ACOUSTIC RECONNAISSANCE OF FISH AND ENVIRONMENTAL BACKGROUND IN DEMERSAL ZONE IN SOUTHERN BALTIC

(PART 2 - SEABED)

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The paper describes results of studies based on measurements of the Sv distribution in 3m layer over the bottom in the southern Baltic area for the period 1995-2004. These are correlated with values of coincident bottom features, estimated on the basis of all available survey data. It is considered that values of Sv are proportional to demersal fish (herring, cod, flatfish) density. Seabed classification was based on analysis of duration of bottom echo recordings collected during the same series of surveys. Normalized (against the depth) bottom echo duration - Θ'/2 was applied as 1D parameter characterizing seabed properties. Geographical distribution of this parameter and its dependence on other determined factors were analyzed. Studies of irregularities in fish distribution and its correlation to Θ'/2 values were made. The paper gives a new method of acoustic classification of seabed and shows also some conclusions on coincidence of bottom features and environmental background.

INTRODUCTION

Developing the bases for responsible administration of marine ecosystem and its resources demands application of methods giving wider and more precise characteristics of the area, and cross-correlations of dynamic processes. Critical element of the marine ecosystem represents 'bottom habitat' – the area closely related to the bottom zone, strongly influenced by environmental and anthropogenic factors. The area, known also as demersal zone, plays an important role in the biological chain. Demersal fish resources can be treated in a consequence as important indicator of the quality of the marine ecosystem. More detail information was given in [1, 2, 3, 4, 7].

Due to historical traditions and technical difficulties [6, 7, 8] acoustic methods were not suggested for direct assessment of demersal fish stocks. They are mostly applied for description of pelagic fish resources. It was shown [15] that acoustic information collected within demersal zone can be effectively utilised to describe 4D fish distribution in correlation to environmental background, enhancing the bases forming fishground surveys strategy.

This paper introduces application of new approach to provide acoustic classification of the seabed and to find out correlation of demersal fish distribution vs. seabed. 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.

1. MATERIAL AND METHODS

1.1. DISTRIBUTION OF DEMERSAL FISH

Systematic acoustic surveys of fish resources in 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 a slice-structured 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. Apart of integration of echoes in the pelagic layers – the bottom channel, collecting measurements within a layer of 3 m above the bottom was recorded. The interval was directly corresponding to the typical opening of the bottom trawl. The process of sweeping the interval to the bottom echo was realized by echo-sounder soft-ware. 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. It must be mentioned that the bottom of the southern Baltic is mostly smoothed what gave a potential easy conditions to provide the integration. The other factor bottom depth was not exceeding 100m and due to indications described in [10] the circumstances of collecting data were comfortable enough.

Both 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. Due to frequency and threshold applied most of measured signals have to be associated with fish echoes. 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 over the period 1995 to 2004 of the area, survey tracks, and the integration process is shown in [15].

Biological samples were collected by pelagic gear, on average every 37 n.mi. of the transect. Fish observed during reported surveys were mostly herring and sprat (Clupeoidae). The fish in the bottom channel was not sampled by the representative way – but it can be considered that herring, cod and flatfish were as the most common. Some conclusions have been done on the basis of bycatch in pelagic hauls also. The results of echo integration for each ESDU were expressed for bottom channel by the average values of S_A (area scattering strength in $m^2 nmi^{-2}$) and S_v (volume back-scattering strength in dB re $m^{-1}sr^{-1}$). Those magnitudes are described in [5].

1.2. HYDROLOGICAL BACKGROUND

Hydrographic measurements (temperature-T, salinity-S, and oxygen level-O_2) were made by a Neil-Brown CTD system with comparable spatial density. These were mostly sampled at haul positions, so sampling density was similar to that of the biological samples. Each hydrological station was characterized by geographical position and values of measured parameters at 10m depth intervals.

The results of echo integration for each nmi unit were expressed for bottom channel by average values of S_v (volume back-scattering strength in dB re $m^{-1}sr^{-1}$). For each unit the value of demersal fish depth-D_f, temperature $T_f(D_f)$, salinity $S_f(D_f)$ and oxygen level $O_{2f}(D_f)$ were estimated [11, 12]. Due to task of characterization the demersal zone D_f value was considered as 3m depth over bottom. In total near 8500 nmi samples were taken for analysis. The cruises from 1994 and 1997 were not taken into account due to low density of the hydrological sampling.

