Underwater noise emissions from Baltic Sea shipping in 2022

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Key messages

1. **Underwater noise emissions from ships, calculated as noise energy, have increased by +4% in the 63 Hz 1/3 octave band in 2022 compared to 2021.**

2. **Liquid tankers, bulk cargo, and containerships combined are responsible for two thirds of vessel noise** (34%, 20% and 12%, in 63 Hz 1/3 octave band).

3. Applying similar performance metric as for energy efficiency (in mass per ton km cargo carried), unit noise energy emissions, over the 63 Hz 1/3 octave band considered, the **LNG tankers emit most noise energy per tonne km** (573 millijoules ton^{-1} km^{-1}) and **general cargo ships are the most silent ones** (98 millijoules ton^{-1} km^{-1}).

4. The **noise efficiency of ships was slightly improved in bulk carriers** (2021→2022: 163→140 milliJ tonnne^{-1} km^{-1}; -4%), **LNG tankers** (2021→2022: 638→573 milliJ tonne^{-1} km^{-1}; -10%) , **and refrigerated cargo** (2021→2022: 108 →103 milliJ tonne^{-1} km^{-1}; -5%) **ship segments**.

5. **Noise efficiency of vehicle carriers** (2021→2022: 149 →172 milliJ tonne km; +15%) and **RoRo passenger ships slightly deteriorated** (2021→2022: 274→280 milliJ tonne^{-1} km^{-1};+4%).

6. Noise energy emitted by Cruise passenger ships increased by +61% when compared to 2021. However, at the same time, cruise ship travel distances in 2022 were 2.1 times of those observed during 2021.

1. Underwater noise emissions from ships

The values listed in this document represent noise energy emitted and it cannot be taken as representative of shipping noise experienced by marine animals. Emission report of underwater noise should be taken in a similar manner as the emissions of atmospheric pollutants. They indicate the quantity emitted at the pollution source and consecutive impact assessments should be based on pollutant dispersion, or in case of noise, noise propagation modeling.

Note, that the STEAM model version now includes the impact of ambient conditions on modeled quantities.

1.1. Modeling of noise sources

The STEAM (Jalkanen et al., 2009, 2012, 2018; Johansson et al., 2013, 2017) emission modeling system was used for this work, which incorporates the Wittekind noise source module for ships (Wittekind, 2014). The noise model is based on vessel technical properties, and it describes separately contributions from vessel cavitation and machinery (Figure 1). Cavitation occurs when a fast-rotating propeller generates a large pressure difference between different sides of propeller blades and vacuum forms on the backside of the blade. Gas bubbles are formed which collapse generating loud noise. The noise quantities reported in this document include noise emissions at three specific frequency bands, 63, 125 and 2000 Hz, which are found to be relevant for animals. The two lowest frequencies are in the hearing range of several fish species and 2 kHz band is seen relevant for marine mammals, but it is outside the hearing range of most fish.

Figure 1. Noise contributions of a cargo ship according to Wittekind (2014)**. Low and high frequency cavitation contributions (Blue, Red lines) describe the contributions from vessel propeller whereas engine noise is depicted with Green color. Total source level is indicated with the Black line.**

The time integration of noise emissions yields noise energy, which is reported in Joules. In **Table 1**, noise emitted is given as sum of energy emitted to water as noise in three different frequency bands (63, 125 and 2000 Hz). This allows cumulative description of noise in contrast to the logarithmic decibel scale which is used to describe instantaneous values.

The source levels (dB) obtained from the Wittekind formulation are related to the power emitted:

$SL[dB\ re\ 1m, 1\ \mu Pa] = 10log_{10}\frac{P}{P_{ref}}$where

$$P_{ref} = \frac{4\pi p_{ref}^2}{\rho c}$$

with p_{ref} is 1 µPa, ρ and c are water density and speed of sound in water. With this, the total emitted power is accumulated over time from all M ships in area A:

$$P_k^{tot}(t) = \sum_{m=1}^{M} P_{k,m}(t)$$

The sound power $P_{k,m}(t)$ in Joules per second describes the emitted energy of a single ship. This is summed over time and over all ships, which yields noise energy emitted over an area. The calculation of noise source maps is described in (Jalkanen et al., 2018). It should be noted that the accumulated energies of **Table 1** are totals for all the Baltic Sea area and cannot be converted back to source levels of individual ships. Thus, the noise source maps reported in this document are a visual aid than input data for noise propagation modeling.

Table 1. Emissions of noise energy from Baltic Sea shipping in 2022. Noise energy is given in gigajoules. Unit emissions (noise index) are calculated by dividing the energy contributions from the 63 Hz 1/3 octave band and by the transport work.

