

UDK/UDC: 616-036.21:629.5.015.6(262.3)(497.4)

Prejeto/Received: 23.07.2025

Strokovni članek – Professional paper

Sprejeto/Accepted: 13.05.2026

DOI: [10.15292/acta.hydro.2026.02](https://doi.org/10.15292/acta.hydro.2026.02)

Objavljeno na spletu/Published online: 01.10.2026

UNDERWATER NOISE REDUCTION IN THE SLOVENIAN SEA DUE TO RESTRICTION MEASURES DURING THE COVID-19 PANDEMIC

ZMANJŠANJE PODVODNEGA HRUPA V SLOVENSKEM MORJU ZARADI OMEJITVENIH UKREPOV V ČASU PANDEMIJE COVID-19

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Abstract

The aim of this study was to analyze the reduction of underwater noise levels measured in the Slovenian Sea during the year 2020, when restriction measures due to the declared COVID-19 pandemic were applied to shipping. Annual average values of the sound level in 1/3-octave bands, one centered at 63 Hz and the other at 125 Hz, were calculated from the measured sound levels in each year according to the methodological standards for monitoring and assessment. This study shows that underwater noise levels in the Slovenian Sea in 2019 and 2020 were reduced compared to 2019, because of the reduction in ship traffic due to COVID-19 pandemic restriction measures. Furthermore, the reduction of underwater noise levels in 2020 was also confirmed by modelling using a parabolic equation method based on the ship traffic data from the Automatic Information System. Modeled values were influenced mostly by the speed of the ships. These findings indicate that the application of simple operational measures, such as rerouting and speed limitation, might prove useful to make seas and oceans quieter in the future.

Keywords: underwater noise, reduction, COVID-19 pandemic.

Izvleček

Namen te študije je bila analiza zmanjšanja ravni podvodnega hrupa, izmerjenih v slovenskem morju v letu 2020, ko so bili zaradi razglašene pandemije COVID-19 uporabljeni omejitveni ukrepi. Glede na metodološke standarde za spremljanje in ocenjevanje so bile iz izmerjenih ravni hrupa v letih 2019 in 2020 izračunane letne povprečne vrednosti ravni zvoka v terčnih frekvenčnih pasovih s središčnima frekvencama 63 Hz in 125 Hz. Študija kaže, da so se ravni podvodnega hrupa v slovenskem morju v letu 2020 v primerjavi z letom 2019 zmanjšale zaradi manjšega ladijskega prometa kot posledica omejitvenih ukrepov pandemije COVID-19. Poleg tega je bilo zmanjšanje ravni podvodnega hrupa v letu 2020 potrjeno tudi z modeliranjem ravni podvodnega hrupa s parabolično enačbo na podlagi podatkov o ladijskem prometu iz avtomatskega informacijskega sistema. Na modelirane vrednosti je najbolj vplivala hitrost ladij. Te ugotovitve kažejo, da bi

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bila uporaba preprostih operativnih ukrepov, kot sta preusmerjanje ladij in omejevanje hitrosti, lahko zelo koristna za to, da bodo morja in oceani v prihodnosti tišji.

Ključne besede: podvodni hrup, zmanjšanje, pandemija COVID-19.

1. Introduction

Low-frequency sound from commercial ships is a main source of anthropogenic underwater noise in seas and oceans. Most of the noise from ships is generated by propeller cavitation (Southall et al., 2017; Wales and Heitmeyer, 2002; Jalkanen et al., 2022), as well as onboard machinery (Lamoni and Tougard, 2023).

Shipping noise disrupts the communication of marine animals and may affect their behavior, ranging from freezing responses to habitat avoidance, changes in feeding, or disruptions in reproduction (Lamoni and Tougard, 2023).

Global restriction measures in trading and traveling during the coronavirus disease (COVID-19) pandemic led to a reduction in commercial and passenger shipping traffic. Many studies of measured underwater noise levels in the world's seas and oceans during COVID-19 restrictions showed a decrease in the low-frequency noise compared to the underwater noise levels before or after that period (Thomson and Barclay, 2020; Ryan et al., 2020; Ryan et al., 2021; Dahl et al., 2021; Gabriele et al., 2021; Basan et al., 2021; Robinson et al., 2023; Jalkanen et al., 2022; Nath, 2023).

Decreased low-frequency underwater noise levels observed in the Port of Vancouver, Canada, in the first quarter of 2020 coincide with the 21.5 % reduction in AIS transmissions as compared to the same three-month period in 2019, which reflected a considerable drop in commercial ship traffic over this period. An average reduction of 1.5 dB in mean weekly noise power spectral density at 100 Hz was observed during the first quarter of 2020 (Thomson and Barclay, 2020).