The area of the southern Baltic was divided into regular sub-areas (0.5˚N.x1.0˚E.), identical to ICES statistical rectangles. For each rectangle, average temperatures at standard depths (0, 10, 20,etc.) were estimated considering all hydrological measurements made in the area during the cruise. It means that equivalent CDT station in the middle of the unit was introduced. Values of corresponding temperature T_f, salinity S_f, and oxygen level O_{2f} at the depth D_f were estimated by computer interpolation [11, 12] for each EDSU sample. In result each unit was characterized by geographic position, date, time of day and sea bottom depth, S_A, S_v, D_f, T_f, S_f, and O_{2f} values in the demersal zone.

1.3. ACOUSTIC SEABED CLASSIFICATION

The method applied in this paper was introduced for classification of the seabed the first time. Previously the author introduced application of multiple echoes measurements for evaluation the seabed [9]. Numerous methods based on acoustic measurements intend to provide description of the seabed properties as mentioned i.e. in [16]. The main intention of the method presented below is to simplify classification procedure 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 four basic components:

$$\tau_s = \tau_1 + \tau_2 + \tau_3 + \tau_4 \tag{1}$$

where: τ_s - superposition of all components,
τ_1 - component dependent on pulse length,
τ_2 - component dependent on beam width,
τ_3 - component dependent on scattering properties,
τ_4 - component dependent on reflections from below bottom surface.

Component τ_1 is related to the sounding pulse length. It has to be compensated by diminish τ_1 time length from τ_S. Component τ_2 is directly joint with Lloyd's mirror effect and with effective width of the echosounder transducer beam pattern. The scattering from the seabed is responsible for τ_3 component. This component is strongly dependent on morphological and sedimentary structure of the seabed. Rough bottom gives much bigger value of τ_3 that the smooth one. The bottom roughness and the type of the sediment and sedimentation structure are responsible on reverberation level, effectively enhancing duration of this component. Component τ_4 is quite strongly dependent on type of vertical geological structure of sedimentary layers. In situation when seabed material is characterized by high porosity the acoustic pulse is not reflected effectively and can propagate through deeper sediment layers, producing series of reflections. Their superposition influences a final τ_4 value.

Measurements of τ_s have to be 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.

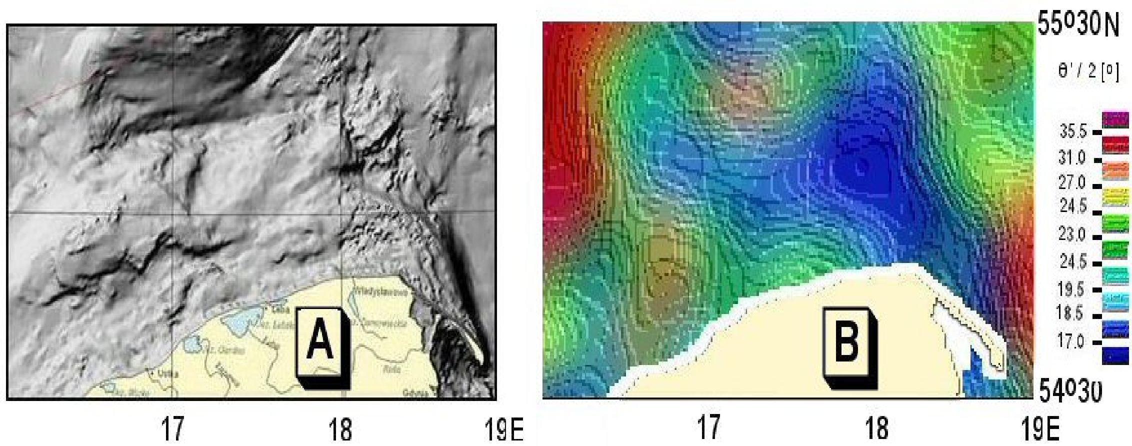

Fig.1 Comparison of semi-3D chart of the Baltic bathymetry (A) and chart generated by "Θ' method" (B)

The value of Θ'/2 parameter is closely related to the sum of $\tau_2 + \tau_3 + \tau_4$ and expresses their complex influence on seabed echo time pattern. If we apply for surveys the echosounder of stabilized transmitting and receiving characteristics, then Θ'/2 values, measured with a constant threshold S_v, will be fully comparable and applicable for seabed classification.