	E(noise, 63Hz) [GJ]	E(noise, 125 Hz) [GJ]	E(noise, 2000 Hz) [GJ]	Transport Work [10^6 tonne km]	Unit emissions [millijoules $tonne^{-1}$ km^{-1}]
Total	186.5 (3.9%)	52.3 (5.7%)	0.8 (5.6%)	1 058 480	
Baltic Proper	111.4 (2.4%)	30.7 (4.7%)	0.5 (4.9%)	639 564	
Kattegat	44.9 (8.1%)	12.3 (9.1%)	0.2 (9.2%)	235 807	
Gulf of Finland	20.2 (4.0%)	6.4 (2.0%)	0.1 (1.1%)	149 309	
Gulf of Bothnia	8.9 (1.5%)	2.4 (8.7%)	0.0 (7.7%)	43 474	
Gulf of Riga	1.1 (18.2%)	0.4 (26.3%)	0.0 (22.3%)	9 158	
RoRo-Passenger vessels	8.5 (1.8%)	3.6 (6.4%)	0.1 (5.8%)	30 650	280
Vehicle carriers	0.7 (-31.0%)	0.2 (-37.1%)	0.0 (-39.7%)	6 442	172
RoRo-cargo vessels	21.6 (11.9%)	5.5 (21.0%)	0.1 (21.9%)	52 731	381
Bulk carriers	36.6 (-14.1%)	9.0 (-6.9%)	0.2 (-5.8%)	261 340	140
General cargo	11.9 (-11.8%)	2.9 (-11.8%)	0.1 (-12.1%)	138 603	98
Container ships	23.1 (-20.2%)	9.2 (-13.6%)	0.1 (-12.7%)	168 803	175
Reefers	0.5 (-6.4%)	0.4 (-3.5%)	0.0 (-4.0%)	5 347	103
Tankers	63.4 (24.1%)	15.9 (22.9%)	0.3 (21.6%)	380 489	143
LNG tankers	7.2 (67.7%)	1.4 (71.4%)	0.0 (71.7%)	6 749	573
Gas tankers	3.9 (25.4%)	0.8 (27.4%)	0.0 (25.0%)	7 327	444
Passenger ships	0.2 (212.0%)	0.1 (106.3%)	0.0 (94.1%)		
Cruisers	5.1 (61.3%)	1.2 (71.2%)	0.0 (80.2%)		
Fishing vessels	0.1 (0.9%)	0.1 (2.2%)	0.0 (2.5%)		
Service ships	0.1 (-15.5%)	0.1 (-29.8%)	0.0 (-28.5%)		
Unknown	1.4 (-6.2%)	1.1 (-7.3%)	0.0 (-7.3%)		
Misc	2.0 (25.5%)	1.0 (26.6%)	0.0 (23.1%)		

In general, the three largest emitters of noise energy (63 Hz 1/3 octave band) are the liquid tankers (63 GJ; 34%), bulk carriers (36 GJ; 20%), and containerships (23 GJ; 12%), which together contribute over 65% to vessel noise emissions at 63 Hz band. However, they are also responsible for 78% of the transport work in the Baltic Sea area. If noise efficiency is considered (analogous to energy efficiency reported in grams of CO_2 emitted per tonne km cargo carried), LNG tankers have largest unit emissions of noise (573 millijoules per tonne km), whereas lowest unit noise comes from general cargo ships (98 milliJ $tonne^{-1}$ km^{-1}). Figure 2 indicates the noise energy emission shares of various types of ships at 63 Hz frequency band.

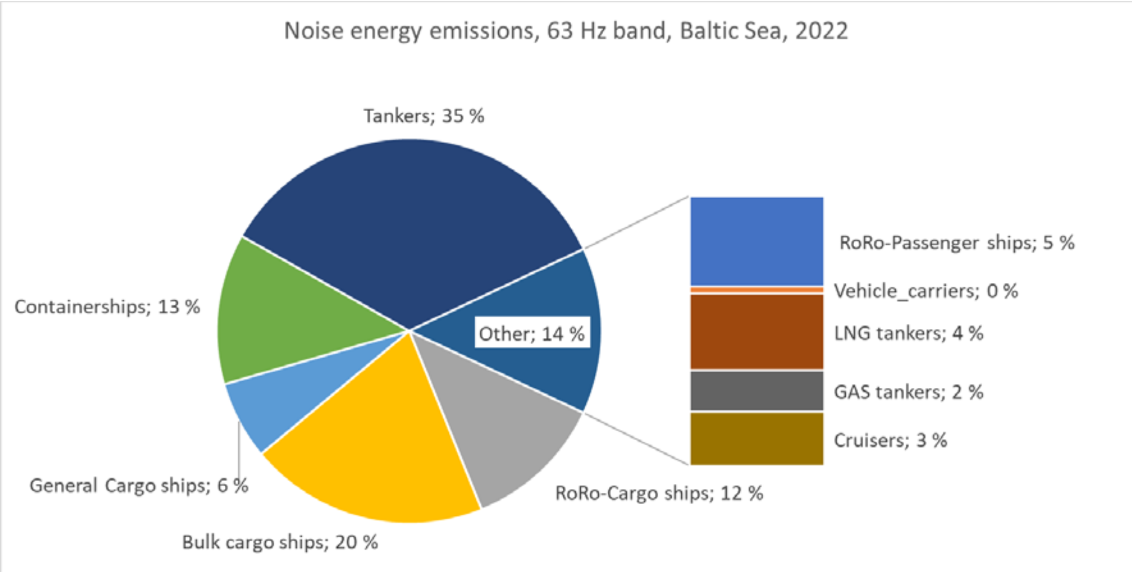

Figure 2. Share of emitted noise energy from various vessel types at 63 Hz band during year 2022. Note, that the tankers include all types of liquid (Crude, Product, Chemical) tankers.

