



Mesozooplankton in a stressed area of the Nile Delta Coast, Egypt.

Mohamed Dorgham^{1*}, Wael El-Tohamy², Jian Qin³, Nagwa Abdel-Aziz⁴ and
Ahmed El-Ghobashy²

1- Oceanography Department, Faculty of Science, Alexandria University, Egypt.

2- Zoology Department, Faculty of Science, Damietta University, Egypt.

3- School of Biological Sciences, Flinders University, Adelaide SA, Australia.

4- National Institute of Oceanography and Fisheries, Alexandria, Egypt.

*Corresponding author: mdorgham1947@yahoo.com,

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ABSTRACT

The mesozooplankton was studied biweekly for one year in a part of the Nile Delta coast laying under the stress of different human activities. The study recorded 59 species amounted totally to an average of 59.7×10^3 orgm/m³. Copepods were the highest diverse group (25 species), constituting 86.4% of the total mesozooplankton count. The other holoplankton groups were poorly represented and collectively formed 5% in addition to 8.6% for meroplankton. The community structure and numerical abundance experienced pronounced spatial and temporal variations relative to the surrounding environmental conditions. The Shannon index and dominance index were low over the whole area, while the evenness index appeared high. Salinity seems to be the essential factor that controls the distribution of the different groups, but other environmental parameters were also encountered. The nauplii larvae of copepods were the major mesozooplankton component, while a few species displayed clear abundance and were responsible for the abundance of the adult forms.

INTRODUCTION

Zooplankton can be used as “bioindicators” for water pollution (Oliver, 1996), changes in marine ecosystems (Falcão *et al.* 2012), and the effect of human activities (Leonardo *et al.* 2009; Vadadi-Fülöp *et al.* 2009). This because they have substantial different structure (Havens and Hanazato, 1993; Gyllström *et al.* 2005), different life cycles (Jakhar, 2013), and they are of high susceptibility to the environmental changes (Neto *et al.* 2014). The plankton analysis helps in explaining the cause of color, turbidity, presence of odor, taste and visible particles in water (Vaidya, 2017).

During the past two decades, the zooplankton in the Egyptian Mediterranean waters has drawn great attention, particularly along the Alexandria coast (e.g. Abdel-Aziz, 2006; Abdel Aziz *et al.* 2006; Zakaria, 2006, 2007, 2014, 2015; Abou-Zaid *et al.* 2014; Aboul-Ezz *et al.*, 2014a; Abo-Taleb, 2014; Heneash, 2015; Abo-Taleb *et al.* 2016). Some studies were done on other parts of the Egyptian Mediterranean Coast (e.g. Aboul Ezz *et al.* 2014b; Zakaria *et al.* 2016, 2018). The total zooplankton was also studied in different parts of the coastal waters off the Nile Delta (El-Tohamy, 2005, 2012, 2015; Abdel Aziz *et al.* 2007; Dorgham *et al.* 2009, 2013; El-Tohamy *et al.* 2012, 2017, 2018, 2019). All the previous studies were restricted to localised areas

or concerned with certain groups, and based mainly on seasonal samples. The present study was carried out at short time intervals, aiming to follow the biweekly structure and abundance of mesozooplankton community along a part of the Nile Delta coast relative to the surrounding environmental conditions for a complete year.

MATERIALS AND METHODS

The area of study

The concerned area extends along the Damietta coast on the south eastern Mediterranean Sea between 31°10 and 32°05 E and 31°20 and 31°35 N. This area is an important part of the Egyptian Mediterranean Coast, because it is directly affected by freshwater discharge from Damietta branch of the River Nile. It also receives different effluents of domestic, industrial, and agricultural wastes, and is influenced by fishing industry and fish farming in the surrounding land. The present study was carried out at five stations, representing different ecological entities (Fig. 1).

Station I: lies at the connection between Manzalah lagoon and the Mediterranean Sea, and is affected directly by the fresh water of Damietta Branch, domestic wastes, industrial wastes from a sardine factory, and wastes from fish ponds.

Station II is located at the connection between the Damietta Harbour and Mediterranean Sea, and is influenced by sewage and agricultural wastes, chemical fertilizers, and wastes from methanol production and liquefaction of natural gas.

Station III lies west to the River Nile Branch at Isbet Setta and receives great volume ($6 \times 10^6 \text{ m}^3$ /day) of untreated agricultural, industrial and sewage discharge from the City of New Damietta.

Station IV is located at the mouth of Gamsa Drain, which receives about $13.1 \times 10^6 \text{ m}^3$ /day of untreated sewage and agricultural waste waters from the Talkha fertilizers factory.

Station V lies at the mouth of El-Kasara Drain, receiving approximately $8.6 \times 10^6 \text{ m}^3$ /day of industrial, agricultural, and sewage wastes, in addition to the waste water of the surrounding fish ponds.

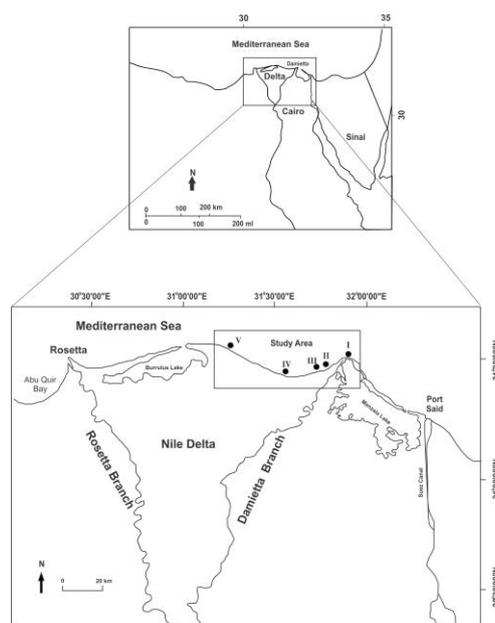


Fig.1: Map of the study area showing the positions of the sampling stations.

