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Acoustic evaluating the Baltic fish behaviour

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ABSTRACT

Acoustic methods could play an important role in studies of fish group behaviour in relation to environmental factors, being one of the most promising tools of research of ecosystems. The paper presents new conceptions of treatment acoustic, biological and hydrological data collected during surveys of pelagic fish resources. A method of macrosounding was enriched by complex imaging of environmental factors for single transects. More developed version, called "matrix macrosounding", destinied for description of selected cross-sections, characteristic for the Baltic ecosystem, was introduced and examples of its application for short-term or long-term ecological studies were given. Basic diel fish environmental preferences were estimated owing to correlating acoustic and hydrological data collected over the period 1981-1996 in the southern Baltic. In a consequence, preliminary models of day life-cycle of fish in relation to main environmental factors were formulated and applied for fish behavioural studies. Examples of fish behaviour models, determined for the autumn are shown.

INTRODUCTION

Research on fish behavioural aspects becomes important from the point of view of complex ecosystems studies [13] likewise for fishery acoustics, in which behavioural changes of fish as an acoustic target plays an important role in the field of methods for fish biomass assessment [5, 11, 14]. Better knowledge of fish behavioural characteristics becomes necessary to avoid problems joint with other applications of acoustic technology in the sea. Some examples of specific applications of acoustics for fish bahavioural studies are described in [1, 2, 3, 6, 7, 8, 9, 12, 15] . It has been suggested [4] that acoustic methods may lead in marine ecosystem studies in the 1990s.

The most information on fish behaviour was previously collected by traditional net sampling or by underwater photography. The precision of such observations was very accurate but the volume of sampling was strongly limited. Many questions on better understanding of ecosystems could be explained if the volume of observations could significantly increase. Such a chance is given if acoustic sampling is carried out along profiles sufficiently long in a comparison with 3D ecosystem characteristics. To realize the mentioned task the paper suggests two methods of joint presentation of acoustic, biological and hydrological data: complex and matrix macrosounding.

If survey data are collected from significantly large spatial units of the echosystem - some behavioural reactions of fish can be estimated also. In the case when localization of fish (schools or single fish) is acoustically determined and intensity of reflected sound (target strength or volume scattering strength) is recorded - it is possible to correlate them with magnitudes of selected environmental parameters, simultaneously measured. On the basis of empirically reconstructed characteristics of fish environmental preferences, mathemathical models of fish behaviour can be formulated. Collation of models, estimated for different time or space parameters should significantly enrich the knowledge of fish behaviour due to ecosystem dynamics. The paper presents first examples of acoustically reconstructed preliminary models of day life-cycle of fish in relation to main environmental factors.

MATERIALS

During the period 1981- 1996 ships of the Sea Fisheries Institute in Gdynia carried out series of research cruises, collecting acoustic, biological and environmental materials, in the area of the southern Baltic. The first cruises were conducted during the summer and spring seasons and the last five cruises were organised during the autumn. Each cruise lasted approximately two weeks, and had the potential to collect data from more than one thousand of nautical miles of acoustic transect.

Acoustic samples (echo-integrations, echograms) were collected continuously, 24 hours a day, at frequency 38 kHz. Time distribution of samples was homogeneous, what gave a good base for analysis of diel fish behaviour characteristics. The acoustic magnitudes were collected over one mile intervals but the average for each 4 n.mi was taken as most representative to minimize autocorrelation effects for matrix macrosounding and for modeling the day life-cycle of fish [8].

Biological samples were collected at the average every 36 n.mi of acoustic transect and hydrological ones every 30 n.mi (approximately). Fish observed during mentioned surveys was mostly pelagic one, from the family Clupeidae (herring and sprat).

COMPLEX MACROSOUNDING METHOD

Method of macrosounding was introduced by the author of the paper firstly in 1989 [7, 10]. A method was based on computer transformation of acoustic data, collected over selected distance units, into graphical picture, showing a vertical distribution of fish targets and corresponding volume backscattering strength. Traditional echogram was converted by computer into graphical pattern, in which the density of dots within depth limits of fish occurence was directly proportional to volume backscattering strength. The main aim of the method was to give a synthetic presentation of fish distribution in the optional scale, matched to analysed phenomena. The chart of analysed situation was displayed at the monitor.