Fig.1. gives comparison of the quasi-3D chart of the Baltic [17] and the chart generated by "Θ' method". Values of Θ'/2 were estimated as an average per one nautical mile units of ship track. Presented results correspond to 8139 mile samples collected during 1995-2003 period.

2. RESULTS AND DISCUSSION

Analysis of distribution of Θ'/2 values was made at the first stage as the method was applied the first time to characterize Baltic seabed. Parallel to echo length measurements estimating the seabed vertical structure was provided from echo recordings. One n mi units were classified into three basic groups: 1. simple, non-layered structure, 2. mixed structure (partly layered within the unit), 3. fully layered structure over the whole nautical mile. It has to be explained that layered structure differs from scattering one by depth cross-correlation of sub-layers echoes from ping to ping. Mentioned classification was introduced to identify the range of Θ'/2 corresponding to determined class of the bottom structure.

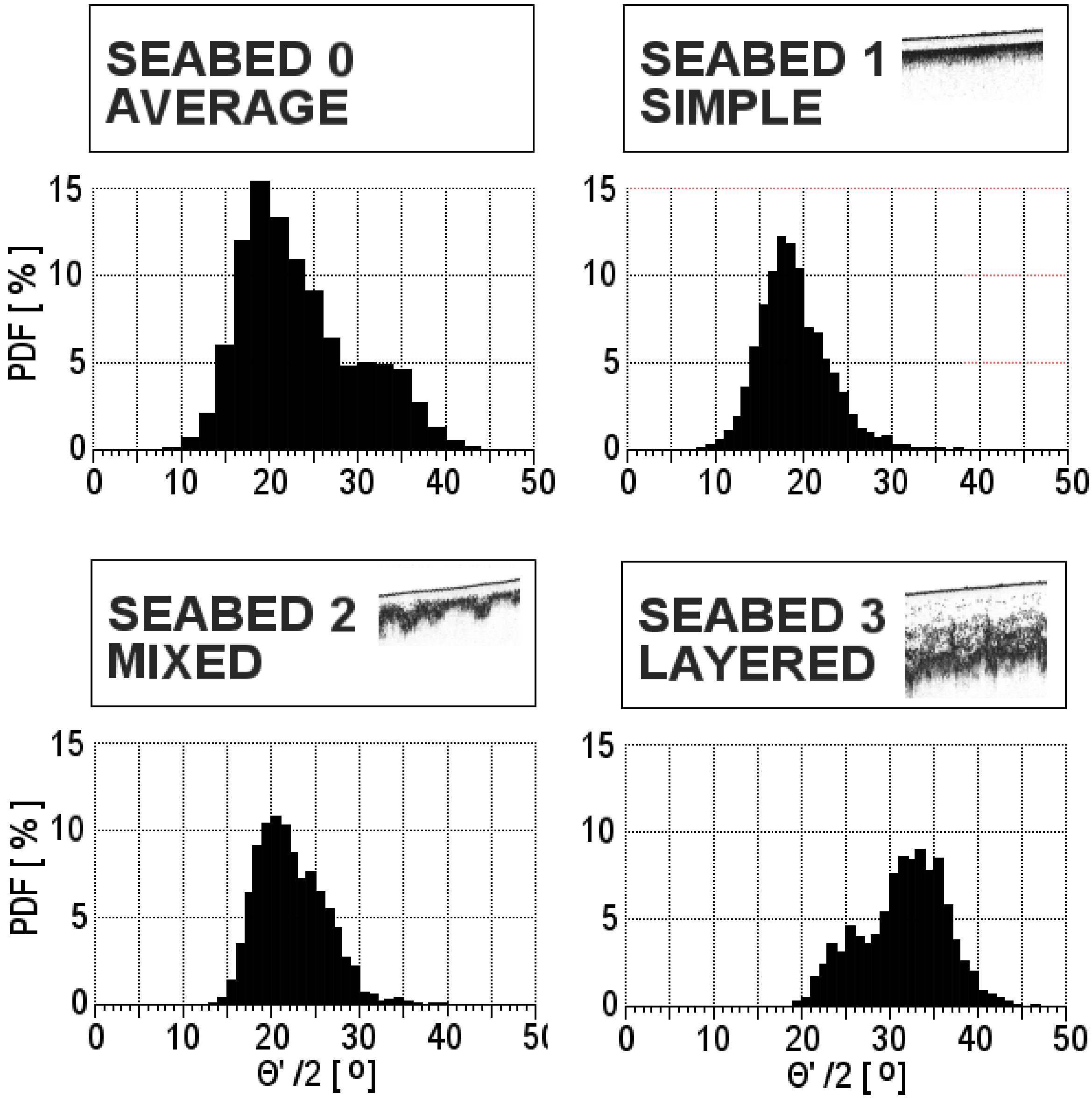

Fig.2 Distributions of Θ'/2 parameter for four different types of seabed measured on basis of cruises curried out in 1995-2003 period

In Fig.2 we can observe how distribution of Θ'/2 parameter varies with the type of the seabed. The type "0" corresponds to the sum of all measurements carried out in the area of the southern Baltic. The distribution of Θ'/2 values is mixed and represents superposition of two separate sub-types of seabed categories. The range of values is maximal and corresponds to the total dynamic range of measuring abilities by the system applied for sounding.When the bottom is not layered (case 1) bottom echo duration is mostly related to the transducer beamwidth (τ_2) and scattering properties of the bottom (τ_3). The output Θ'/2 range is much narrow (13.4-26.0º) and the average is the lowest (18.97º).

Tab.1 Statistical parameters of Θ'/2 values for four different classes of seabed vertical structure