2. Temporal evolution of noise emissions of the Baltic Sea fleet

The development of underwater noise emissions in the Baltic Sea shipping fleet during the time of 2014-2021 is illustrated in Figure 3. Noise energy emissions have not yet reached the pre-pandemic levels despite the increase (+4%) in 2022 when compared to the previous year. In Figure 3, the emission totals for 2014-2019 are based on a recent paper of global shipping noise emissions (Jalkanen et al., 2022) which reports results for dozens of sea regions, including the Baltic Sea. Based on global data for seven years, the noise emissions from ships sailing the Baltic Sea increase at a significantly slower rate than the global average.

Noise emissions are impacted by vessel operating speed, which have decreased during the same period (Figure 4). This figure plots the relation of average cruising speed to vessel design speed. A value of 1.0 indicates that a vessel would operate at its design speed, but a value lower than that indicates slower operation speed.

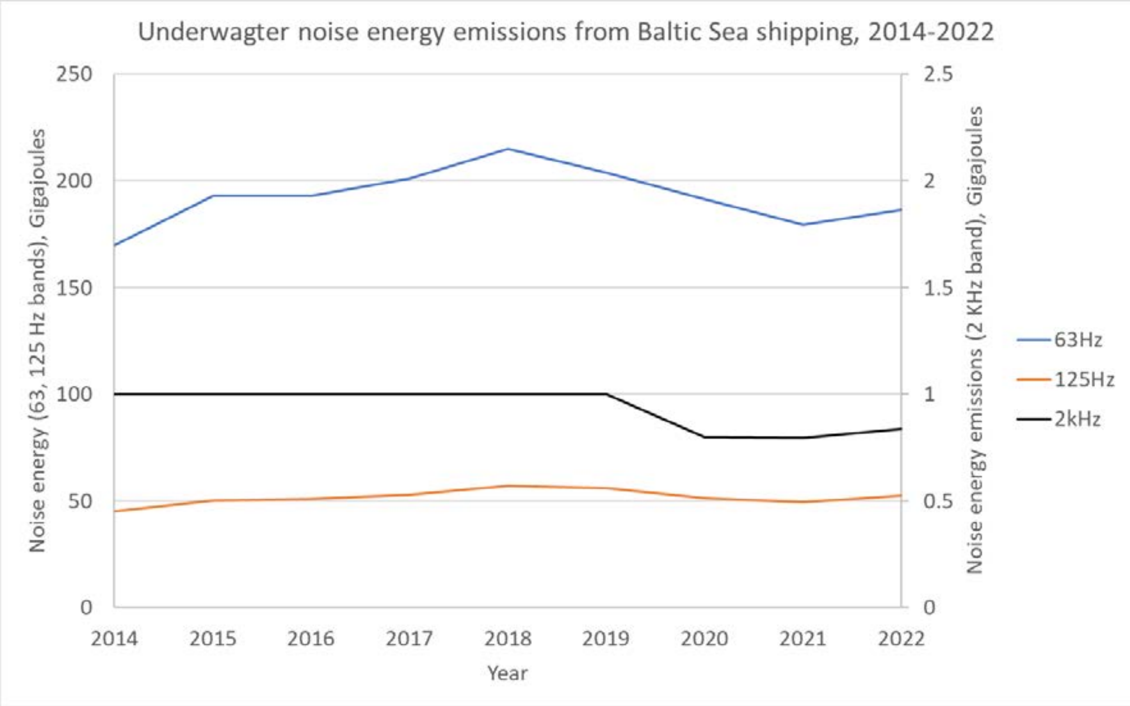

Figure 3. Underwater noise energy emissions from Baltic Sea shipping during 2014-2022. Energy is reported in gigajoules (GJ).