The macrosounding method was supplemented by adding all available characteristics of environmental factors, observed along the acoustic transect. Such a final method was called complex macrosounding. Its essence consists in numerical processing of the collected acoustic and hydrological data in such a way as to - on a selected route - generate average distribution of fish distribution against the background of the sea bottom profile and the isolines, expressing the pattern of temperature, salinity or oxygen level. Range of isolines is optional and have to be matched to the situation observed. Isoline steps can be read or saved as the files, what makes a systematical research process easier for standardization. For the same acoustic transect unlimited number of environmental analisis can be tracked.

The complex macrosounding method was directly destinied for analisis of environmental characteristics of fish stocks distribution. The method gives unlimited range of creating cross-sections, by linking (in optional sequence) geographic positions of survey distance units. Localization of them is taken from the cruise chart, generated by PC soft-ware, associated with the method.

MATRIX MACROSOUNDING

Multi-dimentional transects generated by complex macrosounding method were very illustrative for marine ecologists but comparability of macrosounding patterns among different cruises was strongly limited. Full comparability of cruise complex macrosounding pictures requires following the same geographic

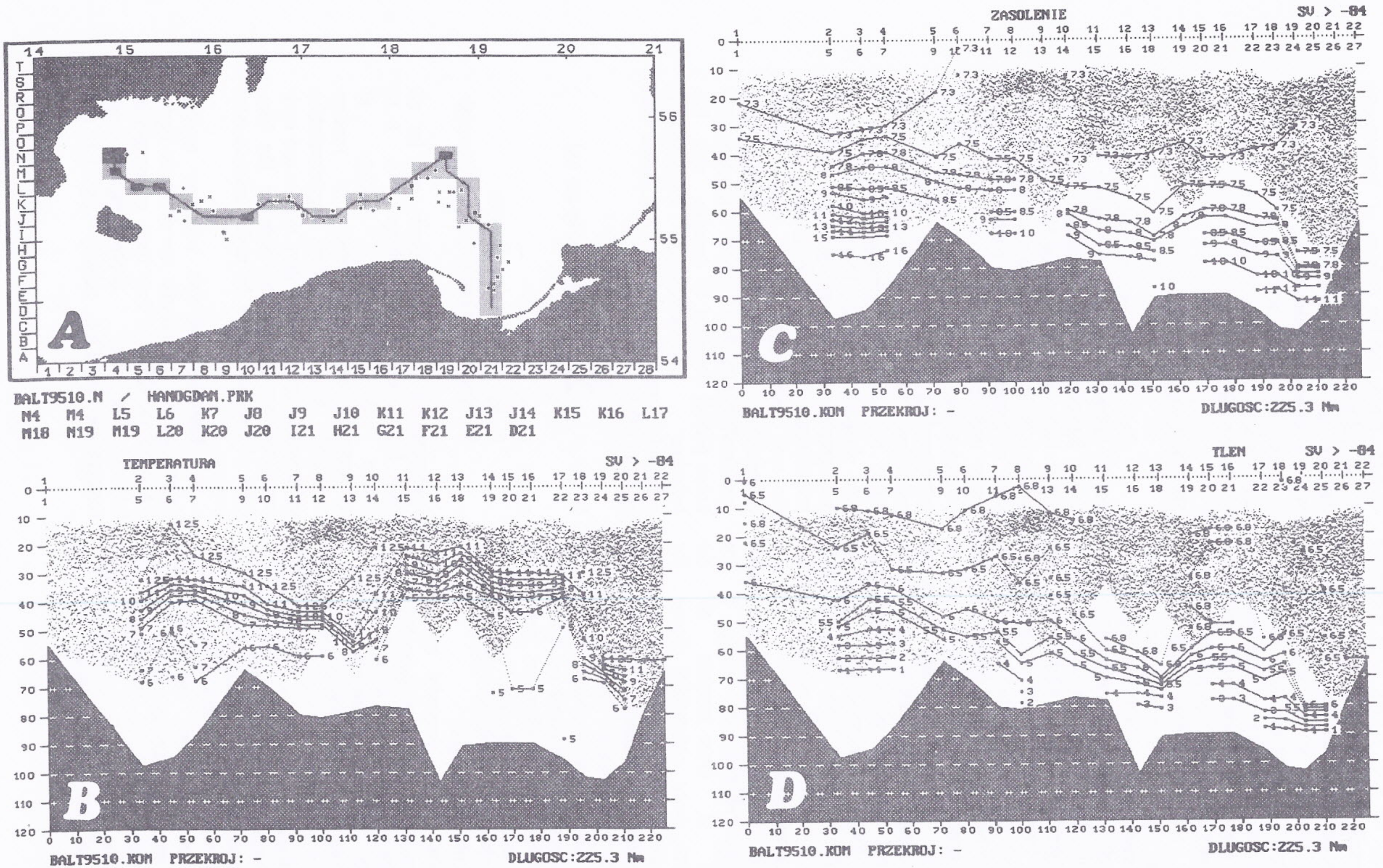

Figure 1. Basic characteristics of matrix macrosounding method: A – chart of standardized (or optional) cross-section selected for visualisation of vertical profile of fish and environmental factors distribution, B – night distribution of fish layers against the sea bottom profile and the isolines of temperature, C – night distribution of fish layers against the sea bottom profile and the isolines of salinity, D – night distribution of fish layers against the sea bottom profile and the isolines of oxygen level.

cross-sections for each survey. It is unpossible to keep exactly the same grid of profiles from cruise to cruise. As the fish distribution pattern during the day-time is not comparable with the night-one - degree of complication becomes higher, requireing keeping geographic and hour identity of cruise track each year. Such a demand is unpossible to satisfy.

In order to make more possible comparisons of multi-dimensional cross-sections, made during different surveys, a method of matrix macrosounding was proposed. In this case the whole surveyed area is divided into elementary units (rectangles) forming the matrix of columns and lines. For each elementary rectangle values of all factors, describing fish layers distribution and correlated environmental background can be estimated on the basis of cruise results and explicitly attached. If in particular case cruise data are not available within the elementary rectangle limits, interpolation could be performed. The value of bottom depth for each rectangle is constant and evaluated as the average from hydrographic charts.

