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Underwater radiated noise level database of vessels – Description of the data collection method used in Finland

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Underwater noise emission of vessels is usually declared by radiated noise level (LRN). LRN must be tested in Finnish seas using a method which is suitable for shallow water (30–150 m). There is not much public data about the LRNs of vessels sailing in Finnish seas nor vessels built in Finnish shipyards. Knowledge of LRN of current vessels is needed in maritime industry since IMO has encouraged all member countries to reduce LRN in the future. Our purpose was to describe the method which was recently applied in Finland to collect LRN data, and to demonstrate the data obtained so far. All measurements were undertaken within 10 – 20 000 Hz using hydrophone recorders and applying "DNV shallow" test method. Measurement stations were placed along such shipping lanes, where the traffic is frequent. The station consisted of two hydrophone recorders. The movements of vessels were obtained from AIS system. Vessel passes which took place sufficiently close to the station were accepted and analyzed. So far, 645 passes have been analyzed. The database consists of 164 different vessels. The method will be applied in 6 more shipping lanes during 2026. The final database will be available in 2027.

1 Introduction

Underwater noise emission of vessels is usually declared by radiated noise level (LRN). The global maritime industry is increasingly interested in combating underwater noise, as the IMO (International Maritime Organization) has encouraged all member countries and maritime companies to reduce LRN [1]. There are also beliefs that IMO may in the future set quantitative LRN limits for vessels. Some limits have already been set in some waterways because of, e.g., local nature conservation campaign. However, there are probably no such shipping lanes where noise emissions are controlled by authorities and excessive noise emissions are penalized.

Maritime industry is prepared for the arrival of target values. The starting point is to improve the measurement capacities and basic knowledge related to the factors that affect noise emission. For example, Finnish vessels should be extensively mapped to know the current noise emissions and to be able to make fact-based progress in potential noise abatement planning for new ships in the future.

LRN of vessel depends, in large perspective, on three factors: vessel type, draft, and speed [2]. Two latter are quantitative variables while the first is nominal. Propulsion solutions and noise abatement solutions can be vessel-specific, so that noise emission of a specific vessel may not be precisely predicted based on vessel type, draft, and speed. However, there is evidence that simple prediction models work reasonably well so that they can be safely applied in, e.g., the assessment of environmental impact on different species [3].

Our goal was to collect noise emission database of vessels and to examine the database obtained from four shipping lanes.

2 Materials and methods

2.1 Measurement apparatus

Hydrophone recorders (SoundTrap ST600 HF, Ocean Instruments) were used in the underwater sound measurements. The recording was made at a sampling frequency of 48 kHz. The recording is stored in SUD format, which contains an X3-compressed signal. When the data is extracted from the recorder to acoustic analysis, it is converted to WAV format.

The hydrophones were calibrated before every measurement using the internal calibration method. In addition to that, the hydrophones passed our internal calibration procedure. The procedure took place in loud diffuse airborne sound field (pink noise played in reverberation room). The SPLs of the hydrophones are compared with traceably calibrated microphone/analyzed combination while setting the reference pressure to 1 μPa both in the microphone and hydrophones.

The recorders were installed on the seabed according to the DNV method (Figure 1). The distance between the hydrophone and the reflective plate was 70 mm, which fulfills the DNV's minimum requirement of 200 mm.

