Turk J Zool
24 (2000) 417-427
@ TÜBİTAK

The Diel Vertical Distribution of Zooplankton in the Southeast Black Sea

Funda ERKAN, Ali Cemal GÜCÜ
Middle East Technical University, Institute of Marine Sciences, P. O. Box: 28 Erdemli 33731 İçel-TURKEY
Julia ZAGORODNYAYA
Institute of Biology of the Southern Seas National Academy of the Sciences of Ukraine, Nakhimov Av. 2, Sevastopol 335011, UKRAINE

Received: 13.04.1999

Abstract: The diel changes in the vertical distribution of zooplankton in the southeast Black Sea were described in this study. The zooplankton were sampled using two different sampling methods throughout one day in October 1996 and July 1997 at the same station. The zooplankton counts, the length measurements and biomass estimates showed that the zooplankton in the southeast Black Sea is dominated by small organisms, among which *Noctiluca scintillans* is the dominant species. In the vertical distribution of zooplankton, three groups were observed in different layers. *Calanus euxinus* and *Pseudocalanus elongatus* showed a clear vertical migration pattern. Conventional measurements (settling volume, displacement volume and wet weight measurements) were also carried out and the results were compared with the zooplankton counts and biomass values. Among those, abundance of zooplankton correlated well with the wet weight measurements ($r = 0.473$; $p<0.05$) of the October 1996 samples. The length converted biomass of zooplankton also significantly correlated with the wet weight measurements ($r = 0.717$; $p<0.05$).

Key Words: Zooplankton, vertical distribution, abundance, biomass, southeast Black Sea

Güneydoğu Karadeniz Zooplanktonun Günlük Dikey Dağılımı

Özet: Bu çalışmada Güneydoğu Karadeniz'deki zooplanktonun günlük dikey dağılımı verilmiştir. Zooplankton iki farklı metodla aynı istasyonda tüm bir gün boyunca Ekim 1996 ve Temmuz 1997 tarihlerinde örneklenmiştir. Örneklerdeki zooplankton sayımları, uzunluk ölçümleri ve biyokitle tahminleri, güneydoğu Karadeniz'deki zooplanktonda küçük boyutlu olanların, bunlar arasında ise *Noctiluca scintillans'ın* baskın olduğunu göstermektedir. Zooplanktonun dikey dağılımında, farklı tabakalarda üç ayrı grup gözlenmiştir. *Calanus euxinus* ve *Pseudocalanus elongatus* belirgin dikey göç sergilemektedir. Klasik ölçümler (çökelti hacmi, taşırma hacmi ve yaş ağırlık ölçümleri) de gerçekleştirilmiştir. Sonuçlar zooplankton sayımları ve biyokitle değerleriyle karşılaştırılmıştır. Bunlar arasından, zooplankton bolluğu Ekim 1996 örneklerinin yaş ağırlık ölçümleriyle uyumlu bulunmuştur ($r = 0.473$; $p<0.05$). Bunun yanısıra biyokitle değerlerinin de yaş ağırlık ölçümleriyle belirgin bir uyumluluk gösterdiği saptanmıştır ($r = 0.717$; $p<0.05$).

Anahtar Sözcükler: Zooplankton, dikey dağılım, bolluk, biyokitle, güneydoğu Karadeniz

Introduction

The Black Sea is the largest land-locked basin in the world with a maximum depth of ~ 2200m and 87% of its water is anoxic (1). A pycnocline (coinciding with the halocline) separates the anoxic deep waters and oxic upper waters of the Black Sea. Life is therefore restricted to the upper 70-200 meters depending on the hydrology of the region. Recent studies show that in the Black Sea, some hydrochemical properties could be better explained by water density rather than depth (2). For example, the depth of the beginning of anoxic layer differs at different locations, but it is always situated at the density of sigma t = 16.2.

The Black Sea was classified amongst the oligotrophic seas in the early years of the century (3) and some basins, such as the Northwestern shelf area, were mesotrophic in the 40s (4). As a result of increased nutrient input by the major rivers, it became a eutrophic sea (5). Moreover, due to increased eutrophication the shallow Northwestern shelf area of the Black Sea has shown dystrophic properties occasionally (6).

Increase in nutrients has elevated the rate of primary and secondary production. The nutrient composition has also changed. The rate of silicate, which is only originated from natural resources, is suppressed by the anthropogenic nitrogen-based nutrients and phosphorous. Consequently, phytoplankton species composition was altered and the large diatoms whose biomass is largely dependent on the silicate availability in the sea were replaced by the dinoflagellates. The domination of dinoflagellates in the Black Sea ecosystem led to a change in the species composition of the zooplankton. Many large species of crustacean zooplankton feeding mainly on diatoms were replaced by small opportunistic species (6).

In the water column, different species of zooplankton occupy certain depths due to temperature, light intensity, feeding, age, reproductive stage and some other biological, chemical and physical factors (7). Several groups can be distinguished in the Black Sea zooplankton by the character of their vertical distribution. According to Zenkevitch (8) the first group inhabits the upper layers, and its vertical distribution is only slightly affected by variations in temperature and light through the seasons. *Acartia clausi, Oikopleura* sp. and *Noctiluca scintillans* are examples in this group. The species belonging to the second group are found at all depths in winter, and in summer they are found in the greater depths of the water column. These species are also called cold water species. *Calanus euxinus, Pseudocalanus elongatus, Oithona similis* and *Sagitta setosa* are representatives of this group. The third group develops only in summer and are found in the upper, warm layers of water, which includes mainly Cladocera species.

Daily migrations have been observed for a number of species, depending primarily on variations in light intensity. During the night many species migrate to surface layers and during the day they are concentrated in deep layers (9). Amongst the species/groups of zooplankton, Zenkevitch (8) pointed out that *Calanus euxinus* and *Sagitta setosa* show the most pronounced daily migrations driven largely by the change in light intensity.

The natural light:dark cycle which the diel vertical migrations are tuned to, suggests that changes in ambient light intensity may be of primary importance as stimuli in the initiating and timing of migrations (7). Light intensity changes also act as orienting cues for vertically migrating animals. Natural daily changes in light intensity can alter the depth ranges inhabited by particular species.

