ACOUSTICAL STUDIES OF ARCTIC ZOOPLANKTON

JOANNA SZCZUCKA, EMILIA TRUDNOWSKA, ŁUKASZ HOPPE

Institute of Oceanology, Polish Academy of Sciences
Powstańców Warszawy 55, 81-712 Sopot, Poland
szczucka@iopan.gda.pl

Comprehensive knowledge on zooplankton distribution in the sensitive Arctic frontal zone allows us to better foresee a possible consequences of climate change. This paper presents the results of two series of zooplankton abundance measurements conducted in the shelf waters of Svalbard in summer 2009 and 2010. Three methods were used: traditional net sampling on the stations, Laser Optical Plankton Counter measurements on the stations and along the transects and high frequency echosounding along the transects. Modelling the acoustic backscattering cross-section of the entire spectrum of zooplankton individuals determined by LOPC enabled us to calculate total backscatter, compare it with the value measured by echosounder and to scrutinize the results obtained by all three methods.

INTRODUCTION

Information on zooplankton abundance and their spatiotemporal distributions is needed to predict their contribution to many environmental processes, but investigation of a large oceanic area with traditional plankton nets requires a large amount of time and gives only a 1-dimensional snapshot information about zooplankton assemblages in the water column. We describe here three complementary methods - biological, optical and acoustical – applied to studies on Arctic zooplankton in the frontal zone of the West Spitsbergen Shelf. Plankton nets deliver a detailed zooplankton species composition, size spectrum and abundance at the fixed points, while towed LOPC (Laser Optical Plankton Counter) gives the particle size distributions at a specific depth along the transect. Echosounder measures the 2-dimensional field (depth distribution along the transect) of volume backscattering strength, being proportional to the concentration and size of zooplankters.

Different parts of the study area are dominated by different water masses: the southern part near the Hornsund fjord is influenced by the cold South Cape Current which carries water originating from the northern Barents Sea and transports cold-water fauna. The northern part is under the influence of the West Spitsbergen Current, which flows northward carrying warmer and more saline Norwegian Atlantic Water with Atlantic fauna. These two distinct external water masses are separated by a hydrological Arctic Front.

Our main goal is to compare the acoustic backscattering strength measured by the echosounder and backscattering strength mathematically modelled on the basis of zooplankton size spectra delivered by LOPC and nets. Equally important oceanographic goal is to find differences in zooplankton assemblages between different water masses and to observe inter-annual variability of zooplankton abundance and distribution influenced by variable temperature conditions.

1. DATA COLLECTION

The research was conducted during two summer cruises 2009 and 2010 (July/August) of research vessel 'Oceania' (Institute of Oceanology, Polish Academy of Sciences). The cruise surveyed the area of four West Spitsbergen fjords and their foregrounds with a focal point in two different hydrological regimes of the frontal zone of the West Spitsbergen Shelf, where the abundant plankton assemblages were advected northwards.

Three parallel methods were used. In addition to the traditional net sampling conducted at the chosen oceanographic stations, the sampling transects were organized to spread across the surface frontal system – about 40 hours of acoustic and LOPC underway measurements in 2009 and 35 hours in 2010.

Laser Optical Plankton Counter (Brook Ocean Technology Dartmouth, Canada) is the *in situ* sensor which autonomously provides the reliable abundance and community size structure of plankton and particles in marine and freshwater environments [1]. It measures cross-sectional area of each plankton particle in its collimated laser beam path in the sampling tunnel 7x7cm wide. As the particle passes the sensor, the portion of light blocked is recorded as digital size. The technical specifications allow to count and size particles in the size range of 100 μm to 35 mm ESD (Equivalent Spherical Diameter) which is often given as a range for mesozooplankton to which LOPC is best suited. Additionally LOPC is capable of assessing large-scale, rapid and continuous characterization of zooplankton distribution concurrently with environmental parameters (e.g. temperature, salinity, depth, fluorescence).

The mesozooplankton samples were collected with WP2 net (0.25 m^2 opening area) with 500 μm mesh size in vertically stratified hauls from 50 m to the surface. Individual zooplankton samples were preserved and returned to the laboratory for microscopic analysis, where they were identified, measured and counted. For each sample the total number of individuals was converted to concentration per 1 m^3 using filtered water volume.

