BNAM 2026
Baltic-Nordic Acoustics Meeting
May 04-06 2026 Gothenburg, Sweden

Detection range of harbour porpoise pingers by a hydrophone in Swedish waters

Frida Thörn, Christophe Mattei and Mathias H. Andersson
FOI Swedish Defence Research Agency, SE-16440 Kista, Sweden. frida.thorn@foi.se, christophe.mattei@foi.se, mathias.andersson@foi.se

One of the greatest threats harbour porpoises are facing is to get entangled in fishing nets. One effective measure for preventing this bycatch of porpoises are pingers. However, there is a lack of knowledge regarding what signal is emitted from the pingers and at what distance the pingers can be detected. This study aims to improve this knowledge by estimating the source level of four pinger models and modelling the detection range for a standard hydrophone system at four typical environments in Swedish waters. The source level in one-third octave band is measured in the Swedish Defence Research Agency's (FOI) indoor basin for four pinger models from two different manufacturers, Fishtek and Future Oceans. The result shows a difference in both frequency content and source level between the manufacturers. Signals from Fishtek's pingers have a varied frequency content between 50-150 kHz with clear frequency sweeps. Signals from Future Oceans pingers have less variation in frequency but clearer overtones yielding a broader frequency range from 50 to 200 kHz. The estimated broadband source levels from the measurements have a standard deviation less than 2 dB and for all models the dominating one-third octave band is 63 kHz. To estimate the detection range, the propagation loss is computed and subtracted from the signal's source level. Depending on the receiver depth, month and bearing, the estimated propagation loss varies up to 20 dB. The detection range also depends on the receiving system. As an example, the system SoundTrap ST640 HF with a hydrophone of type HTI-99-UHF is used. For a Yellow Fishtek (PB-FR) the detection range varies between 760-2200 meters in typical environments used for the north Baltic Sea and 390-940 meters in Kattegat. Both the longest and shortest detection ranges are deemed realistic.

1 Introduction

In Swedish waters, the harbour porpoises (*Phocena phocena*) occur mainly in the Western Sea, the Sound and the southern Baltic Sea [1]. In the Western Sea and the Sound, the population is viable, but in the southern Baltic Sea it is critically endangered. One of the major threats to harbour porpoises is accidental catches in fishing nets, known as bycatch, where the harbour porpoise drowns. To prevent this, it has been proposed that fishing nets, mainly bottom nets, should be equipped with so-called pingers in the Harbour Porpoise Action Programme [1]. Pingers have been shown to be effective in warning harbour porpoises to avoid specific parts of the water [2]. In this paper, pingers refer to transmitters that generate sound with the main energy above 50 kHz in order to deter harbour porpoises. They are designed to have the most energy in the porpoise's best hearing range but above the frequencies that seals can hear (i.e. above 50 kHz). The recommendation to use pingers to reduce bycatch is also described in Regulation (EU) 2019/1241 of the European Parliament and of the Council [3]. There are a number of different pingers on the market that transmit different pulse types at different frequencies and source strengths, see examples in [4]. Unfortunately, the technical information from manufacturers can in some cases be brief, and to calculate at what distance a pinger can be detected by a receiver (such as a measuring system or a porpoise), the technical specifications need to be quantified through measurements. The hearing range of porpoises extends from around 1 kHz up to over 150 kHz. The lowest unweighted sound pressure level that a harbour porpoise can perceive is around 45–57 dB re 1 µPa in the frequency range 32–100 kHz when 50–1500 ms long narrowband pulses have been played [5].

The purpose of this study is to investigate how far commonly occurring pingers can be detected in four representative locations in Swedish waters by a measurement system and was funded by Swedish Agency for Marine and Water Management. First, an estimation of the source level in one-third octave bands, which is not commonly found in technical descriptions from the manufacturers, is performed. Then, the propagation loss is estimated at different locations. The distance at which a pinger can be detected by a hydrophone depends on where, and at what depth, the pinger is placed and where the receiver is located. This paper presents some of the results from the study. All results and a more in-depth description on the methodology can be found in [6].

2 Pingers in the study

The study encompasses four distinct models, presented in Table 1 and depicted in Figure 1. Among these, the Yellow Fishtek is currently the most prevalent on fishing nets according to the Swedish University of Agricultural Sciences (SLU), whereas the Red Netshield is currently prohibited in Swedish waters. Results related to the Yellow Fishtek will be the focus in this paper. The specifications indicate a broadband source level, which is insufficient for estimating detection ranges, thus necessitating experimental measurements.

