ACOUSTIC CLASSIFICATION OF SOUTHERN BALTIC BENTHIC HABITAT

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Seabed characteristics applied for classification was based on analysis of echo recordings collected aboard RV "Baltica" during regular surveys in 1995-2003 period. Hypothetical effective angle of a bottom echo $\theta'/2$, corresponding to its normalized length was applied to characterize complex seabed acoustic reflecting and scattering properties. The $\theta'/2$ values were determined for each EDSU. Classification of southern Baltic area was provided by comparison of two acoustically measured factors: statistical distribution of $\theta'/2$ and correlated depth structure within selected standard areas. Both factors are very closely related to biological characteristics of the benthic habitat. Joining them gives a wide possibility of differentiating the habitat by its basic ecological properties. The classification applied gave a unique identification and comparison of dynamics of seabed structures, useful for benthic surveys and helpful in ecologically friendly administration of the zone.

INTRODUCTION

Benthic habitat is formed by seabed structure, hydrologic dynamics of the water column, and influence of light from the surface. All these elements have a fundamental influence on the benthos character [2]. Benthic habitat is strongly influenced by environmental and anthropogenic factors. Its state directly reflects the quality of the marine ecosystem. More detail information was given in [1, 6, 7, 9, 12, 13, 14, 15, 17, 19].

Acoustic methods are very effective to recognize sea depth and seabed structure. They were applied in the Baltic sea for bottom classification since early seventies [11, 12, 8, 17]. In 2005 the author [16] introduced a new method applying acoustic information to distinguish seabed structure. The classification was provided by simple algorithm, based on normalized bottom echo length. The measurements were based on acoustic bottom recordings collected during series of cruises (1995-2003). Results of those surveys, spatial statistical distributions of hypothetical effective angle of a bottom echo ($\theta'/2$) and bottom depth structure were used to provide two parameter classification of the bottom habitat in the southern Baltic.

1. MATERIAL AND METHODS

1.1. ACOUSTIC TRANSECTS

Systematic acoustic surveys of the Polish EEZ started in 1989 as the part of the ICES autumn international survey programme. The recording of samples 24 hours a day for each nautical mile distance unit (Elementary Standard Distance Unit - ESDU), in computerized database started aboard RV "Baltica" in 1994. An EK400 echosounder and a QD echo-integrating system and bespoke software were used. In 1998 an EY500 scientific system was introduced to meet international standards of acoustic measurements and allow the research to continue. The bottom detection minimum level was –60 dB (re EY500 standards). This level was giving a stable bottom echo detection within the whole area of research. The bottom depth in the area was not exceeding 100m and due to indications described in [10] the circumstances of collecting data were comfortable enough.

Both mentioned systems were using a frequency of 38 kHz and the same hull-mounted transducer of 7.2˚x8.0˚. Calibration took place with a standard target in the Swedish fjords in 1994-97 and in the Norwegian fjords in the period 1998-2004. The cruises were carried out in October and lasted two to three weeks so that samples were collected over a distance of between 1000 and 1500 nmi.

The survey tracks of all cruises followed mostly the same grid to give higher comparability of measurements. A schematic chart of transects over the period 1995 to 2004, expressed by positions of ESDU ends is shown in Fig.1.

