ACOUSTIC BACKSCATTERING CHARACTERISTICS OF *MYTILUS EDULIS TROSSULUS* (SOUTHERN BALTIC SEA)

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Study of benthic habitats is significant from ecological and economical point of view. Non–invasive, rapid and relatively cheap methods of the habitat classification are required. It is the reason why the hydroacoustic classification techniques are developed. These techniques are sensitive to the seabed sediments type and the backscattering properties of the benthic habitats, and are developed for individual marine conditions.

Last few years the hydroacoustic classification algorithms are developed for the Southern Baltic Sea. To improve the algorithms it is required to know the backscattering properties of the typical benthic individual and aggregated organisms. The main objective of the article is the study of the backscattering characteristics of benthic shelled animals Mytilus edulis trossulus, which is one of the dominant species in the southern Baltic Sea. The approach is based on the numerical modelling of the acoustic wave backscattering by the individual organisms and their aggregations and comparison of the modelling results with the measured backscattered data.

INTRODUCTION

The benthic habitats play a key role in the southern Baltic ecosystem. The methods of the non–invasive, rapid and relatively cheap monitoring of the benthic habitats are required. The hydroacoustic techniques satisfy these criteria.

The acoustic algorithms of the benthic habitat classification are developed in the Polish Economic Zone (Faghani *et al*., 2004, Tęgowski *et al*., 2003, Klusek *et al*., 2003). In order of the further improvement of the algorithms, the information of the scattering characteristics of individual and aggregated benthic organisms is required.

The acoustic characteristics of individual organisms have been studied basing on the numerical modelling (Stanton, 2000, Shenderov, 1998) and the *ex situ* measurements (Gavrilov and Pestricov, 1992). In this paper, the mathematic model to describe the scattering of the acoustic wave by individual and aggregated benthic shelled animals *Mytilus edulis trossulus* is presented.

The numerical modelling is performed in order to understand the impact of the shell morphometry and the length distribution of the *Mytilus edulis trossulus* individuals. The biological data collected in the study area near Rowy (southern Baltic Sea) in the frame of the project financed by Polish Government and titled: *Development of hydroacoustic techniques for study of benthic habitats of Southern Baltic Sea (study area: Rowy)* (Gorska, 2009) were used as the input data in the numerical modelling. The modelling results have been verified using the hydroacoustic data collected by the single beam BioSonics echosounder at the frequency 420 kHz.

1. MATERIALS AND METHODS

1.1 MAIN MODEL ASSUMPTIONS

To study the backscattering of the acoustic waves by benthic shelled animal *Mytilus edulis trossulus* in the Southern Baltic Sea, the numerical model (Stanton, 2000) was adopted. This model accounted for that:

a) scattering by the shell-covered bottom is modelled using only volume scattering considerations
b) the layer is dense enough so that it dominates the scattering
c) the multiple scattering within the layer is not considered
d) the shape of the individual shell is close to spherical and the backscattering by *Mytilus edulis trossulus* individuals is described like the backscattering by the sphere of the same volume with the radius:

$$a_{esr} = \frac{1}{2} l \sqrt[3]{\delta^2} \tag{1}$$

where l is length of the shelled individual, δ is the ratio of the individual width to the length

e) high-frequency acoustics (i.e., geometric optics) approximation is satisfied for the backscattering by the single target: $ka_{esr}>>1$, and the phases from the individual scatterers are randomly and uniformly distributed over the range from 0 to 360 degrees

The applicability of the approximations in the southern Baltic Sea conditions has been demonstrated accounting for the size diversity of the *Mytilus edulis trossulus* individuals and their morphometric features.

1.2 MODEL EQUATIONS

Accounting for that the aggregated animals differ by their size, the mean backscattering cross-section can be expressed as:

$$<\sigma_{bs}> = \int_{l_{\min}}^{l_{\max}} w(l)\sigma_{bs} dl \tag{2}$$

where σ_{bs} is the backscattering cross-section of *Mytilus edulis trossulus* individual, $w(l)$ is the length distribution of the individuals, the target length varies in the range from l_{min} to l_{max}. It can be shown that $w(l)$ can be described as:

$$w_i(l) = \frac{P_i}{l_{\max i} - l_{\min i}}$$

$$(3)$$

where *i=1,2,3* is the length class number corresponding respectively to the smaller, medium and larger size animals respectively. We consider three length classes as it is presented below in the Section 1.3. Here $l_{min\ i}$ and $l_{max\ i}$ are the minimum and maximum length of the benthic shelled animals in the *i*–size class and the function P_i is the probability that the individual is within the class.

