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Annual variations in biochemical composition of size fractionated particulate matter and zooplankton abundance and biomass in Mersin Bay, NE Mediterranean Sea

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ABSTRACT

Seasonal changes in biochemical composition of different particle size classes (pico-, nano- and micro-particulate matter) and the zooplankton abundance and biomass were studied in NE Mediterranean between November 2004 and January 2006. Sampling was carried out at monthly intervals from two stations representing coastal and open water characteristics. Dominance of size fractions showed seasonal variations in each biochemical component but on annual average pico size fraction predominated and accounted for ≥40% of the chl-a and particulate organic matter (protein + lipid + carbohydrate) concentrations. At most of the sampling periods protein:carbohydrate ratio was <1 at the stations revealed that the studied area was under the nutrient limitation, and nutrient deficiency was severe especially for nano size fraction. On annual average, total zooplankton abundance were 4968 ± 3538 and 603 ± 368 ind. m^{-3}, and total biomass were 22 ± 19 and 3 ± 1 mg m^{-3} at stations 1 and 2, respectively. 200–500 and 112–200 μm size fractions were dominant in zooplankton abundance at both stations. Similarly, 200–500 μm size fraction was dominant in zooplankton biomass at the coastal, whereas >1000 μm size fraction was at the open station. Copepods were the most abundant zooplankton group and determine the distribution of total zooplankton followed by crustacean nauplii, appendicularia, and cladocera.

1. Introduction

The Eastern part of the Mediterranean Sea shows ultra-oligotrophic characteristics because of the limited nutrient supply into the surface waters from external and internal sources (Azov, 1991; Krom et al., 1991). The phosphate and nitrate concentrations in euphotic zone waters varied between below detection limit to 0.04 nM and 0.1–0.3 μM, respectively, in most of the year in the Levantine Basin, except winter upwelling in the Rhodes cyclonic region (Yilmaz and Tugrul, 1998; Zohary and Robarts, 1998). Its water is characterized by relatively high nitrate to phosphorus ratios suggesting that phosphorus is a potential limiting factor for algal growth (Azov, 1986; Krom et al., 1993; Zohary and Robarts, 1998; Yilmaz and Tugrul, 1998). Therefore, the depth-integrated primary production in the euphotic zone is low, ranging from 38.5 for the oligotrophic autumn conditions to 457 mgC m^{-2} day^{-1} for moderately mesotrophic cool winter contiditions. Chlorophyll-*a* concentrations range between 0.02 and 1.0 μg L^{-1} (Ediger et al., 2005).

In the oligotrophic eastern Mediterranean Sea the picoplankton fraction is the main contributor to the chl-a, primary production and particulate matter. Polat (2006) showed that pico + ultraplankton (<5 μm) size fraction made up the most important part of the phytoplankton biomass in Iskenderun Bay, NE Mediterranean. Ignatiades et al. (2002) reported that the picoplankton fraction (0.2–1.2 μm) predominated and accounted for the 56–49% followed by nano + micro-plankton (>3 μm) accounted for 21–31% of the total chl-a in the north and south Aegean Sea, respectively. Ultraplankton (1.2–3 μm) were found the lowest fraction contributing only 18–22% of the total chl-a. The dominance of pico size fraction was found in the particulate matter with extremely low particulate lipid, protein and carbohydrate concentration in the Cretan Sea (Danovaro et al., 2000).

There are several zooplankton studies concerning the distribution and composition in the eastern Mediterranean Sea (El-Maghraby, 1965; Kimor and Wood, 1975; Lakkis, 1976, 1984; Gücü, 1987; Lakkis, 1990; Siokou-Frangou, 1996; Mazzocchi et al., 1997; Siokou-Frangou et al., 1998; Gotsis-Skretas et al., 1999; Siokou-Frangou et al., 2002; Uysal et al., 2002; Isari et al., 2006; Zervoudaki et al., 2006, 2007). A study carried out in the Cretan Sea and the Straits of the Cretan Arc recorded that the zooplankton showed a clear seasonal pattern, with highest abundance in autumn–winter and the lowest abundance in spring–summer (Gotsis-Skretas et al., 1999). However, in the coastal waters of the Saranikos Gulf, the maximum abundance was observed during the summer months till early autumn (Siokou-Frangou, 1996). Copepods generally dominate the mesozooplankton assemblages (Siokou-Frangou, 1996; Gotsis-Stretas et al., 1999). The importance of small size copepods, especially adults and copepodite stages of non-calanoid copepods, in abundance was pointed out by Calbet et al. (2001) in NW Mediterranean, by Zervoudaki et al. (2006, 2007) in the

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northern Aegean Sea and by Krsinic and Grbec (2002) in South Adriatic.

The main aim of this study is to improve our knowledge on the seasonality of biochemical composition of particulate matter and, zooplankton abundance and biomass in the oligotrophic NE Mediterranean Sea. Furthermore, size fractionations were studied in order to understand the relative importance of small and large sizes for each parameter, for which data are lacking the studied area.

2. Materials and methods

The study was performed in the Bay of Mersin, Northeastern Mediterranean Sea at two stations one representing coastal, station 1 (36°33.580′N, 34°15.680′E; 20 m depth) and other representing open waters, station 2 (36°26′N, 34°21′E; 200 m depth), characteristics (Fig. 1). Zooplankton samples were collected from November 2004 to January 2006, except in January 2005. During January 2005, no cruise was accomplished because of the severe weather conditions. Seston samples were collected from December 2004 to January 2006. In December 2004, CTD data, some samples for lipid analysis at stations 1 and 2 were missing. Total suspended sediment samples were collected from February 2005 to January 2006 at monthly intervals.

Sea surface temperature and salinity were recorded by using a Seabird™ sensor (Model SBE 19 plus). Seawater samples were collected with Niskin bottles from the sea surface for chlorophyll-a, total suspended solid and biochemical composition (protein, lipid and carbohydrate) analysis. Samples were taken into the 25 L bottles and kept in dark until laboratory processes.

For the total and organic suspended particulate matter, a well-mixed seawater sample was filtered onto pre-dried at 60 °C and pre-weight Whatman GF/F filters (0.7 μm pore size and 47 mm diameter) and the filter was put into a Petri plate and then preserved at −20 °C in a freezer for further analysis. The filters were dried at 60 °C in an oven for 24 h for total suspended particulate matter (TSPM) measurement and put in a dessicator to reach the room temperature and then, were weighed with an electronic balance. This process was repeated until a constant weight is obtained. For the suspended particulate organic matter (SPOM) measurements, dried filters were combusted at 450 °C for 12 h in a muffle furnace and weighed. Then, SPOM is obtained by subtracting ash weights from the TSPM. The results were given in mg L^{-1}.

For the analysis of total seston chl-a, protein, lipid and carbohydrate, seawater were filtered through 0.7 μm Whatman GF/F filters (25 mm diameter). In order to measure the level of pico, nano and micro particles in the seawater, three types of filters were used; Whatman GF/F filters (0.7 μm pore size and 25 mm diameter), Whatman GF/D filters (2.7 μm pore size and 25 mm diameter) and nylon mesh (18 μm pore size). Precombusted (at 450 °C for 6 h) Whatman filters were used to avoid contamination for the protein, lipid and carbohydrate measurements. About 1 to 2 L of seawater was filtered through Whatman GF/F filters and about 2 to 4 L of seawater was filtered through Whatman GF/D filters under low vacuum. To obtain 0.7–18 μm size fraction, seawater sample was passed through 18 μm Nitex screen before filtration onto 0.7 μm GF/F filters. Another seawater sample was filtered onto 2.7 μm GF/D filters to obtain >2.7 μm size fraction. After filtration, filters were immediately frozen in liquid nitrogen prior to processing (Kleppel and Hazzard, 2000; Hazzard and Kleppel, 2003).

Chlorophyll-a and the biochemical components, i.e. protein, lipid and carbohydrate, concentrations in pico size fraction (0.7–2.7 μm) were estimated by difference between total concentrations (>0.7 μm) and that in the >2.7 μm size fractions. The concentrations in the nano size fraction (2.7–18 μm) were calculated as the difference between the concentrations in the <18 μm and that in the pico size fraction (0.7–2.7 μm). Similarly, the concentrations in the micro size fraction (>18 μm) were calculated as the difference between total concentrations (>0.7 μm) and that in the <18 μm size fraction.

