SELECTED CHARACTERISTICS OF SHIPPING NOISE AT THE FAIRWAY OF THE GDYNIA HARBOUR

ZYGMUNT KLUSEK [1], JOANNA SZCZUCKA [1],
DARIA MRÓZ [2]

[1]Institute of Oceanology PAS, 81-712 Sopot, str. Powstańców W-wy 55, Poland
klusek@iopan.gda.pl
[2]Port of Gdynia Authority S.A., Rotterdamska 9, 81-337 Gdynia, Poland

This paper aims to evaluate the possible impact of shipping noise on marine fauna in the vicinity of the Gdynia Harbour. Measurements were performed in the area at a distance of 0.2 NM from the fairway. For this purpose, statistics of Sound Pressure Level (SPL), Sound Exposure Level (SEL), and Power Spectral Density (PSD) were evaluated.

Some specific changes of the ambient and shipping noise spectra are given in examples.

INTRODUCTION

Studies of the impact of high intensity underwater sound, generated by human technical activities in the marine environment are currently a big concern of marine biologists [1, 2], ecologists [3] and organizations involved in environmental issues.

So far, a number of characteristics of underwater sound fields with significant noise pollution affecting the health of marine organisms have been recognized.

These include the structure of the power spectrum of sounds (acoustic energy distribution at different frequencies), the level of the total noise in a wide frequency band (sound intensity), the duration of acoustic disturbances (acoustic energy) and the difference between the maximum and the minimum sound pressure (see [1,2,3]).

Due to methodological difficulties, there is still some uncertainty in our knowledge regarding of the anthropogenic component of underwater sound and the adverse effects on various species of marine organisms.

It should be also noted that the stressful impact of the high intensity noise on many species of marine fauna is has only recently begun to be studied [2].

That stressful effects of noise change the level of stress hormones (cortisol) in fish blood has been established for many species of freshwater fish [1]. It has also been shown that the anthropogenic component, in particular, of the underwater sound field can harm the health of marine mammals.

Because of potential threats of anthropogenic noise for marine organisms, the underwater acoustic field should be carefully monitored, particularly in areas of intense technical activity, e.g., in the vicinity of harbors or pile driving.

In order to reduce the harmful effects of ship noise on marine fauna, some organizations recommend actions such as reducing the ship speed, avoiding sensitive areas such as spawning grounds or erecting noise barriers in the form of a curtain of air bubbles.

Gdynia Harbor, one of the largest harbours on the Baltic Sea, which is, undergoing expansion, has aroused environmental concern. The port is located near two NATURA 2000 marine conservation areas. Although an assessment of the impacts of ship noise in the area is needed, there is currently not enough data available for a robust analysis. Consequently, the present work aims to evaluate the environmental impact of ship noise in a delimited geographical [eliminate] area around the entrance to the harbour.

Our hope is that this study will be a starting point for monitoring the underwater noise in the area to estimate the effect of the noise on the aquatic ecosystem.

According to the agreement with the Port of Gdynia Authorities SA, the ship noise measurements were stipulated to last one week and performed near the traffic lane leading to the port.

1. DATA ACQUISITION AND ANALYSIS

The registration of acoustic noise was performed with an autonomous underwater buoy equipped with four calibrated hydrophones, an echosounder looking up, and a compass with an inclinometer. This allowed us, in accordance with EU recommendations, to measure not only the sound pressure and its derivatives, but also to determine the bearing of moving noise sources and to measure their speed.

The noise measurements were performed with two types of acoustic transducers: for the 23rd -27th April 2014, four hydrophones RESON TC4032 were used as the sensors, whereas for April 28-29, four RESON TC4056 hydrophones were used. Both sets of hydrophones have adequate recent calibration curves as issued by the manufacturer. The distances between the opposite hydrophones are 4.40 m.

Signals from hydrophones are amplified either 480 or 300 times, depending on the type of hydrophone, and converted to digital form using the 16-bit analog-to-digital converters arranged inside the buoy. The sampling frequency was 30 kHz, for April 23-27 and reduced to 20 kHz for April 28-29. The registrations of the underwater noise were performed continuously.

The signals were accumulated on an SD card and then analyzed in the MATLAB language environment, using software developed by the authors.