Using the approximations, discussed in the Section 1.1, the equation for the individual backscattering cross-section can be presented as:

$$\sigma_{bs} = \frac{1}{16}\delta^{\left(\frac{4}{3}\right)} R_{12}{}^2 l^2 \tag{4}$$

where R_{12} is the reflection coefficient $R_{12} = (gh - 1) / (gh + 1)$, where g and h are the mass density and sound speed contrasts of the target biological tissue, respectively (the mass density and sound speed normalized by the corresponding quantities for the surrounding water). This term represents the echo from the front interface which makes up much of the total echo (Stanton, 2000).

Basing on the Eqs. (2) and (3) the mean backscattering cross-section for the *i*-th length class of the benthic shelled animals can be defined by:

$$< \sigma_{bs} >_i = \frac{1}{48}\delta^{\left(\frac{4}{3}\right)} R_{12}{}^2 P_i (l_{\max i}{}^2 + l_{\max i} l_{\min i} + l_{\min i}{}^2) \tag{5}$$

The target strength can be expressed as:

$$TS_i = 10\log(< \sigma_{bs} >_i) \tag{6}$$

The area scattering strength S_A is equal to:

$$S_A = 10\log(s_a) \tag{7}$$

where s_a is the area scattering coefficient, which depends on the shelled individual density N_i for the *i*-size class and the mean backscattering cross-section $< \sigma_{bs} >_{\mathrm{i}}$ (Eq. (5). It can be presented as:

$$s_a = \sum_{i=1}^{3} N_i < \sigma_{bs} >_i \tag{8}$$

1.3 INPUT DATA FOR THE MODELLING.

The main objective of the project *Development of hydroacoustic techniques for study of benthic habitats of southern Baltic Sea (study area: Rowy)*, financed by Polish Government, was the development of the acoustic techniques of the benthic habitat classification in the southern Baltic Sea. The acoustic, biological and positional data were collected in July 2008 on board of the research vessel IMOR, operated by the Maritime Institute in Gdańsk. The study area is characterized by the benthic habitat diversity. The aggregations of the *Mytilus edulis trossulus* covering the large stones represent one of them. The detailed study was carried out at eight chosen stations, differing in the bathymetry and benthic habitat type.

The analysis of the collected biological material enabled to determine the morphometry proportions of *Mytilus edulis trossulus* individuals and their length distribution, the areal density of the benthic animals and the packing factor (the fraction of seafloor covered by the objects).

The length-frequency histogram of the *Mytilus edulis trossulus* individuals is shown in Fig.1. Three main individual size classes were considered: the benthic shelled animals smaller than the 10mm length (black bars in the figure), the individuals of the length within the range from 10 mm to 30 mm (grey bars) and the individuals of the length larger than 30 mm (white bars) (Gorska, 2009).