Hydroacoustic methods offer two main advantages over conventional net sampling and particle counting: a greater volume of sampled water and a continuous, two-dimensional record. These techniques are relatively nonintrusive and can provide data in near-real time. A dual-beam 420 kHz echosounder DT-X produced by BioSonics Inc. with downward looking transducer mounted on the ship by the special frame was used to map the fine-scale vertical patterns of acoustic backscatter along the ship's transect. A pulse length of 0.3 ms and trigger rate of 2 s^{-1} were established. Echosignals were collected from 1 m to 100m depth.

These three methods differ in resolution, sampling volume, counting accuracy, selectivity, identification capabilities and size range.

2. DATA PROCESSING

Analysis of the net samples, LOPC records and echograms were performed for the transects, where all these measurements were conducted simultaneously. It was not always possible, because echosounding was limited to the ship speed not greater than 3 knots (due to transducer fixing) and sometimes the cruise logistics required greater speed to execute the whole program in time. Fortunately, we have two long transects performed in the north area in 2009 and 2010. Additionally, 6-hour transect crossing the Arctic Front in the south was carried out in 2010. LOPC and echosounder data were logged every half a second, so there are tens of thousands transmissions recorded by both instruments during long transects (9hours x 60min/hour x 120transmissions/min). To reduce their number and their fluctuations they were averaged over some time intervals. Towing depth of LOPC was chosen at the beginning of each transect, but it was varying according to the vessel speed.

3. ACOUSTIC SCATTERING MODEL

From great numbers of mathematical models describing the target strength *TS* of zooplankters with different degrees of complexity based on different mechanisms of scattering for different types of zooplankton, we have chosen the so-called "high-pass" model of *TS* [2], describing scattering on the sphere, prolate spheroid, straight and bent cylinders, made of any materials: fluid, gas, elastic or rigid. It is quite sufficient to calculate the intensity of sound backscattered on the aggregations of different type and different size of animals. The sphere model is the simplest of them, the ellipsoid and cylinder models additionally take into account the elongated shape and spatial orientation of the scatterer. The backscattering cross-section σ_{bs} of any object can be written as:

$$\sigma_{bs} = \frac{X}{1+\frac{X}{YR^2}} = \frac{XY}{\frac{X}{R^2}+Y} = \frac{Y}{\frac{1}{R^2}+\frac{Y}{X}}$$

where X and Y are the exact expressions for σ_{bs} valid in specified object size-sound frequency regions of scattering (*ka* domains):

$X = \sigma_{bs}(ka<<1, fluid)$ for Rayleigh scattering

$Y = \sigma_{bs}(ka>>1, rigid/fixed)$ for geometrical scattering

According to this model, backscattering cross-section σ_{bs} depends on geometrical cross section of the object and is modified by $(ka)^4\alpha^2$ in Rayleigh region (ka<<1), and by reflection coefficient R^2 in geometric region of scattering (ka>>1). α as well as R are in control of density and sound speed contrasts g and h, so the proper choice of these values is crucial. They depend on species, and within the same species, on organism size and season, they vary with the percentage of the lipid content and rigid parts like skeleton and carapace. The literature review gives a large dispersion of contrasts' values [3]:

$$1.016 < g < 1.12 \qquad 1.007 < h < 1.033$$

Acoustical estimates obtained by the mathematical modelling are very sensitive to changes in density and sound speed contrasts. Their impact on *TS* results in up to 16 dB change of the target strength when the extremal values are compared. For our Arctic case model calculations, there were adopted values g = 1.0 i h = 1.027, characteristic for the main representative of Svalbard copepods *Calanus finmarchicus* [4].

4. RESULTS

The first step of our study was to check how acoustical backscattering strength was correlated with zooplankton abundance. In order to perform the statistical analysis on a convenient linear scale, we have used instead of logarithmic form of scattering S_v its linear form $s_v=10^{Sv/10}$ – volume backscattering coefficient, that is proportional to the integral of the product of the number density of zooplankton of a given dimension with the backscattering cross-section of those individuals. The correlation occurred to be very satisfactory for all the transects except the obvious cases of fish presence, giving the regression coefficient values between 0.7 and 0.85.

The main objective of this work, a comparison of model-predicted and measured values of volume backscattering strength, was executed by applying the high-pass model of sound scattering to the distribution of zooplankton sizes measured by LOPC. In this way we obtained the size class contributions to the total volume backscattering. An example is shown in Fig.1. Its upper part presents the size distribution obtained by LOPC in Magdalenefjorden in 2009. Middle part illustrates the dependence of TS on the scatterer's radius, and the lower one shows the individual contributions to total scattering. Pretty big contribution of relatively low number of the larger plankters is seen for 3 mm radius.

