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

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The paper describes results of studies based on four-dimensional measurements of the S_v distribution in 3m layer over the bottom in the southern Baltic area for the period 1995-2002. These are correlated with values of coincident environmental factors: time, depth, water temperature, salinity and oxygen levels, bottom features, estimated on the basis of survey data and wide range of methods, elaborated by the author for fish behaviour studies. The purpose of the paper is to compare results collected during acoustic surveys in the Baltic and to estimate irregularities in fish distribution potentially influencing the results of fish bottom trawling in a sense of its application for demersal fish resources assessment.

INTRODUCTION

The latest indications of the EU scientific support policies are joint with modernisation and sustainability of fisheries. In a consequence the improvement and development of fish resources assessment tools, being fishery statistics independent, has to be taken into consideration. Sea Fisheries Institute co-operates with 11 EU research centres in the Project FISBOAT (Fisheries Independent Survey Based Operational Assessment Tools) dedicated to realize the mentioned task. One of the trends suggests integration of acoustic data to determine spatial, temporal and environmental aspects of fish assessment methods [1].

Most of significant demersal fish species resources [3] are estimated on the basis of :
- fishery dependent data (catch end effort statistics from commercial fisheries),
- fishery independent data (data from research cruises).

The principal base for fish stock management is knowledge on present state of stock and trends in abundance and composition. Majority of groundfish surveys employ stratified random design. more effort is allocated to strata of higher abundance. Positions of samples within a strata are selected randomly.

The strategy is based on historical data, mostly applying fisheries statistics. It means that if spatial distribution of fish changes from year to year the effectiveness of the method can vary

significantly.

It can be clearly seen that better knowledge on dependence of fish distribution on environmental background could effectively minimize the error of groundfish abundance estimates by improving *ad hoc* random strata design.

Due to historical traditions and technical difficulties [7, 10] acoustic methods are not suggested for assessment of demersal fish stocks. They are mostly applied for description of pelagic fish resources. But even the acoustic information on demersal zone not can be useful for absolute abundance of the groudfish – it can be effectively utilised to describe 4D fish distribution in correlation to environmental background. In the paper are presented results of miscellaneous applications of this information in determining detail characteristics of demersal fish behaviour vs environmental background.

During two decades of acoustic surveys of pelagic resources in the Polish EEZ carried out as ICES international co-operation – the integration of fish echoes within the layer close to the bottom was collected with a perspective destination. Due to a mentioned interest in optimization of fish stock assessment methods the analysis of those acoustic data become very reasonable. Most of methods, designed in Sea Fisheries Institute for acoustic studies of pelagic fish behaviour [11, 12, 13, and 14] were adopted to realize that task.

1. MATERIAL AND METHODS

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 1998-2002. 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 2002 of the area, survey tracks, and the integration process is shown in Figure 1.

Biological samples were collected over the period from 1995 to 2002 by the same pelagic trawl, on average every 37 n.mi. of the transect. Fish observed during all surveys were mostly pelagic, herring and sprat (Clupeoidae). The fish above the bottom was not sampled by the representative way – but it can be considered that herring, cod and flatfish are the most common in demersal zone. Hydrographic measurements (temperature-T, salinity-S, and oxygen level-O_2) were made by a Neil-Brown CTD system. These were mostly sampled at haul positions, so sampling density is similar to that of the biological samples. Each hydrological station was characterized in this studies by its geographical position and values of measured parameters at 10m depth intervals.

The results of echo integration for each ESDU and for each slices of depth were expressed for bottom channel by the average values of S_A (area scattering strength in m^2nmi^{-2}) and S_v (volume back-scattering strength in dB re $m^{-1}sr^{-1}$). Those magnitudes are described in [6]. For each unit the depth D_f was calculated on the basis of bottom depth value. 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, 13] for each ESDU 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. The analysis is taking into consideration 6598 ESDU from the period 1995-2002. The cruises from 1994 and 1997 were not taken into account due to low density of the hydrologic sampling.
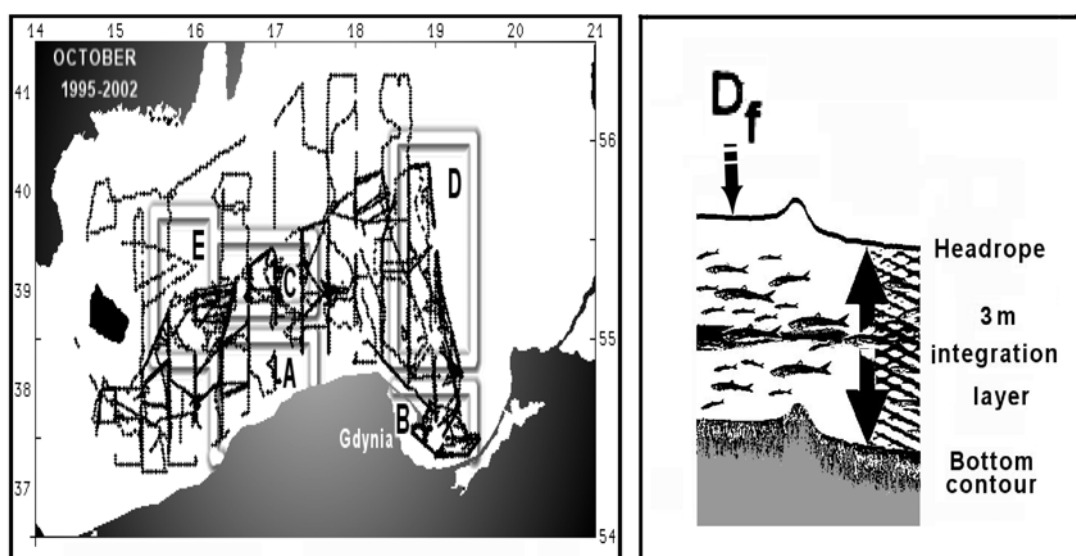