Table 1. Specification of the pingers that were included in the study.

Referred as	Manufacturer	Model	Frequency range (kHz)	Source Level (dB re. 1 μPa^2m^2)
Yellow Fishtek	Fishtek	BP-FR	50-120	145 ± 5
Red Fishtek	Fishtek	BP-FR High Power	50-120	155 ± 5
White Netguard	Future Oceans	Netguard	50-120	145
Red Netshield	Future Oceans	Netshield	50-120	175

Figure 1. Pingers included in the study (from top to bottom): Yellow Fishtek, Red Fishtek, White Netguard and Red Netshield. To the right is the pinger itself and on the left its plastic cover.

When deployed in the water column, the pinger emits a series of well-defined acoustic pulses, referred to as pings, characterized by variable pulse durations and interpulse intervals. Additionally, signal characteristics vary slightly between consecutive pings in both waveform morphology and spectral content. Fishtek and Future Oceans utilize distinct signal generation methodologies. Fishtek pinger signals exhibit complex spectral characteristics with frequency sweeps spanning the broad 50–150 kHz range. When frequency-downshifted to the audible range, such signals are perceived as brief, bird-like chirps. An example of a single ping from a Yellow Fishtek, comprising its time-domain waveform and spectrogram, is illustrated in Figure 2.

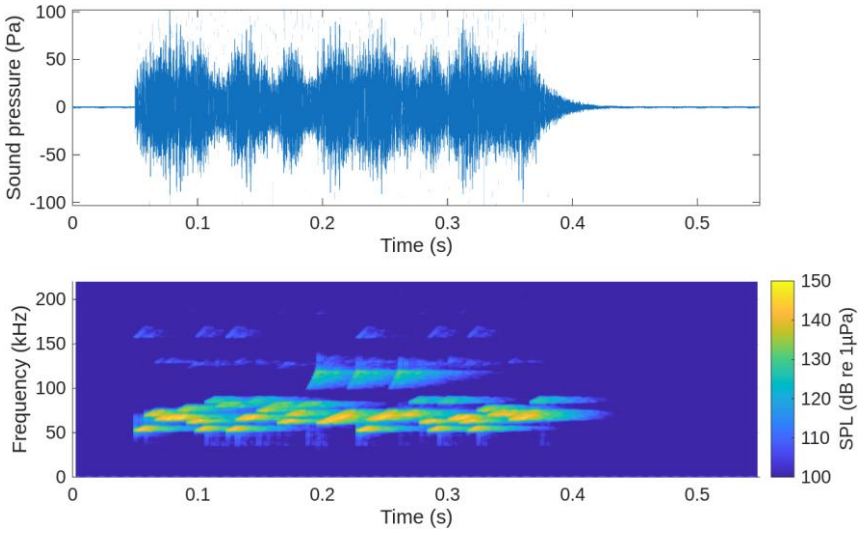

Figure 2. Measured ping from a Yellow Fishtek. The upper figure shows the time signal of the sound pressure. The lower figure shows the Sound Pressure Level (SPL) against time and frequency, so-called spectrogram.

3 Source levels from measurements in an indoor basin

Source level is a characteristic quantity of a source and is defined in ISO18405 as "the root-mean-square sound pressure level at a distance of 1 m from a hypothetical point source, placed in a (hypothetical) infinite, homogeneous and lossless medium" [7]. For practical reasons, the estimation of the pinger source level is based on measurements conducted in FOI's indoor basin which includes an 8 × 4 × 4 m (length × width × height) water basin. The pinger is lowered into the water and connected to a rotation table, allowing it to rotate in front of a calibrated hydrophone (Reson TC4034, SN 1514032) positioned 2 m from the pinger. The measurement methodology must therefore compensate for deviations from the ISO definition arising from the measurement configuration. Furthermore, a pinger represents a very specific type of sound source with inherent variations that must be taken into account. The analysis process for estimating the pinger source level from basin measurements comprises the following steps: 1) average variations between individual pings, 2) account for potential variations related to directivity, 3) compensate for the effect of the diffuse field in the basin.

