ECHOSOUNDER AND ADCP INVESTIGATION OF BALTIC FAUNA

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The Baltic fauna is rather meagre, what is connected with their miserable habitat. The area of our investigation is a specific basin because of its land-locked location, brackish water and small depth. It is characterised by enormous diversity of time-variable hydrological conditions. All species of fauna are subjected to the continuous stress of having to adapt to rapid changes in the temperature and salinity of the surrounding water and are exposed to highly variable environment during their every-day vertical migration between the food-rich sea surface and safer deep.

The purpose of this paper is to present the results of acoustic investigations of the live interior of the Baltic Sea by means of various acoustic instruments (echosounders and acoustic Doppler current meters). The interpretation of our acoustic images helps to understand the nature and behaviour of the sound scatterers.

INTRODUCTION

The Baltic Sea is a non-typical sea of shallow and brackish water, mean salinity about 7 PSU and seasonally changing temperature profiles. In summer there is almost 20°C difference in the vertical temperature profile down the whole water column, oxygen content varies from 8 ml/l at the surface to 0.5 ml/l near the bottom. In the Baltic deeps, due to the North Sea water inflow, salinity changes by several parts per thousand. The thermohaline variability in vertical stratification has a big influence on the distribution of marine fauna and the scheme of their diel vertical migration.

Acoustic scattering layers in the Baltic Sea comprise fish, mainly herring, sprat and cod, and various species of zooplankton. All these organisms are subjected to the continuous stress of having to adapt to an enormous diversity of time-variable hydrological conditions and are exposed to highly variable conditions during their vertical movement.

Acoustic methods enable us to determine zooplankton and fish abundance, their size distribution and their behaviour – aggregation, collective movement and vertical migration.

Taking advantage of multiple frequency equipment we are even able to identify fish species. It is known that the higher is sound frequency, the smaller object can be "seen" by the echosounder. Therefore we need hundreds kilohertz frequencies to detect the zooplankton of the millimetre size and tens kilohertz for fish. Marine mammals produce sounds themselves and the most common way of mammal research is listening to them by use of hydrophones (passive acoustic methods). This work, however, presents active methods only by use of echosounders and ADCPs.

This paper presents the results of investigations of marine fauna behavioural characteristics obtained by use of two echosounders working at the frequency of 30 and 120 kHz and two Acoustic Doppler Current Profilers (ADCP), vessel-mounted (150 kHz) and bottom-moored (300 kHz). Special interest is focused on the aggregative behaviour of marine animals on the hydrological background and their diel vertical migration. The velocity of this vertical movement is determined in three different ways: (1) from the shape of the scattering layers on the echogram, (2) from the slope of the mean gravity centre depth of the signal envelope, (3) directly from the value of vertical component calculated by ADCP.

1. EXPERIMENTAL MATERIAL

The sound backscattering measurements presented here were carried out during the Baltic cruises of r/v OCEANIA in various seasons from 2001 to 2006 at different locations. Data recorded by SIMRAD EK500, HONEYWELL ELAC, vessel-mounted ADCP and bottom-moored ADCP have been used. We specially concentrate on ADCP data, both on measured echo and vertical Doppler velocity – vertical component of sea current. They are compared with the scientific echosounders results.

ELAC 4700 echosounder works at a frequency of 30 kHz. Its pulse length is 1 ms and trigger rate is 1 s. The echo envelope is sampled with a frequency 3 kHz and 64-ping sequences separated by 1-minute breaks are recorded together with the time and the technical settings of the echosounder (power, gain, pulse length, pulse rate, TVG).

SIMRAD EK-500 echosounder uses a 120 kHz transducer with a pulse duration of 0.3 ms and trigger rate of 0.5 s. Vertical profiles of backscattering strength *SV* with depth resolution 0.5 m are recorded together with other data (time, geographical position, etc.)