Zooplankton collection

Zooplankton samples were collected by filtering 100 litres of seawater through a plankton net of 55 μm mesh size. The filtered samples were concentrated to 100 ml volume and preserved in 5% neutralized formalin solution. The mesozooplankton was identified mostly to species level, following the known taxonomic references. The standing crop was estimated from the mean count of three sub samples of 5 ml and expressed as organisms/ m^3 .

Diversity Indices:

The zooplankton diversity was assessed by calculation of some indices, like Shannon Diversity index, Evenness index, and Dominance index, following Hossain *et al.* (2017).

Statistical analysis

ANOVA and Correlations were performed using SPSS 18. The spatial environmental status of the five sampling stations was summarized using Principle Component Analysis (PCA) ordination. Canonical Correspondence Analysis (CCA) was performed to assess the association of zooplankton species with environmental factors. A Monte Carlo test was used to evaluate the significance of canonical axes and the environmental variables by using 999 unrestricted permutations (Sousa *et al.* 2008). Software package CANOCO version 4.5 was used for both PCA and CCA analyses.

RESULTS

Physical chemical parameters:

The environmental parameters of the concerned area were measured concurrently with the data of the present study (Dorgham *et al.* 2019). As shown in Table 1, the area of the present study comprised water masses with pronouncedly different environmental characteristics which would influence the structure and abundance of mesozooplankton.

Table 1: Hydrographic conditions and nutrients along the study area (After Dorgham *et al.* 2019)

	Site I	Site II	Site III	Site IV	Site V
Temp.	22.1 \pm 5.26	22.17 \pm 5.14	22.17 \pm 5.17	22.3 \pm 5.1	22.27 \pm 5.29
Salinity (‰)	25.03 \pm 6.26	16.43 \pm 9.61	18.55 \pm 7.58	1.37 \pm 1.86	4.02 \pm 1.02
pH	7.9 \pm 0.16	7.98 \pm 0.2	7.73 \pm 0.2	7.59 \pm 0.21	7.74 \pm 0.2
DO	6.37 \pm 1.5	7.35 \pm 2.07	5.56 \pm 1.94	2.63 \pm 1.77	4.42 \pm 3.15
Turbidity	18.59 \pm 24.84	3.86 \pm 3.49	44.84 \pm 36.02	34.65 \pm 11.89	32.32 \pm 10.61
Silicate	52.28 \pm 68.52	39.66 \pm 25.47	106.3 \pm 90.08	149.26 \pm 66.96	255.84 \pm 80.18
Nitrate ($\mu\text{M/L}$)	0.42 \pm 0.36	0.83 \pm 0.74	1.08 \pm 0.81	9.71 \pm 5.61	3.42 \pm 2.76
Nitrite ($\mu\text{M/L}$)	0.24 \pm 0.24	0.57 \pm 0.69	0.76 \pm 0.66	7.46 \pm 4.99	2.63 \pm 2.40
Ammonia	0.27 \pm 0.36	1.07 \pm 1.32	4.27 \pm 3.63	31.14 \pm 21.99	4.05 \pm 3.29
Total phosphorus	11.72 \pm 21.41	14.45 \pm 25.48	16.71 \pm 26.34	14.96 \pm 22.51	16.72 \pm 24.15
Chlorophyll a	7.04 \pm 10.38	12.55 \pm 9.67	8.12 \pm 6.63	8.77 \pm 4.29	80.56 \pm 49.73

Mesozooplankton diversity

The present study identified 59 mesozooplankton species, with more diverse copepods, and less diverse cladocerans, nematodes, and cnidarians (Table 2). The high salinity stations (I, II, III) hosted 40-41 species, while the low salinity stations (IV and V) hosted 29 species (Fig. 2), displaying biweekly variation, with the highest number in spring and the lowest in autumn (Fig. 4).

The Shannon-Weaver index (H') reflected low diverse mesozooplankton in the area of study, attaining close annual average (1.57, 1.67, 1.44, 1.56 and 1.87 respectively) at all the sampling stations (Fig. 3) and experienced temporal fluctuation at each station, with high values during winter and spring and clearly low value during autumn (Fig. 4).

Table 2: The richness of mesozooplankton groups.

Group	Sp.No.	Group	Sp.No.
Cnidarian	5	Amphipods	4
Nematodes	6	Mysidacean	2
Pteropoda	1	Cumacean	1
Copepods	25	Chaetognaths	1
Cladocerans	10	Larvacean	2
Ostracods	2	Total	59

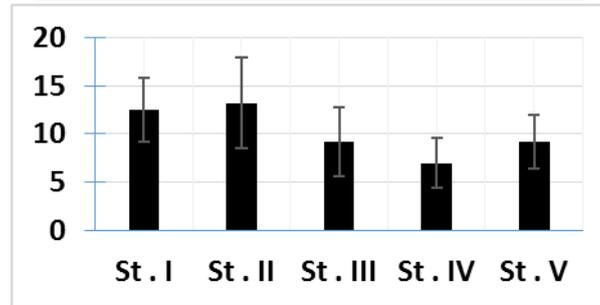
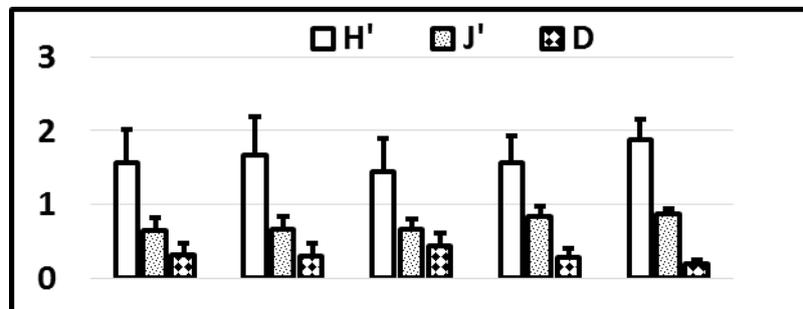
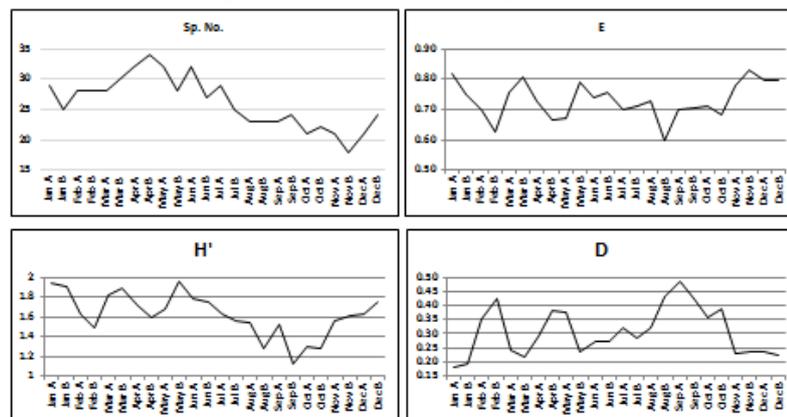


Fig. 2: Mean and standard deviation of species number of mesozooplankton at the sampling stations.