Fig. 1. The area of research and sub-areas A, B, C, D, E of studies. Dots represent ESDU positions. Scheme of echo-integration in the bottom channel.

Charts of S_v, D_f, T_f, S_f, and O_{2f}, presented in Fig. 2. were produced by using technique described in [14]. The method allows for effective observation of important space gradients of each factor. Ranges of factors analyzed were estimated as determined levels (25%, 50%, and 75%) of the cumulative distributions weighted vs S_A values [12, 13] for the whole survey area and selected geographical regions: A, B, C, D. and E (Fig. 5).

Diel models of the variability of S_v average values (Fig. 7) were constructed on the bases described in [11].

2. RESULTS AND DISCUSSION

Additional application and processing of wide range data from acoustic cruises in the southern Baltic allowed to discover detail and differentiated characteristics of the demersal zone in relation to its potential evaluation for the groundfish surveys. In Fig.2 there are given charts of five basic factors: S_v, D_f, T_f, S_f, and O_{2f}. The charts present a picture averaged for autumns 1995-2002. Due to this fact single year irregularities were filtered.

The distribution of S_v shows very irregular pattern, which is associated with availability of demersal fish in the near-bottom zone. We can observe highest S_v values (>-66.4dB) in three separate areas along the Polish coast: vicinity of Odra and Slupsk Banks, and Gdansk Bay. Higher values of S_v (>-68.6dB) are noticed in the Slupsk Furrow also. Areas north off 56º N are not discussed, as two cruise were made in that part only. The lowest values of S_v (< -74 dB) were clearly associated with Gdansk, Gotland, and Bornholm Deeps. The dynamic range of the S_v averages can be estimated at 20 dB, what gives a multiplier of 100-fold for biomass density.

Next chart shows D_f distribution, what illustrate how demersal zone is distributed in the southern Baltic from bathymetric point of view. We can observe Bornholm and Gdansk - two main basins, joint with separate deep zones. The basins are connected by Slupsk Furrow, which enables movements from the west to the east of high salinity waters at high depths. The chart is being the negative of the previous one except of this area.