Acoustic Doppler Current Profiler (ADCP) measures the water flow basing on the Doppler shift of sound scattered by the naturally floating particles (mainly zooplankton). It consists of four acoustic transducers mounted at 90° azimuthal increments (Janus configuration), with each beam pointing 20° or 30° off the instrument axis. In a vessel-mounted system (VM ADCP), the transducers are installed in the ship hull and aimed downward; in a moored system (BM ADCP) the transducers look upward. In order to increase the precision of the Doppler shift computation, the averaging over depth bins and time intervals is performed automatically. The vertical bin size is 2–4 m and ensamble interval is 2 minutes. This makes the spatiotemporal resolution of the ADCP data limited. There is no useful signal from the first several metres from the transducer because of the dead zone dependent on hull depth, transmit pulse and blank after transmit. ADCP gives a possibility of collecting bioacoustic data in a continual way as a by-product of sea current monitoring.

Echo intensity data collected by the ADCP are converted to mean volume backscattering strength *SV* measured in decibels by use of special formula. The standard calibration methods are impossible to be applied in the case of the inclined beams, so in order to obtain the *SV* values the computational formula given by the producer is exploited [1]. Data from echosounders are converted to the form of *SV* by the adequate sonar equations [3]. For each individual instrument many specific technical parameters (pulse length, transmit power) and of the environmental characteristics (temperature, absorption coefficient) are necessary. Absorption coefficient, depending on frequency, temperature, salinity and depth, is calculated. For the low-saline Baltic its value at 10°C and depth 10 m is enclosed in the range 0.0015÷0.04 dB/m for the frequencies from 30 to 300 kHz.

Additionally the problem of interference between ADCP and echosounder SIMRAD has occured. SIMRAD EK 500 and VM ADCP work at very close frequencies, 120 and 150 kHz respectively, so they disturb one another, each of them receives the echosignals of another. In many studies dealing with multiple frequencies, the 120 kHz record is simply rejected because of the interference with 150 kHz ADCP signal. In our case, the 120 kHz is the only frequency of SIMRAD echosounder, we had therefore to cope with the distorted signals, both of echosounder and of ADCP, and we tried to get rid of the disturbances and analyse the useful parts of the registered signals. These undesirable signals must be removed from the original record. Different procedures have been tested. The simplest one is based on fact that strange signals are easily distinguishable from the original background. Their level is a few dB higher than others in the neighbouring area, their width is 1 ping and length is close to the stranger's pulse duration. Such fragments of scattering matrix are detected and identified as strangers, and removed or replaced by the average value of the appropriate element taken from the adjacent columns.

Zooplankton samples were collected using WP-2 net with a 100-μm mesh size and opening 0.255 m^2. The biovolume of each sample was quantified by the normalised displacement volume method [2]. CTD profiling was conducted concurrently in order to give the hydrological background.

2. RESULTS AND DISCUSSION

Some features of variability in scatterer configuration appear after constructing the condensed echogram spanning many hours or even many days of sounding. In this way, the animal aggregations in the area of density gradient are presented on the hydrological background – transformed echogram is compared with the CTD profile. Detected animals concentrated at the density jump zone (where floating is easier and the energetic yield is smaller) become the indicators of the density gradient. The speed of migration is also investigated by use of the different methods with special interest focused on analysing the vertical component of current obtained directly from ADCP. Finally, we present the first test of comparing the acoustic results with biological data from net sampling.

