Summer mesozoooplankton assemblages in relation to environmental parameters in Kavala Gulf, northern Aegean Sea

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Summary: Shallow coastal areas are ecosystems with high productivity. Although the eastern part of the Mediterranean Sea is oligotrophic, the shallow coastal waters of the northern Aegean, such as Kavala Gulf, are productive due to the influence of the Black Sea water and the presence of freshwater input from three rivers. The aim of this work was to determine the structure of zooplankton communities in Kavala Gulf in the summer of 2002 and 2003 and to investigate their relation to environmental variables. Zooplankton communities were characterized by the presence of common coastal Cladocera, such as *Penilia avirostris*, small pelagic Copepoda, such as the calanoid *Acartia clausi* and the cyclopoid *Oithona plumifera*, and Tunicata, such as *Oikopleura*, *Fritillaria* and Doliolidae. The abundances corresponded to the peak of the warm period and were significantly greater in 2002 because of a *P. avirostris* bloom, which seemed to have better exploited the environmental sources favouring its dominance in the area. Overall, the structure of summer mesozooplankton communities in Kavala Gulf follows the pattern exhibited by mesozooplankton communities in other Greek coastal areas of the northern Aegean Sea.

Keywords: abiotic factors; quantitative distribution; ecological associations; diversity patterns; coastal zone; zooplankton community composition.
INTRODUCTION

Zooplankton play an important role in marine pelagic food webs, connecting primary producers, small pelagic fish populations and benthic communities, and thus transferring organic matter through the pelagic food webs (Fenchel 1988). Plankton and fish larvae communities are often structured in assemblages that are closely related to environmental characteristics (Cowen et al. 1993). Their response to alterations of the environmental conditions can be detected by observing changes in diversity, community structure and species distribution (e.g. Dorich et al. 1989, Richardson 2008). Moreover, zooplankton population dynamics can be indicative of environmental changes and may affect higher trophic levels (Beaugrand et al. 2003, Frederiksen et al. 2006).

As an important part of the pelagic food web and fisheries ecology, zooplankton has thus been used in the evaluation and modelling of marine ecosystems (e.g. Triantafyllou et al. 2007, Petihakis et al. 2009).

The northern Aegean Sea, in the northeastern Mediterranean, is a complex and dynamic marine ecosystem (Tsarakakis et al. 2010). Its hydrodynamic complexity is closely linked to the influence of the Black Sea water masses, which outflow in the upper part of the water column through the Dardanelles Straits and are characterized by low salinity and temperature (Zodiatis and Balopoulos 1993, Zervakis and Georgopoulos 2002). Almost permanently, one branch of the Black Sea current follows a northward direction towards the Thracian Sea, where it is captured by an anticyclonic gyre formed around the island of Samothraki and is mainly restricted to the upper 0 to 20 m layer (Zodiatis and Balopoulos 1993, Zervakis and Georgopoulos 2002). The water circulation pattern in the northern Aegean has a considerable influence on the horizontal oceanographic variability of zooplankton assemblages (Isari et al. 2006, 2007, Zervoudaki et al. 2006). These hydrological conditions lead to high productivity, in contrast with the rest of the eastern Mediterranean Sea (Isari et al. 2006, 2007, Zervoudaki et al. 2006). These oceanographic variability of zooplankton assemblages is closely linked to the influence of the Black Sea water masses, which outflow in the upper part of the water column through the Dardanelles Straits and are characterized by low salinity and temperature (Zodiatis and Balopoulos 1993, Zervakis and Georgopoulos 2002). Almost permanently, one branch of the Black Sea current follows a northward direction towards the Thracian Sea, where it is captured by an anticyclonic gyre formed around the island of Samothraki and is mainly restricted to the upper 0 to 20 m layer (Zodiatis and Balopoulos 1993, Zervakis and Georgopoulos 2002). The water circulation pattern in the northern Aegean has a considerable influence on the horizontal oceanographic variability of zooplankton assemblages (Isari et al. 2006, 2007, Zervoudaki et al. 2006). These hydrological conditions lead to high productivity, in contrast with the rest of the eastern Mediterranean Sea (Lykousis et al. 2002), making the northern Aegean contrast with the rest of the eastern Mediterranean Sea (Lykousis et al. 2002), making the northern Aegean

Kavala Gulf and the surrounding area constitutes one of the most well-known fishing and nursery grounds of the northern Aegean Sea (Stergiou et al. 1997), which is particularly important for small pelagic fish populations such as European anchovy (Engraulis encrasicolus), the European pilchard (Sardinia pilchardus) and the round sardinella (Sardinella aurita) (Stergiou et al. 2007, Sylaios et al. 2010), which may compete for resources (Tsikliras 2014).

