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Scattering Patterns of Diurnal Migration of Fish and Zooplankton in Different Waters - Baltic Sea, Lake Wdzydze and Lake Tanganyika - Similarities and Differences.

Joanna Szczucka

Institute of Oceanology, Polish Academy of Sciences
ul.Powstańców Warszawy 55, 81-712 Sopot, POLAND
e-mail: szczucka@iopan.gda.pl

In spite of a well known fact that biological objects migrate up and down in a diurnal cycle according to the variable light conditions, there exist some detailed features characteristic for the specific areas. Vertical migrations were detected in different seasons at various points of the Baltic Sea, in Lake Wdzydze (Northern Poland) and in Lake Tanganyika (Africa). Those three areas are very different in size, water content and structure, biological life and meteorological conditions. Analysis of the vertical distribution of echoes and temporal dynamics of the aggregative behaviour is presented on the base of the spatial heterogeneity of abiotic environment.

1. Introduction

Diurnal variation in mean volume backscattering strength is well documented in the literature [e.g. 1, 3, 6, 7]. Day and night scattering patterns in the Baltic Sea are also well recognized [5, 8, 9]. They are strictly connected with season and thermohaline conditions. The most characteristic feature of the Baltic scattering layers is their persistence at night and weakening in the day time. After sunrise they either spread over the water column or rest at the halocline (salinity jump region close to the bottom). Generally, during the warm seasons, when there is a well-defined thermocline (strong tempe-rature gradient region), after sunset the scatterers form a well-marked subsurface layer at or above the thermocline. This formation disappears in the light phase of a day. In the cold periods of the year, when the water temperature is nearly constant, at night the scatterers occupy the whole lower part of the water column (not reaching the sea surface), whereas during the day they stay in the vicinity of the halocline. Similar situation was observed in Lake Wdzydze during a 2-year monitoring project. Seasonal variability of the temperature field and zooplankton abundance, and in consequence, varying scattering patterns, were observed [4]. It seemed interesting to compare those features characteristic for temperate climate areas with analogous features of tropical regions. Such a possibility occurred because of two acoustics-fisheries surveys held on Lake Tanganyika within an FAO project.

All three basins vary significantly in thermal and salinity conditins, oxygen content and biological species composition. The Baltic Sea is a non-typical sea (shallow and brackish water, mean salinity about 7 psu) of seasonally changing temperature profiles. Lake Wdzydze is of glacial origin, well oxygenated, with teperatures depending on the season. Lake Tanganyika lying in a continental rift is the second deepest lake in the world (1470 m!) with a typical for tropics very warm water (23 - 29°C in the whole water column) and lack of oxygen below 150 m depth [2].

Table 1. Morphometric data.

	area [km^2]	volume [km^3]	max depth [m]	mean depth [m]
Baltic Sea	415 266	21 721	459	52
Lake Tanganyika	32 900	18 800	1470	570
Lake Wdzydze	14.5	0.0022	68	26

The aim of this paper is to compare scattering patterns of diurnal migration in those three basins.

2. Experimental and Data Processing

The sound backscattering measurements presented here were carried out in the Baltic Sea and Lake Wdzydze in a routine way in different seasons of the last few years, whereas acoustic images of Lake Tanganyika were obtained as a side effect of acoustic estimation of fish abundance conducted during two cruises in 1997 and 1998. „Northern" measurements were stationary, their main task was to detect temporal changes. In order to eliminate the spatial variability in the plankton migration patterns the fixed points of observation were chosen. It was impossible to keep the same experimental conditions during African expeditions, because all data were recorded along transects and the detected variability was always temporal and spatial as well. The Baltic Sea and Lake Wdzydze measurements were performed by means of the ELAC 4700 echosounder working at frequencies of 30 and 50 kHz. A pulse length of 1 ms and trigger rate of 1 s were established. The echo envelope was sampled with a frequency 3 kHz and 64-ping sequences separated by 1-minute breaks were recorded together with the time and the technical settings of the echosounder (power, gain, pulse length, pulse rate, TVG). The measurements in Lake Tanganyika were carried out by means of the SIMRAD EY-500 echosounder using a 120 kHz hull-mounted transducer with a pulse duration of 0.3 ms and trigger rate of 2 s. Vertical profiles of backscattering strength *SV* with depth resolution 0.5 m were recorded every 2 seconds together with other data (time, geographical position, etc.)

