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ENVIRONMENTAL EFFECT ON ACOUSTIC MEASUREMENTS OF BALTIC FISH (PART 2)

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Behaviour of fish is one of most potential sources of bias in fisheries acoustics. The paper describes methods and results of analyses of unique acoustic, hydrologic, and biologic data base collected by RV "Profesor Siedlecki" and RV "Baltica" in the southern Baltic in the autumns 1994-2000. In comparison to the first part of the paper, presented in 2000, the influence of fish behaviour was examined separately in two different and specific sub-areas. On the basis of numeric models of measurements, interactions between environmental and behavioural factors and fish acoustic response for two different circumstances have been estimated and classified. Significant influence of environmentally modulated fish behaviour on effective value of the acoustic back-scattering cross-section was described and discussed.

1. INTRODUCTION

Fish back-scattering cross-section σ, being also known as a target strength TS, represents the most important but not too precise [2] multiplier in biomass assessment. It was shown [9, 10] that in the southern Baltic that fish acoustic response has been significantly varying within a diel cycle. The ICES Working Group on Fisheries Acoustic Science and Technology has confirmed during the meeting in Haarlem [1] in 2000 that fish behaviour is one of most potential sources of bias in fisheries acoustics and has recommended studies of σ measurements due to diel effect of fish behaviour. The main aim of the paper is to estimate, following conclusions presented in [10], when and which factors could play more significant role in diel variability of σ. Two more specific and biologically stabilized but different between themselves sub-areas of the southern Baltic were selected with a task to observe local differences in relationship among σ and adequate physical factors of fish environment, depending on behavioural reactions.

2. MATERIALS AND METHODS

Data for this investigation were collected during cruises of RV "Profesor Siedlecki" and RV "Baltica", conducted in October in the southern Baltic in the years 1989-2000. Each cruise lasted three weeks and had a potential to collect data from approximately 1-1.5 thousand nautical miles of acoustic transect. Samples were collected continuously, every one nautical mile, 24h a day. The time distribution of samples in relation to the whole period of studies was homogeneous to give a good base on which to analyse the diel characteristics of fish echoes. Measurements of S_a [6], corresponding to the whole water column, were collected over one mile intervals. Average for 3-5 nautical miles were taken as more representative ESDU to minimize auto-correlation effect. Acoustic system was calibrated with a standard target. The same hull-mounted transducer 7.2° x 8.0° was used in the studies. Hydrologic samples were collected by Neil-Brown CTD system approximately every 35 n.mi. Sample trawls were made with a similar frequency. Fish observed during all surveys were mostly pelagic, herring and sprat (Clupeidae). Two specific areas (see Fig.1 and Table 1) were selected from acoustic data base with a purpose to find local differences in diel variability of observed factors. First area (**R**) corresponded to the Bornholm Basin, the second (**U**) was associated with the South Gotland Deep.

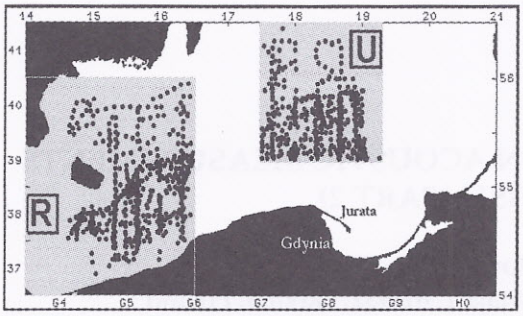

Figure 1. Areas of acoustic studies.

AREA	R		U	
ESDU N°	617		506	
Mean depth [m]	63.8		82.8	
Herring [%]	50.6		42.9	
Sprat [%]	41.7		51.9	
Cod [%]	7.6		5.1	
	Night	Day	Night	Day
Df [m]	33.3	47.3	32.3	57.2
Tf [°C]	10.4	7.7	10.1	5.9

Table 1. Basic features of areas of research.