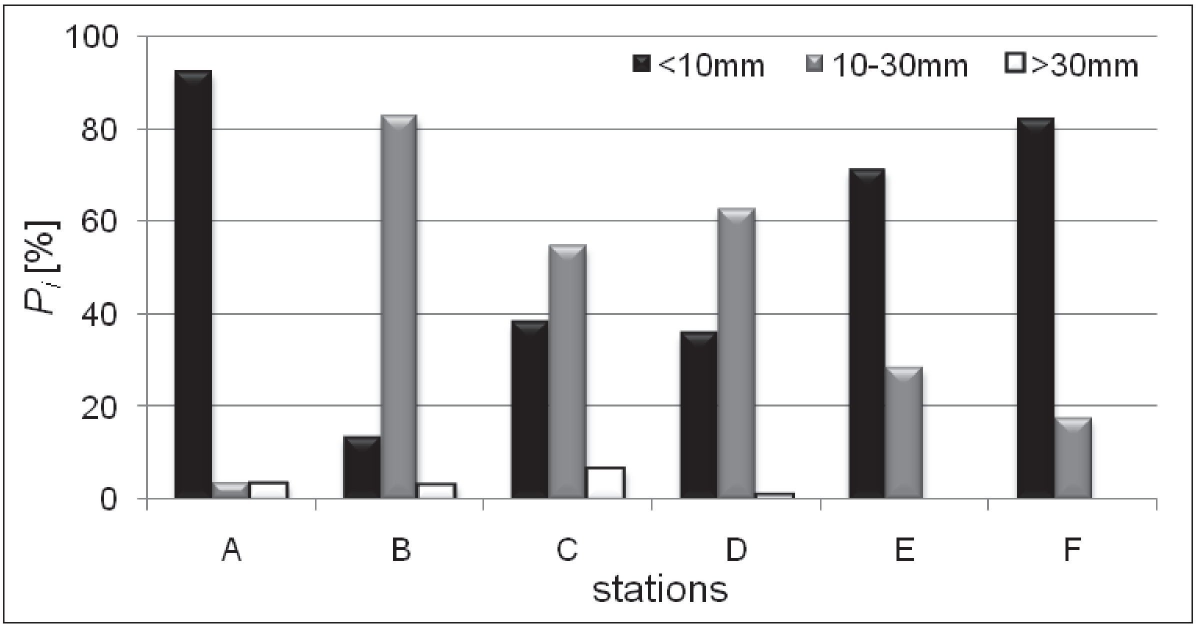

Fig.1. The length-frequency histogram of the *Mytilus edulis trossulus* individuals at the chosen stations.

The biological analysis indicated that: the characteristic ratio of the individual width to the length and the ratio of the individual height to the length are equal to 0.5±0.07 and 0.4±0.02 respectively (Gorska, 2009). The packing factor varies from 90% to 100% and the mean thickness of the benthic shelled animal coverage was approximately 20 mm (Gorska, 2009).

The presented biological data were used as the input data in the modelling of acoustic wave backscattering by the *Mytilus edulis trossulus* individuals.

1.4 PROCESSING OF HYDROACOUSTIC DATA

Hydroacoustic data were collected using down-looking 420 kHz BioSonics DT–X 42000 single-beam echosounder at the chosen stations marked as A, B, C, D, E, and F. Then the data were processed using the MATLAB, ArcGIS and specialized VBT software. The pre-processing included the conversion of the collected raw data (dg8 file format) to the data in the format convenient for the further signal processing, excluding the noisy pulses, and the exclusion of the negative vessel sway impact. The area scattering strength S_A (Eq. 7) was calculated for the finally selected pings at the stations.

2. RESULTS AND DISCUSSION

2.1 THE LENGTH DISTRIBUTION OF THE *MYTILUS EDULIS TROSSULUS* INDIVIDUALS

The length distribution of the individuals *w(l)* at the different study stations are presented in Fig. 2. The figure was obtained using the Eq. 3 and the results presented in Fig. 1 for the probability P_i. Similar to the legend of Fig. 1, black, grey and white bars in the figure correspond respectively to the benthic animals smaller than 10 mm length, individuals of length within the range from 10 mm to 30 mm and individuals of the length larger than 30 mm.

The figure demonstrates that the small size class animals are dominant at the stations A, C, D, E and F. The medium size class shelled animals prevails at the station B.

The middle size class individuals are presented at all stations excluding the station marked by A. At this station the small size class was especially numerous.