The TC4032 hydrophones are characterized by their high sensitivity (approx. -170 dB re V/μPa), and a low self-noise, which allows for carrying out registration of the underwater ambient noise in a wide range of frequencies, starting below the Beaufort Sea State zero noise level according to the spectrum level given by Wenz [4].

The high level of the signal from the sensors permits separation from interferences produced by ambient electrical noise inside of the buoy. The aim in using high sensitivity TC4032 hydrophones was to distinguish ambient sea noise from distant anthropogenic sources and from noise emitted by sea surface natural sources, despite the fact that passing ships near the buoy can cause an overload in the A/D systems which indeed occurred.

The bandwidth of the TC4032-5 hydrophones ranges from 100 Hz to 120 kHz. However, using digital correction on the basis of the measured frequency response of the hydrophone and its preamplifier, the noise spectra investigation could be extended to the lowest third-octave bandwidth, with a center frequency of 63 Hz.

RESON TC4056-1, 3 hydrophones have a typical sensitivity of -188 dB re 1V/μPa; in the version employed in this study, the frequency band starts from the frequency of 7 Hz. However, the high-pass filter in the buoy prevented frequencies below 20 Hz from being recorded.

The measurement point was located near the fairway approach to the Gdynia port at a distance of 2 cables northerly to the navigational buoy GD, with coordinates λ = 018˚ 39.84'E, φ = 54˚32.07' N) (the position of which has been designated by the Maritime Office in Gdynia). Depths at the harbor fairway and beyond are approximately 25.0 m. The depth of hydrophones was approximately half of the sea depth. The position of recording point was selected as the on the basis of a compromise between high intensity intermittent noise from local fairway traffic and ambient noise from more distant shipping, mostly heading for and coming out of Gdansk Harbour.

The sound speed profiles during the conducted observations were typical of the sound propagation conditions in the winter-spring season.

The wind speed and direction were recorded at the measuring station located at the pier in Sopot whose coordinates are λ = 018°34'33" E, φ = 54°26'52" N (this station was erected as a consequence of the WAB project – "Monitoring of parameters of air and sea water at the pier in Sopot - Southern Baltic").

2. DATA ANALYSIS

There is disagreement among many authors concerning the functional relations between ship characteristics, including the tonnage of the vessel, the actual speed of the vessel, and the number of blades of the screws, and the associated spectra [5, 6, 7, 8, 9]. This is partly due to difficulties in determining the level of an extended sound source, viz the vessel and its mechanisms in free field conditions.

The basic characteristics of the sound field exploited in prediction of the impact of the anthropogenic component of the underwater noise on marine animals are

a) equivalent continuous noise level (Leq) in decibels relative to a reference pressure (mean square pressure averaged over time - rms), defined as follows:

$$Leq = 10\log_{10}\left(\frac{1}{T}\int_0^T \frac{p^2(t)}{p_{ref}^2}dt\right), \tag{1}$$

where p(t) =instantaneous acoustic pressure, p_{ref} = a reference pressure equal 1 μPa and T = the time over which the mean is computed; the units of Leq are in dB re 1 μPa,

b) the sound exposure level (SEL), a cumulative measure of acoustic energy allowing the energy radiated by sounds of differing duration to be compared,

c) the spectral levels (Due to the fact that hydrophones and the acoustic receiving system were calibrated, the noise spectra and spectral levels are represented in absolute values (in dB re 1 $\mu Pa^2/Hz$)),

d) weighted characteristics (It is indisputable that different species, depending on the construction of the hearing organ and the body as a whole are exposed in varying degrees to harmful effects of noise. Just as in physiological acoustics, in assessing the impact of noise on marine animals, we should consider the sound pressure thresholds of audibility for the most representative for given area species. Thus, weighted calculations were performed in the frequency domain of the noise, factoring in exposure to noise, with due attention to the levels of hearing and reaction to noise for fishes and mammals.