Fig. 3: Mean and standard deviation of diversity index (H'), evenness (J') and dominance index (D) of mesozooplankton at the sampling stations.

The evenness index (J') was high and showed approximately similar patterns of spatial and temporal variations to those of diversity index, but with different ranges of variation. As shown in Figure 3, comparatively higher evenness was observed at the low salinity (0.82 - 0.86) than those at the high salinity (0.64 - 0.66), while in winter and spring it was higher than in summer and autumn (Fig. 4). The dominance index (D) was generally low, with annual mean fluctuated between 0.19 at station V and 0.43 at station III (Fig. 3), with high values during February, May and September, and relatively low values during most of the year (Fig. 4).

Fig. 4: Biweekly variation of diversity index (H'), evenness index (E) and dominance index (D) of mesozooplankton at the sampling stations.

The mesozooplankton count displayed great fluctuation over the area of study (3.0×10^3 - 631.3×10^3 orgm/m³), attaining an annual average of 59.7×10^3 orgm/m³. Figure 5 illustrates that station II hosted the maximum count (129.2×10^3 orgm/m³) and station IV hosted the minimum count (15.6×10^3 orgm/m³). The biweekly abundance recorded three distinguished peaks during March, April-May and June (Fig. 6).

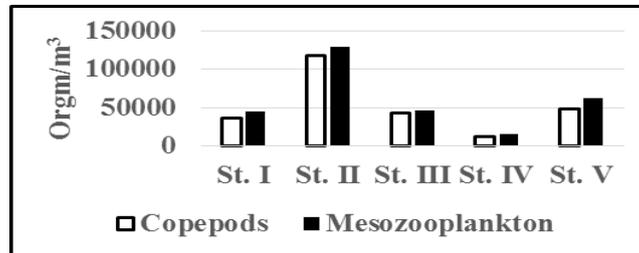


Fig. 5: The annual average count of total mesozooplankton and copepods at the sampling stations.

Copepods dominated the total mesozooplankton count by 86.4%, while all other holoplankton groups formed 5 % and meroplankton 8.6%. However, the role of these components appeared different at the sampling stations, whereas copepods formed 91.0 and 91.4% of the total mesozooplankton at the high salinity stations (II, III), decreased to 82.2 and 80.4 at stations I and IV, and reached the minimum (77.6%) at station V. Meanwhile, copepods abundance displayed similar pattern to that of the total mesozooplankton on the spatial scale (Fig. 5), as well as the temporal scale (Fig. 6). The nauplii larvae were responsible for 70.5% - 78% of copepod population at the sampling stations, while copepodite stages formed 3.7% - 11.9%.

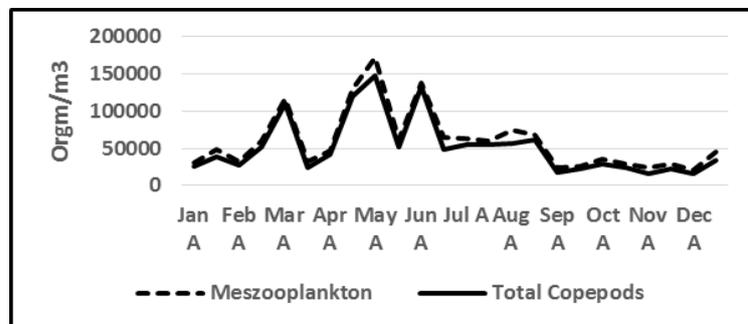


Fig. 6: Biweekly count of mesozooplankton and total copepods in the study area.

The adult copepods demonstrated pronouncedly small contribution, but the three major copepod groups had different contributions. The cyclopoids constituted 75.0% of the adults count, against 6.1% for calanoids and 18.9 % for harpacticoids. As shown in Figure 7, cyclopoids attained pronouncedly higher counts at stations I, II and V than at stations III and IV, but harpacticoids recorded the highest count at station II, high count at stations I and V, and dropped at stations IV. In the meantime, calanoids sustained mostly low count. The abundance cycle showed different patterns for the three groups, including three peaks for cyclopoids, four peaks for harpacticoids and one peak for calanoids, all in different timing (Fig. 8).

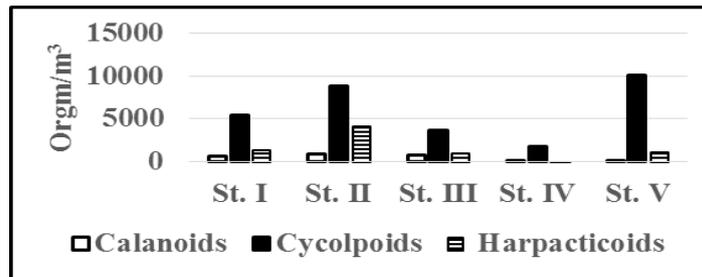


Fig. 7: The annual average count of major adult groups at the sampling sites.

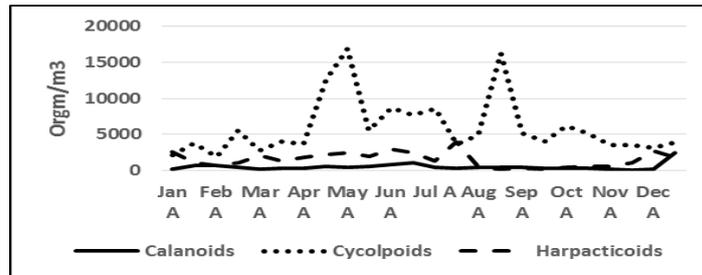


Fig. 8. Biweekly abundance of the adult copepod groups in the study area.

