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Biological diversity and seasonal variation of mesozooplankton in the southeastern Black Sea coastal ecosystem

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Abstract: In this study, the seasonal distribution of mesozooplankton was investigated between 1999 and 2006 at a station located in the southeastern Black Sea region. A total of 40 cruises were done within the southeastern continental shelf throughout this period in order to collect mesozooplankton samples. A total of 10 mesozooplankton species were identified. The average annual highest abundances of species were 67,770 ind./m^2 in 2000 (*Penilia avirostris*), 50,048 ind./m^2 in 2001 (*Sagitta setosa*), 42,143 ind./m^2 in 2006 (*Oikopleura dioica*), 27,987 ind./m^2 in 2005 (*Acartia clausi*), 25,792 ind./m^2 in 2001 (*Oithona similis*), 24,806 ind./m^2 in 2005 (*Pseudocalanus elongatus*), 12,094 ind./m^2 in 2005 (*Paracalanus parvus*), and 11,697 ind./m^2 in 2001 (*Calanus euxinus*). *Calanus euxinus* and *Pseudocalanus elongatus* were determined as cold-water species, having high abundance in winter and early spring. The species of *Acartia clausi* and *Oithona similis* were assessed as species observed in all seasons. According to the Bray–Curtis similarity index, the copepod species showed seasonal differences. Summer and early autumn were found to be different from other sampling periods in terms of population structure. The results of this study will form a basis for long-term mesozooplankton monitoring studies in the Black Sea coastal ecosystem.

Key words: Black Sea, zooplankton, copepod, seasonal dynamic, abundance

1. Introduction

One of the most important environmental factors that control commercial fish stocks showing great fluctuations throughout the year is food supply. Fish larvae start life as ichthyoplankton and feed on zooplankton during their initial feeding periods. The food of zooplankton is constituted of phytoplankton (Gislason and Silva, 2009). Zooplankton has a key role in the pelagic food chain for energy transfer to the upper energy level (Mauchline et al., 1998; Harris et al., 2000; Hays et al., 2005).

Many organisms of commercial importance in many parts of the world depend mostly on copepods as a food source at the planktonic larvae stage (Murdoch, 1990). Anchovy (*Engraulis encrasicolus*), which is the most important fish species in the Black Sea ecosystem, feed in winter (when they form a shoal) on *Calanus helgolandicus* and *Acartia clausi*, which abound. These 2 calanoid copepod species are of great importance in the energy cycle of the Black Sea ecosystem (Kideys et al., 2000).

Studies concerning planktonic organisms, which are greatly important in the food chain in the Black Sea, are usually based on discrete sampling in the western and northern territories during certain periods (Besiktepe et al., 1998; Kideys et al., 2000; Besiktepe, 2001; Gubanova et al., 2001). In particular, this provides an opportunity to explain the long-term seasonal dynamics of zooplankton populations. The regime shifts occurring in the Black Sea in the last 20 years have had important effects on zooplankton and fishery. At the beginning of the 1990s, a decrease was observed in the production of second and third trophic levels in the marine ecosystems of the world. The Black Sea was negatively affected by global warming after the mid-1990s. This effect caused decreases in phytoplankton and zooplankton abundance (Oguz et al., 2006a). The changes observed throughout the Black Sea continued after the 2000s. The coastal ecosystem belonging to the southeastern Black Sea, in particular, is still under the influence of these changes. No data belonging to coastal ecosystems about time series for mesozooplankton abundance were available until the end of the 1990s. There are still no data on the annual zooplankton abundance, diversity, and species composition so far. This has caused a significant insufficiency in the interpretation of the ecosystem.

The aim of this study was to reveal the changes in the seasonal structure of mesozooplankton throughout the

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years in the southeastern Black Sea coastal ecosystem, and to provide data about the annual zooplankton abundance, diversity, and species composition in the region. Moreover, eliminating the shortage of data on the time series between 1999 and 2006 was also an aim. Data belonging to former periods were also used. In this context, it is intended to present the changes in planktonic structure due to regime shifts and climate change on a global level, which has been frequently discussed in recent years. In addition, the study presents the differences between the southeastern Black Sea and southwestern Black Sea in terms of species composition and the point at which the eastern Black Sea coastal ecosystem comes under the Mediterranization process.

2. Materials and methods

2.1. Study area

The Black Sea is the largest anoxic marine environment in the world. The maximum depth of the Black Sea is 2200 m; its surface area and volume are 4.2×10^5 km^2 and 5.3×10^5 km^3, respectively. The Black Sea is almost completely isolated from the oceans of the world. It has a limited connection to the Mediterranean Sea via the Turkish Straits system and the Sea of Marmara. Strong density stratification prevents vertical mixing. The oxygenated upper layer reaches up to 150 m; the water mass at the lower layers (only 13% of the sea volume) is anoxic and contains hydrogen sulfide. A temporary halocline separates oxic and anoxic waters (Özsoy and Ünlüata, 1997). There is a well-determined oxygen-minimum zone between these waters. General cyclonic circulation of the Black Sea appears as wind effect (Oguz et al., 1991). Along with this, the Batumi anticyclone is located in the southeastern part of the Black Sea. This anticyclone provides the continuity of coastal currents (Korotaev et al., 2011).

In order to collect mesozooplankton samples in the southeastern Black Sea, 40 cruises were done between 1999 and 2006 to a station 15 nautical miles from the coast and located at the coordinates of 41°11′15″N, 40°14′15″E (Figure 1). The depth near the permanent station is about 780 m. The advantage of the sampling station is that it is close to the Faculty of Marine Sciences and less affected by anthropogenic pollution. Moreover, the oceanographic conditions represent the eastern Black Sea ecosystem.