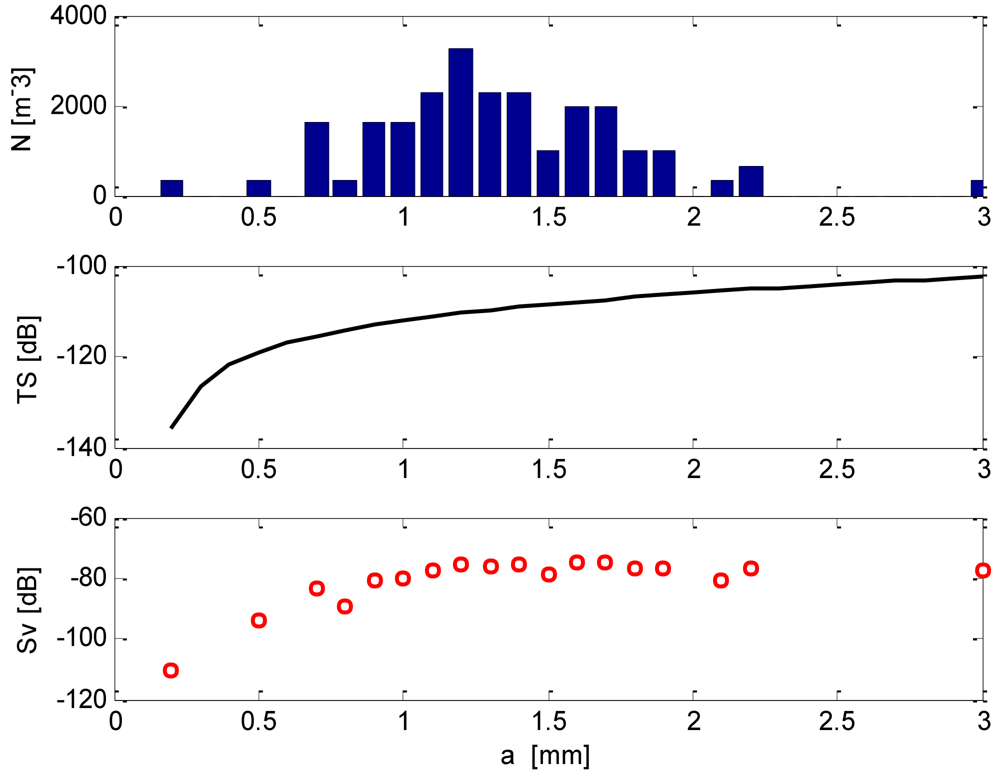

Fig.1. Histogram of plankton radii (upper), target strength calculated by model (middle) and contributions of particular size group to total backscattering (lower).
Density contrast g=1, sound speed contrast h=1.027.

The sum of all S_v terms from the lower part of Fig.1 (strictly, $10\log \Sigma s_v$) should give the total S_v comparable with the value measured by echosounder. Such a comparison is depicted in Fig.2. Despite some differences in absolute values, the shapes of both curves are quite similar, with synchronous minima and maxima.