Oithona nana (Giesbrecht, 1893) was the most abundant adult cyclopoid (55.4 - 62.5%) at the high salinity stations, dropped to 18.5% and 1.2% respectively at the low salinity stations. Similarly, other species showed relatively more active contribution at the high salinity than at the low salinity, like the cyclopoids *Oithona plumifera* (Baird, 1843), *Ergasilus sieboldi* (Nordmann, 1832), the harpacticoids *Nitokra lacustris* (Schmankevitch, 1875), *Euterpina acutifrons* (Dana, 1847), and the calanoid *Paracalanus parvus* (Claus, 1863). At the low salinity, the fresh water cyclopoids *Halicyclops magniceps* (Lilljeborg, 1853) formed 33.3 - 34.6% of the adult copepods, followed by 31.7 - 32.9% for *Acanthocyclops americanus* (Sars, 1863) and 6.5 - 19.5% for *Cyclops vernalis* (Fischer, 1853).

Other crustacean groups, including cladocerans, ostracods, and amphipods accounted totally for 2.6% of the total mesozooplankton. Cladocerans were abundant and persistent, particularly at the low salinity stations, mainly due to *Moina micrura* (Kurz, 1875). which attained a maximum of 21818 orgm/m³ (18% of total mesozooplankton) in early May at station V.

The ostracods were represented mainly by *Cypraea* sp. and *Candona* sp., and persisted at stations II, IV and V. *Cypraea* sp. frequently attained high counts (2000 - 2727 orgm/m³) over the year, particularly at station V. Amphipods were missed from the area most of the year, except in a few occasions, recording the highest count (1637 - 2424 orgm/m³) during March and early April at station II.

The planktonic crustacean groups displayed different frequency of occurrence relative to the total number of collected samples during the period of study. As shown in Table 3, cyclopoids appeared as the most persistent component, existing at all sampling stations over the whole year. Harpacticoids were observed in 83.3 % - 100 % at most stations, decreased to 45.8% at station IV, while calanoids were persistent (100%) at stations I and II, less persistent (83.3 %) at stations III, and became less frequent (20.8% and 8.3%) at stations IV and V respectively. The other crustacean groups showed less persistence, with variable percentage of frequency at the sampling stations (Table 3). Cladocerans were more persistent (66.7% - 87.5%) at the low salinity stations, and comparatively less persistent at the high salinity, meanwhile ostracodes displayed irregular persistence regardless to the salinity distribution in the study area. Furthermore, cnidarians, pteropods and larvaceans were restricted to the

high salinity, but nematodes showed high percentage of frequency at all the sampling stations, with higher percentage at the low salinity stations (Table 3).

Since the crustaceans were the major component of the mesozooplankton, the TWINSPLAN analysis based on a data set of 120 samples (Fig. 9) containing all crustaceans in the study area. This analysis displayed four significantly different groups (A-D) at level 2 of the sample hierarchy.

Group A: comprises 20 samples, mostly from station V and indicated by *Onychocamptus mohammed* (Blanchard & Richard, 1891) and *Canthocamptus glacialis* (Lilljeborg, 1902) These samples are subdivided into two groups, A. *americanus* that indicated the negative one and *Arctodiaptomus saltellinus* (Brewer, 1898) indicating the positive and mostly at station V.

Group B: includes 32 samples, 22 of them belong to station IV and indicated by *Cyclops vernalis*, *Bosmina longirostris* (O.F.Müller, 1785), and *Ceriodaphnia reticulata* (Jurine, 1820), the indicator species of groups A and B are freshwater species.

Group C: comprised 43 samples, 15 of them from station III and 17 from station I. The indicator species was *Centropages kroyeri* (Giesbrecht, 1892 (F,M), and *O. plumifera*.

Group D: comprised 25 samples, which mostly belong to station II, with *O. plumifera*, *E. acutifrons*, *Acartia clausi* (Giesbrecht, 1889), *N. lacustris*, and *Gammarus aequicauda* (Martynov, 1931) as indicator species.

Table 3: The frequency of occurrence (%) and the mean abundance ($\times 10^3$ orgm/m³) of different crustaceans at the sampling stations.

<i>Taxa</i>	I	II	III	IV	V	Total
Calanoida	100 (0.665)	100 (0.857)	83.3 (0.79)	20.8 (0.044)	8.3 (0.042)	62.5
Cyclopoida	100 (5.47)	100 (8.777)	100 (3.644)	100 (1.732)	100 (10.088)	100
Harpacticoida	91.7 (1.274)	100 (4.114)	95.8 (0.878)	45.8 (0.103)	83.3 (1.026)	83.3
Cladocera	25 (0.063)	50 (0.42)	16.7 (0.17)	66.7 (0.79)	87.5 (3.26)	49.17
Ostracoda	58.3 (0.89)	75 (0.43)	33.3 (0.091)	54.2 (0.21)	87.5 (1.9)	61.7 (0.54)
Amphipoda	33.3 (0.034)	29.2 (0.26)	16.7 (0.017)	4.2 (0.0004)	0.0 (0.0)	16.7
Mysidacea	0.0 (0.0)	4.2 (0.0004)	0.0 (0.0)	0.0 (0.0)	4.2 (0.0004)	1.67
Cnidaria	37.5(0.057)	41.7 (0.18)	20.8 (0.06)	0.0 (0.0)	0.0 (0.0)	20 (0.068)
Nematoda	75 (0.74)	41.7 (0.26)	45.8 (0.37)	79.2 (1.37)	87.5 (3.39)	65.8 (1.23)
Pteropods	29.2 (0.24)	29.2 (0.053)	4.2 (0.008)	0.0 (0.0)	0.0 (0.0)	12.5 (0.06)
Chaetognatha	16.7 (0.02)	25 (0.43)	8.3 (0.008)	0.0 (0.0)	0.0 (0.0)	10 (0.014)
Larvacea	33.3 (0.08)	41.7 (0.086)	41.7 (138.9)	4.2 (0.008)	4.2 (0.26)	25 (0.068)
Polychaetes	91.67*(2.23)	95.83*(3.69)	91.67*(1.72)	70.83*(0.24)	87.5*(4.7)	87.5*(48.9)
Bivalve	83.3*(17.96)	70.8*(3.32)	66.7*(4.53)	20.8*(1.36)	4.2*(2.42)	40.2*(35.3)
Cirripedes lar.	83.3*(24.8)	75.0*(57.64)	70.8*(7.55)	37.5(0.88)	25.0(0.0004)	58.3*(11.5)
Other	3.0(1.8)	2.0 (0.9)	2.0 (5.5)	3.0 (30.8)	2.5 (9.6)	2.5(4.27)

