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Underwater noise level in Klaipėda Strait, Lithuania

Donatas Bagočius

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Abstract Underwater noise is an issue with rising importance in the Klaipėda Strait, as man-made activity grows in this area. The article presents methods and results of the first attempt to measure underwater noise in the Klaipėda Strait connecting the Baltic Sea and the Curonian Lagoon. Emphasis is placed on the background underwater noise in the area, where vessels traffic makes its general contribution to it. Dredging and vibro-pile driving noise have been studied as contributors to the background noise as well. Comparison of background noise in the Klaipėda Strait and an unaffected Curonian Lagoon area is given. Possible impacts of underwater noise on migrating fish species are shortly discussed.

Keywords *• Acoustics • Underwater noise • Pile driving • Dredging • Ship traffic •Klaipėda Strait • Lithuanian* Baltic Sea coast

✉ *Donatas Bagočius (donatas.bagocius@corpi.ku.lt), Klaipėda University, Coastal Research and Planning Institute, H. Manto Str. 84, LT-92294 Klaipėda, Lithuania.*

INTRODUCTION

The noise level in the seas began to rise with the onset of industrial revolution in 1850. The substantial increase in number of commercial vessels during the past 50 years implies that there has been a gradual growth in noise level from the shipping and other man-made activities (Frisk et al. 2003). The underwater noise levels and effects of underwater noise on aquatic animals in the Klaipėda Strait and Lithuanian sector of the Baltic Sea are unknown. There is some literature available presenting underwater background noise measurement results in the Baltic Sea areas as the Gulf of Finland (Poikonen, Madekivi 2005), Gdansk and Bornholm deep (Klusek, Lisimenka 2006). The Klaipėda Strait area has been chosen for the primary survey of underwater noise as an area with increasing man-made activity. Major noise sources contributing to the background noise in the Klaipėda Strait are related to shipping, dredging and vibro-pile driving. The background noise level in the Klaipėda Strait has been found to be higher than that in the Ventė area by 20 dB particularly within 0.025–6 KHz frequency range. The survey sites in the Curonian Lagoon have been chosen according to the man-made activities carried. Site No. 1 is selected as one mostly affected by shipping noise, as all ships in the Klaipėda Strait pass by this survey site, while the Site No. 2 is chosen as the nearest field to dredging activities, which were implemented in the area at the time of the survey, Site No. 3 is chosen as the nearest field to the pile driving activity in the construction site, and the survey sites Nos. 5 and 6 are chosen as mostly unaffected areas in the southern area of the Lithuanian part of the Curonian Lagoon. The sound speed profiling has been completed at the Site No. 4 (Fig. 1).

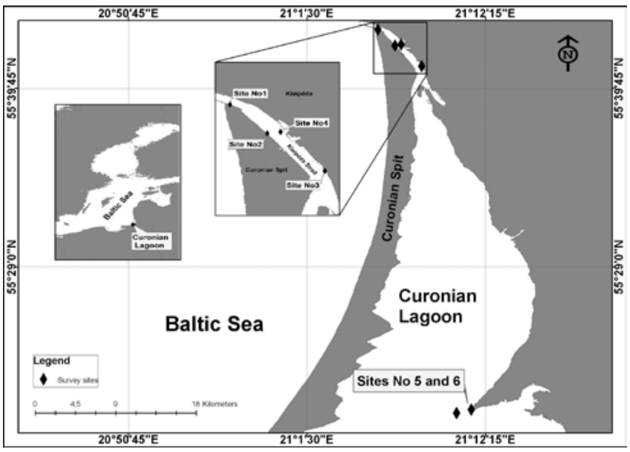

Fig. 1 Location map of Curonian Lagoon, Klaipėda Strait and the survey sites.