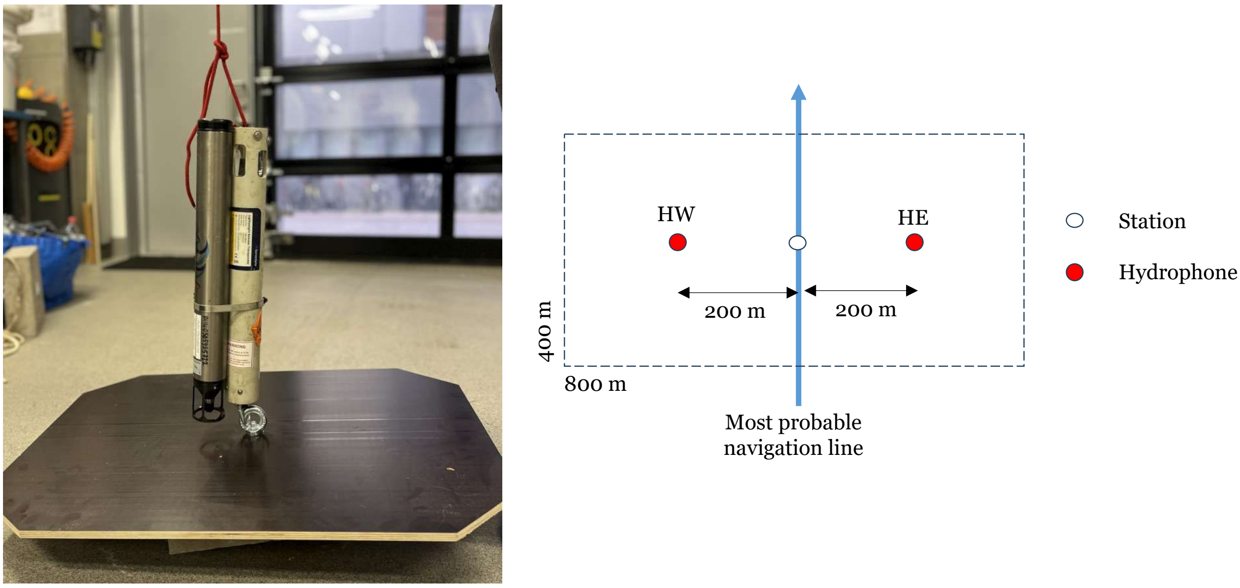

Figure 1: Left) Hydrophone recorder (left) and release transponder (LRT 7986, Solardyne) attached to the hook of the 15 mm plywood plate. There is a 15 kg concrete weight below the plate. The plate was used to avoid any contact between the hydrophone and seabed mud. The rope ends to a buoy (not shown) that keeps the package in upright position. Right) Each measurement station consisted of two hydrophones placed on both sides of the most probable expected navigation line. All vessels passing through the dashed line area can be analyzed with at least one hydrophone.

2.2 Measurement stations

Measurement stations were created on three shipping lanes in Southern coast of Finland. The lanes lead to major Finnish harbors in Turku/Naantali, Porvoo, and Kotka. Stations were located approximately 50 km from the harbor in area, where the vessels usually navigated with constant speed and constant heading. The exact location of the station was selected on the shipping lane in such position where the vessels are likely to sail. This was checked using the AIS history of previous year. In each station, two hydrophones were installed at the station as shown in Figure 1.

2.3 Noise emission test method

Measurements were carried out using the DNV shallow water method [4]. The method is suitable for sea depth range 30–150 meters. The vessel must be located at a horizontal distance of 100–200 m from the hydrophone. In our study, distance range 50–200 m was accepted, because we could not see any significant differences between the results for the same pass, if the horizontal distance was 50–100 m or 100–200 m.

Figure 2 shows the DNV measurement principle, when speed exceeds 5 knots and vessel length is L. The measurement duration is determined as the time for the vessel to propagate two vessel lengths (t_{2L}).

Vessels passing the measurement point were identified using AIS (Automatic Identification System). AIS data was obtained from the Finnish Transport Infrastructure Agency. AIS data includes following important data: time stamp, vessel's IMO identification information, position, and speed. Class A vessels transmit AIS messages every 2–10 seconds depending on their speed.

Data handling of AIS database was programmed with Matlab. The handling consisted of the following checks: distance between the vessel and the hydrophone (r_{CPA}) is within 50 – 200 m; other vessels are beyond 2000 m distance from any hydrophone; noise exceeds ambient background noise in the audio data within the pass-by time window given by AIS coordinates; and vessel has an IMO number. If these conditions were fulfilled, the acoustic analysis was conducted.

Based on the position information reported by the vessel and the position of the hydrophone, the horizontal distance between the vessel heading and hydrophone, i.e., distance with closest point of approach, r_{CPA}, was determined. The distance between the hydrophone and the closest point of the vessel was determined using the Haversine formula, which is used to calculate large distances on the surface of the Earth.

If another vessel was closer than 2 000 meters, the measurement was rejected to avoid uncontrollable contamination due to background noise.