Distribution of temperature T_f in 3m near bottom layer shows high supremacy of warm water in the coastal zone (>11.8ºC). The lowest temperatures were noticed in Gotland and Bornholm Deep (<6.4ºC).
Salinity was proportional to D_f depth. Due to pressure of the high salinity waters from the North Sea the gradient of the values for D_f >70 m was observed from the west (> 14 PSU) to the east (< 11 PSU).
The most interesting is the chart of oxygen level(O_{2f}). Comparing it to S_v distribution we can observe near ideal similarity if both patterns. That phenomenon indicates a dominant role of the oxygen in relative distribution of the fish within a near-bottom layer.
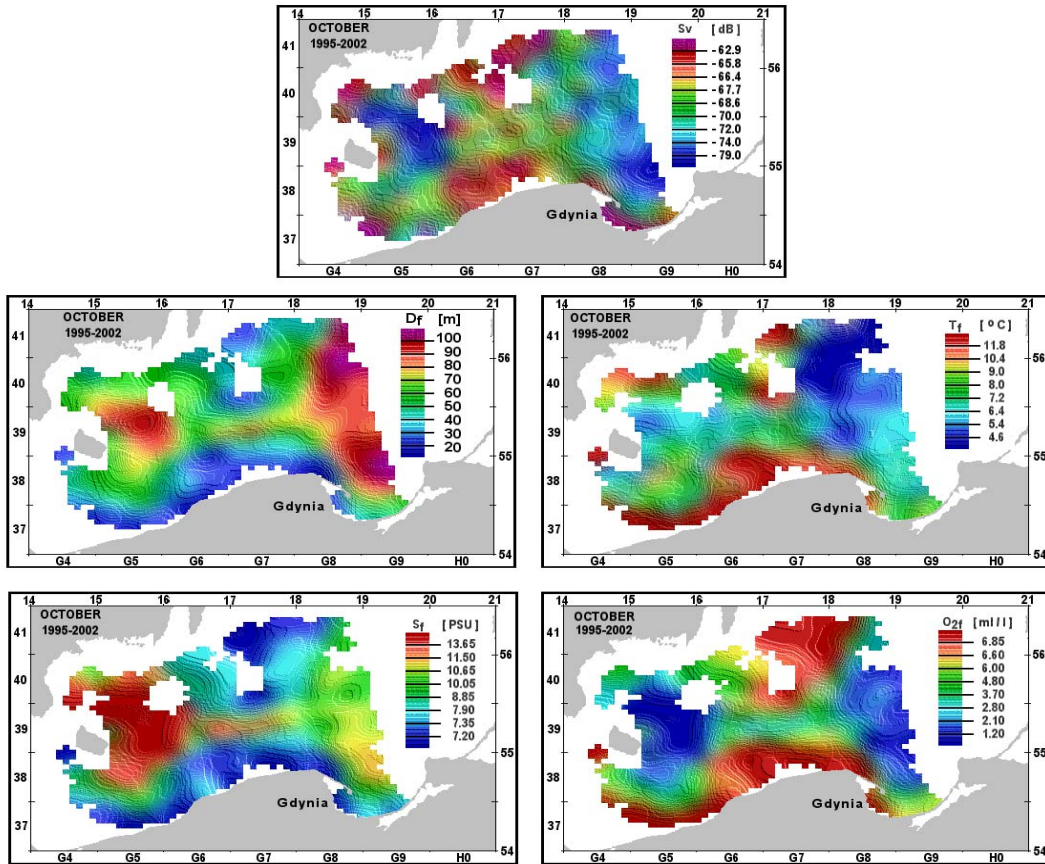
Fig. 2. Charts of distribution of five basic factors: S_v, D_f, T_f, S_f, and O_{2f} in southern Baltic for autumns 1995-2002.
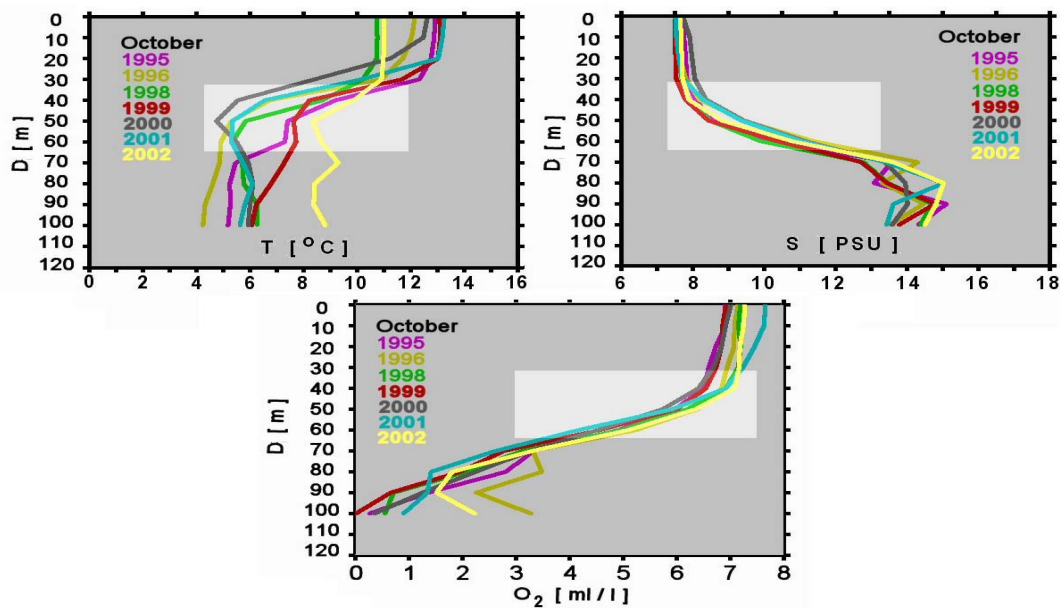

Fig. 3. Variability in consequent years of average values of hydrological factors at standard depths. Light rectangles indicate 25-75% of fish biomass intervals.

Fig.3 shows year by year variability of the average depth dependent structure of temperature, salinity, and oxygen levels during the period of the studies. The lighter rectangles at each diagram correspond to the depth of 25% and 75% values of cumulative distribution of demersal fish weighted by S_A values. This interval can be directly interpreted as a main depth range of this fish.

The biggest variability of hydrologic factors is observed for the temperature. Extremely patterns were measured in 1996 and 2002 years. Temperature at 50m depth (close to the median of the fish depth distribution) was 4.94ºC in 1996, while in 2002 was equal 8.96ºC (near double). Most of fishes were concentrated in depths below thermocline. The lower depth limit of fish concentrations was not conditioned by temperature, as this factor was relatively stable in this range.

The salinity depth distribution was characterized by strong gradient between 40m and 65 m. The variability is observed mostly in the deeper water and depended on particular inflows from the North Sea. The fish were concentrated mostly in the area of the gradient. There is no any visible direct correlation between the lower limit of fish range and the absolute value of the salinity.

The diagram of the oxygen level is similar but negatively correlated to the salinity one. The variability of this factor is strongly noticed below 70m. The lower limit of fish concentrations corresponds to the value 4.15 ml per litter. As the oxygen level monotonically decreases below this depth it can be considered that absolute value of this factor plays dominant role in limitation of the fish depth range.

Trends showing the correlation between the determined class of demersal fish density, expressed by S_v and corresponding average values of D_f, T_f, S_f, and O_{2f} were calculated for all the data from autumns in the period 1995-2002, in the whole area of research. The results are shown in Fig. 4.