The multivariate analysis

The DCA recorded a maximum of 2.56, suggesting either linear or unimodal relationship between crustaceans and environmental parameters. The results of CCA analysis indicated that the environmental parameters had a significant influence on crustaceans distribution (*F-ratio* = 4.954, *P*<0.001), explaining 48.5% of the total variance. The Monte Carlo test revealed that seven environmental parameters had significant influences on the distribution of crustacean species, with more pronounced effect of salinity, chlorophyll *a*, and temperature (Table 4).

Table 4: Results of forward selection and Monte Carlo permutation Tests from CCA.

Physiochemical parameters	Lambda-A	P-value	F-ratio
Salinity	0.28	0.001	28.28
Chlorophyll <i>a</i>	0.07	0.001	7.42
Temperature (°C)	0.03	0.001	2.86
NO ₃	0.01	0.005	2.06
PO ₄	0.02	0.004	1.97
SiO ₃	0.02	0.002	2.14
Turbidity	0.02	0.012	1.82
NH ₄	0.01	0.066	1.49
pH	0.01	0.287	1.13
DO	0.01	0.553	0.94
NO ₂	0.01	0.891	0.64

As shown in Figure 10, amphipods and about 56 % of copepods were found in the right half of the ordination diagram where the gradients of salinity, DO, pH, the lowest nutrients and chlorophyll *a* were demonstrated, especially at stations I, II, and III. On the other hand, ostracods and about 78% of cladocerans were associated mainly with the low salinity, the gradients of nutrients and phytoplankton biomass at stations IV and V. *Clytemnestra scutellata* (Dana, 1847), *Cyclops minutus* (Claus, 1863) *C. vernalis*, *Moina micrura*, *Candona* sp., and *Cyprea* sp. were associated with the gradients of silicate and phytoplankton biomass, especially at station V.

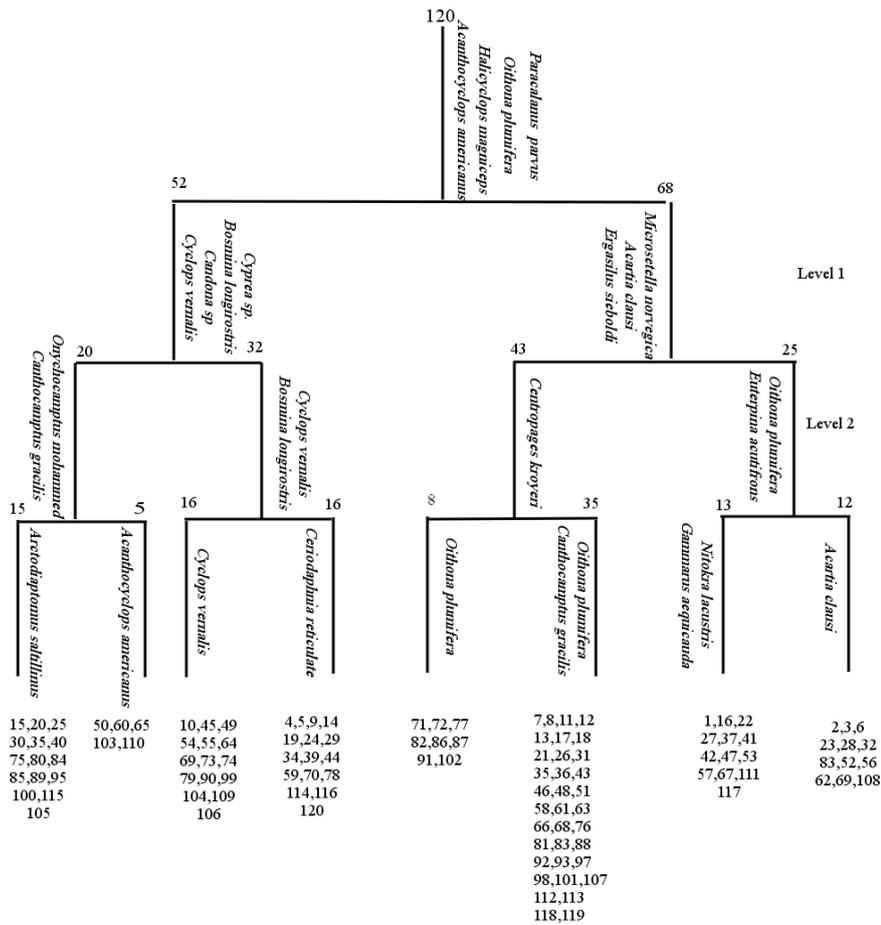


Fig. 9: TWINSpan dendrogram of 120 samples based on density in the study area. Indicator species are shown at each level of classification. Four groups (A-D) are shown at level 2.

The vector of turbidity found between the sample units of stations IV and V; the cyclopoid *A. americanus* and *H. magniceps*, and the cladoceran *Euryalona occidentalis* (Sars, 1901) were associated with turbidity. The cladocerans *B. longirostris* and *Ceriodaphnia cornuta* (Sars, G.O., 1885) accompanied the highest nitrogen concentrations and the lowest salinity at station IV. The species which close to the point of the origin (0.0) of the diagram (*N. lacustris* and copepod nauplii and copepodides) indicated their wide distribution in the study area. Most of the other species like *A. clausi*, *Acartia grani* (Sars, G.O., 1904), *E. acutifrons*, *Microsetella norvegica* (Boek, 1865), *O. nana*, *O. plumifera*, *P. parvus*, and *G. aequicauda* were associated with the highest salinity, low nutrients and phytoplankton biomass.