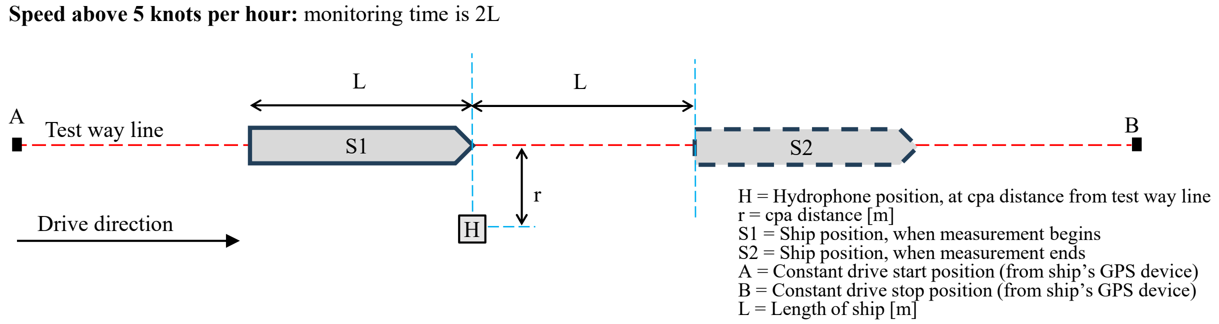

Figure 2: DNV method measurement principle, when speed exceeds 5 kn (9.3 km/h).

2.4 Determination of LRN using the DNV method

Radiated noise level, L_{RN}, is the sound pressure level (SPL) of a point-like sound source measured at 1-m-distance from the source in free field. Our frequency range was 10–20 000 Hz. The measurement time of sound pressure is the time it takes for the ship to travel two ship lengths (t_{2L}). DNV [4] defines the determination of LRN in shallow water situation according to Eq. (1):

$$L_{RN} = 20 \cdot log_{10}\left(\frac{p_{rms}}{p_0}\right) + 18 \cdot log_{10}\left(\frac{r}{r_0}\right) - 5 \quad (1)$$

where

p_{rms}	[Pa]	root-mean-square sound pressure during time t_{2L}
p_0	[Pa]	reference sound pressure, 1.00 µPa;
r	[m]	distance between the vessel heading and the hydrophone: $r = \sqrt{s^2 + r_{CPA}^2}$;
r_0	[m]	reference distance, 1.00 m;

The method attempts to take the directivities of sound from different vessel components into account by conducting the measurement during the time of two vessel lengths as shown in Figure 2. However, the directivities are differently considered if the vessel is close (100 m) or far (200 m): the width of sector 2L becomes larger when the vessel is closer to the hydrophone. Based on our calculations, the energy remaining outside the period t_{2L} is significant if the vessel is far. Therefore, we wanted to determine the LRN based on the whole event to avoid any dependence of the test result on horizontal distance.

First, we determined the sound exposure level, L_E, of the pass-by event using pass-by time t_{4L}. This longer period always contained nearly all of the sound energy of the event (longer measurement time influenced L_E less than 0.1 dB). Based on this, the equivalent SPL was determined for the period t_{2L} required by DNV. The mathematic steps are shown in Equations (2–5):

$$L_{eq,t4L} = 20 \times log_{10}\left(\frac{p_{rms}}{p_0}\right) \quad (2)$$

$$L_E = L_{eq,t4L} + 10 \times log_{10}\left(\frac{t_{4L}}{t_0}\right) \quad (3)$$

$$L_{eq,t2L} = L_E - 10 \times log_{10}\left(\frac{t_{2L}}{t_0}\right) \quad (4)$$

$$L_{RN} = L_{eq,t2L} + 18 \cdot log_{10}\left(\frac{r}{r_0}\right) - 5 \quad (5)$$

where

$L_{eq,T}$	[dB re 1 μPa]	equivalent SPL during time T (either t_{4L} or t_{2L});
L_E	[dB re 1 μPa]	sound exposure level of the event lasting t_{4L};
t_{XL}	[s]	time taken to sail X ship lengths (XL/v);
t_0	[s]	reference time, 1.00 s;
L_{RN}	[dB re 1 μPa]	radiated noise level;
$L_{eq,XL}$	[dB re 1 μPa]	equivalent SPL during time taken to sail X ship lengths;
s	[m]	sea depth at the position of the hydrophone;
v	[m/s]	vessel speed during the pass-by (speed over the ground);
L	[m]	vessel length.