Variations between individual pings for a given measurement position are addressed by calculating an arithmetic mean and standard deviation over 35 pings. A one-third octave band spectrum is calculated for each ping, and statistical values of the measured sound pressure levels (mean and standard deviation) are estimated in each one-third octave band.

To evaluate the effect of directivity, spatial averaging is performed by rotating the pinger in front of the measurement hydrophone in both the vertical and horizontal directions. The standard deviation of the broadband sound pressure level across different angles for the Yellow Fishtek in the vertical direction and horizontal direction in front of the hydrophone is measured to be ± 1 dB. This motivates to consider the pinger as an omni-directional source.

When measuring in a finite basin, the requirement that the sound source be situated in an infinite and lossless medium is not satisfied. The attenuation in the basin is estimated to be at 0.023 dB/m at 200 kHz and is therefore considered negligible. However, the ping duration for all pingers is of the same order of magnitude as the basin's reverberation time, which means that the measurement is conducted in a diffuse field where wall reflections mix with the contribution from the direct path. This results in a relatively constant amplitude beyond a certain distance from the source, which in turn implies that the effect of the diffuse field must be compensated for.

Trinh et al. [8] propose a method for calculating the source level of an underwater sound source in a basin, based on principles from airborne acoustics. The method uses the basins reverberation time to calculate the distance from the source at which the direct sound field has the same amplitude as the diffuse sound field in the basin—the so-called critical radius, R_c. If the actual measurement position (2 m) and the desired measurement position (1 m for source level) are both located beyond R_c, a compensation for the effect of the diffuse field can be derived through simple geometric reasoning. The relationship between the sound pressure level at 1 m distance (i.e., the source level) and the measured sound pressure level in the diffuse field is according to [8] is then:

$$L_p(1m) = L_p(R > R_c) + 20\log\left(\frac{R_c}{1}\right). \quad (1)$$

The critical radius, is related to the reverberation time in the water basin, T_{60} , by [8]:

$$R_c = \sqrt{\frac{55.26}{16\pi}\frac{V}{c\,T_{60}}} \tag{2}$$

where V is the basins volume and c is the speed of sound in water.

Thinh's method is used in this study. The reverberation time in the FOI basin is measured to be 0.16 s at 50 kHz, 0.15 s at 100 kHz, and 0.14 s at 150 kHz, resulting in R_c=0.74 ± 0.02 and a compensation factor of 2.6 ± 0.2 dB within the frequency range 50–150 kHz. A compensation factor of -2.6 dB is then used to estimate the source level from the SPL measurements in the FOI basin.

The source level in one-third octave band for the Yellow Fishtek estimated from the process described above is shown in Figure 3 where the arithmetic mean and standard deviation are displayed for each one-third octave band. The dominant contribution is centred in the 63 kHz one-third octave band and the broadband source level is estimated at 143 ± 1.6 dB re. 1 µPa²m². This dominant 63 kHz is also found in the other three pinger models which is presented in Table 2. White Netguard and Red Netshield models have a higher energy contribution at 200 kHz compared to the two Fishtek models.

