ACOUSTIC TRANSECTS AS CLASSIFICATION UNITS OF THE BENTHIC HABITAT

ANDRZEJ ORLOWSKI

Sea Fisheries Institute
Kollataja 1, Gdynia, Poland
orlov@mir.gdynia.pl

The benthic habitat consists from abiotic (physiotope) and biotic (ecotope) components. The physiotope is characterized by seabed and associated waters properties. They influence on diversity of the flora and fauna. This process is directly dependent on the physical and chemical characteristics of the physiotope and its spatial structure. In conclusion the analysis of the benthic habitat along selected transects becomes more reasonable than limitation of the information to the static units (statistical rectangles). The paper describes 12 selected acoustic transects of the southern Baltic. For each transect nine parameters representing values of acoustic and environmental parameters were calculated and analyzed on the base of data collected in the autumns in the period 1995-2003 aboard the R.V. Baltica. Four parameters were characterizing seabed, next three hydrologic properties of water in the demersal zone, and last two – fish distribution. The parameters were estimated with the resolution of one nautical mile. Detail analysis of statistical and spatial distributions of all parameters was applied to classify and to compare the transects.

INTRODUCTION

Each marine ecosystem is characterized by a number of static and dynamic factors playing an important role in forming its biotic and a-biotic functions. One of the most important and critical elements of the ecosystem is known as benthic habitat. This area represents the seabed and surrounding waters, together with populations of biological organisms [1, 3, 9, 17, 22, 24, 28, 29]. Due to special functioning of this zone its characterization has to related to static and dynamic features of the basic parameters. Spatial variability of those factors, expressed by gradients and radiuses of correlation, effectively influences the final distribution of biological organisms [1, 7, 10, 12, 14, 14, 18, 23, 24, 29, 30] . Taking this into consideration the author suggests to enhance the classification of the benthic habitat by introducing acoustic transects as quasi-linear units of the spatial variability of the features of the ecotope.

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 of the XX century [11, 15, 16, 18, 19, 25]. In 2005 the author [20, 21] introduced a new method applying acoustic information to distinguish seabed structure. The classification was provided by simple algorithm, based on normalized bottom echo length, extracted from 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 (θ'/2 – called theta) together with scattering mode, layers indicator, volume scattering strength, percentage of cod and hydrological factors were used to provide nine parameter classification of the bottom habitat in the southern Baltic. It was shown [19, 21] that acoustic information collected within demersal zone can be effectively utilised to provide 4D description of this ecotope, by joining acoustic, environmental and biological information. The paper indicate the way of classification of the benthic habitat by multi-parameter spatial and statistical analysis, related to selected transects.

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 Distance Standard Unit - EDSU), 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 [13] 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 n.mi. In total 8149 mile samples collected during 1995-2003 period were taken to create the data base.

The survey tracks of all cruises followed similar grid to give higher comparability of the measurements. Spatial density of the transects over the period 1995 to 2003 is shown in Fig.1. This pattern was taken into consideration to decide about the selection of transects for this research. In result of this analysis and by considering the functioning of the southern Baltic ecosystem twelve transects were extracted from the data (Table 1). For each transect 9 parameters were calculated from the data base for the resolution of one nautical mile, along the meridians, and 2 n.mi. or 3 n.mi. along the parallels, according to available sampling density. The detail characterization of the transects is given in Table 1. To obtain easy comparisons for verification of the procedures applied, two overlapping transects L-#1 and L-01, were determined.