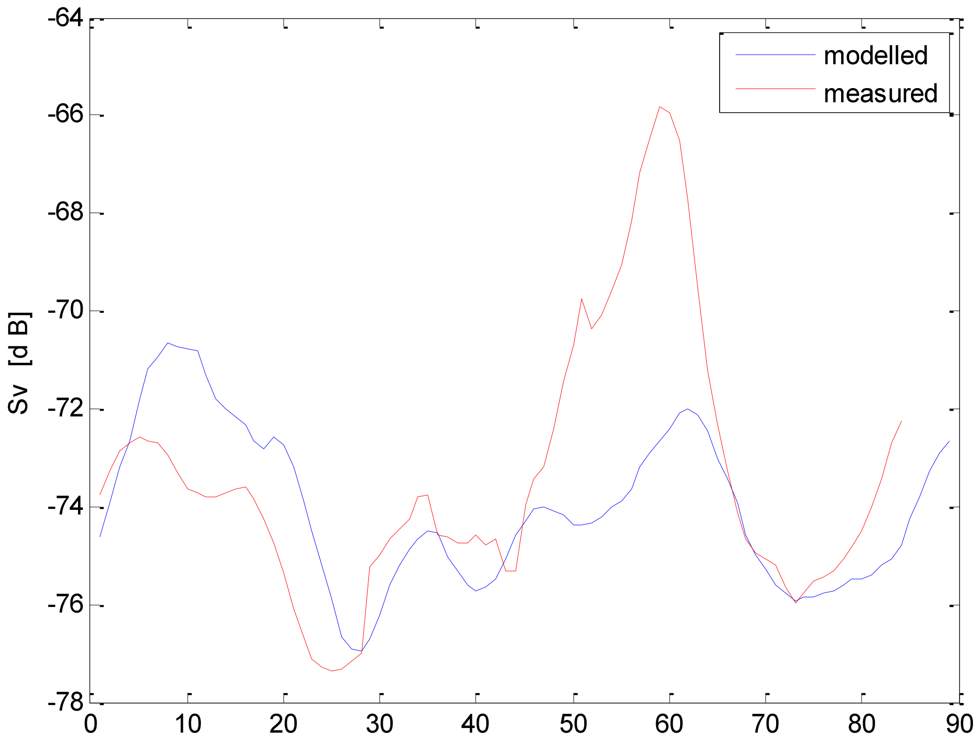

Fig.2. 47-minute echosounder record of S_v measured by echosounder (red curve) and S_v calculated by the model on the basis of zooplankton concentration measured by LOPC (blue curve) along the same transect at the same depth. Both signals are averaged over 60 transmissions (0.5 min). 31 July 2009.

Some interesting oceanographic features have been revealed [5]. Inter-annual variation could be easily observed. The inflow of warm Atlantic water was significantly stronger in 2009 than in 2010 – it was connected with lower acoustic scattering in warmer 2009. The intense temperature gradient across the Arctic Front in both years was associated with high peaks of zooplankton abundance; indicated both by echosounder and LOPC. Additionally in the warmer year 2009 more melt water with suspensions discharged from the glacier was recorded.

5. SUMMARY

Direct comparison of optical and acoustical results concerning Arctic zooplankton were executed. Despite the discrepancies including sampling volume, counting accuracy and length range under measurement, scatter plots of the zooplankton abundance determined by LOPC against the volume backscattering coefficient showed a significant correlation.

The measured values of volume backscattering strength were compared with the model-predicted values by applying the high-pass model of sound scattering to the distribution of zooplankton sizes measured by LOPC. There was a surprisingly good agreement between measured and modelled values of backscattering strength along the transects.

Generally speaking, we managed to discern the different water masses on West Spitsbergen Shelf studying associated zooplankton assemblages using three complementary methods – conventional net sampling and acoustic and laser optical methods. We conclude that this approach can be a novel method in mapping a full spatial zooplankton picture in an area of great importance for climate changes. Along the transects several net sampling stations were organized to support optical and acoustical measurements with detailed taxonomic information. These data will be used for further zooplankton composition analysis as well as to strengthen the inference on zooplankton distribution in the context of dynamic processes in the Arctic system. The challenge is to model the real zooplankton individuals size spectrum which will correspond to different species and will be consistent with acoustic backscattering and LOPC cross-section measurements.

ACKNOWLEDGEMENTS

This work was supported by a grant from Norway through the Norwegian Financial Mechanism, project Nr PNRF-234-AI-1/07.

REFERENCES

[1] A.W. Herman, B. Beanland, E.F. Philips, The next generation of Optical Plankton Counter: The Laser-OPC, Journal of Plankton Research, 26(10), 1135-1145, 2004.

[2] T.K.Stanton, Simple approximate formulas for backscattering of sound by spherical and elongated objects, JASA, 86(4), 1499-1510, 1989.

[3] C.S.Clay, H.Medwin, Acoustical Oceanography, John Wiley & Sons, New York, 544 pp., 1977.

[4] J.W.Kogeler, S.Falk-Petersen, A.Kristensen, F.Pettersen, J.Dalen, Density- and sound speed contrasts in Sub-Arctic zooplankton, Polar Biol., 7, 231-235, 1987.

[5] E.Trudnowska, J.Szczucka, Ł.Hoppe, R.Boehnke, H.Hop, K.Błachowiak-Samołyk, Multidimensional zooplankton observations in the northern West Spitsbergen Shelf, Journal of Marine Systems 98-99, 18-25, 2012.