2.1. BACKSCATTERING AT THE THERMOHALINE STRUCTURE

Four multi-hour echograms are prepared in order to visualise the strong influence of environmental parameters, especially temperature and salinity, on the scatterers behaviour. It is illustrated in Fig.1 in form of ADCP and ELAC echograms and respective CTD profiles. They demonstrate quite different migration patterns recorded by 150 kHz ADCP and 30 kHz ELAC echosounder in early spring 2004 in the nearby places. During two consecutive nights, at the locations separated by less than 30 nautical miles, one night we observed very weak migration from the bottom (95 m) to the depth of 80 m (upper pictures). The next night, the intensive migration throughout the whole water column with the strong nocturnal aggregation close to the sea surface was observed (lower section). This series of measurement was performed much closer to the shore, to the Vistula mouth, in totally mixed winter water, so the content of animals could be quite different. Due to the frequency distance – 150 and 30

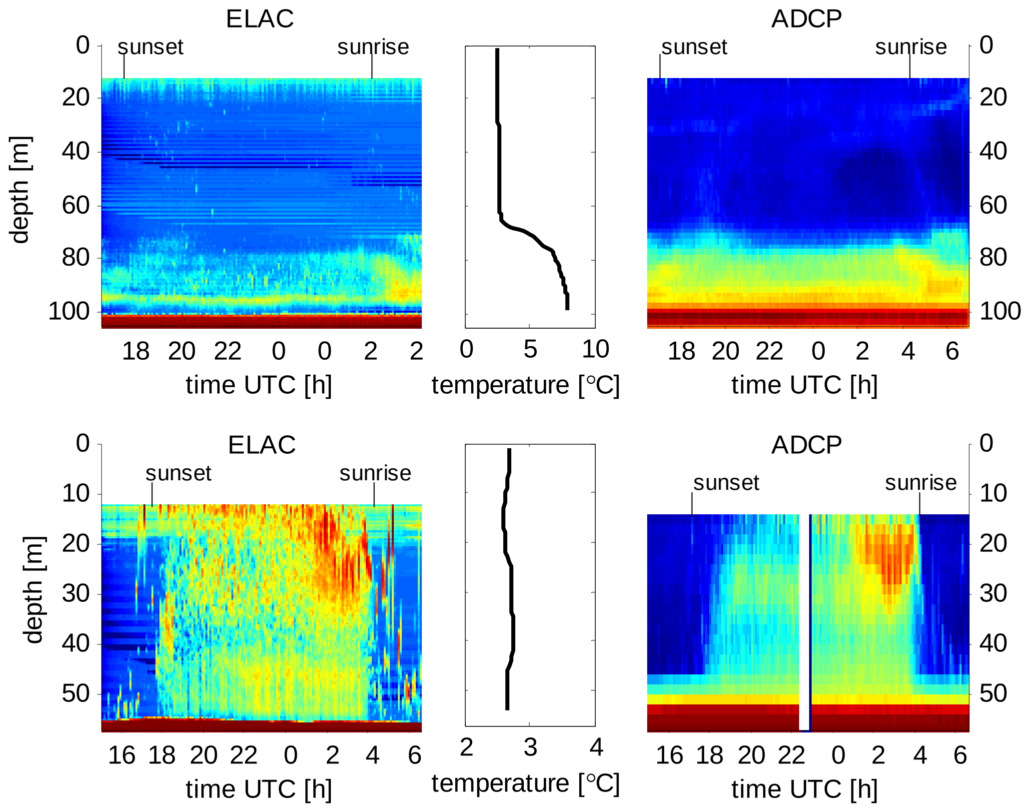

Fig.1 Echograms and STD diagrams for two series of sounding: 27–28 March 2004 (upper part) and 28–29 March 2004 (lower part). Gulf of Gdansk

kHz – and disparate time and space resolution of both instruments, the ADCP and ELAC echograms are not identical. In order to show the difference in scattering at various frequencies, the matrices of *SV*, averaged over the same time and depth intervals and having identical dimensions, are subtracted. Areas of big differences, positive or negative, mark the regions of domination of scattering at particular frequency. The difference echogram $\Delta SV_{150\text{-}30}$ is constructed for ELAC echosounder (30 kHz) and VM ADCP (150 kHz) for the second series of sounding presented in Fig.1. This difference echogram is displayed in Fig.2. It reveals at sunset and sunrise two bands of strong negative values (blue colour). They are