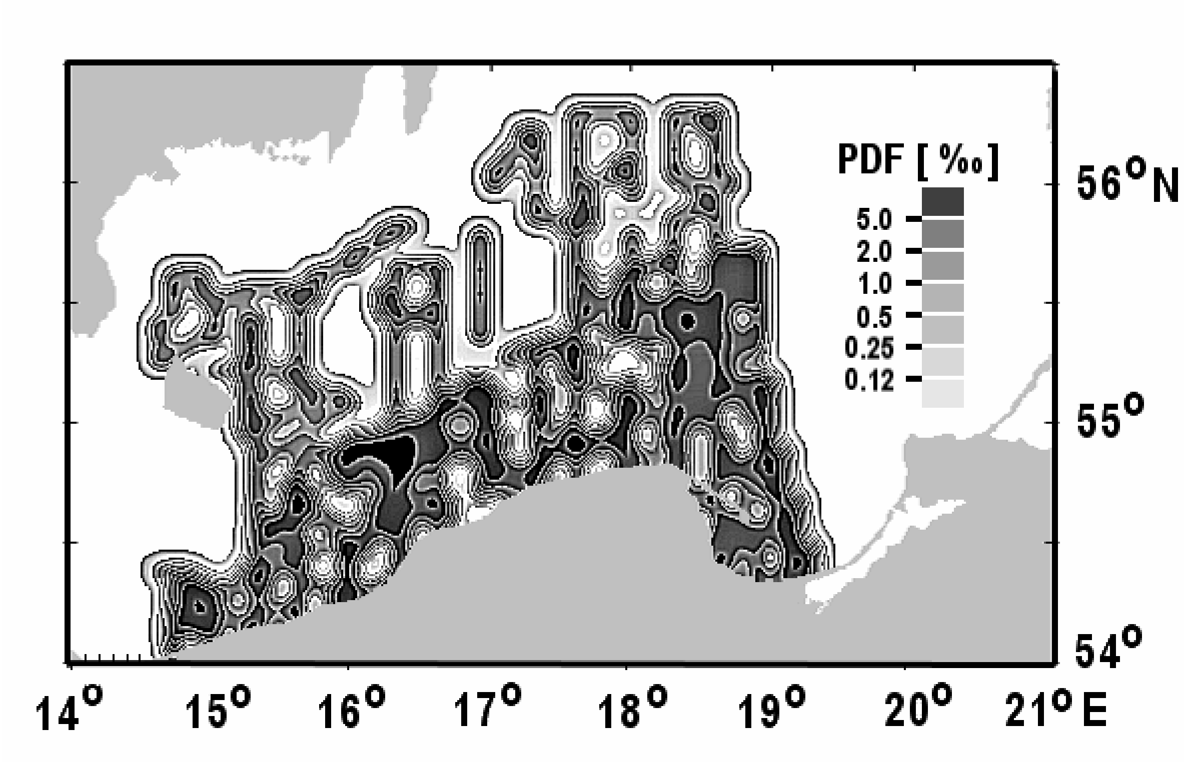

Fig.1 Spatial density of survey tracks of RV Baltica over 1995-2003

Tab.1 Geographical characterization of the transects selected for the analysis over the period 1995-2003 (autumn season)

No	Transect	Longitude Range [º N]		Length along meridian [n.mi.]	Longitude Range [º E]		Length along parallel [n.mi.]
1	F-01	5430	5541	71	1518	1524	3,4
2	F-03	5430	5531	61	1618	1624	3,4
3	F-03	5438	5551	73	1636	1642	3,4
4	F-04	5449	5534	45	1718	1724	3,4
5	F-05	5449	5557	68	1818	1824	3,4
6	F-06	5444	5550	61	1836	1842	3,4
7	F-07	5430	5553	83	1854	1900	3,4
8	L-#1	5508	5510	2	1518	1920	3x46
9	L-01	5507	5511	4	1518	1920	2x68
10	L-02	5512	5516	4	1518	1910	2x66
11	L-03	5503	5507	4	1518	1920	2x68
12	L-04	5459	5503	4	1518	1920	2x68

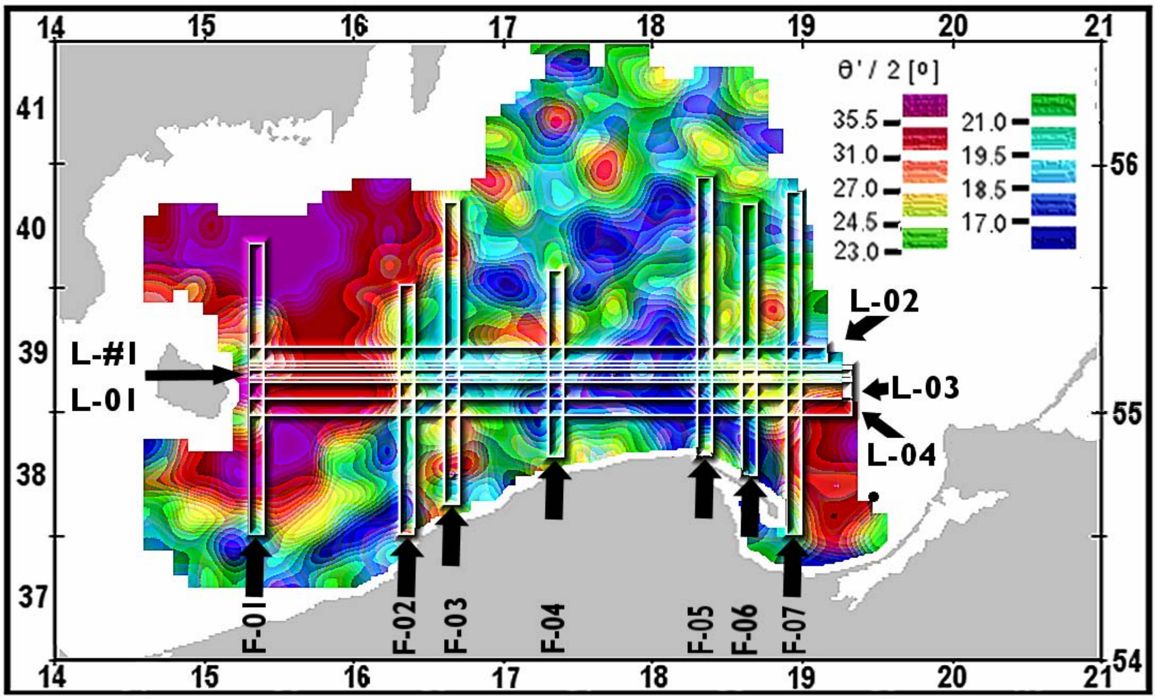

Fig.2 Localization of selected 12 selected transects (Table 1) over the distribution of theta parameter

1.2. HYDROLOGICAL BACKGROUND

Hydrologic measurements (temperature-T, salinity-S, and oxygen level-O2) 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 the measured parameters in 2m depth intervals.