Many hypotheses have been advanced concerning vertical migration (7). One hypothesis is that animals which remain in darkness are less visible to predators, and this situation can be achieved by migrating to deeper, darker layers. The upward migration is to the surface zone where food is most abundant. The second idea is that zooplankton conserve energy by spending non-feeding time in deeper, colder water where metabolic energy demands are lower. The third hypothesis is that the zooplankton moving vertically are subjected to currents moving in different directions at different speeds, thus, each time they ascend, they encounter a new feeding area.

In recent years, the vertical distribution of mesoplankton and the pelagic community structure in the Black Sea were studied by Vinogradov et al. (10-17), and diel vertical distribution of mesozooplankton within the Turkish Exclusive Economic Zone was studied by Besiktepe (13) and Besiktepe et al. (14).

In the present study, the diel vertical distribution of the zooplankton in the southeast Black Sea is described by means of time series sampling. Two different sampling methods were applied and compared. Also the additional methods, such as measuring the settling and displacement volume and wet weight, were tested to show the vertical distribution of zooplankton.

Materials and Methods

Plankton sampling

Vertical plankton samples were collected during October 1996 and July 1997 surveys at a fixed station, 41°30` N, 39°45` E, located within the Batumi anticyclonic gyre (Fig. 1), where the thickness of the oxic layer is largest (1) and reached 183 meters (Fig. 2).

In October 1996, plankton samples were taken at two hour intervals throughout one day by Nansen Closing Net with a 112 µm mesh size and 70 cm mouth opening. In order to see the variation in zooplankton abundance in the water column, 70 samples were taken between 02:15 and 23:50, in order to cover the daily cycle of the vertical migration. The depth ranges covered by the Nansen Net were 190-150 m, 150-125 m, 125-80 m, 80-25 m and 25-0 m, and they were chosen in terms of density levels according to major biochemical characteristics of the water column which affect the distribution of mesozooplankton in the Black Sea (Fig. 2). The depth ranges covered were: i) from the seasonal

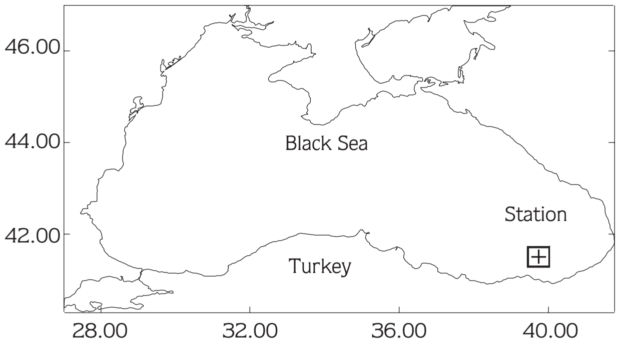

Figure 1. Position of the zooplankton sampling station: (+) = Net sampling in October 1996; □= Niskin Bottle sampling in July 1997.

thermocline to the surface (mixed layer), ii) from the lowest boundary of the euphotic zone (sigma t = 14.6) to the mixed layer, iii) from sigma t = 15.4, where the majority of nitrification and remineralization of organic matter take place, to the lowest boundary of the euphotic zone (15), iv) from sigma t = 15.8 to sigma t = 15.4 where the denitrification processes begin at the depth of 15.4 (16), v) from sigma t = 16.2 to sigma t = 15.8, where 16.2 corresponds to the bottom of oxygen minimum zone (OMZ) and the daytime aggregation layer for *Calanus euxinus* individuals (11).

In July 1997, plankton were sampled throughout one day, between 00:00 and 22:00, using a Niskin Bottle with a capacity of 30 l. at the same station (41°30` N, 39° 45` E) as in the October 1996 survey. The samples were collected at the times that were thought as important in the vertical movement of the zooplankton, e.g., at dawn, at noon and at sunset. An echosounder was used to select the sampling depths that were chosen according to the acoustic back-scattering in the water column at the time of sampling. High and low biomass reflectances on the acoustic profile were selected and sampled.

All the samples were preserved in formaldehyde solution of 4%, and the examination of them was done under a stereoscopic binocular microscope. The net samples taken by Nansen Closing Net were subsampled using a Folsom Plankton Splitter and a Stempel Pipette. Large species were identified and counted for the whole sample before subsampling. The Niskin Bottle samples were not subsampled, since the number of individuals in the samples were few enough to be counted totally. The length measurements of the zooplankton in the samples were done with an ocular micrometer. The length of the crustaceans was measured from the rostral tip to the posterior border of the furca. For the other organisms, like *Noctiluca scintillans* or Chaetognaths, the longest axis of the body was measured. The length measurements were summarized in length frequency histograms. Every peak in the length frequency distribution was assumed to indicate a distinct size class. The nearest troughs just before and after the peak were taken as the limits of the size class.

Total biomass of the samples were calculated according to the following formula:

$$TB = \sum_{i}^{n} \sum_{j}^{m_i} (W_{ij} * N_{ij})$$

n = number of species

m_i = number of stage-based size classes of species *i*

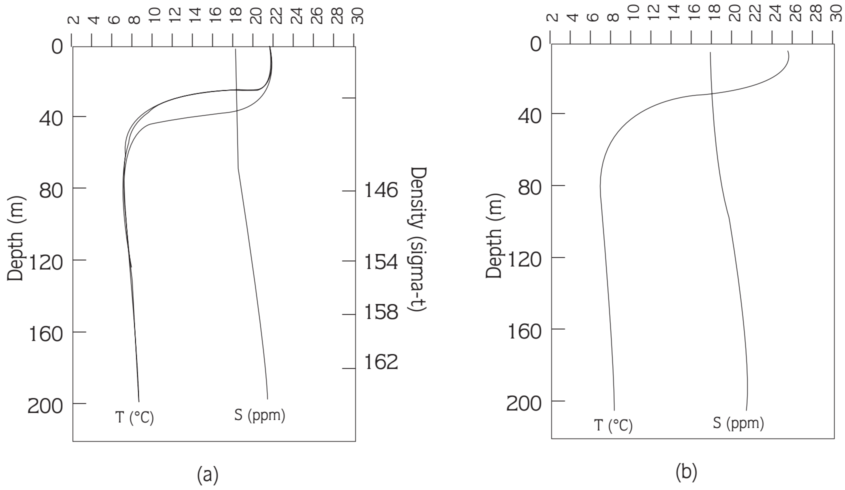

Figure 2. The salinity and temperature profiles are plotted against depth and water density in (a) October 1996, (b) July 1997. Measurements were repeated several times during the stay at the station 41°30` N, 39°45` E. The solid horizontal lines show the sampling layers.