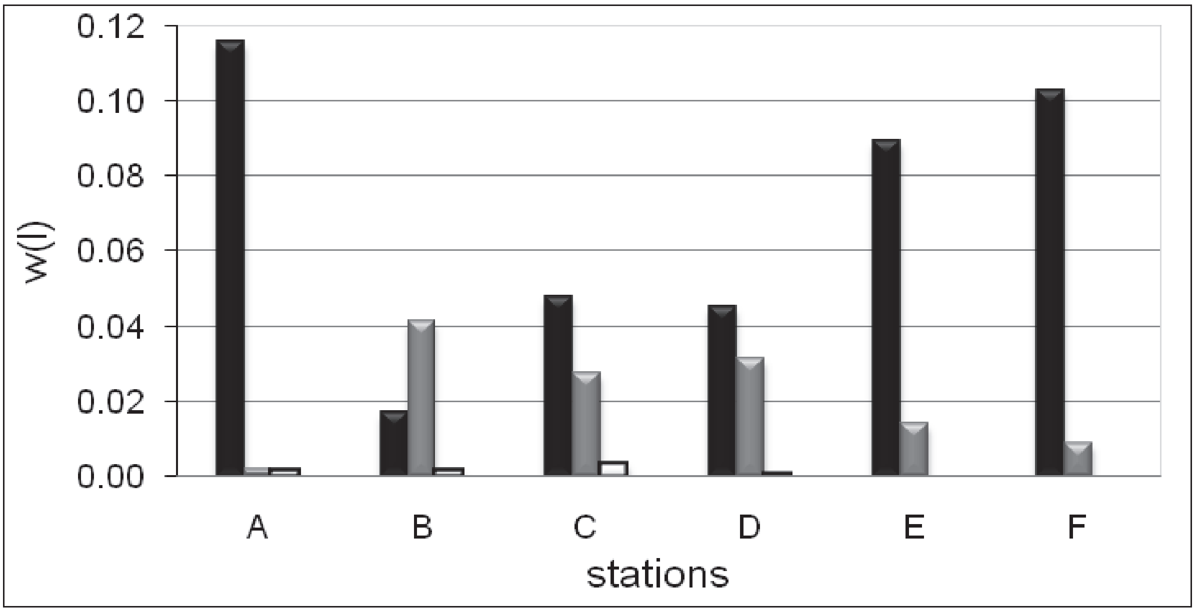

Fig.2. The length distribution of the individuals *w(l)* at the different stations.

2.2 THE MODELLING DEPENDENCIES

The Eq. 5 demonstrates that the mean backscattering cross-section depends on the shape of the shelled individual (on the morphometric proportion parameter δ) and the acoustic properties of the tissue (the reflection coefficient R_{12}). The mean backscattering cross-section $<\sigma_{bs}>_i$ increases with the increase of the parameters δ and R_{12}.

The variation range of the target strength *TS* of the different size classes at the different stations is shown in Fig. 3. The calculations were performed for the acoustic frequency 420 kHz; the reflection coefficient R_{12} varies from 0.6 to 1, the values of the parameter δ, presented in the Section 1.3 and the individual length distribution presented in Fig. 2. The Eqs. 5 and 6 were used. The lowest and highest TS values for each size class correspond respectively to the smallest and the largest considered values of the both parameters δ and. R_{12}. The labels on the horizontal axis of the plot "small", "middle" and "large" mean that the presented results are obtained for the small- , middle- and the large length classes respectively.

Two parameters govern the mean backscattering cross-section (Eq. 5) and the respective target strength (Eq. 6) for the selected size class. The first one is the not-averaged cross-section of the individuals, which is larger for the larger size class individuals, and the second is the animal abundance in the selected size class. They defined the TS variation range for the different length classes. The calculations demonstrated that the lowest TS were observed for the small size class individuals because of the smaller not averaged cross-section of the individuals in this class. The values for the medium size class are higher. It is noted at the all stations excluding the station marked by A. The reason is that the smallest shells significantly dominate at the station A. It is interesting to note that the TS values for the largest shelled animals, the not-averaged backscattering cross-section of which is significant, are not the highest due to the relatively small abundance within this size class.

