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# SPATIAL DISTRIBUTION AND MIGRATION OF SOUND SCATTERING LAYERS AND ZOOPLANKTON IN FRONT OF BULGARIAN BLACK SEA COAST

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***Key words:*** *acoustic, sound scattering layers, zooplankton, Western Black Sea, distribution*

***Abstract:*** *Sound scattering layers (SSLs) and spatial distribution of zooplankton were studied in the western Black Sea in October 2008. Acoustic backscatter measurements, net tow samples at different depths and Conductivity Temperature Depth (CTD) measurements from the upper 150 meters of the water column were collected. In addition, measurements of fluorescence and dissolved oxygen were made. Zooplankton species were identified, enumerated, and measured. Two characteristic layers of sound scattering were found in the examined area. The SSLs performed diurnal vertical displacements. The migration speeds were estimated. The contribution of the species composition of zooplankton community to the SSLs was analyzed. A clear horizontal pattern could be outlined with the highest values of abundance in coastal and shelf area and decreasing trend toward the sea. The main type of vertical distribution regarding the position of the greatest zooplankton density was with maxima in surface waters, excluding the deepest station where maximum was at the thermocline layer. Generally, according to the vertical spatial distribution, the community in the upper mixed layer was dominated by copepods A. clausi, P. parvus and their larval stages, while P. elongatus and C. euxinus were concentrated at lower depths. A comparison between the vertical distribution of SSLs, zooplankton communities and hydrological parameters of water was made.*

## Introduction

The Black Sea is the most isolated inland basin in the world ocean, where the deep waters do not mix with the upper layers of water that receive oxygen from the atmosphere. As a result, about 87% of the deeper Black Sea volume is anoxic water. The anoxic deep waters and oxic upper waters of the Black Sea are separated from the pycnocline, coinciding with the halocline. Life is therefore restricted to the upper 80-200 meters depending on the hydrology of the region. The thermohaline variability in vertical stratification has a big influence on the distribution of marine fauna and the scheme of their diel vertical migration.

Diel vertical migration (DVM) is a phenomenon observed in many planktonic organisms, both marine and freshwater. The general pattern is for these animals to ascend from depths beneath the photic zone near dusk, feed in the prey abundant surface waters at night, and then descend again to dark waters near dawn. It is hypothesized that the vertical migrations lead to a reduced rate of predation of the migrating animals, because in the dark the animals are not as visible to most predators [1]. However, other benefits to DVM may exist including a reduced metabolic rate at lower ambient temperatures encountered at greater depths.

Traditionally, studies of the spatial distribution and diel migrations of zooplankton were generally done by collecting samples from plankton nets. Opening and closing nets targeted at specific times in specific depth layers will give a profile for species abundance and biomass at each depth.

An alternative method for studying biological organisms is a non-invasive acoustic approach. Acoustic methods enable to determine zooplankton and fish abundance, their size, distribution and their behaviour – aggregation, collective movement and vertical migration. Aggregations of the biological objects are called the Sound Scattering Layers (SSL). SSLs distribution and vertical migrations are of considerable ecological significance as the main constituents, the fishes and the major zooplankton groups, occupy adjacent links in the food chain. In the Black Sea SSLs comprise fish, mainly sprat and anchovy, and various species of zooplankton.

This paper presents an example of utilization of acoustic techniques to detect zooplankton community associated with the sound scattering layers and vertical stratification of the water column. Sound scattering due to the physical gradients is considered a minor source compared with the

presence of biota and hence the recorded scattering levels are mainly attributed to these organisms. The main goals of the analysis were: (1) describe the diurnal variations in depth distributions of the SSLs including calculations of migrational speeds; (2) evaluate the role of some hydrological and hydrochemical gradients as the initiation of the vertical displacements and (3) establish the horizontal and diel vertical distributions of the species composition, abundance and biomass of the zooplankton.

## Material and methods

*Study area*

A research cruise was carried out from 29 September to 4 October 2008 by the RV ''Akademik'', IO-BAS, Varna. The sampling area was the West Shelf of the Black Sea, located in a transect in front of Varna town – c. Galata and a transect in front of c. Kaliakra - standard transects from the IO-BAS routine sampling grid extended to the open sea. Cape Galata transect was under the consideration in the resent study. Map of stations is presented on fig. 1 and the station coordinates on Table 1 respectively.