W_{ij} = mean weight of size class *j* of species *i* (mg)

N_{ij} = number of individuals in each size class

In the formula, W, mean weights of stage-based size classes, were taken from Niermann et al. (17).

After enumeration, the net samples (October 1996) were examined gravimetrically; the settling volume, displacement volume and wet weight of the samples were measured according to Wickstead (18). The concentration of the zooplankton in the samples collected by Niskin Bottles in July 1997 were not sufficient to be detected volumetrically or gravimetrically.

Results

The composition of the zooplankton in the samples is given in Table 1. In October 1996, the dominant zooplankton species was *Noctiluca scintillans* (41.7%; 199 ind/m^3). Second was *Oithona* spp. which comprised 17.5% (83 ind/m^3) and the third most common species was *Pseudocalanus elongatus* (10.9%; 52 ind/m^3).

The zooplankton in the samples had a wide range of length spectrum. The length distribution of the *zooplankton* from the net samples is given in Fig. 3, in which the length classes are presented on a common abscissa, whereas the frequencies are presented by two different ordinates.

Table 1. Abundance and percentage of the zooplankton species/groups in October 1996 samples.

SPECIES/GROUPS OF ZOOPLANKTON	abundance (#/m^3)	%
Noctiluca scintillans	198.56	41.7
Oithona spp.	83.38	17.5
Pseudocalanus elongatus	51.84	10.9
Acartia spp.	20.72	4.4
Cladocera	18.60	3.9
Calanus euxinus	15.43	3.2
Polycheta larvae	9.63	2.0
Appendicularia	7.34	1.5
Lamellibranchiata	2.45	0.5
Chaetognatha	2.15	0.5
Ostracoda	1.89	0.4
Mnemiopsis leidyi	1.68	0.4
Tintinnide	0.54	0.1
Pleurobrachia pileus	0.49	0.1
Gastrapod larvae	0.39	0.1
Harpacticoid copepods	0.10	0.0
Paracalanus parvus	0.07	0.0
Aurelia aurita	0.04	0.0
Undefined Copepod and	48.96	10.3
Nauplii	11.74	2.5

As can be seen on the left side of Fig. 3, the small organisms were the most abundant group in the samples. To understand which zooplankton group dominated in which size group, length classification was made and eight different length classes were selected. The selected ranges and the percentage of zooplankton groups included in each length class are given in Table 2. Among these, in the first size class (0.1-0.3 mm) *Oithona similis* dominated. *Noctiluca scintillans* and *Pseudocalanus elongatus* constituted 84% and 81% of the zooplankton in the 0.4-0.8 and 0.9-1.2 mm size classes, respectively. *Acartia* spp. was the main group in the 1.3-1.7 mm length class with 73 %. The following three size classes were dominated by different stages of the species *Calanus euxinus*; copepodites were mainly found in the 1.8-2.3 mm, where the copepodite V and adult stages were found in 2.4-3.0 and 3.1-3.6 mm size classes. The macrozooplankton constituted the last class larger than 4 mm.

The length distribution of all individuals encountered in the July 1997 Niskin samples is given in Fig. 4. Note that, like in Fig. 3, the chart has a common abscissa and two different ordinates, and the smaller zooplankton were much higher in number than the larger ones.

For the same purpose as in October 1996, the length classification was made and the data were subdivided into eight length classes. The selected ranges and the percentage of taxonomic groups in each length class are given in Table 3. In the July 1997 survey, nauplii were the dominant zooplankton group in the 0.1-0.3 mm size class (35%). The main zooplankton species in the 0.4-0.8 mm size class was *Noctiluca scintillans* (77%). *Pseudocalanus elongatus* and *Acartia* spp. dominated in the third size class (0.9-1.2 mm) with nearly the same percentages: 39% and 38%, respectively. Appendiculari-an was the main group in the size classes 1.3-1.7 and 1.8-2.3 mm, where the copepodite stages of *Calanus euxinus* form the second taxonomic group in the latter size class. The following two size classes (2.4-3.0, 3.1-3.6 mm) were composed of *Calanus euxinus* individuals and the last size class consisted of macrozooplankton species/groups of the samples.

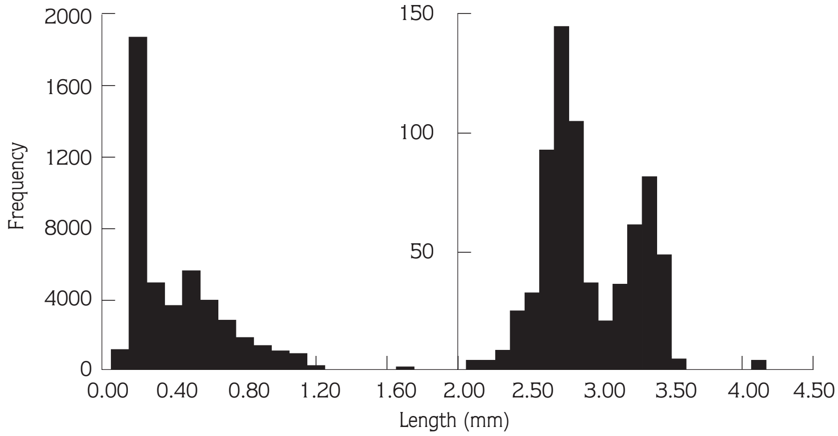

Figure 3. Length frequency distribution of total zooplankton in the samples in July 1996 (the abscissa of the figure is common to both sides of the figure, the ordinate differs in order to emphasize the larger size groups having low abundance).