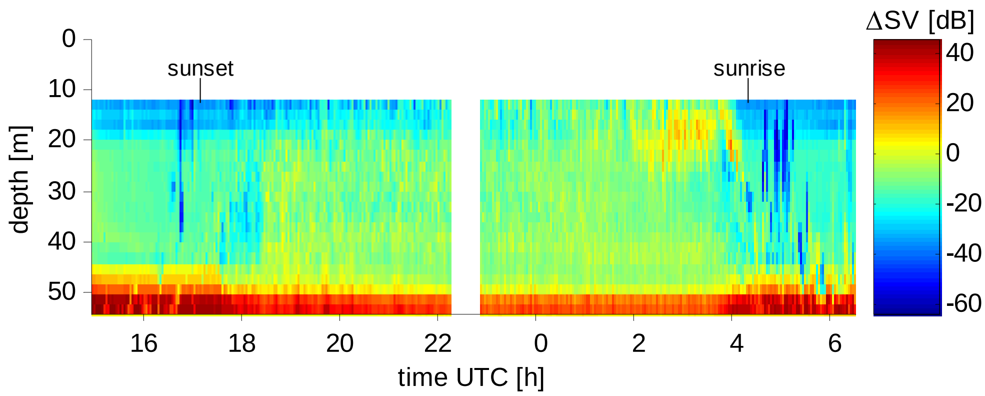

Fig.2 The difference echogram ΔSVADCP 150 kHz – ELAC 30 kHz , 28–29 March 2004. Gulf of Gdansk

related to the areas of 30 kHz scattering domination and are connected in all probability with resonating swimbladders of fish, easily recognisable by the lower frequency only and much weaker visible at the higher one. Yellow and red patches represent the regions of 150 kHz domination. Near surface yellow spot occurring before sunrise can be caused by small zooplankton aggregation, too small to be seen by 30 kHz acoustic wave (of the length of 5 cm), but big enough for 150 kHz (1-cm wavelength).

2.2. DIEL VERTICAL MIGRATION

Upward and downward migration can be studied by various direct and indirect methods. One of them is to calculate the speed from echogram by finding the trailing edge of migrating organisms (Fig.3a). Usually it is clearly seen in the echogram and can be found out by the simple thresholding method. Vertically migrating group of animals causes at given time the local maximum of *SV* at given depth. The point x_i (on the time axis), in which the difference between the SV_{ij} value for a given depth and time cell and the mean value of *SV* for the whole row exceeds the threshold value, is determined. In the next step, the collection of points x_i is linearly interpolated. The slope of this line is used as an estimate of the speed of vertically migrating layer. In the presented case, $v\uparrow = 18.5$ mm s^{-1} and $v\downarrow = -4$ mm s^{-1}.

Another method uses the running mean with different window width. It can be used in rows to find the area of rapidly rising *SV* values. These row maxima together with the window width constitute the vertical migration path, ascending at dusk and descending at dawn. For this path the values of vertical velocity calculated by ADCP can be determined (Fig.3b) and histograms of such values show the character of their distribution.