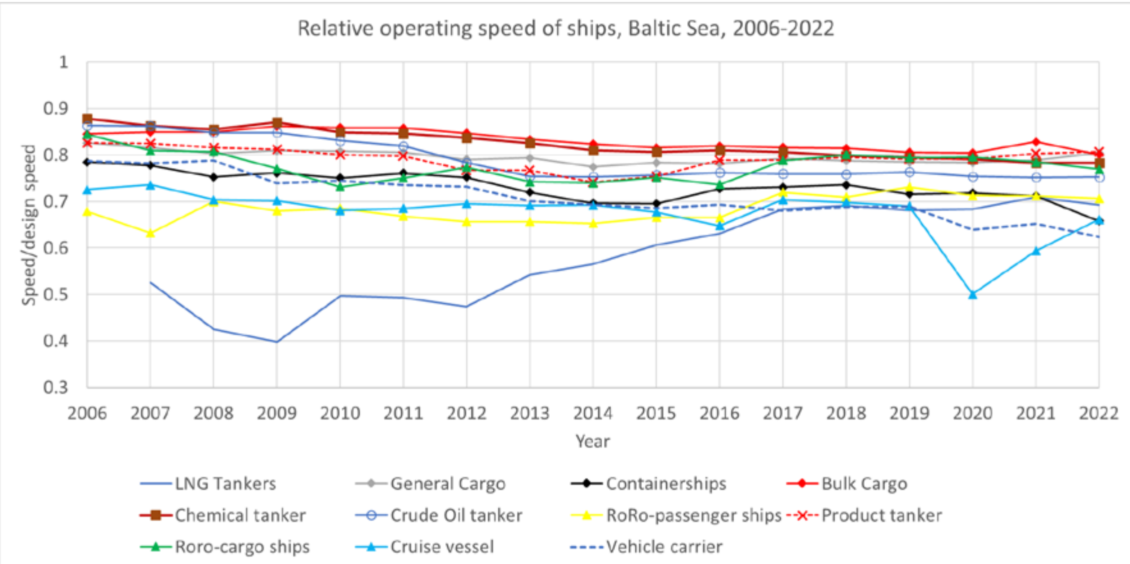

Figure 4. Operating speeds of various types of ships in the Baltic Sea fleet. The numbers presented report the relation between average cruising speed to the design speed of each class. This figure illustrates a widespread use of slow steaming across all ship types in the Baltic Sea fleet, and the recovery of cruise ship traffic in the area.

Most of the vessels sailing the Baltic travel slower than their design speed. A consistent increase in the operating speeds can only be observed for LNG tankers and some small vessels, like pilot boats, search and rescue vessels and icebreakers, but some temporary speed increases may also be observed in cases of RoPax and RoRo vessels. However, most ships have slowed down during the 17-year period. The speed profiles of most significant vessel types in 2022 indicate -17…+2% speed change (average -6%) compared to corresponding values of 2006.

Figures 5, 6 and 7 illustrate the contributions to underwater noise emissions from different types of ships and their evolution during 2021-2022.

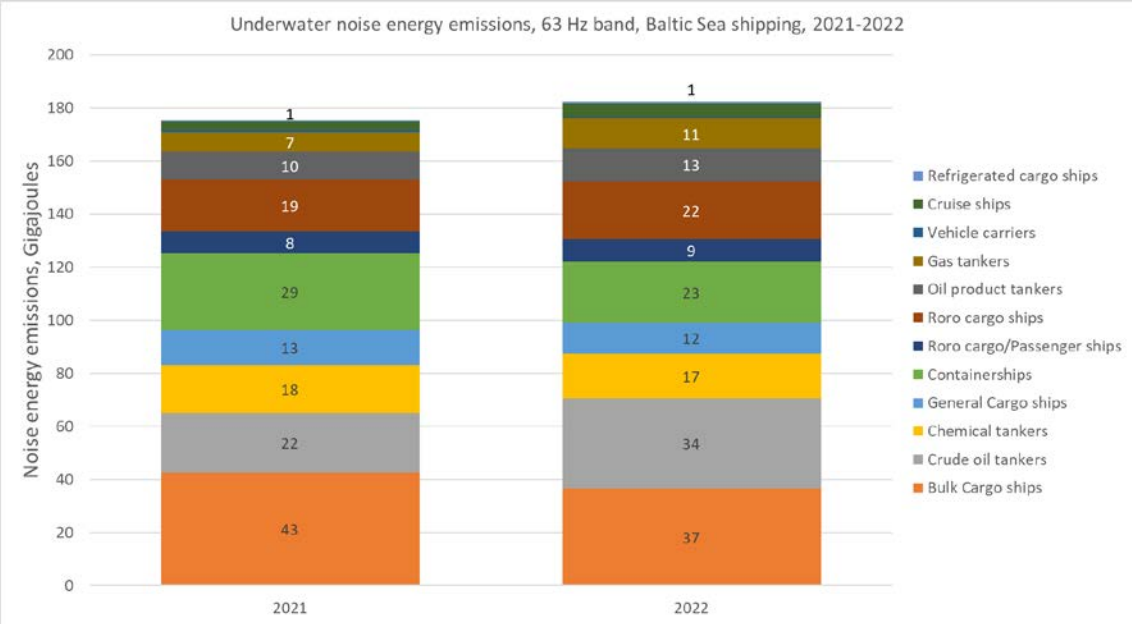

Figure 5. Emissions of shipping noise energy during 2021-2022 in the Baltic Sea area. Noise energy is given in Gigajoules. The columns indicate total noise energy at 63Hz band, whereas the colours indicate contributions from different types of ships. Numerical values (in Gigajoules) are provided for each vessel type.