Bottom type	Θ'/2 [normalized effective angle of bottom echo]			
	No of n mi	Mean	SD[a]	Range[b]
0 - average	8139	23.51	6.56	11.50 – 35.80
1 - simple	3045	18.97	6.93	13.40 – 26.00
2 - mixed	2938	22.30	3.90	17.00 – 29.00
3 - layered	2156	31.57	4.80	23.20 – 38.80

[a]SD, standard deviation.

[b]Range corresponding to 5%-95% of cumulative percent of Θ'/2 distribution

In the case 2 the distribution of Θ'/2 values is swept about 3º towards the higher values, what is caused by increase of share of τ_4 component. In the case 3 the distribution pattern is strongly different. Average value of Θ'/2 is distinctly higher (18.97º and 22.30º in cases 1 and 2 against 32.57º in case 3) and the range is strongly swept to the higher values (23-38.8º while 13.40-26.0º and 17.0-29.0º in cases 1 and 2). Taking into consideration those results it can be easily found that the overlapping of results from simple and mixed bottom type against layered one is very limited. It means that distinction of those types is quite simple by application the parameter Θ'/2. The figure 3 gives a comparison of two charts of the southern Baltic calculated from two separate data collections of Θ'/2 parameter. The similarity of the results is self-evident. Small differences are mostly related to differences in sampling tracks.

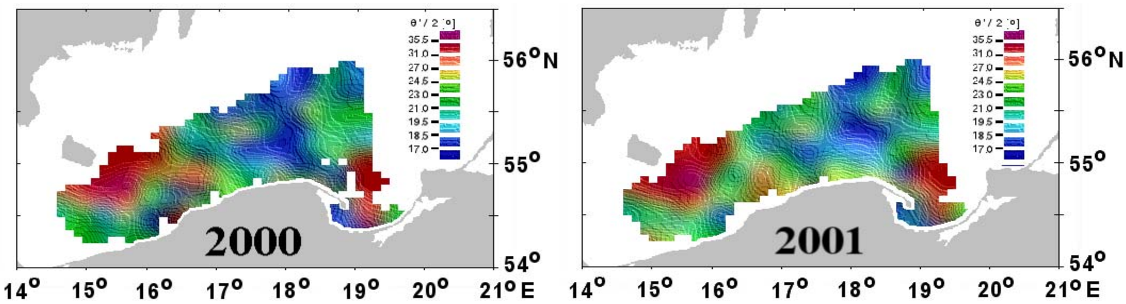

Fig.3 Charts of Θ'/2 parameter calculated for 2000 and 2001 data collections

The chart of southern Baltic bottom expressing distribution of Θ'/2 parameter measured during 1995-2003 period is given in Fig.4. The map shows clearly local differences in seabed type, which are well correlated to main ecological units: Bornholm and Gdansk Basins. It is easy to identify layered areas of cumulating sediments (Θ'/2>31°), associated with Bornholm and Gdansk Deep. Gradients of Θ'/2 indicate transformation seabed, what strongly influences the benthic biodiversity. Areas of stabilized properties and high dynamic changes are easy to differentiate. The coastal zone is characterized by strong variability of Θ'/2 parameter.