Such a definition of a matrix macrosounding allowed for using it for visualisation of cross-sections of the surveyed area, being comparable among the other cruises. The cross-section would be chosen by entering coordinates of the series of elementary rectangles or by reading a selected file, corresponding to one of standardized profiles. Operations on cruise data for the matrix macrosounding are identical as for complex macrosounding, but the positions of track units should be identified with the centres of the elementary rectangles.

Figure 1.A-D. presents an example of matrix macrosounding image (transferred into black & white version) for the night-time during October 1995. The chart of the cross-section is given by elementary rectangles in Fig.1.A. The starting point is marked by a darker rectangle. The profile starts in Hanö Bay, spreads out to the East through the Bornholm Deep, Slupsk Sill, Slupsk Furrow, Slant Sill, South Gotland Deep, Gdansk Deep and Gdansk Bay. The transect is considered as the one of the most important ones for analysis of the Southern Baltic ecosystem. Its total length equalled 225 nautical miles. Figures 1.B., 1.C. and 1.D. show distribution of fish layers against the sea bottom profile and the isolines of temperature (1.B.), salinity (1.C.) and oxygen level (1.D.). Analisis of the pictures shown gives a wide range of unique conclussions on inter-reactions between the fish vertical and horizontal distribution and the fields of separate environmental factors.

FISH BEHAVIOURAL MODELS

Basic diel fish environmental preferences can be estimated owing to correlating acoustic and hydrological data collected during the cruise. Data over the period 1981-1996 in the southern Baltic were analysed and values of the basic environmental factors, as fish main depth, upper and lower limits of fish echoes. Temperatures, salinities and oxygen levels corresponding to mentioned depths were calculated. Values of environmental factors were estimated for acoustic data units (4 n.mi distance intervals), being the closest to hydrography stations only. Means of mentioned magnitudes for 2-hour intervals were calculated for each cruise and for their groups, representing different seasons. Taking into consideration periodical form of a function (24-hours period) destinied to describe diel fish behaviour characteristics, trigonometric polynomial approximation for the model was applied [12]:

$$T_m(x) = \sum_{k=0}^{m} (a_k \cos kx + b_k \sin kx)$$

where:

a_k, b_k - Fourier's coefficients,

m - degree of approximation polynomial

Approximations for each cruise and for all basic factors were calculated up to 6-th degree of polynomial. Analisis of aproximation errors (coefficients of random variation) allowed to limit approximation polynomials up to the third degree and such functions were applied for modeling the life-cycle of fish in relation to main environmental factors.

