Spatio-temporal variations in zooplankton communities and influence of environmental factors on them in SW Black Sea and the Sea of Marmara

Ahsen Yüksek[1], Noyan Yılmaz[1, 4], Erdoğan Okuş[1], Zahit Uysal[2], Alexandra A. Shmeleva[3], Alexandra D. Gubanova[3], Dennis Altukhov[3], S. Çolpan Polat-Beken[1]

noyan@istanbul.edu.tr
[1]*Institute of Marine Sciences and Management, Istanbul University, Turkey*
[2]*Institute of Marine Sciences, Middle East Technical University, Turkey*
[3]*Institute of Biology of the Southern Seas, Ukraine*

Abstract- Spatio-temporal fluctuations in abundance and community structure of upper layer mesozooplankton in relation to hydrography and phytoplankton community structure were studied fortnightly for a period of one year (May 1997-May 1998) at the Black Sea exit of the Strait of Istanbul and the Sea of Marmara. Multivariate analyses presented a polarized picture of zooplankton communities, particularly enlightening dominant seasonal patterns. On the other hand, differences due to trophic structure of basins, as revealed by higher phytoplankton abundance and chlorophyll a concentrations at the Sea of Marmara, resulted in differentiation of Black and Marmara Sea samples within seasonal groups. This pattern is attributed to enhanced abundance of particular groups that increased their relative abundance in zooplankton samples in accordance with increasing anthropogenic eutrophication in last three decades, particularly at the Sea of Marmara.

Keywords- zooplankton, community structure, Marmara Sea, Black Sea, hydrography, food availability

Introduction

Abundance and community structure of zooplankton largely depends on the physical and dynamic characteristics of the water masses they inhabit, on contrary adaptations to physical environment are also described as of secondary importance by Margalef (1984), arguing primary control of communities by a broader variety of environmental gradients, particularly those including a sufficient supply of external energy. Therefore, ecological studies of zooplankton require use of multivariate methods in order to understand influence of environmental factors on shaping of zooplankton communities. Differentiation of zooplankton communities according to environmental variables is well documented by multivariate methods for other regions (Siokou-Frangou *et al.* 1998; Sabates *et al.* 1989), however, there has been no quantitative assessment of temporal and spatial variability due to biotic and abiotic factors at the study area. Marmara zooplankton is usually studied for fisheries research purposes and investigations are very scarce, particularly dealing

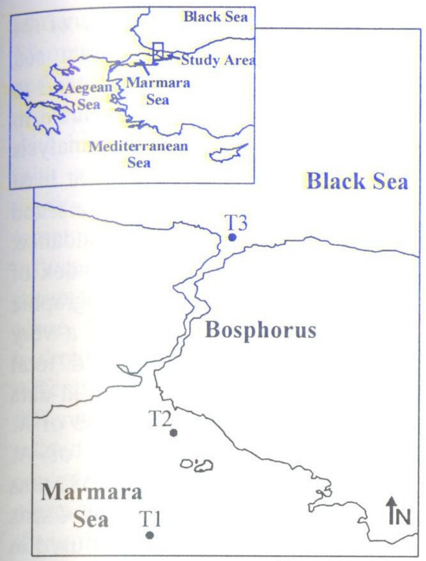

Fig.1. Study area.

with species composition and community structure (Demir 1955; 1958; 1959 a, b; Cebeci 1984; Uysal 1987; Ünal *et al.* 2000).On the other hand, Black Sea zooplankton is relatively well studied (Kovalev *et al.*, 1999; Kıdeyş *et al.*, 2000). Nevertheless, there is no time series data based on simultaneously collected samples at the SW Black Sea and The Sea of Marmara. In order to understand mesozooplankton community structure and influence of environmental factors on shaping of communities in this two adjacent but different basins, in terms of hydrography and trophic conditions (Polat-Beken *et al.*, 2000), studies were carried out fortnightly at three stations for a period of 13 months (22.05.97 to 28.05.98) by the Institute of Marine Sciences and Management of Istanbul University. Offshore Marmara Sea station (T1) is located at the deep eastern basin, away from direct impact of coastal inputs (Fig. 1). On contrary, T2 is selected as the characteristic coastal station for the Sea of Marmara, displaying a shallow structure (~28m) and directly influenced by the waste input of the metropolis, Istanbul. T3, located at the Black Sea entrance of the Strait of Istanbul, represented inflowing Black Sea waters to the Sea of Marmara, influenced from NW Black Sea shelf originated waters seasonally (Sur *et al.* 1994). The biweekly cruises were successfully realized for stations and 25 upper layer samples of T1, 24 of T2 and 21 of T3 are evaluated.