Beside the crustaceans, some other mesozooplankton groups were found in the coastal water of the Nile Delta, namely cnidarians, nematodes, pteropods, larvaceans and chaetognaths, with greatly variable counts (Table 3). Nematodes were abundant and persistent at most stations, with counts up to 17,272 orgm/m³, particularly at station V. However, the nematodes population was pronouncedly poorer at the high salinity (annual average: 261 – 740 orgm/m³) than at the low salinity (annual average: 1,383 – 3,393 orgm/m³). *Anonchus* sp. and *Dorylaimus* sp. were the most abundant nematodes over the whole area of study, with clearly higher counts at the low salinity. *Anonchus* sp. was persistent at the high salinity station I as well as at the low salinity stations, while *Dorylaimus* sp. and *Ethmoliemus* sp. were abundant at the low salinity. The highest peak of nematodes occurred in May at station V, forming 14.3% of the total metazooplankton, due to the abundance of *Anonchus* sp., *Ethmoliemus* sp., and *Dorylaimus* sp. respectively.

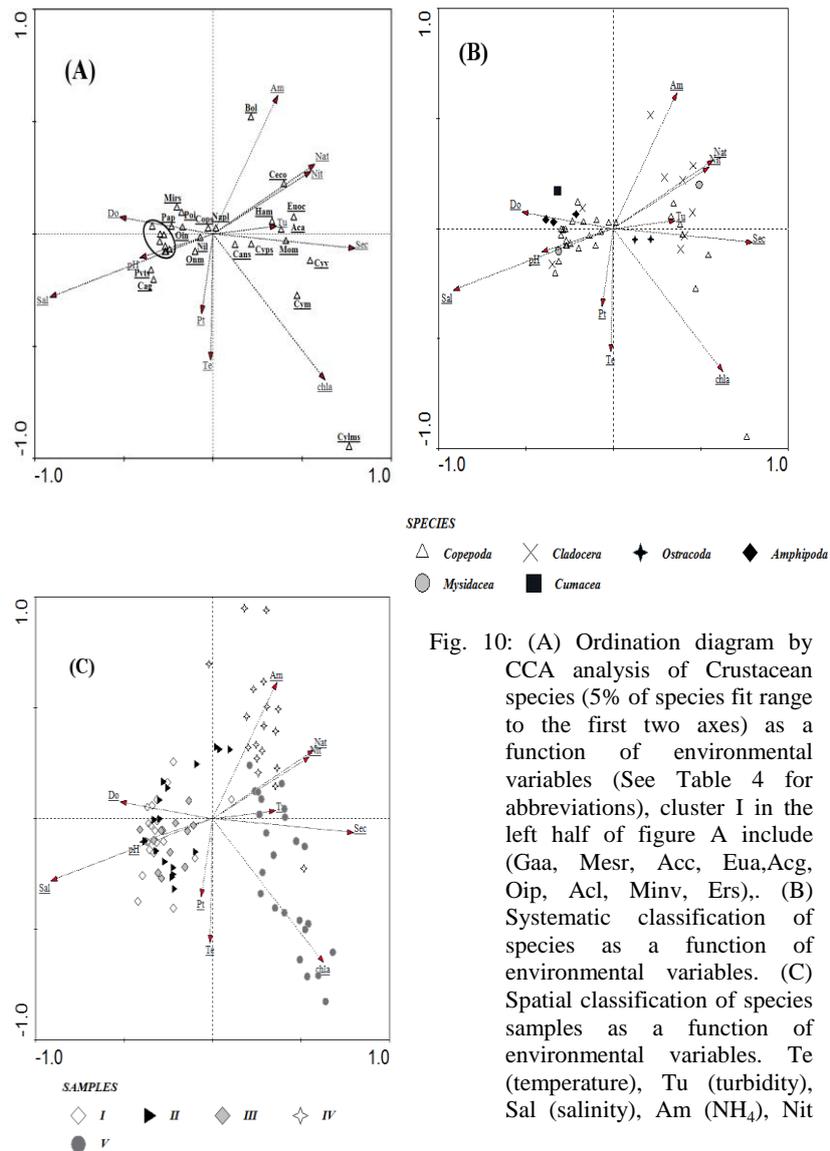


Fig. 10: (A) Ordination diagram by CCA analysis of Crustacean species (5% of species fit range to the first two axes) as a function of environmental variables (See Table 4 for abbreviations), cluster I in the left half of figure A include (Gaa, Mesr, Acc, Eua, Acg, Oip, Acl, Minv, Ers),. (B) Systematic classification of species as a function of environmental variables. (C) Spatial classification of species samples as a function of environmental variables. Te (temperature), Tu (turbidity), Sal (salinity), Am (NH₄), Nit

Larvaceans were represented by *Oikopleura dioica* (Lohmann, 1933) and *Appendicularia sicula* (Fol, 1874), with clear abundance of the former species (up to 606 orgm/m³), particularly at the high salinity stations (I-III) during spring and summer. Cnidarians occurred intermittently at high salinity stations, reaching a maximum of 1,414 orgm/m³ in early June at station II. The planktonic pteropod molluscs comprised only *Limacina inflata* (d'Orbigny, 1834) which appeared only at the high salinity station I, attaining relatively high count (up to 1818 orgm/m³) from August to early October. One species only of Chaetognatha, *Parasagitta friderici* (Ritter-Zahony, 1911) occurred intermittently in low counts at the high salinity stations, increased to 404 orgm/m³ in early July at station II.