Examples of fish behaviour models, determined for the autumn are shown in Figure 2.A-D.Diel variability of four basic environmental factors: fish main depth (Fig.2.A.) and temperature (Fig.2.B.), salinity (Fig.2.C.) and

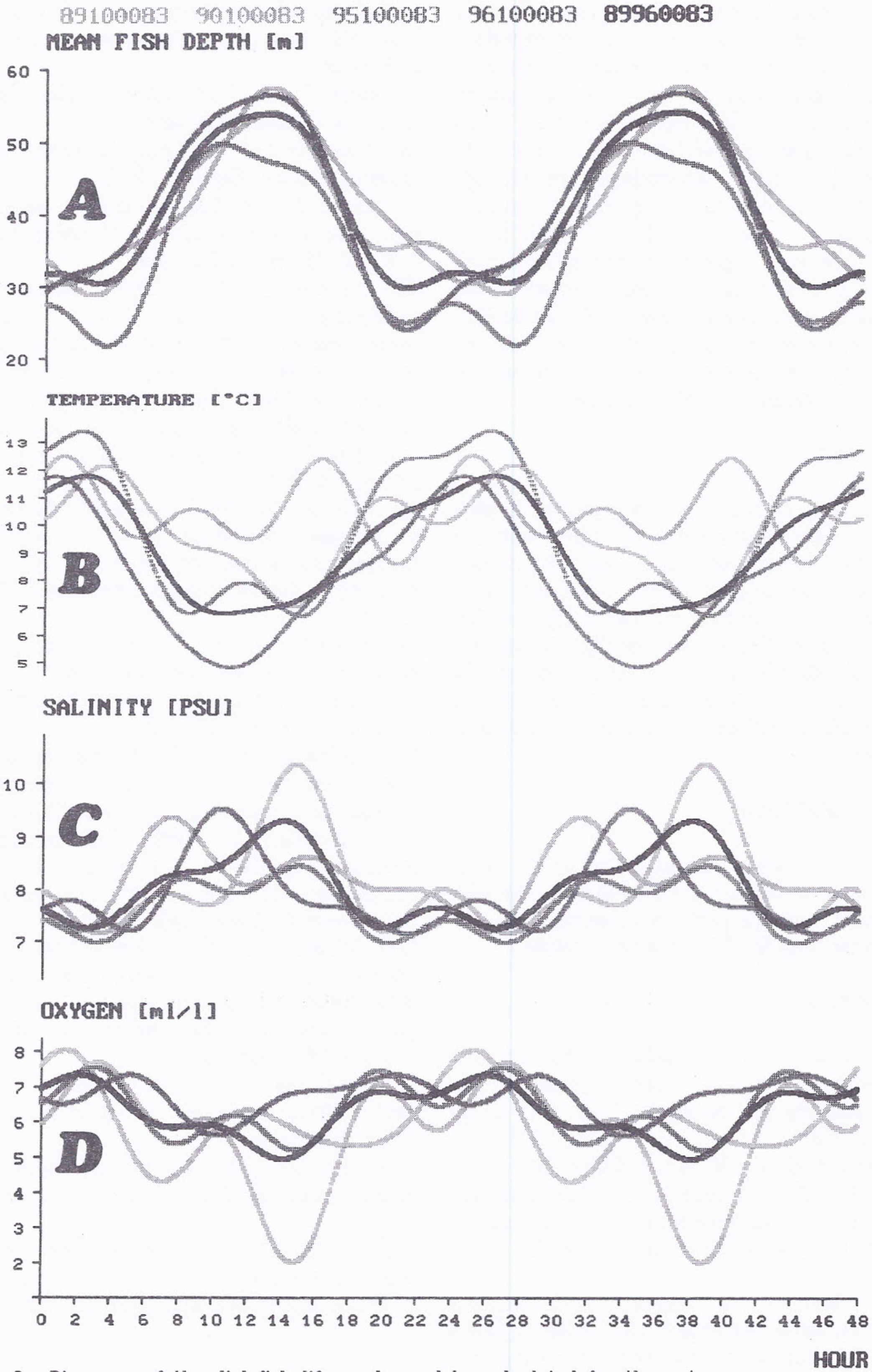

Figure 2. Diagrams of the diel fish life-cycle models, calculated for the autumn season over the period 1989–1996. A black curve model corresponds to the whole period 1989–96; grey curves, with increasing degree of grey tint, correspond to single cruises between 1989 and 1996. A – diel variability of main fish depth, B – temperature at the main fish depth, C – salinity at the main fish depth, D – oxygen level at the main fish depth.