For each unit of a transect the depth Dd (3m over the bottom) was calculated on the basis of the bottom depth. Values of temperature (Td), salinity (Sd) , and oxygen level (O2d) at the depth Dd were estimated by computer interpolation of hydrologic data collected during all autumn cruises. The method of calculations was described in [17, 18, 19].

1.3. ACOUSTIC SEABED PARAMETERS

Numerous methods based on acoustic measurements intend to provide description of the seabed properties [2, 4, 6, 7, 11, 15, 20, 21, 25]. Seabed in this research was described for each nautical mile unit by values of four factors: bottom depth, theta ($\Theta'/2$), scattering mode (M), and layers indicator (L).

The method of estimating the theta factor was introduced by the author in [20, 21]. Previously the author introduced application of multiple echoes measurements for evaluation of the seabed [15]. The main intention of the applied method, was to simplify classification procedure. The signal reflected from the seabed is characterized by the amplitude and the time duration. The time duration of the bottom echo τs is dependent on components resulting from pulse length, beam angle, scattering from the bottom and from reflections below the water-bottom interface. Value of τs depends on all mentioned components and increases with depth due to spherical spreading of acoustic wave. Application of τs for characterizing the seabed demands normalization of its value against the depth. The value of Θ'/2 angle was determined as one-dimensional parameter describing complex properties of the seabed and fulfilling the condition of normalization of τs against the bottom depth. The definition of the Θ'/2 angle is given by the formula (1):

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

where: Θ'/2 – parameter "theta", characterizing acoustic seabed properties,
τs - superposition of all seabed echo time components,
τ1 - component dependent on pulse length,
td - pulse travelling time (between transducer and seabed surface).
In addition two more factors were evaluated. Scattering mode M was estimated for each nautical mile from the echo-recordings. For echoes produced by strongly scattering bottom the factor was equal 1, while for the smooth bottom value of M was equal 2.

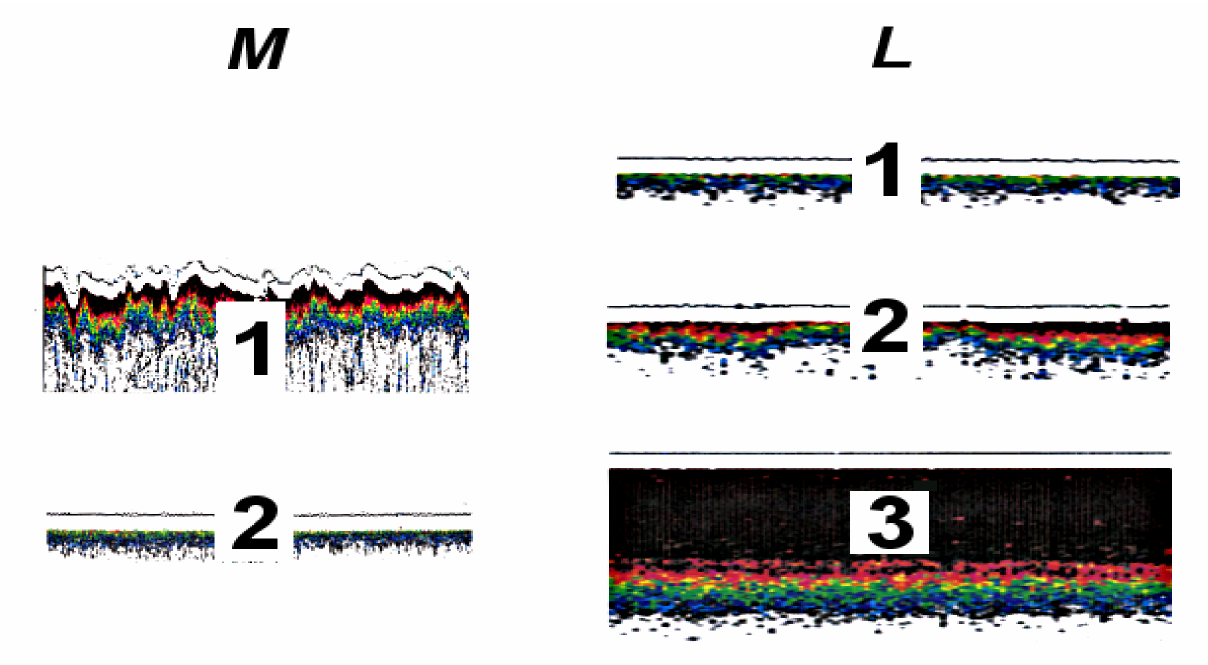

Fig.3 Classification of seabed by scattering mode M and layers indicator L

The value of layers indicator L was also estimated on the analysis of the echo-recordings. For simple seabed echoes the L value was assumed as 1, for partly layered echoes as 2. For continuously layered seabed the value of L was equal 3. The classification is simply presented in the Figure 3.

1.4. FISH DISTRIBUTION

The biological characterization of the demersal zone was limited to the pair of parameters. One of them has a stricly acoustic origin and expresses the volume density of the fish echoes within the transect. The echo integration for each EDSU was carried out in the bottom channel (3m layer over the bottom profile). The density of fish was measured as the average values of SA (area scattering strength in m2nmi-2) and Sv (volume back-scattering strength in dB re m-1sr-1).