The quieting of low-frequency (31–100 Hz) underwater noise levels within Monterey Bay National Marine Sanctuary (California, USA) was observed during January–June 2020, when the mean spectrum levels were up to 2.7 dB re 1 μ Pa2Hz-1

below those of the years 2018 and 2019 (Ryan et al., 2020; Ryan et al., 2021).

Underwater noise levels in the 1/3 octave frequency band centered at 63 Hz were reduced at the measuring station located 87 km offshore of Newport in Oregon, USA, in the spring of 2020 by about 1.6 dB relative to the mean of the prior five years, owing to the reduced shipping activity initiated by the COVID-19 pandemic (Dahl et al., 2021).

The number of vessel entries in Glacier Bay National Park in SE Alaska was 44–49 % lower in 2020 compared to the years 2018 and 2016. Broadband (17.8–8,910 Hz) sound levels in the tourist season between May and September 2020 were 2.7 dB lower than in 2018 and 2.5 dB lower than in 2016 (Gabriele et al., 2021).

Underwater noise levels were analyzed at two monitoring stations in the German Baltic Sea for the period between 2013 and 2020. A decline in sound pressure of 13 % (1.2 dB) for low frequencies (10 Hz – 1 kHz) was observed at both stations, which corresponded to the reduced level of shipping activity (Basan et al., 2021).

A reduction of deep-ocean acoustic noise was observed in three ocean basins (Atlantic, Pacific, and Indian Ocean) in 2020, based on the data obtained by hydroacoustic stations as part of the International Monitoring System of the Comprehensive Nuclear-Test-Ban Treaty. The noise levels in the frequency range from 10 Hz to 100 Hz measured in 2020 were between 1 dB and 3 dB lower than predicted levels obtained from modelling data from previous years using Gaussian process regression (Robinson et al., 2023).

The measures during the COVID-19 pandemic changed vessel traffic patterns on a global scale. Modelling results indicated a reduction of 6 % in global shipping noise source energy in the 1/3 octave band with a centre frequency of 63 Hz. This reduction was largest in the Greenland Sea, the

Coastal Waters of Southeast Alaska, British Columbia, and the Gulf of California. However, in some sea areas, such as the Indian Ocean, the Yellow Sea, and the East China Sea, the emitted noise source energy was only slightly reduced (Jalkanen et al., 2022).

The COVID-19 lockdown led to a global decline in commercial and cruise shipping. The model quantified the reduction in noise levels before and during the lockdown in the Arctic, Atlantic, Pacific Oceans, and Mediterranean Sea. Hydrophone data from seven ocean observatories were analyzed at 1 Hz spectral and 1-minute temporal resolution. Three hydrophones were in the North Pacific Ocean, while the other four were in the Arctic Ocean, the Atlantic Ocean, the Mediterranean Sea, and the South Pacific Ocean. The analysis revealed that global oceans quietened by an average of 4.5 dB. The maximum decrease was at locations close to major shipping channels and cruise tourism destinations. The findings were validated by comparing shipping traffic using the satellite-based Automated Identification System (AIS) (Nath, 2023).

The aim of our study was to analyze the reduction of underwater noise levels measured in the Slovenian Sea during the year 2020, when restriction measures due to the declared COVID-19 pandemic were applied, compared to the underwater noise levels measured in the previous year of 2019. Furthermore, the reduction of underwater noise levels in 2020 was also analyzed by modelling underwater noise levels in 2019 and 2020 based on the ship traffic data from the Automatic Information System (AIS).

2. Materials and methods

2.1 Underwater noise measurements and data processing methodology

A permanent measuring station for underwater noise is located on the lighthouse 300 m off the coast at Debeli Rtič (lat.: 45°35' 28.2" N, long.: 13°41' 59.1" E). The Bruel & Kjaer Type 2250 sound level meter system is locked inside the lighthouse. It consists of a sound level meter and an octave-based frequency analyzer that calculates half-hour equivalent continuous sound levels (L_{eq})

in the 1/3-octave bands with centre frequencies ranging from 6.3 Hz to 20 kHz. A spherical omnidirectional hydrophone of type Bruel & Kjaer 8105 is installed 1 m above the seabed (water depth is 5 m) beside the concrete lighthouse foundation and connected with a cable to the sound level meter (Popit, 2021).