The stored acoustic data enabled echograms to be retrieved and some statistical parameters to be calculated during the post-processing phase.

Some additional environmental measurements like STD (salinity, temperature, depth) and oxygen sampling were carried out simultaneously to deliver the hydrological background.

No biological samples were analysed in a scope of this study.

3. Results

The images of diurnal changes in sound scattering objects configuration can be presented in the form of a transformed echogram, which shows a temporal dependence of the echo energy on depth. The multi-hour Baltic Sea and Lake Wdzydze echograms were already presented [8, 9, 4]. As an example the 120 kHz echogram recorded in

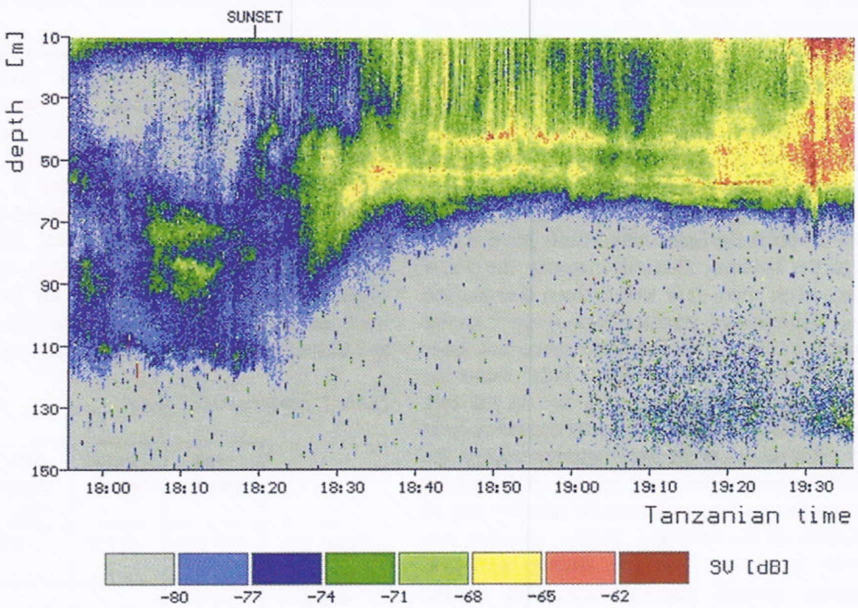

Fig. 1. Condensed echogram showing the evening upward migration of the biological objects in Lake Tanganyika (February 1998).

February '98 in Lake Tanganyika is shown in Fig. 1. This 1.5-hour record displays the process of upward vertical migration typical for dusk period. Each vertical line in the picture is a 12-second mean value (averaged over 6 successive echoes). The image is limited to the depth interval 10 - 150 m. Signals from less than 10 m depth were suppressed, as they were dominated by transducer back lobe reflections from the water surface and ship's hull. The lower boundary is chosen because of the scarcity of life below 150 m caused by the oxygen deficiency (see Fig. 2). The echochart in Fig. 1 presents the evening ascent of the biological objects - zooplankton and fish - to the subsurface layer of a width of about 60 m. Before sunset the scatterers are rather uniformly distributed in the broad layer 0 - 120 m. Just after sunset they start to move up and after several minutes they constitute two distinct sheets of strong scattering. About 1 hour after sunset the formation of uniform dense aggregation close to the lake surface can be observed. Very often such a configuration lingers on for the whole night.