Material and Methods

Samplings were performed by vertical hauls of a Nansen net (200 μm mesh, 0.57 m diameter) within the upper seasonal thermocline layer. Zooplankton analyses were performed under stereomicroscope on a Bogorov tray. For common species, 1 ml aliquots (at least twice) were taken from samples by a Stempel pipette. Entire sample was examined for its macro-zooplankton and rare species content. Physical data was collected by SBE-9/11 and SBE-25 Sea-Logger CTD profilers. Chlorophyll a analyses were performed according to Parsons *et al.* (1984). Phytoplankton sampling and analysis were carried out according to methodologies of McAlice (1971) and Sournia (1978). Phytoplankton related parameters are given as an average for the euphotic zone (Okuş, unpublished data). Temperature, salinity and chlorophyll a values are of 5m depth, representing upper layer characteristics best (Polat-Beken, 2000).

In order to assess influence of hydrography and phytoplankton on zooplankton communities, univariate and multivariate procedures were applied to a variety of data sets. First data set included zooplankton counts, forming a matrix of 74 species×70 samples. Second data set is a reduced version of first data set, concerning relative occurrence of species in each sample. Since rare taxa tend to have little impact on the structure of communities and problems should arise in computation of eigenvalues in large datasets by principal components analysis (Clarke and Warwick 1994), species, having ≥5% occurrence in samples at least once are used, thus reduced former 74 species to 17. Third data set consisted phytoplankton community structure related parameters; phytoplankton abundance, number of species, relative abundance of dominant species as a simple index of dominance and chlorophyll a concentrations. Last data set included hydrographic parameters, including temperature and salinity. *Noctiluca scintillans* was a very important component of samples and its abundance usually surpassed total zooplankton abundance in great fold. Therefore *N. scintillans* is excluded in data matrices, in order to provide more meaningful ordinations, while response of *N. scintillans* to environmental gradients and zooplankters to presence of *N. scintillans* are investigated. A non-metric multidimensional scaling (MDS) was applied to the first data set after root-root transformation of data, using Bray-Curtis similarity matrix and group-average linkage technique. Latter data sets are used in principal components analysis (PCA). Reduced zooplankton data is log (x+1) transformed while no transformation was applied to hydrography data set, but normalized. Phytoplankton dataset is root-root transformed and normalized. A canonical correlation analysis was used to compare influence of hydrography and food availability on development of zooplankton communities. First two axis scores of MDS and PCA are used in canonical correlation analysis. Pearson product moment correlations are calculated in order to understand influence of environmental gradients on zooplankton community structure and positioning of stations on the ordination plane. One-way ANOVA was applied to seek temporal and spatial patterns.