The annual average of the sound level in 1/3-octave bands, one centered at 63 Hz and the other at 125 Hz, expressed as a level in decibels in units of dB re 1 μ Pa, was calculated from the measured sound levels in the period from 18 April 2019 to 31 December 2019 and from 1 January 2020 to 31 December 2020, according to the methodological standards for monitoring and assessment from the Regulation on the implementation of the Commission Decision EU/2017/848 (Official Gazette RS, 2022/156). For this purpose, the arithmetic mean expressed as sound pressure level (SPL) in dB re 1 μ Pa was calculated according to the methodology described by Dekeling et al. (2014) using Equation (1):

$$L_{AM}(T) = 10 \log_{10} \frac{AM(T)}{p_{ref}^2} \quad (1)$$

where AM is the arithmetic mean in time T , and p_{ref} is the reference sound pressure level equal to 1 μ Pa.

The locations of ships in the Slovenian Sea in 2019 and 2020 were obtained from the data collected by the Automatic Identification System (AIS) in order to prepare hourly data on ship densities in four areas around the underwater noise measuring station. These areas were within radii of 2 nautical miles (NM) and 5 NM from the measuring station, in the Gulf of Trieste and the Gulf of Venice (Figure 1). Arithmetic average hourly ship densities in the four areas were calculated as the sum of the values of all observations divided by their number n (Pirc, 1997), using Equation (2):

$$\bar{x} = \frac{\sum_{i=1}^n x_i}{n} \quad (2)$$

where $i = 1, 2, \dots, n$ are observations. The arithmetic standard deviation (σ) is the square root of the variance (Davis, 1986) in Equation (3):

$$\sigma = \sqrt{\sigma^2} \quad (3)$$

Average hourly ship densities were presented on diagrams in combination with the average hourly continuous underwater noise levels in 1/3-octave

bands with centre frequencies of 63 Hz and 125 Hz (Figures 2 and 3).