MATERIAL AND METHODS

The underwater noise measurements were conducted using H2M cabled hydrophone with the recording device Zoom H1 that has an effective frequency range within 0.01–100 KHz. Recordings were made using different sampling rate due to size of the files: pile driving noise with the sampling rate of 48 KHz, dredging noise with the sampling rate of 44.1 KHz and background noise with the sampling rate of 22.05 KHz. The sound files were analysed using the software packages: WAVELAB7 and MATLAB based *Virtual Sound Level Meter (VSLM)*, which gives the result in graphical and numerical form and can be post processed in MATLAB. VSLM software was calibrated using 74 dB, 1 KHz calibration test tone setting calibration factor to 100 dB as a medium reference level (Withlow, Hastings 2008). Sound pressure levels (LEQ) were computed in band mode using FFT method averaging spectral amplitudes. The spectrogram analysis was performed using Welch Modified Periodogram method for each segment, where periodograms averaged at each frequency to get the estimated power spectral density (PSD) for the entire measurement file using size of 512. The charts were drawn using MATLAB 7.1 and the maps were drawn using ARCGIS 9.3 software. All the measuring in the Klaipėda Strait took place during the daytime at a depth of two-three metres under calm weather conditions (wind speed less than 7 m/s).

The background noise survey at the Site No. 1 was conducted on 30 April and 14 May 2012. The measurements were taken twice using cabled hydrophone submersed to a 2-m depth and lasted for 5 hours each with likewise results. The background noise measurements in the Ventė area were taken on 13 June 2012 in shallow waters at the Site No. 5 with hydrophone depth of 0.5 metre and 16 May 2013 at the Site No. 6 with hydrophone depth of 2 m under windy conditions (wind speed at least 10 m/s) and both lasted for 5 hours. The pile driving noise was measured using cabled hydrophone submersed to 2 m depth on the 28th of May 2012 during the harbour construction works, when the double-T pile was being driven into the Lagoon bottom, by recording from 68 m distance. The dredging underwater noise was measured on the 7th of April and the 14th of May 2012 with two different dredgers operating. A suction dredger of gross tonnage 18.000 t was recorded from the distance of 350 m and a drag dredger of gross tonnage 278 t recorded from the distance of 150 m using cabled hydrophone submersed to 3 m depth in both cases. The measured noise results were tabled using the following units: the sound pressure level (SPL) reference to 1 μPa also equivalent sound level (LEQ) using 1/3 octave bands reference to 1 μPa, power spectral density (PSD) reference to 1 $\mu Pa^2/Hz$ and sound exposure level (SEL) normalised to 1 second reference to $1 \mu Pa^2.s$. Sound exposure level was calculated using formula (Erbe 2010):

$$SEL = SPL+10log_{10}T \quad (1),$$

where SEL is sound exposure level in dB, SPL is sound pressure level in dB; T is time of the sound event in seconds. Transmission losses TL were calculated using formula (Simonds *et al.* 2004):

$$TL = TL_{(spreading)}+TL_{(absorption)}+A \quad (2),$$

where TL is transmission loss in dB, $TL_{(spreading)}$ are effects of spreading losses in dB, $TL_{(absorption)}$ are effects of water absorption in dB, A is transmission loss anomaly in dB.

In our case, losses due to absorption and transmission anomaly were ignored according to measured relevantly low frequency noise, fresh water and short distances, where absorption and transmission anomalies usually are less than 0.001dB/km (Ainslie, McColm 1998). Generally, a simplified transmission loss formula was used taking into consideration that sound in shallow waters propagates twice a distance of an equal sound source in the open ocean (Simonds *et al.* 2004):

$$TL = 20log_{10}(R) \quad (3),$$

where TL is transmission loss in dB, and R is the range of sound propagation in metres.

Comparing the results, the noise levels were back calculated to 1 metre from noise source (@1m) as transmission loss refers to decay of acoustic signal as it travels from a source and can be expressed as:

$$TL = 20\ log_{10}(p_o/p_1) \quad (4),$$

where SPL is a sound pressure level in dB, p_o is a corresponding sound pressure at the distance of 1 meter and p_1 is a corresponding sound pressure at the distant point (Withlow, Hastings 2008).