Results

Temporal and spatial fluctuations of temperature, salinity and chlorophyll a are given in Fig. 2. The seasonality of fluctuations is clear for temperature ($p<0.001$), however no significant temporal pattern is extracted from salinity or chlorophyll a data. On contrary, spatial patterns were significant in chlorophyll a and salinity among stations and regions, differentiation being more significant at the latter for both parameters. Mean temperature was ~2°C higher at T3 (15.52±5.93 °C) than T1 (13.75+4.37 °C) and T2 (13.99±4.7 °C). It must be noted that both minimum and maximum values were detected at T3 (6.14 and 24.72 °C). Despite of clear difference in mean temperature among stations and basins, no significant pattern is identified by one-way ANOVA. Salinity, displaying a great difference among basins, reached highest values in winter at the Sea of Marmara, pointing out presence of wind induced mixing processes and weakening of stratification during this period. Chlorophyll a distrubition had strong spatial pattern between both stations and regions ($p<0.001$), reaching highest concentrations at the Sea of Marmara, particularly at T2 (6.70 µg/l in 04.09.1997). Shallow nature of the station and coastal discharges resulted in a very dynamic nature and high primary production at the station. Phytoplankton distribution reflects a different structure with highest concentration and lowest mean being detected at T3. In accordance with spatial distribution of chlorophyll a, phytoplankton abundance displayed significant alterations within stations ($p<0.05$) and regions ($p<0.01$) but no temporal pattern is extracted. Mean values are highest at T2 among stations, highly influenced from coastal discharges. PCA of hydrography and phytoplankton related parameters revealed in a good separation of regions and stations on the ordination plane. Spatial and temporal patterns were significant in both axes of PCA of hydrography data, differentiations being more significant along PC1. Highest differentiation is determined among regions and this pattern is attributed to differences in salinity of basins (Table 1). PCA of phytoplankton community related parameters explained 72.9% of variation in the first two principal components. PC1, where highest percentage of variance is explained (40.8%), represented spatial patterns in data, whereas temporal patterns were significant along the second PC, pointing out that regional differences predominates seasonal effects.

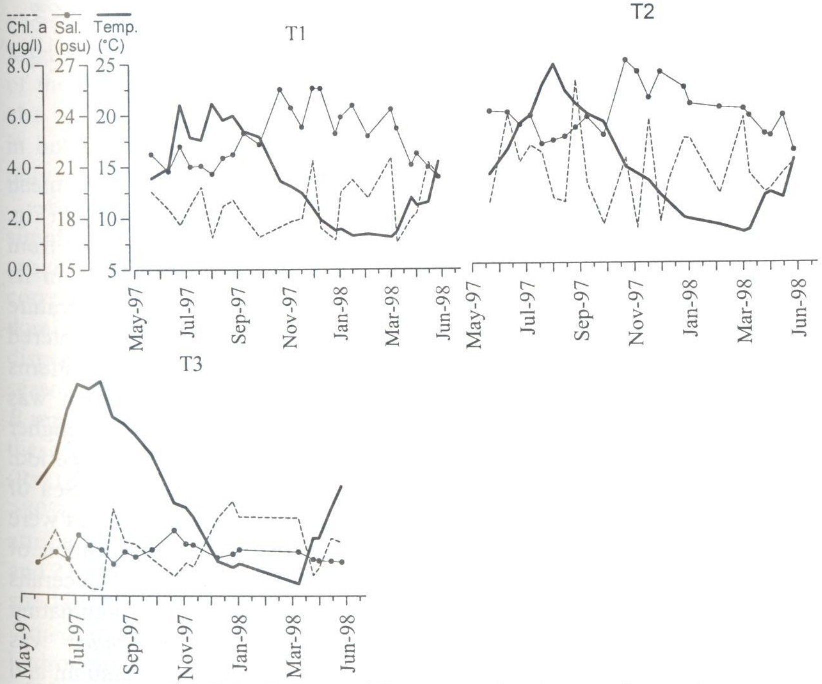

Fig. 2. Spatio-temporal fluctuations of environmental parameters.

During the study period 74 species/groups were identified at the upper layer. Among those 62 determined at T1, 47 at T2 and 43 at T3, indicating a small decrease in number of species towards Black Sea. Higher zooplankton abundance is attained at Marmara stations than T3, T1 having highest concentrations (Fig. 3). At T1, densities particularly increased in August-November and April, all due to enhanced abundance of cladocerans, while at T2, copepods dominated high abundance periods, recorded in October-November. Tertiary groups were responsible from peaks in zooplankton abundance at T3, particularly bivalve larvae and cirripeds. ANOVA extracted significant temporal ($p=0.043$) and spatial (regions, $p=0.031$) patterns from abundance data, however no significant correlation is attained with any environmental parameter.