3. RESULTS

3.1 WIND

Wind is the one of the main sources of ambient sea noise and, due to its influence on transmission loss, should be included in an analysis of the recorded underwater noise. The coastline in the testing area is oriented from north to south. Consequently, the prevailing winds in northwestern, southwestern, and western directions during the experiment are from the nearby shore (Fig.1), with the result that the fetch was relatively short and the wind wave heights were lower, as in open sea. Wind speed during noise registration varied within a relatively wide range, with wind from almost still weather to gusting up to about 10 m/s and the sea state from practically smooth water to the intensive wave breaking (Fig.2.). Therefore, despite the short fetch, a noticeable increase in the level of the ambient noise emitted by the breaking waves, associated with the higher wind speed, was recorded in the absence of near ships. This increase has been observed both as an increase of the noise level in the whole frequency range and as characteristic changes of the spectrum slope of the noise. On the other hand, due to the relatively short distance of measurement point from the passing ships, there was no statistically significant correlation between noise from a single ship and the wind speed. This was expected due to well-known fact that mounting sea surface roughness causes deterioration of sound propagation conditions.

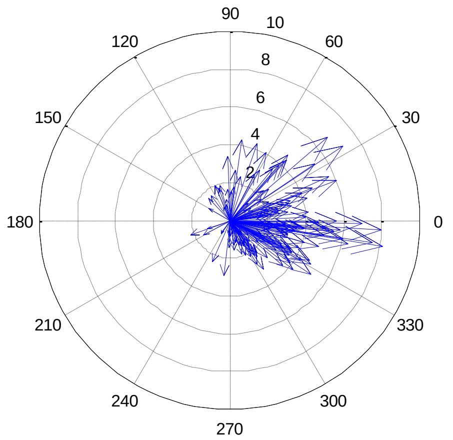

Fig. 1. Direction and wind speed during the observations (given according to oceanographic convention). Data averaged over one hour period.

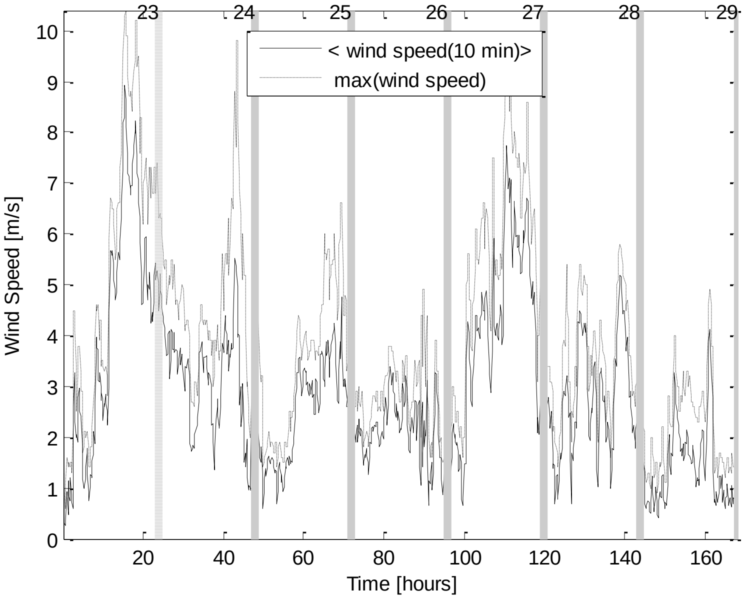

Fig. 2. Time series of wind speed during 23-29 April, 2014 measurements. Wind speeds averaged over intervals of 10 minutes are displayed as continuous lines and maximum values in the respective time periods as dashed lines.

3.2 SHIPPING NOISE

3.2.1. Spectral characteristics

According to expectations for the area studied, the highest contribution to the underwater noise field comes from passing vessels.

An asymmetrical form of acoustic pressure time series was observed for practically all ship-types, and the noise level of approaching ships was usually 3 to 10 dB lower than that for retreating ships (stern aspect), which is in agreement with most other studies (see [5] as example). However, we should note that some studies state the opposite: source levels are generally higher at bow aspects compared to stern aspects [6].

Ship noise levels are commonly represented as a one-third octave spectrum for the standard set of central frequencies. This noise representation has been proposed [5] as a tool to identify the ship’s predominant noise sources and to build up a ship's total acoustic signature for classification of a ship.

The broadband noise level (in frequency band 50 Hz – 10 kHz) and the one-third octave band SPLs registered over the course of about 20 hours on 29 April 2014 are given in Figs. 3 and 4. Fig. 3 provides detailed data on how ambient noise levels varied at the study site.