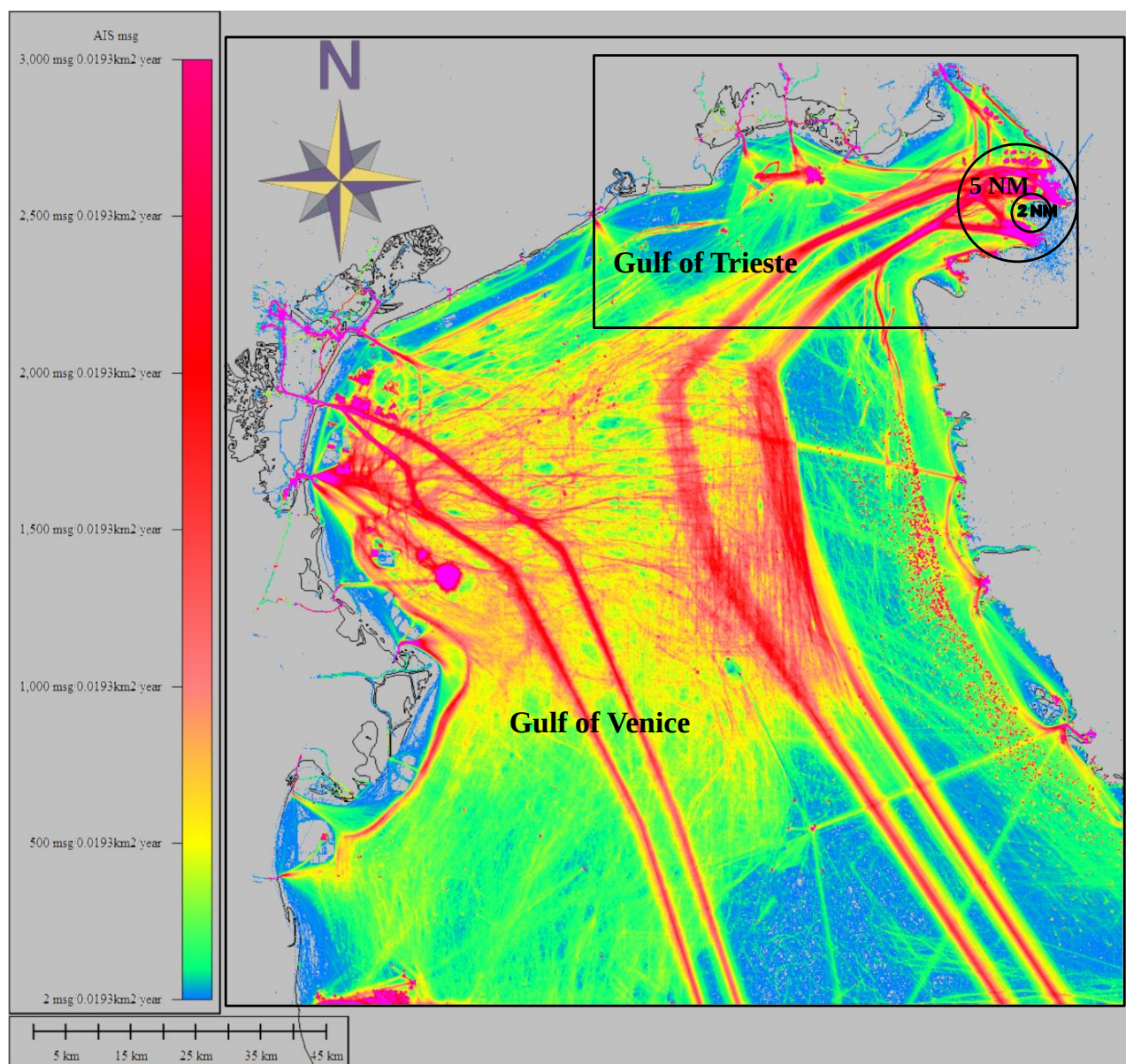


Figure 1: Ship densities within 2 NM and 5 NM from the measuring station, in the Gulf of Trieste and the Gulf of Venice in 2019 (Perkovič et al., 2021).

Slika 1: Gostota ladij 2 NM in 5 NM od merilne postaje, v Tržaškem in Beneškem zalivu v letu 2019 (Perkovič s sod., 2021).

2.2 Underwater noise modelling methodology

The method used in this study to calculate underwater noise combines a sound emission model and a sound propagation model (Erbe et al., 2012). The details of the calculation model can be found in Popit and Čurović (2022). For reasons of consistency, the most important aspects of the method are also presented in this section.

The sound pressure levels (L) caused by shipping traffic at 63 Hz and 125 Hz at the Debeli Rtič monitoring station were calculated using the following Equation (4):

$$L = SL(r_0, f) - TL(r, f) - TL_a(r, f) \quad (4)$$

where SL is the source level used to characterize the sound emission characteristics of ships, TL is the transmission loss function between the source and the receiver position, and TL_a is the attenuation factor due to sound absorption, f is the frequency of the sound waves, and r is the distance between the source (ship) and the receiver.

SL was calculated using the RANDI model (Erbe et al., 2012), which uses the length and speed of the ship to determine the frequency-dependent emission values. TL_a was calculated using Francois and Garrison's empirical model (Francois and Garrison, 1982). The range-dependent TL was determined by solving the parabolic equation (PE) with the RAMGeo algorithm implemented in the open-source software AcTUP (CMST, 2022). To account for the bathymetry of the northern Adriatic, the transmission loss function was evaluated for ten typical cross-sections. The TL used for modelling was calculated as the median value of the ten functions. Finally, the TL functions at 63 Hz and 125 Hz were expressed as a function of the distance r determined by the least squares method (Popit and Čurović, 2022) using Equation (5):

$$TL(r, f) = \begin{cases} 11.2000 \log r - 0.00020 r; & f = 63 \text{ Hz} \\ 10.9736 \log r - 0.00001 r; & f = 125 \text{ Hz} \end{cases} \quad (5)$$

Equation (4) was also used to calculate the noise maps, which show the spatial distribution of noise

levels in 1/3 octave bands with centre frequencies at 63 Hz and 125 Hz. The input data for the modelling included bathymetry data and ship traffic data (length, speed, location). The bathymetry data were obtained from a database accessible on the TOPEX website (TOPEX, 2021).

Ship traffic data, including location, speed, and length of vessels for each year, were taken from AIS data. The ships were divided into 5 classes according to their length. The smallest ships under 50 m in length were included in class 1. The maximum lengths of classes 2 to 4 were set at 100 m, 150 m, and 230 m, respectively. Class 5 included ships with a length of more than 230 m.

The AIS data was further processed. The map area was divided into 1 km x 1 km segments or cells. For each cell and each class of ship, the cumulative time that the vessels were in a cell was calculated, along with their average speeds and lengths (Perkovič et al., 2021). The average sound pressure level was calculated as the energy average of the sound pressure levels generated by the vessels in all cells. The Python programming language was used to calculate noise maps.

3. Results and discussion

Yearly average underwater noise levels in the 1/3-octave bands with centre frequencies of 63 Hz and 125 Hz in dB re 1 μ Pa in 2019 and 2020 were calculated (Table 1) based on the methodology described in this paper. In 2020, two average values were calculated: the first for January–August 2020, when only continuous noise was present, and the second for the whole year of 2020, when impulsive noise from pile driving in the Port of Koper (August–December 2020) was present in addition to continuous noise.

The results of yearly average ship densities in the four areas around the measuring station in 2019 and 2020 are presented in Table 2.

Table 1: The results of average value (AVE) and standard deviation (STDEV) calculations of $L_{eq,63Hz}$ and $L_{eq,125Hz}$ in dB re 1 μPa , and the reduction in 2020.