For comparison, the data from different studies was obtained and tabulated presenting minimum and maximum values over given frequency range (see Table 1). The results obtained in Klaipėda Strait and presented in Fig. 4 have been averaged over spectral amplitudes using FFT method and presented in 1/3 octave as an equivalent level (LEQ).

Measurements and data processing generated certain amount of errors. These relevantly emerged from hydrophone sensitivity error +/- 4dB and transmission loss calculations, which are robust. The rough data obtained from charts were used for comparison of background levels in the different areas. Windy conditions at the survey sites Nos 5 and 6 and very shallow waters with possible echoes generated relevant uncertainties.

The sound speed profile (SSP) was measured in the Klaipėda Strait at the Site No. 4 using multi parameter probe CTD-48. The sound speed measurement results

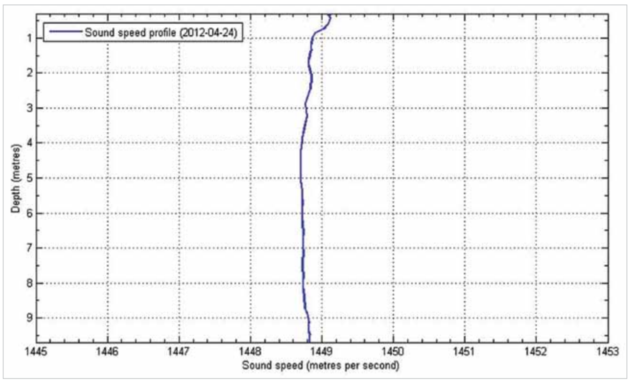

Fig. 2 SSP measured in the Curonian Lagoon.

show a minimum sound speed change from 1448.5 to 1449.1 (m/s) throughout water column, which depends on water temperature, salinity and depth change. In this case (Fig. 2), the sound speed change has almost no impact on sound propagation (Withlow, Hastings 2008).

RESULTS

Background noise level in Klaipėda Strait was measured at the Site No. 1. The survey results show that the average background broadband noise reached 53.2–58.4 dB within 63–125 Hz frequency range in 1/3 octave bands. The maximal broadband sound pressure level (SPL) reached 97.4–106.8 dB level. Having analysed the obtained results, it is clearly seen that the sound pressure level in the Ventė area reached a peak at very low frequencies, particularly at 16–115 Hz, proving that the noise at these frequencies is of natural origin (Fig. 3). Noise levels in the Klaipėda Strait are higher than those in the Ventė area by 19.3–24.3 dB in 500 Hz frequency band (Fig. 4). The difference between the noise levels can be explained by vessels traffic with one ship passing every 0.5–1.5 hour. Noise from one ship of 3000 Gt passing a survey site at a distance of 400 m is shown in the Fig. 3 pane A. The local maximum of one vessel noise constituted LEQ 78.5 dB, while LEQ in undisturbed area constituted 74.21 dB. The local maximum of one vessel SPL in a specific frequency band e.g. 500 Hz reached 66.2 dB, while undisturbed area noise reached 52.0 dB, where difference between one vessel noise and undisturbed area noise reached 14.2 dB. Comparing LEQ between undisturbed area level of 74.21 dB and LEQ at two nearest passages measured as 78 dB, the difference obtained is 3.79 dB. The difference in SPL values in the undisturbed area and the nearest measured two passages in 500 Hz is found to reach 18.6 dB. It implies that every passing vessel through the Klaipėda Strait raises background noise by a certain level.