2.2. Hydrography

Vertical profiles of temperature and salinity were measured continuously from the surface down to 1 m above the bottom using the General Oceanic Idronaut 316 CTD.

2.3. Zooplankton sampling procedure

All tows were made by vertical hauls from the different depth layers from the beginning of the anoxic layer to the surface in the southeastern part of the Black Sea. The beginning of the anoxic water layer was determined according to sigma-t values. If sigma-t values are greater than 16.2, water bodies are considered to be anoxic (Baştürk et al., 1994). All samples were collected during the day by vertical hauls using a Hydro-Bios net (39 cm mouth diameter and 200 µm mesh size). A Hydro-Bios digital 5-digit flowmeter was used for the calculation of seawater filtration (UNESCO, 1968). To eliminate differences attributable to vertical migration, samples were taken between 1100 and 1400 hours.

After each haul, the nets were carefully rinsed. The contents of the cod-ends after collection were fixed immediately and preserved in a 4% formaldehyde seawater solution buffered with sodium borate. The samples were concentrated in jars for quantitative analyses, depending on the density. Counting was done under an Olympus BH2 stereomicroscope and Nikon E 600 using 4× and 10× objectives and a Bogorov–Rass counting chamber. Quantitative analyses of species were performed by using 9-mL subsamples. Counts were repeated on 8 subsamples (Harris et al., 2000). Zooplankton data were classified at the phylum, class, or order level. Adult copepods (females and males), copepodites, copepod nauplii, and the cladocerans were identified to species or genus level

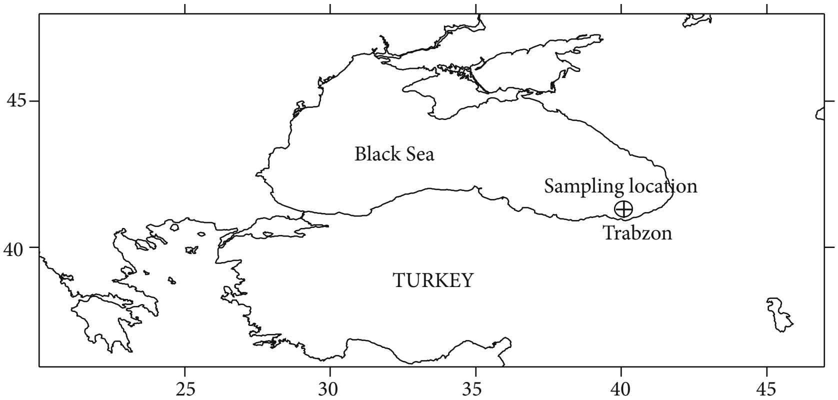

Figure 1. Sampling station.

following the inventory of Mauchline et al. (1998) and Johnson and Allen (2005).

Marine ecologists use the Bray–Curtis index to explain the similarities and differences between samples (Yoshiyoka, 2008). Biological and environmental data were analyzed by using PRIMER v. 5 and Stat 200 statistical software packages. In order to examine the mesozooplankton population in the eastern Black Sea coastal ecosystem, copepods, the most common group, were used as the base. The Bray–Curtis index was utilized to reveal the differences and similarities of this group throughout the year. In order to determine the similarity of sampling periods throughout the year, the Bray–Curtis similarity index was calculated by the equation below:

$$BCİJ = 100\left\{\frac{\sum_{k=1}^{s}|n_{ik} - n_{jk}|}{\sum_{k=1}^{s}(n_{ik} - n_{jk})}\right\},$$

where s is the number of core taxa present in sampling periods i and j, n_{ik} is the number of individuals in taxon k in sampling period i, and n_{jk} is the number of individuals in taxon k in sampling period j.

3. Results

3.1. Environmental parameters

In order to determine the environment in which mesozooplankton organisms live, the variation in temperature and salinity with respect to depth is given in graphs (Figure 2).