Turning our attention to noise time series, in the presence of passing vessels, we observe rapid growth of the noise level by 20-35 dB above the background noise in the analysed frequency bands.

It is generally accepted that the noise spectrum level and the form of the spectra of the ship noise component mainly depend on the spatial distribution of vessels in the waters, on their type and speed, and on concomitant acoustic wave propagation conditions.

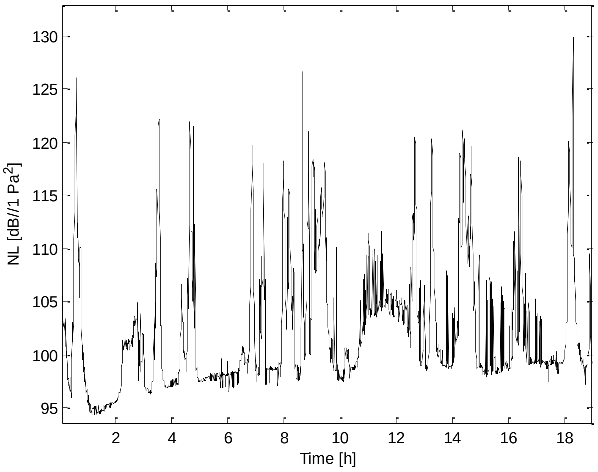

Fig. 3. Example of time series of the noise level in the vicinity of the Gdynia Harbour waterway. Data are averaged over 1 minute period.

To describe the local shipping noise properties, we calculate the time series of the Sound Pressure Level (SPL), the Sound Exposure Level (SEL), and the Power Spectral Density (PSD). The SPL and SEL were similar to levels reported from other regions with similar intensities of the [eliminate] traffic, reaching values that could interfere locally with the behaviour of some marine species.

A typical day’s observations, expressed in terms of variations in the spectral components of the noise, are shown in the spectrogram of Fig. 4.The time window of the spectral analysis was 1 second. In Fig. 5, the frequency of occurrences in the spectra of a maximum in the 1/3 octave bands is displayed.

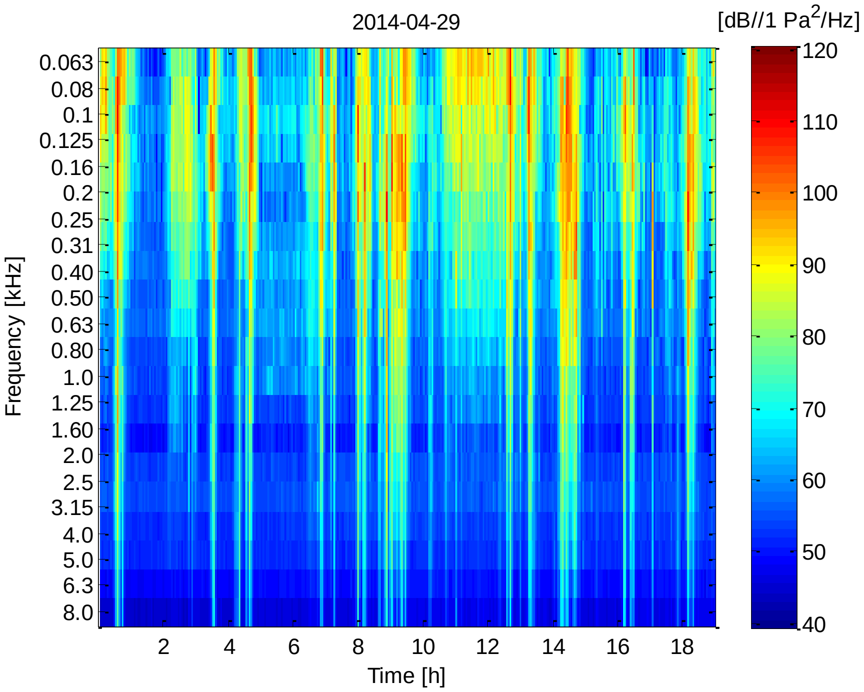

Fig.4. Spectrogram of noise in the 1/3 octave band. The same point and time of observation as in Fig.3.