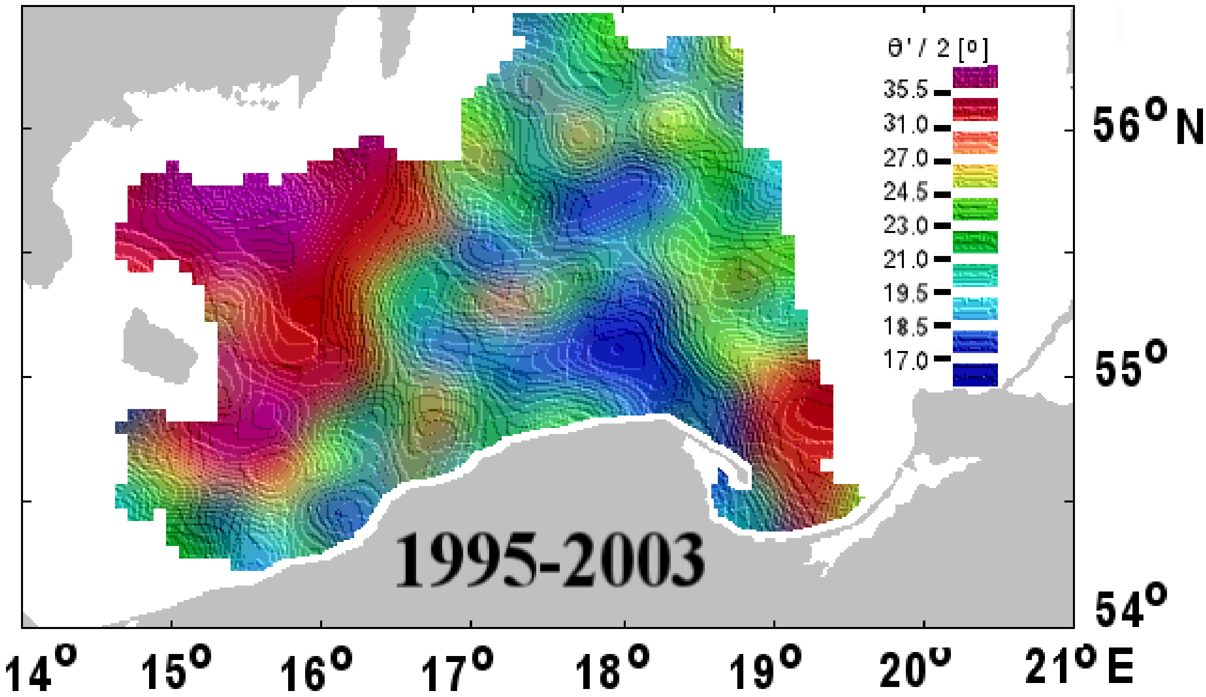

Fig.4 Final chart of seabed properties of southern Baltic expressed by Θ'/2 parameter

Measurements of Θ'/2 parameter were applied also to describe sea bottom properties along transects. Fig. 5. presents distributions of the Θ'/2 values for different profiles. In Fig. 5.A they are shown five versions of the same profile along meridian 16ºE, recorded each year in 1998-2002 period. The similarity of results verifies well the repeatability of classification.

Fig. 5.B gives comparison of two factors observed along the survey track and expressed along the bottom profile. The distribution 1 corresponds to values of Θ'/2 parameter, and the distribution 2 expresses percentage of cod along the same profile along meridian 15º40E. Both patterns are calculated on the basis of the whole period of research to minimize cases of detail variability in particular years. It is very visible how both factors are related in this profile and how the percentage of cod increases in the areas of high Θ'/2. In Fig.6 dependence of bycatch of different species and seabed acoustic characteristics are given to show practical validity of the method applied.