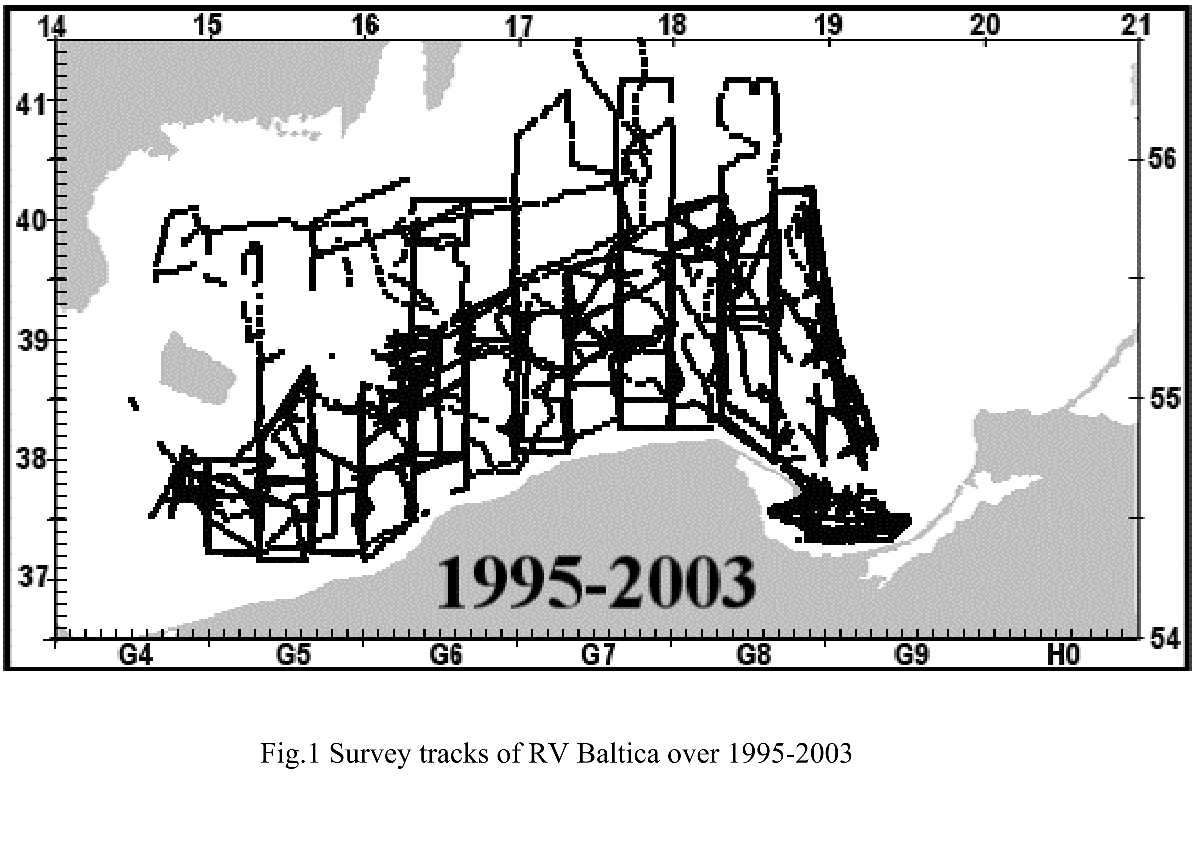

Fig.1 Survey tracks of RV Baltica over 1995-2003

1.2. HYDROLOGICAL BACKGROUND

Hydrologic measurements (temperature-T, salinity-S, and oxygen level-O_2) were made by a Neil-Brown CTD system with spatial density of one station per approximately 35 square nautical miles. Each hydrological station (in total 277) was characterized by geographical position and values of measured parameters in 2m depth intervals.

1.3. ACOUSTIC SEABED PARAMETERS

Seabed was described by two parameters by values collected for each nautical mile: bottom depth and Θ'/2 factor (8139 mile samples collected during 1995-2003 period).
The method of estimating Θ'/2 factor was introduced by the author in [16]. Previously the author introduced application of multiple echoes measurements for evaluation the seabed [11]. Numerous methods based on acoustic measurements intend to provide description of the seabed properties [1, 3, 4, 5, 11, 17, 19]. The main intention of the method is to simplify classification procedure primarily by limiting the output to one-parameter values.

Signal reflected from seabed is characterized by the amplitude and the time duration. Time duration of the bottom echo τ_s is dependent on components resulting from pulse length, beam angle, scattering from the bottom and from reflections below the water-bottom interface.
Measurements of τ_s were related to stabilized sensitivity of the system, expressed by calibrated S_v threshold (-64 dB was applied in this studies). Systems can be easy inter-calibrated by finding the correlation between values measured for the same geographical elementary units.

Value of τ_s depends on all mentioned components and increases with depth due to spherical spreading of acoustic wave. Application of τ_s for characterizing the seabed demands normalization of its value against the depth. The value of Θ'/2 angle was applied as one-dimensional parameter describing complex properties of the seabed and fulfilling the condition of normalization of τ_s against the bottom depth:

$$\Theta'/2 = \arccos\left(1 + c(\tau_s - \tau_1)/d\right)^{-1} \qquad (2)$$

where: Θ'/2 – parameter characterizing acoustic seabed properties,
τ_s - superposition of all seabed echo time components,
τ_1 - component dependent on pulse length,
c - sound speed,
d - bottom depth.

The distribution of Θ'/2 values represents superposition of two separate sub-types of seabed categories. When the bottom is not layered echo duration is mostly related to the transducer beamwidth and scattering properties of the bottom. The output Θ'/2 range is much narrow (13.4-26.0°) and the average is the lowest (18.97°).