As zooplankton is the basic component in the diet of the early stages of fish and of the adults of small pelagic fish, zooplankton communities in Kavala Gulf are key organisms of the pelagic web (Tsikliras et al. 2005, Catanã et al. 2010, Karachle and Stergiou 2013). Although zooplankton communities have been widely studied in the northern Aegean Sea (Table 1), Kavala Gulf was not included among the study areas. Filling this gap could provide a valuable asset, adding to the theoretical knowledge of ecosystem functioning and fisheries modelling that could be used to refine or expand the ecosystem models that have already been developed for the area (Tsagarakis et al. 2010). The aim of the present study was to fill this knowledge gap regarding mesozooplankton in Kavala Gulf through the analysis of a fine grid of 17 stations during two summer cruises in 2002 and 2003.

In particular, our analysis aimed to (i) demonstrate the spatial variability of major zooplankton species/taxonomic groups and (ii) investigate the relation between sea surface abiotic factors and the structure of zooplankton communities.

MATERIALS AND METHODS

Study site

Kavala Gulf (40.88056°N, 24.41667°E) is a semi-enclosed area located on the continental shelf of the northern Aegean Sea in the eastern Mediterranean Sea (Fig. 1). It is connected to the Aegean Sea through its main mouth in the south, which is wide (20 km) and deep, and in the east, through the smaller (7.3 km wide), shallower mouth, the strait of the island of Thasos (Fig. 1). As Kavala Gulf is shallow (mean depth: 43 m), it is characterized by high primary production due to the frequent incursions of Black Sea water masses.
The hydrology of the gulf is influenced by the fresher Black Sea water, which oscillates seasonally (Fig. 1). The major mesozooplankton taxa (e.g. Copepoda, Cladocera, Doliolidae, Appendicularia, etc) were identified using the appropriate taxonomic keys. Copepoda (only adults) and Cladocera were further identified down to species level when possible, whereas copepodites were grouped together and were not further identified. For the abundance estimation, each sample was enumerated in aliquots under the stereoscope. Subsamples were taken with a pipette, their size ranging from 1/2 to 1/30 of the total sample depending on the sample’s density. The total number of counted organisms was on average 1844.47±646.58 ind.

**Data analysis**

Mesozooplankton abundance data were expressed as number of individuals per volume unit (m³) by dividing the individuals per sample by the volume of the filtered water. The standardized numbers were used to calculate the percentage contribution of each taxon to the total abundance. In order to identify the similarity of mesozooplankton communities among stations and years, hierarchical cluster analysis based on the Bray-Curtis similarity index (Bray and Curtis 1957) was performed on the mesozooplankton taxa’s abundance matrix. Abundance data were log (x+1) transformed in order to approach normality and homogeneity of variances and to reduce bias due to highly abundant groups. CLUSTER was run using group-average linking. The similarity profile (SIMPROF) permutation test option (default settings of 999 permutations and significance level 0.05) was applied to indicate significant groups in the resulting dendrogram. The similarity analysis routines, analysis of similarity (ANOSIM) and similarity percentage analysis (SIMPER) were used to test the significance levels and sources of variance between the various zooplankton assemblages associated with the groupings identified in the hierarchical cluster analysis. The above analyses were conducted with the Plymouth Routine In Multivariate Ecological Research (PRIMER) v.5 software package (Clarke and Gorley...
2001). Permutational multivariate analysis of variance (PERMANOVA), based on Euclidean distance resemblance matrix, was used to test for statistical differences in the mesozooplankton abundances between the sampled periods (July 2002 and 2003) and between water depth categories (stations at less than 30 m and more than 30 m depth). Analyses were performed using the Permutational Multivariate Analysis of Variance software package (Past v.3.15) (Hammer et al. 2001).

Direct ordination analyses were used to assess significant relationships between biological and environmental data. All environmental variables (temperature, salinity, depth and dissolved oxygen) were log (x+1) transformed. Previously, a detrended correspondence analysis (DCA) was performed and, as biological data showed a linear response with respect to environmental gradients, a redundancy analysis (RDA) was applied. All environmental parameters with an inflation factor smaller than 20 were included in the analysis as explanatory variables (Ter Braak and Verdonschot 1995); the abundance of each zooplankton taxon was included as a response variable. The statistical significance of the variation in the parameters and the overall significance of the ordination were tested with the Monte Carlo permutation test (as default settings of 499 unrestricted permutations; P<0.05). Ordination analyses were performed using the CANOCO program, version 4.5 (Ter Braak and Smilauer 2002).

RESULTS

Environmental parameters

The values of sea surface environmental parameters (temperature, salinity, oxygen) and maximum depth of the sampling stations in Kavala Gulf are given in Table 2. Salinity and oxygen differed significantly between the years (ANOVA; P<0.005), whereas temperature did not (ANOVA; P>0.005).

Community composition and structure

Overall, a total of 9 main holoplanktonic and 6 main meroplanktonic groups were recorded (Table 3). Nineteen taxa were further identified, 12 of them down to species level and 7 to genus level (Table 3).