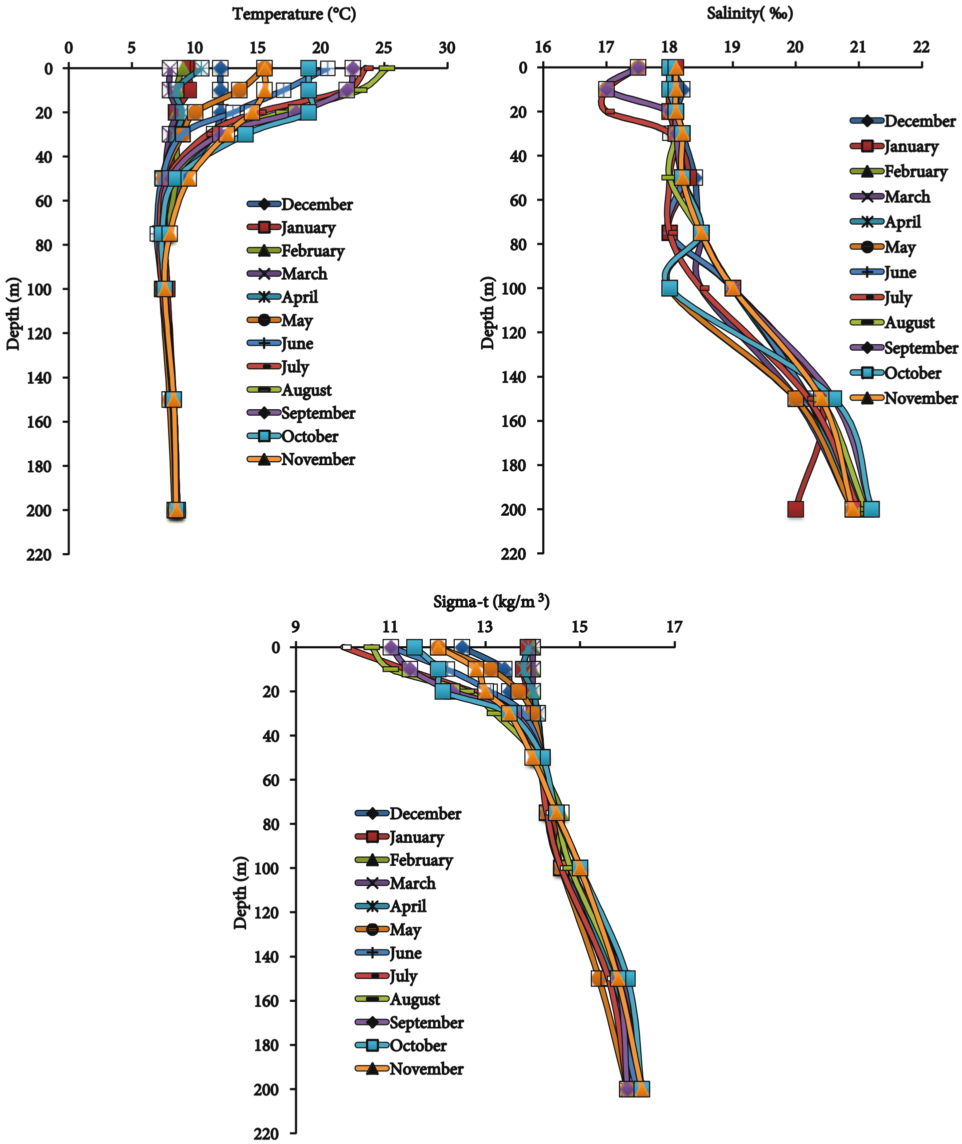

Figure 2. Monthly average temperature (°C), salinity (‰), and density (sigma-t kg/m³) profiles in the Black Sea.

It was determined in CTD profiles obtained during the study that the variation in water temperature with respect to depth was statistically significant for all seasons except winter ($P < 0.05$). The surface water temperature ranged from 8.5 °C to 28.3 °C in the region of concern. The thermocline layer was observed at depths of 15–25 m in spring, whereas in summer and autumn it was observed at depths of 25–45 m. This shows that the mixing layer moved to higher depths in summer and autumn. It was observed in the temperature profile that the temperature did not change after a depth of 100 m. Moreover, the cold intermediate layer was encountered at a depth of 35–75 m. According to our sigma-t profile, the beginning of the anoxic zone water body was at 155 and 162 m during the summer and winter sampling periods, respectively.

The salinity profiles measured within the study area are given in Figure 2. It was determined that the salinity of 17‰ measured at the surface showed a gradual change, reaching 21.2‰ at a depth of 200 m. The measurements showed that the average salinity of 17.6‰ at the surface rose to 19‰ at 100 m and to 21.2‰ at 200 m.

Monthly sigma-t profiles used in expressing seawater density are given in Figure 2. The sigma-t value in the surface waters was lower in the summer months than in the winter months. The average sigma-t value was 9.6 kg/m^3, while it increased to 14.3 kg/m^3 in winter months. The sigma-t profile, which varied greatly by season up to 50 m, did not reveal a statistically significant change after 50 m. It reached 16.6 kg/m^3 after 200 m. The anoxic zone started at the sigma-t value of 16.2 kg/m^3 and varied between 120 and 130 m throughout the year, depending on the season.

3.2. Mesozooplankton abundance and distribution

Ten mesozooplanktonic species belonging to 10 orders were identified during the study. Four of these orders belong to the phylum Arthropoda (Copepoda, Cirripedia, Cladocera, and Decapoda) and 2 to the phylum Mollusca (Bivalvia and Gastropoda). The phyla Cnidaria, Chordata, Chaetognatha, and Annelida were each represented by 1 order. Seven species in the Copepoda group and 2 species in the Cladocera group of Arthropoda were determined. The Appendicularia and Chaetognatha groups were represented by 1 species each. The Bivalvia, Cirripedia, Decapoda, Gastropoda, Polychaeta, and Hydrozoa groups were evaluated as meroplankton. The systematic groups to which these species belong and their abundances are presented in Table 1.

Differences were observed in terms of mesozooplankton abundance ($P < 0.05$). The lowest abundance was determined in 1999 (Figure 3). Three peaks were observed in summer (June), autumn (September), and winter (December). The maximum mesozooplankton abundance was reached in September, with 162,042 ind./m^2. Copepods were observed in all sampling periods. In addition, it was seen that the copepod group had its maximum value in terms of abundance in December. The copepods were determined as 73,638 ind./m^2 (Figure 4). The Cladocera species were the second dominant group in September. The number of organisms belonging to this group reached up to 90,409 ind./m^2.

The highest mesozooplankton abundance was determined in August 2000 (Figure 3). In this period, the number of organisms in the water column reached 479,369 ind./m^2. The Copepoda species were continuously observed in the year 2000 (Figure 4). The highest value of copepods was determined in May as 136,382 ind./m^2. In samplings done in 2000, the Cladocera species were encountered only at the end of summer.

During 2001, the highest mesozooplankton abundance was determined in August (491,856 ind./m^2) (Figure 3). The Copepoda group was the dominant group during the sampling period (Figure 4). This group had its maximum value in terms of abundance in December, with 185,662 ind./m^2. The number of organisms of the Cladocera species, however, reached its maximum in August. The Cladocera abundance reached 261,091 ind./m^2 in this period.