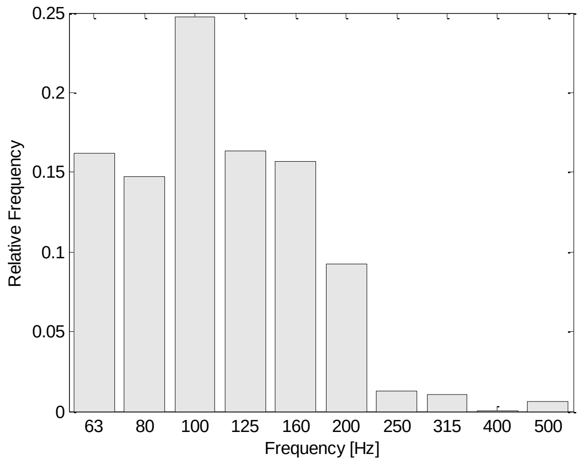

Fig. 5. Histogram of maxima in the noise spectra averaged in 1/3 octave bands.

Even though the separation of the wind and ship contributions might not be possible, local shipping noise has a high probability of being the dominant contributor in the whole frequency band. Specifically when the study area is in relatively sheltered conditions.

It is well established that the wind driven constituent of the ambient sea noise has a local maximum of around 500-800 Hz and, typically, this component of the underwater noise in the absence of traffic noise above maximum is characterised by a spectrum slope with values between - 5 and -8 dB/octave

On the other hand, it is commonly recognised that the typical spectra of underwater noise of commercial ships have maximum in frequency range of 20 - 200 Hz [7]. Furthermore, their 1/3 octave spectrum could have more local maxima.

Fig. 5 shows variability of time series of noise level in the investigated broadband range between 50 Hz and 10 kHz (black dashed line) and the spectrum slope (blue line) for frequencies above 500 Hz. It is apparent that there is strong negative correlation between spectrum slope and the noise level in the area. The estimated spectrum slope in the presence of ship noise is steeper than in the case in which prevailing dynamic ambient noise conditions quite frequently reach -20 dB/octave. Wind sources contributions at frequencies above 500 Hz are likely to cause less of a decrease of the spectral slope of the noise.

Comparing the data of other authors, Ross [7] gives spectrum slope for all ship classes as 20 log(f), where f is frequency in Hz; Scrimger and Heitmeyer [8] support his results; on the other hand, Wales and Heitmeyer [9] propose more complex formula in the form

$$NSL(f) \sim 35.94 \log(f) + 9.17 \log(1+f^2/340). \qquad (2)$$

In the absence of ships, the noise from dynamic surface sources has diminished the mean spectral slope to -6 ÷ -8 dB/octave. In the area, different as open sea wind/wave relationships, the mean spectrum slope of the wind driven component of the ambient noise is similar to that observed in the open sea [10].

Regardless of the relatively large number of cases reported in the literature, there is no generally accepted functional relationship between the spectral level of noise generated by ships and ship class, or their respective tonnage and speed [6].

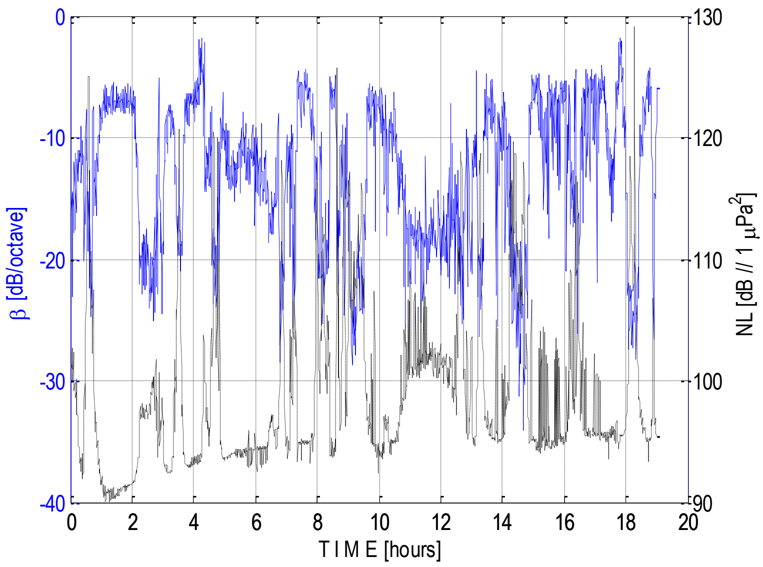

Fig. 6. The spectral slope of spectra (blue line) and noise level (black line).