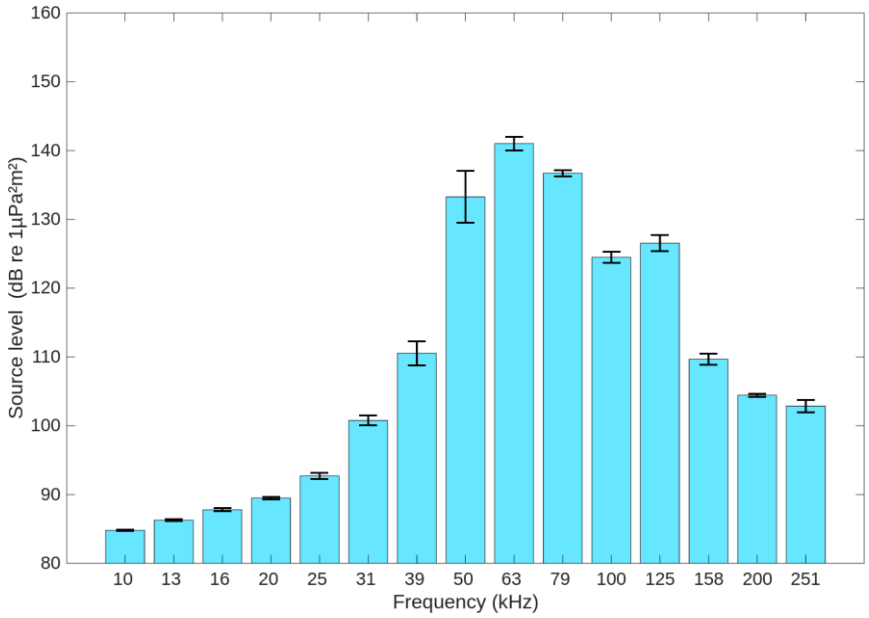

Figure 3. The source level in one-third octave bands for the Yellow Fishtek model. The bars correspond to the arithmetic mean and the error bars to the standard deviation over 35 pings.

Table 2. Source levels in one-third octave band (mean) and broadband source level (mean and standard deviation) in dB re 1µPa²m² for the four pingers.

Frequency (kHz)	10	13	16	20	25	31	39	50	63	79	100	125	158	200	251	Broadband
Yellow Fishtek	85	86	88	90	93	101	111	133	141	137	124	126	110	104	103	143 ± 1.6
Red Fishtek	85	87	89	92	98	105	114	136	149	141	125	125	111	110	106	150 ± 0.6
White Netguard	85	86	87	89	91	95	105	122	145	135	114	117	108	120	97	145 ± 1.8
Red Netshield	85	87	88	91	97	104	114	130	155	148	125	116	110	129	104	156 ± 1.2

4 Calculation of sound propagation loss

After the determination of source levels in one-third octave bands for the pinger models under investigation, the subsequent step involves estimating sound propagation losses across diverse marine environments. Four representative

environments are utilized and described in Table 3. These areas are known to have harbour porpoises and/or commercial net fisheries. Bathymetry is obtained from EMODnet [9] with a spatial resolution of approximately 115 m × 115 m. Salinity and temperature data are obtained from the Coriolis Ocean Dataset [10] and converted to sound speed using the Mackenzie equation [11]. Bathymetry and sound speed profiles are shown in [6].

To calculate the propagation loss, a ray tracing code developed FOI [12] is used. Ray tracing constitutes a high-frequency approximation of sound propagation. To provide general estimates of propagation loss within each one-third octave band, incoherent ray tracing with stochastic volume scattering is employed to approximate conditions in the Baltic Sea and Kattegat.

Table 3. Representative environments with estimated environmental parameters.

Environment	Representative of	Salinity (psu)	Depth at source position (m)	Sediment
1	Hanö bay	7.5-8.1	18.9	Glacial till
2	Northern Baltic	6.3-7.3	22.7	Crystalline bedrock
3	Southern Kattegat	17.5-31.9	23.6	Sand
4	Southern Baltic	8.1-9.9	43.4	Glacial clay

The sound source, in this case a pinger, is modelled as an omni-directional point source three meters above the seabed. Receivers are modelled using 50 evenly distributed points vertically from the maximum depth to the sea surface, corresponding to more than one point per meter in all representative environments. As bathymetry varies, some receiver points consequently fall within the sediment; these are excluded from the analysis. In the horizontal direction, receivers are spaced at 25-meter intervals up to five kilometres from the source. The propagation loss is calculated for the following combinations:

- Representative environments: Hanö bay, Northern Baltic Sea, Southern Kattegat, Southern Baltic.
- Frequencies: One-third octave bands within 10–250 kHz according to the measurements described previously.
- Sound speed profiles for months: March, June, September, December.
- Receiver depths: 50 points from maximum depth within the area to the sea surface.
- Bearings: north, northeast, east, southeast, south, southwest, west, northwest.
- Salinities: the minimum and maximum salinities in the vertical direction.

Propagation losses are subsequently calculated as a function of range for each representative environment, one-third octave band, and month, yielding median, minimum, and maximum losses across depth, bearing, and salinity. An example of calculated propagation loss for representative environment 1 (Hanö bay) for March is shown in Figure 4. All propagation loss results can be found in [6]. As evident from the figure, the propagation loss increases with both frequency and range, exhibiting local variations. Further, it can be concluded that the propagation loss for different receiver depths, bearings and salinities differ by several decibels.