Preglednica 1: Rezultati izračunov povprečne vrednosti (AVE) in standardnega odklona (STDEV) za $L_{eq,63Hz}$ in $L_{eq,125Hz}$ v dB re 1 μPa in zmanjšanje v letu 2020.

Average and standard deviation of underwater noise levels	From 18. 4. 2019 to 31. 12. 2019	From 1. 1. 2020 to 31. 12. 2020	From 1. 1. 2020 to 31. 12. 2020 – including the period with impulsive noise from Avg-Dec 2020	Reduction between 2019 and 2020 – in the period without the impulsive noise
AVE & STDEV of $L_{eq,63Hz}$	97.9 $\pm$ 9.0	95.3 $\pm$ 8.1	134.9 $\pm$ 41.5	-2.6
AVE & STDEV of $L_{eq,125Hz}$	102.7 $\pm$ 6.4	97.1 $\pm$ 7.1	129.8 $\pm$ 34.2	-5.6

Table 2: The results of average value (AVE) and standard deviation (STDEV) calculations of ship densities ($\rho_{L,2NM}$, $\rho_{L,5NM}$, $\rho_{L,Trieste}$, and $\rho_{L,Venice}$) in each year, and the reduction in 2020.

Preglednica 2: Rezultati izračunov povprečne vrednosti (AVE) in standardnega odklona (STDEV) gostote ladij ($\rho_{L,2NM}$, $\rho_{L,5NM}$, $\rho_{L,Trieste}$ in $\rho_{L,Venice}$) za vsako leto in zmanjšanje v letu 2020.

Average and standard deviation of ship densities	From 18. 4. 2019 to 31. 12. 2019	From 1. 1. 2020 to 31. 12. 2020	Reduction between 2019 and 2020
AVE & STDEV of $\rho_{L,2NM}$	5 $\pm$ 3	5 $\pm$ 3	0
AVE & STDEV of $\rho_{L,5NM}$	57 $\pm$ 8	54 $\pm$ 7	-3
AVE & STDEV of $\rho_{L,Trieste}$	76 $\pm$ 12	72 $\pm$ 10	-4
AVE & STDEV of $\rho_{L,Venice}$	266 $\pm$ 54	235 $\pm$ 57	-31

Average hourly ship densities in the four areas around the underwater noise measuring station ($\rho_{L,2NM}$, $\rho_{L,5NM}$, $\rho_{L,Trieste}$, and $\rho_{L,Venice}$) in combination with the average hourly continuous underwater noise levels in 1/3 octave bands with centre frequencies of 63 Hz and 125 Hz are presented in diagrams (Figures 2 and 3). The blue curve presents $L_{eq,63Hz}$, the black curve presents $L_{eq,125Hz}$, the brown curve presents ship density 2NM from the measuring station, the green curve presents ship density 5NM from the measuring station, the yellow curve presents ship density in the Gulf of Trieste, and the violet curve presents ship density in the Gulf of Venice.

Pile driving activities in the port of Koper from August 2020 to December 2020 can be seen in Figure 2, with increased underwater noise levels above 120 dB re 1 μPa .

Underwater noise levels were predicted from the AIS data using the model described in the methodology. The results of the modelling were noise maps showing the spatial distribution of the noise levels in 1/3-octave bands with centre frequencies of 63 Hz and 125 Hz in the years 2019 and 2020 (Figures 4 to 7).

The model was validated based on the measured underwater noise levels in 2019 and 2020 (Table 3).