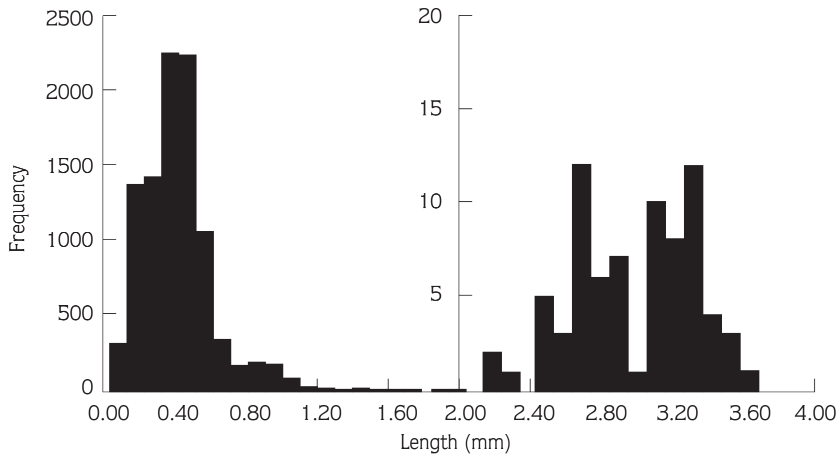

Figure 4. Length frequency distribution of total zooplankton in the samples in July 1997 (the abscissa of the figure is common to both sides of the figure, the ordinate differs in order to emphasize the larger size groups having low abundance).

Table 2. Percentage of the abundance of dominant taxonomic groups in the selected length classes of October 1996 cruise.

Size classes (mm)							
0.1 - 0.3	0.4 - 0.8	0.9 - 1.2	1.3 - 1.7	1.8 - 2.3	2.4 - 3.0	3.1 - 3.6	4 <
Oithona similis (42.5%)	*Noctiluca scintillans* (84 %)	*Pseudocalanus elongatus* (81 %)	*Acartia spp.* (73 %)	*Calanus euxinus* (40 %)	*Calanus euxinus* (93 %)	*Calanus euxinus* (96 %)	*Mnemiopsis leidyi* (47 %)
Undefined Egg (27 %)	*Pseudocalanus elongatus* (7 %)	*Acartia* spp. (7 %)	Appendicularian (19 %)	Polycheta larvae (35 %)	Polycheta larvae (3 %)	*Sagitta setosa* (4 %)	*Sagitta setosa* (39 %)
Cladoceran (10 %)	*Acartia* spp. (3 %)	Appendicularian (6 %)	*Calanus euxinus* (5 %)	*Sagitta setosa* (14 %)	*Sagitta setosa* (2 %)		*Pleurobrachia pileus* (14 %)
Pseudocalanus elongatus (9 %)		*Calanus euxinus* (3 %)	*Polycheta larvae* (3 %)	*Appendicularian* (11 %)	*Appendicularian* (2 %)		
Nauplii (6.5 %)							

Vertical distribution

October 1996

The vertical movements of the zooplankton are shown in Fig. 5. According to the zooplankton counts, some species, like *Calanus euxinus*, underwent distinctive and deep vertical movements reaching 170 meters, while some others remained at moderate layers (50-100 m) during daytime. For instance, *Acartia* spp. preferred to remain at the surface layers before sunrise. At about 07:00 they moved downward while part of the population remained within the 0-25 m layer. The rest

Table 3. Percentage of the abundance of dominant taxonomic groups in the selected length classes of July 1997 cruise.

Size classes (mm)							
0.1 - 0.3	0.4 - 0.8	0.9 - 1.2	1.3 - 1.7	1.8 - 2.3	2.4 - 3.0	3.1 - 3.6	4 <
Noctiluca scintillans (77 %)	*Pseudocalanus elongatus* (39 %)	Appendicularian	Appendicularian (93 %)	*Calanus euxinus* (80 %)	*Calanus euxinus* (97 %)	*Calanus euxinus* (100 %)	*Sagitta setosa* (67 %)
Undefined Egg (23 %)	*Oithona* spp. (5 %)	*Acartia* spp. (38 %)	*Acartia* spp. (2 %)	*Calanus euxinus* (2 %)			*Pleurobrachia pileus* (33 %)
Cladoceran (17 %)	Cladoceran (4 %)	Appendicularian (21 %)	Other Calanoids (2 %)				
Noctiluca scintillans (14 %)	Other Calanoids (4 %)	Other Calanoids (1 %)	*Calanus euxinus* (2 %)				
Bivalve (8 %)	*Acartia spp.* (3 %)	*Calanus euxinus* (1 %)					

descended further and they were observed at 25-80 meters (Fig. 5). *Sagitta setosa, Noctiluca scintillans* and Appendicularia did not show a clear vertical movement, but they were found in surface layers (< 60 m). Similar to *Calanus euxinus, Pseudocalanus elongatus* showed a clear-cut vertical migration pattern (Fig. 5). According to the zooplankton counts, *Oithona similis* were found in the same depth layers as *Calanus euxinus* but its vertical movement cannot be seen clearly in the figure (Fig. 5).

July 1997

Since the sampling depths in the July 1997 survey were chosen according to the acoustic observations of the water column, they were not in order, because the vertical acoustic profile of the water column differed between the subsequent sampling times. Although the samples were taken throughout one day to complete the daily cycle, the vertical movement of the zooplankton cannot be seen clearly as in the October 1996 samples. In the July 1997 survey, *Acartia* spp., Appendicularia and *Noctiluca scintillans* were found in the upper layers throughout the day (Fig. 6). In contrast to the results of the October 1996 survey, the vertical movements of *Calanus euxinus* and *Oithona similis* cannot be seen, but the specimens of *Pseudocalanus elongatus* showed remarkable vertical movement.

The vertical distribution of biomass of the zooplankton is shown in Fig. 7. According to the distribution pattern, the biomass of zooplankton was concentrated in the upper layers (< 60 m). The highest biomass values were observed between 25 and 80 m. In the deeper layers, (100-160 m), high biomass values were also observed. In addition, there was a decrease in biomass values at noon in the surface layer.

Volumetric and gravimetric measurements

The results of displacement volume, settling volume and wet weight of the samples of the October 1996 survey are shown in Fig. 8.