Table 2 – Sea surface physical-chemical parameters and maximum depth of the 17 stations in Kavala Gulf. Stations' abbreviations are consistent with the formula ST (number of station; sampling year; 02 for 2002 and 03 for 2003).

| Year | Station | Temperature (°C) | Salinity | Oxygen | Depth (m) |
|------|---------|------------------|----------|--------|-----------|
| 2002 | ST0102  | 24.3             | 34.0     | 8.2    | 37.0      |
| 2002 | ST0202  | 24.2             | 33.8     | 8.5    | 35.2      |
| 2002 | ST0302  | 23.7             | 33.7     | 7.6    | 34.0      |
| 2002 | ST0402  | 23.9             | 33.5     | 8.4    | 43.0      |
| 2002 | ST0502  | 24.4             | 33.9     | 8.4    | 37.0      |
| 2002 | ST0602  | 25.1             | 33.8     | 8.7    | 29.0      |
| 2002 | ST0702  | 25.5             | 33.8     | 8.6    | 25.0      |
| 2002 | ST0802  | 24.3             | 32.9     | 8.5    | 28.0      |
| 2002 | ST0902  | 24.5             | 34.0     | 8.4    | 28.0      |
| 2002 | ST1002  | 24.3             | 34.3     | 8.5    | 16.0      |
| 2002 | ST1102  | 24.6             | 33.2     | 8.6    | 30.0      |
| 2002 | ST1202  | 24.5             | 33.3     | 7.8    | 30.0      |
| 2002 | ST1302  | 25.1             | 34.3     | 8.0    | 30.0      |
| 2002 | ST1402  | 25.0             | 34.2     | 8.3    | 35.0      |
| 2002 | ST1502  | 24.6             | 34.4     | 8.3    | 45.0      |
| 2002 | ST1602  | 25.0             | 34.3     | 8.0    | 43.0      |
| 2002 | ST1702  | 25.2             | 34.2     | 8.1    | 44.5      |
| 2003 | ST0103  | 24.7             | 31.6     | 8.3    | 36.5      |
| 2003 | ST0203  | 24.8             | 32.5     | 8.1    | 36.0      |
| 2003 | ST0303  | 25.3             | 31.5     | 7.9    | 43.0      |
| 2003 | ST0403  | 25.3             | 32.4     | 7.8    | 40.5      |
| 2003 | ST0503  | 24.4             | 31.3     | 8.5    | 38.5      |
| 2003 | ST0603  | 24.2             | 32.5     | 8.3    | 27.8      |
| 2003 | ST0703  | 24.2             | 31.4     | 8.3    | 25.0      |
| 2003 | ST0803  | 24.9             | 30.5     | 7.9    | 27.0      |
| 2003 | ST0903  | 25.4             | 32.6     | 7.8    | 28.0      |
| 2003 | ST1003  | 25.3             | 32.7     | 7.7    | 13.6      |
| 2003 | ST1103  | 24.6             | 32.9     | 8.1    | 36.5      |
| 2003 | ST1203  | 24.7             | 32.7     | 8.0    | 30.0      |
| 2003 | ST1303  | 25.0             | 32.7     | 8.0    | 30.0      |
| 2003 | ST1403  | 24.7             | 30.6     | 8.3    | 39.0      |
| 2003 | ST1503  | 24.3             | 30.5     | 8.4    | 45.0      |
| 2003 | ST1603  | 24.4             | 32.4     | 8.3    | 45.0      |
| 2003 | ST1703  | 25.4             | 32.6     | 7.9    | 41.0      |

Table 3 – List of the dominant zooplankton taxa in 2002 and 2003.

| Taxon | 2002 (ind m⁻³) | 2003 (ind m⁻³) |
|-------|----------------|----------------|
| Cladocera | 18 | 20 |
| Copepoda | 16 | 18 |
| Small-sized cladocera | 14 | 16 |
| Small-sized copepoda | 12 | 14 |
| Small-sized appendicularia | 10 | 12 |
| Small-sized harpacticoida | 8 | 10 |
| Other | 4 | 6 |

Note: The values are given as total abundance values for each sampling station (ST) and sampling year (02 for 2002 and 03 for 2003).