The distribution of S_v values is very quite simple, with one mode pattern and the average -72.36 dB, with SD = 7.29 dB. Approximation curves were matched taking into consideration values of correlation coefficient r and approximation error AE. In all cases the correlation of the pairs was very high (0.985, 0.929, 0.942, and 0.973). The value of approximation error was mostly dependent on less representative areas of extremely values of S_v. It is important to underline that the correlation is positive for D_f, T_f, O_{2f}, and negative for S_f. Those trends are resulting from depth structure of the hydrological factors and their cross-correlations. The most individual relation is observed for the temperature. The trend between fish concentration and T_f has a form of potential curve while the remain ones are linear. This phenomenon indicates the temperature as the most important factor influencing autumn distribution of biggest concentrations of demersal fish.

Analysis of the charts presented in Figure 2 indicates strong geographical irregularity of factors $S_v \sim S_A$, D_f, T_f, S_f, and O_{2f}. Due to all aspects observed - five differently characterized regions (A, B, C, D, and E) were determined to provide details of demersal fish distribution (see Fig.1). Area A (Darlowo-Kolobrzeg fishing grounds) and B (Gdansk Bay) are the most populated and the average values of area scattering strength is as follows: A - S_A = 48.91 (CI=5.72, SD=59.86) $m^2 nmi^{-2}$ and B - S_A = 36.61 (CI=4.73, SD=66.24) $m^2 nmi^{-2}$. Area C (Slupsk Furrow) is representing transition zone and the average S_A = 24.56 (CI=2.46, SD=37.59) $m^2 nmi^{-2}$. The area D (Gdansk and Gotland Deep) and E (Bornholm Deep) are characterized by the lowest values of the demersal fish density: D - S_A = 6.14(CI=0.57,SD=8.50) $m^2 nmi^{-2}$ and E - S_A =5.94 (CI=1.50,SD=18.29) $m^2 nmi^{-2}$.

For all those regions and for the whole southern Baltic corresponding ranges of S_A, D_f, T_f, S_f, and O_{2f} factors, as 25%, 50%, and 75% of cumulated distribution weighted by S_A [12] were calculated. The graphical presentation of range intervals are given in Fig. 5.
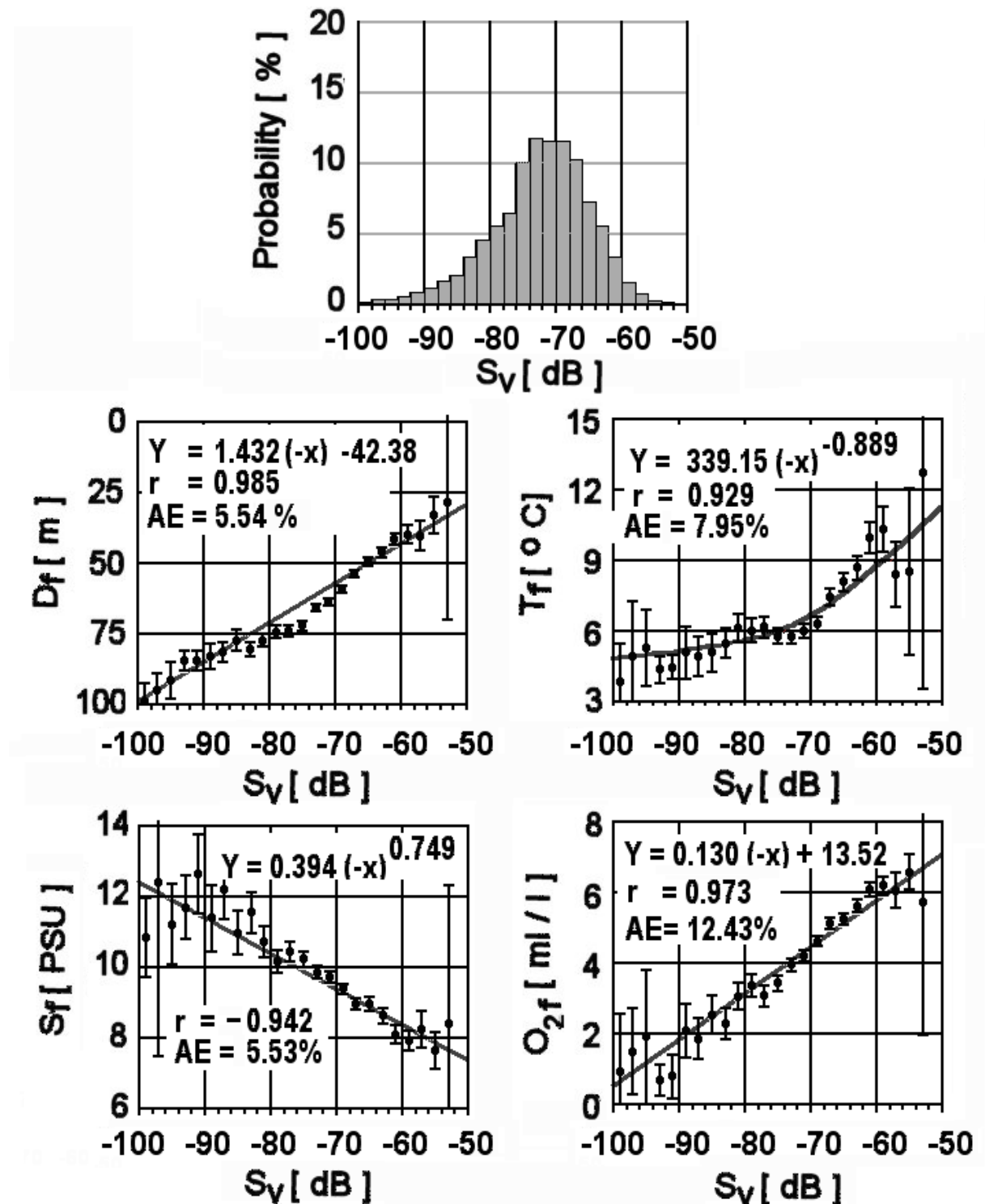