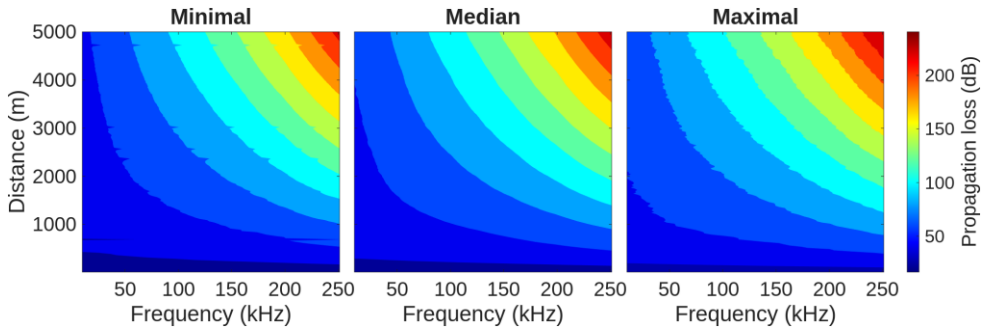

Figure 4. Propagation loss for environment 1 (Hanö bay) in March for a pingers positioned 3 meters above the seafloor. From left to right: minimal, median and maximal loss over receiver depth, bearings and salinities.

5 Detection range

The detection range, i.e. the distance at which a pinger is detectable by a hydrophone system, is calculated using the derived source model, the computed propagation loss, and a background noise. The sound pressure level at the receiver is obtained by subtracting the propagation loss (PL) from the source level (SL). For the sound source to be detectable, the signal must exceed the background noise (NL). Consequently, the ranges at which the signal is detectable are defined by the condition:

$$SL - PL(r) \geq NL, \tag{3}$$

where the largest range that fulfils the condition is called the detection range. Ambient noise in the marine environment arises from multiple sources. Typically, reference is made to wind- and wave-induced noise, commonly termed sea state noise; however, at very high frequencies (>180 kHz), thermal noise typically dominates. Thermal noise originates from molecular agitation in the water. Electronic receivers (such as hydrophone systems) exhibit an electronic noise floor that limits the detectable sound levels. It is therefore often unrealistic in practical applications to assume thermal noise as the minimum detectable level, since electronic self-noise often dominates and thus constitutes the limiting factor for the range at which a sound is detectable (see Figure 5).

As a reference for realistic electronic noise in this study, the self-noise of the commercial hydrophone system SoundTrap ST640 HF with an HTI-99-UHF hydrophone was measured (see Figure 5).

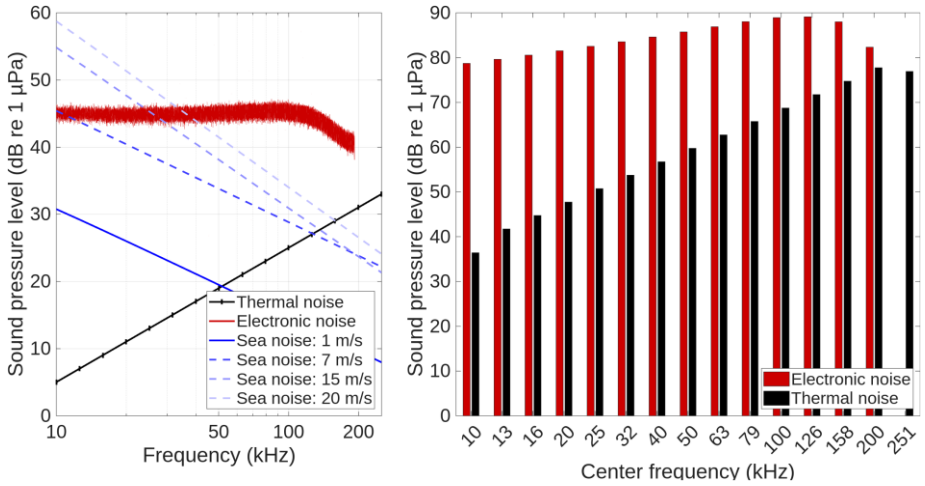

Figure 5. Models for sea state noise and thermal noise, along with measured electronic self-noise for the SoundTrap ST640 HF hydrophone system equipped with an HTI-99-UHF hydrophone, presented in 1 Hz narrowband (left panel) and one-third octave bands (right panel). Note that electronic noise data is unavailable for the 251 kHz one-third octave band.