Fig. 1. – Spatial distribution of mesozooplankton taxa in Kavala Gulf in 2002 (A) and 2003 (B).
### Table 3. – List of recorded taxa. Mean abundance values (Abu) and mean relative abundance % (Abu %) in the summer of 2002 and 2003 in Kavala Gulf. Abb, abbreviation of each taxon as used for further analyses; Ca, Calanoida; Cy, Cyclopoida; Ha, Harpacticoida.

| Taxa                    | Abb     | 2002 Abu | 2003 Abu | 2002 Abu % | 2003 Abu % |
|-------------------------|---------|----------|----------|------------|------------|
| **Holoplankton**        |         |          |          |            |            |
| Amphipoda               | Amp     | 242.99   | 0.00     | 0.58       | 0.00       |
| Appendicularia          | App     | 3155.50  | 1759.59  | 4.46       | 5.12       |
| Fritillaria spp.       | Fol, 1872 Fri | 1979.21  | 1043.77  | 2.92       | 3.01       |
| Oikopleura spp.        | Mertens, 1830 Oik | 1249.80  | 715.82   | 1.87       | 2.20       |
| Chaetognatha           | Sag     | 194.61   | 155.24   | 0.38       | 0.49       |
| Cladocera              | Cla     | 60358.22 | 26220.55 | 76.01      | 68.14      |
| Evadne nordmanni       | Lovén, 1836 Evn | 2517.24  | 1032.31  | 3.11       | 3.26       |
| Evadne spinifera       | P.E.Müller, 1867 Evs | 1073.36  | 300.84   | 1.41       | 1.00       |
| Penilia avirostris (Dana, 1852) | Pea | 55344.58 | 24135.30 | 47.61      | 48.58      |
| Pseudevadne tergestina | Claus, 1862 Pst | 1423.04  | 752.09   | 1.89       | 2.29       |
| Copepoda               | Cop     | 8087.28  | 5130.61  | 11.10      | 16.07      |
| Acartia (Acartiura) clausi Giesbrecht, 1889 (Ca) | Acc | 1986.01 | 1659.70 | 2.62 | 5.55 |
| Calocalanus pavo (Dana, 1849) (Ca) | Cap | 48.31 | 0.00 | 0.52 | 0.00 |
| Centropages typicus Kroeyer, 1849 (Ca) | Cet | 1175.98 | 455.20 | 1.93 | 1.60 |
| Conesa rapax Giesbrecht, 1891 (Cy) | Cor | 31.98 | 32.55 | 0.17 | 0.44 |
| Corycaeus spp. Dana, 1845 (Cy) | Crc | 265.92 | 200.21 | 0.33 | 0.65 |
| Ctenocalanus vanus (Dana, 1849) (Ca) | Cv | 737.62 | 455.60 | 1.08 | 1.58 |
| Macrosetella spp. Scott A., 1909. (Ha) | Mac | 0.00 | 8.38 | 0.00 | 0.51 |
| Mecynocera spp. Thompson I.C., 1888 (Ca) | Mec | 206.53 | 81.17 | 0.47 | 0.54 |
| Oithona plumifera Bair, 1843 (Cy) | Oip | 1192.12 | 1010.17 | 1.74 | 2.93 |
| Paracalanus parvus (Claus, 1863) (Ca) | Pap | 750.34 | 222.76 | 1.14 | 0.63 |
| Temora stylifera (Dana, 1848) (Ca) | Tem | 550.51 | 235.25 | 0.83 | 0.67 |
| unidentified Copepoda | Cop | 1472.83 | 924.01 | 2.10 | 2.89 |
| Doliolidae             | Dol     | 3063.61  | 917.41   | 4.17       | 2.35       |
| Ostracoda              | Ost     | 355.36   | 23.78    | 0.52       | 0.80       |
| Medusae                | Hyd     | 611.48   | 380.50   | 0.90       | 1.14       |
| Siphonophores          | Sip     | 731.62   | 2156.19  | 1.12       | 6.00       |
| **Meroplankton**       |         |          |          |            |            |
| Decapoda larvae        | Dec     | 269.15   | 126.34   | 0.60       | 0.42       |
| Echinodermia           | Ech     | 455.16   | 94.48    | 0.74       | 0.43       |
| Gastropoda             | Gas     | 64.68    | 0.00     | 0.44       | 0.00       |
| Mysidae larvae         | Mys     | 2625.70  | 0.00     | 3.77       | 0.00       |
| Polychaeta             | Pol     | 51.21    | 62.67    | 0.61       | 0.40       |
| Cirripedia             | Cir     | 169.28   | 133.76   | 0.25       | 0.43       |
| **Total**              |         |          |          |            |            |
|                       |         | 77610.34 | 37060.20 |            |            |