The results show evidently that bycatch of traditionally pelagic fish (herring and sprat) is not dependent on seabed type while the percentage of cod (demersal fish) quite strongly increases with Θ'/2 values. A similar relation for cod was described in [10], where the area of high presence of cod was associated with very low coefficient of reflection of acoustic waves. Small reflection was caused by a presence of very soft organic material at the bottom. High porosity caused circumstances of deeper penetration and generation of echoes from layered media. And in a consequence the same geographical area was characterized by different acoustic parameters (Θ'/2 and reflection coefficient), giving the same answer in relation to the cod preferences.

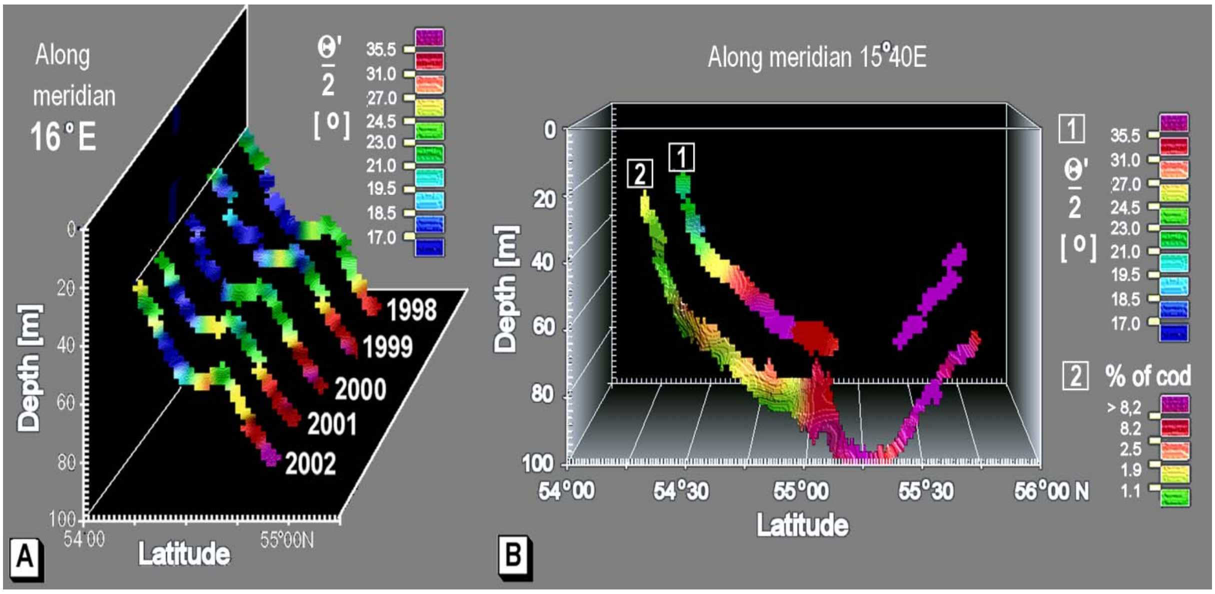

Fig.5 Transects representing measurements of distribution of Θ'/2 parameter

A-successive soundings for selected profile, B.1- average for period 1995-2003, B.2- % of cod for period 1995-2004.