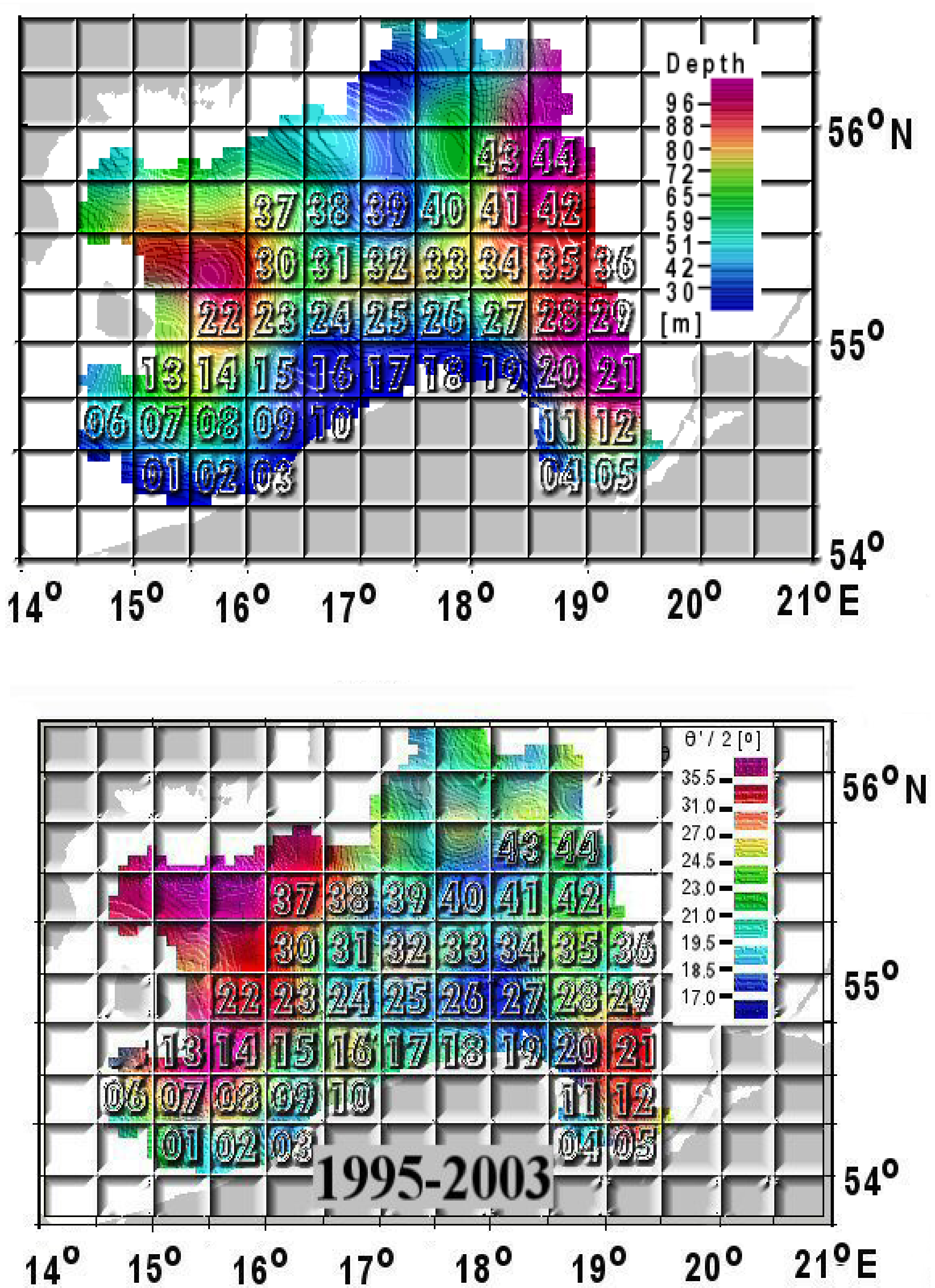

Fig.2 Charts of both parameters: bottom depth and Θ'/2 values, evaluated from data collected. Division of the analysed area into standard rectangles 01-44

For layered bottom (sediments acumulation zones), the average Θ’/2 value is 31.57 º, and the range 23.20 – 38.80º (5-95% of cumulative distribution).

1.4. CLASSIFICATION METHOD

The sub-area, characterized by higher density of sampling was selected from data collected in the southern Baltic in 1995-2003 period. This area was divided into 44 standard rectangles of 30’ longitude (17.2nmi or 31.8km) and 15’ of the latitude (15 nmi or 27.7km). Each of rectangles was characterized by approximately 200 units of Θ’/2 and depth measurements, estimated for each ESDU. For each rectangle two basic characteristics were found: a statistical distribution of Θ’/2 values and average values of bottom depths within each interval of Θ’/2.
The idea of classification was based on hypothesis that both parameters play an important role in forming physical, chemical, and morphological conditions of the bottom habitat. The parameter Θ’/2 can be correlated with a type of bottom surface morphology (scattering properties) and under bottom layers structures, reflecting cumulative character of the seabed. Depth structure of the rectangle, correlated to Θ’/2 values, describes other properties as relation to light intensity, salinity, and oxygen level. All those factors are spatially variable in the southern Baltic and significantly correlated to sea depth and geographical position. Figure 3. gives mentioned characteristics of both factors calculated for the whole southern Baltic (00) and for two strongly differentiated rectangles 24 and 20.