Chlorophyll-a measurements were done by the fluorometric method (IOC, 1995) with a Hitachi F 3000 fluorometer. In order to determine the sample fluorescence concentration, standard chlorophyll-a obtained from Sigma™ was used. Seston protein, lipid and carbohydrate analyses were performed by using Helios type spectrophotometer. For seston protein extraction, modified Lowry method (Clayton et al., 1988) was used. Bovine serum albumin was used as a standard to estimate the protein concentrations in the samples. Seston lipids were extracted according to Barnes and Blackstock (1973). Cholesterol was used as a standard. Carbohydrate extraction was performed by using phenol–sulfuric acid method (Dubois et al., 1956). Glucose was used as a standard to estimate the carbohydrate contents in the samples.

Zooplankton samples were collected throughout the water column using a Nansen Closing net with 70 cm mouth diameter and 112 μm mesh size. Zooplankton from the first tow were fractionated into different size classes (112–200, 200–500, 500–1000, and >1000 μm) by filtering through mesh filters; each size fraction was then collected on GF/C filters (pre-dried at 60 °C and pre-weighted) and kept at −20 °C for biomass estimation. At the laboratory, filters were dried at 60 °C for 24 h in an oven for dry weight determination. Afterwards, those dried samples were combusted at 450 °C for 12 h for ash-free dry weight determination (organic weight).

Zooplankton from the second tow were used for the abundance and major taxonomic group identification. The cod-end content was

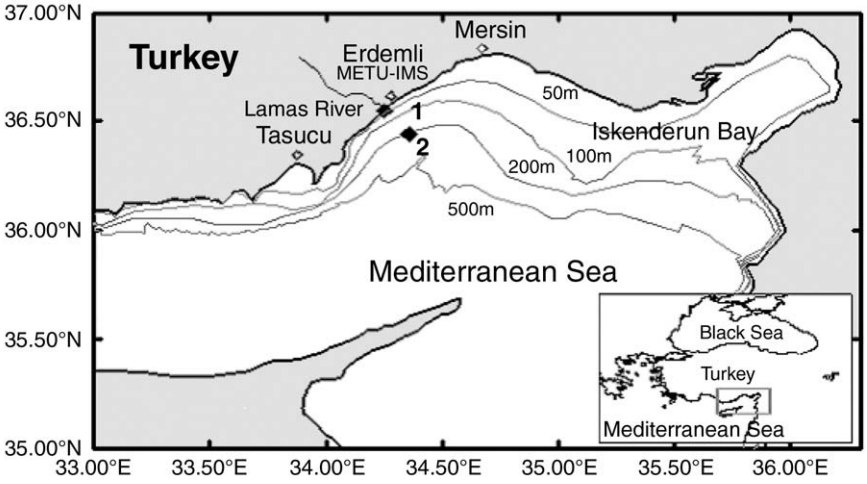

Fig. 1. Locations of sampling stations (station 1: coastal, station 2: open).

fractionated into four different size classes (112–200, 200–500, 500–1000, and >1000 μm) as biomass samples and each size groups were preserved with borax-buffered formaldehyde (5% final concentration) in 250 ml bottles for further analysis. Folsom splitter was used to divide samples into sub-samples and at least 400 organisms were counted per each fraction under an Olympus-SZX12 model stereo-microscope. Rare groups were counted by analyzing the whole sample.

3. Results

3.1. Hydrological conditions

The surface water temperature ranged between 16 and 29.4 °C being lowest in February 2005 and highest in August 2005 at station 1 (Fig. 2a). The surface salinity varied between 37 (in March 2005) and 39.5 (in October 2005) (Fig. 2a). Low surface salinity observed especially in February 2005 and March 2005 can be explained by Lamas River influence nearby the station.

At station 2, surface temperature ranged from 17.2 to 29.18 °C being coldest in January 2006 and hottest in August 2005 (Fig. 2b). Surface salinity ranged from 38.96 (in June 2005) to 39.48 (in October 2005) (Fig. 2b).

3.2. Seasonal changes in surface seston composition

Monthly changes in TSPM and SPOM at stations 1 and 2 are shown in Fig. 3a and b, respectively. During the sampling period, they showed seasonal pattern with the primary peak in March 2005, and the secondary peak was in July-05 at station 1, but there was no any clear seasonal pattern for SPOM. At station 2, although they fluctuated a lot during the sampling period, the maximum values were observed in March and April (Fig. 3b). On annual average, SPOM content accounted for 28% and 33% of the TSPM at stations 1 and 2, respectively. On average, concentrations of total suspended particulate matter (TSPM) at station 1 were significantly higher than those at station 2 (Mann–Whithey Rank Test, $n=15$, $P<0.01$).

Temporal distributions of total and size fractionated chl-a at station 1 are presented in Fig. 4a. Total chl-a concentrations ranged between 0.1 μg L^{-1} (June 2005) and 2.4 μg L^{-1} (March 2005). The highest concentration was in spring (March 2005). The relative contribution of the different size fractions to the total chl-a was different during the sampling period. Nano size fraction predominated and accounted for around 94% of spring chl-a maximum. Rest of the sampling period it was the second dominant group after pico size fraction. On annual average pico size fraction constituted 44% of the total chl-a concentrations. Total chl-a concentrations were very low and ranged between 0.03 μg L^{-1} (July 2005) and 0.35 μg L^{-1} (January 2006) at station 2 (Fig. 4b). High concentrations were observed during the winter and spring periods. Pico size fraction constituted the majority (54–80%) of the total chl-a throughout the year, while the micro size fraction was relatively important in spring (February and March 2005, about 37–27% contribution). On average, concentrations of total chlorophyll-a at station 1 were significantly higher than those at station 2 (Mann–Whithey Rank Test, $n=15$, $P<0.01$).

Total protein concentrations ranged between 5.4 μg L^{-1} in January 2006 and 348 μg L^{-1} in March 2005 at station 1 (Fig. 5a). In March 2005, pico size fraction was responsible for around 58% of the total protein, and being generally the dominant fraction. On annual average, the contributions of pico, nano and micro size fractions were 43, 25 and 32% to the total protein concentration, respectively. At station 2, total protein concentrations ranged between 2.5 μg L^{-1}

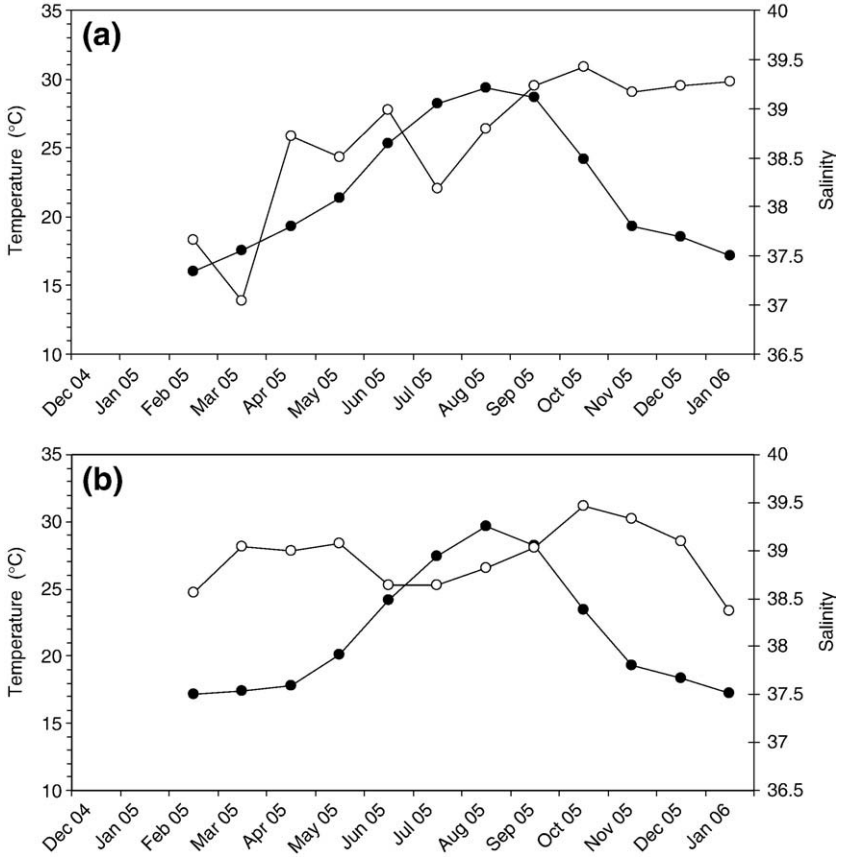

Fig. 2. Annual changes in surface temperature (dark circle) and salinity (open circle) at stations 1 (a) and 2 (b).