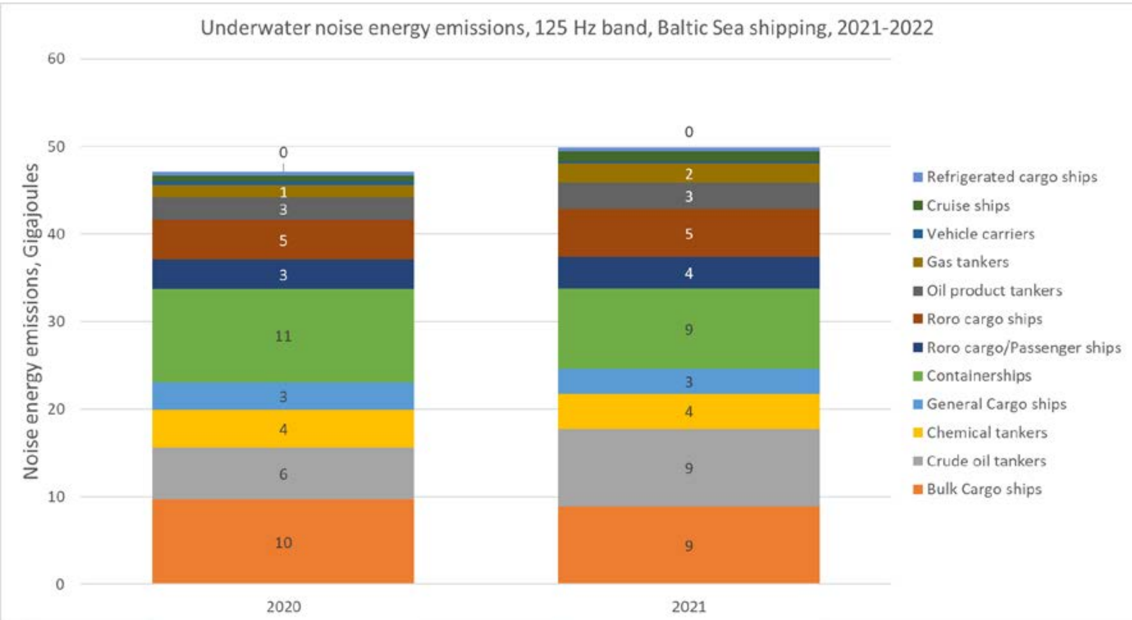

Figure 6. Emissions of shipping noise energy during 2021-2022 in the Baltic Sea area. Noise energy is given in Gigajoules. The columns indicate total noise energy at 125Hz band, whereas the colours indicate contributions from different types of ships. Numerical values (in Gigajoules) are provided for each vessel type.

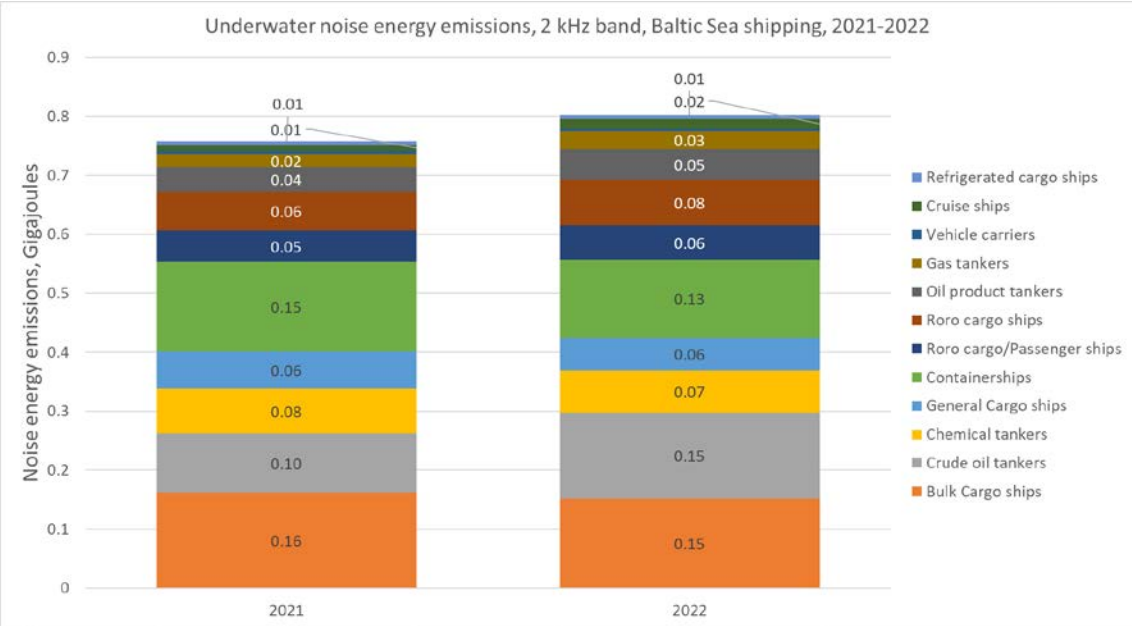

Figure 7. Emissions of shipping noise energy during 2021-2022 in the Baltic Sea area. Noise energy is given in Gigajoules. The columns indicate total noise energy at 2 kHz band, whereas the colours indicate contributions from different types of ships. Numerical values (in Gigajoules) are provided for each vessel type.

The monthly totals of underwater noise over the whole study period are given in Figure 8. The emissions of noise during summer months usually have a maximum, which is like the observed maximum of atmospheric emissions during the holiday period each year. However, the disruption of passenger travel because of Covid19 seems to have temporarily broken this trend, and daily corrected noise energy emissions (gigajoules/day) peak during the months of September and October.

