BACKSCATTERING PROPERTIES OF SOUTHERN BALTIC HERRING

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Reliable TS(L) relationship is required to improve acoustic algorithms of abundance estimation of Baltic herring. The relationships, empirically obtained in different parts of the Baltic Sea, produce up to 8 dB – difference in the herring TS. In order to develop an accurate TS(L) relationship, it is important to analyze factors controlling the TS variability. The possible impact of the regional difference in the swimbladder morphometry, critical in the backscattering by fish, should be considered. The paper is addressed to the numerical analysis of the backscattering properties of the southern Baltic herring. The input morphometric data for the modelling were obtained basing on the X-ray image collection of the herring individuals caught in the Polish coastal zone (ICES Subdivision 26) in November 2011. The optimal methodology of the morphometry study, including the fish catch, transport, storage and the X-ray analysis has been developed. The backscattering sensitivity to the fish morphometry and the width of fish orientation distribution was shown.

INTRODUCTION

Following the recommendations of the international organization of ICES, in order to effectively manage the Baltic clupeids resources, the remote acoustic methods of their abundance estimation are used (ICES Reports 2004, 2005a, b, 2006a). However, further use of the techniques requires their development towards improving the accuracy. The application of the acoustic techniques requires the accurate relationship *TS(L)* between fish total length (*L*) and its backscattering characteristics (target strength *TS*). The relationship is used to convert the collected acoustic data into the biological data (fish abundance and biomass) (MacLennan and Simmonds, 1992). In contrast to the Norwegian and North Seas, for which detailed modelling and experimental study was made and the accurate relationship has been obtained, it has not been done yet for the Baltic Sea.

The *TS(L)* relationship for Norwegian herring is used for the Baltic clupeids in the acoustic estimation of their biomass. In the Baltic Sea the relationship study included *in situ* measurements (Rudstam *et al*., 1988, 1999; ICES, 2000; Didrikas and Hansson, 2004;

Didrikas, 2005; Peltonen and Balk, 2005; Kasatkina, 2009) and numerical modelling of the acoustic wave backscattering by sprat and herring. (Gorska, 2007; Fässler *et al*., 2008; Fässler and Gorska, 2009; Gorska and Idczak, 2010). These studies showed that the target strength of the Baltic herring is higher than the target strength of the herring from the Norwegian and North Seas. The large (up to 8 dB) difference in the target strength of fish of a specific size from the different regions of the Baltic was also demonstrated. Further research of *TS(L)* relationship is required in the different areas of the Baltic Sea. Therefore, study of the *TS(L)* relationship for the southern Baltic Sea (ICES Subdivisions 24, 25, 26) is important.

The ICES Working Group FAST recommends the numerical modelling of acoustic wave backscattering by the Baltic herrings and sprats. Accounting for that the backscattering significantly depends on the shape of fish swimbladder (Blaxter and Batty, 1990), the data concerning the detailed swimbladder shape are required in the modelling. This motivates to the more detailed study of the swimbladder morphometry of the southern Baltic clupeids, to which this article is devoted.

The article presents the results of the study of the backscattering properties of herring from the Polish coastal zone (ICES Subdivision 26). The herring morphometric database was extended due to the improving the methodology of the obtaining herring individual X-ray images. The data were used as the input data in the modelling of the herring mean backscattering cross-section and the target strength. The target strength sensitivity to the fish length and the fish orientation distribution was demonstrated.

1. MATERIALS AND METHODS

The methodology of the study of the swimbladder morphometry of the southern Baltic herring individuals was developed in the frame of the project *Study of swimbladder morphometry of Baltic herring and sprat (development of measurement methodology)* financed by Polish Government (grant number G210-5-0499-0, the year of the realization – 2010). The conservation of the natural shape of the fish swimbladder was the main concern of the study. In the project, the input morphometric data for the modelling of the backscattering by herring individuals from the Polish coastal zone (ICES Subdivision 26) were obtained basing on the X-ray study of herring individuals. The project was a pilot study and the collection of the good quality X-ray images included only 28 herring individuals. In 2011, in the frame of the project *Study of the backscattering properties of Baltic clupeids (ICES Subdivision 26)*, (the project number 538-G210-0442-1, Polish Governmental funds) the study methodology was significantly improved and the collection of the good quality X-ray images was expanded (135 individuals). It is used in the study of the backscattering properties of the southern Baltic Sea herring.