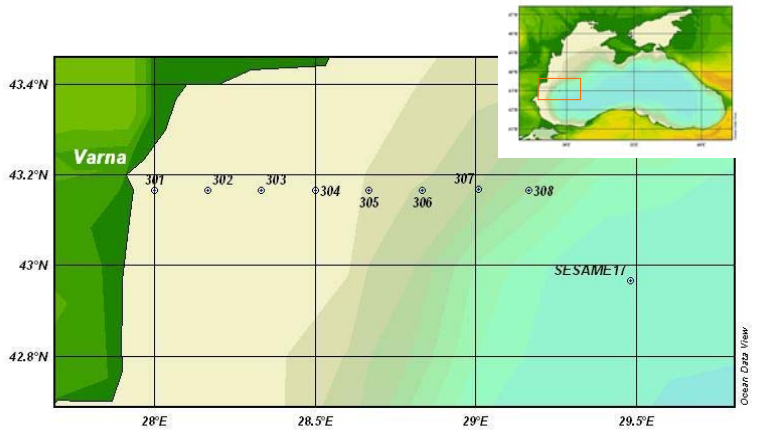


Fig. 1. Map of sampling stations during RV "Akademik" SESAME cruise (29 September – 4 October'2008)

Table.1. Coordinates of sampling stations along the c. Galata transect (Western Black Sea) during the multidisciplinary cruise

| Station Name | Bottom depth (m) | Latitude | Longitude |
|---|---|---|---|
| S-BG00-01-(301) | 22 | 43˚ 10' N | 028˚ 00' |
| S-BG00-02 (302) | 23 | 43˚ 10' N | 028˚ 10' E |
| S-BG00-03-(303) | 41 | 43˚ 10' N | 028˚ 20' E |
| S-BG00-04-(304) | 78 | 43˚ 10' N | 028˚ 30' E |
| S-BG00-05 (305) | 94 | 43˚ 10' N | 028˚ 40' E |
| S-BG00-06-(306) | 360 | 43˚10'N | 028˚50' E |
| S-BG00-07-(307) | 1026 | 43˚10'15"N | 029˚00'45"E |
| S-BG00-08-(308) | 1550 | 43˚10'N | 029˚10' E |
| S-BG00-09-(SESAME17) | 2007 | 42˚58' N | 029˚29'E |

Hydrophysical parameters (temperature and salinity) were measured in situ by using a Sea-Bird Electronics SBE 19*Plus* SEACAT Profiler. The downcast data was binned to 1 m depth intervals using SBE Data Processing Software version 7.18 (Sea-Bird Electronics, Bellevue, Washington, USA). Water samples were collected using Rossette sampling system on the following depths: 0, 10, 25, 50, 75, 100, 150, 200, 250 m and thermocline location depth. Dissolved oxygen (DO) and oxygen saturation (OS) were analyzed in the onboard laboratory by standard methods [2].
Vertical sections of temperature, salinity, density and dissolved oxygen were contoured along transect line using triangulation with linear interpolation in SURFER version 8 (Golden Software, Golden, CO, USA).

The sound scattering layers were continuously monitored with a Simrad EK60 echosounder using hull mounted 38, 120 and 200 kHz split-beam transducers. The transducers were located at 4.5 m depth. The raw data were logged by Simrad ER60 software (20 log R TVG). Echograms were

visualized in Matlab and EchoView, and additional postprocessing of data was done by software written in Matlab. The 200 and 120 kHz frequencies were used to detect plankton while 38 kHz was used to distinguish fish from plankton.

Zooplankton samples were collected by vertical plankton Juday net, 0.1 $m^2$ mouth opening area, 200 μm mesh size from 2 meters above the bottom to the surface at sampling layers depending of water stratification and thermocline depth. Total of thirty zooplankton samples were collected from 9 stations during the early autumn cruise.