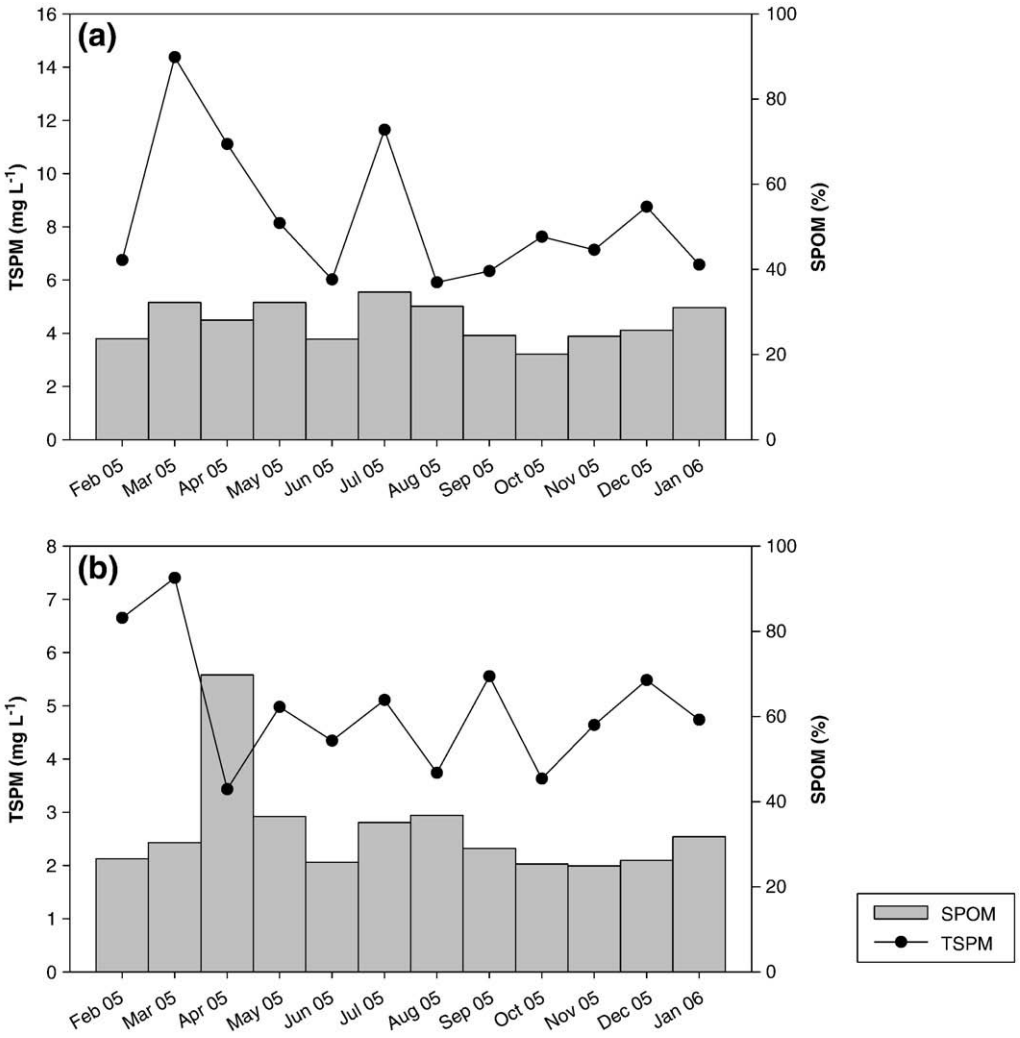

Fig. 3. Annual changes in surface total suspended particulate matter (TSPM) and suspended particulate organic matter (SPOM) at stations 1 (a) and 2 (b).

in January 2006 and 101 μg L^{-1} in June 2005 (Fig. 5b). At this station, three high values were observed, with the values of 65 μg L^{-1} in spring (March 2005), 101 μg L^{-1} in summer (June 2005) and 55.4 μg L^{-1} in autumn (November 2005). Pico size fraction was the main contributor to the summer peak (in June 2005), constituting 76%. In spring maximum (March 2005), >80% of the total protein was in the pico (41%) and nano (47%) size fractions. However in November, the micro size fraction accounted for 68% of the total.

At station 1, the peak of total lipid concentration was found in March 2005 (315.2 μg L^{-1}) (Fig. 6a). In this peak, 68% and 31% of the lipid were associated with the nano and micro size fractions, respectively. The relevance of the pico size fraction increased during the period of low lipid content. At station 2, total lipid concentration exhibited a pronounced spring maximum (83 μg L^{-1} in March 2005 and 97.8 μg L^{-1} in April 2005) and decreased drastically after April 2005 till November 2005 (Fig. 6b). In April 2005, >90% of the total lipid was in the pico (47%) and micro (50%) size fractions. On annual average, the contributions of pico, nano and micro size fractions to the total lipid were 49, 27 and 24%, respectively.

Total carbohydrate concentrations ranged between 21.4 μg L^{-1} in January 2006 and 419.5 μg L^{-1} in March 2005 at station 1 (Fig. 7a). In March 2005, nano and micro size fractions accounted for 49 and 31% of the total carbohydrate, respectively. On annual average, the contributions of pico, nano and micro size fractions to the total carbohydrate were 31, 47 and 22%, respectively. At station 2, the highest concentrations of total carbohydrate were found in December 2004 and May 2005 (164 μg L^{-1}) (Fig. 7b). In December 2004, >70% of the total carbohydrate was in the pico (31%) and micro (44%) size fractions. In May 2005, approximately half of the total carbohydrate was associated with nano size fraction constituting the 53% of the total. On annual average, the contributions of pico, nano and micro size fractions to the total carbohydrate were 38, 34 and 28%, respectively.

Using seston lipid, carbohydrate and protein concentrations, the biopolymeric carbon concentrations (BPC: as the sum of the carbohydrate, lipid and protein carbon) were estimated for two stations shown in Fig. 8. Conversion factors were used as 0.75, 0.4 and 0.49 g C g^{-1} for particulate lipids, carbohydrates and proteins, respectively (Danovaro et al., 2000). At the coastal station, BPC ranged between 23 (January 06) and 575 (March 05) μg C L^{-1}, and annual average was 152 ± 147 μg C L^{-1}. It was generally high in spring period. At the open station, it varied from 32 (January 06) to 120 (April 05) μg C L^{-1}, and annual average was 75 ± 31 μg C L^{-1}. It was always higher than 100 μg C L^{-1} during the spring period.

3.3. Zooplankton abundance and biomass

Total zooplankton abundance and biomass are shown in Fig. 9. Zooplankton abundance and biomass at station 1 were significantly higher than those at station 2 (Mann–Whithey Rank Test, $n = 14$, $P < 0.01$). High abundance and biomass values were observed in spring, summer and in autumn at both stations. On annual average small sizes' (112–200 and 200–500 μm) contribution to the total