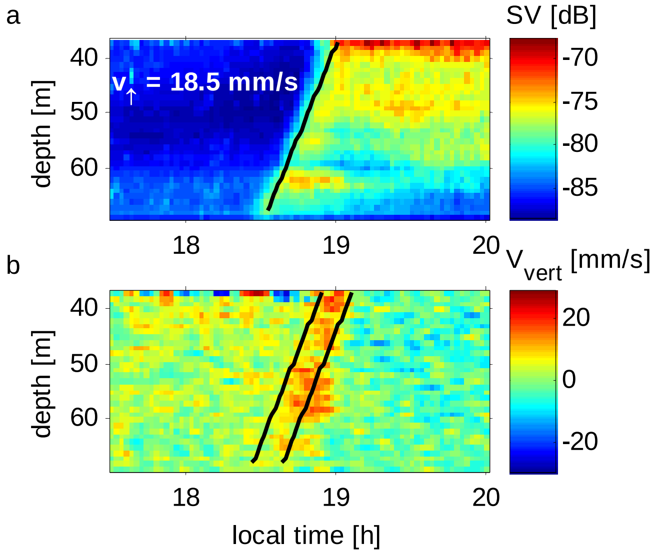

Fig.3 (a) Echogram recorded at sunset by BM ADCP 300 kHz with the line approximating the edge of migrating scatterers; (b) Vertical velocity field calculated by ADCP within the migration path determined from the echogram. Positive values for upward velocity. 4 October 2006, Gdansk Deep

To show, how the mean value of vertical velocity changes during twilight hours, we averaged the vertical velocity component in the water column related to the migration zone. The upper part of Fig.4 shows the depth-averaged Doppler vertical velocity calculated by ADCP in transition periods of dusk and dawn. This mean velocity is computed in the depth interval of 40–67 m, which spans the migration zone from the sea bottom to the thermocline depth, where the organisms constitute at night the intensive scattering layer. This profile relates to the mean velocity of vertical migration of organisms. It has two characteristic periods: one of positive values around sunset with a distinct peak of v_{max} = 9.1 mm s^{-1} observed after sunset (left diagram) and the second of negative values with v_{min} = – 5.6 mm s^{-1} around sunrise (left diagram). The lower part of Fig.4 shows the histograms of the vertical velocities obtained by ADCP in the migration path area of the width of 14 minutes – respectively the left one for dusk with dominating positive values (upward movement) and the right one for dawn with dominating negative values (downward movement). Generally, the upward speed is bigger than the downward one. In the evening the hungry animals actively swim, while in the morning, after heavy meal, they passively sink towards the bottom.

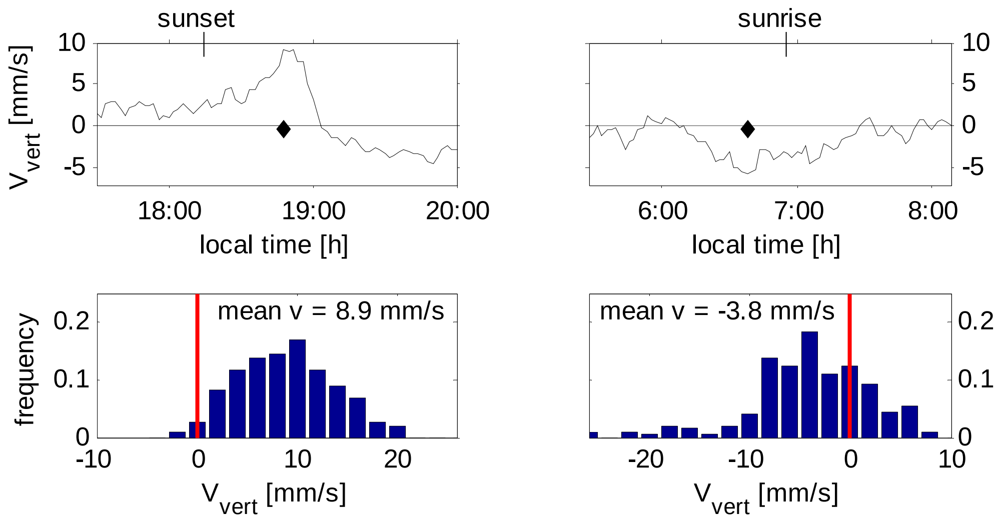

Fig.4 (a) Vertical velocity averaged over depth interval 40-67 m; (b). histograms built from 224 velocity data calculated directly by ADCP within the migration path. BM ADCP 300 kHz, 6–9 May 2006, Gulf of Gdansk

Another way of analysing the temporal variability of scatterers configuration is based on computation of the gravity centre depth of the signal envelope, which mirrors vertical displacements of sound scatterers within the water column [5]. Usually we can notice the characteristic shallowing of the depth of the centre of gravity at sunset and its sinking at sunrise. From the slope of this curve in transition phase we can determine the speed of migration which is very close to the obtained by the other procedures [4].