The second parameter taken to characterize the demersal zone from biological point of view was the average percentage of the cod (C%) in the catches made during the surveys. The catches were reported each year in ICES statistical rectangles and the values for each EDSU was calculated due to the localization of the one mile unit.

1.5. CLASSIFICATION METHOD

At last nine parameters were determined and calculated for each one nautical mile distance unit in the data base for every transect (Figure 2, Table 1):
- bottom depth Dd+3m,
- theta parameter (Θ'/2) ,
- scattering mode M,
- layer indicator L,
- volume scattering strength Sv,
- percentage of cod C% ,
- temperature Td at 3m over the bottom,
- salinity over Sd at 3m over the bottom,
- oxygen level O2d at 3m over the bottom.

Characterization of the spatial structure of the selected parameters was made by calculation of the autocorrelation function and by determining the radius of correlation of each parameter at every transect. As the radius of correlation was considered the distance in which the autocorrelation of the samples was equal zero. The example of the basic set of data applied for further classification analysis is shown for the transect F-01 in the Figure 4.

The classification of the transects applied in this paper is based on comparison of two different classes of the indicators: spatial correlation and distribution range of the parameters values.

The first case corresponds to the spatial structure of the parameters listed above. Each transect was determined by radiuses of the spatial correlation of nine parameters.

The euklides distance was applied as the likeness factor of tested transects For each pair of transects the euklides distance between them was calculated by the 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 (9) of elements of 1 and 2 aggregation=transect,
Wp 1-2	- euklides distance between aggregation 1 and 2,
x1i, x2i	- elements of aggregation 1 and 2

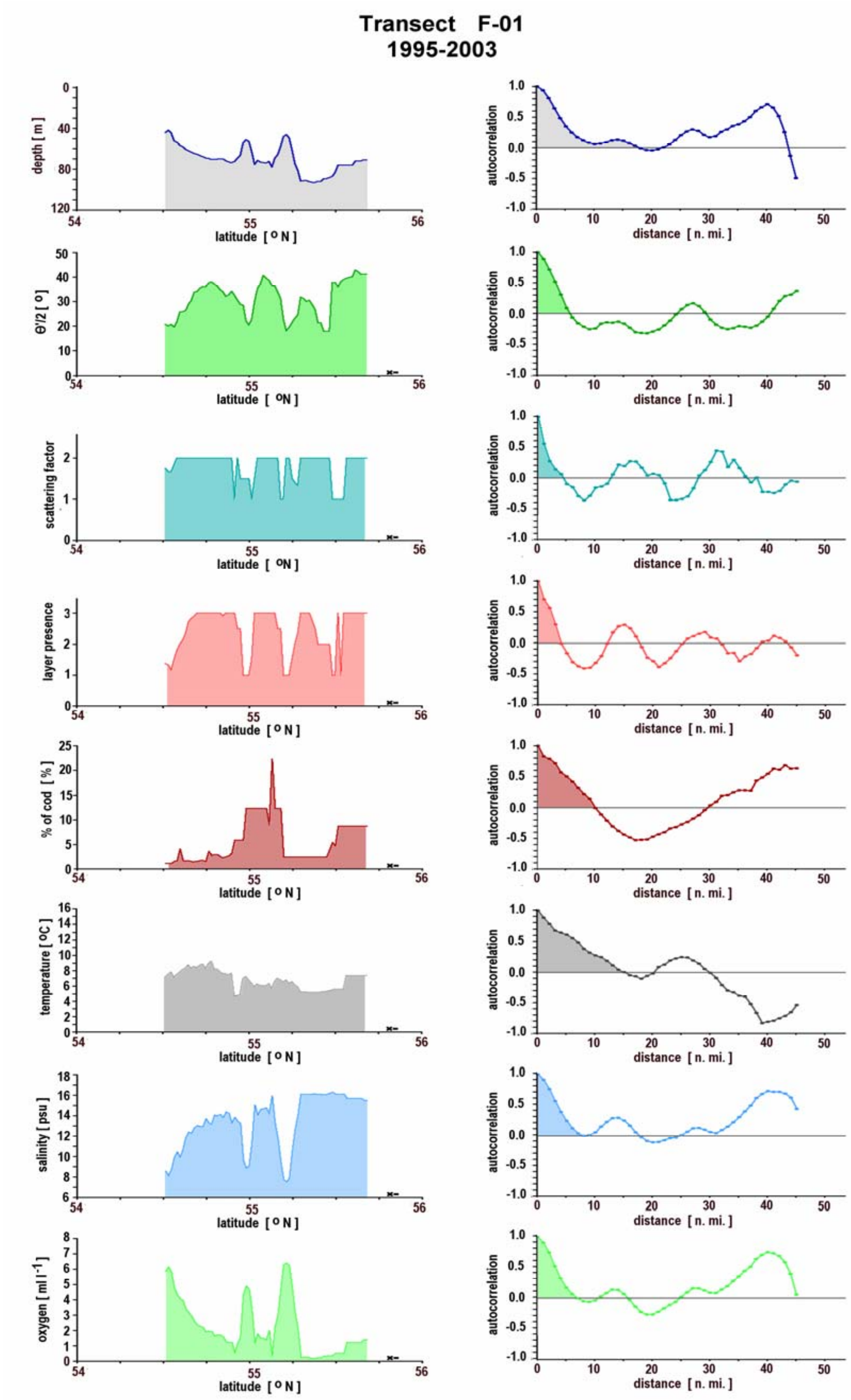

Fig.4 Patterns of characteristic magnitudes applied for classification of transectsects calculated for the transect F-01