Before sample preservation, the gelatinous species (*Aurelia aurita, Mnemiopsis leidyi* and *Beroe ovata*) were removed, rinsed, measured and counted on board. The samples were preserved in 4% buffered to pH 8-8.2 with disodiumtetraborate (borax) (Na2B403 ·10 H20) formalin solution. In the laboratory, the samples were settled to 100-150 $cm^3$ before being divided into sub-samples. A Bogorov's chamber was used for quantitative (abundance and biomass calculation) and qualitative (taxonomic structure) assessment [3, 4]. The sub-samples were examined by using an Olympus SZ30 Stereoscopic Zoom Microscope. For each sample, 2 aliquots were totally counted and, in addition: i) if there were no dominant species, then other aliquots were examined; ii) if there were dominant species (any species of copepod or other non-copepods species present with at least 100 specimens (sum of males, females, juveniles), these were counted only in the first 2 aliquots. The entire sample was examined for the rare species.

## Results and discussion

### *Hydrology*

Vertical profiles of water temperature $(T)$, salinity $(S)$, density $(\sigma_\theta)$ at the all sampling stations and dissolved oxygen (DO) at deeper stations (from st. 306 to SESAME17) are shown in fig. 2. At most stations, a surface mixed layer was observed in the top (upper) 30 m, only at station 304 it reached to 32 m depth. At shallower station 301 and 302, the water mass at the surface to the bottom was homogenous with a temperature 19.8°C. At offshore stations, the situation was very different. Below the mixed layer, a sharp seasonal thermocline formed down to about 50-58 m, with temperatures decreasing from 19.8 to 8°C. A layer of cold intermediate water (CIL), the typical hydrographic structure of the Black sea, was found between 50-58 and 88-98 m. The temperature of the water below CIL slowly increased, reaching about 9.1°C at the seabed. The surface salinity was a comparatively low, about 17.4-18.1 psu. Vertically salinity increased steadily from ~30 m at the surface to the seabed.

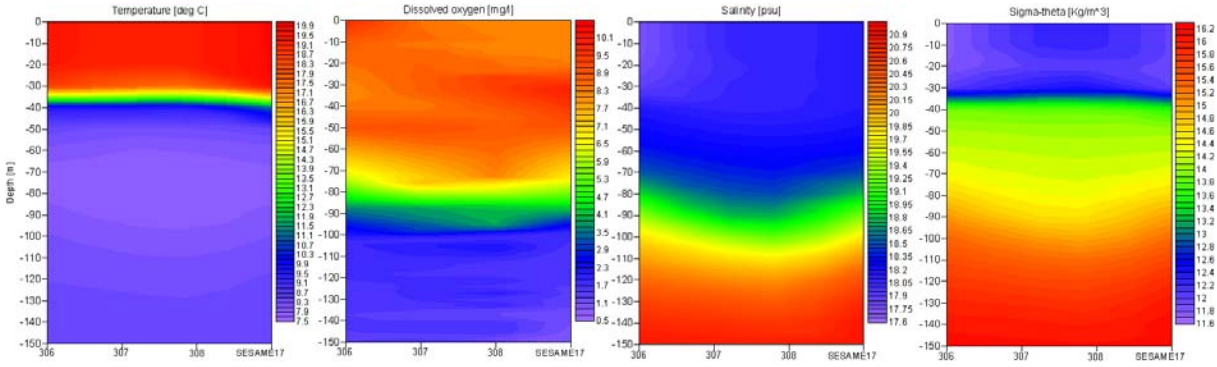


Fig. 2. Temperature, dissolved oxygen, salinity and sigma-theta profiles – open water stations: 306, 307, 308, SESAME17.

The vertical distribution of salinity and temperatures determine the density of seawater. The picnocline characterised here by the maximum vertical salinity gradient, deepened to 140–150 m. It was accompanied by the oxycline, where oxygen concentration decreases from 6.1-7.6 $mg.l^{-1}$ at the water density 14.3-14.5 $Kg.m^{-3}$ to 0.85-1.17 $mg.l^{-1}$ at density 15.4-15.8 $Kg.m^{-3}$. The oxygen minimum zone (OMZ) was observed below the oxycline at sigma-theta ~16.2 $Kg.m^{-3}$.