As it was already mentioned, measurement of the components of the current vector is founded on the assumption that scatterers are neutrally buoyant in water and their speed is identical with the speed of medium. Nevertheless, this assumption is not fulfilled during transition periods of sunset and sunrise vertical migration, when vertical components of current are not the water speed but the speed of moving plankters. We have observed that during the migration periods also the measured horizontal flow components are disturbed. Fig.5 presents the 16-hour echogram and three components of the current vector recorded by 300 kHz bottom-moored ADCP in April 2001. The migration episode is clearly seen (Fig.5a). In areas of larger concentration of scatterers the vertical component of water flow measured by ADCP becomes negative (Fig5.b). During the intensive vertical migration at sunset and sunrise the flow changes its north-south direction by 180° (Fig5.c). During the upward migration the horizontal flow has an east direction, while in the morning, during the downward movement, the flow becomes west (Fig5.d). Two lower plots show that mean flow direction is the south-east with the exception of the near-bottom layer and subsurface nocturnal aggregation. The first effect can be caused by the bottom current, but the second one is evidently connected with the animal movement. During the day the plankters do not move and passively float with current. Just before sunset (20:13) they start to move upward and are forced to swim against current, hence the horizontal direction changes from south to north. The same effect is observed during sunrise, when the animals start their escape to deeper water.