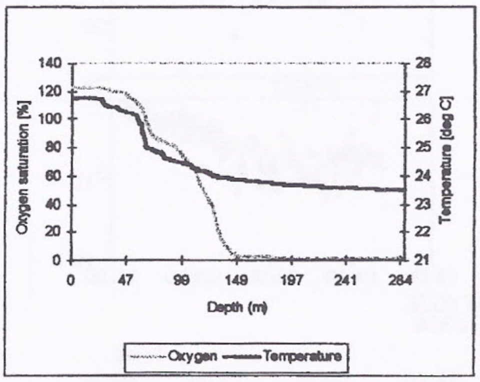

Fig. 2. Vertical profiles of temperature and oxygen typical for Lake Tanganyika.

It must be emphasised here that, as it was mentioned above, the presented echogram does not apply to the stationary observation. It was recorded, like all data from Lake Tanganyika, during zigzagging across the lake. The mean vessel speed was ~ 8 kn, hence the 1.5-hour action comprised a space interval of about 12 nautical miles. In order to avoid the influence of a littoral zone, Fig. 1 was constructed totally on a basis of the deep water, pelagic transect. In other case some undesirable effects of uneven distribution of live scatterers in space can be expected. The slope regions of Lake Tanganyika are very dynamic indicating the relevant increase in fish and zooplankton abundance close to the shore. There is also a possibility of horizontal migration of fish from pelagial to littoral in the morning and reversely - from littoral to pelagic zone in the evening. Such displacements can disturb the patterns of the vertical migration itself.

In order to compare migration patterns in different basins, it is useful to visualise the time dependence of two parameters calculated for the echo envelope: the depth of the gravity centre and the mean scattering strength. They are defined as follows:

- the depth of the centre of gravity

$$z_{gc} = \sum_{i=1}^{N} Sv_i z_i \Big/ \sum_{i=1}^{N} Sv_i$$

- the mean backscattering strength

$$\overline{SV} = 10 \log\left(\sum_{i=1}^{N} Sv_i \Big/ N \right)$$

where

N - the number of samples in the ping

M - the number of pings in one block

Sv_i - the mean backscattering coefficient of the i th sample averaged over M pings

$$Sv_i = \frac{1}{M} \sum_{j=1}^{M} Sv_{i,j}$$

z_i - the depth related to the i th sample

The temporal variability of the gravity centre location allows to estimate the speed of vertical migration of plankton. The mean backscattering strength is a parameter enabling the absolute values of energy backscattered from the whole water column to be compared at different moments of observation and the changes in scatterers biomass to be estimated.

The volume backscattering coefficient Sv in nonlogarithmic form was computed and vertically integrated completely through the feature of interest - 80 m in the Baltic Sea, 30 m in Lake Wdzydze and 140 m in Lake Tanganyika. After averaging it was normalised by the maximum value and reversed to logarithmic form SV. Such a normalisation was necessary for comparison purpose because of differences in absolute values of SV caused by various frequencies used in individual experiments - 30 and 120 kHz - and various intervals of averaging - 30 to 140 m. Figure 3 shows the time dependence of the depth of the gravity centre and the mean scattering strength normalised by its maximum