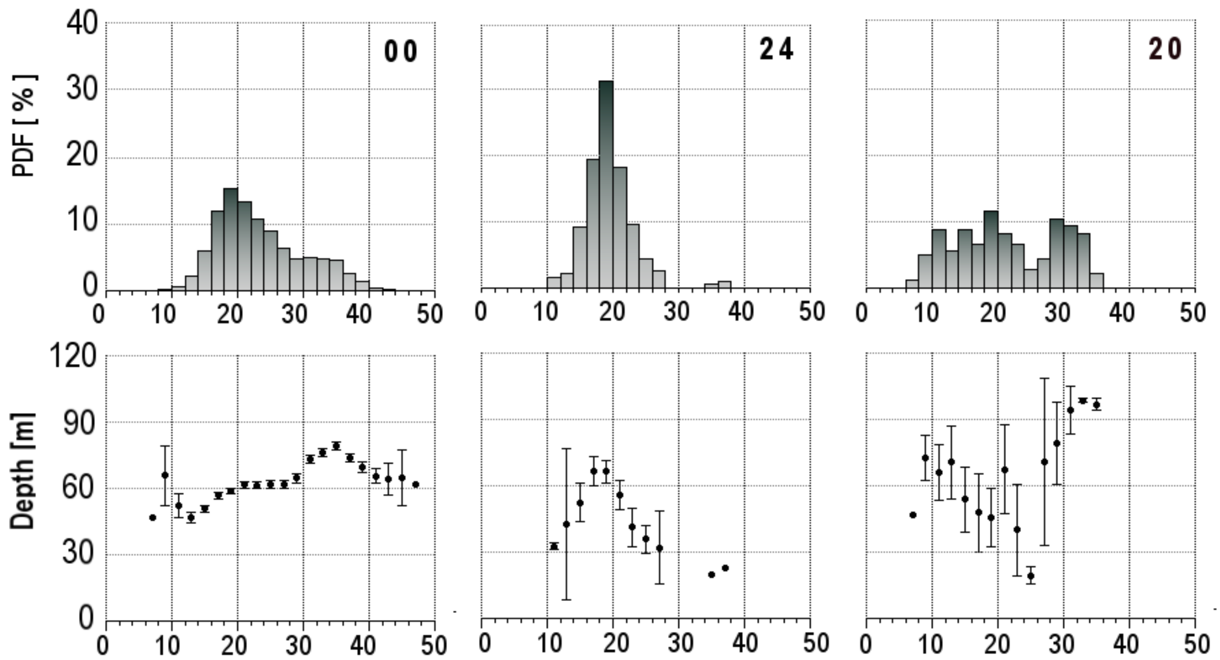

Fig.3 Examples of PDF distributions of Θ’/2 and average depths for each statistical intervals for the whole southern Baltic (00) and two characteristic rectangles 24 and 20 (see Fig.2)

The value of euklides distance Wp was calculated by the universal formula:

$$Wp_{1-2} = \frac{1}{n}\sqrt{\sum_{i=1}^{n}(x_{1i} - x_{2i})^2}$$

where:

- n - number of elements of 1 and 2 class (aggregation),
- Wp_{1-2} - euklides distance between aggregation 1 and 2,
- x_{1i}, x_{2i} - elements of aggregation 1 and 2.

The euklides distance was applied as the likeness factor of tested aggregations (singular rectangles). Its low value expresses high similarity of parameter analyzed and *vice versa*. The analyses were made for Θ'/2 and average depths for each Θ'/2 classes of 2°. The calculations were made for the whole southern Baltic and 44 standard rectangles. In total 1990 combinations of pairs, for each factor were calculated and normalized in relation to the average of values for all 45 areas (whole southern Baltic and 44 standard rectangles). Wp normalized values for Θ'/2 were expressed as $W_{\Theta i\text{-}j}$ and for adequate bottom depth structure were expressed as $W_{di\text{-}j}$. The lengths of vectors $R_{i\text{-}j}$, being built on components corresponding to $W_{\Theta i\text{-}j}$ and $W_{di\text{-}j}$, were calculated. Following complementary characteristic elements were also estimated for each analyzed rectangle:

- average, standard deviation and confidence intervals, and quartiles of cumulative distribution of $W_{\Theta i\text{-}j}$ and $W_{di\text{-}j}$, Θ'/2, and bottom depth,
- average and standard deviation of $R_{i\text{-}j}$, against the remain rectangles.

2. RESULTS AN DISCUSSION

First application of the method applied for acoustic classification of seabed was described by Orlowski and Kujawa in [16]. In the analysis suggested in this paper for classification two basic parameters Θ'/2 and average depths for each Θ'/2 classes are taken into consideration. Both parameters and their statistical characteristics differentiate all selected standard rectangles. The charts of both parameters are shown in Figure.2. Bathymetric pattern of the area (upper panel) is characterized by existing of two main basins: Bornholm Basin at the West, and Gdansk Basin on the East. They are connected in the deepest area by Slupsk Furrow. Distribution of Θ'/2 values is given in a lower panel of Fig.2. The charts indicate similarity and differences of both dynamic structures, what gives a good base to enhance classification range by application of both parameters simultaneously.

In Figure 3 are given examples of three characteristics of selected areas of the southern Baltic. The first area (00) corresponds to the whole southern Baltic, the second (24) – north vicinity of Slupsk Bank and (20) - western gradient of Gdansk Deep. Characteristics represent average relation between Θ'/2 and bottom depth.