Comparison of the statistical distributions of each parameter at every transect was realized by calculations of the euklides distance also. This comparison was not involving the distribution of the volume scattering strength Sv . The comparison of this parameter was considered as not reasonable, due to year by year fluctuations of fish resources in the demersal zone.
At last the comparison of the transects was based on estimation of the differences between the transects in:
A – spatial structure of bottom depth Dd+3m, theta parameter (Θ'/2), scattering mode M, layer indicator L, percentage of cod C% , volume scattering strength Sv, temperature Td at 3m over the bottom, salinity over Sd at 3m over the bottom, oxygen level O2d at 3m over the bottom,
and statistical distribution of:
B –bottom depth Dd+3m,
C -theta parameter (Θ'/2),
D -scattering mode M,
E -layer indicator L,
F- percentage of cod C% ,
G- temperature Td at 3m over the bottom,
H- salinity Sd at 3m over the bottom,
I - oxygen level O2d at 3m over the bottom.
In each singular comparison (A-I) the rank of each pair of the transects was identified as the position in the series of euklides distances ordered from the smallest to the greatest.
In example for A comparison of the spatial structure gave in result:
the smallest distance – rank = 1 for the pair L-#1 and L-01 transects,
rank = 2 for the pair L-03 and L-04 transects,
the biggest distance - rank = 66 for the pair F-06 and L-02 transects.
The global comparison was based on summing the ranks for all A- I combinations for each pair of the transects. The pairs were the most similar when the sum of the ranks was the smallest. The order of the ranks correspond to the order of similarity of the pairs. By selecting the types of parameters A-I we can limit the range of comparison according to the range of interest.

2. RESULTS AND DISCUSSION

In result of interpolation of all the data within the grid as shown in the Table 1 the autocorrelation radiuses for nine basic parameters were estimated and given in the Table 2. In the upper panel of the Table 2 are localized the transects along the meridians (symbol F), in a lower panel along the parallels (symbol L). Average values of the correlation radiuses for each parameter, and for all of them are given for two types of the transects (F & L) separately.

Observed range of the autocorrelation is strongly differentiated. The variability is observed among the transects and the parameters. For single transects the structure of each parameter is not dependent on the radius of the bottom depth autocorrelation. Such a situation is observed for the transect F-05. It means that the spatial structure of each transect is very individual and gives a good reason to identify the differences among them. It is important to underline, that the average radius of correlation for the transects along the meridians (F) is near two times smaller than for the transects along the parallels. This phenomenon is not associated with the structure of the bathymetry. The average radiuses of correlation for the bottom depth are very similar (20.6 n.mi. for F, 22.2 n.mi. for L transects), while average for all the parameters are 13.7 n.mi. for F, and 26.0 n.mi for L transects. This situation shows different spatial character of the natural forces forming the fields of observed parameters. One of such factors can be associated with the currents in the demersal zone. The bottom structure (theta parameter) is well correlated with the model of the currents presented by Kurths et al [12].

Tab.2 Autocorrelation radiuses of parameters analysed for different transects

Transect	Autocorrelation radius for parameters listed below [n.mi]									
	Bottom depth D_d+3*m*	*Theta* parameter (Θ'/2)	Scattering mode *M*	Layer indicator *L*,	Volume scattering strength S_v,	Percentage of cod $C_{\%}$	Temperature T_d	Salinity S_d	Oxygen level O_{2d}	Average
F-01	18	5.5	4.5	4	10	10	15	8	7	**9.11**
F-03	37	12	5.5	33	8.5	22	29	32	31	**22.7**
F-03	15	14	16	8	4.5	11	23	10	10	**12.4**
F-04	9.5	6.5	4	8.5	11	5.5	10.5	8.5	9	**6.0**
F-05	44	6.5	7	26	8	4	10	25	25	**17.3**
F-06	9.5	8	21.5	9.5	4	4	42.5	8	10	**13.0**
F-07	11	15	43	11	10	8	3	9	26	**15.1**
Average	**20.6**	**9.6**	**13.7**	**14.3**	**8**	**9.2**	**17.5**	**13.1**	**16.9**	**13.7**
L-#1	24	30	15	24	23	24	33	35	24	**25.8**
L-01	24	30	15	24	24	24	28	36	24	**25.4**
L-03	14	32	8	32	16	53	21	67	20	**29.2**
L-03	26	33	9	27	24	34	19	29	26	**25.2**
L-04	23	32	8	26	25	34	22	26	25	**24.6**
Average	**22.2**	**31.4**	**11**	**26.6**	**22.4**	**33.8**	**24.6**	**38.9**	**23.8**	**26. 0**

Application of the euclides distance to compare the spatial structure of the transects (comparison of all columns in the Table 2) gave in result following pairs as the most similar:

- L-#1-L-01 – euklides distance (ed) = 1.73
- L-03-L-04 – ed = 1.89
- F-01-F-04 - ed = 3.94 .

while the most different pairs were:

- F-06-L-02 - ed = 29.58
- F-07-L-02 - ed =29.34
- F-04-L-02 - ed = 28.23.