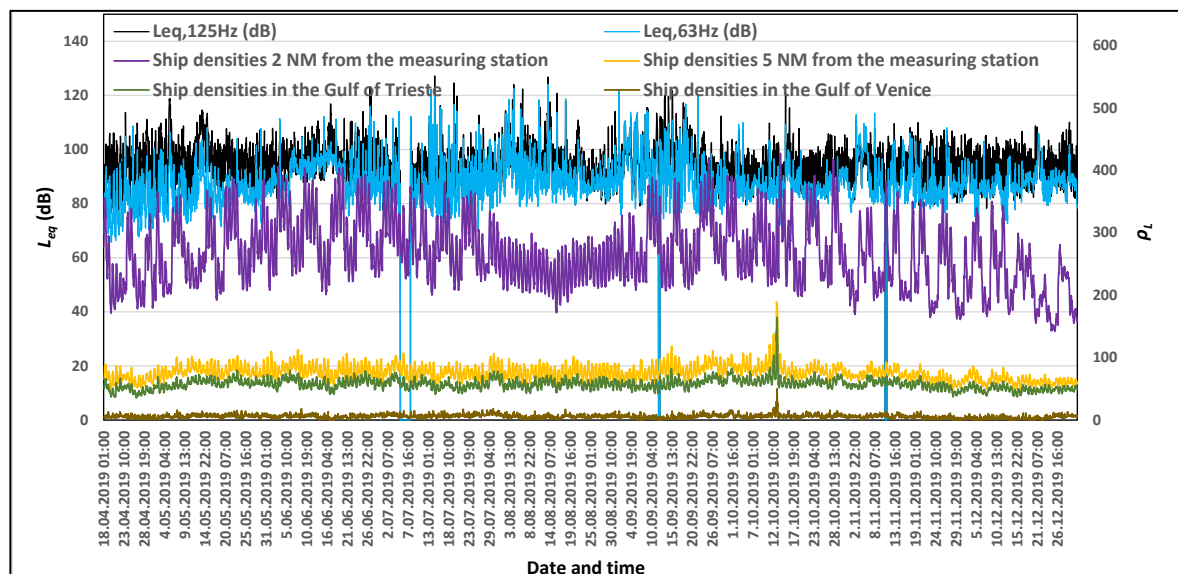


Figure 2: Diagram of the average hourly ship densities in the areas of 2 NM and 5 NM from the measuring station in the Gulf of Trieste and in the Gulf of Venice in combination with the average hourly continuous underwater noise levels in 1/3 octave bands with centre frequencies of 63 Hz and 125 Hz (L_{eq}) in the period from 18 April 2019 to 31 December 2019.

Slika 2: Diagram urnih povprečij gostote ladij 2 NM in 5 NM od merilne postaje, v Tržaškem in Beneškem zalivu v obdobju od 18. 4. 2019 do 31. 12. 2019 v kombinaciji s povprečnimi urnimi kontinuirnimi ravnmi podvodnega hrupa v terčnih pasovih s središčnima frekvencama 63 Hz in 125 Hz (L_{eq}) v dB.

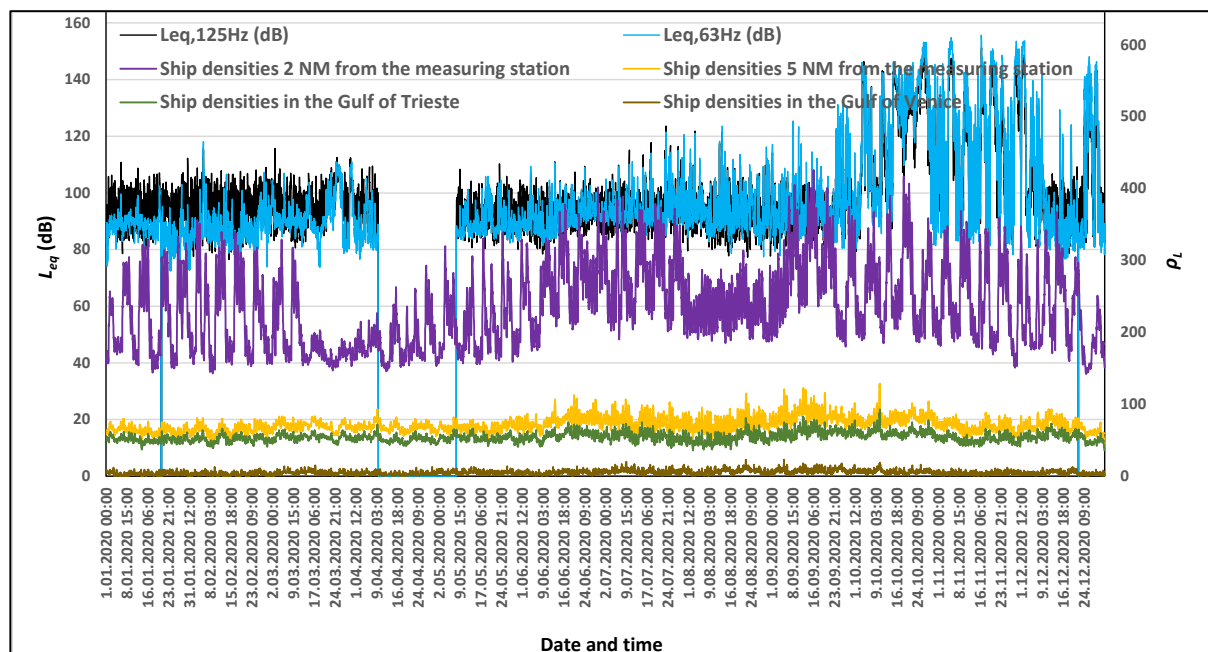


Figure 3: Diagram of the average hourly ship densities in the areas of 2 NM and 5 NM from the measuring station in the Gulf of Trieste and in the Gulf of Venice in combination with the average hourly continuous underwater noise levels in 1/3 octave bands with centre frequencies of 63 Hz and 125 Hz (L_{eq}) in the period from 1 January 2020 to 31 December 2020.