### *Zooplankton composition, abundance and biomass, horizontal and vertical distribution*

During the investigated period a total of 28 zooplankton species and taxa were identified. Taxonomically, the area was dominated by copepods. Common representatives of Copepoda included: *Acartia clausi, A.tonsa, Paracalanus parvus, Oithona similis, Centropages ponticus, Pseudocalanus elongatus, Calanus euxinus*. The key groups of Copepods, Cladocera, Meroplankton,

Appendicularia (*Oicopelura dioica*) and Chaetognatha (*Sagitta setosa*) constituted a major component of plankton fauna with an ecological importance in zooplankton structure. *Noctiluca scintillans* was also relatively well presented in plankton community (1090 ±1226 ind.m$^{-3}$). Concerning Jellyfish species, the exotic ctenophores *Mnemiopsis leidyi* and *Beroe ovata*, the medusa *Aurelia aurita* and native ctenophore *Pleurobrachia pileus* occurred constantly in the area with minor range in abundance fluctuation (from 1 to 15 ind.m$^{-3}$).

Spatial distribution of zooplankton quantity revealed differences between sites (inshore and offshore). The abundance of the mesozooplankton decreased as a function of distance from the coast towards the sea. Numerical zooplankton abundance varied from 1 662 ind.m$^{-3}$ to 23 180 ind.m$^{-}$3 (SD ± 7107) with maximum at the coastal station 302 and almost equal density (from 1662 to 3465 ind.m$^{-3}$) at open sea area (st. 306, 307, 308, SESAME17, fig. 3 a, b). Copepods were numerically abundant, contributing up to 70 % with an exception of near shore station 301 where copepods shared 48 % with Meroplankton (28 %), *O.dioica* (15 %) and *S.setosa* (8 %). The biomass distribution pattern corresponds to those of abundance. It varied between minimum 65.44 mg.m$^{-3}$ (st. 308) and maximum 774.53 mg.m$^{-3}$ (st. 302). *S setosa* and copepods dominated in the biomass with identical percentage (43 %). The progressive decreasing of biomass from coastal to deeper stations was evident.

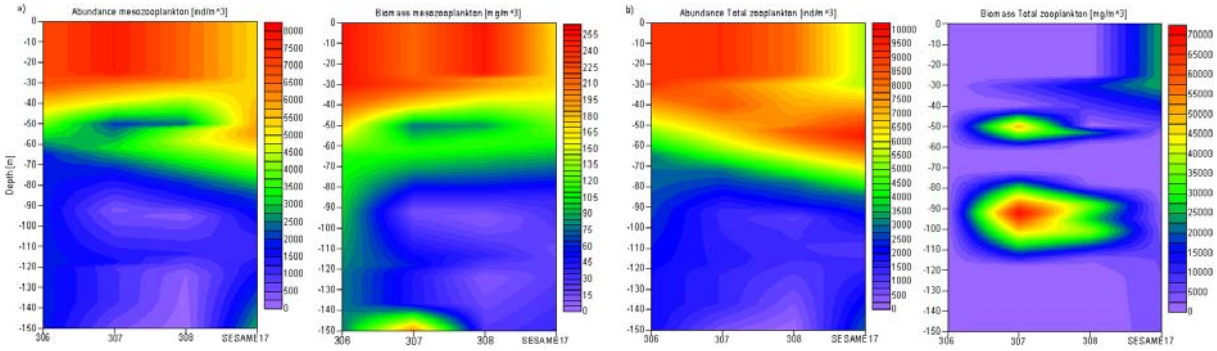


Fig. 3. Spatial distributions of mesozooplankton abundance and biomass (a) and total zooplankton abundance and biomass (b) - open water stations: 306, 307, 308, SESAME17.

The main type of vertical distribution at deeper stations (from 305 to SES 17) regarding the position of mesozooplankton abundance maximum was with maxima in surface waters (upper mixed layer - UML), excluding st. 305 and SESAME17 where UML and thermocline strata were with equal density. Higher biomass values at stations 307 and 308 under termocline were due to of *M.leidyi* presence (fig.3 b). Generally, according the vertical species separation, the community in upper mixed layer was dominated by copepods and co-dominated by Cladocera and *S.setosa* juveniles. Copepoda species *A. clausi, P. parvus, C. ponticus* and their larval stages occupied surface layer in the water column while *P. elongatus* and *C. euxinus* with their copepodite stages preferentially inhabited under thermocline and CIL (cold intermediate layer) waters. *S.setosa* adults were concentrated at lower depths bellow thermocline as well. Jellyfish showed not clear vertical distribution pattern.