It is very obvious that the most similar were overlapping transects L-#1 and L-01, but it is very important to notify that the transects along the parallel L-03 and L-04, and two others, along the meridian F-01 and F-04 were spatially the most similar between themselves.

In the second step the comparison of spatial structure of the transects was enriched by comparisons of statistical distributions of the 8 parameters (B-I), characterizing seabed, environment, and cod distribution. This comparison was realized by calculation of the sum of the ranks of similarity for each pair of the transects. In result we obtain the table of the ranks for each pair of transects, where every column expresses the degree of similarity of each of all 9 factors. To avoid citation of the whole table the seven the most similar and seven the lowest similar pairs are given below.

Tab.3 Comparisons of seven most and lowest similar pairs of transects in relation to sum of ranks of 9 selected factors

Pair of transects	Bottom depth rank	Theta rank	Scattering mode rank	Layer indicato	Percentage of cod rank	Temperature rank	Salinity rank	Oxygen level rank	Autocorrelation rank	**Σ rank**
L-#1-L-01	1	2	4	3	3	4	1	1	1	**20**
L-03-L-04	3	3	1	1	8	16	10	7	2	**51**
L-#1-L-02	8	6	32	6	2	2	5	11	34	**106**
L-01-L-02	6	22	26	5	1	5	8	8	28	**109**
L-#1-L-03	29	5	13	16	10	12	15	4	9	**113**
L-01-L-03	30	26	21	25	36	13	9	3	5	**168**
F-03-F-04	4	11	29	27	41	15	6	19	22	**174**
The lowest similar pairs of transects										
F-04-L-02	42	12	52	64	56	34	57	53	64	**434**
F-01-F-06	62	64	58	50	47	57	59	25	17	**439**
F-06-L-04	56	56	49	31	27	60	64	44	58	**445**
F-07-L-04	59	52	37	55	5	61	63	63	56	**451**
F-04-F-07	60	37	23	66	54	64	66	66	21	**457**
F-06-L-03	57	59	53	33	57	53	51	47	59	**469**
F-04-F-06	58	62	44	53	63	63	65	62	18	**488**

It is not the surprise that the most similar transects identified in this approach are L-#1 and L-01. These transects were selected as overlapping and this fact is well verifying effectivity of the procedure applied. The same result was obtained also after application of the spatial analysis only.

The second most similar pair consisted from L-03 and L-04 transects (see Fig. 2 and Fig. 5). Both are localized along the parallels and run from the Bornholm Deep to the Gdansk Deep. The similarity of them is observed for most of the factors taken into consideration. The biggest difference between them is observed for the temperature in the demersal zone (rank 16 – Table 3). Comparison of the basic elements analyzed for this transects is given in Figure 5.

It is very significant that the biggest similarity is observed (Table 3) for the transects running along the parallels (6 pairs among the seven most similar). As we could observe before, those transects were characterized also by smaller spatial dynamics of the variability of selected parameters (autocorrelation radius). It means that the variability of the ecotope is much smaller along the East-West direction.

The most similar pair among the transects which run towards South-North direction is represented by F-03 and F-04. Both of them of them cross perpendicularly the Slupsk Furrow, through similar bathymetric profile. It can be concluded, that the area between them represents more stable zone of the benthic habitat.