Slika 3: Diagram urnih povprečij gostote ladij 2 NM in 5 NM od merilne postaje, v Tržaškem in Beneškem zalivu v obdobju od 1. 1. 2020 do 31. 12. 2020 v kombinaciji s povprečnimi urnimi kontinuirnimi ravnmi podvodnega hrupa v terčnih pasovih s središčnima frekvencama 63 Hz in 125 Hz (L_{eq}) v dB.

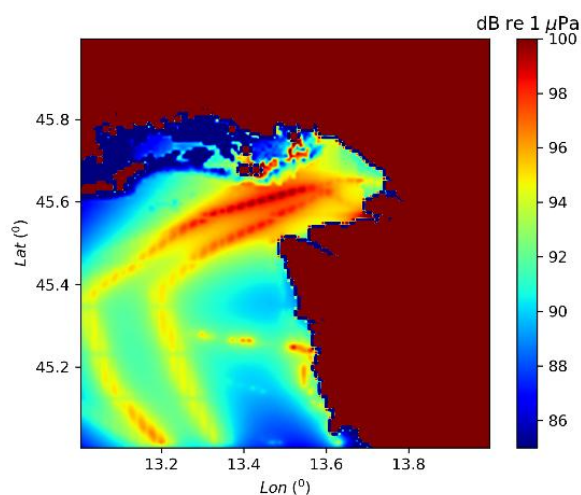


Figure 4: Noise map in 1/3-octave band with the centre frequency of 63 Hz in the year 2019.

Slika 4: Karta hrupa v terčnem frekvenčnem pasu s srednjo frekvenco 63 Hz za leto 2019.

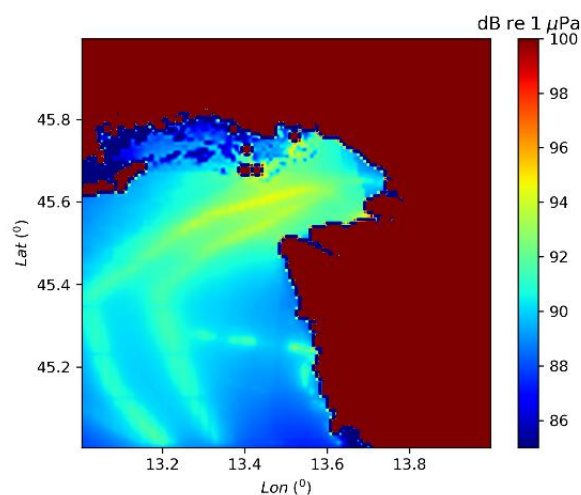


Figure 5: Noise map in 1/3-octave band with the centre frequency of 125 Hz in the year 2019.

Slika 5: Karta hrupa v terčnem frekvenčnem pasu s srednjo frekvenco 125 Hz za leto 2019.

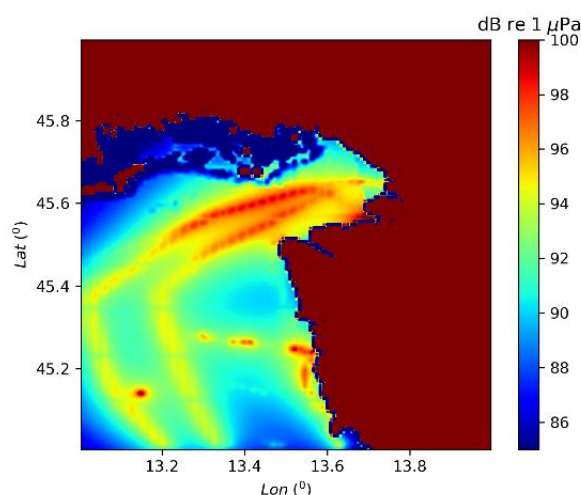


Figure 6: Noise map in 1/3-octave band with the centre frequency of 63 Hz in the year 2020.

Slika 6: Karta hrupa v terčnem frekvenčnem pasu s srednjo frekvenco 63 Hz za leto 2020.

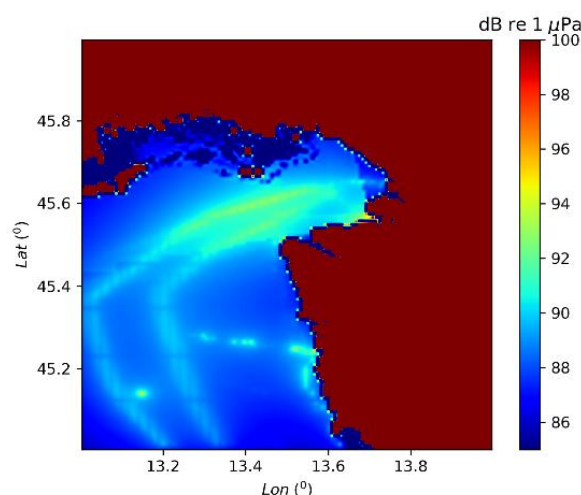


Figure 7: Noise map in 1/3-octave band with the centre frequency of 125 Hz in the year 2020.