The samplings done in 2002 covered the winter, spring, and summer seasons. The highest abundance was determined in February (417,073 ind./m^2) (Figure 3). Copepoda species were regularly observed in the samples taken (Figure 4). The Copepoda became dominant in 2002 and reached 269,046 ind./m^2 in February. While the Cladocera species were not observed in the winter or spring months, the highest value was determined in August as 7280 ind./m^2.

In 2005, sampling was done in February, April, May, and June. The highest mesozooplankton number was determined in April, with 251,821 ind./m^2 (Figure 3). In this sampling period, the Copepoda group had its maximum value in April, with 170,184 ind./m^2 (Figure 4).

For the sampling done in 2006, mesozooplankton abundance was the highest in June (319,258 ind./m^2) (Figure 3). *Oikopleura dioica* was the species with the highest abundance in the water column, with 178,493 ind./m^2 organisms in June (Figure 4). The Copepoda species were again observed in all samples and became the second dominant group of 2006. It was seen that the Copepoda group reached 85,325 ind./m^2 in 2006. The Cladocera species reached 24,623 ind./m^2 in June.

The results of similarity index applications for copepods are presented in Figure 5. Population structure showed similarities between the other periods and July 1999 (23%), August–September 2000 (53%), July 2001 (57%), May–June 2002 (63%), June 2005 (78%), and September 2006 (52%). Those sampling months showed differences due to a low similarity rate in these periods. Thus, the copepod group had a significantly different population structure in July

Table 1. Average annual abundance of mesozooplankton species determined at the station of concern in 1999, 2000, 2001, 2002, 2005, and 2006 (ind./m^2).

Phylum	Order	Species	Years (Sampling depth: 0–150 m)					
			1999	2000	2001	2002	2005	2006
Arthropoda								
	Copepoda	*Acartia clausi*	6254	17,973	12,579	12,524	27,987	16,629
		Calanus euxinus	5253	9214	11,697	11,409	9459	6771
		Centropages ponticus	759	45	223	30	-	48
		Oithona similis	28	2857	25,792	9772	7252	7219
		Paracalanus parvus	756	4981	11,695	10,137	12,094	3097
		Pseudocalanus elongatus	8068	16,595	11,695	10,137	24,806	6243
		Harpacticoid copepod	15	2760	871	321	153	414
	Cirripedia	*Cirriped nauplii*	935	23	3707	35	-	545
	Cladocera	*Penilia avirostris*	16,054	67,770	33,411	1072	925	1354
		Pseudoevadne tergestina	5589	269	1963	100	75	5820
	Decapoda	Decapoda larvae	38	67	161	11	-	152
Mollusca								
	Bivalvia	Bivalvia larvae	210	3825	30,770	44,902	23,606	5219
	Gastropoda	Gastropoda larvae	9	134	-	47	185	274
Chordata								
	Appendicularia	*Oikopleura dioica*	1462	8284	22,455	9817	13,038	42,143
Chaetognatha								
	Aphragmorphora	*Sagitta setosa*	44,353	33,355	50,048	2590	1825	9321
Annelida								
	Polychaeta		102	1457	324	1237	2660	2142
Cnidaria								
	Coelenterata	*Medusae planula*	-	27,597	2972	8350	-	5167

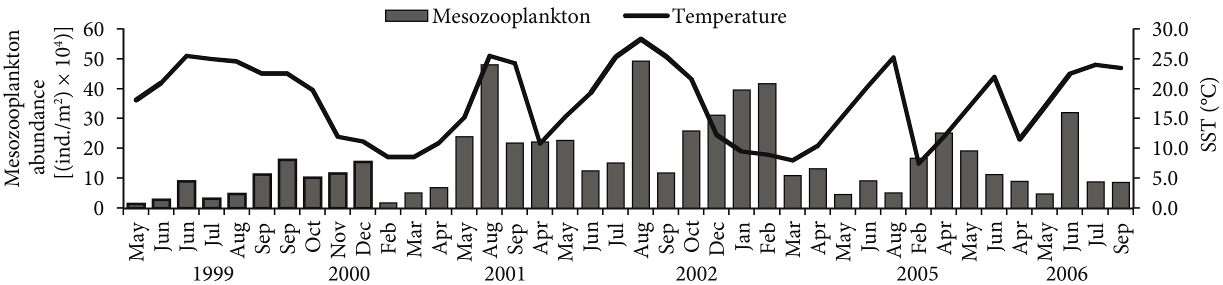

Figure 3. The variation in total mesozooplankton abundance and temperature with respect to years (SST: sea surface temperature).