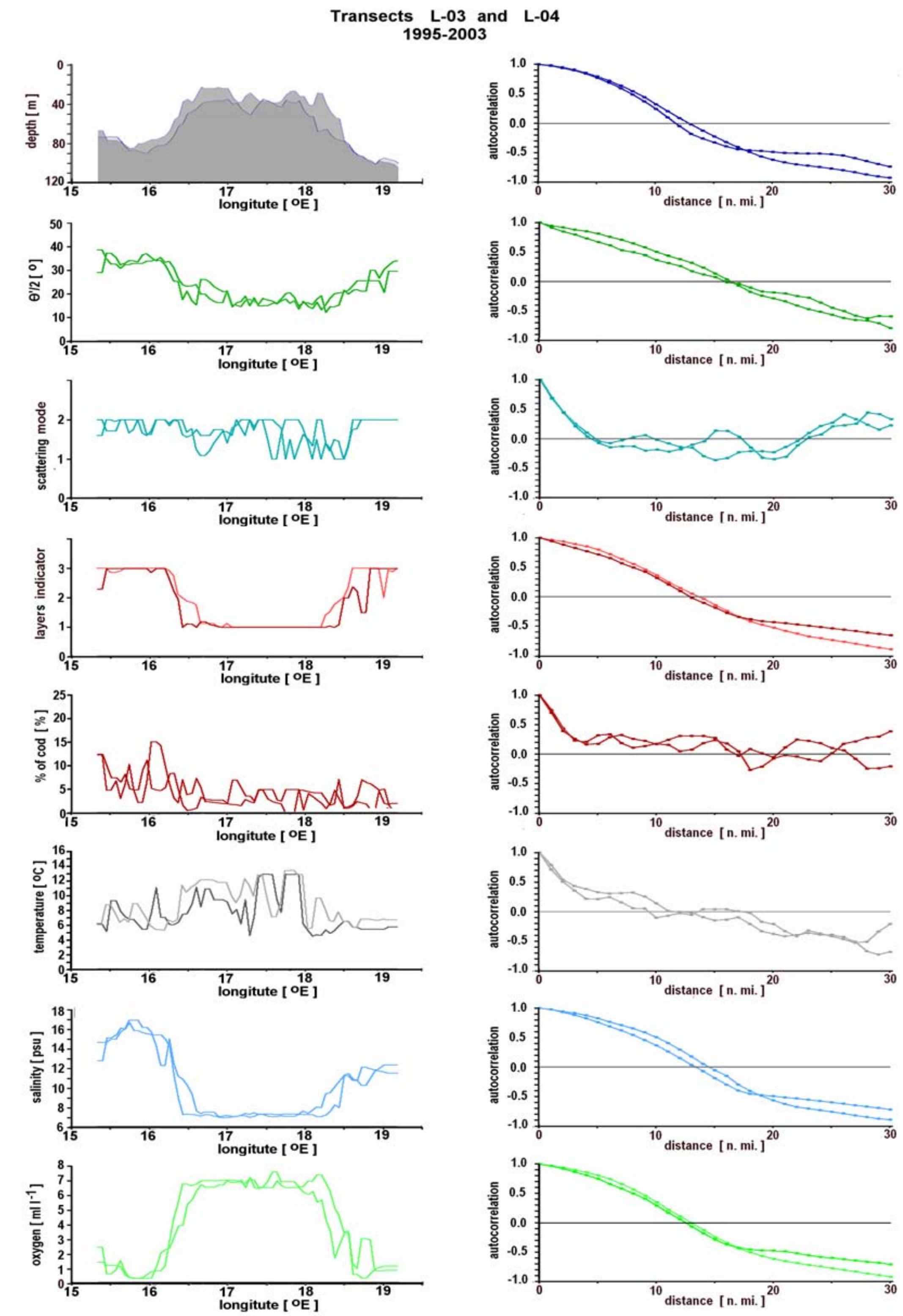

Fig.5 Comparison of transects L-04 and L-04 in relation to main considered factors

It is interesting to pay attention to the most different pair of the transects F-04 and F-06. First of them passes the Slupsk Furrow, while the second one is localized at the western slope of the Gdansk Deep. The transects are separated by parallel Slant Sill, the shallower area effectively differentiating the benthic environment.

3. CONCLUSSIONS

The application of acoustic, hydrologic, and biological information to characterize dynamics of the benthic habitat along the selected transects showed new opportunities for enriching the knowledge on marine ecotope. In the majority of papers the classification of the bethic habitat is not correlated to the spatial patterns of multi-disciplinary data. The importance of such a consideration is strongly underlined in [1, 9, 12, 14, 14, 22, 23, 27, 29]. The classification of the demersal zone usually achieved by acoustic measurements has to be enhanced by other factors, to cover most significant part of the spectrum of the ecotope characteristics. The knowledge on spatial correlation of those factors can be very useful in administration of the demersal zone and planning its research and conservation. This necessity is clearly seen in [9, 14, 14, 22, 24, 28, 30]. As an example can be given anticipation of time and space the spreading of the pollution [24, 27, 29].
The methods of research described above enable to provide observation much sensitive in relation to the spatial and temporal variability of the benthic habitat. It can be suggested to plan systematic monitoring of the basic factors associated with the functioning of the benthic habitat along the selected transects.

ACKNOWLEDGEMENT

I would like to thank Mrs Anna Kujawa for their contribution in providing the elaboration of the acoustic data due to estimation of *theta*, scattering mode and layers indicators.

REFERENCES

[1] J.Y. Aller, Benthic community response to temporal and spatial gradients in physical disturbance within a deep-sea western boundary region, Oceanographic Literature Review Volume: 44, Issue: 7, July, 736-737, 1997.
[2] J.T. Anderson, R.S. Gregory, W.T. Collins, Acoustic classification of marine habitats in coastal Newfoundland, ICES Journal of Marine Science, 59, 156-167, 2002.
[3] R.S.K. Barnes, K.H. Mann, Fundamentals of Aquatic Ecology, Blackwell Science, 1-270, Oxford, 1991.
[4] J. Craig Brown, A. Mitchell, D.S. Limpenny, M.R. Robertson, M. Service, N. Golding, Mapping seabed habitats in Firth of Lorn off the west coast of Scotland: evaluation and comparison of habitat maps produced using the acoustic ground-discrimination system RoxAnn and side sonar, ICES Journal of Marine Science, 62, 790-802, 2005.
[5] K.E. Ellingen, J.S. Gray, E. Bjørnbom, Acoustic classification of seabed habitats using QTC VIEW system, ICES Journal of Marine Science, 59, 825-835, 2002.
[6] R. Freitas, S. Silva, A. Rodriques, V. Quintino, Benthic biotopes remote sensing using acoustics, Journal of Experimental Marine Biology and Ecology, 339-353, 2003.
[7] R. Freitas, S. Silva, V. Quintino, A. Rodriques, K. Rhynas, W.T. Collins, Acoustic seabed classification of marine habitats: studies in the western coastal-shelf area of Portugal, ICES Journal of Marine Science, 60, 599-608, 2003.