Mean depth of fish biomass gravity centre (D_f) was calculated and verified with echograms. Values of temperature T_f at D_f depths were estimated for each ESDU in radius of 20 n.mi. from equivalent CTD stations. Equivalent CTD stations were calculated for regular grid (0.5°N x 1.0°E) on the basis of all CDT data inside each rectangle. Means of S_a, D_f and T_f for 1.5-h intervals of a day were calculated for the whole period 1989-2000, assuming that samples were dispersed randomly from a geographic and bathymetric point of view. Following the homogeneous time distribution of samples and taking into consideration periodical form of approximations, trigonometric polynomial functions for modeling were applied [3] and approximations curves $S_a(t)$, $D_f(t)$, and $T_f(t)$, were calculated. Influence of salinity and oxygen level were neglected due to conclusions given in [10]. Comparison of approximation errors (coefficients of random variation) and a smoothing effects let to limit modelling polynomials up to 4-th degree. On the basis of time dependent approximations relationships between $(S_a(t)/\langle S_a \rangle)$ and $D_f(t)$ and $T_f(t)$ were regenerated with step 0.1h, constituting a main result of research. Approximations of $S_a(t)$ were normalized in relation to diel average value $\langle S_a \rangle$ to make a comparability clear. Due to all assumptions made it is considered that variability of normalized $S_a(t)/\langle S_a \rangle$ can be interpreted as a relative diel variability of equivalent $\langle \sigma_n \rangle = \sigma(t)/\langle \sigma \rangle$, where $\langle \sigma \rangle$ is diel average value.

3. RESULTS AND DISCUSSION

In Fig. 2 are given diagrams expressing average (1989-2000) diel variability of $S_a(t)$ for two areas of studies. Approximation curves shows similar pattern of modulation in time but a dynamic range of S_a variability is much greater for the **U** area. Highest $S_a(t)$ values were observed during the night time, with a peaks around the midnight and closely to the sunset hour (0600). Ratio between extreme values of $S_a(t)$ achieved value 2.11 in area R and 3.10 in

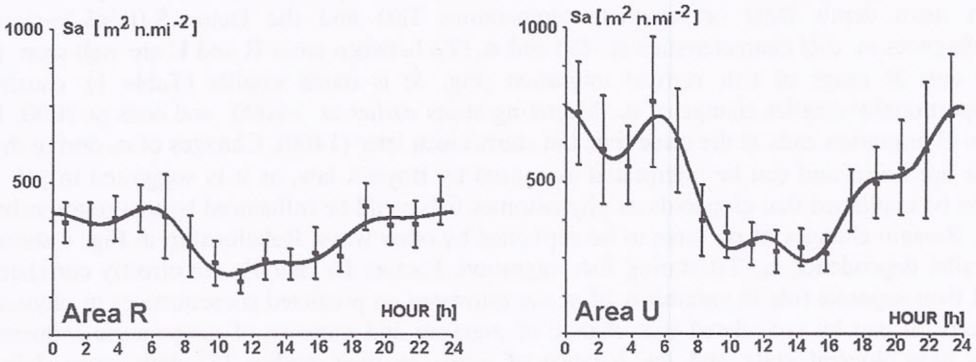

Fig. 2. Curves expressing approximations of diel variability of S_a mean values in 1.5h intervals in two areas (**R** and **U**) of studies (1989-2000). Experimental values and limits of confidence intervals shown.