Slika 7: Karta hrupa v terčnem frekvenčnem pasu s srednjo frekvenco 125 Hz za leto 2020.

Table 3: Measured and modelled average underwater noise levels.

Preglednica 3: Merjene in modelirane povprečne vrednosti podvodnega hrupa.

Period	Measured underwater noise levels		Modelled underwater noise levels	
	$L_{eq,63Hz}$ (dB re 1 μ Pa)	$L_{eq,125Hz}$ (dB re 1 μ Pa)	$L_{eq,63Hz}$ (dB re 1 μ Pa)	$L_{eq,125Hz}$ (dB re 1 μ Pa)
18. 4. 2019 – 31. 12. 2019	97.9	102.7	94.0	89.9
1. 1. 2020 – 11. 8. 2020 Period with continuous noise.	95.3	97.1	88.7	85.9

Discussion

Yearly average underwater noise levels in the 1/3-octave bands with centre frequencies of 63 Hz and 125 Hz were reduced in the Slovenian Sea in 2020 compared to the previous year by 2.6 dB and 5.6 dB, respectively (Table 1). A similar reduction was observed in the global studies in the Pacific, Atlantic, Indian, and Arctic Oceans and in the Mediterranean Sea (Ryan et al., 2020; Ryan et al., 2021; Dahl et al., 2021; Robinson et al., 2023; Nath, 2023).

Yearly average ship densities in the Slovenian Sea in 2020 in the area of 5 NM from the measuring station, in the Gulf of Trieste, and in the Gulf of Venice were reduced compared to 2019 by 3, 4, and 31 vessels, respectively (Table 2). Reduced shipping traffic was also reported in the Pacific, Arctic, and Atlantic Oceans, and in the Mediterranean Sea (Ryan et al., 2020; Ryan et al., 2021; Nath, 2023).

Furthermore, underwater noise levels in the Slovenian Sea were modelled using a parabolic equation based on the AIS data in the Northern Adriatic Sea. The model was validated with measured underwater noise levels in the Slovenian Sea. In 2019, the difference between the measured and modelled values for the $L_{eq,63Hz}$, and $L_{eq,125Hz}$ was within the range of ± 4 dB and ± 13 dB, respectively (Table 3). In 2020, the difference between the measured and modelled values for the $L_{eq,63Hz}$, and

$L_{eq,125Hz}$ was within the range of ± 7 dB and ± 11 dB, respectively. Such differences can be expected, especially in shallow waters. Measurements are influenced by all sources and events at specific locations, including wind-induced and flow noise, and can achieve high precision at specific points but exhibit high temporal variability, which strongly affects average values. Modelling is based on ship source level data and is more appropriate for analyzing specific noise levels due to marine traffic.

More important than the comparison of modelled values with noise measurements were the differences in the modelled noise levels for the $L_{eq,63Hz}$ and $L_{eq,125Hz}$ between 2019 and 2020 in the period without impulsive noise (Table 3), which were -5,3 dB and -4,0 dB, respectively. Modeling results indicated a similar reduction of underwater noise levels as reported in the global studies during the COVID-19 pandemic in the Mediterranean Sea, in the Pacific, Atlantic, and Arctic Oceans, in the Greenland Sea, and in the coastal waters of SE Alaska (Jalkanen et al., 2022; Nath, 2023). Therefore, the model can primarily be used to observe trends in noise levels.

4. Conclusions

This study shows that measured and modelled underwater noise levels in the Slovenian Sea in 2020 were reduced compared to 2019, because of the reduction in ship traffic due to COVID-19

pandemic restriction measures. Noise maps show that the Slovenian Sea is burdened with low-frequency noise due to the proximity of shipping corridors and larger ports in Koper and Trieste.

The obtained results of noise reduction in our study were similar to those reported in the global seas and oceans during the declared COVID-19 pandemic, which showed that reduced shipping traffic had a major impact on the globally reduced underwater noise levels. Another important finding based on our developed propagation model is that modeled values were influenced mostly by the speed of the ships (Popit and Čurović, 2022). These findings indicate that the application of simple operational measures, such as rerouting and speed limitation, might prove useful to make seas and oceans quieter in the future.

Declaration of interests

We declare that we have no conflict of interest.

Data availability statement

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Funding

This study was funded by the Ministry of the Environment and Spatial Planning.

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