Fig. 2. – A, distribution of mesozooplankton abundance in the water column in Kavala Gulf, northern Aegean in July 2002 and 2003. Values for smaller and larger disc (range of abundance values) are indicated. B, box plots of mesozooplankton abundance in Kavala Gulf, northern Aegean in July 2002 and 2003 grouped by sampling year. Outliers are plotted as dots.
2002 and 2003, respectively) (Fig. 4). This was mainly
due to Mysidae, Ostracoda and Amphipoda abundance
for Group A (SIMPER, average dissimilarity ≤27.18%;
Appendix 1) and to Cirripedia, Echinodermata, Decapoda and Polychaeta abundance for Group D (SIMPER,
average dissimilarity 14.48%; Appendix 1). However,
according to ANOSIM, these groupings had no sta-
tistical significance (ANOSIM, Group A, R ≥0.986, 
P>0.05 and Group D, R=0.645, P>0.05; Appendix 1).
The rest of the sampling stations of 2002 and station 9
of 2003 were grouped together in the upper group of
the cluster (Group B), while the stations of 2003 were
placed in Group C (Fig. 4). Groups B and C differed
significantly, as shown by pairwise comparison (ANOSIM, R=0.703, P=0.01; Appendix 1). Their dissimilarity
was mainly due to the contribution of Ostracoda, Echinodermata, Polychaeta and Doliolidae (SIMPER,
average dissimilarity 15.06%; Appendix 1), whereas
the similarity among stations in the same groups was
in both cases mainly due to Cladocera, Copepoda, Ap-
 pendicularia and Doliolidae or Siphonophora in rank
order (SIMPER, average similarity Group B 91.50% and
Group C 89.72%; Appendix 1).

Relationships between physical-chemical parameters and zooplankton community structure

To assess significant relationships between surface
environmental data and mesozooplankton community
structure, ordination analysis of taxa assemblages, ex-
pressed in terms of biomass, was conducted (Fig. 5).
In the diagnostic DCA, the highest value of the length
of gradient of axis was 0.819, indicating that the rela-
tionship between mesozooplankton and environmental
variables was linear (Ter Braak and Šmilauer 2002), and
an RDA was performed. The significant environmental
variables (P<0.05) included in the RDA were salinity
and maximum depth. Although dissolved oxygen was
not a significant variable (P=0.06), it was included in
the analysis as an explanatory variable of zooplankton
distribution. The Monte Carlo test confirmed that the
selected RDA model was significant (F ratio=9.531,
P=0.002). The eigenvalues of the first two axes were
0.241 and 0.072, and both of them together explained
90.4% of the variation in species-environment relation.
The first axis, which accounted for a total variance of
69.6%, was negatively and strongly correlated with
Moreover, mesozooplankton communities in 2002, being in contrast with those of 2003, were negatively correlated with Axis 1 (Appendix 2) and consequently positively correlated with sea surface salinity. Axis 2 showed 20.8% variation and was strongly and negatively correlated with maximum depth (r=–0.9768). Dissolved oxygen was strongly and negatively correlated with the third axis (r=–0.9355), which accounted for a total of 9.6% variation. Cumulative fit indicated that the predominant mesozooplankton groups affiliated with Ostracoda and...
Cladocera displayed stronger correlations with Axis 1 than the rest of the groups (Appendix 3). Ostracoda, Doliolidae, Cladocera, Appendicularia and Mysidae were notable taxonomic groups with higher correlations with Axis 2 (Appendix 3).

DISCUSSION

The present study focuses on the community structure of mesozooplankton in Kavala Gulf in the summer of 2002 and 2003. Although our dataset is relatively old, this is to the best of our knowledge the first published study on mesozooplankton in Kavala Gulf. Mesozooplankton sampling was part of a fisheries survey in the area, whose data on hydrology and fisheries have already been published (Tsigkiras et al. 2005, 2009, Tsigkiras 2014). Since Kavala Gulf is an important fisheries and nursery ground (Stergiou et al. 1997), data on mesozooplankton could contribute to the theoretical knowledge of ecosystem functioning in the area. Moreover, though our dataset lacks seasonality, it could be useful for comparisons with present and future data, and for further meta-analyses in fisheries and ecosystem modelling through the refining or expanding of models that have already been developed for the area (Tsagarakis et al. 2010).

The hydrological data collected during the present study were limited to the surface layer. Nevertheless, they are in accordance with other studies in the northern Aegean (e.g. Isari et al. 2008). The differences recorded between the two sampling years for salinity are attributed to the rainier days just before the 2003 survey (Tsigkiras et al. 2009). The composition of the zooplankton community found in the present study is typical of coastal areas in the Aegean and Ionian Seas, such as Saronikos Gulf (Siokou-Frangou 1996), Peraikos Gulf, the northern Euboikos Gulf, Pagasitikos Gulf (Ramfos et al. 2005) and the Thracian Sea (Isari et al. 2007). Moreover, a similar zooplankton community composition has been recorded during the summer in other coastal ecosystems of the Mediterranean and Black Seas (e.g. Apostolopoulou and Kiortsis 1973, Christou and Stergiou 1998; Thracian Sea (Isari et al. 2007); Ionian and central Aegean Sea (Ramfos et al. 2005)) and in the Black Sea (e.g. Sazhina 1964). This may be linked to the special conditions occurring in this semi-enclosed gulf, namely the effects of the Black Sea water, the nutrient rich intake from the nearby river outflows and the urban and industrial activity in the area (Friligos 1985, Kardaras 2005, Sylaios et al. 2005, Isari et al. 2006). A water circulation study that was synchronous with our sampling in Kavala Gulf states that northern Aegean water enters westwards in the Gulf from the Strait of Thassos (near station 10, Fig. 1), forming a cyclonic sea surface pattern (Tsigkiras et al. 2009). Moreover, in Kavala Gulf cold water masses with low salinity are provided by the outflow of the Nestos River during winter and spring (Kardaras 1998), whereas in the summer period water circulation is influenced by the low-salinity water masses entering from the Dardanelles (Kardaras 1998, Tsigkiras et al. 2009). The influence of the Black Sea water on zooplankton communities has been previously studied in the northern Aegean Sea, showing that it favours the dominance of Cladocera and small-sized Copepoda due to its lower salinity (Isari et al. 2006, 2007, 2011), as is the case with the mesozooplankton communities of Kavala Gulf. Moreover, the abundance recorded in 2002 was higher than in 2003, while the reverse pattern is observed in the ichthyoplankton data (Tsigkiras et al. 2009). This reverse relationship may be indicative of fish larvae predation on the mesozooplankton communities (Cushing 1990). However, inter-annual variability of the mesozooplankton- ichthyoplankton trophic link and longer time-series would be needed to support this hypothesis with more evidence.