The actual background noise level (LEQ) in Klaipėda Strait constituted 85.69 dB showing an increase in overall level by 11.48 dB, if compared to that in the undisturbed Ventė area. Comparing the results (Fig. 3), we can conclude that underwater background noise levels depend on shipping density and specific depth as well as weather conditions. As the scientific literature indicates, shipping noise above the frequency band of 500 Hz dissipates in the ocean, and increasing wind lowers the shipping noise (Zakarauskas 1986), though sound propagation in shallow waters is a complex issue (Withlow, Hastings 2008). As measurements in the Klaipėda Strait were taken under calm weather conditions and shallow waters not exceeding 15 m depth, the shipping noise dominated within frequency range of 0.016–6 KHz. The noise levels can be compared with

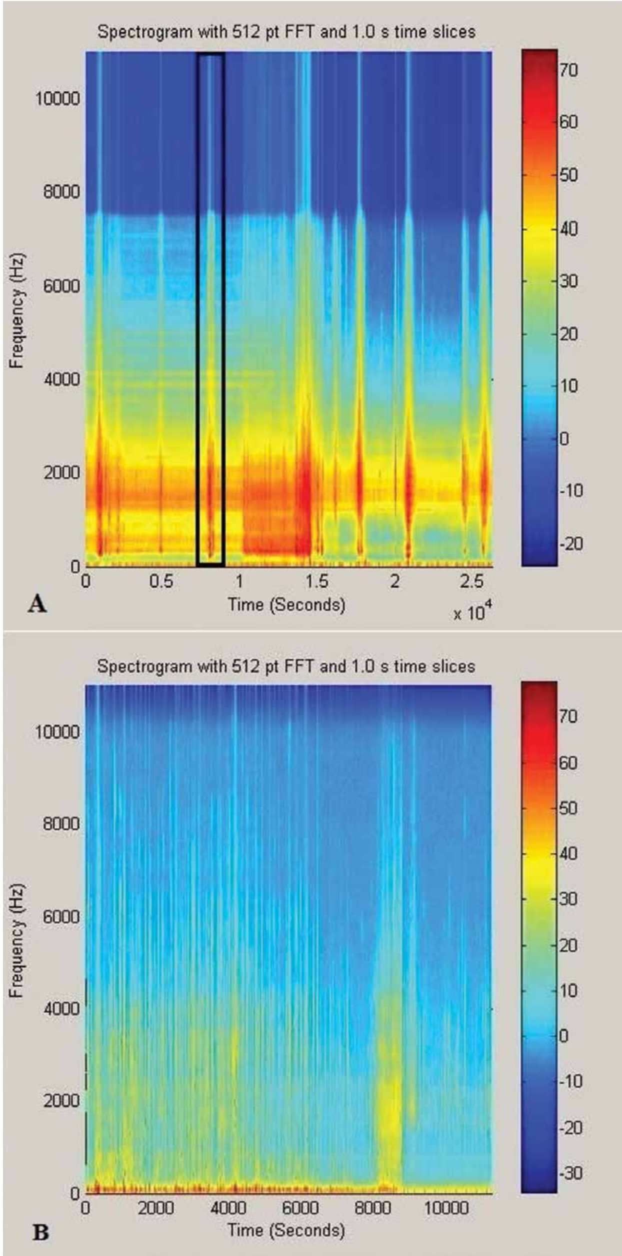

Fig. 3 Examples of different background noise spectra (bar scale PSD dB re 1µPa^2/Hz) for two survey sites: **A** – Site No. 1 with dense shipping traffic (ships every 0.5–1.5 h). Red thin lines indicate broadband shipping noise propagation in 0.016–6 KHz frequency range. Black rectangle in the figure indicates noise generated by a 3000 Gt vessel passing the survey site in a distance of 400 metres. **B** – Site No. 5 at Ventė area with natural noise spectra, where red short lines indicate noise propagation in a 16–115 Hz low frequency range.

the results from other areas. Background SPL measured in the Klaipėda Strait within 0.025–1 KHz frequency range varied between 55.79 dB–77.15 dB, which was relatively lower than the levels in the Danish straits and Stellwagen Bank (Table 1).

Table 1 Comparison of background noise levels in the 0.025–1 KHz frequency range with dense shipping traffic in different areas.