00 – Average Θ'/2 = 23.51°, standard deviation 6.56º, range (25%-75% of cumulative distribution) 9.14°. The distribution of Θ'/2 indicate existing of two basic modes, while the lower range is caused by surface scattering of seabed, and the upper by vertical scattering within seabed layers. Pattern of average depths for each Θ'/2 classes is locally differentiated in trends, what gives better source for differentiating single statistical rectangles.

24 – Average Θ’/2 = 19.51° , standard deviation 3.73º, range 4.01°. Only first mode of Θ’/2 distribution is noticed in this rectangle. The most numerous class is very well correlated to maximum of bottom depths, while lower and higher Θ’/2 values are characteristic for lower depths. The area is strongly influenced with water current, which influences its narrowband characteristics. It can be concluded that the current is the strongest at depth over 60m. Very similar situation is observed in the vicinity in rectangle 31 (Fig.2).

20 - Average Θ’/2 = 21.53°, standard deviation 7.75º, range 14.0°. This is the area of very big dynamic range of both parameters and can be classified as gradient zone, between coastal shallow and dynamic waters (coastal current), and stagnated waters of the Gdansk Deep. The range of Θ’/2 is very wide, without domination of one class. The smoothest bottom (< 12°) is observed for 50-65m depths. For depths over 65m seabed has a layered structure with Θ’/2 >29º, characteristic for soft muds and absence of currents.

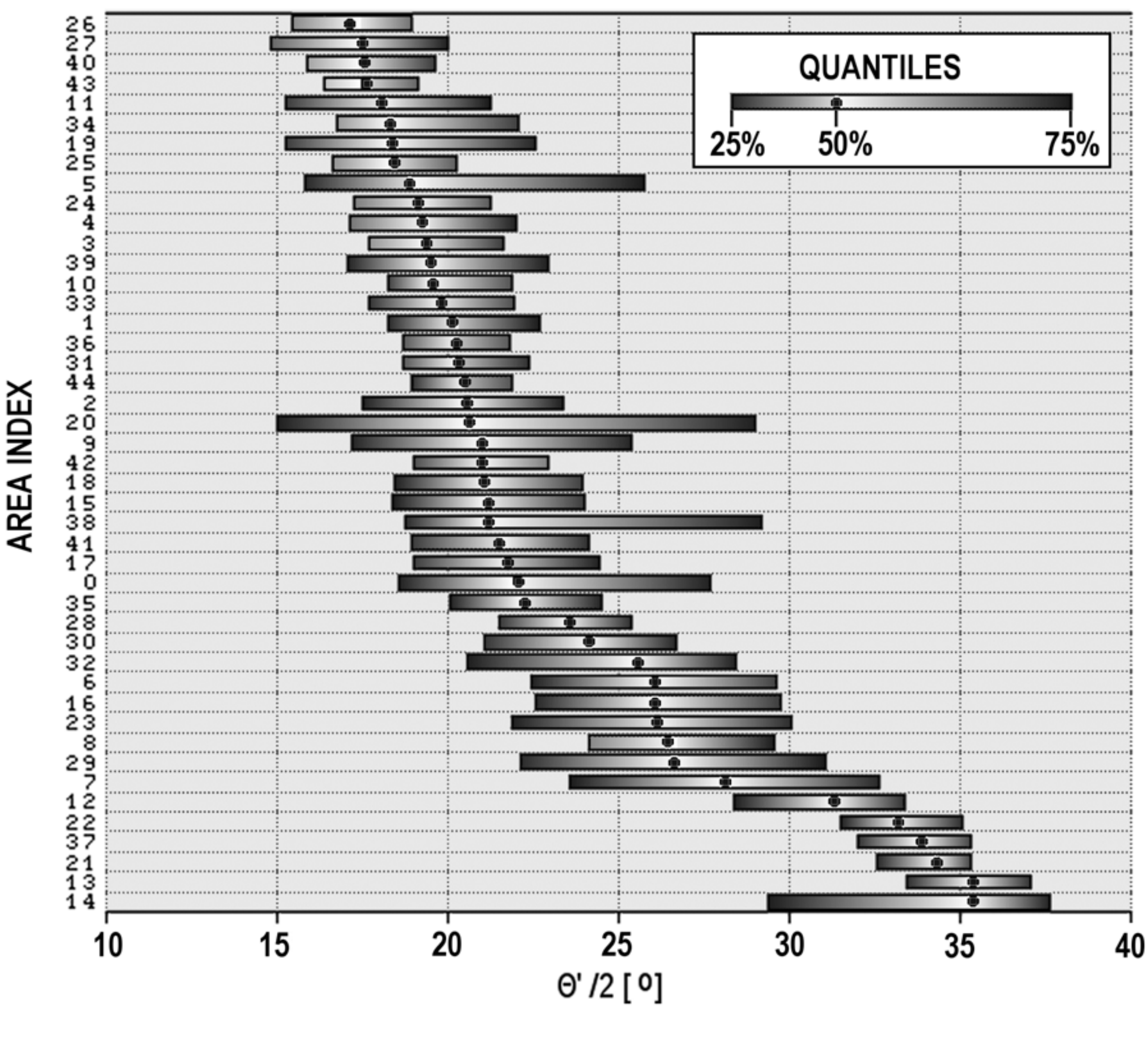

Fig.4 Medians and quantiles of Θ’/2 per each statistical rectangle (area index), ordered in relation to median values of Θ’/2