The dominant zooplankton group in both sampling years were Cladocera, followed by Copepoda and Tunicata (Fig. 4). Cladocera dominate coastal areas in the summer period according to similar studies, contributing to the summer peak [e.g. Christou and Stergiou 1998; Strymonikos and Ierissos Gulfs (Michaloudi 1999); Thracian Sea (Isari et al. 2007)]. They are favoured by high temperatures, low salinity (Moraitou-Apostolopoulou and Kiortsis 1973, Christou and Stergiou 1998) and low depth (Siokou-Frangou 1996), which are conditions encountered in Kavala Gulf during the summer. This trend was reflected in the RDA (Fig. 5), with stations being grouped by depth and surface salinity. In 2002, mesozooplankton communities were positively correlated with the sea surface salinity values, which were significantly higher, whereas in 2003...
they were negatively correlated. Although salinity was significantly differentiated between the years studied, it was not an actual forming factor of the communities’ distinctness because of the narrow range of the measured values (1.89±0.95). According to Siokou-Frangou et al. (1998), temperature is the main driving factor of mesozooplankton community formation.

In our study, the Cladocera community consisted almost entirely of *P. avirostris*, which is a highly efficient filter feeder feeding mainly on phytoplankton, such as diatoms, nanoflagellates (HNF) and bacterio-plankton (Turner et al. 1988, Kim et al. 1989, Aitzena et al. 2006). *P. avirostris* peaks may be favoured by the presence of *Cymodocea* and *Posidonia* meadows in Kavala Gulf (Orfanidis et al. 2010), taking advantage of the dissolved organic carbon enrichment in the pelagic food web and the microbial loop that is favoured in such D. habitats (Barrón et al. 2004, Barrón and Duarte 2009). Moreover, massive populations of *P. avirostris* may be a result of the combination of its ability to exploit the available food resources and of its life cycle characteristics (a short life cycle and parthenogenetic reproduction) (Colton 1985, Valentí and Marrazzo 2003). In conclusion, the zooplankton community of a semi-enclosed gulf in the northern Aegean Sea during the summer was mainly dominated by Cladocera, small pelagic Copepoda and Tunicata. The high abundance values might have been favoured by the Black Sea water and river input in the upper layer of the water column. Our results on the mesozooplankton communities of Kavala Gulf may provide valuable information concerning the function of the pelagic food web in the gulf and contribute to the construction and/or improvement of models used in fisheries management of economically important fish stocks of the area.

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APPENDICES

Appendix 1. – Results of the similarity percentage analysis and the pairwise analysis of similarity of variance among the four groups indicated by the hierarchical cluster analysis (Fig. 4B). Taxa with a cumulative contribution of more than 50% are indicated in bold. Taxa abbreviations are shown in Table 3.