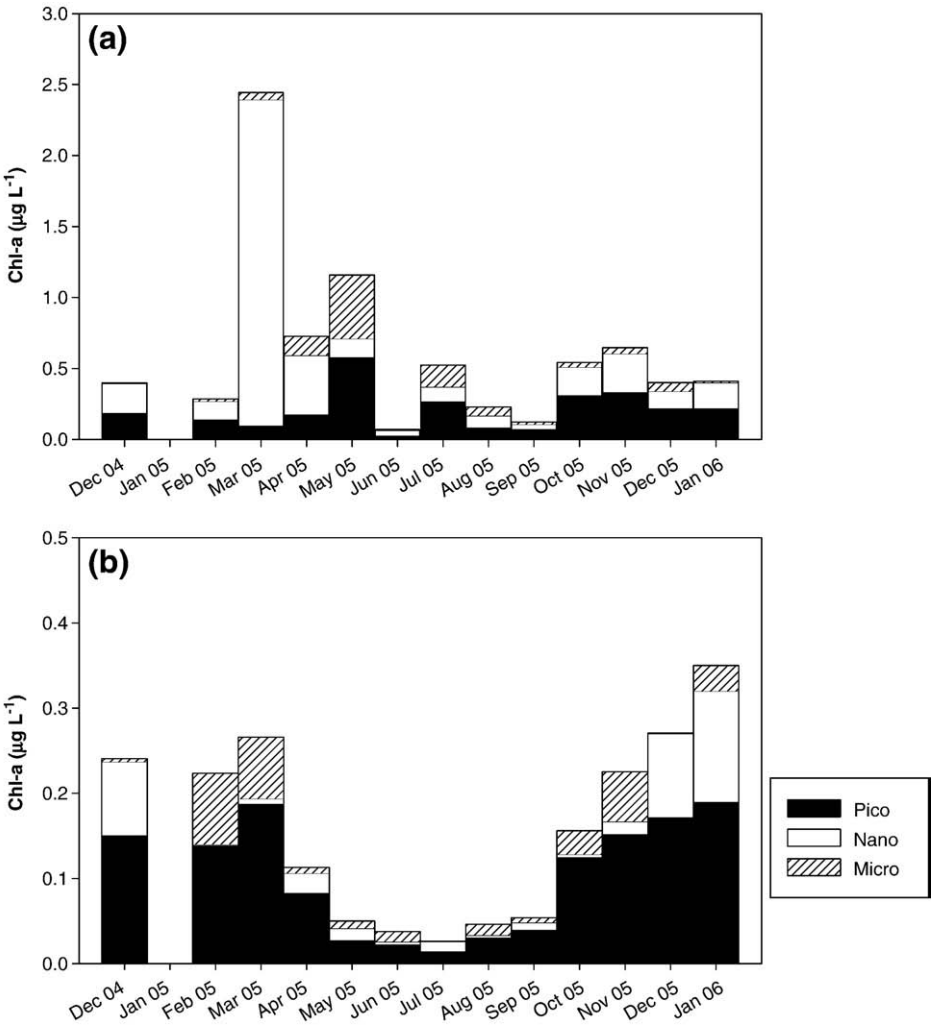

Fig. 4. Annual changes in size fractionated surface water chlorophyll-a at stations 1 (a) and 2 (b).

abundance was >40%, while >1000 and 500–1000 µm size fractions contributed ≤10%.

The biomass values at station 1 ranged between 5.3 and 68.2 mg m^{-3}, being highest in June 2005 and the minimum in September 2005 (Fig. 9a). Highest contribution to the total dry weight was from 200 to 500 µm size fraction with 34%. Other size fractions contributed more or less the same with 22% (>1000 µm), 21% (500–1000 µm) and 24% (112–200 µm). At station 2, total biomass values varied between 1.4 (both in December 04 and May 2005) and 4.6 mg m^{-3} (in November 2005) (Fig. 9b). On annual average, the contributions of >1000, 500–1000, 200–112 and 112–200 µm size fraction to the total biomass were 36, 21, 29 and 14%, respectively.

Ash-free dry weight (organic weight) of the total zooplankton group varied between 4.1 (in September 2005) and 35 mg m^{-3} (in April 2005), and between 0.9 (in December 2004) and 3.3 mg m^{-3} (in November 2005) at stations 1 and 2, respectively. On the annual average, organic content of the total zooplankton constituted around 60% of the total zooplankton dry weight at both stations.

A total of 19 holoplankton and 9 meroplankton groups were observed in the sampling period. Temporal variations in zooplankton group composition in percentages at stations 1 and 2 are given in Tables 1 and 2, respectively. The main taxonomic groups were protozoa, siphonophora, cladocera, ostracoda, copepoda, chaetognatha, doliolida, appendicularia, crustacean nauplii, polychaeta larvae, gastropoda larvae, bivalvia larvae and echinodermata larvae at both stations.

Copepods generally constituted the majority of the total zooplankton at both stations (Tables 1 and 2) and in all size fractions (Fig. 10). Second dominant group was the crustacean nauplii, especially in the smaller size fractions (112–200 and 200–500 µm). The level of contribution of appendicularia was higher at station 1 than at station 2, and appendicularia was the second dominant group in the larger two size fractions (500–1000 and >1000 µm) at both stations. Contribution of cladocera was observed especially during spring and summer periods in all size fractions except the smallest size fraction at station 1. Meroplankton was abundant especially at the coastal station (Fig. 10). Echinodermata larvae showed their highest contribution in August at station 1, even exceeded the copepod contribution in 500–1000 µm size fraction. Chaetognaths were found mostly in >1000 and 500–1000 µm size fractions at both stations. The level of contribution was higher at station 2 compared to station 1 (Tables 1 and 2). Abundance of siphonophora was high at 500–1000 and >1000 µm size fractions at both stations throughout the year.

Total zooplankton abundance positively correlated with chl-a at both stations (Spearman Rank Correlation, $P<0.05$) but biomass correlated with POM only at station 1 ($r_s=0.727$, $P<0.01$). At the coastal station, micro and pico size chl-a did not show any significant correlation with any size of zooplankton abundance. However, significant correlation was observed between total and nano chl-a, and >1000, 1000–500 and 500–200 µm size zooplankton ($P<0.05$). At this station, the significant relationships observed between total

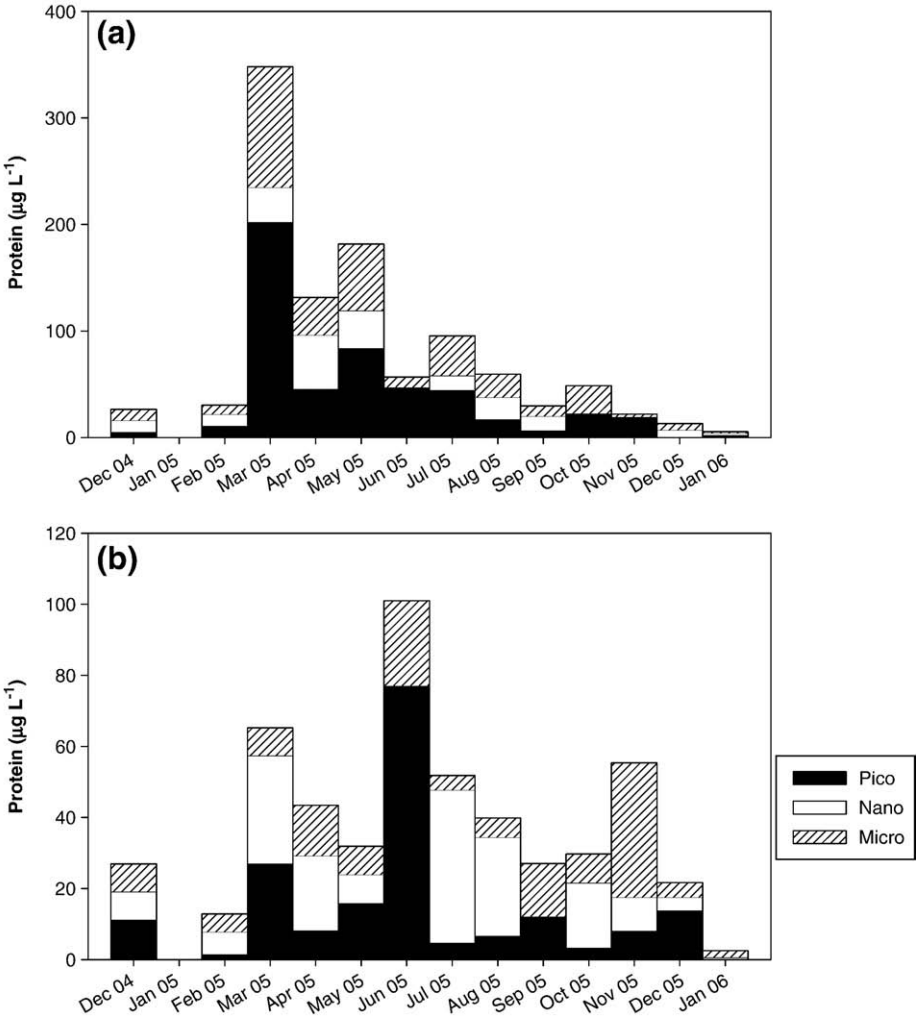

Fig. 5. Annual changes in size fractionated surface seston protein at stations 1 (a) and 2 (b).

and nano size chl-a and above mentioned zooplankton size fractions were affected by the abundance of appendicularians and copepods. At station 2, total and pico chl-a were found to correlate with the 1000–500 and 200–500 µm zooplankton, while >1000 and 1000–500 µm zooplankton were well correlated with micro chl-a. Among the major groups of zooplankton in these two size fractions, appendicularians, copepods, ostracods and crustacean nauplii showed significant relationships with total and pico size chl-a ($P<0.05$). In >1000 µm size zooplankton, siphonophores and copepods were well correlated with micro chl-a. 112–200 µm size fraction of zooplankton was not correlated with any size of chl-a at both stations. Temperature and salinity did not show any significant effect on the total abundance and biomass. But negative significant relationships were observed between abundance of appendicularians and temperature at both stations ($P<0.03$). At station 2, abundance of cladocerans affected positively by temperature ($r_s=0.84$, $P<0.01$).