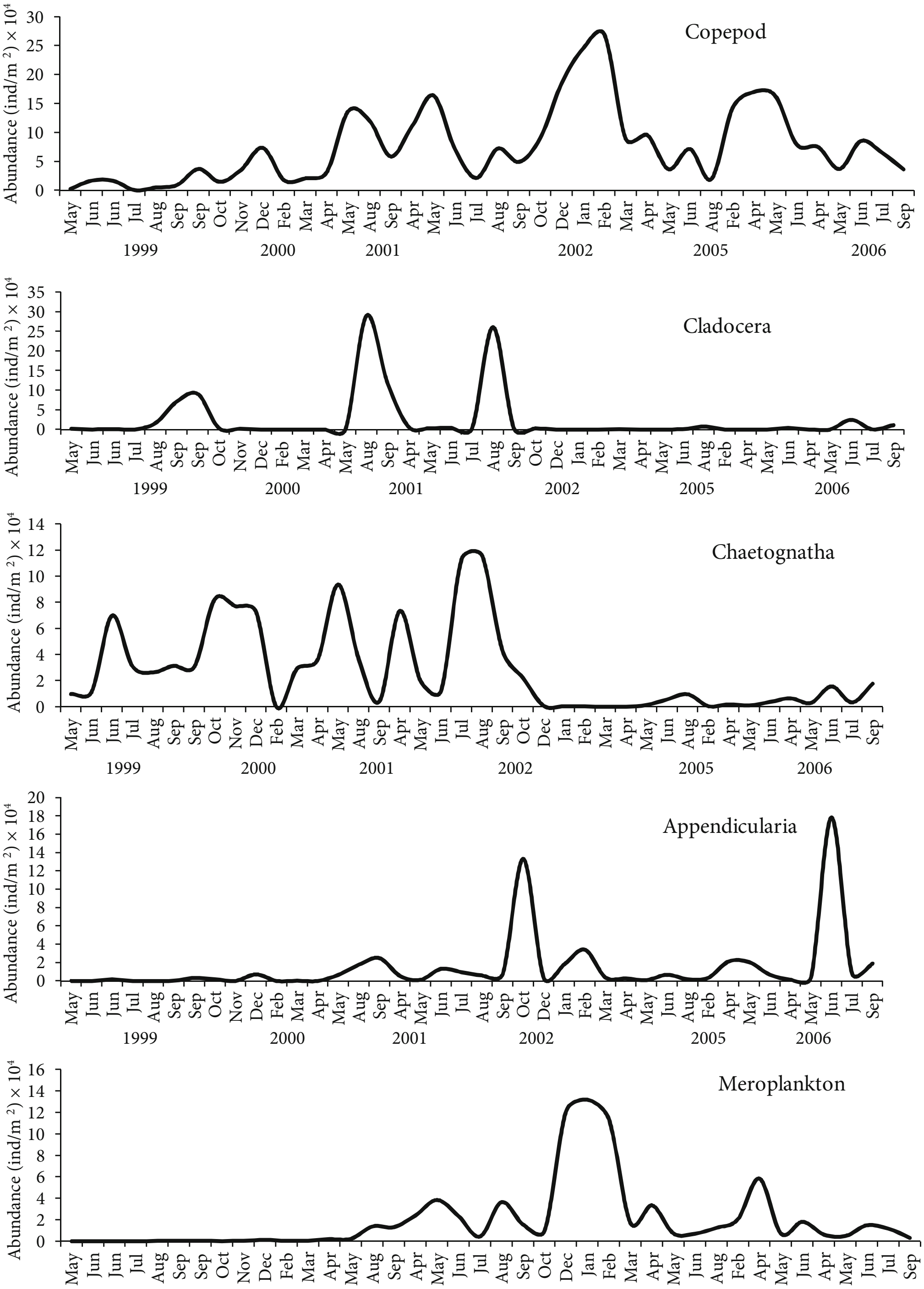

Figure 4. Seasonal abundance values of the mesozooplankton groups of Copepoda, Cladocera, Chaetognatha, Appendicularia, and meroplankton species in 1999, 2000, 2001, 2002, 2005, and 2006 (ind./m^2).

compared to the other months of 1999. This difference was observed because the *Paracalanus parvus* species and copepodite stages of the species had been encountered in July. However, the reason for the difference observed at the end of summer in similar applications in 2000 was because *Oithona similis*, harpacticoid copepods, and the copepodite stages of other copepod species had reached higher numbers than in other months. Since *Calanus euxinus* was