No clear relation was seen between the vertical distribution of the results of displacement volume and settling volume, and the vertical movement of the zooplankton in the samples. Only the vertical distribution of the wet weight results were related with the time series of the abundance of major zooplankton species/groups in the water column.

The results of the volumetric and gravimetric measurements of the zooplankton samples were statistically compared with the abundance of major species/groups of zooplankton (Table 4). Among the three measurements, the highest correlation with the abundance of zooplankton was given by wet weight (WW) values. Between the zooplankton species/groups, *Calanus euxinus* gave the highest correlation with wet weight results. Although the vertical distribution pattern does not visually reflect an apparent relation, there is a statistically significant correlation between settling volume and displacement volume and the number of total zooplankton. The highest correlations between the abundance of zooplankton, and settling and displacement volumes were given by *Acartia* spp. and *Calanus euxinus*, respectively.

Moreover, the biomass values of the zooplankton were statistically compared with the settling volume,

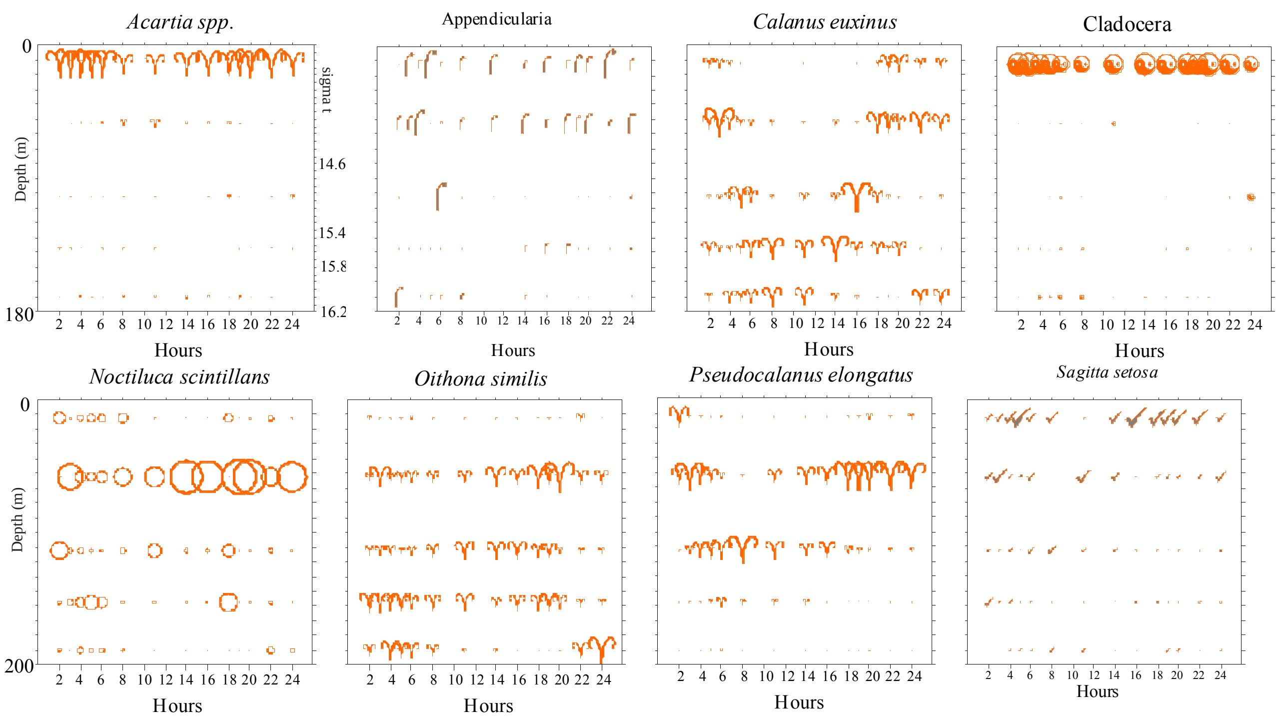

Figure 5. Time series of the percentage of abundance of major zooplankton species/ groups in the water column during a 24 hour period in October 1996.

Table 4. Correlations between zooplankton species/groups in the samples and settling volume (SV), displacement volume (DV) and wet weight (WW). Marked correlations are significant at p < .05000. N=69

	Calanus euxinus	*Pseudocalanus elongatus*	*Acartia* spp.	*Oithona* spp.	*Noctiluca scintillans*	Cladoceran	Appendi-cularian	*Sagitta setosa*	Total zoopl.	Biomass
SV	0.388 p=.001	0.062 p=.612	0.492 p=.000	0.176 p=.147	0.208 p=.087	0.373 p=.002	0.204 p=.092	0.425 p=.000	0.433 p=.000	0.509 p=.000
DV	0.432 p=.000	0.025 p=.836	0.344 p=.004	0.090 p=.463	0.172 p=.158	0.340 p=.004	0.143 p=.241	0.253 p=.036	0.341 p=.004	0.534 p=.000
WW	0.743 p=.000	0.272 p=.024	0.250 p=.038	0.411 p=.000	0.223 p=.066	0.357 p=.003	0.090 p=.464	0.095 p=.439	0.473 p=.000	0.717 p=.000

displacement volume and wet weight values (Table 4). The highest correlation was given by wet weight values (r = 0.717; p<0.05). The biomass values were also significantly correlated with the other two measurements, settling volume (r = 0.509; p<0.05), and displacement volume (r = 0.534; p<0.05).