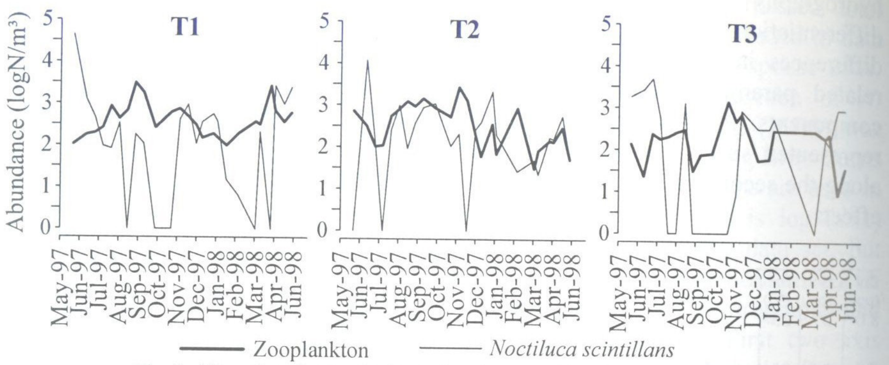

Fig. 3. Alterations in zooplankton abundance and *Noctiluca scintillans*.

Acartia clausi and *A. tonsa* were most abundant copepods at all stations, mean while relative abundance of other copepods increased in winter-spring period (Fig. 4). Thermophilic *A. tonsa* was monitored only for a limited period of the year; from mid June till early November. *A. tonsa* had significant temporal patterns in its distribution ($p<0.001$) and was moderately correlated to fluctuations in temperature ($r=0.44$, $p<0.05$, $n=70$). On the other hand, eurythermal *A. clausi* was encountered throughout the year, reaching higher densities in autumn. Only spatial patterns were evident in the distribution of *A. clausi* ($p<0.01$) and no correlation was detected with any environmental parameter. *Acartia* species reached higher concentrations at the Sea of Marmara throughout the year, excluding spring period. Due to enhanced abundance of cladoceran *Pleopis polyphemoides* at the Sea of Marmara, *A. clausi* was detected higher at T3, where cladoceran assemblages were less populated than copepods. This pattern was also observed in distribution of other important copepod species, excluding *Paracalanus parvus*. Cladocerans *Penilia avirostris* and *Pleopis polyphemoides* were frequently dominating zooplankton, particularly at the Sea of Marmara. *P. polyphemoides* was encountered in samples throughout the year, reaching high densities in autumn and spring, while thermophilic *P. avirostris* was detected only for a limited period of the year. Temporal patterns were significant in the distribution of *P. avirostris* ($p<0.001$) and abundance displayed a good correlation with temperature ($r=0.54$, 0.70 and 0.51 for T1, T2 and T3, respectively, $p<0.05$). Meanwhile, *P. polyphemoides* displayed significant spatial alterations ($p<0.01$) and no correlations was detected with any environmental parameter at the Marmara stations, while at T3 appearance of *P. polyphemoides* was significantly influenced from fluctuations in temperature ($r=0.53$, $p<0.05$). Bivalve larva reached high concentrations in late autumn and winter particularly at T3 and at all stations abundance was significantly correlated with increasing salinity ($r=0.55$, 0.47 and 0.56 for T1, T2 and T3 respectively, $p<0.05$), pointing out influence of transportation of the larva to the upper layer by increasing vertical mixing processes during these periods. *O. dioica* was monitored in warmer periods of the year and densities were higher at Marmara stations. Abundance was weakly correlated to fluctuations in phytoplankton abundance ($r=0.31$, $p<0.05$, $n=70$), while temperature had no affect on distribution of the species. *N. scintillans* population had peak densities at all three stations in late spring (Fig. 3). Mean numbers were the highest at T1 and decreased towards Black Sea. *N. scintillans* had no significant spatio-temporal pattern in its distribution and fluctuations in abundance of the species was not related to any environmental parameter.