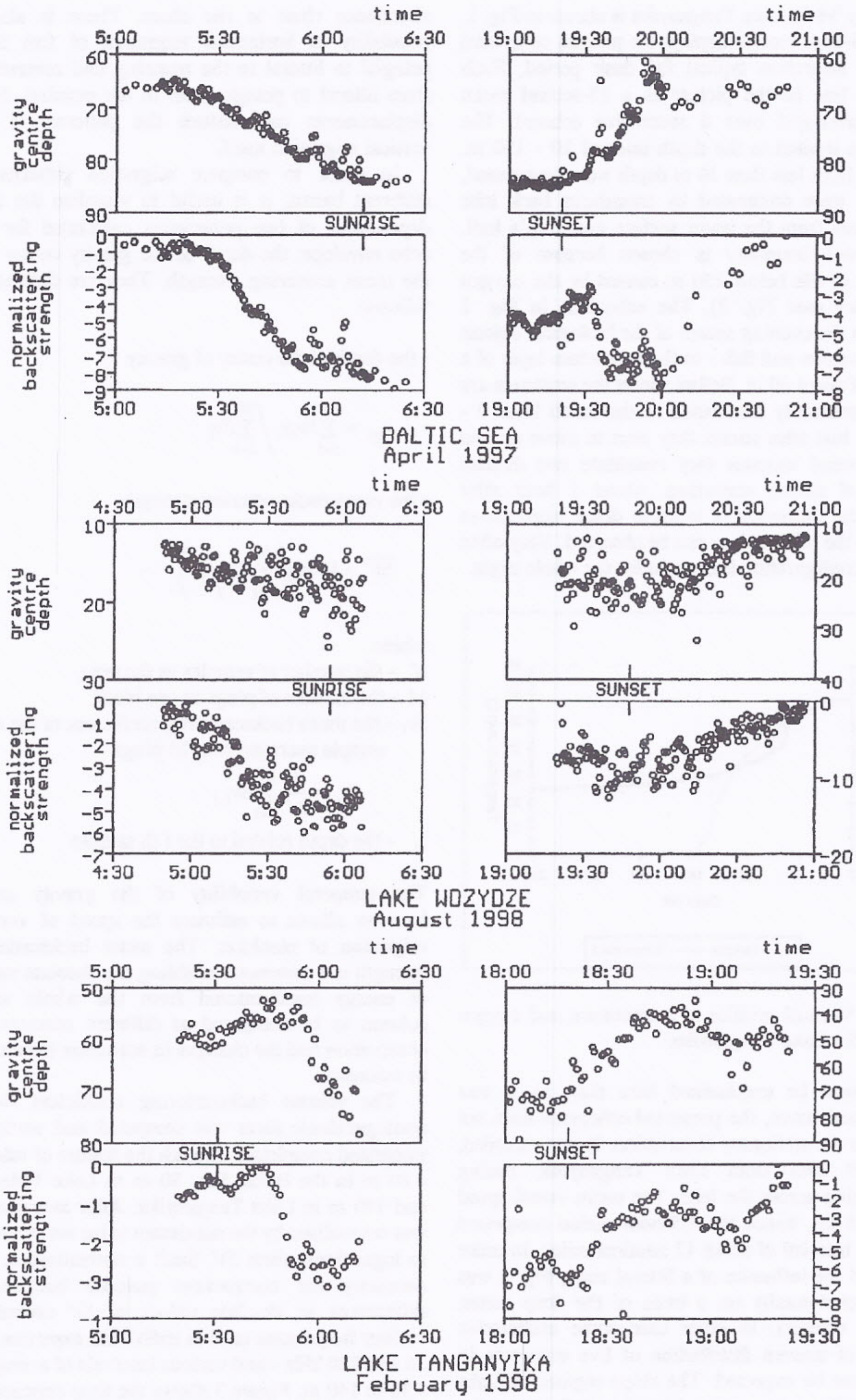

Fig. 3. Temporal changes of the depth of the centre of gravity and the normalised mean backscattering strength during transition periods for all three basins.

value They are obtained for all three investigated localities - the Baltic Sea, Lake Wdzydze and Lake Tanganyika - for the transition periods. The left and right parts of the individual diagrams concern dawn and dusk respectively. These are the two periods of a day, when the intensive vertical migration takes place. Some common features are striking. In each case a descent of the gravity centre at dawn and an ascent at dusk are notified. It mirrors a downward and upward diurnal vertical migration of sound scattering layers. In the different seasons this migration starts at different time in accordance with the sunrise and sunset moments, but intensive migration is always closely connected with these moments and is rather short-lived. Generally, the morning and evening vertical redistribution occupies less than 1 hour total.