Discussion

The size distribution and the abundance of the zooplankton were taken into account in this study, and the results showed that the zooplankton in the southeast Black Sea were dominated by small species. The most important species in the small zooplankton is Noctiluca

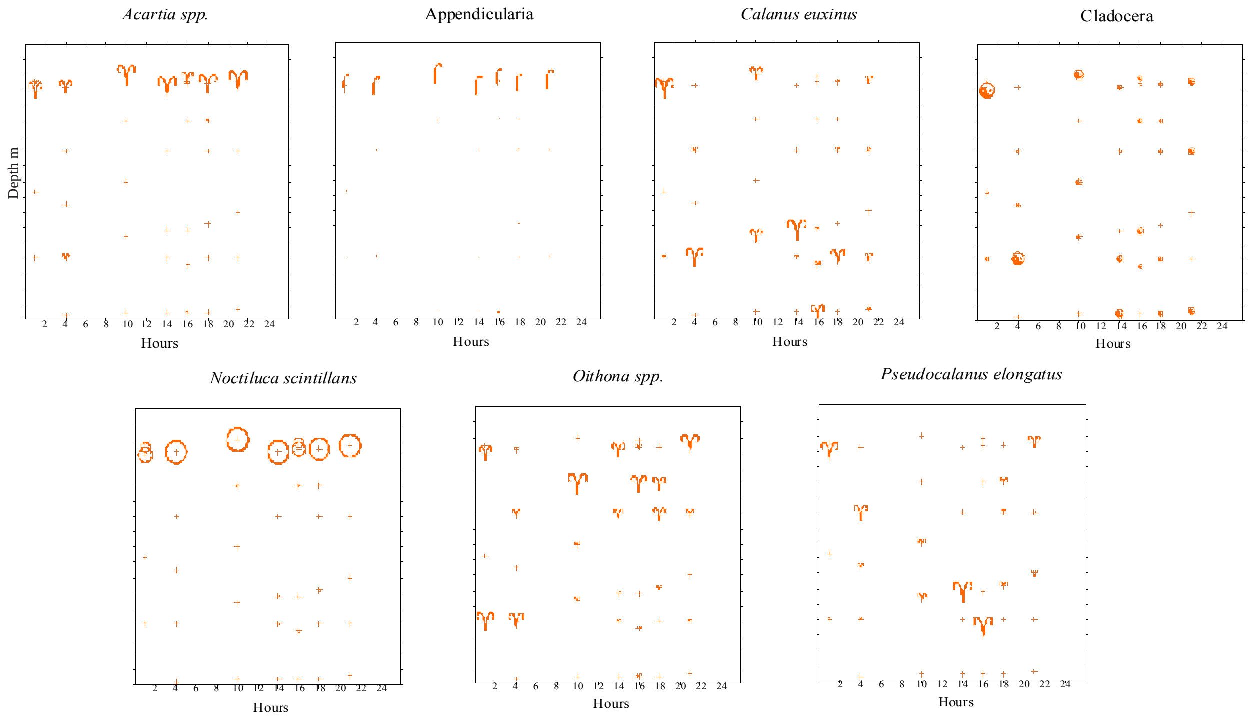

Figure 6. Time series of the percentage of abundance of major zooplankton species/ groups in the water column during a 24 hour period in July 1997.

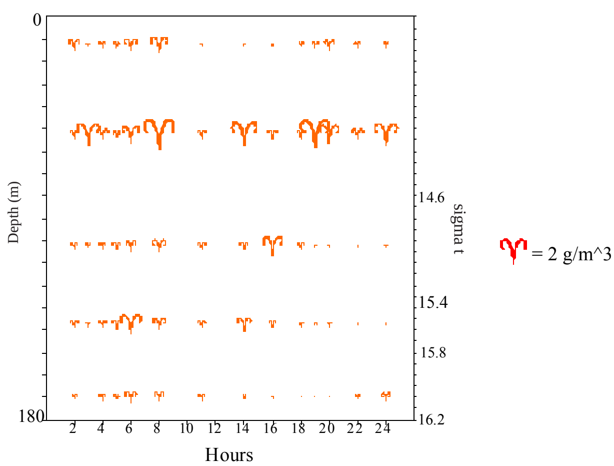

Figure 7. Vertical distribution of biomass of total zooplankton.

scintillans due to its high abundance and biomass. Kovalev et al. (19) and Shiganova et al. (20) also observed that the abundance of *Noctiluca scintillans* increased in the Black Sea in recent years. Its importance is more striking within the small size classes defined in Figs. 3 and 4 which are in fact the size classes on which the fish larvae feed (21). On the other hand, the nutritional value of the water retaining vacuolous *N. scintillans* is not as high as the fodder copepods (G. E. Shulman, pers. comm., IBSS, Sevastopol, Ukraine).

There is a gap in the length frequency chart of October 1996 (Fig. 3) between 1.2 and 2 mm. This part of the spectrum should have been covered by the sub-adult *Calanus euxinus*. The eggs and the nauplii of this species presented in the first large cohort was probably the new generation produced during the period following the presumed autumn phytoplankton bloom. The other two cohorts between 2.0 and 3.5 mm are the remnants of the group produced after spring phytoplankton bloom. The season is therefore too late to see the copepodite stages of the spring cohort and too early to find the early stages of the autumn group. The findings presented above are within the general expectations and in agreement with the results of Arashkevich et al. (22).

The samples were collected using different sampling tools in early autumn and in summer. The vertical profiles provided in Fig. 5 are based on 70 samples collected with a Nansen Closing Net within a 24 h cycle in the October 1996 survey. The duration of the sampling was the main

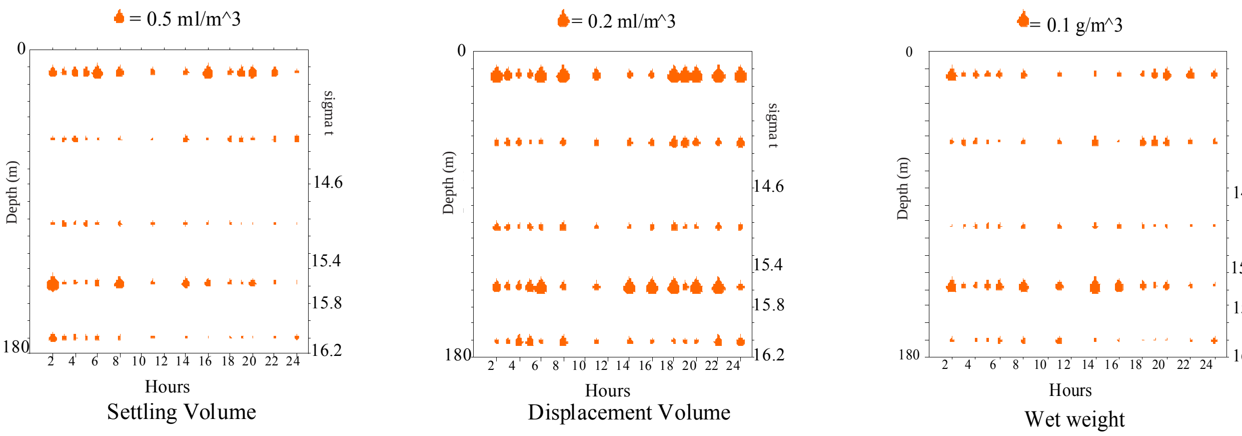

Figure 8. Vertical distribution of settling volume (A), displacement volume (B) and wet weight (C) values of the samples (October 1996).