MDS ordination of zooplankton data provided a polarized picture of community structure, particularly enlightening dominant seasonal patterns (Fig. 5). Moderately high stress value of the ordination (0.23) may be attributed to the size of the dataset ($n=70$). Projected months reflect high seasonality among samples, also supported by one-way ANOVA results and temporal patterns were significant in both axes of the ordination ($p<0.001$), while, spatial patterns were significant only along the second axis ($p<0.05$).

Second axis had no correlation with any parameter whilst, axis 1 had significant correlations. Particularly temperature and number of phytoplankton species are well correlated ($r=0.73$ and 0.61 respectively, $p<0.05$, $n=70$). Weaker correlation is attained by phytoplankton abundance ($r=0.30$, $p<0.05$) and increasing dominance in phytoplankton community appeared to have negative aspects on dispersal of stations on the ordination plane ($r=-0.25$, $p<0.05$). A marked seasonality is identified among samples. Group *A* consisted spring samples, while *B* represented summer-early autumn samples and *C* winter period. Significance of these groups are tested by ANOSIM and differentiation appeared to be significant ($R=0.55$, $p<0.001$). *P. polyphemoides* and *A. clausi* are equally responsible from >80% of similarity in Group *A*, while similarities of summer samples may be attributed to *P. avirostris*, *A. tonsa* and *P. polyphemoides* abundance (32.5, 25.4 and 21.3% respectively). In spring numerous species were responsible from 80% of similarity in the group (*A. clausi*, bivalve larva, *P. polyphemoides*, *P. parvus*, *O. dioica*). Canonical correlation analysis among MDS axis scores and PC scores of hydrography data explained 60% of variation in zooplankton community structure, while only 45% of variation is explained by principal components (PC) scores of phytoplankton related parameters.

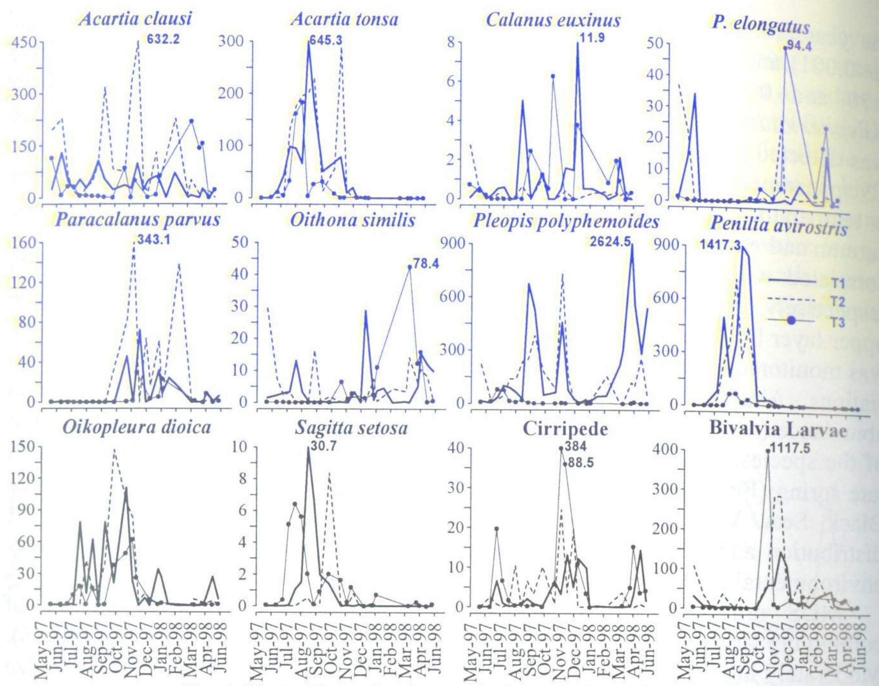

Fig. 4. Fluctuations of major zooplankton species and groups.