[8] J. E. Hewitt, S.F. Thrush, P. Legendre, G.A. Funnel, J. Ellis, M. Morrison, Mapping of marine soft-sediment communities: integrated sampling for ecological interpretation, Ecological Applications, 14 (4), 1203-1216, 2004.

[9] A.J. Jaureguizar, R. Menni, C. Bremec, H. Mianzan, C. Lasta, Fish assemblage and environmental patterns in the Río de la Plata estuary, Estuarine, Coastal and Shelf Science Volume, 56, Issue: 5-6, April, 921-933, 2003.

[10] Z. Klusek, J. Tegowski, J. Szczucka, Characteristic properties of bottom backscattering in the southern Baltic Sea at ultrasound frequencies, Oceanologia, 36(1), 81-102, 1994.

[11] Ch. Kurths, W. Fennel, T. Seifert, Model studies of transport of sedimentary material in the western Baltic, ICES Journal of Marine Science, 52, 167-190, 2004.

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

[13] S. McClatchie, R.B. Millar, F. Webster, P.J. Lester, R. Hurst, Demersal fish community diversity off New Zealand: Is it related to depth, latitude and regional surface phytoplankton? Deep Sea Research Part I: Oceanographic Research Papers, Volume: 44, Issue: 4, April, 647-667, 1997.

[14] A. Nissling, U. Johansson, M. Jacobsson, Effects of salinity and temperature conditions on the reproductive success of turbot (Scophthalmus maximus) in the Baltic Sea, Fisheries Research, Volume: 80, Issue: 2-3, September, 230-238, 2006.

[15] A. Orlowski, Application of multiple echoes energy measurements for evaluation of sea bottom type, Oceanologia, 19, 61-78, 1984.

[16] A. Orlowski, 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, 1989.

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

[18] A. Orlowski, Acoustic reconnaissance of fish and environmental background in demersal zone in southern Baltic, Annual Journal: Hydroacoustics, Volume 7, Polish Acoustics Society, Gdańsk, 183-194, 2004.

[19] A. Orlowski, A. Kujawa, Acoustic reconnaissance of fish and environmental background in demersal zone in southern Baltic, Part 2 – Seabed, Annual Journal: Hydroacoustics, Volume 8, Polish Acoustics Society, Gdańsk. 127-146, 2005.

[20] A. Orlowski, Acoustic information applied to implement 4D environmental studies in the Baltic, Oceanologia, 48/04, 509-524, 2005.

[21] N. Prista, R.P. Vasconcelos, M.J. Costa, H. Cabral, The demersal fish assemblage of the coastal area adjacent to the Tagus estuary (Portugal): relationships with environmental conditions, Oceanologica Acta, Volume: 26, Issue: 5-6, November, 525-536, 2003.

[22] R. Rosenberg, A. Grémare, J.M. Amouroux, H. Nilsson, Benthic habitats in the northwest Mediterranean characterised by sedimentary organics, benthic macrofauna and sediment profile images, Estuarine, Coastal and Shelf Science Volume: 57, Issue: 1-2. May, 297-311, 2003.

[23] A. Serrano, A. Sánchez, F. Preciado, P. Izaskun, Santiago, I. Frutos, Spatial and temporal changes in benthic communities of the Galician continental shelf after the *Prestige* oil spill, Marine Pollution Bulletin Volume: 53, Issue: 5-7, 315-331, 2006.

[24] J. Tegowski, Acoustical classification of the bottom sediments in the southern Baltic Sea, Quarternary Inernational, Vol. 130, Issue: 1 153-161, 2005.

[25] Sz. Uścinowicz, J. Zachowicz, Geological chart of the Baltic 1:200000, Polish Geological Institute, Warsaw, 1991.

[26] C. Wienberg, A. Bartholoma, Acoustic seabed classification in coastal environment (outer Weser Estuary. German Bight) – a new approach to monitor dredging and dredge spoil disposal, Continental Shelf Research, 25, 1143-1156, 2005.

[27] T.M. Ward, S.J. Sorokin, D.R. Currie, P.J. Rogers, L.J. McLeay, Epifaunal assemblages of the eastern Great Australian Bight: Effectiveness of a benthic protection zone in representing regional biodiversity, Continental Shelf Research Volume: 26, Issue: 1, January, 25-40, 2006.

[28] L.D. Wright, L.C. Schaffner, J.P.-Y. Maa, Biological mediation of bottom boundary layer processes and sediment suspension in the lower Chesapeake Bay, Marine Geology Volume: 141, Issue: 1-4, September, 27-50, 1997.

[29] J. Zachowicz, R. Kramarska, Sz. Uscinowicz, The southern Baltic Sea – test field for international co-operation, Przegląd Geologiczny, vol. 53, 8/2, 38-743, 2004.