Despite the presence of pile driving performed at the time of our observations in the Gdynia Harbour, we did not detect noise from this kind of activity.

It is interesting that during the first rush hour of the day for April 24-27, commencing at about 6 hours in the morning local time, the ambient noise in the sea was increasing by 3-5 dB, corresponding to the increase in the traffic in the city and slowly declining in the evening hours.

We also registered cyclic broadband electromagnetic interferences of unknown origin, with a repetition period of about 4 hours.

3.2.2. Tracking the noise source.

The ability to determine bearings of ships by means of their radiated sounds has been useful, often as complementary information to noise propagation modelling [11]. With only one pair, or with a better array of hydrophones, it is possible to obtain bearings to a noise source from differences of arrival time. The theory of estimation of bearing and tracing obtained from the calculation of cross-correlations between signals for the case of an array of transducers placed horizontally, with a symmetrical fixed configuration, is well known in the literature (see [12] and [13] for examples).

The results shown are based on the application of the classical cross-correlation method between signals coming from all four hydrophones. Before computing the cross-correlation function, the signals were pre-filtered in the frequency range of 60-500 Hz. The filtering in frequency bands considerably improved the process of tracking.

Correlograms were computed for all pairs of hydrophones. Information about the time lag between acoustic signals arriving at the hydrophones was obtained from the position of a maximum on the time axis for the cross-correlation function.

The bearing angles were calculated with reference to the shortest distance between the buoy and the waterway. The example given in Fig.7 is presented for the case of two incoming and outgoing ships. In the panels of the Figure are displayed the time delay between a pair of hydrophones (at this time placed on the axis parallel to the waterway), the bearing angles, and the noise level registered at the measurement point. The presented data are from time series obtained on the 24th of April with highly sensitive hydrophones and the noise level values near 125 dB. The data are distorted due to oversaturation of the ADC circuitry. However, this oversaturation does not influence the quality of the passive tracking. Negative bearing angles are from western directions. The computation is performed for the most convenient conditions – low wind speed and during night hours.

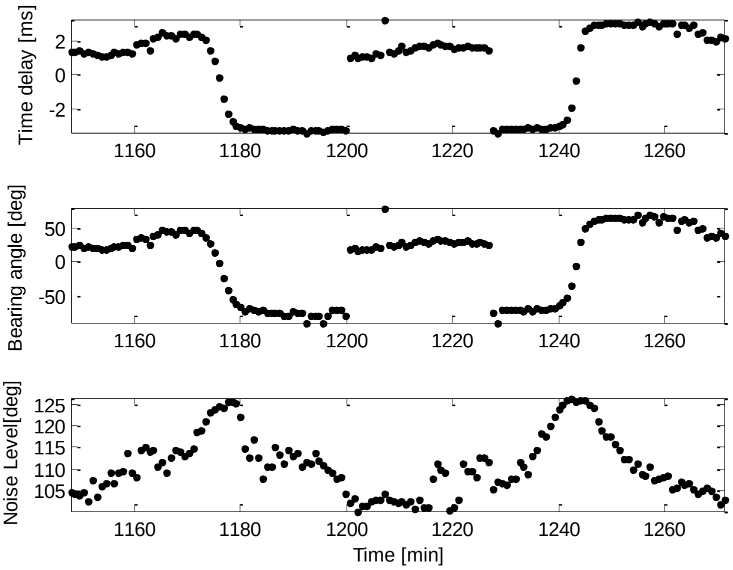

Fig. 7. Example of acoustic tracking of two ships coming and outgoing from the port. The panels, starting from the upper one, represent time delay between a pair of hydrophones, the bearing angles and the noise level registered at the measurement point, respectively.

3.2.3. Noise Statistics

For modelling of the sound exposure levels or noise level statistics over the broader area, the measured noise level must be converted to the standard source level SL expressed in dB//1μPa @ 1m, i.e. at a distance of 1m from the source.

To illustrate the level of noise and observed fluctuations in the environment, three percentiles of the sound levels were calculated, equal to 10, 50 and 90, both for noise in a wide frequency band and for the recommended for monitoring of two frequency bands (63 and 125 Hz). Data are in 10 second intervals.