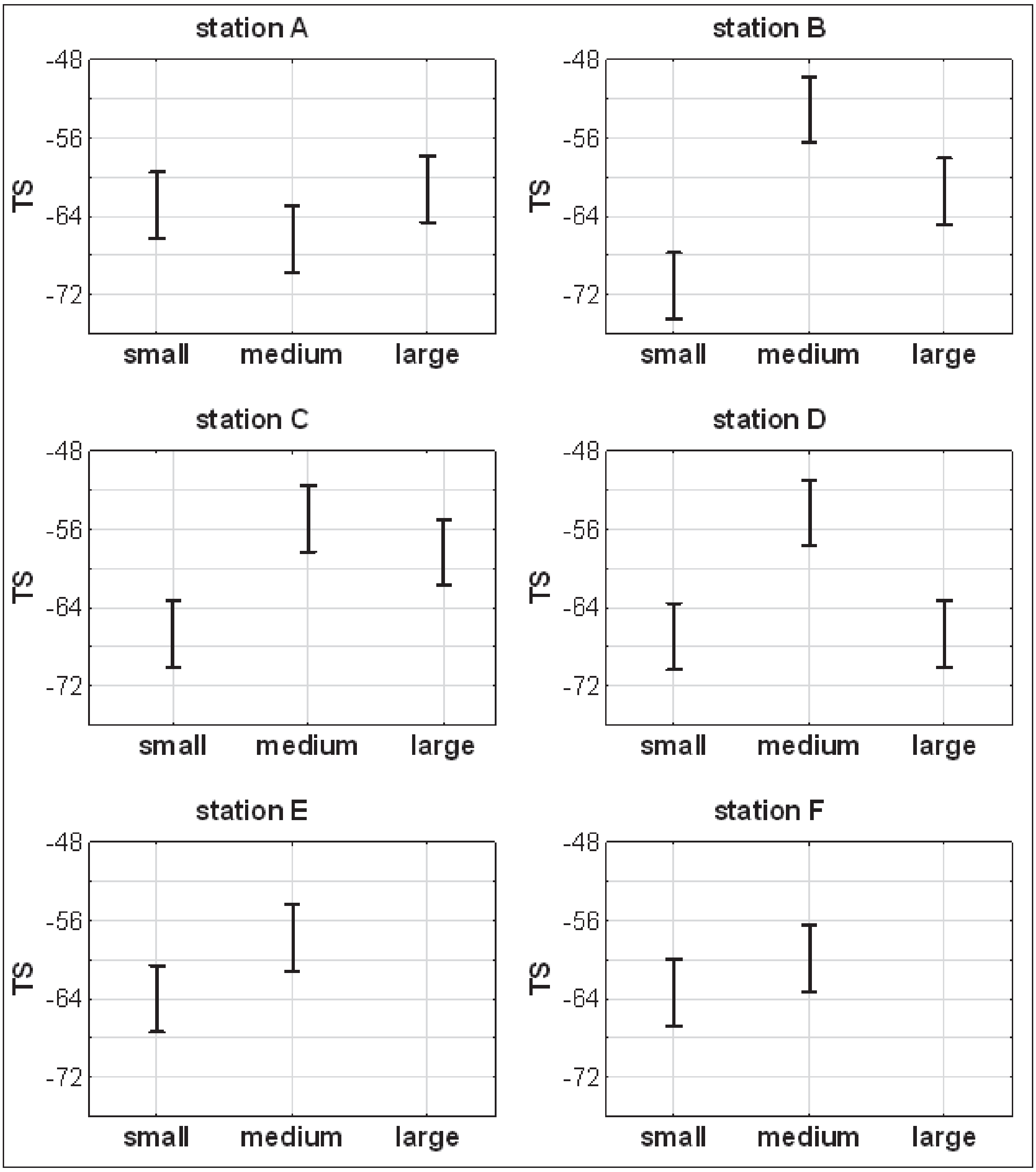

Fig.3. Target strength TS for the different length classes of *Mytilus edulis trossulus* individuals.

2.3 THE MODEL VERIFICATION

The verification of the used model describing the acoustic wave backscattering by the *Mytilus edulis trossulus* individuals was performed. The verification was based on the comparison of the obtained modelling results with the results of the analysis of the collected backscattering data (Section 1.4). The comparison is presented in Fig.4. The measurements are indicated by diamonds. Two black curves and the marked domain between them refer to the calculations. The figure is drawn for the same calculation parameters as Figure 3. The Eqs. 7 and 8 were employed. The values of the areal density N_i were obtained accounting for the length-frequency histogram of the *Mytilus edulis trossulus* individuals (Fig. 1) and the areal density data, obtained in the project mentioned in the Section 1.

The comparison demonstrates that the area scattering strengths S_A are lower for the measurements than for the numerical modelling. The differences between the results obtained by these two ways may be partially explained by the backscattering model limitations.