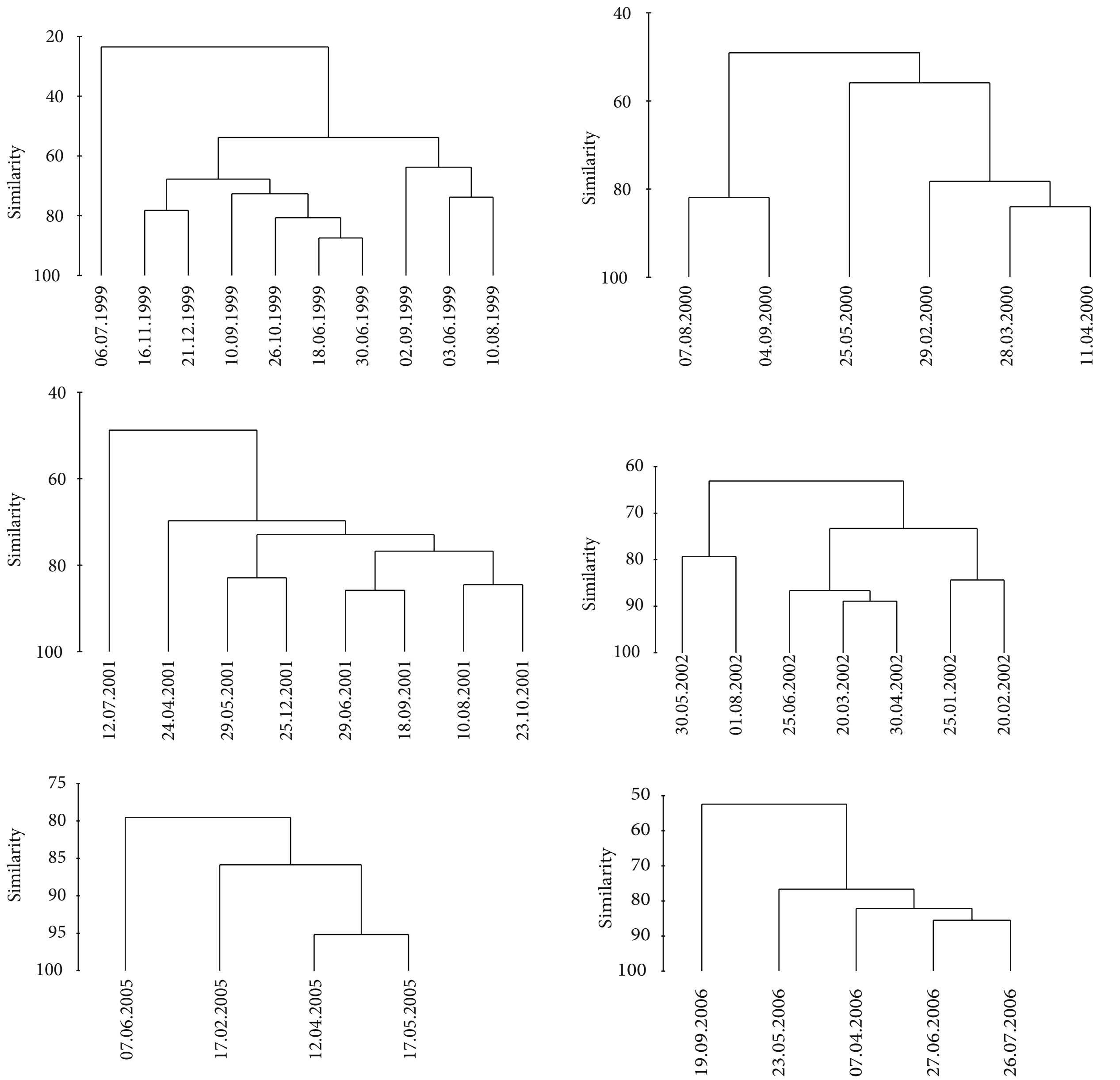

Figure 5. Similarity index values of the Copepoda group in 1999, 2000, 2001, 2002, 2005, and 2006.

highly abundant even though the numbers of other species decreased in July 2001, the copepod group displayed a different population structure. Because of the decrease in the numbers of copepod species in May and August 2002, this period showed characteristic differences. A similar situation is valid for June 2005. The difference in September 2006 can be explained by the increase in the abundance of *Acartia clausi* and *Centropages ponticus* species.

4. Discussion

4.1. Environmental parameters

The surface temperature in the Black Sea shows seasonal and spatial variations. Sea surface temperature in the winter period (February–March) decreases down to an average of 6–7 °C (Figure 2). The temperature gradient, showing spatial differences, is given as 8–9 °C in southern parts and 2–3 °C in northern parts. Sea surface temperature, having an average of 20–22 °C in summer months, increases up to 24–25 °C along the eastern and southern coasts. No anomalies were observed during the sampling done between 1999 and 2006. Yearly temperature variations in the sea surface remained within the seasonal temperature limits found in previous studies (Oguz et al., 2006b). The seasonal thermocline layer changed between 15 and 25 m, starting from spring to midsummer. The change from midsummer to the end of autumn was between the depths of 25 and 45 m. The surface mixed layer in the winter season reached a depth of 75 m, whereas yearly water temperatures showed no change after a depth of 100 m (Figure 2).

The difference in salinity observed between the surface waters and deep waters is one of the most characteristic properties of the Black Sea. Low salinity and density in surface waters and high salinity and density of deeper waters cause stagnation. This situation leads to the existence of hydrogen sulfide in circular cyclonic stream edges (periphery) at depths of 160–200 m in regions close to the coast and at depths of 80–120 m in the central parts of the Black Sea (Vinogradov et al., 1985).

The salinity of surface water ranges between 17‰ and 18‰ in the Black Sea (Figure 2). Even though changes with respect to months were observed in salinity, these were not statistically significant ($P < 0.05$).

4.2. The composition and seasonal distribution of mesozooplankton species

Zooplankton is the most important component of the food chain in seas and oceans. Copepods are the most important mesozooplanktonic group constituting the primary food supply of fish larvae and some fishes having high economic value. The other important groups are Cladocera, Cirripedia, Polychaeta, Chaetognatha, Appendicularia, and meroplankton. In our study, a total of 15 zooplankton, 7 of which belonged to the copepod group, were identified (Tables 1 and 2). The *Acartia tonsa* and *Pontella mediterranea* species found in previous studies in the Sinop region were not encountered in this study (Ünal, 2002; Üstün, 2005). In our study, unlike in Üstün's (2005) study performed to determine the composition and distribution of zooplankton in the central Black Sea, harpacticoid copepod abundance was also identified.

It is seen that species diversity in the southeastern Black Sea region is lower than in the Marmara Sea and western Black Sea. In the samples obtained during the study, 7 copepods and 2 Cladocera species were identified. The species *Evadne nordmani*, *Evadne spinifera*, and *Pleopis polyphemoides* (Cladocera), which are present in the western Black Sea, were not observed in this study. Furthermore, *Aetideus* sp., *Ctenocalanus vanus*, *Metridia lucens*, *Microcalanus pusillus*, *Oncaea media*, *Oncaea minuta*, *Oncaea subtilis*, and *Scolecithricella* sp., which are among the Mediterranean species, were not encountered in the southeastern Black Sea ecosystem, either. It has been reported that Mediterranean-origin mature zooplanktonic organisms died within 24 h if the salinity decreased to below 18‰ (Isinibilir et al., 2011). This situation explains why Mediterranean-origin species of plankton cannot be found away from the straits in the Black Sea.

During 10-year sampling in the Mediterranean, important interannual variability emerged when the total zooplankton abundance was considered (Berline et al., 2012). The copepods were the most abundant group, as in the Black Sea. Three higher peaks were determined in mesozooplankton during the annual cycle in both marine environments (Black Sea and Mediterranean). Monthly zooplankton abundance data indicated that the highest peaks were found during the first part of cool years, and the lowest values during the second part (Berline et al., 2012). According to the literature, annual peaks of similar taxonomic groups take place during almost the same periods in the Mediterranean and Black Seas.