Survey site	Background SPL with a vessel traffic	References
Stellwagen Bank, Atlantic Ocean	73.0 – 100.0 dB	Hatch *et al.* 2008
Arhus Bay, Belt, Baltic Sea	80.5 – 92.0 dB	Mortensen *et al.* 2011
Samsø, Belt, Baltic Sea	79.5 – 101.5 dB	Mortensen *et al.* 2011
Sejerø, Belt, Baltic Sea	89.0 – 108.0 dB	Mortensen *et al.* 2011
Hatter reef, Belt, Baltic Sea	87.5 – 115.0 dB	Mortensen *et al.* 2011
Klaipėda Strait, Baltic Sea	55.79 – 77.15 dB	-

Pile driving noise survey was conducted at the survey site No. 3. The noise recording lasted for 13 min 18 sec. The results of underwater noise recording show that the pile driving noise (SPL) peaked at 140.5 dB in 315 Hz frequency range, though the broadband sound pressure level (SPL) reached its maximum at 154.2 dB showing sound exposure level (SEL) of 183.2 dB. The underwater broadband noise propagating in the pile driving vicinity with the radius of ~290 m reached a broadband sound pressure level (SPL) in this area higher than 100 dB (Table 2).

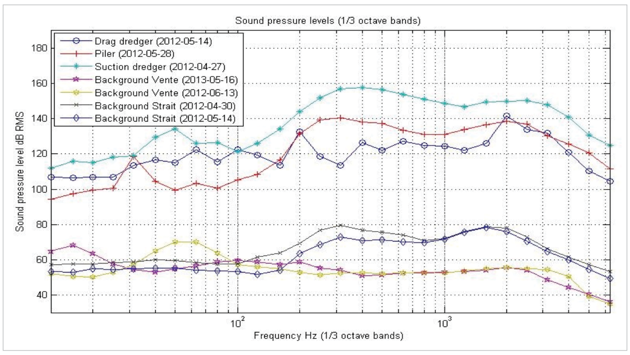

Fig. 4 Underwater noise levels at different study sites. Marks on the curves indicates SPL at centre frequencies of 1/3 octave bands.

Dredging noise survey was conducted at the Site No. 2. The underwater drag dredger noise measurement results show that the sound pressure level (SPL) was 137.49 dB in 500 Hz frequency band, and the highest sound pressure level (SPL) was 141.5 dB at frequency of 2 KHz, while the broadband noise level (SPL) clearly reached 154.9 dB. Therefore, underwater broadband noise propagated in the drag dredger vicinity with a radius of ~315 metres reaching a sound pressure level higher than 100 dB. The underwater suction dredger noise measurement results (Fig. 4) show that the noise sound pressure level (SPL) was 156.69 dB re 1µPa at relatively low 500 Hz frequency band. The highest sound pressure level was in 200–800 Hz frequency range, while broadband noise (SPL) reached 166.2 dB. Thus, the underwater broadband noise propagating in the suction dredger vicinity with a radius of ~1150 m reached a broadband sound pressure level (SPL) higher than 100 dB along the propagation distance.

DISCUSSION

The aim of this underwater noise survey was to present methods and results of the first attempt to measure underwater noise levels. The survey showed that background noise equivalent level (LEQ) at the Site No.1 (where the densest shipping takes place in the

Table 2 Underwater noise levels in the Klaipėda Strait and the Ventė area (ref @1 m back calculated).

Noise source	LEQ actual	SPL max broadband	SPL at 500Hz	SEL	Broadband omnidirectional noise propagation distance R, with levels higher than 100dB along the distance
Ventė background 2013-05-16	73.1 dB	90.0 dB	51.3 dB	-	-
Ventė background 2012-06-13	75.1 dB	94.9 dB	52.0 dB	-	-
Strait background 2012-04-30	86.9 dB	106.8 dB	75.6 dB	-	-
Strait background 2012-05-14	84.0 dB	97.4 dB	71.3 dB	-	-
Vibro-piler @1 m	147.7 dB	154.2 dB	137.99 dB	183.2 dB	290 m
Drag dredger @1m	143.7 dB	154.9 dB	157.89 dB	-	315 m
Suction dredger @1m	164.1 dB	166.2 dB	126.53 dB	-	1150 m