4. Discussion

4.1. Seston composition and characteristics

Low concentrations of seston biochemical compounds showed that the studied area is extremely oligotrophic. Chlorophyll-a concentrations were on average 0.61 and 0.16 µg L^{-1} at stations 1 and 2, respectively. Maximum chl-a concentration was observed in March 2005 at station 1. This corresponds to the nutrient input from the Lamas river into the system. The highest concentrations of NO*x* and PO_4 were observed in March 2005. The concentrations of NO*x* and PO_4 ranged between 0.06 (in July 2005) and 5.69 µM (in March 2005) and between 0.02 (in June 205) and 0.27 µM (in March 2005), respectively (Tugrul, unpublished data). Effects of riverine input to this station were reported during the spring time (Eker-Develi, 2004; Dogan-Saglamtimur and Tugrul, 2004; Uysal and Koksalan, 2006). At station 2, high chl-a concentrations were observed in spring and autumn–winter periods when the vertical mixing occurred. Surface warming started in April 2005 and strong stratification was observed in June, July, August, September and October 2005 at this station during the study period. In Northeastern Mediterranean, highest chl-a concentrations were reported in autumn and winter periods due to winter mixing (Berman et al., 1984, 1986; Azov, 1986; Salihoğlu et al., 1990; Krom et al., 1991, 1993; Gotsis-Skretas et al., 1999; Ediger et al., 2005). Therefore, this gradual increase in chl-a value during spring and winter periods could be a result of nutrient transport from lower layers to the upper layers by mixing processes at station 2. Highest PO_4 was observed in March and December with the value of 0.04, and highest NO*x* was found in March with 0.2 µM at this station. Lowest chl-a concentration (0.05 µg L^{-1}) was observed during summer period in which the highest temperature values were recorded. Strong negative correlation (Spearman Rank Correlation, $r_s=-0.76$, $P<0.01$) is evident between chl-a and temperature at this station. Low chl-a concentrations during the summer months could be due to the photo inhibition and strong nutrient limitation, or the composite function of these two. Because of the thermocline during the summer months, there is no nutrient supply from below, so the nutrient

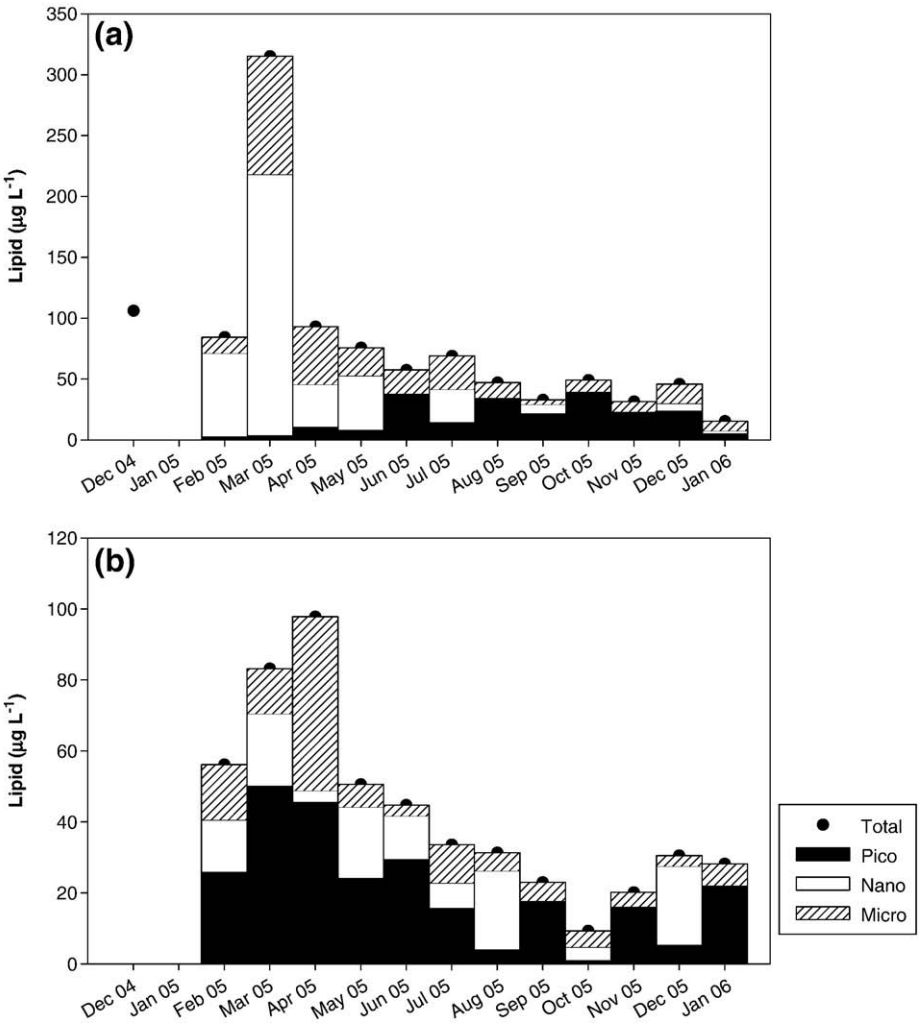

Fig. 6. Annual changes in total and size fractionated surface seston lipid at stations 1 (a) and 2 (b).

sources may be the biological activity and the atmospheric inputs (Kress and Herut, 2001; Markaki et al., 2003). Effects of grazing on phytoplankton cannot be ruled out during the summer period, because of the increase in temperature, grazers become more active, and increase their reproductive and feeding activities (Valiela, 1995; Bamstedt et al., 2000). During the present study, we observed increases especially in small size (112–200 and 200–500 µm) zooplankton abundance in July and August at both stations.

In the present study, nano size fraction made up the spring bloom at station 1. Nutrient concentrations were very low in the rest of the year (Tugrul unpublished data) and pico size fractions (0.7–2.7 µm) took the advantage, and became dominant in the rest of the year. Pico size fraction was always dominant at station 2 throughout the year constituting 65% of total annual chl-a. Small size dominance implies the oligotrophy of the area and similar results were observed in the other oligotrophic part of the basin. Azov (1986) showed that the pico size fraction (<3 µm) dominated in summer and fall, while nano size fraction dominated during spring at the neritic station of Levantine Basin. Yacobi et al. (1995) and Psarra et al. (2005) reported that >60% of the chl-a was confined to the picoplankton in the eastern Mediterranean. Ignatiades et al. (2002) showed that the picoplankton predominated the total chl-a in spring and autumn in the S. and N. Aegean Sea.

Among the three biochemical compounds, carbohydrates were the dominant group at both stations. At most of the sampling periods, the protein to carbohydrate ratio (prt:cho) at both stations was <1, indicating N deficiency (Mayzaud et al., 1989; Danovaro et al., 2000). N deficiency was severe particularly for the nano size fraction. Thingstad et al. (2005) discussed the co-limitation of P and N for phytoplankton growth in eastern Mediterranean. Low prt:cho ratios were also reported in the oligotrophic Cretan Sea (Danovaro et al., 2000).

Biochemical composition of POM (sum of the total carbohydrate, protein and lipid) varied between 42 and 1083 µg L^{-1} at the coastal station and between 54 and 247 µg L^{-1} at the open station (station 2) in the study area. These values are within the range of those reported for the less productive part of the Mediterranean Basin. In the Ligurian Sea, the POM values were observed between 105 and 335 µg L^{-1} (Danovaro and Fabiano, 1997), and between 54 and 200 µg L^{-1} in Cretan Sea (Danovaro et al., 2000). In the productive part, such as in the Basque Shelf (Bay of Biscay), it ranged from 234 to 4587 µg L^{-1} (Diaz et al., 2007). In the present study, the coastal station had higher POM concentrations compared to the open water station. Similar results were observed in the Cretan Sea (Northeastern Mediterranean) by Danovaro et al. (2000). They have found that POM concentration was decreasing from coast to open waters. In the present study, among three size fractions, pico size was the dominant size fraction in the biochemical composition of POM, followed by nano and then micro size fractions at both stations. Danovaro et al. (2000) observed the similar result for the Cretan Sea and they claimed that there is a shift toward smaller size classes from the productive areas to the oligotrophic systems. On the annual average, the pico size constituted ≥40% of POM at both stations. This result indicated that