According to Figure 2, the measurement procedure expects that the measurement operator knows the exact position the vessel bow. However, this information is not available in AIS data. The position of the GPS device sending position information to AIS is highly vessel specific. Some vessels are longer than 400 m. Therefore, the lack of GPS sensor location information is a large source of uncertainty in our automatic measurement system. To minimize LRN measurement errors, we decided to analyze the vessel passes by focusing on the period where the SPL is the largest and ignoring the exact position of the vessel bow as suggested in Figure 2. The principle of finding the maximum SPL (midpoint) is shown in Figure 3. The midpoint (loudest SPL) was determined using three steps in a Matlab routine. First, we identified the point where the SPL reached maximum. Second, we determined the start and end points (A, B) where the SPL is 10 dB below the maximum SPL. Third, we defined the midpoint exactly between points A and B.

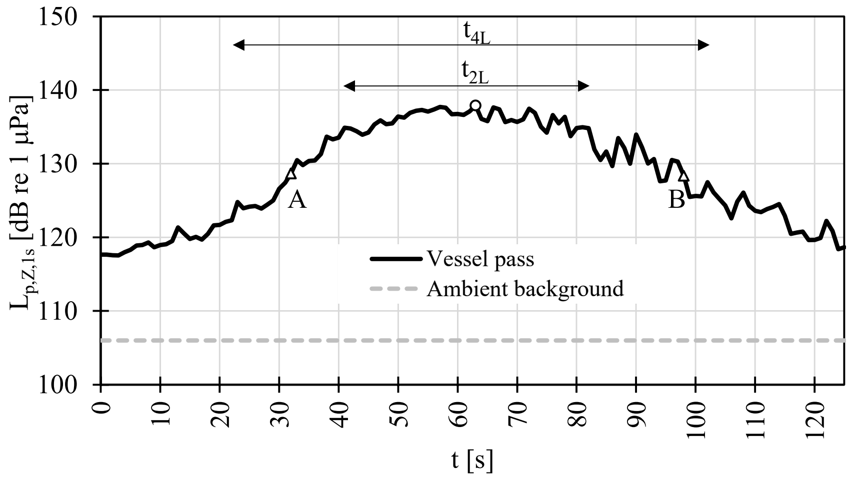

Figure 3: An example of the SPL profile measured by the hydrophone during a vessel pass. We conducted the analysis from the time window t_{2L}, where the loudest SPL (midpoint) was centralized. In this example, t_{2L}=40 s, since the speed was 21 kn (38.9 km/h).

3 Results

The description of our database is summarized in Table 1 divided into four vessel types. The frequency dependent LRN values for all approved passes are shown in Figure 4 for all vessel types.

4 Discussion

Our study reports the first LRN database created from ships operating in Finnish seas and measured using DNV shallow water method. However, this work is preliminary since it has still many limitations. Certain vessels passed the measurement station several times so that the overview of our data may give a biased picture of the distribution of LRNs among the studied vessel types. Our database is also significantly smaller than the ECHO database published by

MacGillivray et al. [2]. Therefore, we are going to continue the material collection during 2026–2027 to extend our database by at least 200%. In 2027, it might be possible to develop simplified statistical models, how the LRN depends on the main factors, such as vessel type, vessel speed, and draught. Furthermore, it is also possible to test how the models summarized by Ref. [3] predict our experimental LRN values.

Table 1: Description of the data collected at the measuring station. Other vessels include, for example, tugboats, fishing vessels or research vessels. $L_{RN,tot}$ involves the whole frequency range 10–20 000 Hz.

	Passenger	**Cargo**	**Tanker**	**Other vessel**
No. of approved passes	128	130	374	13
No. of vessels	5	49	102	8
Speed range [kn]	12.4 – 21.4	8.3 – 17.8	3.2 – 15.4	4.7 – 10.7
$L_{RN,Tot}$ [dB re 1 µPa]	164 – 183	163 – 189	156 – 193	162 – 180

Although many territorial waters or ports favor low-noise vessels or low-noise modes of transport, they generally do not set general quantitative noise guidelines that would be monitored by measurements. For example, in Finland, there are no target values for the underwater noise emission of vessels. However, underwater environmental effects are carefully investigated if underwater construction work is planned due to, e.g., bridges or wind turbines. If the construction work requires blasting, noise control measures are required to protect aquatic life.

DNV presents some target values which are well-known in Nordic maritime industry [5]. They are increasingly used in the classification of new vessels since both industry and DNV believe that numerical target values may be applied in (some sensitive areas or harbors) in the future.