1.1. X-RAY STUDY OF BALTIC HERRING

Study area and fish catch

In order to extend the herring X-ray image collection the 2011 year study was conducted in the same season (beginning of November). Fish were collected by the same way using a fishing boat HEL-125 and on the same area located southeast of the Hel Peninsula. The material was collected along the transect described by the geographical coordinates: 54°27.026' N, 19°02.745' E – 54°30.510' N, 18°57.036' E. (Fig. 1, transect AB). Herring and sprat were caught from an average depth of 15 m during about one and a half hour.

Fish transport and storage

240 herring individuals, which were in the best condition, were chosen for further research. The fish were located in the plastic bags filled by marine oxygenated water. After fish transporting to the Marine Station in Hel, they were placed into a large tank, where hydrological conditions were close to the natural marine environment. In the tank, herrings were kept from about 12 to 24 hours, before they were transported to the place of the X-ray study. This allowed the individuals to adapt to the changed hydrostatic pressure conditions. During the transport to the hospital, where the X-ray study was done, the fish were packed in the plastic bags (20 individuals per one bag) with marine oxygenated water.

Comparing with the 2010 year, the optimization of the fish transport and storage, significantly contributed to the improvement of the condition of herring individuals intended for the X-ray study. As the result, the larger collection of the high quality X-ray images of herring individuals was obtained. An image was classified as the good quality image if the shape of the fish swimbladder in this image wais similar to the natural.

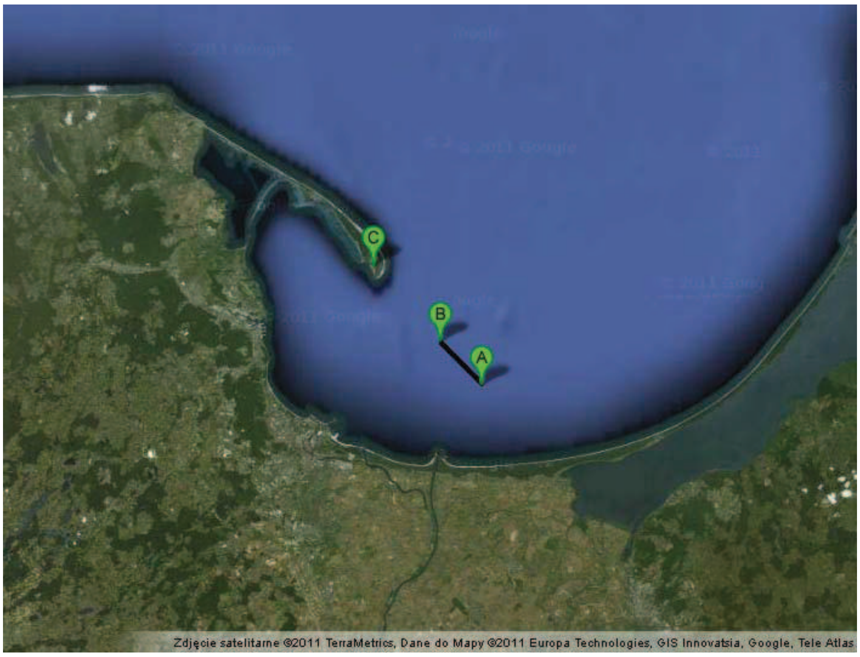

Fig.1. A-B – herring fishing area (November 2011); C – place of fish storage and X-ray analysis (Marine Station in Hel, 115th Military Hospital in Hel).

Fish preparation to X-ray study

The X-ray study of herring was made in the 115 Military Hospital at Hel and lasted for two days. 220 herring individuals (from the all 240 caught fish) were selected for the further research. The remaining 20 herring individuals were excluded, due to the significant deterioration of their condition. The X-ray study of the 136 and 84 herring individuals were performed during the first and second days respectively.

Before the X-ray analysis, fish were anesthetized using a solution of clove oil and 40%-ethanol (Nagababu and Lakshmaiah, 1992) to reduce their activity and then fish were placed on the table of the X-ray machine.