Fig. 4. gives the confrontation of Θ’/2 medians and ranges corresponding to 25-75% of its cumulative distribution per each statistical rectangle. The comparison of ordered values

indicates cases of similarity and differentiation among rectangles. It is easy to determine groups of similar seabed properties and rectangles of high variability, characteristic for transition zones (i.e. rectangles 5, 20, 38). Trend of median variability indicates interesting instability, observed for determined ranges of Θ'/2 medians. Thus for values over 23° strong increase is observed. Next such phenomena appear for thresholds 28 ° and 32°. Taking into consideration analysis presented in [16] mentioned thresholds can be associated with changes in basic structure of seabed, from simple and flat, to morphologically more complicated, through partly layered, till strongly layered and covered with soft sediment.

As it was mentioned in 1.4. the classification of seabed was based on analysis of values of two factors: $W_{\Theta i\text{-}j}$ - expressing normalized difference between Θ'/2 statistical distribution in rectangle i and j and $W_{di\text{-}j}$ expressing differences of depth structure of Θ'/2 classes in the same rectangle. In addition vectors $R_{i\text{-}j}$, built on components corresponding to $W_{\Theta i\text{-}j}$ and $W_{di\text{-}j}$, can be apply to sort results.

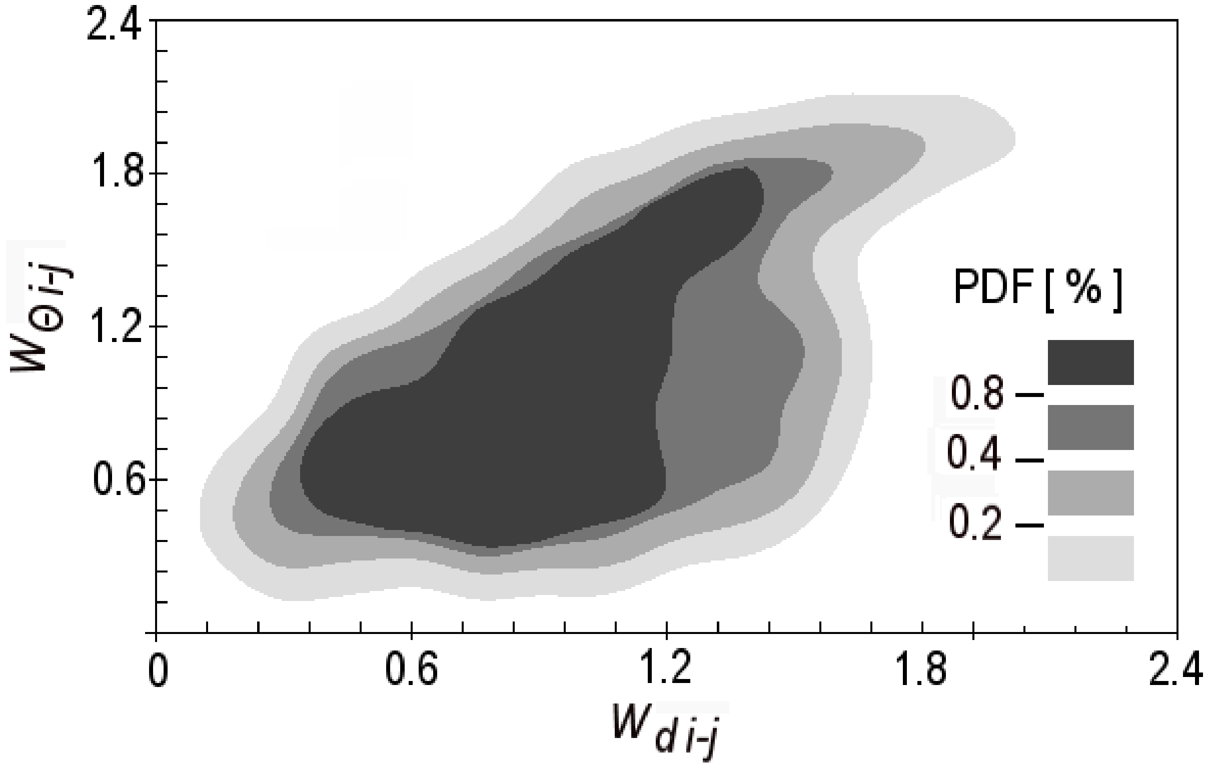

Fig.5 Probability density distribution of factors $W_{di\text{-}j}$ and $W_{\Theta i\text{-}j}$ calculated for pairs characterizing 44+1 statistical rectangles of southern Baltic