Fig. 4. Trends between the concentration of demersal fish (S_v) and corresponding average values of factors T_f, S_f, and O_{2f} expressed by empirical values (confidence intervals included) and approximation curves. Characteristics are calculated for the whole southern Baltic for autumns 1995-2002.

As the regions A, B, C, D, and E are situated at the drawing in a consequence related to the demersal fish density, we can easily find when corresponding ranges of factors observed are confirming or not the relations shown in Fig. 4.
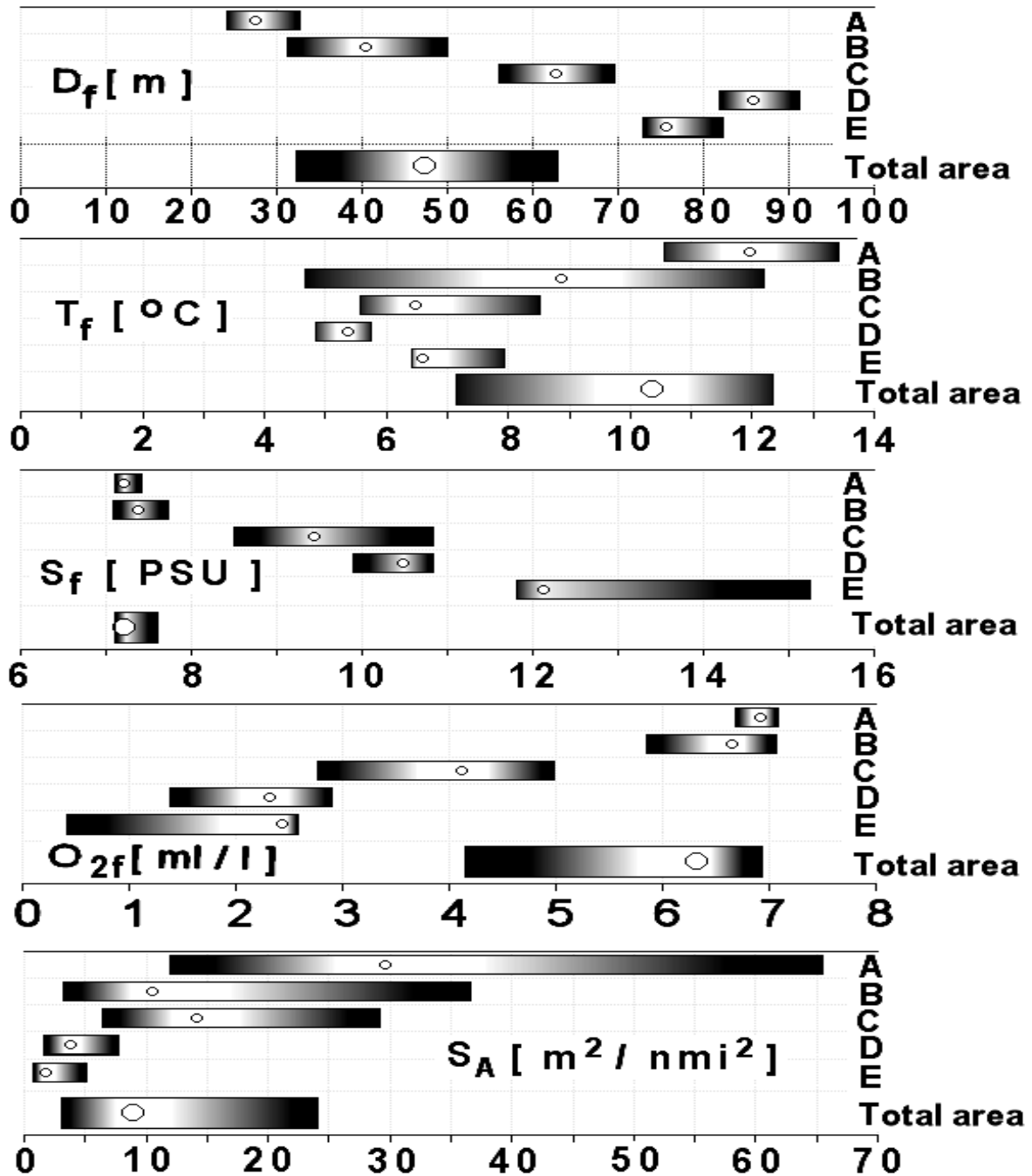

Fig. 5. Ranges of D_f, T_f, S_f, O_{2f}, S_A values associated with main concentrations of demersal fish, in the southern Baltic for the autumns between 1995 and 2002, calculated for regions and the whole southern Baltic.