*Sound scattering layers (SSLs) and their daily migration patterns*

Typical picture of the vertical and horizontal structure of the sound scattering layers (SSLs) along the transect c. Galata is shown in fig. 4. Biological scattering was found between the surface and lower part of the oxygenated zone in the Black Sea, usually, it was horizontally and vertically distributed in more than one scattering layer. The largest and densest scattering layers were located offshore stations. On the shelf, deeper scattering layer was found close to the bottom in areas shallower than 100 m. Acoustic scattering was remained homogeneous in coastal zone (<30m). The sound scattering layers exhibited diel migrations. They were inhabited at least two separate groups of organisms undergoing distinctive vertical migration. One group remained at moderate layers (40 to 50 m), and spent the daytime at this layer. The other group reached greater depths, almost down to the onset of the anoxic layer. The ascent to the surface began at the end of the afternoon, the surfacing occurred after sunset. At night, all groups were observed very close to the surface, above the thermocline. The descent began about 1 h before sunrise, with the first light of dawn.

The daily migration patterns of SSLs were presented better in offshore site of the study area. Figure 5 a shows the 200 kHz compressed echogram, recorded on 2-3 October 2008 (st. 307), of SSLs, which were seen migrating upward to the surface at dusk and downward to deeper water layers before sunrise. Three distinct SSLs were recorded in the upper 150 m. The SSL1 was distributed between 30 and 50 m throughout the day, corresponding to the depth of seasonal thermocline. This

layer showed varying thickness in the day time and it dispersed to the surface at night. Diffuse scattering was seen above this layer although it did not constitute a definite scattering layer. By day, deeper scattering layers SSL2 and SSL3 remained at depths of 95 to 110-120 m, with temperature of 8 to 8.17°C,where the density and oxygen concentrations ranged with the limits from 15.09 to 15.53-15.8 Kg.m$^{-3}$ and from 3.65 to 0.85 mg.l$^{-1}$ respectively (fig. 2). DSLs started to ascend around 16:05 (SSL2l) and 16:15 (SSL3). They reached the surface water layers at 19:00 (SSL2) and 19:45 h (SSL3) (fig. 3, a,b), so that their migration upward took nearly 2h 55 min and 3h 30 min. The acoustical volume backscattering strength $(S_v)$ of the central part of the surface layer measured -90 dB at the beginning of the ascent and increased to -78 dB at the end of the migration.

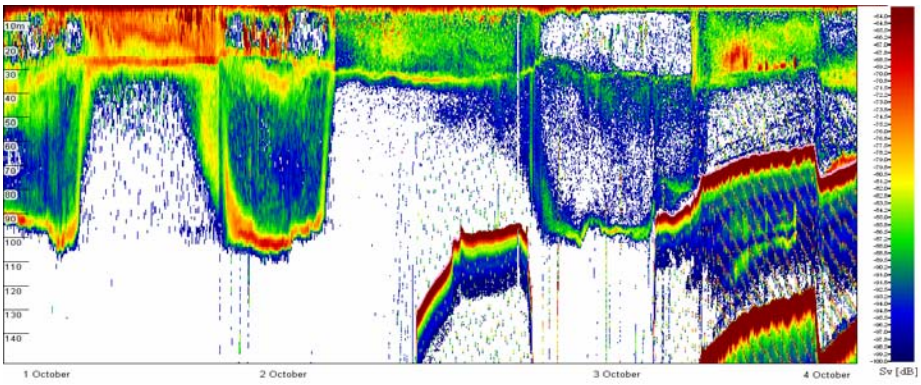


Fig. 4. Condensed echogram prepared on the basis of a 4-day acoustic sounding in October 2008.

Mean swimming speed of SSL2 was ~ 1.2 cm.s$^{-1}$ and of SSL3 – ~0.95 cm.s$^{-1}$. In the morning, DSLs started migrating downward at 5:15 hrs (SSL3) and 5:30 hrs (SSL2). They were reached to the lower border of their habitat at 7:20 hrs (SSL3) and 7:25 hrs (SSL2). The mean swimming speeds of DSLs during descent were 1.74 cm.s$^{-1}$ (SSL3) and 2.04 cm.s$^{-1}$ (SSL2).