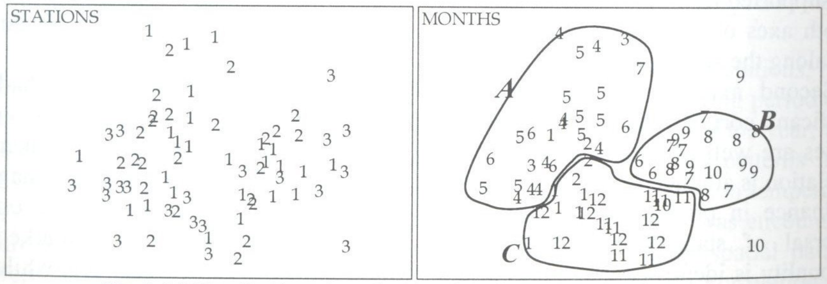

Fig. 5. MDS ordination of zooplankton data. Projection of stations and months.

Table 1. Summary of one way ANOVA results of MDS and PCA axis scores.

		Months (11 df)		Stations (2 df)		Regions (1 df)	
		F	p	F	p	F	p
Full zooplankton data (MDS)	**Axis1**	16.37	<0.001	Not significant		Not significant	
	Axis2	5.79	<0.001	Not significant		5.09	0.027
Reduced zooplankton (PCA)	**PC1**	14.44	<0.001	Not significant		4.81	0.032
	PC2	6.58	<0.001	Not significant		Not significant	
Hydrography (PCA)	**PC1**	8.54	<0.001	24.77	<0.001	49.92	<0.001
	PC2	3.85	<0.001	21.99	<0.001	43.11	<0.001
Phytoplankton (PCA)	**PC1**	Not significant		8.86	<0.001	13.43	<0.001
	PC2	6.25	<0.001	Not significant		Not significant	

First two PC scores of PCA of reduced zooplankton data explained 51.6% of variation in the data (Fig. 6). Temporal patterns was more significant in the ordination and only a weak spatial pattern is detected along PC1 (Table 1). Both axes were significantly correlated to fluctuations in temperature (r=-0.67 and r=0.37 for PC1 and PC2, p<0.001). Distribution of samples along PC2 was also moderately influenced from salinity (r=-0.41, p<0.001), while positioning of samples along PC1 was weakly correlated to phytoplankton abundance (r=-0.33, p=0.005). Similar to MDS ordination a clear seasonality is observed among samples and summer-autumn, winter and spring samples grouped relatively apart from each other. Regional alterations are particularly evident within samples of summer-early autumn group and this pattern may be attributed to differences in abundance of *Penilia avirostris* and *Acartia tonsa* among regions. Diminished distances between spring samples reflect increased similarity of communities within this period. Principal component scores of hydrographic parameters explained 64% of variation in community structure of reduced zooplankton data. Meanwhile, phytoplankton related parameters appear to affect dominant zooplankton component less and only 38% of variation is attributed to differentiation of stations along a gradient of food availability.

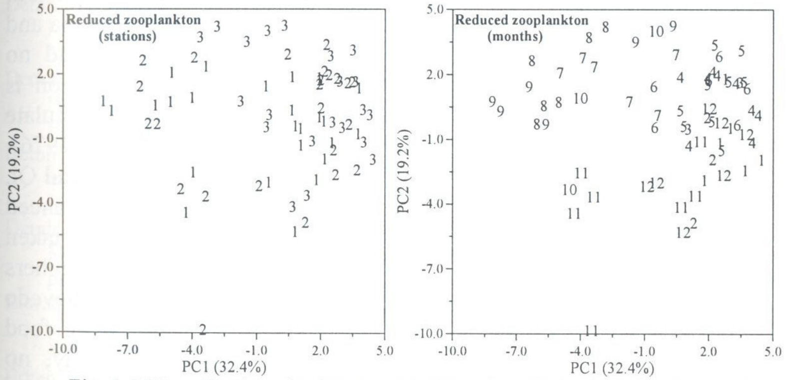

Fig. 6. PCA ordination of reduced zooplankton data. Projection of stations and months.