In all the cases correlation between the factor analyzed and demersal fish density confirms the relations shown in Fig. 4. The comparison of particular regions with the average response calculated for the whole southern Baltic indicates strong local differentiation. In a consequence it indicates a sense of treating each region separately and to estimate its individual characteristic. Results of such approach are reviewed in Fig.7, as a series of D_f, T_f, S_f, and O_{2f} average values within intervals of corresponding to S_v distributions in each separate region. The matrix of diagrams expresses very individual patterns of variability, what means that regressions formulated for the whole southern Baltic could do not work in separate regions.
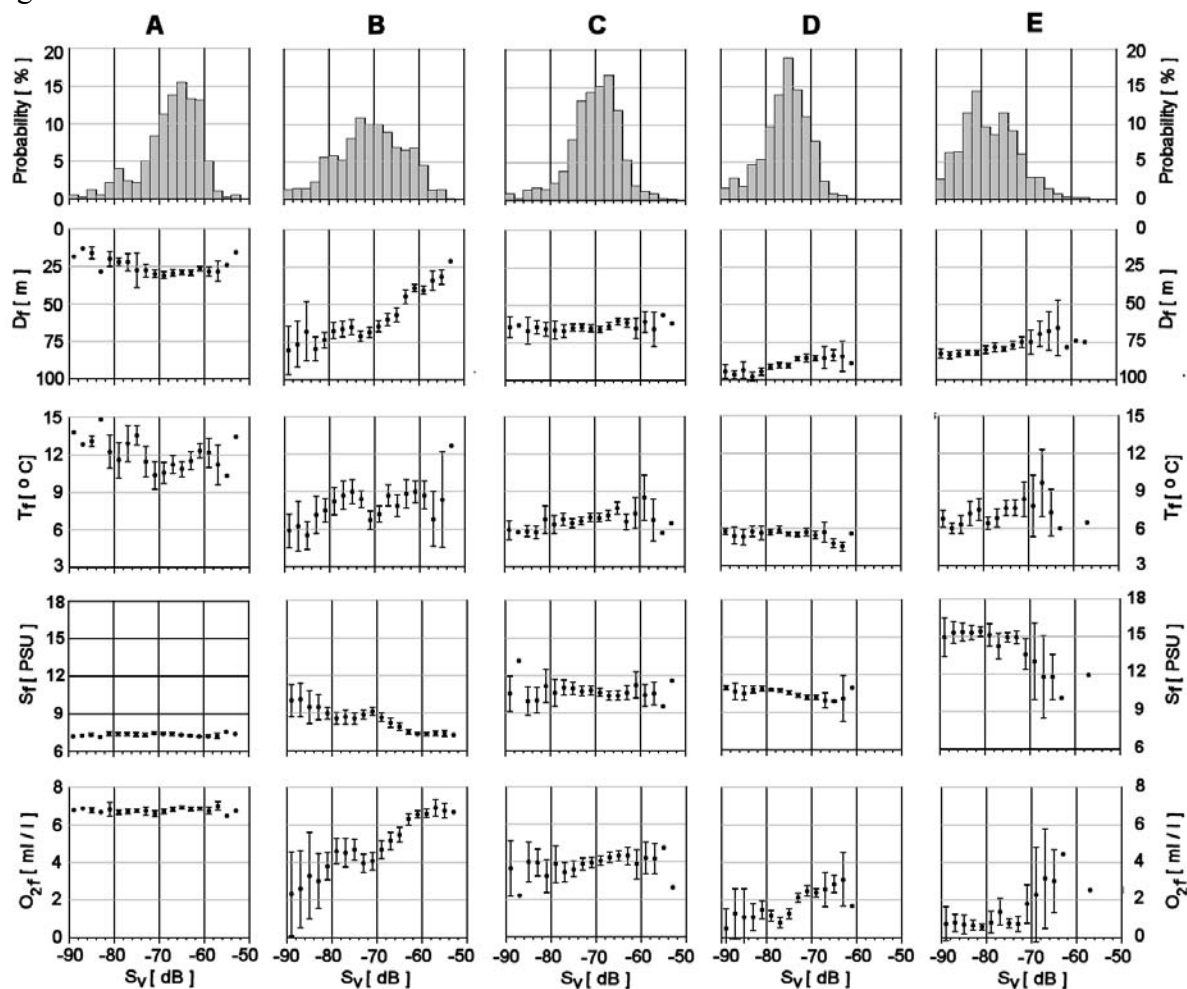

Fig. 6. Review of series of D_f, T_f, S_f, and O_{2f} average values within intervals of corresponding to S_v distributions in each separate region. Confidence interval marked.

In highly populated region A (Kolobrzeg-Darlowo fishing grounds) demersal fish is mostly associated with very small range (24-33 m) of shallow water of high T_f, high and stable O_{2f}, and low S_f values. The biggest variation is observed for T_f but no determined trend can be observed.