For the situations presented in Fig. 3, the approximate values of the vertical migration velocity were calculated (Table 2). There is thus good evidence, that the deeper the water is, the quicker is the vertical movement. While upward movement at dusk seems principally for the purpose of feeding, the return to deeper waters at dawn is probably attributable to predator avoidance. In the Baltic Sea and Lake Wdzydze vertical migration is limited by the thermohaline conditions, while in Lake Tanganyika the organisms migrate to the depth of 150 m or more where depth of oxygenation permits. In contrast to temperate climate lakes and seas, the entire water column in Lake Tanganyika is warm and the annual temperature cycle is unlikely to control biological processes.

Table 2. Vertical migration velocities [m/h]

	SUNRISE	SUNSET
Baltic Sea 05.04.97	23	36
Lake Wdzydze 27.08.98	9	8
Lake Tanganyika 10.02.98	75	60

The mean backscattering strength displayed in Fig. 3 is evidently higher at night than during the day and varies by 3 - 13 dB between day and night depending on the region and season. For some other observations, not shown in these examples, the night-to-day difference in the mean *SV* often exceeds 20 dB. These dramatic diurnal variations can be a result of various factors: multiple scattering and coherent effects in dense aggregations, lateral and vertical migration of organisms out of the echosounder range, diurnal variation of target strength caused by the changes of scatterers orientation in space. Coherent and multiple scattering as well as changes in *TS* seem to be the most probable reasons for the observed effect.

An amount of the backscattered energy is determined by the value of S_v, which is directly related to a combination of the number of scatterers and their individual scattering properties. As the first approximation, it can be assumed that higher values of *SV* reflect bigger biomass of scatterers. Interseasonal comparison of the mean backscattering strength measured in Lake Wdzydze, separately in light and dark part of a day, is displayed in Fig. 4. Two things are worth noting. Firstly, daily values of the mean *SV* are lower than the nightly ones. Secondly, warm months are characterised by higher values of scattering strength connected in all probability with more intensive life and higher biomass. Very similar dependence was obtained also for the Baltic Sea.

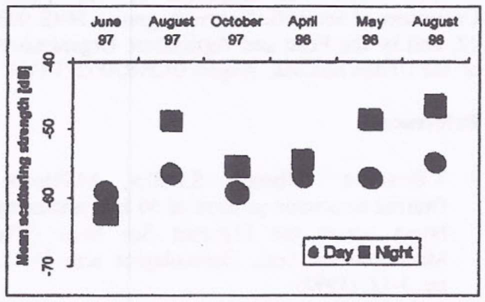

Fig. 4. Seasonal changes of the mean backscattering strength in Lake Wdzydze.

4. Summary

Distinctive aggregations of fish and zooplankton were found at night in all three basins. Despite the substantial differences in morphology of the investigated basins and some discrepancies in experimental conditions, it was possible to discern some features of similarity in day-night vertical migration of biological layers:

1. The distributive patterns of the biological aggregations are related to the physical-chemical properties of the habitat. In temperate areas they vary distinctively between seasons.
2. The temporal variability of the location of the gravity centre and mean backscattering strength indicate a significant day-night redistribution of the biological scatterers.
3. The vertical migration at dusk and dawn takes place with various speeds, which seems to depend on the local life space determined by the depth, temperature and oxygen content.

4. There are significant differences in the mean backscattering strength (up to 20 dB) between day and night. Those differences represent combined effects of changes in abundance and changes in target strength. Such strong variability of the number of scatterers is rather unlikely, therefore there might be a risk of systematic error in biomass estimation, when target strength value is assumed to be constant.

The interpretation of our acoustic images calls for more knowledge about the nature and behaviour of the sound scatterers and understanding of factors which lead to heterogeneity in zooplankton distributions. The most important task for limnologists and oceanographers is resolving the spatial and temporal scales over which physical and biological agents in the sea are associated.

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