Finally, the detection range can be derived using Equation 3. The calculated detection ranges for the Yellow Fishtek are shown in Figure 6, Each bar indicates the detection range calculated using the median propagation loss (median across receiver depths, bearings, and salinities) for the month yielding the maximum range. Error bars denote the minimum and maximum detection range (across receiver depths, bearings, salinities and months).

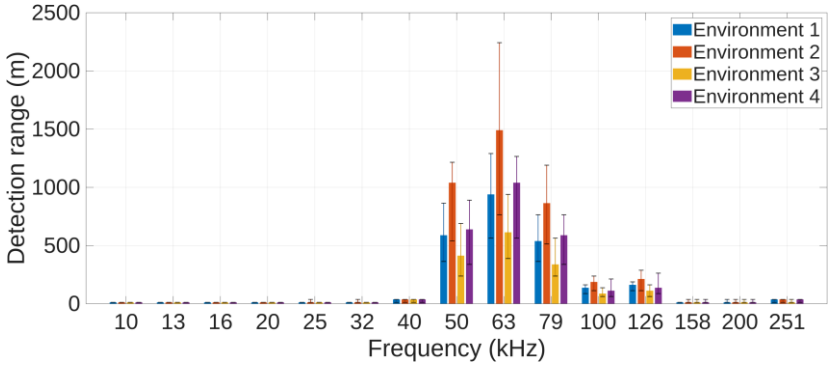

Figure 6. Estimated detection ranges for one-third octave bands for Yellow Fishtek for a receiver with noise characteristics and directivity equivalent to the SoundTrap ST640 HF hydrophone system equipped with an HTI-99-UHF hydrophone.

Detection ranges for all modelled pingers are displayed in Table 3. The detection ranges are computed from the total level, by summarizing the signal excess (*SE*) in one-third octave bands to a total level. Then the detection range is given by the longest distance *r* that fulfil

$$SE(r) = 10log_{10}\left(\sum_{n} 10^{\frac{SL-TL(r)-NL}{10}}\right) > 0, \quad (4)$$

where *n* equals relevant one-third octave bands. It can be seen that the prohibited pinger (Red Netshield) has the longest detection ranges, while the most common Yellow Fishtek has the shortest. The detection range varies significantly depending on the receiver depth, bearing and salinity used in the propagation loss computation.

Table 3. Detection ranges for the SoundTrap ST640 HF hydrophone system with an HTI-99-UHF hydrophone.

Environment	Yellow Fishtek	Red Fishtek	White Netguard	Red Netshield
1	639-1541m	1090-2343 m	840-1792 m	1391-2895 m
2	1140-2118 m	1917-3020 m	1190-2544 m	2293-3571 m
3	439-1090 m	639-1541 m	514-1216 m	840-1842 m
4	689-1516 m	1140-2218 m	840-1817 m	1466-2744 m

To illustrate the effect of environmental parameters on propagation loss, variations have been calculated for the 63 kHz one-third octave band. Table 3 shows the maximal variations of the calculated propagation loss when the specified environmental parameter varies within the interval specified above. It can be seen that the salinity difference has a particularly large effect in environment 3, but an almost negligible effect on environments 1, 2 and 4. For environment 2, the bottom depth varies greatly, which along the harder bottom type gives a large difference in propagation loss depending on bearing. For all representative environments, there is also a large difference related to receiver depth and month.

Table 4. Maximum variation in propagation loss for the 63 kHz one-third octave band corresponding to variations within the pre-defined ranges of the given environmental parameters.

	Salinity	Bearing	Receiver depth	Month
Environment 1	1.5 dB	5 dB	17.4 dB	8.9 dB
Environment 2	2.5 dB	10 dB	18.8 dB	5.3 dB
Environment 3	38.0 dB	2 dB	16.6 dB	8.7 dB
Environment 4	5.0 dB	5 dB	13.7 dB	7.8 dB

6 Summary

In order to improve knowledge about the type of signal emitted by harbour porpoise pingers and their detection range for a typical measurement system, four pingers models are first characterized in an indoor basin. A pinger emits well defined pings with varying signal characteristics between consecutive pings in both waveform morphology and spectral content. The source levels of the pingers are estimated taking variations between individual pings, directivity and compensate for the effect of the diffuse field in the size limited basin into account. Propagation losses are then calculated using ray tracing in four representative marine environments of Swedish waters where pingers may be encountered. For each environment, a typical range of conditions, such as salinity and temperature, is simulated leading to minimal, mean and maximal propagation losses. Finally, detection ranges of these four pinger models for a typical measurement system (Soundtrap STF640HF) are deduced from estimated source levels, calculated propagation losses and measured noise levels from the measurement system.