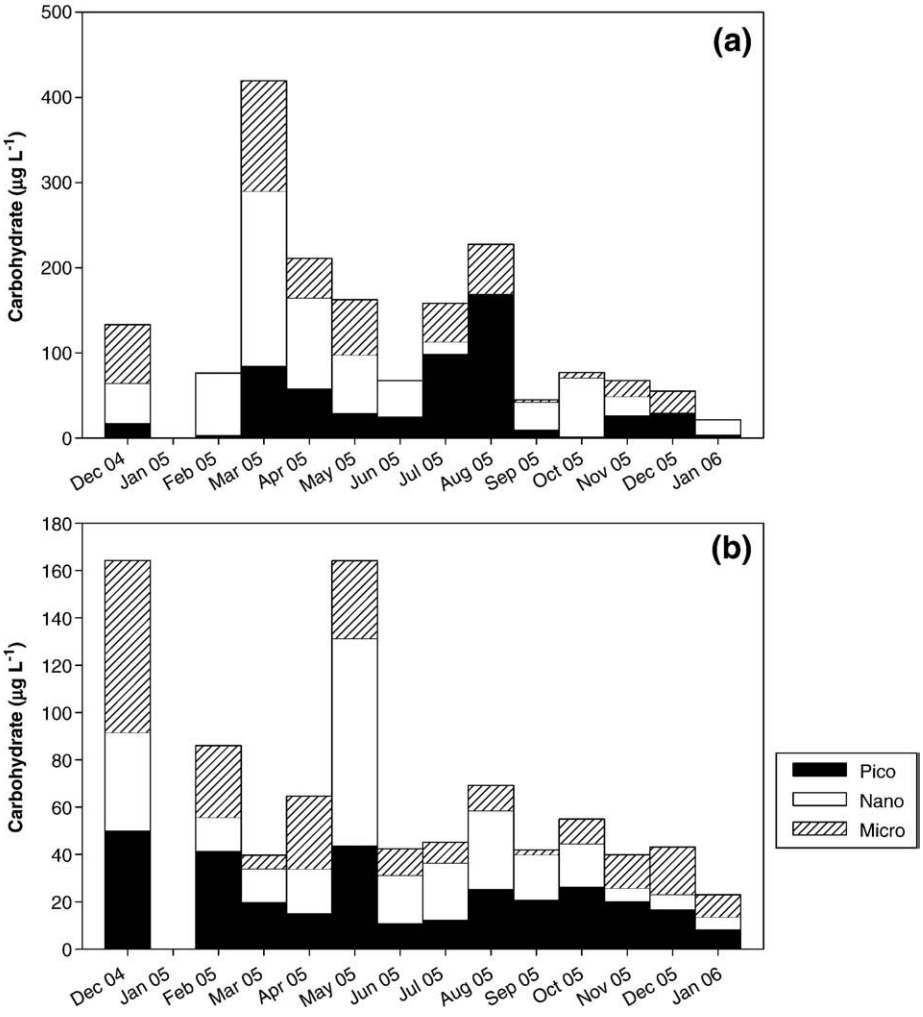

Fig. 7. Annual changes in size fractionated surface seston carbohydrate at stations 1 (a) and 2 (b).

the pico size fraction had higher nutritional values during the study period. This nutritionally valuable small size was not appropriate for larger animal to feed directly on, they might be used in the microbial loop before they reach the larger animals, such as copepods. According to Siokou-Frangou et al. (2002), small sized cell (<3 µm) predominated in autotrophic carbon biomass and primary production in the Aegean Sea and they stated that microheterotrophs play a significant role in transferring the energy to the higher level especially in the South Aegean Sea ecosystem. They found that the energy transfer towards copepods is low in that area.

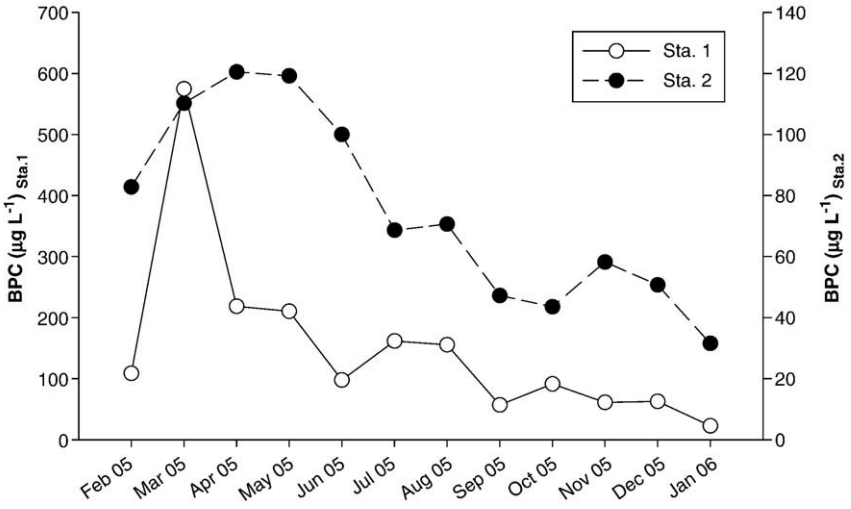

Fig. 8. Temporal variations of BPC (biopolymeric carbon) concentrations at both stations.

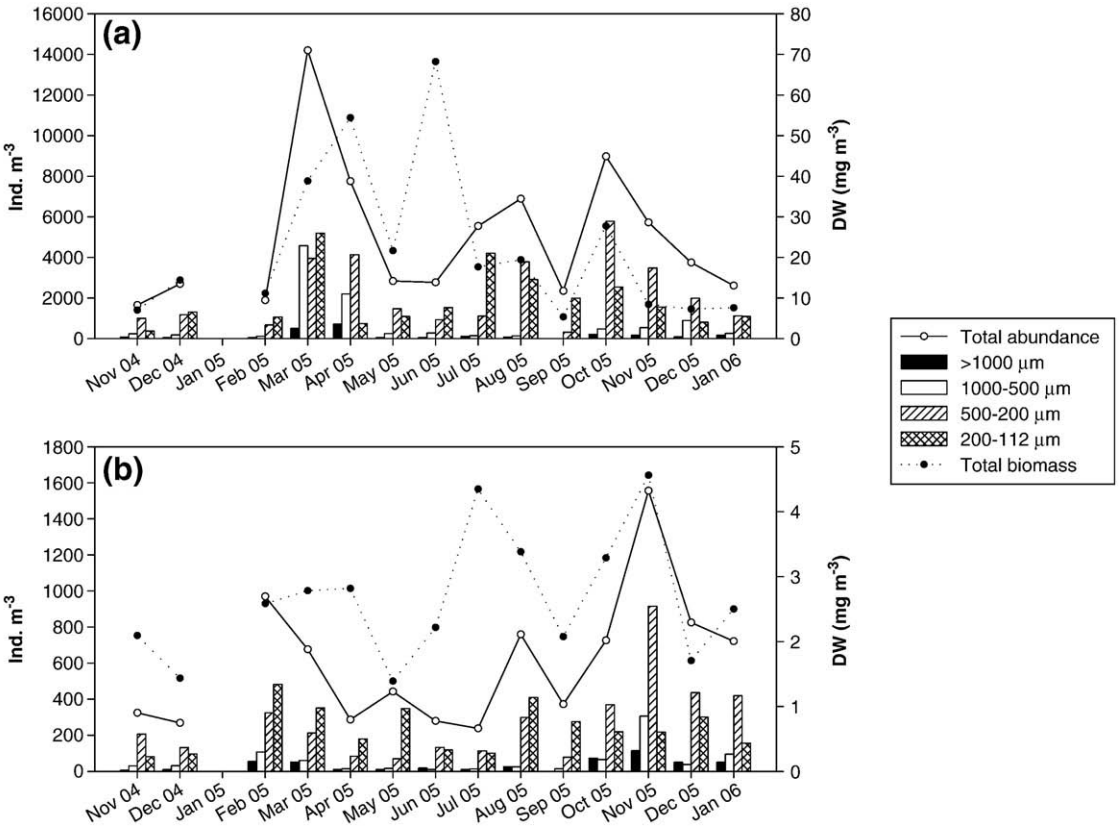

Fig. 9. Temporal variations of size fractionated and total zooplankton abundance and total zooplankton biomass at stations 1 (a) and 2 (b).

Table 1
Percent composition of major zooplanktonic groups from station 1.