Discussion

Multivariate analysis presented a clear evolution of zooplankton communities at all stations, displaying heterogeneous distribution, both spatially and temporally. Particularly spring appeared as a transitional zone for species succession, with increased number of species contributing to similarities. However, in winter and summer-autumn, similarities are focused on *Acartia* species and cladocerans *P. avirostris* and *P. polyphemoides*, particularly at the Sea of Marmara. The dominance of these species is lower at T3, thus resulting in spatial differentiation of samples during these periods. Recent and historic data reflect a great change in upper layer mesozooplankton community of the Sea of Marmara, explaining possible causes of this pattern. According to Zagorodnyaya *et al.* (1999) *A. clausi* abundance was lower at the Sea of Marmara in 1970's and copepod composition was similar to Black Sea, however, abundance of *A. clausi* increased in great fold in 80's and 90's, probably due to eutrophication and followed by intrusion of *A. tonsa* in 90's (Gubanova, 1999), dominating *Acartia* population in warmer periods of the year. A similar trend is observed in Sevastopol Bay and as a consequence of anthropogenic eutrophication biomass percentage of *A. clausi* increased from 17% to 85% in 30 years (from 1964 to 1994; Kıdeyş et al., 2000). Similar shifts were observed in abundance of cladocerans in the last three decades. Cladocera abundance was occupying 0.4-1.8% of zooplankton samples in May of 1979 and 0.4-4.9% in August 1977 collected from Southern Marmara Sea (Cebeci, 1984). Uysal (1987) reported Cladocera ratio as 7.6% in May and June of 1986, for northeastern Sea of Marmara. It must be underlined that May and August are months under dominance of *P. polyphemoides* and *P. avirostris* at the Sea of Marmara and cladocerans occupied 86 and 55% of samples, respectively. In accordance with spatial distribution of chlorophyll a and phytoplankton, cladocerans reached higher densities at the Sea of Marmara, as direct consumers of primary production. Non-crustacean zooplankton also display different abundance ratios at the Sea of Marmara than Black Sea. Among them *Oikopleura dioica*, described as strictly temperature dependent by various researchers (e.g. Acuna and Anadon, 1992), reached higher densities at the Sea of Marmara and had no correlation with fluctuations in temperature. Meanwhile, positive correlation is attained with phytoplankton abundance, indicating importance of particulate organic material in life history of the species, as stated by Allredge (1976). *Noctiluca scintillans*, a well-known indicator of eutrophication (Elbrachter and Qi, 1998), also reached very high densities at the Sea of Marmara, where enhanced abundance of this species (regardless of any environmental parameter) can be taken as another indicator of trophic structure of the region. Various researchers discussed grazing impact of *N. scintillans* on zooplankton eggs or naupli (Quevedo *et al.*, 1999; Fock *et al.*, 2002) and aspects of competition for the same food resources, particularly with crustacean zooplankton. In the present study, no zooplankter or total zooplankton abundance responded significantly to alterations in *N. scintillans* population. However a thesis performed at the study area for a longer period demonstrated that, *N. scintillans* population significantly depressed zooplankton abundance in some periods of the year (Yılmaz, 2002).

Our results demonstrated that zooplankton communities are primarily controlled by fluctuations in physical environment, particularly by temperature, causing high seasonality among samples. On the other hand, availability in phytoplankton abundance and community structure affect development of zooplankton communities relatively less and patterns that may be attributed to these factors are usually hidden under seasonal effects. However, results discussed above clearly depict influence of differences in trophic conditions of stations on zooplankton species composition and succession. High stratification of the Sea of Marmara may also play an important role in differentiation of both regions (Yılmaz, 2002) by limiting vertical migration greatly (Ünal *et al*, 2000), when compared to the Black Sea (Erkan *et al.*, 2000).

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