The result shows an interval of detection ranges from a couple of hundred meters up to three kilometers. For each pinger model and environment the interval of detection ranges is mainly due to which depth the hydrophone is placed.

References

[1] Havs- och vattenmyndigheten, 'Åtgärdsprogram för tumlare - *Phocoena phocoena*', Havs- och vattenmyndigheten, Göteborg, 2021:11, 2021. [Online]. Available: https://www.havochvatten.se/download/18.764c2cb917a6c5c85b03c106/1625648670494/rapport-2021-atgardsprogram-for-tumlare-v2.pdf

[2] S. Königson, R. Naddafi, M. Hedgärde, A. Pettersson, Ö. Östman, E. Benavente Norrman, and M, Amundin. 'Will harbor porpoises (*Phocoena phocoena*) be deterred by a pinger that cannot be used as a "dinner bell" by seals?', *Marine Mammal Science*, vol. 38, no. 2, pp. 469–485, 2022, doi: 10.1111/mms.12880.

[3] EU, *Regulation (EU) 2019/1241 of the European Parliament and of the Council of 20 June 2019 on the conservation of fisheries resources and the protection of marine ecosystems through technical measures*. Accessed: Apr. 10, 2026. [Online]. Available: http://data.europa.eu/eli/reg/2019/1241/2026-01-01

[4] T. McGarry, D. Silva, R. Mendes, A. Stephenson, and S. Wilson, 'Evidence base for application of Acoustic Deterrent Devices (ADDs) as marine mammal mitigation (Version 4)', Joint Nature Conservation Committee, Peterborough, JNCC Report 615, 2022. [Online]. Available: https://jncc.gov.uk/about-jncc/corporate-information/evidence-quality-assurance/.

[5] R. A. Kastelein, L. Hoek, C. A. F. de Jong, and P. J. Wensveen, 'The effect of signal duration on the underwater detection thresholds of a harbor porpoise (Phocoena phocoena) for single frequency-modulated tonal signals between 0.25 and 160 kHz', *J. Acoust. Soc. Am.*, vol. 128, no. 5, pp. 3211–3222, Nov. 2010, doi: 10.1121/1.3493435.

[6] F. Thörn, C. Mattei, and M. Andersson, 'Utredning av detektionsavstånd av pingers för tumlare', Totalförsvarets forskningsinstitut, FOI Memo 9236, 2026. [Online]. Available: https://www.foi.se/rapporter/rapportsammanfattning.html?reportNo=FOI%20Memo%209236

[7] ISO, '18405:2017 Underwater acoustics - terminology', International Organization for Standardization, 2017.

[8] V. Trinh, L. Chen, and J. Forrest, 'Free-field Acoustic Source Levels from Measurements conducted in a water tank', presented at the Proceedings of Acoustics, Adelaide, Australia, 2018. [Online]. Available: https://acoustics.asn.au/conference_proceedings/AAS2018/papers/p51.pdf

[9] EMODnet, 'EMODnet Bathymetry Consortium, EMODnet Digital Bathymetry'. 2024. Accessed: Oct. 14, 2025. [Online]. Available: doi: https://doi.org/10.12770/cf51df64- 56f9-4a99-b1aa- 36b8d7b743a1

[10] S. Tanguy, G. Jerome, P. Sylvie, and R. Gilles, 'CORA Coriolis Ocean Dataset for Reanalysis'. 2025. Accessed: Oct. 14, 2025. [Online]. Available: https://doi.org/10.17882/46219

[11] K. V. Mackenzie, 'Nine-term equation for sound speed in the oceans', *Journal of the Acoustical Society of America*, vol. 70, no. 3, pp. 807–812, 1981, doi: 10.1121/1.386920.

[12] S. Ivansson M., 'Stochastic ray-trace computations of transmission loss and reverberation in 3-D range-dependent environments', presented at the European Conference Underwater Acoust, in Proceedings of the 8th. Cavoeiro, Portugal, 2006, pp. 131–136.