X-ray analysis

According to the previously developed methodology, two X-ray images for individual lateral and dorsal positions were made for each fish. The X-ray machine parameter settings were optimised: applied voltage = 42 kV, product of the current through the X-ray tube (mA) and the X-ray exposure time (s) = 1.2 mAs for the fish lateral position images and respectively: 42 kV and 1.6 mAs – for the fish in a dorsal position. Before performing the X-ray images, the metal number, visible on the X-ray images, was placed next to the studied fish in order of individual identification. The final product was the image on the X-ray membrane.

Measurements of fish morphometric parameters

The morphometric parameters of the fish body (total length, standard length, height and width) were measured just after the X-ray study. After the scanning the X-ray images (using a specialized scanner) and after the selecting the images in which the natural shapes of fish swimbladders were preserved, the swimbladder morphometric parameters were measured. In addition, the shift angles α between the axes directions of fish body and swimbladder were measured. The angle α, as well as the morphometric parameters of fish body and swimbladder, are important in the modelling the backscattering of acoustic waves by fish. By this way, morphometric data were collected for 135 herring individuals and subsequently used in the modelling study.

1.2. MODEL DESCRIPTION

Accounting for the differentiation of the individual orientations in respect to the direction of the incident acoustic wave in fish aggregations, the mean backscattering cross-section was expressed as:

$$\langle \sigma_{bs} \rangle = \int d\theta \, W_\theta(\theta) \left(\sigma_{bs}^{b} + \sigma_{bs}^{sb} \right), \tag{1}$$

where σ_{bs}^{b} and σ_{bs}^{sb} are the backscattering cross-section of fish body and swimbladder respectively; $W_\theta(\theta)$ is a probability density function described by the equation:

$$W_\theta(\theta) = \frac{1}{\sqrt{2\pi} S_\theta} \exp\left(-\frac{\left(\theta - \overline{\theta}\right)^2}{2S_\theta^2} \right), \tag{2}$$

where θ is the orientation of the fish body axis in regard to the incident acoustic wave ($\theta = 90°$ for broadside incidence), the parameters S_θ and $\overline{\theta}$ represent the standard deviation and the mean of the orientation distribution.

The solutions for the backscattering cross-sections of individual swimbladder (σ_{bs}^{sb}) and body (σ_{bs}^{b}) were obtained in the paper Gorska and Idczak, 2010 (Eqs. (1) and (4)) and were used in the analysis.

Using the definition of the target strength *TS* (Simmonds and MacLennan, 2005) and accounting for the fish orientation diversity in the aggregation, the target strength can be expressed as:

$$TS = 10 \log \langle \sigma_{bs} \rangle \, . \tag{3}$$

2. RESULTS AND DISCUSSIONS

Backscattering properties of the southern Baltic herring (ICES Subdivision 26)

Basing on the morphometric data obtained as it was described in the previous Section, acoustic properties of the southern Baltic clupeids were examined and the relationship *TS(L)* for fish from this area was determined.

There are no data on the width of the fish orientation distribution in the herring aggregation in the southern Baltic Sea. However, it was demonstrated that the target strength *TS* is strongly dependent on the width (Gorska and Ona, 2003). Therefore, it is reasonable to make the sensitivity analysis for the southern Baltic herring, assuming that the width varies from 5 to 20 degrees. Fig. 2 demonstrates the *TS(L)* relationships for the different width of fish orientation distribution (respectively 5°, 10° and 20°). The point data present the results of modelling for 135 individuals of herring caught in the Polish coastal zone respectively for the width of the fish orientation distribution equals to 5° (black points), 10° (red points) and 20° (blue points). Regression curves of *TS* vs. total length *L* (in cm) of the form $TS = m \log_{10} L + b$ were fitted to the modelled data for herring and sprat (the curve colours correspond to the point colours and differ for the different orientation distribution width).