Mesozooplankton peaks were determined in every season in studies performed on the middle part of the Black Sea's Anatolian coast (Sinop). It was reported that the most important of these peaks were observed in the autumn and winter months (Ünal, 2002; Üstün, 2005). Zooplankton seasonal peaks were affected by phytoplankton seasonality and population structure (Kovalev et al., 2003). Phytoplankton populations of the eastern and western parts of the Black Sea show differences in community structure in the same periods (Uysal and Sur, 1995; Feyzioglu and Guneroglu, 2011). When the present data were compared with the literature (Üstün, 2005), it was observed that the western and eastern Black Sea showed differences in zooplankton peak seasons during the same period.

In this study performed between 1999 and 2006, the mesozooplankton abundances changed with respect to the years. Depending on the temperature and phytoplankton intensity, peaks were identified in the summer season of 2000–2001, at the beginning of the spring of 2005, and in the summer season of 2006 (Figure 3). Seasonal variations in biomass of different zooplankton groups occur together with seasonal variations in phytoplankton, bacterioplankton, and water temperature (Kovalev et al., 2003).

The contribution of Cladocera to the autumn peak in 1999 was very high (90,409 ind./m^2). When the seasons are compared, as seen in Table 1 and Figure 4, the group showed differences for 1999 ($P < 0.05$). *Penilia avirostris*, in particular, reached a high abundance. *P. avirostris* plays an important role in the food chain in the transportation of organic matter to higher levels (Paffenhöfer and Orcutt, 1986; Turner et al., 1988; Atienza et al., 2006a, 2006b).

The highest mesozooplankton abundance was observed in August 2000 and 2001, due to the high contribution of *P. avirostris* (Table 1; Figure 4). It was reported in research that Cladocera species were intermittently present in the marine environment year-round, and after a rapid decrease following a very high abundance, they disappeared from the plankton (Onbé and Ikeda, 1995; Tang et al., 1995; Marazzo and Valentin, 2003; Valentin and Marazzo, 2004). The factors controlling the abundance of this group are not

Table 2. Seasonal distributions abundance of Copepoda species with respect to years during the sampling period (ind./m²).

Year	Month	*Calanus euxinus*	*Acartia clausi*	*Centropages ponticus*	*Paracalanus parvus*	*Pseudocalanus elongatus*	*Oithona similis*	Harpacticoid copepod
1999	May	46	727	0	137	1546	0	0
	Jun	7894	1464	0	732	6534	0	0
	Jun	4436	1560	0	1673	8800	0	73
	Jul	272	91	0	0	46	46	0
	Aug	2131	682	0	256	1705	0	0
	Sep	1114	3580	2307	158	2069	0	0
	Sep	4868	3015	4172	1623	23,298	0	0
	Oct	3346	2764	873	218	7418	0	73
	Nov	9665	12,291	238	597	13,125	0	0
	Dec	18,750	36,364	0	2159	16,137	114	0
2000	Feb	4789	1114	0	1113	10,579	0	0
	Mar	7821	6893	0	530	5568	0	0
	Apr	5581	16,743	0	1280	7791	0	0
	May	30,890	31,867	0	10,624	62,756	0	0
	Aug	3580	43,219	265	8617	5701	12,595	10,076
	Sept	2620	7997	0	7721	7170	4412	6480
2001	Apr	52,690	1715	0	5433	3972	25,270	0
	May	15,610	18,711	154	24,959	5787	49,959	0
	Jun	2548	23,916	580	8689	6218	12,109	462
	Jul	2423	14,909	0	1304	2050	0	186
	Aug	8381	3922	500	5109	7128	28,508	2002
	Sep	1081	12,351	377	3717	2640	13,556	2239
	Oct	3714	3452	173	24,305	12,772	34,002	1723
	Dec	7127	21,651	0	20,037	22,310	21,430	350
2002	Jan	4928	9786	0	8750	12,953	14,464	913
	Feb	20,714	32,044	209	25,918	8850	21,583	419
	Mar	11,821	10,282	0	10,491	8031	6232	0
	Apr	19,646	14,353	0	12,924	12,602	10,424	81
	May	5447	9720	0	1495	2030	5768	107
	Jun	16,592	6421	0	8865	18,864	7968	0
	Aug	709	5058	0	2513	1680	1964	727
2005	Feb	1063	15,482	0	12,882	26,473	5318	119
	Apr	12,273	36,000	0	15,137	33,955	5932	0
	May	15,869	39,256	0	13,698	30,904	10,357	0
	Jun	8630	21,207	0	6658	7891	7398	493
2006	Apr	10,868	16,202	0	5524	14,643	2653	108
	May	7671	4517	0	1182	6800	7540	0
	Jun	8810	14,884	236	4383	5156	13,012	1667
	Jul	4674	25,142	0	3887	3435	12,805	293
	Sep	1828	22,396	9306	509	1182	85	0

clear despite the studies performed up to now. According to some researchers, temperature variation throughout the year plays an important role in the population dynamics of *P. avirostris* (Onbé and Ikeda, 1995).

The peak in autumn 1999 occurred through the high abundance of *Sagitta setosa* (82,618 ind./m^2) and Copepoda (36,976 ind./m^2) (Figure 4). Copepods are the primary food source of *Sagitta setosa* (Feigenbaum, 1991). In this period, high copepod abundance was followed by the breeding and growth of *Sagitta setosa*. It is known that the most important factors affecting the growth of *S. setosa* in the Black Sea are temperature and food supply (Besiktepe and Unsal, 2000). Therefore, the high abundance of *Sagitta setosa* was affected by the existence of appropriate food intensity during the previous month.