To clarify the percentile definitions, we recall the definition of a quantile of order k, where k = 1,..., 99. In effect, a quantile is the percentile, the value below which is the determined percentage of the samples.

L50 has been recognized by the American Community of Noise Assessments as an important indicator of the physiological noise nuisance threshold for organisms.

The difference L10-L90 is a measure of scattering of the noise data.

The noise level for a given percentile, for two day periods for all frequency bands was the following:

L90= 146.1 dB re1μPa; L50 = 148.9 dB re 1μPa and L10 = 160.05 dB re 1μPa, respectively.

The arithmetic mean for the same period of measurements was L90 = 126.4 dB re1μPa, L50 = 136.6 dB re1μPa and L10 = 159.1 dB re 1μPa.

For the one-third octave bands 63 and 125 Hz, the mean values of percentile's level of noise spectral density are respectively 63 Hz: 99.0, 113.0 and 131.5 dB re 1μPa. 125 Hz: 103.3, 116.1 and 131.1 dB re 1μPa. These values define the condition of the existing shipping noise in the area, and would be designated as the reference for determining trends in the noise changes.

3.2.4 Sound exposure level (SEL)

According to the EU's Marine Strategy Framework Directive (2008/56/EC) it is highly desirable that the annual average ambient noise level in the 1/3 octave bands centred at 63 and 125 Hz should not exceed the reference point values of the year 2012 or 100 dB re 1 μPa root-mean-square (rms) [14]. In the case of the Gdynia harbour we observe and predict an increasing number of ships arriving at the port. Consequently, the first part of the condition cannot be fulfilled. However the second part is fulfilled.

The cumulative sound exposure level was estimated on the basis of two days registration for 28-29 April 2014, based on the assumption that traffic during both days is representative for the year (as it was found to be in retrospect):

For broadband noise registered at each of hydrophones the data obtained were almost equal: SEL_1= 158.1 dB re 1 μPa^2 s, SEL_2=157.6 dB re 1 μPa^2 s, SEL_3=158.1 dB re 1 μPa^2 s, SEL_4=158.2 dB re 1 μPa^2 s. However, for data in narrow 1/3 octave bands, fluctuations are dispersed and are equal to, using the same order of the hydrophones, the following:

in the 63 Hz 1/3 octave band 144.79, 142.8, 144.3 and 145.4 dB re1 μPa^2 s,

and at 125 Hz 147.1 146.4, 139.1 and 147.1 dB re1 μPa^2s.

The annual average noise level from shipping was predicted on the basis of estimation of the SEL minus 49.4 dB (-10·log10(24h 60min 60sec) and we see that noise does not exceed the suggested European target of 100 dB re 1μPa in either the 63 or 125 Hz 1/3 octave band at the point of observations.

4. SUMMARY

The aim of the measurements was not only to provide data for today's requirements regarding evaluation of the impact of the ship noise on the environment, including marine NATURA 2000 sites, but to provide a basis for forecasting the impact on the environment of increased shipping traffic associated with new investments [14]in the future.

Due to modest dynamic range of the recording system (16-bits), the measurements of the ambient and traffic noise were performed in two options. First, during the lengthier time period, we registered and analyzed the background noise in the Gulf of Gdansk in the absence of transiting ships; and second we recorded ship noise in more detail with less sensitive hydrophones, thereby avoiding signal saturation.

The results show that the vessel noise is a major contributor to the ambient noise in the area in all investigated frequency ranges.

With about 20 ships transiting per day, the Gdynia waterway may be considered a rather low traffic area if compared to the Western Baltic seaways (a minimum of one order times higher). Results clearly show that mean anthropogenic noise measurements can be locally high. It was found that contributions of other sources to underwater ambient noise, such as road noise from the Gdynia city or pile driving in the harbour, are prevalent but nevertheless insignificant compared to shipping.

In any case], shipping noise from vessels on the waterway cannot be considered as a danger for marine life in the NATURA 2000 areas.

The acoustic measurements were made at a single depth, which implies that recorded levels are not fully representative of the whole water column. At small distances and relatively low frequencies, acoustic interference affects the radiated noise at a given range and depth.