| Group A | Group B | Group C | Group D |
|---------|---------|---------|---------|
| Fewer than 2 samples in group | Fewer than 2 samples in group | Fewer than 2 samples in group | Less than 2 samples in group |
| **Contrib (%) Cum (%)**<br>Average dissimilarity: 20.29 % (Global R=0.986. P=0.056) | **Contrib (%) Cum (%)**<br>Average dissimilarity: 27.18 % (Global R=1. P=0.063) | **Contrib (%) Cum (%)**<br>Average dissimilarity: 22.82 % (Global R=0.974. P=0.056) |
| **Mys** 22.92 22.92 | **Mys** 18.43 18.43 | **Mys** 21.97 21.97 |
| **Ech** 16.72 39.64 | **Ost** 16.06 34.49 | **Ost** 19.73 41.7 |
| **Amp** 16.13 55.77 | **Amp** 14.29 48.77 | **Amp** 17.04 58.74 |
| **Gas** 13.62 69.4 | **Gas** 12.08 60.85 | **Gas** 15.73 74.47 |
| **Dec** 8.53 77.92 | **Dec** 7.61 68.46 | **Gas** 14.4 88.87 |
| **Ost** 5.07 82.99 | **Ech** 6.24 74.7 | **Sip** 3.22 92.09 |
| **Cir** 3.87 86.87 | **Dol** 4.47 79.17 | **Chi** 3.21 86.8 |
| **Cha** 2.73 89.59 | **Pol** 4.42 83.59 | **Sip** 2.66 89.47 |
| **Pol** 2.58 92.18 | **Sip** 2.64 92.11 |
| **Average Similarity**: 91.50 % | **Average Similarity**: 91.50 % | **Average Similarity**: 91.50 % | **Average Similarity**: 91.50 % |
| **Contrib (%) Cum (%)**<br>Average dissimilarity: 15.06 % (Global R=0.703. P=0.01) | **Contrib (%) Cum (%)**<br>Average dissimilarity: 17.24 % (Global R=0.974. P=0.056) |
| **Cla** 15.41 15.41 | **Cla** 15.41 15.41 |
| **Cop** 12.60 28.01 | **Cop** 12.60 28.01 |
| **App** 11.28 39.29 | **App** 11.28 39.29 |
| **Dol** 10.90 50.19 | **Dol** 10.90 50.19 |
| **Sip** 8.93 59.12 | **Sip** 8.93 59.12 |
| **Med** 8.52 67.64 | **Med** 8.52 67.64 |
| **Ech** 7.59 75.23 | **Ech** 7.59 75.23 |
| **Ost** 7.01 82.24 | **Ost** 7.01 82.24 |
| **Cha** 6.64 88.88 | **Cha** 6.64 88.88 |
| **Dec** 5.61 94.49 | **Dec** 5.61 94.49 |
| **Average Dissimilarity**: 14.48 % (Global R=0.646. P=0.063) | **Average Dissimilarity**: 14.48 % (Global R=0.646. P=0.063) |
| **Contrib (%) Cum (%)**<br>Average dissimilarity: 89.72 % | **Contrib (%) Cum (%)**<br>Average dissimilarity: 89.72 % |
| **Cla** 16.73 16.73 | **Cla** 16.73 16.73 |
| **Cop** 14.37 31.1 | **Cop** 14.37 31.1 |
| **App** 12.29 43.39 | **App** 12.29 43.39 |
| **Sip** 11.97 55.36 | **Sip** 11.97 55.36 |
| **Dol** 10.13 65.49 | **Dol** 10.13 65.49 |
| **Med** 9.42 65.92 | **Med** 9.42 65.92 |
| **Cir** 7.48 82.39 | **Cir** 7.48 82.39 |
| **Cha** 7.07 89.45 | **Cha** 7.07 89.45 |
| **Dec** 6.79 96.24 | **Dec** 6.79 96.24 |
| **Average Dissimilarity**: 91.89 | **Average Dissimilarity**: 91.89 |
| **Contrib (%) Cum (%)**<br>Average dissimilarity: 89.72 % | **Contrib (%) Cum (%)**<br>Average dissimilarity: 89.72 % |
| **Cla** 16.73 16.73 | **Cla** 16.73 16.73 |
| **Cop** 14.37 31.1 | **Cop** 14.37 31.1 |
| **App** 12.29 43.39 | **App** 12.29 43.39 |
| **Sip** 11.97 55.36 | **Sip** 11.97 55.36 |
| **Dol** 10.13 65.49 | **Dol** 10.13 65.49 |
| **Med** 9.42 65.92 | **Med** 9.42 65.92 |
| **Cir** 7.48 82.39 | **Cir** 7.48 82.39 |
| **Cha** 7.07 89.45 | **Cha** 7.07 89.45 |
| **Dec** 6.79 96.24 | **Dec** 6.79 96.24 |
### Appendix 2 – Sample scores which are linear combinations of environmental variables.