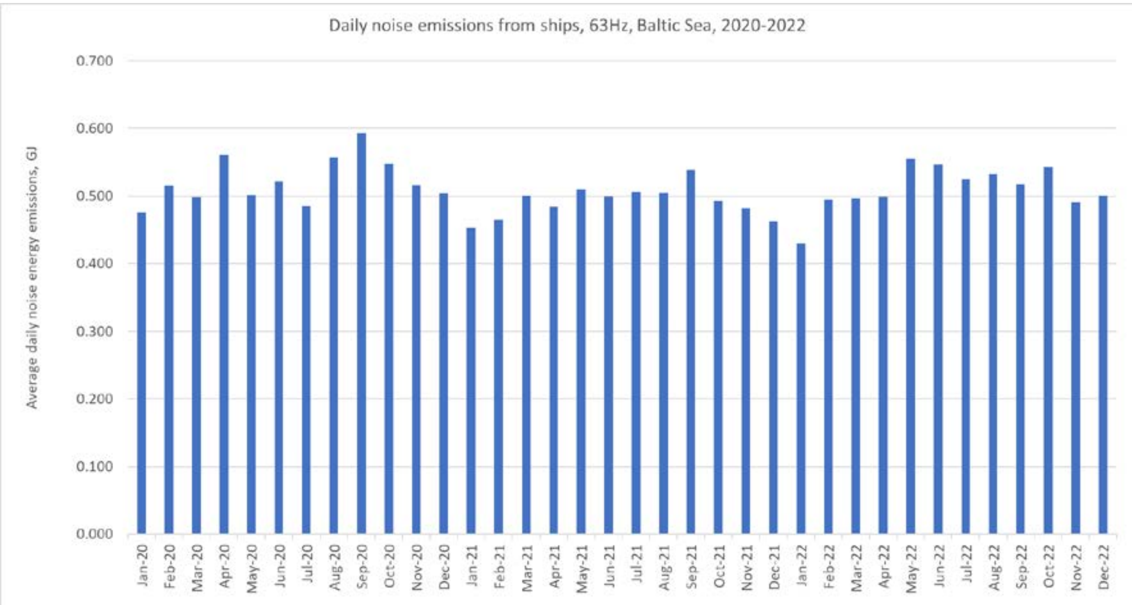

Figure 8. Daily average noise energy emissions (63 Hz 1/3 octave band) from ships in 2020-2022. The unit is gigajoules of average of energy released as noise from ships in one day.

For energy efficiency there exists various efficiency indices, like the Energy Efficiency Operational Index of the IMO, but also noise efficiency index can be calculated for each vessel. In that case, the reported quantity would be the noise energy (in millijoules) towards each cargo mass (tonne) and distance unit (km). This leads to a performance index with unit of mJ $tonne^{-1}$ km^{-1}, which facilitates comparison of performance indices across various ship types. This way, the transport work done by each ship type is included in the evaluation. The development of noise efficiency of various ship types is depicted in Figure 9. According to the Wittekind noise module, vessel noise increases as a function of speed. The changes in emitted noise are more likely to be a result of operating speed changes because no reduction targets currently exist for shipping noise.

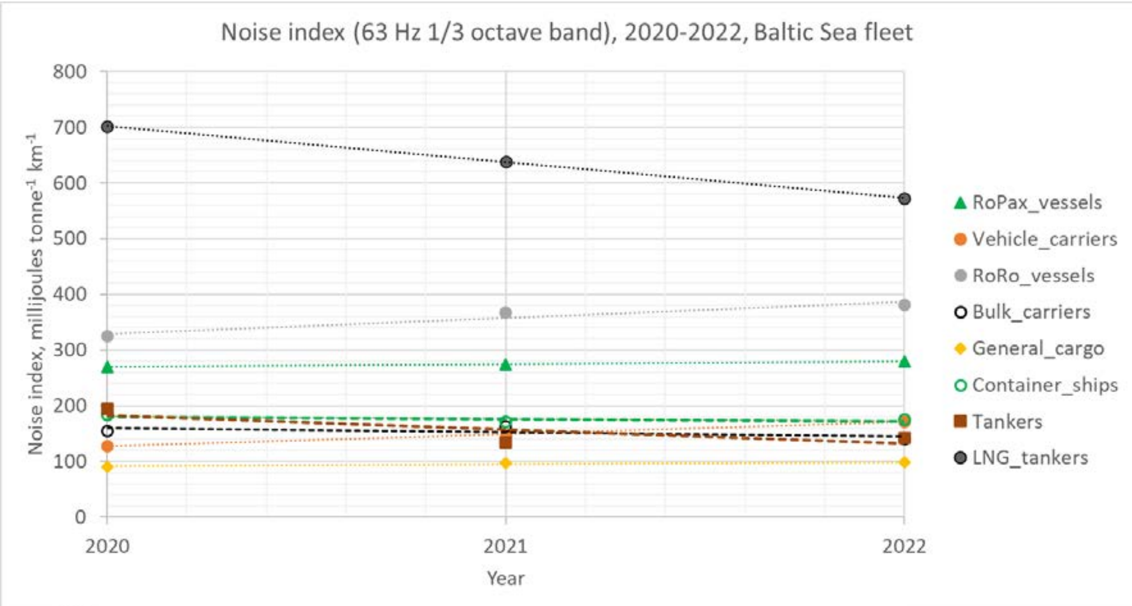

Figure 9. Noise efficiency index for various ship types sailing the Baltic Sea area. The period of 2020-2022 was studied, and an annual performance index was calculated for each ship type.