Figure 5. gives the summary distribution of both factors $W_{\Theta i\text{-}j}$ and $W_{di\text{-}j}$. The pattern corresponds to density of points representing pairs of similarity of expressed by $W_{di\text{-}j}$, localized against the Ox axis, and $W_{\Theta i\text{-}j}$ against Oy axis. For the set of 44 rectangles (plus the whole area) 1990 permutations were calculated. The pattern exposes uniform distribution of both factors within wide limits of values. Ranges for both factors are very comparable. Such a situation give very good principle to apply $W_{di\text{-}j}$ and $W_{\Theta i\text{-}j}$ to distinguish and classify all

statistical rectangles. Each factor expresses a similarity in different domain: $W_{\Theta i-j}$ estimates the distance according to the Θ'/2 paramater, W_{di-j}. compares depth structures of Θ'/2. When diagram presented at Fig. 5 is expressed by points, identifying each pair of comparison, we can assess in every case separately distance to Ox (depth structure) and distance to Oy (Θ'/2 distribution). This enable to evaluate the dominant source of the difference (Θ'/2 or depth structure). Explanation of such a categorization is given in Fig.6. for rectangle 24.

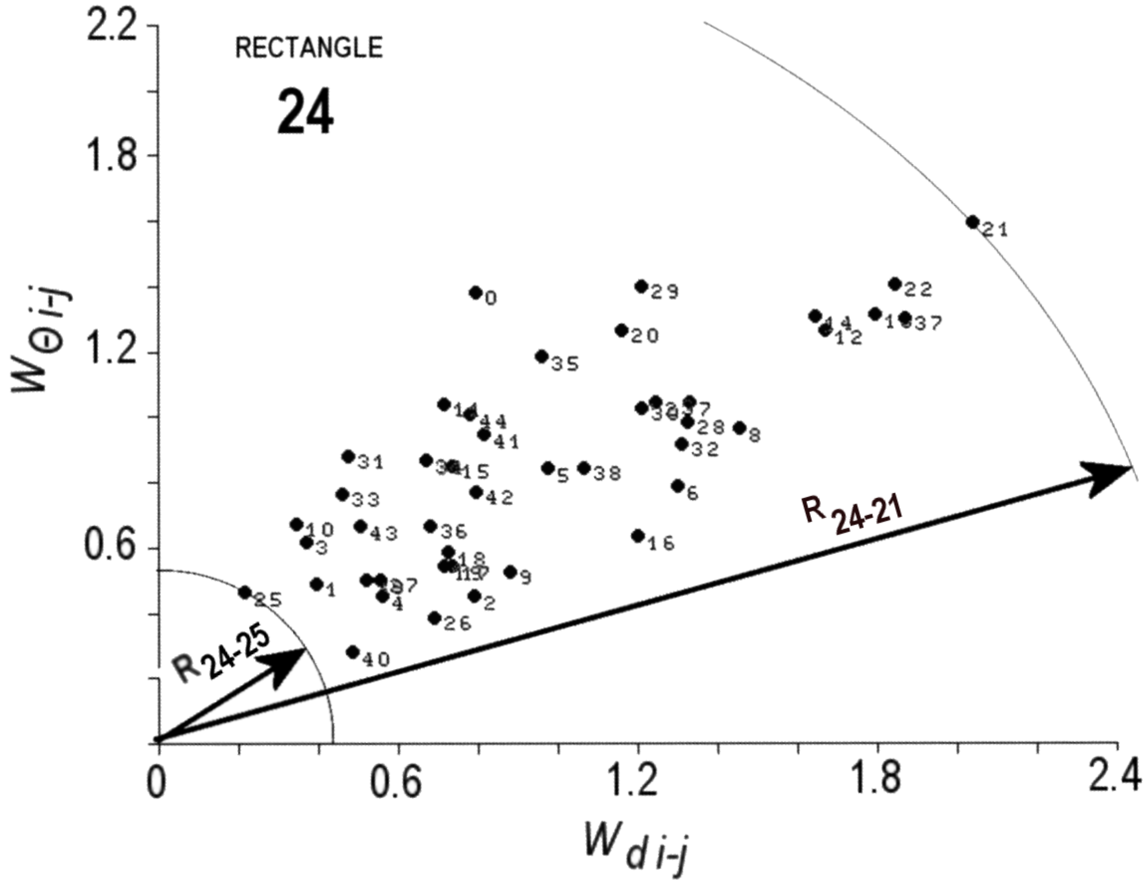

Fig.6 Comparison of acoustic characteristics of selected statistical rectangle (24 in this example) to all remained areas. R_{24-25} – distance between rectangle 24 and 25, R_{24-21} – distance between rectangle 24 and 21. Numbers correspond to rectangle in compared pair

The rectangle 24 was also presented in detail in the Fig. 3. (see also Fig. 2). The area is characterized by narrow range of Θ'/2 distribution, strongly modulated with a depth structure. Two extreme cases are marked in the figure: the most similar rectangle - 25 (distance $R_{24-25}= R_{i-j}$) and the most different rectangle - 21. Among the remain combinations we can easily identify similar areas 40, 1, 39, 4, 3 , and 27, while area 40 and 4 are most similar in the depth structure, and 3, 1, and 39 in the Θ'/2 domain. By such an analysis we can simply estimate the similarity of all standardized areas of seabed habitat.