obstacle preventing collection of more samples. The duration between the subsequent hauls was not less than 15 minutes, so that it was not possible to sample more layers within a given time range. As can be easily seen from the vertical distribution pattern (Fig. 5), 5 layers were not enough to understand the vertical movements of the individuals since the sampling depth ranges were too large to see the fine movement of zooplankton.

In the July 1997 survey, Niskin Bottles were used and the duration between the subsequent samples was only a few minutes (3-5 min), which enabled the collection of more samples in a short period of time. Also it is possible to collect samples from very narrow depth ranges to show the vertical movement of individuals precisely. On the other hand, because of the low sampling volume capacity and the shape of the Niskin Bottle, some groups of the macrozooplankton, such as chaetognaths and gelatinous macrozooplankton, can escape and so are not effectively sampled. However, the results of the vertical movements of the zooplankton groups/species obtained from Niskin bottle sampling show similarities to the results of net sampling in the October 1996 survey, especially for the small individuals. The vertical distribution of *Acartia* spp., *Oithona similis*, Appendicularian and *Noctiluca scintillans* individuals were similar in both sampling periods.

Although each species has its own vertical migration characteristics, in general, there are three major migrating groups. The first was dominated by *Calanus euxinus*. This species started to migrate downwards at dawn. After resting in the deep layers, in search of food, they began ascending before sunset, and they spent the night in the upper layers. The results of vertical migration pattern of *Calanus euxinus* were similar to the results of the previous studies (13), that is during the night these species are concentrated in the upper layer, and in the early morning they migrate down to the deep layers, stay there during the day and rise again to the surface in the late afternoon and early evening.

Another important feature of *C. euxinus* is that a part of the population always remained in the deepest part of the oxygenated zone and formed the majority of the permanent zooplankton biomass just in the suboxic zone (Fig. 5). This group is considered as diapausing copepods (22). Diapausing phase is commonly observed in seasonal and ontogenetic vertical migration of copepods. Diapause is an adaptation to avoid unfavorable conditions such as food shortage, heat, etc., which is characterized by suppression of growth and development (23).

The second group was formed mainly by *Pseudocalanus elongatus*. Their migration pattern was very similar to that of *Calanus euxinus* but they did not reach the greater depths.

The third group was the subsurface group represented by *Acartia* spp., *Noctiluca scintillans* and

Appendicularia. It can be said that these species prefer surface layers. They do not undergo deep vertical migration. However it is expected that they should respond to solar radiation. The sampling interval was too wide to see vertical movements of the *Noctiluca scintillans*. Therefore, by simply referring to five layers, it was not possible to comment if this species react to the light intensity at the surface.

Vinogradov et al. (10) stated that intensive migrations are made by chaetognaths, *Calanus* and *Pseudocalanus*. In their study it was also shown that at night *Calanus euxinus* form a well-marked concentration maxima within the upper 20 m layer, whilst *Pseudocalanus elongatus* forms a concentration maximum within the thermocline. According to the same study, in the day time, both species were concentrated at lower depths. In contrast to *Vınogradov's* statement, in this study, we did not observe intensive vertical migration of the chaetognath *Sagitta setosa* in either of the sampling periods (July and October). According to the vertical distribution pattern (Fig. 5), it can be said that *Sagitta setosa* prefers surface layers and does not contribute to vertical migration. This is primarily due to the population structure of this species. During summer and early autumn, the juveniles of *Sagitta setosa* dominate the population, which is generally distributed in the upper layers and does not display vertical migration as the migratory adult individuals (13).

The conventional methods, such as measuring the settling and displacement volume and wet weight, were also tested to show the vertical distribution of zooplankton in the water column throughout one day. Among these, only vertical distribution of wet weight results showed significant correlation with the time series of the vertical distribution plots of zooplankton species/groups. This was largely due to the inaccuracy of settling and displacement volume measurements. In the measurement of the settling volume, the organisms varied in size. Due to the shape of the volumetric flasks large organisms did not settle completely and allowed large volumes of settled interstitial fluid to remain between organisms, which in turn led to inaccuracy in the measurement. In displacement volume measurements, the sensitivity of the flasks was apparently not precise enough to detect the changes in the different cells. Therefore these very crude readings did not reflect meaningful results. Compared with the former two methods, statistical and visual comparisons of wet weight measurement were more meaningful (Fig. 8). The vertical distribution presented using wet weight of the samples seems more realistic and in better agreement with the zooplankton counts. But the method was slightly biased due to removal of the preservation fluid before weighing. This bias could be overcome and the measurements could be further improved by dry weight measurement.

Conclusions

The zooplankton of the southeast Black Sea was dominated by the small organisms, such as *Noctiluca scintillans*, *Oithona similis*, young stages of *Pseudocalanus elongatus*, etc.

In the vertical distribution, three different groups were recognized during summer. Each group was composed of different species of different ecological origin. The first group, represented by *Acartia* spp., *Noctiluca scintillans*, *Cladocera* spp. and Appendicularian, preferred the surface layers throughout the day. The species in the second group, such as *Pseudocalanus elongatus,* dispersed in the upper layers at night and migrated to deeper layers in day time, but not as deep as *Calanus euxinus* and *Oithona similis*, which belong to the third group in vertical distribution. *Calanus euxinus* and *Pseudocalanus elongatus* also showed a clear-cut vertical migration pattern. Chaetognaths did not show vertical migration since the population was mostly composed of juvenile individuals which do not display vertical migration as the adults.