A significant increase in noise occurs with vessels which travel above the cavitation inception speed. This speed is the threshold value after which cavitation starts to occur and low- and high frequency contributions to cavitation noise increase sharply.

3. Geographical distribution of vessel noise emissions

The geographical distribution of annual noise energies in 63Hz band is given in Figure 10. The main shipping lanes are clearly visible in the noise maps, but it should be noted that this does not illustrate underwater noise propagation.

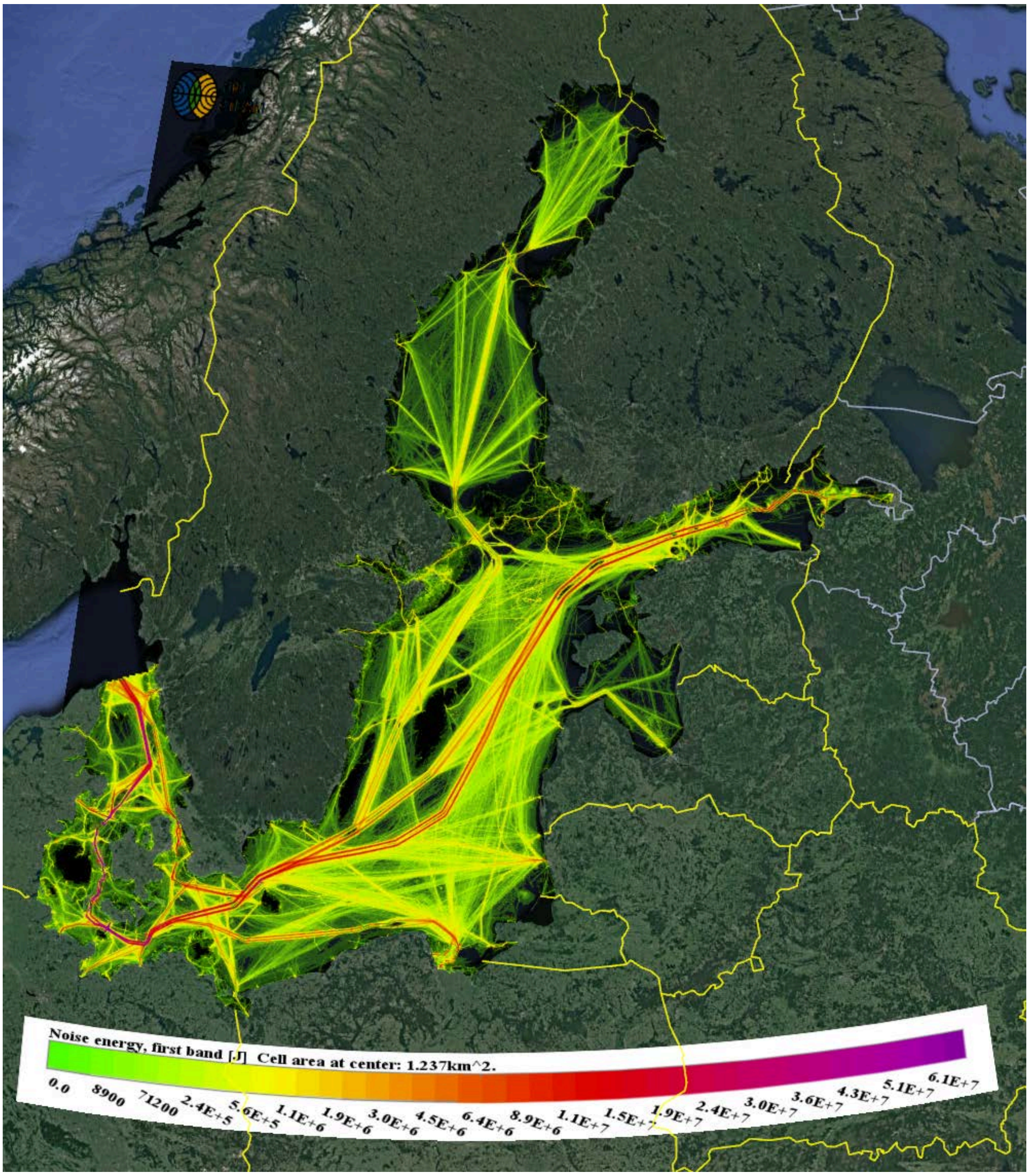

Figure 10. Noise energy emitted in the 63 Hz 1/3 octave band by the Baltic Sea fleet in 2022. Unit is joules per grid cell area (1.237 km^2)

Values exceeding 100 dB are well within the hearing range of cod (Nedwell et al., 2004), but propagation modelling of noise is required to determine the noise levels experienced by marine life and assess the impacts of noise in the Baltic Sea area. A noise source emitting one megajoule of energy for one year corresponds to 156 dB source level. Noise maps of this report are visual aids to illustrate the geographical distribution of noise emissions, but further propagation modelling should be done to indicate how noise travels underwater. Only then the impacts of noise can be assessed.