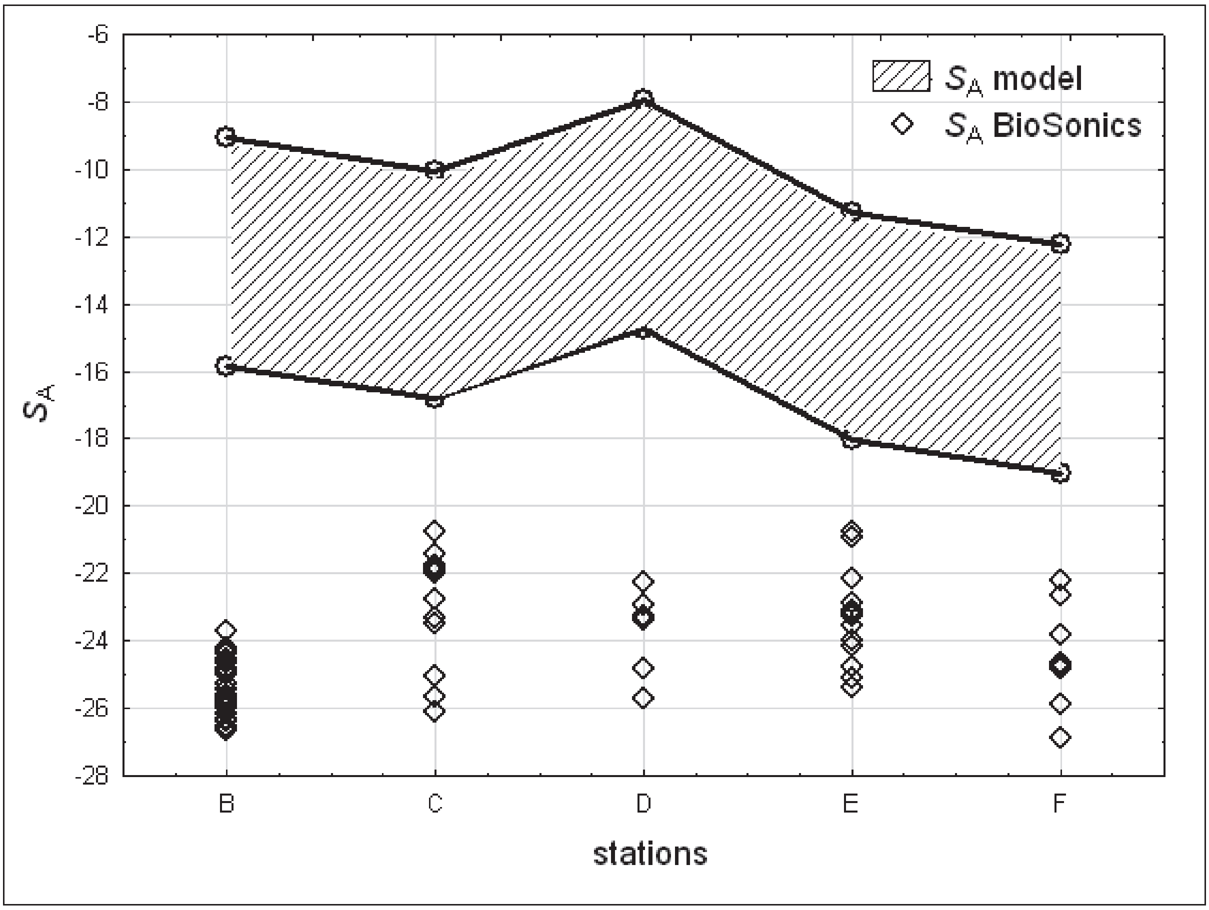

Fig.4. The model verification. The comparison of the obtained modelling results with the results of the analysis of the collected backscattering data.

3. CONCLUSIONS

The numerical modelling has been conducted in order to better understand the backscattering properties of the *Mytilus edulis trossulus* representative for the southern Baltic benthic habitats. The model developed by Stanton (2000) was adopted for the southern Baltic conditions. The biological data collected in the study area near Rowy (southern Baltic Sea) in the frame of the project financed by Polish Government entitled: *Development of hydroacoustic techniques for study of benthic habitats of Southern Baltic Sea (study area: Rowy)* (Gorska, 2009) were used as the input data in the numerical modelling. The impact of the shell morphometry and the length distribution of the *Mytilus edulis trossulus* individuals on the mean backscattering characteristics were demonstrated. The modelling results have been verified using the hydroacoustic data collected by the single beam BioSonics echosounder at the frequency 420 kHz.

Comparison of the numerical modelling and data analysis results showed that the values of the parameter S_A from the numerical modelling are higher than hydroacoustic measurement about 3 dB to 7.5 dB. It is probably result of the modelling approximations. The further improvement of the numerical model is recommended.

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