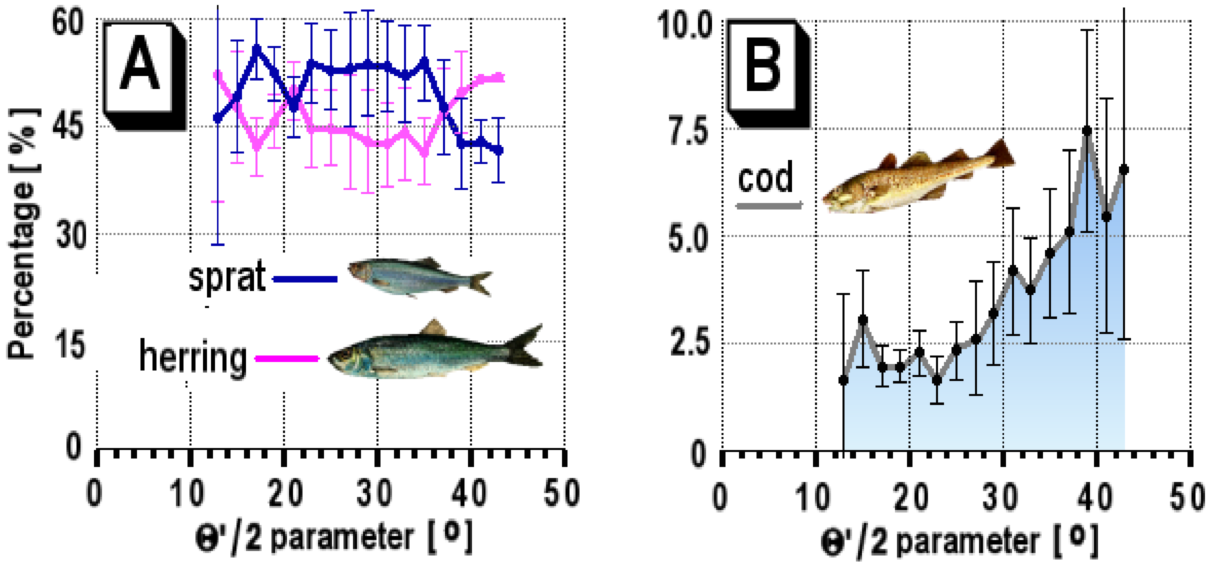

Fig.6 Bycatch of pelagic and bottom fish in the areas characterized by Θ'/2 parameter

Fig. 8 illustrates correlation between the values of salinity, oxygen, and Θ’/2. It was shown (Table 1) that the higher values of Θ’/2 are corresponding to the layered bottom. Sedimentation processes can be increased by favourable factors such as high viscosity and low dynamics of water masses, or accessibility of the sediment material. In a consequence high salinity helps in increase of intensity sedimentation process. Low oxygen level indicates higher intensity of decomposition of organic material, what indicates higher production of soft organic sediment.

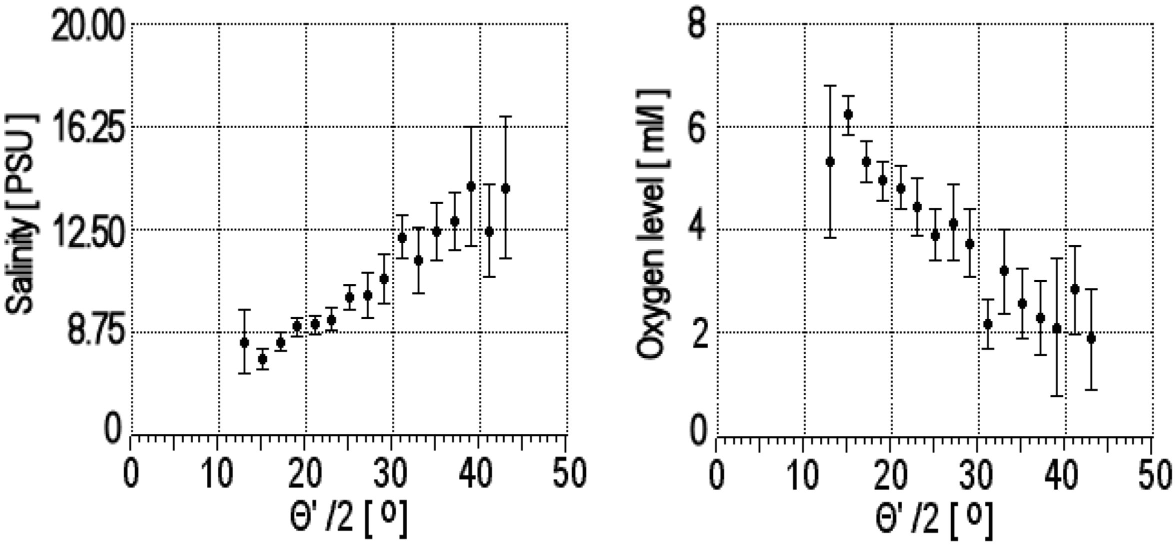

Fig.7 Values of salinity and oxygen level corresponding to different classes of Θ’/2 values

3. CONCLUSIONS

Multi-directional analysis of acoustic and generated on this bases parameters describing the distribution of demersal fish and correlated environmental factors showed a simple way to identify significant heterogeneity in geographical patterns in distribution of fish resources.

Verification of results and correlations gives quite important conclusions on environmental bases for administration of fish resources from one side, and shows which methods of measurements are more or less sensible for monitoring particular elements in the marine ecosystem.

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