Calculation of the average distance R_{i-j} among all statistical rectangles indicates the rectangle 9 as the closest to all remain ones, while rectangle 21 was the most different. Such a qualification makes possible to assess ecological uniqueness of each bottom habitat geographical unit.

The method and results of classification of the bottom habitat by two parameters, measured by acoustic sounding show it as effective tool for comparisons of seabed characteristics, seen from ecological point of view. The methods described in the literature [1, 3, 4, 5, 6, 7, 8, 9, 11, 16, 17, 19], are considering very large list of parameters, what provide to serious increase of indetermination of comparability. The other problem is associated with application of discrete scale of bottom properties, without continuous variability of properties. In reality, due to the diameter of the beam the insonified volume corresponds to adequate range of bottom properties. Geological classification of the sediments, based on particle size measurements produces also discrete scale of classification, what is not comfortable to provide comparisons of bottom habitat dynamics. If we observe results of seabed classification in [18, 20], the geographical limits among different classes seem to be ecologically unreasonable (artificial). They reflect discrete philosophy of differentiating seabed classes.

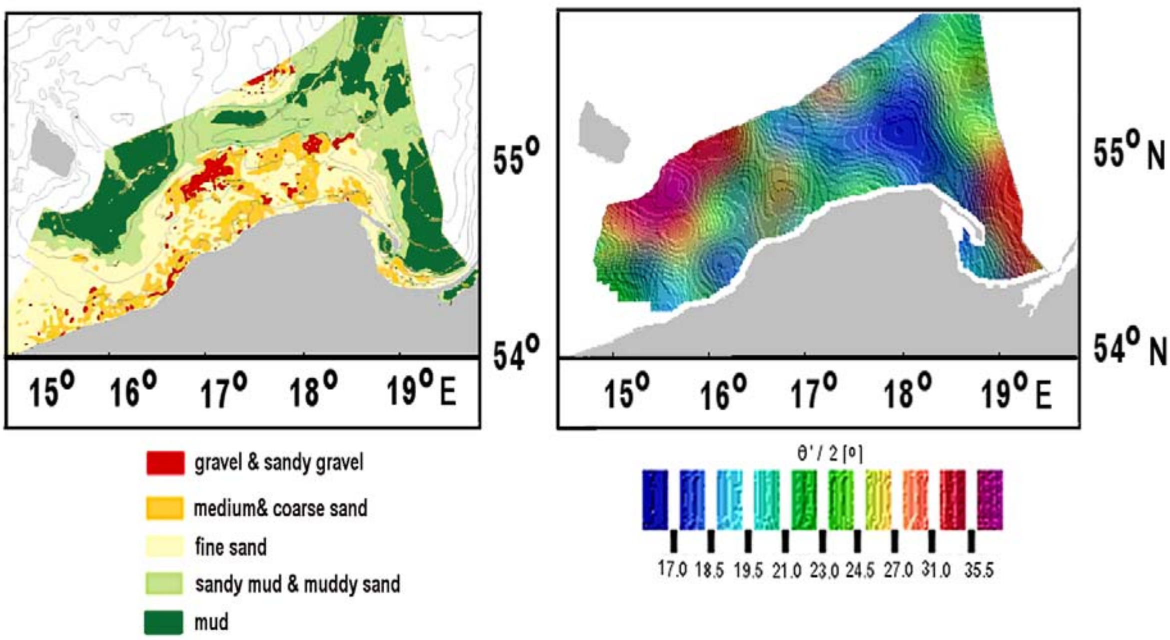

Fig.7 Comparison of geological and acoustic (Θ'/2 measurements) classification of the southern Baltic seabed

In the Fig. 7 the comparison of two charts of the southern Baltic is given. Left map [20] is made by classic geological ground-truth surveys. The bases of classification are discrete, and the visualization of ground properties is poorly reflecting gradients of properties. Map on the right is based on Θ'/2 measurements, and the scale is statistically uniform. Each step (basic colour) corresponds to 10% of cumulative distribution of the Θ'/2 []. In a consequence the classification and type of visualization (not possible for geological scale) allows to express dynamics of the seabed in more convenient form. It is interesting to observe, how the Θ'/2 parameter defines the zones of sediment accumulation (mud, Θ'/2> 27°) and gradients zones. Taking into consideration both elements (Θ'/2 distribution and depth structure) for classification of the bottom habitat the comparison can be significantly better matched to ecological standards. In result such form of classification can help in determining areas of ecological significance and to improve analysis in benthic research.

3. CONCLUSIONS

Taking into consideration both elements: Θ'/2 distribution and depth structure for classification of sea bottom habitat the comparison can be significantly better matched to ecological standards. In result such a classification can help in determining areas of ecological significance and to improve analysis in benthic research.

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