Despite of the small depth, varying year long sound speed profiles would influence propagation conditions, as could be verified using propagation models. Additionally, vertical hydrophone arrays and measurements of sound speed profiles would give a more complete picture of ship noise.

Future studies, based on more extensive material with multiple samples of the comparable ship-types, aimed at deriving statistical relationships of underwater radiated noise from ship characteristics, and more detailed sound propagation conditions could give more detailed picture of the shipping noise in the area.

ACKNOWLEDGMENTS

We gratefully acknowledge the financial support provided by the Port of Gdynia Authority S.A and publish with their permission their involvement in this project.

Deployment and docking of the buoy from the board of rv “Oceania” and partial data processing were performed in the framework of the statutory activity of the Institute of Oceanology, Polish Academy of Sciences in Sopot.

REFERENCES

[1] L.E. Wysocki, Dittami J.P., Ladich F., Ship noise and cortisol secretion in European freshwater fishes, Biol. Conserv., vol. 128, 501-508, 2006.

[2] R. McCauley, Fewtrell J., Popper A., , High intensity anthropogenic sound damages fish ears. J. Acoust. Soc. Am., vol. 113, 638–642, 2003.

[3] J.R. Nedwell, Turnpenny A.W.H., Lovell J., Parvin S.J., Workman R. Spinks J.A.L., Howell D., A validation of the dBht as a measure of the behavioural and auditory effects of underwater noise. Subacoustech Report Reference: 534R1231, Published by Department for Business, Enterprise and Regulatory Reform. 2007.

[4] G.M. Wenz, “Acoustic ambient noise in the ocean: spectra and sources,” J. Acoust. Soc. Am. vol. 34, 1936–1956, 1962.

[5] I. Gloza, Józwiak R., Buszman K., The one–third–octave spectrum as a method of vessel identification Hydroacoustics, vol. 17, 63-68, 2014.

[6] M.F. McKenna, Ross D, Wiggins S.M, Hildebrand J.A., Underwater radiated noise from modern commercial ships, J. Acoust. Soc. Am., vol. 131, 92-103, 2012.

[7] D. Ross, Ship sources of ambient noise, IEEE Journal of Oceanic Engineering, 30 (2), 257-261, 2005.

[8] P. Scrimger, Heitmeyer R.M., Acoustic source-level measurements for a variety of merchant ships, J. Acoust. Soc. Am., vol. 89, 691-699, 1991.

[9] S.C. Wales, Heitmeyer R.M., An ensemble source spectra model for merchant ship-radiated noise, J. Acoust. Soc. Am., vol. 111, 1211-1231, 2002.

[10] Z. Klusek, Lisimenka A., Are the Knudsen curves acceptable in the Baltic Sea?, Hydroacoustics vol. 9, 77-88, 2007.

[11] E. Kozaczka, Domagalski J., Gloza I., Investigation of the underwater noise produced by ships by means of intensity method, Polish Maritime Research 3(66), vol 17; 26-36, 2010.

[12] Chung KilWoo, Sutin A., Sedunov A., Bruno M., DEMON Acoustic Ship Signature Measurements in an Urban Advances in Acoustics and Vibration, Harbor, Hindawi Publishing Corporation, Article ID 952798, 13 pages, 2011.

[13] A. Dragan, Klusek Z., Swerpel B., Passive acoustic detection and observations of wind-wave breaking processes, Hydroacoustics, vol. 14, 29-38, 2012.

[14] [EU TSG Noise 2014] “Monitoring Guidance for Underwater Noise in European Seas, Parts I-III: Executive Summary”, Dekeling R.P.A., Tasker M.L., Van der Graaf A.J., Ainslie M.A, Andersson M.H., André M., Borsani J.F., Brensing K., Castellote M., Cronin D., Dalen J., Folegot T., Leaper R., Pajala J., Redman P., Robinson S.P., Sigray P., Sutton G., Thomsen F., Werner S., Wittekind D., Young J.V. JRC Scientific and Policy Report EUR 26557 EN, Publications Office of the European Union, Luxembourg, 2014, doi: 10.2788/29293, ISBN 978-92-79-36341-2. Available from: http://publications.jrc.ec.europa.eu/repository/handle/111111111/30979.