| Sampling Station | Axis 1    | Axis 2    | Axis 3    | Axis 4    |
|------------------|-----------|-----------|-----------|-----------|
| 1 ST0102         | -0.8411   | -0.5768   | 0.3497    | 0.0000    |
| 2 ST0202         | -0.9135   | -0.4763   | -0.7983   | 0.0000    |
| 3 ST0302         | -0.1902   | 0.0178    | 25.070    | 0.0000    |
| 4 ST0402         | -0.4984   | -11.283   | -0.2767   | 0.0000    |
| 5 ST0502         | -0.9059   | -0.6397   | -0.4054   | 0.0000    |
| 6 ST0602         | -10.944   | 0.1859    | -14.292   | 0.0000    |
| 7 ST0702         | -11.123   | 0.7544    | -12.995   | 0.0000    |
| 8 ST0802         | -0.2537   | 0.5127    | -10.020   | 0.0000    |
| 9 ST0902         | -11.055   | 0.3737    | -0.5790   | 0.0000    |
| 10 ST1002        | -15.789   | 23.624    | -0.8948   | 0.0000    |
| 11 ST1102        | -0.5673   | 0.1631    | -13.868   | 0.0000    |
| 12 ST1202        | -0.0967   | 0.4432    | 14.408    | 0.0000    |
| 13 ST1302        | -10.722   | 0.2064    | 0.7571    | 0.0000    |
| 14 ST1402        | -10.931   | -0.4368   | -0.0023   | 0.0000    |
| 15 ST1502        | -11.154   | -13.828   | 0.3497    | 0.0000    |
| 16 ST1602        | -0.9109   | -11.220   | 10.375    | 0.0000    |
| 17 ST1702        | -0.8897   | -12.741   | 0.6717    | 0.0000    |
| 18 ST1003        | 10.388    | -0.2370   | -0.8713   | 0.0000    |
| 19 ST0203        | 0.4060    | -0.2388   | 0.1755    | 0.0000    |
| 20 ST0303        | 14.875    | -0.6614   | 0.8881    | 0.0000    |
| 21 ST0403        | 0.7248    | -0.5517   | 13.264    | 0.0000    |
| 22 ST0503        | 12.157    | -0.4431   | -14.167   | 0.0000    |
| 23 ST0603        | 0.1046    | 0.6280    | -0.7349   | 0.0000    |
| 24 ST0703        | 10.942    | 12.159    | -0.8678   | 0.0000    |
| 25 ST0803        | 21.468    | 11.963    | 0.1212    | 0.0000    |
| 26 ST0903        | 0.4371    | 0.8049    | 13.587    | 0.0000    |
| 27 ST1003        | 0.1616    | 34.563    | 14.138    | 0.0000    |
| 28 ST1103        | 0.0236    | -0.3742   | 0.0612    | 0.0000    |
| 29 ST1203        | 0.2437    | 0.4425    | 0.4255    | 0.0000    |
| 30 ST1303        | 0.3189    | -0.2361   | 0.4735    | 0.0000    |
| 31 ST1403        | 18.935    | -0.3218   | -0.8472   | 0.0000    |
| 32 ST1503        | 19.689    | -0.8876   | -13.035   | 0.0000    |
| 33 ST1603        | 0.4317    | -11.246   | -0.3015   | 0.0000    |
| 34 ST1703        | 0.5417    | -0.6505   | 10.894    | 0.0000    |

### Appendix 3 – Cumulative fit per taxon as fraction of variance of species in the redundancy analysis. Taxa with higher correlation (0.25<) with Axis 1 and 2 are marked in bold.

| Taxa             | Ax1     | Ax2     | Ax3     | Ax4     | Var (y) | % Expl |
|------------------|---------|---------|---------|---------|---------|--------|
| Cladocera        | 0.2669  | 0.2830  | 0.3658  | 0.5322  | 0.29    | 36.58  |
| Copepoda         | 0.1782  | 0.1833  | 0.1981  | 0.3547  | 0.12    | 19.81  |
| Appendicularia   | 0.2311  | 0.2461  | 0.3727  | 0.5473  | 0.15    | 37.27  |
| Chaetognatha     | 0.0505  | 0.0537  | 0.1364  | 0.1415  | 0.38    | 13.64  |
| Siphonophora     | 0.1264  | 0.1277  | 0.1623  | 0.1925  | 0.36    | 16.23  |
| Medusae          | 0.1423  | 0.1527  | 0.1888  | 0.2908  | 0.21    | 18.88  |
| Decapoda         | 0.0055  | 0.2294  | 0.2446  | 0.3334  | 0.78    | 24.46  |
| Cirripedia       | 0.0000  | 0.0345  | 0.1562  | 0.1562  | 1.11    | 15.62  |
| Amnelida         | 0.1719  | 0.1251  | 0.1951  | 0.1967  | 1.74    | 19.67  |
| Echinodermat     | 0.1877  | 0.3616  | 0.3664  | 0.8367  | 2.87    | 36.64  |
| Ostracoda        | 0.5890  | 0.5922  | 0.5951  | 0.8444  | 3.72    | 59.51  |
| Dollolidae       | 0.3691  | 0.3716  | 0.4695  | 0.6237  | 0.55    | 46.95  |
| Mysidaceae       | 0.0755  | 0.2447  | 0.2689  | 0.3017  | 0.87    | 26.89  |
| Amphipoda        | 0.0628  | 0.1758  | 0.1870  | 0.2031  | 1.14    | 18.70  |
| Gasteropoda      | 0.1397  | 0.2272  | 0.2508  | 0.2509  | 0.73    | 25.08  |