Major taxonomic groups	Nov 04	Dec 04	Feb 05	Mar 05	Apr 05	May 05	Jun 05	Jul 05	Aug 05	Sep 05	Oct 05	Nov 05	Dec 05	Jan 06	Average
Holoplankton															
Protozoa	–	0.013	1.904	3.848	0.358	–	0.044	0.106	–	–	0.515	0.585	–	–	1.012
Jelly organisms	0.189	2.116	0.083	0.156	0.072	0.015	0.155	0.106	–	0.328	0.013	0.016	0.014	0.282	0.171
Siphonophora	0.526	0.516	0.773	0.020	0.004	0.031	0.421	–	–	0.328	0.039	0.538	0.542	0.235	0.176
Polychaeta	–	0.019	1.214	1.094	–	–	–	–	0.006	0.012	–	0.008	0.445	–	0.285
Pteropoda	0.694	0.181	–	–	2.183	4.367	0.952	0.352	–	0.012	0.296	0.285	0.042	–	0.580
Cladocera	–	0.052	–	0.488	8.697	8.117	13.045	1.995	7.248	0.140	0.039	0.696	–	0.012	2.891
Ostracoda	–	1.458	0.350	–	–	0.015	–	–	–	–	–	–	1.598	–	0.154
Copepoda	72.150	74.661	65.271	50.098	48.137	41.467	69.402	60.014	51.789	60.700	93.356	80.781	71.665	72.868	64.252
Cumacea	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Isopoda	–	0.013	–	–	–	0.010	–	–	–	–	–	–	–	–	0.001
Amphipoda	–	0.006	–	–	–	–	–	–	–	–	–	–	–	–	0.000
Mysidacea	–	–	–	–	–	–	–	–	0.006	–	–	–	–	–	0.001
Euphausiacea	0.063	0.052	0.009	–	–	–	–	–	–	0.023	–	–	–	–	0.005
Decapoda	–	–	0.037	–	–	–	–	–	–	–	–	–	–	–	0.001
Chaetognatha	0.168	0.722	0.442	0.801	–	0.919	0.720	0.070	0.206	0.152	0.064	0.759	2.168	0.235	0.506
Doliolida	0.084	0.077	0.313	–	–	0.061	0.177	–	–	–	0.464	0.253	–	–	0.105
Salpida	–	0.026	0.018	–	–	0.010	–	–	–	0.012	–	–	0.014	–	0.003
Appendicularia	9.886	1.897	6.191	4.824	10.486	29.228	3.311	1.948	1.372	2.482	0.798	1.897	5.878	6.897	5.208
Crustacea nauplii	13.925	6.748	19.991	21.719	11.560	10.385	4.651	8.201	10.724	29.291	3.103	8.301	9.394	13.279	12.369
Unidentified organisms	–	0.413	0.018	3.770	–	–	–	–	–	–	–	–	–	–	0.794
Meroplankton															
Polychaeta larvae	0.168	3.999	–	8.477	2.434	0.991	0.709	26.634	3.307	0.667	0.026	1.518	1.126	2.111	5.017
Gastrapoda larvae	1.998	0.832	1.628	3.828	2.112	2.815	3.699	0.023	1.245	2.306	0.103	0.917	0.222	0.798	1.752
Bivalvia larvae	–	0.413	0.607	0.625	13.349	1.476	1.949	0.375	1.566	1.276	0.824	3.320	–	1.877	2.487
Cirripedia larvae	–	5.225	–	–	–	0.010	–	–	0.967	0.187	–	–	6.893	1.408	0.735
Stamopoda larvae	–	–	–	–	–	–	–	–	–	0.047	0.013	–	–	–	0.003
Decapoda larvae	0.084	0.045	–	–	–	0.005	0.100	0.023	0.024	0.304	0.142	0.063	–	–	0.046
Echinodermata larvae	–	0.464	1.132	0.254	0.501	0.020	–	–	21.527	1.697	0.206	0.063	–	–	2.400
Phoronida larvae	–	–	–	–	0.072	–	–	–	–	–	–	–	–	–	0.008
Fish eggs and larvae	0.063	0.052	0.018	–	0.036	0.056	0.664	0.153	0.012	0.035	–	–	–	–	0.050
Total (ind.m^{-3})	1648	2686	1848	13,652	7721	2828	2761	5534	6881	2338	8927	5686	3742	2607	

Table 2
Percent composition of major zooplanktonic groups from station 2.

Major taxonomic groups	Nov 04	Dec 04	Feb 05	Mar 05	Apr 05	May 05	Jun 05	Jul 05	Aug 05	Sep 05	Oct 05	Nov 05	Dec 05	Jan 06	Average
Holoplankton															
Protozoa	0.394	–	3.872	3.482	0.690	0.123	–	0.507	0.041	0.147	2.812	0.834	0.050	0.288	1.233
Jelly organisms	0.074	0.634	0.269	0.470	0.336	0.062	0.318	1.246	0.138	0.042	0.371	0.343	0.025	0.058	0.272
Siphonophora	0.781	1.368	0.319	0.891	0.649	0.634	0.936	0.359	0.332	0.706	0.265	1.226	0.959	0.346	0.720
Polychaeta	0.008	1.090	1.034	0.259	0.350	0.388	0.212	0.274	0.014	0.035	0.159	0.123	0.227	0.173	0.301
Pteropoda	1.142	0.734	0.308	–	1.617	1.760	0.901	0.866	0.041	0.042	0.106	0.294	0.025	0.029	0.382
Cladocera	0.066	0.634	–	–	–	–	1.148	3.230	1.964	0.587	0.690	–	–	–	0.419
Ostracoda	1.405	1.209	2.128	0.518	1.072	1.328	1.113	1.013	0.041	1.189	0.212	0.785	0.883	1.386	0.986
Copepoda	70.184	75.829	75.723	69.555	77.378	70.246	75.274	82.415	77.867	73.842	79.788	81.104	77.144	69.078	76.952
Cumacea	–	–	0.005	–	–	–	–	–	–	–	–	–	–	–	0.001
Isopoda	–	0.020	0.176	–	0.005	–	–	–	–	–	–	–	–	–	0.021
Amphipoda	0.008	0.005	–	0.016	0.027	0.032	0.018	0.718	–	0.014	0.053	–	0.050	–	0.036
Mysidacea	–	–	0.005	–	–	–	–	–	–	–	–	–	–	–	0.001
Euphausiacea	0.016	0.030	0.192	0.146	0.086	0.015	0.124	0.021	0.014	0.014	0.053	0.012	0.050	0.043	0.062
Decapoda	0.008	0.010	0.082	0.032	–	–	–	–	–	–	0.053	0.049	0.025	–	0.029
Chaetognatha	0.592	0.317	0.451	1.555	0.890	0.761	1.148	1.731	0.775	0.217	0.318	0.785	0.429	0.923	0.747
Doliolida	0.403	0.178	0.044	0.291	0.059	0.476	0.795	0.148	0.636	0.056	0.584	0.981	0.050	0.115	0.418
Salpida	0.016	0.377	0.077	0.194	0.014	0.144	–	0.253	0.083	0.098	0.106	0.049	–	0.058	0.088
Appendicularia	4.520	0.317	3.921	1.344	1.036	3.927	0.936	0.380	0.692	–	0.743	4.513	3.456	5.420	2.818
Crustacea nauplii	18.302	12.291	5.868	18.559	13.712	18.638	14.889	4.729	12.132	19.702	10.239	7.603	15.388	19.489	12.891
Unidentified organisms	–	–	0.176	0.016	–	0.200	–	0.063	0.028	0.119	–	–	–	–	0.042
Meroplankton															
Polychaeta larvae	0.994	2.934	–	0.518	0.586	0.097	0.018	1.056	0.996	0.930	0.690	0.490	0.277	1.557	0.677
Gastrapoda larvae	0.994	0.020	4.603	1.101	1.490	0.846	1.713	0.760	2.711	1.846	1.538	0.785	0.429	0.634	1.546
Bivalvia larvae	–	0.952	0.638	0.340	–	–	0.212	0	1.328	–	0.212	–	–	–	0.279
Cirripedia larvae	–	–	–	0.065	–	–	–	0.021	–	–	–	–	0.101	–	0.016
Stamopoda larvae	–	–	–	–	–	–	–	0.063	–	–	–	–	–	–	0.002
Decapoda larvae	0.082	0.089	0.011	–	–	0.135	0.247	0.148	0.111	–	0.955	0.025	–	0.288	0.150
Echinodermata larvae	–	0.952	0.093	0.648	–	0.188	–	–	0.041	0.413	0.053	–	–	0.058	0.136
Phoronida larvae	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.000
Fish eggs and larvae	0.008	0.010	–	–	0.005	–	–	–	0.014	–	–	–	0.025	0.058	0.010
Total (ind.m^{-3})	323	269	932	652	284	442	279	237	759	371	706	1543	821	719	

BPC implies the autochthonous origin of the particles (Danovaro and Fabiano, 1997), and in the oligotrophic Cretan Sea it was ranged between 24.2 and 113.7 μgC L^{-1} (Danovaro et al., 2000). These values are very similar to our findings. Generally, it is estimated that BPC forms 40 to 80% of the particulate organic carbon (POC). But this contribution depends on the source of POM (Danovaro et al., 2000). Low contribution was observed in the areas under terrestrial influence (Pusceddu et al., 1996). In the Cretan Sea, the contribution of BPC to the total POC pool was high, 80–100% (Danovaro et al., 2000). This high contribution implies that the origin of POM is autochtonous in the Cretan Sea. Unfortunately, we do not have POC measurements in the present study. So, to obtain a precise picture of the origin of the POM in the studied area, a comprehensive series of measurements containing POC concentrations over different seasons should be carried out.