The meroplankton displayed relatively low contribution (8.6%) to the total mesozooplankton in the study area, with the highest percentage (14.8%) at station I, and the lowest role (4.3%) at station IV. Polychaetes larvae comprised 48.9% of the total meroplankton, followed by lamellibranch veligers (35.3%) and Cirripedes larvae (11.5%). Figure 11 illustrates that polychaetes larvae had smaller role at stations I, II and IV, as compared to stations III and V, while lamellibranch veligers displayed less active role at stations IV and III than at stations I and II, and completely disappeared at station V. In the meantime, cirripedes larvae showed the highest contribution at stations I and IV, and became less abundant at stations II, III and V. It is to be noticed that active role was observed for insects (19.2%) and fasciola (10.0%) at station IV.

The meroplankton demonstrated different biweekly distribution along the study area, but the larvae of polychaetes and lamellibranchs followed the distributional pattern of the total meroplankton, while cirripedes larvae displayed slightly different pattern (Fig. 12). The polychaetes larvae were the most frequent meroplanktonic group, occurring in 70.8 – 95.8% of the collected samples, while the larvae of both lamellibranchs veligers and cirripedes were pronouncedly less frequent, particularly at the low salinity stations (Table 3).

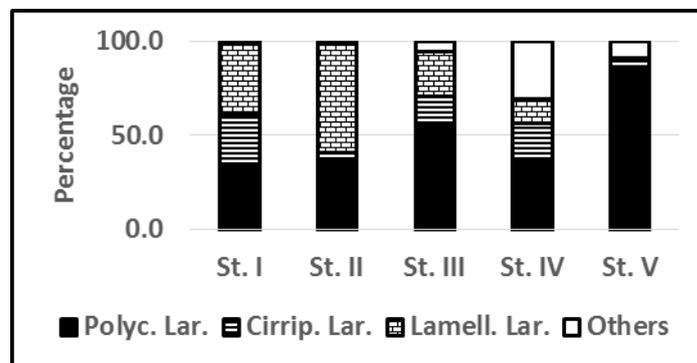


Fig. 11: Relative abundance (%) of the different meroplankton groups to the total meroplankton at the sampling stations.

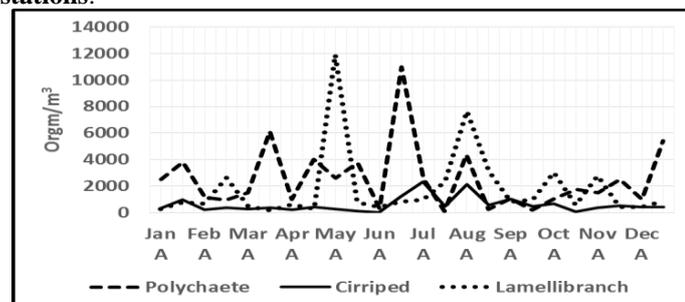


Fig. 12: Biweekly abundance of the total and major Meroplankton groups in the study area.

DISCUSSION

The present study recorded 59 mesozooplankton species in the coastal water of the Nile Delta. This number was pronouncedly higher than earlier records along the Damietta coast (El-Tohamy *et al.* 2017; El-Tohamy *et al.* 2019), but lower than those observed off the Nile Delta coast (Abdel-Aziz and Abu-El Ezz, 2003). The higher number of species during the present study may be attributed to the environmental differences among the sampling stations and the occurrence of several freshwater forms. Salinity played crucial role in the distribution of mesozooplankton species throughout the study area, as indicated from the positive significant correlation between the two parameters ($r= 0.4363$, $n: 120$, $p<0.05$). This was also clear from the preference of some species to the high salinity and others to low salinity. The high salinity species comprised *A. clausi*, *A. grani*, *A. latisetosa*, *C. kroyeri*, *Leptocaris brevicornis* (Douwe, 1904), *Mesochra rapiens* (Schmeil, 1894), *M. norvegica*, *Microsetella rosea* (Dana 1847), *Evadne* sp., *Podon intermedius* (Lilljeborg, 1853), *Elasmopus* sp., *Gammarus* sp., *Hyperia* sp., *Appendicularia* sp., and *Sagitta* sp. The low salinity species were represented by the cladocerans *C. cornuta*, *C. reticulata*, *Daphnia* sp., *Diaphanosoma* sp., *Euryalona* sp., and the calanoid *A. saltillinus*. This was in consistent with earlier observations which stated that salinity has been considered as the main environmental factor, pronouncedly affecting the structural and functional characteristics of aquatic biota in estuaries (Dorgham and Hussein, 1997; Marques *et al.* 2007, Telesh and Khlebovich (2010). Other environmental factors like turbidity, pH, DO, ammonia, nitrite, nitrate, and silicate appeared to be effective on the community structure, whereas significant correlations were observed between the environmental parameters and both the number of species and evenness of the mesozooplankton (Table 5).

Table 5: Pearson’s correlation coefficient between diversity indices of mesozooplankton community and environmental parameters.

	Sp. no.	H'	J'	D
Temp.	ns	- ^x	ns	ns
Turbidity	- ^{xxx}	ns	^{xx}	ns
Salinity	^{xxx}	ns	- ^{xxx}	^{xx}
pH	^{xx}	ns	- ^{xx}	ns
DO	^{x xx}	ns	- ^{xx}	ns
Ammonia	- ^{xx}	ns	ns	ns
Nitrite	- ^{xxx}	ns	^{xxx}	ns
Nitrate	- ^{xxx}	ns	^{xxx}	- ^x
Silicate	- ^{xx}	ns	^{xxx}	ns
Chl.	ns	^{xx}	^{xxx}	- ^{xx}

Correlation is significant at 0.001 (xxx), at the 0.01 (xx), at the 0.05 (x).

The variation of species diversity could be used as an index for the degree of environmental stress (Omori and Ikeda, 1984), as the pollution causes disappearance of sensitive species and high abundance of the most tolerant species (Gray *et al.* 1979), and moderate eutrophy or oligotrophy renders a higher diversity (Pejler, 1983). These statements support our findings in the study area, whereas a few species were responsible for the total mesozooplankton count, like *O. nana* at the high salinity and *H. magniceps*, *A. americanus* and *Cyclops vernialis* at the low salinity. This pattern was resulted in low diversity (1.44 -1.87), low dominance index (0.19 - 0.48) and high evenness (0.64 - 0.86). These situations could be attributed to the eutrophic conditions, which dominated in the area of study most of the year. The temporal

variation of evenness may be due to the predominance of some species in different times, the effect of food availability, and biotic relationships among the species (Takahashi *et al.* 2014). Although the area of the present study could be considered as stressed area, the dominance index was low, and showed significant positive correlation with salinity and significant negative correlation with chlorophyll. Such conditions may indicate that the high phytoplankton bloom was not favourable for the dominance of the majority of mesozooplankton species. The low Shannon index reflects the stress effect on zooplankton community (Mokhayer *et al.* 2017), which is highly susceptible to suspended sediments (Thorp and Mantovani, 2005).