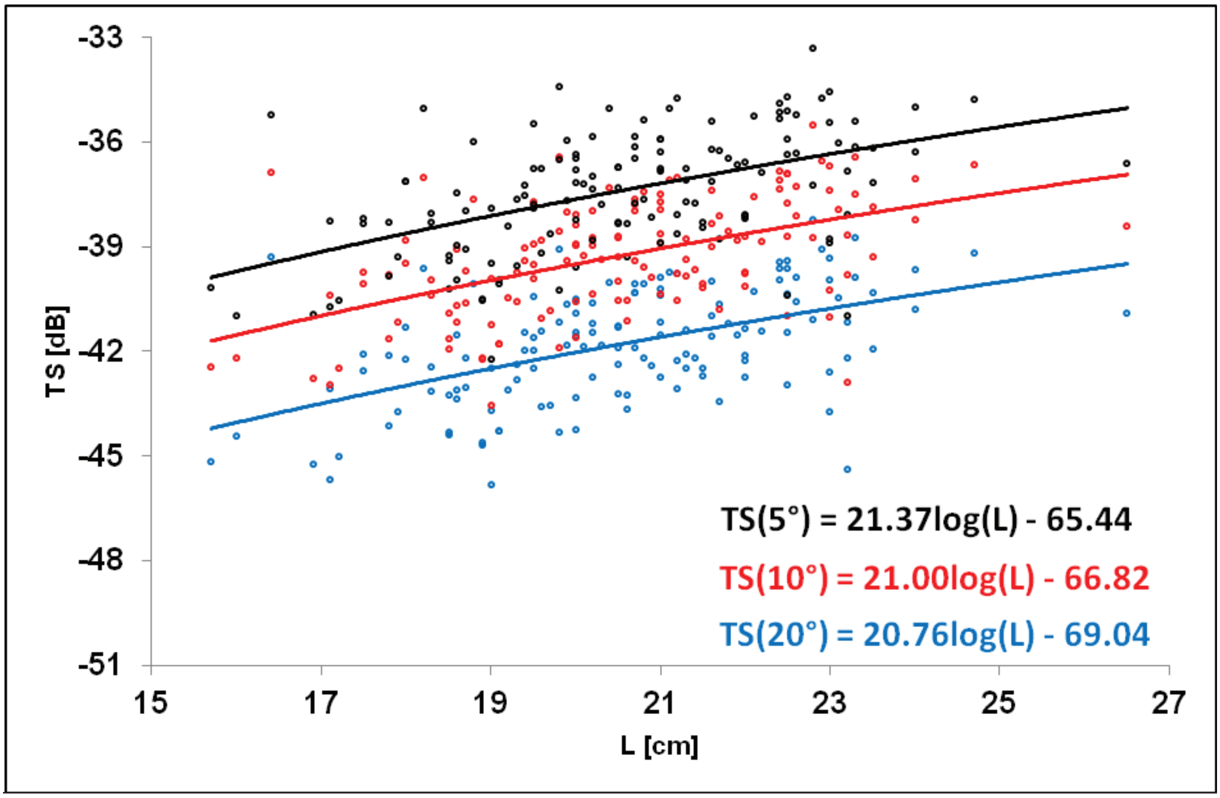

Fig.2. *TS(L)* relationships for the different width of the fish orientation distribution (5°, 10° and 20°).

The Fig. 2 demonstrates that the target strength *TS* decreases with the width increasing. For example: for 22-cm long fish the target strength, determined using the regression relationship *TS(L)*, equals respectively to -37 and -43 dB for the orientation distribution width equals to 5° and 20°. Therefore, the detailed examination of the width of the herring individual orientation distribution is important in order to properly determine the dependence of the *TS(L)* for southern Baltic clupeids.

Fig. 3 presents the comparison of the obtained *TS(L)* regression relationships, for the different width of the fish orientation distribution (blue curves), with the *TS(L)* relationships obtained for the clupeids from the other areas of the Baltic Sea (Rudstam *et al*., 1988; ICES, 2000; Didrikas and Hansson, 2004; Didrikas, 2005; Peltonen and Balk, 2005). In Fig. 3, the map of the Baltic Sea is presented in the right bottom corner. The map shows the areas, where the acoustic and biological data were collected. Using these data, the presented *TS(L)* relationships were obtained. The colour of the arrow on the map corresponds to the colour of the curve *TS(L)* obtained for the area.