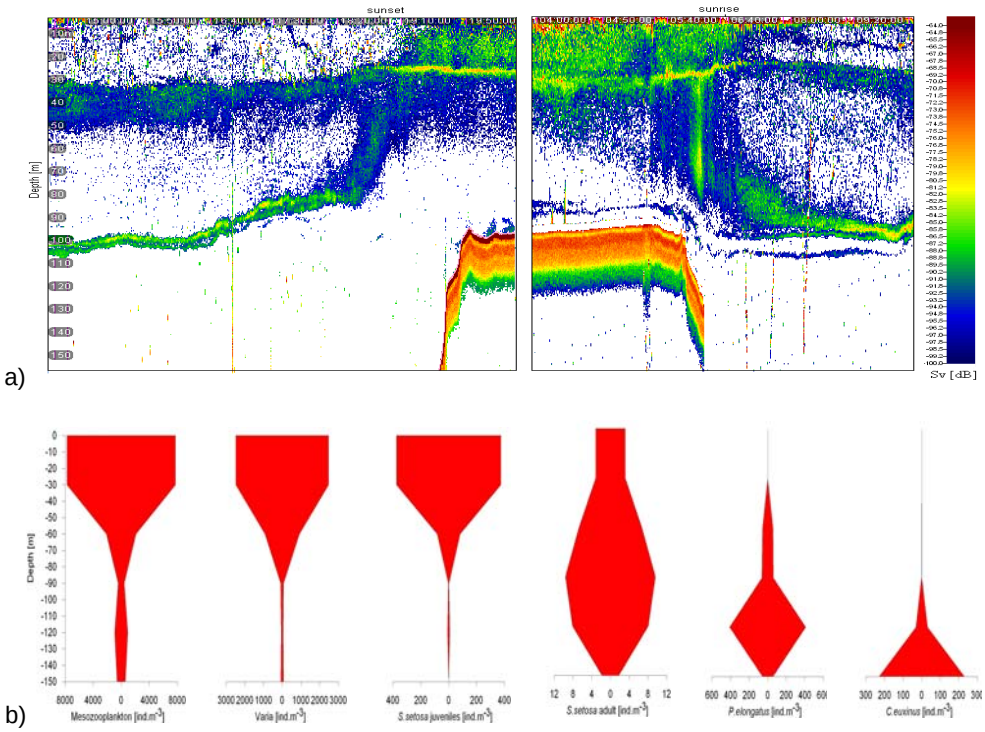


Fig. 5. Vertical distributions and daily migration of SSLs (a) and mesozooplanton abundance at st. 307 in the day time (b).

Swimming speed of scattering layers during migration (upward and downward) varied from a passive sinking speed within the suboxic zone to an active speed through well-oxygenated water and thermocline. Generally, the downward speed is higher than upward the one. Similar behavior and

migration speeds for the deep scattering layers (*C. euxinus* and *S. setosa*) in Black sea were obtained by other authors [5, 6].

The results of zooplankton sampling also showed similar trends to the vertical distribution of the biological scattering obtained by acoustics (fig. 5 b). Figure 5 b shows the abundance and vertical distributions of mesozooplanton at st. 307 in the day time. The sampled organisms in the upper 40 m (*A. clausi, P. parvus, C. ponticus* and their larval stages, *Sagitta setosa* juveniles) correspond with SSL1. Zooplankters as *Pseudocalanus elongatus, Calanus euxinus* and *S.setosa adults,* which have strong swimming ability and prefer deeper cold waters at day, take part in the formation of the deep scattering layers (SSL2, SSL3).

During periods of seasonal temperature stratification cold-water copepods species ascend at night to warm surface layers with high phytoplankton concentration, and in the morning migrate to the cold, hypoxic zone (0.35 to 1.15 $mg.l^{-1}$ $O_2$, $\sigma_\theta$= 15.4 to 15.7), where they form aggregations just below the oxycline [7, 8]. Metabolism in copepods is known to be directly affected by temperature [9, 10] and oxygen concentration [11, 12].

## Conclusions

The high resolution of acoustic methods enables the spatiotemporal monitoring of marine organisms and correlating their behavioral features with SSLS and the abiotic environmental factors. Zooplankton vertical and horizontal distribution patterns appeared to be linked with each other and were primarily species-dependent. The most important features of the diel vertical migration of the SSLs are the following: (1) times of the evening and morning migration are well correlated with the moments of sunset and sunrise; (2) 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, density and oxygen content; (3) downward migration speed is higher than upward speed.

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