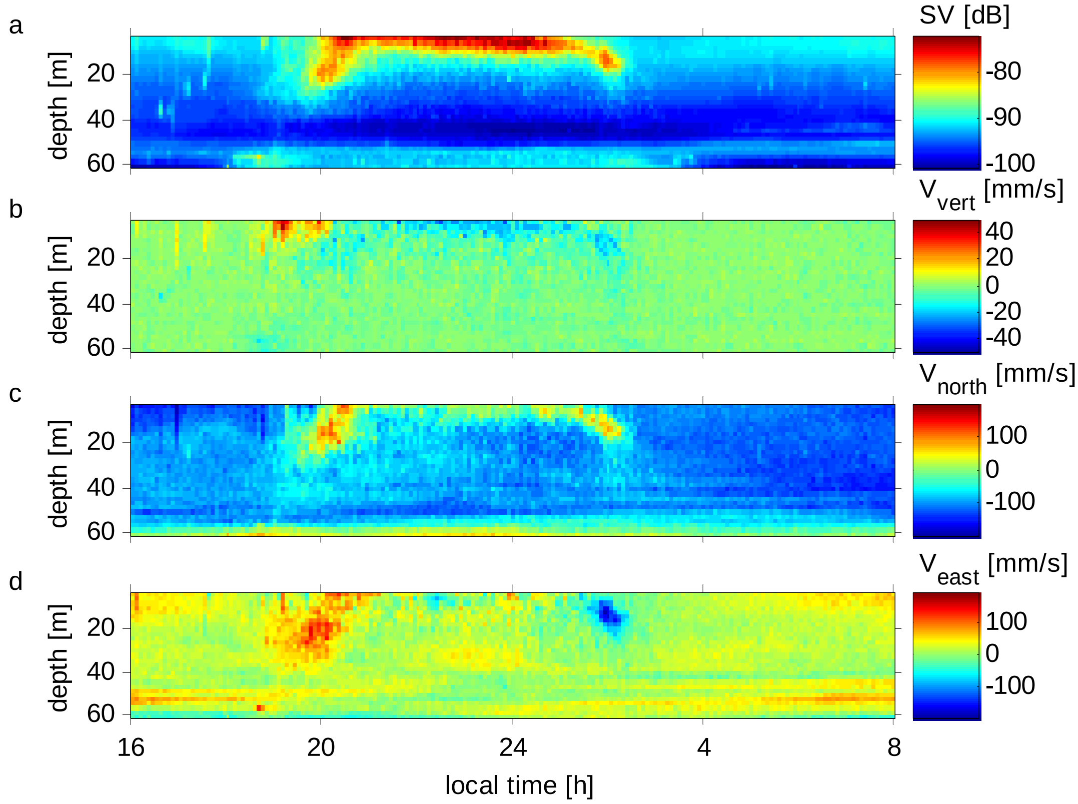

Fig.5 (a) volume backscattering strength; (b) vertical velocity, positive value for upward direction: (c) horizontal north-south component, positive value for north direction; (d) horizontal east-west component, positive values for east direction. BM ADCP 300 kHz, 24–25 April 2001, Słupsk Furrow

2.3. SV – BIOMASS RELATIONSHIP

A limited attempt to correlate acoustic characteristics with zooplankton abundance was made during the October 2006 cruise, when the possibility of collecting some zooplankton samples appeared. Total biovolume of caught zooplankton was determined by the normalised displacement volume method [2]. It was divided by the volume of filtered water and gave as a result the zooplankton density in mg m^{-3}. The scale of these measurements was very small, it was not possible to gather the statistically sufficient sample, but three nocturnal catches gave some promising result. It is presented in Fig.5 as the dependence between mean value of backscattering strength *SV* measured in the entire water column and logarithm of the zooplankton density. Linear relationship seems to be obvious. Similar results have been obtained for the sublayers 0–25, 25–45, 45–70m. Almost 20-dB difference between *SV* values of SIMRAD and ADCP (both after cleaning) can be mentioned. It must be a consequence of bad calibration of ADCP (see Section1).

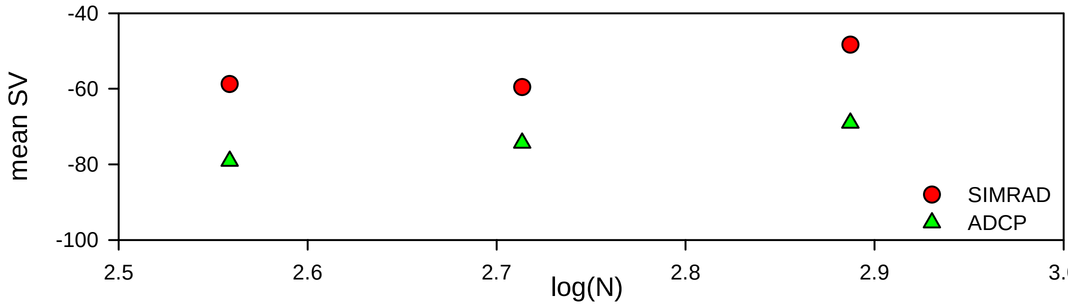

Fig.6 SV averaged over the whole water column versus logarithm of zooplankton density. 3–5 October 2006, Gdansk Deep

3. CONCLUSION

Our study shows that both the range and the position of scattering layers are strongly influenced by hydrological conditions.

Generally, the migration speed values determined from the echogram are higher than the values of the vertical component of water current measured by the Doppler shift. This is connected with the way of ADCP operation and the way in which the zooplankters migrate. Usually organisms do not migrate as a homogenous population with identical speed. Some of them migrate faster, some are immobile. The speed measured by the ADCP is the mean speed calculated for the whole bin (a few metres long), so the real speed of migration is biased low because of the non-migrating or even migrating in opposite direction scatterers.

Care must be taken in velocity current measurement during animal migration. Not only the vertical component of water flow, but also the horizontal ones, are significantly disturbed by the active movement of marine fauna during sunset and sunrise.

The relationship between acoustic scattering and zooplankton biomass requires further examination.

ACKNOWLEDGEMENTS

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