The region B (Gdansk Bay) is characterized by similar fish density as A region. We can observe here very strong dispersion of fish within big range of depths (31-50m) while correlated T_f, S_f, O_{2f} values differ from the range estimated for the previous one. Strong correlation between S_v and remain factors is seen.

The region C (Slupsk Furrow) is playing the role of the transition zone between west Bornholm Deep and eastern Gotland and Gdansk Deeps. High salinity water from inflows, in particular, is entering by this way to the eastern part of the Baltic. It is the only passage where demersal fish associated with higher depths and salinities could migrate. Pattern shown in Fig. 6 shows that fishes in this region prefer zone close to the bottom (56 -70 m). Very slight preference of higher T_f and O_{2f} is observed. Range of the oxygen level 2.77-4.98 ml per litter is surprisingly low in comparison to A and B regions. Trend S_v (S_f) gives the conclusion that the fish concentrates from the west to enter to the eastern part of the Baltic. Those effects can be interpreted as characteristic for migration process.

Regions D and E are representing the lowest densities of fish. But even in this case a strong dependence on oxygen level is noticed. The lower limit of O_{2f} was estimated on 1.39 ml/l for D region (Gdansk and Gotland Deep) and for 0.41ml/l for E region (Bornholm Deep). The limit for E region was correlated to much higher salinity (15.24 PSU) than in D region (10.84 PSU).

All mentioned notices indicate locally individualized relations between demersal fish densities and environmental background. Relationships observed for whole southern Baltic are partly dependent on horizontal migrations of fish along gradients of different factors values. Such a phenomenon is observed for many bottom and demersal fishes and it is reported in [4, 5, 8, 15]. This phenomenon gives an important reason to study mentioned migrations influencing potentially the results of groundfish estimates [1, 3, 9, 13] and causing heterogeneity of fish distribution.

The latest aspect of the studies described is joint with diel cycle of fish activities within near-bottom zone [2, 5]. One of most characteristic diel phenomena is vertical migration of fish, mostly joint with the light factor. The vertical migrations of fish in this area are described in [11, 16]. In the case of the demersal fish the light factor has be taken into consideration in relation to the bottom depth. In the southern Baltic the depth is not high and reaction to light can be expected in a high percentage of water column. Some vertical migrations can be also correlated to migrations of organisms forming a nutrient base of the these fishes.

In Fig. 7 we observe diel variability of S_v - the acoustic factor expressing the density of demersal fish within 3m layer over the bottom. Average values of S_v for 2h intervals were calculated for period of autumns 1995-2002 for three different bottom depth intervals: 0-60m, 60-80m, and 80-120m. Mathematical modeling was applied [11] and approximation curves of 3rd degree trigonometric polynomials were estimated for all depth ranges. Approximation errors were rather small (0.56-1.11%) what indicates high precision of the models used.

In all three depth zones diel instability of S_v is clearly seen. When depth is smaller (0-60m) – the difference between the day and night was the biggest (5.17 dB maximum difference). The factor was smaller for deeper zones (3.22 dB for 60-80m, and 4.00 dB for 80-120m). In two first zones diel rhythm of changes was showing three visible sub-periods, which can be directly correlated to sunrise (0600 hrs), midday (1200 hrs), and sunset (1700 hrs). The fish concentrations are more dense during night and midday time. Some delay of fish reaction on sunrise and sunset between 0-60m and 60-80m zones is observed. Increasing availability of fish in the demersal zone during the midday is reported in many groundfish surveys [3, 4]. For the deepest zone the most visible reaction appears in the midday hour. It is opposite in comparison to the 0-80m depth range.
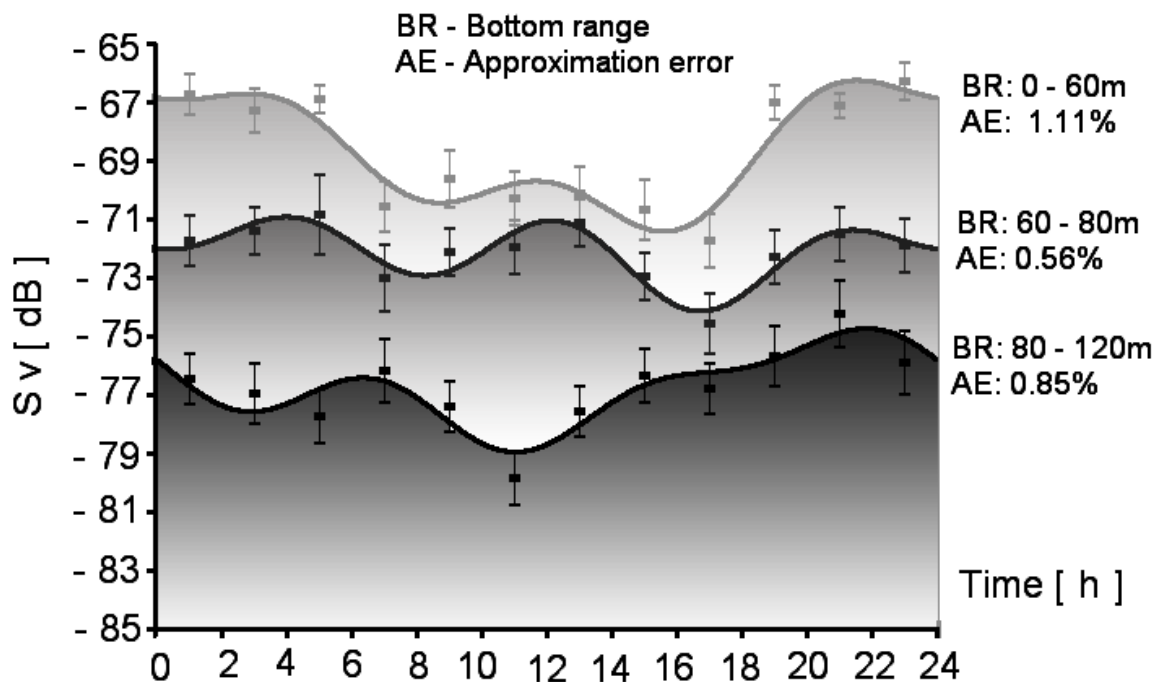
Fig. 7. Diel variability of fish densities in demersal zone expressed by S_v in 3m over bottom layer for three depth zones of the southern Baltic (autumns 1995-2002). Confidence intervals and average within 2h intervals shown for each curve.