Acknowledgments

This study was funded by the Scientific and Technical Research Council of Turkey (TUBITAK), and by the Scientific Affairs Division of NATO within the framework of the Science for Stability Program.

References

1. Ozsoy, E., and Unluata, U., Oceanography of the Black Sea: a review of some recent results. Earth-Science Reviews. 42: 231-272, 1997.
2. Tugrul, S., Basturk, O., Saydam, C. and Yilmaz, A., Changes in the hydrochemistry of the Black Sea inferred from water density profiles. Nature. 359: 137-139, 1992.
3. Ivanov, L. and Beverton, R. J. H., The fisheries resources of the Mediterranean. Part two: Black Sea. Etud. Rev. CGPM/ Stud. Rev. GFCM, 60 : 135 pp., 1985
4. Sorokin, Yu. I., The Black Sea. In: Ecosystems of the World, Estuaries and Enclosed Seas, B. H. Ketchum (ed.), Elsevier, Vol. 26, 253-292, 1983.
5. Caddy, J. F., Toward a comparative evaluation of human impacts on fishery ecosystems of enclosed and semi-enclosed seas. Reviews in Fisheries Science, 1(1): 57-95, 1993.
6. Zaitsev, Yu. P., Recent changes in the trophic structure of the Black Sea. Fish. Ocean., 1(2): 180-189, 1992.
7. Lalli, C.M. and Parsons, T.R., Biological Oceanography: An Introduction. Oxford, 1993, Pergamon Press., 301 pages.
8. Zenkevitch, L., Biology of the Seas of the U.S.S.R. George Allen and Unwin Ltd. London, (1963).403-426 pp.
9. Kovalev, A.V., Bingel, F., Kideys, A.E., Niermann, U., Skryabin, V.A., Uysal, Z., Zagorodynyaya, Yu.A., The Black Sea Zooplankton: Composition, Spatial/ Temporal Distribution and History of Investigations. Tr. J. of Zoology, 23: 195-209, 1999.
10. Vinogradov, M.YE., Flint, M.V. and Shushkina, E.A., Vertical distribution of mesoplankton in the open area of the Black Sea. Mar. Biol., 89 (1): 95-107, 1985.
11. Vinogradov, M.YE., Musayeva, E.I. and Semenova, T.N., Factors determining the position of the lower layer of mesoplankton concentration in the Black Sea. Oceanology, 30 (2): 217-224, 1990.
12. Vinogradov, M.E., Arashkevich, E.G. and Ilchenko, S.V., The ecology of the *Calanus ponticus* population in the deeper layer of its concentration in the Black Sea. J. Plank. Res., 14 (3): 447-458, 1992.
13. Besiktepe, S., Studies on some ecological aspects of copepods and chaetognaths in the southern Black Sea, with particular reference to *Calanus euxinus*. Ph.D. Thesis, Institute of Marine Sciences, Middle East Technical University, Turkey, 1998.
14. Besiktepe, S., Kideys, A.E. and Unsal, M., In situ grazing pressure and diel vertical migration of female *Calanus euxinus* in the Black Sea. Hidrobiologia, 363: 323-332, 1998.
15. Lipp, A. and Kempe, S., The Black Sea. A summary of new results. Presented to International Advanced Study Course on Biogeochemical processes, environment/ development interactions and the future for the Mediterranean Basin. Nice, August 30-September 17, 1993.
16. Basturk, O., Saydam, C., Salihoglu, I., Eremeeva, L.V., Konovalov, S.K., Stoyanov, A., Dimitrov, A., Cociasu, A., Dorogan, L., Altabet, M., Vertical variations in the principle chemical properties of the Black Sea in the autumn of 1991. Mar. Chem., 45: 149-165, 1994.
17. Niermann, U., Kideys, A.E., Besiktepe, S., Bodeanu, N., Goubanova, A., Khoroshilov, V., Mikaelyan, A., Moncheva, S., Mutlu, E., Nezlin, N., et al., T., An assessment of recent Phyto- and Zooplankton investigations in the Black Sea and planning for feature. Report on the meeting of marine biologists in Erdemli, Turkey, 20 Feb- 3 Mar. 1995, TU- Black Sea Project, NATO Science for Stability Program, 100 pages, 1995.
18. Wickstead, J.H., Marine Zooplankton. Studies in Biology, London, 1980, Edward Arnold Limited, 59 pages.
19. Kovalev, A.V., Gubanova, A.D., Kideys, A.E., Melnikov, V.V., Niermann, U., Ostrovskaya, N.A., Prusova, I.Yu., Skryabin, V.A., Uysal, Z., Zagorodnyaya, Ju.A., Long-term changes in the biomass and composition of fodder zooplankton in coastal regions of the Black Sea during the period 1957-1996. Ecosystem Modeling as a Management Tool for the Black Sea, L.I. Ivanov and T. Oguz (eds.), Kluwer Acad. Publ., 47 (1): 209-219, 1998.
20. Shiganova, T.A., Kideys, A.E., Gucu, A.C., Niermann, U., Khoroshilov, V.S., Changes in species diversity and abundance of the main components of the Black Sea pelagic community during the last decade. Ecosystem Modeling as a Management Tool for the Black Sea, L. I. Ivanov and T. Oguz (eds.), Kluwer Acad. Publ., 47 (1): 171-188, 1998.
21. Tkach, A.V., Gordina, A.D., Niermann, U., Kideys, A.E. and Zaika, V.E., Changes in the larval nutrition of Black Sea fishes with respect to plankton. Ecosystem Modeling as a Management Tool for the Black Sea, L.I. Ivanov and T. Oguz (eds.), Kluwer Acad. Publ., 47 (1): 235-248, 1998.
22. Arashkevich E., Svetlichny, L., Gubareva, E., Besiktepe, S., Gucu, A.C. and Kideys, A.E., Physiological and ecological studies of *Calanus euxinus* (Hulsemann) from the Black Sea with comments on its life cycle. Ecosystem Modeling as a Management Tool for the Black Sea, L.I. Ivanov and T. Oguz (eds.), Kluwer Acad. Publ., 47 (1): 351-365, 1998.
23. Hirche, H. Diapause in the marine copepod *Calanus finmarchicus*-a review. Ophelia, 44: 129-143, 1996.