4.2. Zooplankton composition and biomass

Zooplankton abundance and biomass showed three peaks (spring, summer and autumn) at the studied area. Seasonal succession of zooplankton showed differences in the Mediterranean coastal areas depends upon the particular characteristics of the areas (Calbet et al., 2001). In northwestern Mediterranean, at most of the coastal stations, the maximum abundance of zooplankton was observed in spring–summer period (Mazzocchi and Ribera d'Alcala, 1995; Siokou-Frangou, 1996; Gaudy and Champalbert, 1998), three peaks in zooplankton abundance were observed in the coastal waters of Balearic Sea (Fernandez de Puelles et al., 2003), and multiple peaks in abundance were observed in the coastal zone off Blanes, NW Mediterranean (Calbet et al., 2001).

Zooplankton abundance and biomass values were always significantly higher at station 1 than those at station 2. The average abundance values were in the range of 1648–14198 and 238–1556 ind.m^{-3}, and the biomass values were in the range of 5–68 and 1.4–4.6 mg m^{-3} at stations 1 and 2 respectively. Zooplankton abundance values varied in eastern Mediterranean; such as 684 ind.m^{-3} in the Cretan Sea (Fernandez de Puelles et al., 2003), 200 ind.m^{-3} in the Sicily Channel and 56 ind.m^{-3} in the Cretan Passage (Mazzocchi et al., 1997), 130–200 ind.m^{-3} in the surface water of Levantine Basin (Pancucci-Papadopoulou et al., 1992) and 305–4662 ind.m^{-3} in the frontal area of the Aegean Sea (Zervoudaki et al., 2006). Fernandez de Puelles et al. (2003) found the zooplankton abundance and biomass as 328–2010 ind.m^{-3} and 1.4–16.9 mg m^{-3}, respectively in the neritic area of the Balearic Sea (WM). Gaudy et al. (2003), Lakkis (1990) and Champalbert (1996) stated that the biomass values are always found to be higher at coastal waters. The direct comparisons of both biomass and abundance with the other studies may not be convenient because of the different sampling techniques used, especially differences in net types and in mesh sizes.

Total zooplankton abundance and biomass well correlated at station 1, in contrast correlation between biomass and abundance was absent at station 2. At both stations copepoda was the dominant group but the variability of different species succession at the stations and/or different developmental stages of other groups during the sampling period may be the cause of differences in the relations between abundance and biomass.

Zooplankton abundance and total chl-a well correlated at both stations. This positive correlation was strongly related to the abundance of appendicularians. This relation is logic in the small cell sized predominant region, since it has been reported that the smallest seston particles (<2 μm) were exclusively ingested by appendicularians (Deibel and Lee, 1992; Sommer et al., 2000).

In conclusion, the two stations visited during the study period have different water characteristics, the coastal station has variable water characteristics and seasonally exposed to different intensities of anthropogenic and land-related influences. However, the open station is more stable and shows open water characteristics of the Northeastern Mediterranean. Dominance of pico size fraction in the seston and low prt:cho ratio suggested oligotrophy at the stations. Food size is an

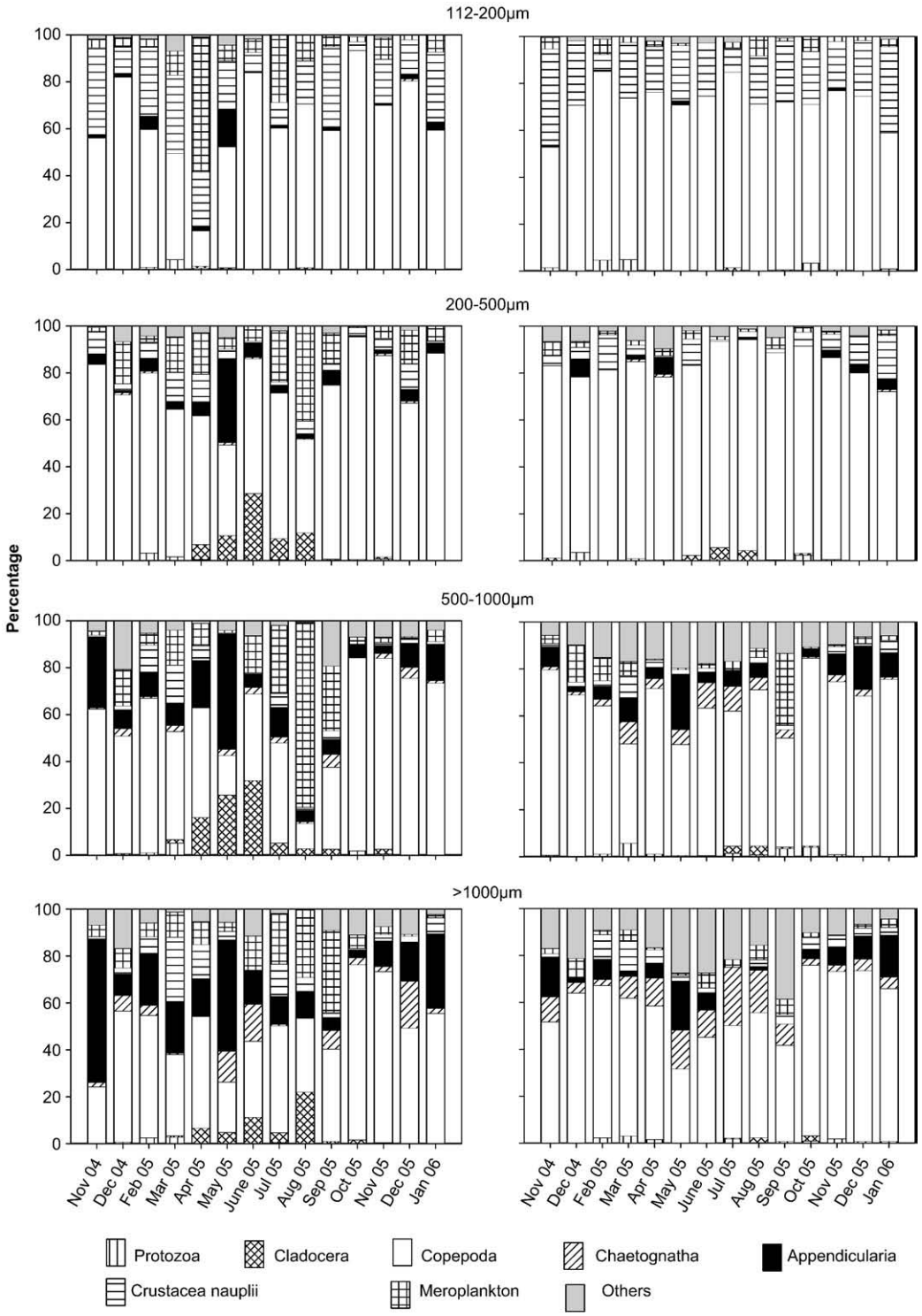

Fig. 10. Temporal variations in size fractionated zooplankton composition at stations 1 (left) and 2 (right). Others: Jelly organisms, Polychaeta, Pteropoda, Cumacea, Isopoda, Amphipoda, Mysidacea, Euphasidacea, Decapoda, Salpida, Doliolida, Siphonophora, Ostracoda and unidentified organisms.

important factor determining the trophic interactions in the marine ecosystems. Dominance of pico size fraction implies that the microbial loop dominates the system. Some of the meso-zooplanktonic organisms can feed directly on pico size particles, like appendicularians. However, copepods were the main zooplankton component in the study area and they have the poor ability to feed directly on pico size particles. So, they may be forced to rely on other food sources that can consume pico size particles efficiently.

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