Due to the fact that densities in the deepest zone are quite small – the most important is to take into consideration the variability of fish densities in demersal zone during a day. This phenomenon can influence strongly (more than 3 times) results of bottom trawl sampling. The reason of big difference in densities of fish observed by echo-sounder in the near bottom zone can be associated with two basic vertical processes: migration of fish between pelagic and demersal zone, and migration of fish from the dead-zone, in which they are not detected by echo-sounder [7, 11]. Preliminary acoustic reconnaissance in the area of the groundfish survey could effectively improve strategy of sampling and positively increase the accuracy of results.

Multi-directional analysis of acoustic and acoustically generated results describing the distribution of demersal fish and correlated environmental factors showed a wide chain of parameters which can produce significant heterogeneity of geographical patterns of fish resources. It was indicated that acoustic exploration could effectively enrich bases at which samples during the groundfish survey could be selected in the most representative strata.

REFERENCES

[1]   Anonymous, Report of the WG on Methods on Fish Stock Assessment, ICES, CM 2003/D:03, Ref ACFM,G, 1-138, 2003.

[2] R. S. K.Barnes, and Mann, K. H., Fundamentals of Aquatic Ecology, Blackwell Science, 1-270, Oxford, 1991.

[3] O. R. Godø: Factors affecting the reliability of groundfish abundance estimates from bottom trawl surveys, ch.9, 166-199 in: A. Fërno, Olsen, S. (eds.), Marine Fish Behaviour in Capture and Abundance Estimation, Fishing News Books, Oxford, 1994.

[4] O. R. Godø, , Michalsen K., Migratory behaviour of north-east Arctic cod, studied by use of data storage tags, ICES Journal of Marine Science, 48 (2), 127-140, 2000.

[5] G. S. Helfman, Colette, B. B., Facey, D. E., The Diversity od Fishes, Blackwell Science, 1-528, Oxford, 1997.

[6] H. P. Knudsen, The Bergen echo integrator: An Introduction, ICES Journal of Marine Science, 47 , 167-174, 1990.

[7] G. L., Lawson, Rose, G. A., The importance of detectability to acoustic surveys of semi-demersal fish, ICES Journal of Marine Science, 56(3), 370-380, 1999.

[8] J. Lloret, de Sola, L. G. , Souplet, A., Galzin R., Effects of large-scale habitat variability on condition of demersal exploited fish in the north-western Mediterranean, ICES Journal of Marine Science, 59(6), 1215-1227, 2002.

[9] K. Michalson, Godø, O. R., Ferno, A., Diel variation in the catchability of gadoids and its influence on the reliability of abundance indices, ICES Journal of Marine Science, 53 (2), 389-395, 1996.

[10] R. B. Mitson, Ona, E., Acoustic sampling and signal processing near the seabed: the deadzone revisited, ICES Journal of Marine Science, 53, 677-690, 1996.

[11] A. Orlowski, Acoustic methods applied to fish environmental studies in the Baltic Sea, Fishery Research., 34(3), 227-237, 1998.

[12] A. Orlowski, Acoustic studies of spatial gradients in the Baltic: Implication for fish distribution, ICES Journal of Marine Science, 56, 561-570, 1999.

[13] A. Orlowski, Influence of thermal conditions on biomass of fish in the Polish EEZ, Fishery Research., 63(3), 367-377, 2003.

[14] A. Orlowski, Acoustic semi-tomography in studies of the structure and the function of the marine ecosystem, ICES Journal of Marine Science, 60, 1392-1397, 2003.

[15] B. K. Stensholt, cod migration patterns in relation to temperature: analysis of storage tag data, ICES Journal of Marine Science, 58(4), 770-793, 2001.

[16] J. Szczucka, Acoustically measured diurnal vertical migration of fish and zooplankton in the Baltic Sea – seasonal variations, Oceanologia, 42(1), 5-17, 2000.