The mesozooplankton abundance during the present study (59.7×10^3 orgm/m³) was higher than those in earlier records (El-Tohamy *et al.*, 2017; 2019). This could be explained by the high phytoplankton biomass, which is used as food for several copepods species in addition to the high contribution of some fresh water species. Similar observations were recorded in other areas (Bonecker *et al.* 2007; Serafim-Ju´nior *et al.* 2010). However, the mesozooplankton showed different correlations with the environmental parameters at the sampling stations (Table 6). Such pattern could be explained by the difference in the abundance of mesozooplankton and in community structure, as every species, particular the dominant ones, has its own response to the surrounding conditions.

Table 6: Pearson's correlation coefficient between mesozooplankton groups and the environmental parameters at the sampling stations.

	St I	St II	St III	St IV	St V
Salinity	ns	××	××	ns	ns
Turbidity	ns	ns	ns	ns	-×
pH	-××	××	ns	ns	ns
DO	-×××	ns	ns	-×	ns
NH ₄	-××	××	-×	ns	ns
Chl.	×	ns	-×	ns	-××

Correlation is significant at the 0.01 (×××), at 0.05 (××), at 0.1 (×).

The water temperature was accounted as essential factor in the dynamics of zooplankton, as it may regulate most ecological mechanisms in temperate areas (Sellami *et al.* 2010). Our findings revealed that water temperature had significant negative correlation with the diversity index, but it was not correlated with mesozooplankton count. However, the mesozooplankton count and species number were low during autumn and early winter at wide temperature range (12.5 - 25°C) and the highest during spring at a temperature range of 23 - 26 °C. Such pattern indicated that the high water mixing in the study area may be fundamental in temporal variations of mesozooplankton abundance and species number, rather than the temperature.

Copepods were pronouncedly less diverse and more abundant in the study area than those recorded in offshore Egyptian Mediterranean waters. Copepods are frequently dominant in most of the estuaries and coastal areas (Day *et al.* 1989), but with lower species richness (Goswami and Selvakumar, 1977). Although phytoplankton serve as essential food for many copepods (Fulton, 1984) no correlation was recorded between the two parameters during the present study.

The numerical abundance ranking (0.5: 5.9: 1.1) of the major copepod groups (calanoids, cyclopoids, and harpacticoids respectively) indicated the dominance of cyclopoids, and was close to that (1:3.5:1.1) recorded earlier in Damietta coast (El-

Tohamy, 2005). The dominance of cyclopoids in aquatic area was considered as indication of eutrophication (Waller *et al.* 2002; Santos-Wisniewski and Rocha, 2007). In addition, the ratios between some zooplankton groups (rotifers, copepods and cladocerans) are used to indicate the trophic condition of the water body, as these ratios are also affected by eutrophication (Sendacz *et al.* 2006; Bini *et al.* 2007), while certain cyclopoid species were used as indicators of water quality in tropical reservoirs (Silva, 2011).

The cladocerans distribution in our area was affected by salinity, as indicated from their significant negative correlation and the occurrence of three marine species at the high salinity and seven freshwater forms at the low salinity. In addition, this group showed significant negative correlation with DO, and significant positive correlation with chl. *a*. The cladocerans were dominated by the freshwater *M. micrura*, particularly at station V and *B. longirostris* at station IV. This is a common species in eutrophic waters and can be indicator of eutrophication (Wang *et al.* 2010).

It is well known that the abundance of meroplankton is usually associated with the numerical density and reproductive efficiency of the benthic animals. During the present study, meroplankton displayed significant positive correlation with both salinity and pH and significant negative correlation with turbidity. Polychaetes larvae were the abundant meroplankton group and widely distributed over the whole area regardless of the environmental differences among the sampling stations. This may be attributed to the ability of polychaetes to regulate the pollutants and resist the organic contaminants and pesticides (Dean, 2008) and their tolerance to polluted conditions (Croquer *et al.* 2016).

In contrast, the lamellibranchs veligers and cirripedes larvae exhibited significant positive correlation with salinity and pH, and significant negative correlation with turbidity (Table 7). This means that both groups are susceptible to the low salinity, and they can tolerate high turbidity. Jeffries (1964) stated that the filter feeding lamellibranchs were adversely affected by the high turbid water, and the abundant phytoplankton may have been responsible for delay reproduction of adult cirripedes.

Table 7: Non parametric Spearman's correlation between total meroplankton, main meroplanktonic larvae and environmental parameters.

	<i>Lamellibranch veliger</i>	<i>Polychaete larvae s</i>	<i>Cirripeds larvae</i>
Temperature	ns	ns	ns
Turbidity	-x	ns	-x
Salinity	xx	ns	xxx
pH	x	ns	xx
DO	ns	ns	ns
NO ₃	ns	ns	-x
NO ₂	ns	ns	-x
NH ₄	ns	ns	ns
PO ₄	ns	ns	ns
SiO ₃	-x	ns	ns
Chlorophyll <i>a</i>	ns	ns	ns

Correlation is significant at 0.001 (xxx), at 0.01 (xx), at 0.05 (x).

CONCLUSION

In conclusions, the present study revealed that the mesozooplankton community of the Nile Delta coast was characterised by high number of species and great numerical abundance as compared to earlier studies in the same area. Both the species number and numerical abundance were clearly different among the sampling stations and displayed pronounced biweekly variations. The changeable environmental parameters appeared to play essential role in the dynamics of the mesozooplankton community, whereas the distribution and abundance of the different groups as well as of the dominant species were significantly correlated the environmental parameters.

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