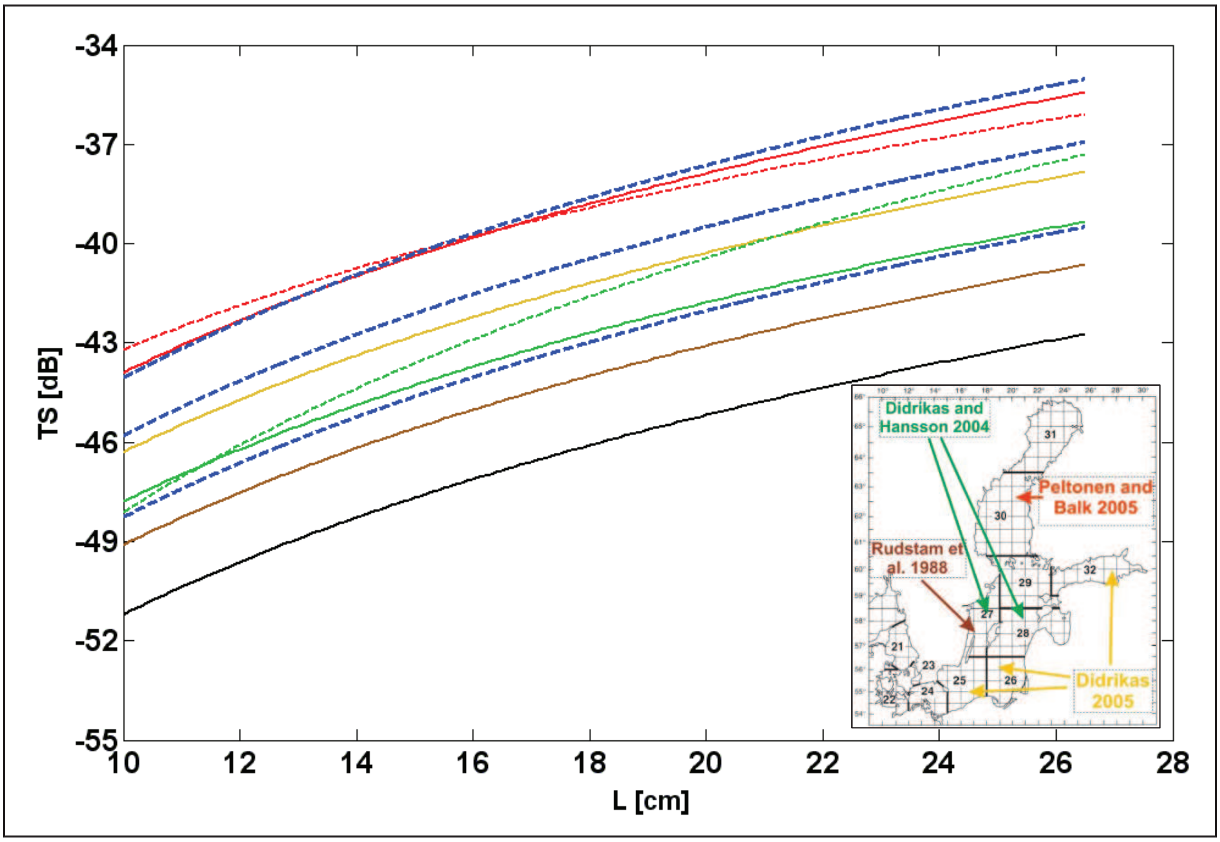

Fig.3. Comparison of the theoretical *TS(L)* relationships (for different width of the fish orientation distribution) with the empirically obtained *TS(L)* for the different parts of the Baltic Sea.

The comparison showed that for the 5° width orientation distribution the individual target strength is similar to the target strength of clupeids from ICES Subdivision 30 (Peltonen and Balk, 2005), while for 10°- and 20° width the *TS(L)* relationships are similar to those, which were obtained respectively in Subdivisions ICES 25, 26, 32 (Didrikas, 2005) and ICES 27 and 28 (Didrikas and Hanson, 2004). This comparison suggests that to explain the geographical variation in *TS(L)* relationships, the information about the orientation of aggregated herring individuals is important.

3. CONCLUSIONS

Basing on the improved methodology of the body and swimbladder morphometry study of Baltic clupeids, the existing collection of X-ray images of southern Baltic herring individuals (ICES Subdivision 26) was significantly expanded. According to the international ICES convention Poland is responsible for fish stock estimation in this subdivision. The database containing the morphometric fish parameters has been created.

Using the input herring morphometric data and modelling the backscattering of acoustic wave by herring individuals, the sensitivity of the target strength to the width of the fish orientation distribution was demonstrated. The *TS(L)* relationships were proposed for the different width of fish orientation distribution for herring from the Polish coastal zone (ICES Subdivision 26). The obtained *TS(L)* relationships were compared with the relationships obtained basing on the measurements in the other parts of the Baltic Sea. The comparison demonstrated that, in order to explain the variation the *TS(L)* relationships for the different Baltic Sea subdivisions, the information about the width of fish orientation distribution is critically important.