Strait) reached 85.69 dB exceeding the overall level by 11.48 dB, if compared to that in undisturbed Ventė area. This difference in specific frequency bands is relatively higher, e.g. noise levels in the Klaipėda Strait are higher than in the Ventė area by 19.3–24.3 dB in the 500 Hz frequency band. The local noise level maximum of a passing vessel showed that every passing vessel increased the overall broadband noise level. Comparing Klaipėda Strait background noise levels with the levels in other locations (see Table 1), the levels measured at the Site No.1 seem to be lower. Relative levels can be explained by shipping density in these areas. Other man-made activities such as pile driving and dredging generated relatively high noise levels in the vicinity of noise sources with noise propagation to the distances of 290–1150 metres. The highest SPL values during dredging activities have been found in case of suction dredger used, i.e. maximum broadband SPL reached 166.2 dB@1m, while vibro piling sound exposure levels (SEL) reached even more – 183.2 dB@1m.

The elevated underwater noise levels can disturb aquatic animals. Usually 20 fish species are normally found in the Curonian Lagoon basin, though sometimes up to 38 species have been observed (Repečka 2003; Lapinskienė *et al.* 2002; L. Ložys, pers. comm. 2012). Scientific papers show that hearing sensitivity has been determined for the majority of common migrating fish species found in the Curonian Lagoon, though hearing thresholds have so far been identified only for salmon (*Salmo salar*) that has the lowest hearing threshold (sounds audible above) 112 dB at 100 Hz, for sea trout (*Salmo trutta*) that has the lowest hearing threshold 100 dB at 100 Hz, for perch (*Perca fluviatilis*) that has the lowest hearing threshold 93.5 dB at 90 Hz and Baltic herring (*Clupea harengus)* 75 dB at 100 Hz (Nedwell *et al.* 2004; Nedwell *et al.* 2003). According to the Nedwell's proposed criterion for noise induced reactions of fish (Nedwell *et al.* 2007), the four local species with described hearing thresholds would demonstrate behavioural reactions from stronger ones to mild reactions or no reactions in the fish schools in the near field of noise sources though the noise would be audible for all four species in the described distances, where broadband sound pressure level (SPL) was above 100-112 dB. In addition, it should be mentioned that all fish are able to detect sounds within the frequency range of the most widely occurring anthropogenic sounds (Popper 2003). The fact that a fish can detect a sound does not necessarily mean that it will react to that sound. In many species, a certain sound pressure level needs to be reached before the behaviour is affected, and some fish species do not show startle responses to sounds no matter how loud they are (Kastelein *et al.* 2008). For instance, rainbow trout (*Salmo trutta*) do not show any behavioural reactions in a presence of a vibro-pile driver noise even at a close distance of about 50 m from a noise source (Nedwell *et al.* 2003). However some scientific papers suggest that the fish species such as perch (*Perca fluviatilis*), carp (*Cyprinus carpio*), sea bass (*Dicentrarchus labrax*) and others due to anthropogenic continuous or impulsive noise experience elevated levels of cortisol hormone in blood, which is a primary indicator of stress response regardless their hearing sensitivities (Wysocki *et al.* 2006, Santully *et al.* 1999).

CONCLUSIONS

The very first attempt to measure underwater noise levels in the Klaipėda Strait has been made. The sound speed profiling done shows almost uniform distribution of sound speed over water column making an ideal condition for sound propagation. Noise measurements show that background underwater noise levels in the Klaipėda Strait are relatively higher as compared to those in the southern part of the Curonian Lagoon in Ventė area. Separate man-made activities such as pile driving, and dredging generates high underwater noise levels in the Klaipėda Strait area, which likely disturbs local fish species in the near vicinity of noise sources. Rough calculations of sound propagation show that sound from man-made activities like dredging activities can propagate as far as in the radius of more than thousand metres having broadband sound pressure levels higher than a hundred decibels.

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