We believe that our data will be very valuable if IMO sets quantitative target values for LRN in the future. Our database can be used to assess how the current vessels are related to the target values and how much noise control is needed. In addition, our data can be used to assess which components of the vessel are critical for noise control measures.

5 Acknowledgements

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6 References

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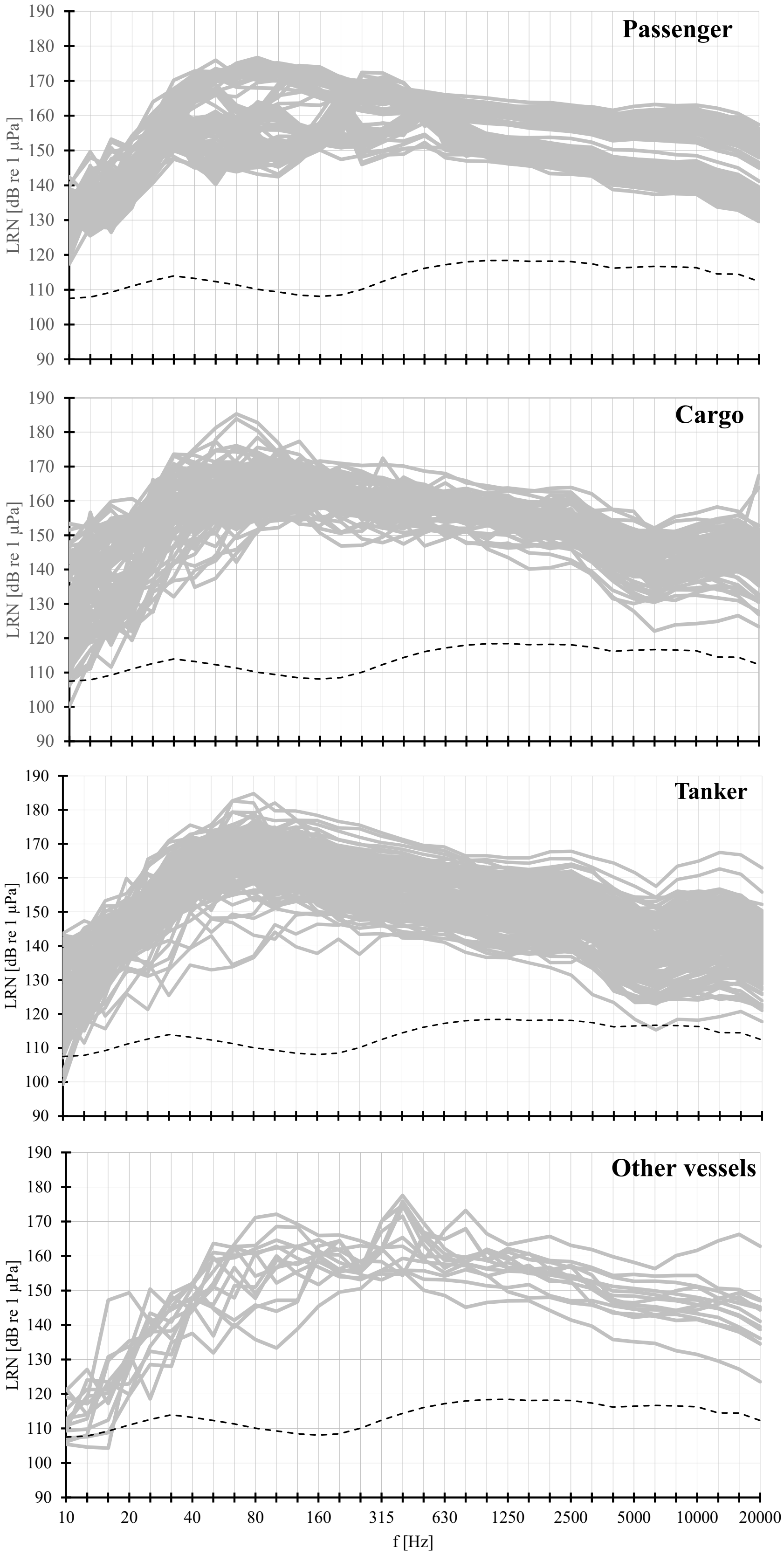

Figure 4: The dependence of radiated noise level, L_{RN}, on frequency, f, for all approved passes among the four vessel types. The grey lines represent individual passes. Dashed line is the LRN without any vessel nearby (background).