The peaks in December 2001, January–February 2002, and winter and spring 2005 were caused by the high abundance of the copepod group (Figures 4 and 6). *Oithona similis* of the cyclopoid copepods contributed most to the mesozooplankton abundance in May 2001 (49,959 ind./m^2, Table 2). Although *Oithona similis* is a cold-water species and represents the cold-water copepods in the Black Sea (Gubanova and Altukhov, 2007), it was also observed in the hot seasons through the years during the sampling period.

This is because the species is also a bathyplanktonic organism and, therefore, it is possible to find it in deep water during the summer. As a result, it was observed in the vertical tow samples in each sampling period. In 2002, however, *Acartia clausi*, which is a euryhaline and eurythermal species, was an important species of the winter peak due to high abundance in February. Moreover, *A. clausi* was continuously identified in samplings in our study. *A. clausi* is abundant in hot and warm seas and is observed within plankton all year. It is known as a species that can survive in negative environmental conditions (Gubanova, 2000; Gubanova et al., 2001). Thus, it is a species continuously observed in the regions that are under the influence of the continental climate.

Regarding the distribution of *Calanus euxinus* and *Pseudocalanus elongatus* in the Black Sea, it has been reported that they are cold-water species and start to reproduce in late autumn (Arashkevich et al., 1998). In our study, the high abundance of *Calanus euxinus* and *Pseudocalanus elongatus* was determined in winter and at the beginning of spring. It was reported that these species, called cold-water species, were dominant in the upper part of the mixed layer of the Black Sea ecosystem, and their abundance increased in the winter (Vinogradov et al., 1992). The species observed in the late summer and autumn peaks in the eastern Black Sea are Cladocera species, *Acartia clausi* and *Oikopleura dioica*. These species are called eurythermic mesozooplankton species. These species observed in the study area were also reported by Shiganova (2005) in offshore waters of the Black Sea. Additionally, peaks of *Penilia avirostris* from Cladocera, *Centropages ponticus* from Copepoda, and *Sagitta setosa* from Chaetognatha were observed in midsummer and at the beginning of autumn. Since *Oithona similis* is a eurythermic species, high abundance was identified in all seasons. *Paracalanus parvus*, which is another eurythermic species, was identified in the sampling periods and in all seasons except summer in the southeastern Black Sea ecosystem.

In our study, while mesozooplankton abundance belonging to 1999–2000 was lower, it was observed that average mesozooplankton abundance increased by a few times. This is parallel to the findings of Finenko et al. (2003). The pressure of *Mnemiopsis leidyi* on zooplankton was very high before 2000. After the 2000s, *M. leidyi*, which fed on zooplankton, was brought under control by the introduction of *Beroe ovata*, which is a predator of *M. leidyi*, into the Black Sea ecosystem. This situation brought about an increase in mesozooplankton numbers (Shiganova et al., 2001; Shiganova, 2005). The increase after 2000 in general mesozooplankton abundance, particularly in copepod nauplii, observed in our study can be explained by *B. ovata*, which brought *M. leidyi* under control. The physical parameters revealing a dynamic structure during the year do not show big differences between years. It seems that the reason species composition and abundance differ with respect to years is food supply and prey–predator relationships. When the density of *Mnemiopsis* declined in 1992–1993, zooplankton abundance began to rise. In 1996, the abundance of zooplankton, and particularly Copepoda, which is the basic food for anchovy, increased significantly (Shiganova and Bulgakova, 2000).

According to the data presented here, it is clearly seen that the increase in zooplankton abundance continued from 1996 to 2002, and copepod abundance reached its peak level in 2002, reflecting an increase in the anchovy catch for the Turkish Black Sea fishery (Figure 6). This period coincides with the highest anchovy catch from the Turkish Black Sea fishery. The anchovy catch was 385,000 t during this period (TSI, 2009). It can thus be said that the anchovy catch is partly dependent on copepod abundance.

According to our results, despite the species diversity changes, the most important mesozooplankton group in the region is Copepoda. The Cladocera group is seen only during the summer period. *Calanus euxinus* and *Pseudocalanus elongatus* have been specified as cold-water species. The eurythermic species of *Acartia clausi* was observed throughout the year. In light of the obtained

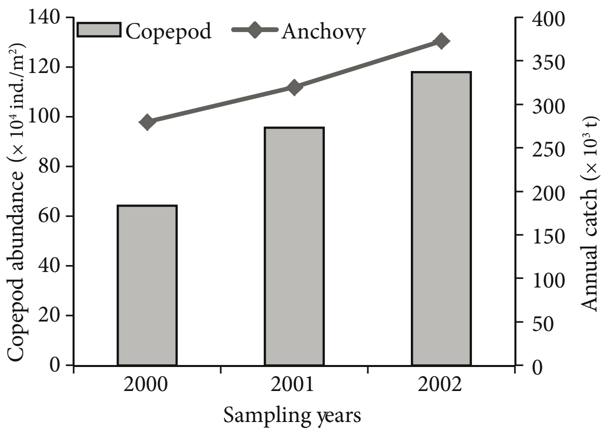

Figure 6. Anchovy production during the sampling period.

data, the Mediterranization process was not observed in the southeastern Black Sea coastal ecosystem until 2006. It has been determined that the southeastern Black Sea region is affected in a similar way by changes on a global scale. Monitoring studies should be given importance in order to put forth the dynamic structure of the ecosystem.

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