Using the obtained collection of the good quality X-ray images of herring individuals, the advanced backscattering model will be further developed, taking into account the accurate shape of the body and swimbladder of the southern Baltic herring individuals.

REFERENCES

[1] J.H.S. Blaxter, R.S. Batty, Swimbladder “behaviour” and target strength, Rapports et Procès-Verbaux des Réunions du Conseil International pour l’Exploration de la Mer, Vol. 189, 223-244, 1990.

[2] T. Didrikas, Estimation of in situ target strength of the Baltic Sea herring and sprat, Department of Systems Ecology, Stockholm University, Sweden, 1-5, 2005.

[3] T. Didrikas, S. Hansson, In situ target strength of the Baltic Sea herring and sprat, ICES Journal of Marine Science, Vol. 61, 378-382, 2004.

[4] S.M.M. Fässler, N. Gorska, On the target strength of Baltic clupeids, ICES Journal of Marine Science, Vol. 66, 1184-1190, 2009.

[5] S.M.M. Fässler, N. Gorska, E. Ona, P.G. Fernandes, Differences in swimbladder volume between Baltic and Norwegian spring-spawning herring: Consequences for mean target strength, Fisheries Research, Vol. 92, 314-321, 2008.

[6] N. Gorska, J. Idczak, On the acoustic backscattering by Baltic herring and sprat, Hydroacoustics, Vol. 13, 89-100, 2010.

[7] N. Gorska, On target strength of Baltic herring. Proceedings of 2007 ICES Annual Science Conference, Helsinki, Finland, 17-21 September, 2007, ICES CM 2007/H: 7 (CD-version), 2007.

[8] N. Gorska, E. Ona, Modelling the acoustic effect of swimbladder compression in herring. ICES Journal of Marine Science, Vol. 60, 548-554, 2003.

[9] ICES 2000, Manual for the Baltic International Acoustic Survey (BIAS), Version 0.72, Report of the Baltic international fish survey working group, ICES CM 2000/H:2, 119-143, 2000.

[10] ICES 2004, ACE Report of the Study Group on Baltic Fish and Fisheries Issues in the BSRP (SGBFFI), ICES CM 2004/H:04, Riga, Latvia, 2004.

[11] ICES SGBFFI Report 2005a, ACFM, ACE Report of the Study Group on Fish and Fisheries Issues in the BSRP (SGBFFI), ICES CM 2005/H:05, Riga, Latvia, 2005.

[12] ICES SGMAB Report 2005b, Report of the Study Group on Multispecies Assessment in the Baltic (SGMAB), ICES CM 2005/H:06, Riga, Latvia, 13-17 June, 2005.
[13] ICES SGBFFI Report 2006a, ACFM, ACE Report of the Study Group on Fish and Fisheries Issues in the BSRP (SGBFFI), ICES CM 2006/BCC:03, Vilnius, Lithuania, 2006.
[14] S.M. Kasatkina, The influence of uncertainty in target strength on abundance indices based on acoustic surveys: examples of the Baltic Sea herring and sprat, ICES Journal of Marine Science, Vol. 66, 1404-1409, 2009.
[15] D.N. MacLennan, E.J. Simmonds, Fisheries Acoustic. Chapman & Hall, London, 325, 1992.
[16] E. Nagababu, N. Lakshmaiah, Inhibitory effect of eugenol on non-enzymatic lipid peroxidation in rat liver mitochondria, Biochemical Pharmacology, Vol. 43, 2393-2400, 1992.
[17] H. Peltonen, H. Balk, The acoustic target strength of herring (Clupea harengus L.) in the northern Baltic Sea, ICES Journal of Marine Science, Vol. 62, 803-808, 2005.
[18] L.G. Rudstam, S. Hansson, T. Lindem, D.W. Einhouse, Comparison of target strength distributions and fish densities obtained with split- and single-beam echosounders, Fisheries Research, Vol. 42, 207-214, 1999.
[19] L.G. Rudstam, T. Lindem, S. Hansson, Density and in situ target strength of herring and sprat: a comparison between two methods of analyzing single beam sonar data, Fisheries Research, Vol. 6, 305-315, 1988.
[20] E.J. Simmonds, D.N. MacLennan, Fisheries Acoustics: Theory and Practice, Blackwell Publishing, Oxford, 437, 2005.