\text{Pa}$ , in [ $\text{km}^2$ ], for a 24-hour continuous duration.
  - o If  $A_{behaviour,24h}$  is a direct output from sound propagation modelling, the value can be used directly in the equation.
  - o If  $A_{behaviour,24h}$  is not a direct output from sound propagation modelling, it can be conservatively calculated through Equation 6.
- $N$  is the number of days with active survey [*days*].

*Equation 6: Calculation of conservative  $A_{behaviour,24h}$  using single point sound propagation modelling results for the harbour porpoise behavioural threshold.*

$$A_{behaviour,24h} = 2 \cdot r_{behaviour} \cdot v_{vessel} \cdot 24$$

Where

- $r_{behaviour}$  is the worst-case impact range for the harbour porpoise behaviour criterion, in [ $\text{km}$ ].
- $v_{vessel}$  is the vessel speed in  $\left[\frac{\text{km}}{\text{hour}}\right]$ .

The following applies for the calculation of PDD.

- The PDD must be calculated individually for each vessel ( $PDD_{vessel}$ ) included in the prognosis
- The PDD must be calculated as a total ( $PDD_{total}$ ), as a sum of  $PDD_{vessel}$  for all vessels included in the prognosis.
- The calculation of  $PDD_{vessel}$  must be based on the equipment type with the longest harbour porpoise behaviour threshold impact range ( $L_{p,125ms,VHF} = 103 \text{ dB re. } 1\mu\text{Pa}$ ).
- All  $PDD_{vessel}$  and  $PDD_{total}$  must be reported in both results section and in the executive summary in the prognosis report.



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