oxygen level (Fig.2.D.), refering the fish main depth are shown by series of approximation curves. Grey curves, with increasing degree of grey tint, correspond to single cruises between 1989 and 1996. A black curve shows the model over the whole period 1989-1996. It is easy to realize, that fish preferences are strongly dependent on diel life-cycle and the models representing the period 1989-1996 (black curve) are very regular. On the other hand particular fish behaviour models shows strong variability for different years of observations. That phenomenon is closely dependent on variability of environmental structure of the Baltic ecosystem in particular years.

CONCLUSIONS

The main goal of this paper was to show that the fish behaviour can be determined and described widely with the help of acoustic methods. Few original such methods were proposed as destinied for different types of fish behavioural studies and for modeling the day-life cycle of fish. The utility of them should be clearly seen, particularly from the point of view of multi-directional ecosystem long-term research.

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REFERENCES

[1] Arnold G. P., J.D. Metcalfe, 1989: Acoustic telemetry: Progress and potencial in understanding fish behaviour. Proc. I. O. A., 11 (3), 96-103.

[2] Arnold G. P., M. Greer Walker and B. H. Holford, 1990: Fish behaviour: achievements and potential of high-resolution sector-scanning sonar. Rapp. P.-v, Cons. Int. Explor. Mer, 112-122.

[3] Aoki, I., T. Inagaki, 1992: Acoustic observations of fish schools and scattering layers in a Kuroshio warm-core ring and its environs. Fisheries Oceanography, Vol.1, No 1, 137-142.

[4] Holliday, D. V., 1993: Application of Advanced Acoustic Technology in Large Marine Ecosystem Studies, 301-319, in: Sherman K., L. M. Alexander, B. D. Gold. Large Marine Echosystems. AAAS Press, Washington.

[5] Huse I., R. Korneliussen, 1995: Diurnal variations in acoustic density measurements of wintering Norwegian spring spawning herring. ICES C.M. , B:12.

[6] Mass_, J., 1989: Daytime detected abundance from echo-surveys in the Bay of Biscay. Proc. I. O. A., Vol. 11, Part 3, 252-259.

[7] Orlowski, A., 1989: Zastosowanie akustycznych metod do badania rozmieszczenia ryb i warstw rozpraszajacych na tle srodowiska morskiego (Application of acoustic methods for study of distribution of fish and scattering layers vs the marine environment). Stud. Mater. Morsk. Inst. Ryb., Gdynia, ser. B, 57.

[8] Orlowski, A., 1989: Seasonal fluctuations of biomass distribution based on results of hydroacoustic surveys of the Polish fihery zone, Fish. Res., (Elsevier Science Publishers B. V.), 8, 25-34.

[9] Orlowski A.,1989: Application of acoustic methods to correlation of fish density distribution and the type of sea bottom. Proc. I.O.A., Vol 11, Part 3, 179-185.

[10] Orlowski, A., 1990: Macrosounding as a new concept in the study of marine ecosystems, Colloque de Physique c2 (n 2), Tome 51, 69-72.

[11] Orlowski, A., 1996: Diel variations of acoustic properties of the Baltic fish. in: Proceedings of the XIIIth Symposium on Hydroacoustics, Gdynia, AMW, 35-48.

[12] Ostrowski M., K. G. Foote, 1996: Acoustic portrait of herring in Vestfjord, January 1996, with geostatistical analysis. ICES C.M. H:31.

[12] Polozy, N., 1966: Metody przyblizonych obliczen. PWN, Warszawa.

[13] Sherman K., L. M. Alexander, B. D. Gold, 1993: Large Marine Ecosystems. AAAS Press, Washington.

[14] Simmonds, E., D. N. MacLennan 1995: Fisheries and Plankton Acoustics, J. Mar. Sc. 53 (2).

[15] Weston, D.E., H. W. Andrews, 1990: Seasonal sonar observations of the diurnal shoaling times of fish, J. Acoust. Soc. Am. 87(2), 673-680.