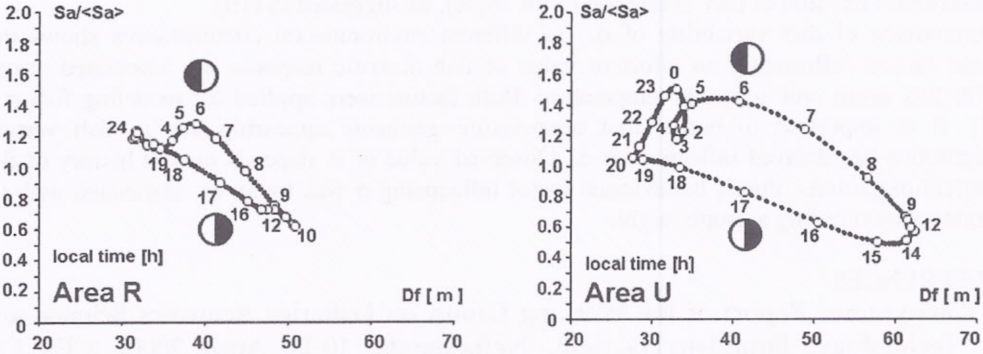

Fig. 3. Relation between relative fish acoustic response expressed by $S_a/<S_a>$ and main fish depth over 24-h period in two areas (**R** and **U**) of studies (1989-2000). Local time, sunrise and sunset moments marked.

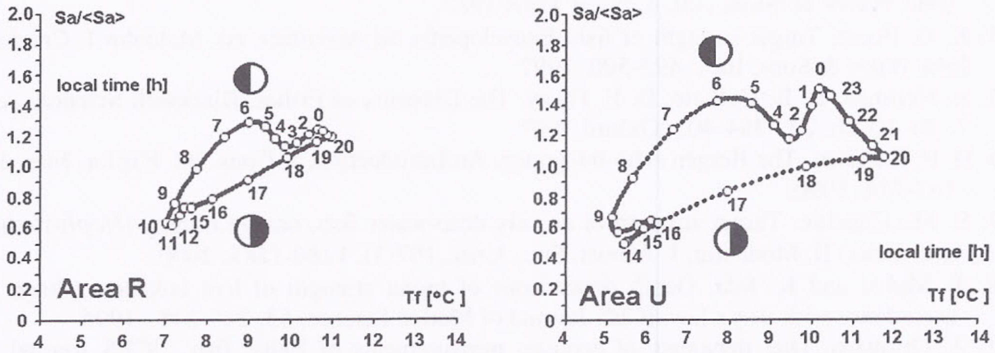

Fig. 4. Relation between relative fish acoustic response expressed by $S_a/<S_a>$ and temperature at fish main depth (T_f) over 24-h period in two areas (**R** and **U**) of studies (1989-2000). Local time, sunrise and sunset moments marked.

area **U**. Figures 3 and 4 present final results of research, expressed by relationships between fish main depth $D_f(t)$ or adequate temperature $T_f(t)$ and the factor $S_a(t)/<S_a>\sim<\sigma_n>$. Differences in diel characteristics σ_n (D_f) and σ_n (T_f) between areas **R** and **U** are well seen. In the area **R** range of fish vertical migration (Fig. 3) is much smaller (Table 1), causing proportionally smaller change of σ_n. Migrating starts earlier at ~1000 and ends at 2000. In area **U** migration ends at the same time but starts much later (1400). Changes of σ_n during that time are linear and can be interpreted as caused by Boyle's law, as it is suggested in [8]. It must be explained that clupeoids as physostomes fish could be influenced by that relationship [4]. Remain changes of σ_n have to be explained by other ways. Relationship in Fig. 4 shows parallel dependence σ_n (T_f) during fish migration. Factors D_f and T_f are directly correlated and their separate role in variability of σ_n can estimated on predicted consequences of physical factors. It can be considered that change of pressure and increase of temperature influence fish physiological state and the balance of gases in their bodies [5] with some delay, increasing σ_n during the night, what is clearly seen for area **U** (greatest D_f and T_f change) between 2000-0000. The same phenomenon could be taken into consideration due to observed hysteresis of σ_n for the same depth but different migration directions. Decrease of σ_n after the midnight and increase before the sunrise in both areas can be explained by behavioural reaction of fish (variation of tilt angle), as suggested in [10].

Comparison of diel variability of σ_n in different environmental circumstances shows that main factors influencing an effective value of fish acoustic response are associated mostly with fish depth and adequate temperature. Both factors were applied for modeling fish σ in [7]. It is important to notice that temperature gradients appearing due to fish vertical migrations has delayed influence on σ_n. Observed value of σ depends on full history of fish vertical migrations. Purely behavioural factor influencing σ was found as associated with tilt angle rotation during a proper night.

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