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Data

The emission estimates for the year 2022 are based on over 882 million AIS-messages sent by 37,144 different ships, of which 9,240 had an IMO registry number indicating commercial marine traffic. The AIS position reports were received by terrestrial base stations in the Baltic Sea countries and collected to regional HELCOM AIS data server. Emissions are generated using the Ship Traffic Emission Assessment Model (STEAM; (Jalkanen et al., 2009, 2012, 2018, 2021; Johansson et al., 2013, 2017).

For 2022, the temporal coverage was for the first time perfect, reaching 100% availability without any gaps. Most of the messages originate from South-Western region of the Baltic Sea near the Danish and southern Swedish sea areas (Figure 11). For 2022, average message count was just over 100,000 messages per hour.

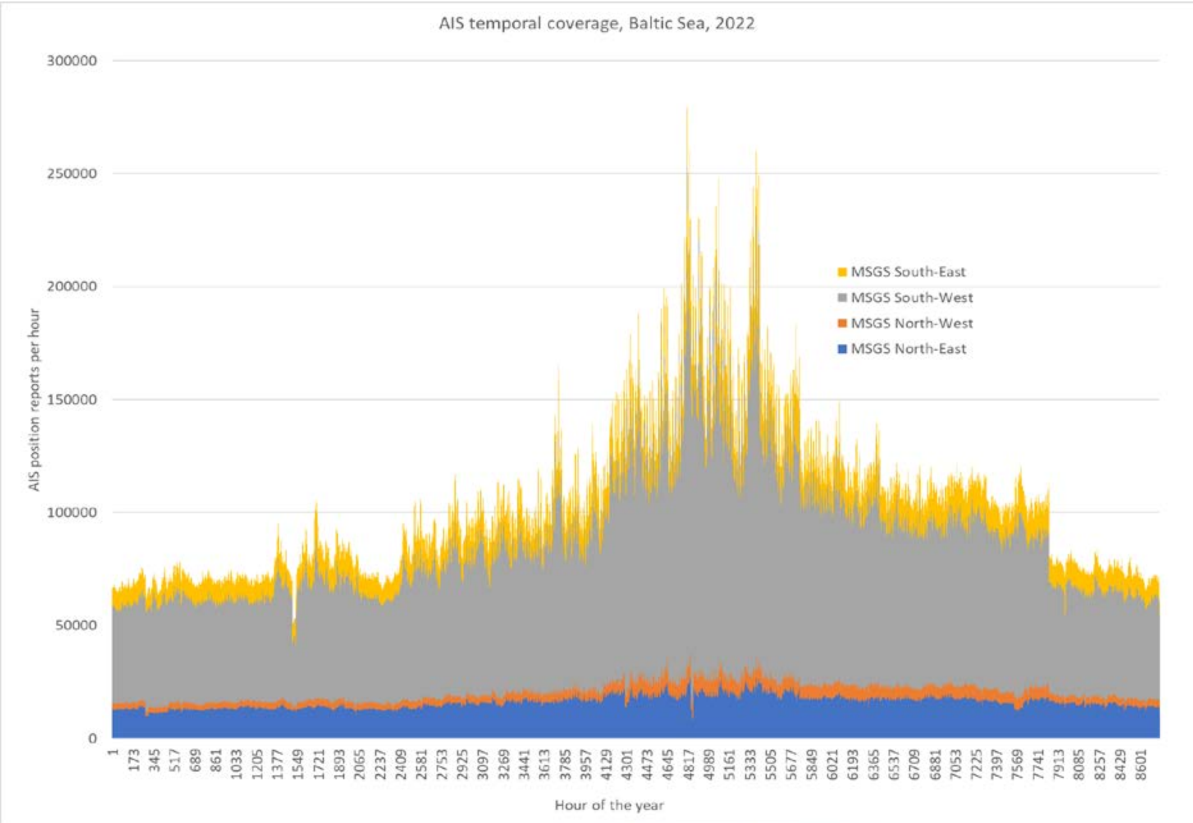

Figure 11. AIS-data hourly coverage in different parts of the modelling region for 2022.

Metadata

The STEAM model version was updated for this work. This update added the capability to track distances and time spent sailing in ice. The update also facilitates the modeling of N_2O and NH_3 emissions, which were added to the list of air pollutants modeled. Vessel operational procedures can have a large impact on emissions of noise and significant uncertainty is involved in estimating the cavitation inception speed of vessels. The STEAM model only includes description of machinery and propeller contributions to noise emissions, but does not consider the noise generated by collisions of floating ice blocks with vessel hulls. Further research efforts are needed for accurate prediction of cavitation of propellers. It should be noted that current estimates do not include contributions from vessels without active AIS equipment.