Egyptian Journal of Aquatic Biology & Fisheries
Zoology Department, Faculty of Science,
Ain Shams University, Cairo, Egypt.
ISSN 1110 – 6131
Vol. 23(2): 317-330 (2019)
www.ejabf.journals.ekb.eg


ISSN 1110-6131
Egyptian Journal Of Aquatic Biology And Fisheries

Mesozooplankton of the Damietta Branch, River Nile, Egypt.

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ARTICLE INFO

Article History:
Received: April 16, 2019
Accepted: May 9, 2019
Online: May 15, 2019

Keywords:
Mesozooplankton
River Nile
Damietta Branch
Diversity
Distribution
Eutrophication

ABSTRACT

Mesozooplankton abundance and distribution at Damietta Branch, Nile River was studied to assess the impacts caused by human activities. The sampling was done monthly at seven stations during October 2013-September 2014. A plankton ring net with 180 µm mesh size was used to avoid the bias toward the collection of smaller mesozooplanktons such as rotifers and copepod larvae. Thirty-six mesozooplankton taxa were recorded. Cladocera was the most abundant group (41.6%), followed by Copepods (29.9%), Rotifera (14.8%), and Ostracoda (13.2%). The decrease in rotifers density in favor of copepods and cladocerans in the ROT:CLA:COP ratio suggesting an increase in the area eutrophication. According to SIMPER analysis, the most important taxa were *Bosmina longirostris*, *Ceriodaphnia reticulate*, *Moina micrura*, *Acanthocyclops americanus*, *Brachionus calyciflorus*, and *Candona subgibba*. Multivariate analysis indicated that the variations in species distribution were associated with environmental factors, especially water temperature, conductivity, and nitrate. The degree of anthropogenic disturbance determines the quality and quantity of plankton in the study area. Consequently, the discharged post-cooling waters should be controlled to protect zooplankton fauna and in consequence the planktivorous fish of the study area.

INTRODUCTION

Rivers and streams ecosystems are sensitive to many environmental stressors; human activities mainly responsible for most of these stressors (Sala *et al.*, 2000). Streams in developing countries such as Egypt have suffered from severe environmental problems such as chemical and organic pollution, caused by runoff from agricultural chemicals, poorly managed industrial process, and the absence of suitable treatment of sewage and other urban wastes. The results may include the denaturation of water which is no longer sustain healthy ecosystems to aquatic organisms (Arthington *et al.*, 2010). Although the well known adverse effect of pollution in many river systems (Pernet-Coudrier *et al.*, 2012; Xiong *et al.*, 2017; Zhang *et al.*, 2017), it remains indistinct how variety and differences in environmental variables interact to determine community structure of living organisms in stressed river ecosystems in a narrow geographical range, especially for those the critical but poorly studied communities such as zooplankton. Such communities are highly sensitive to environmental fluctuations. The variations in zooplankton abundance and ⁄ or composition can be used as an significant sign of ecological changes or disturbance (Joseph and Yamakanamardi, 2011).

Nile River is one of the longest rivers of the world, flowing from south to north, covering the whole of Egypt between latitudes 21°55′–31°17′N. At El-Kanater El-Khyria (close to Cairo) the Nile bifurcates into two branches, namely; the Rosetta and Damietta branches. Ending dams were erected on both branches. The Damietta Branch is about 240 km long. The lower 21 km of the branch is cut-off from the river and remains freely connected to the sea. This is achieved by the open⁄closed dam (Faraskour dam), 3 km south to Damietta City. This dam is rarely opened and usually closed for most of the year to prevent invasion of the sea water into Damietta Branch. Although the great benefit of this dam which maintains the river water levels by controlling the flow between the Damietta Branch and Mediterranean Sea, the significant reduction in river flow accumulated the wastes and converting the river into a waste collecting system.

Zooplankton of freshwater rivers tends to be dominated by rotifers and bosminids; other cladocerans and copepods were relatively few (Bum and Pick, 1996; Mola and Ahmed, 2015; Rodríguez *et al.*, 2013). Zooplankton are considered to be one of the essential players in the Nile River ecosystem, acting as a link between the first trophic level (primary producers or phytoplankton) and higher trophic levels including planktivorous fish (El-Otify and Iskaros, 2015; Rzoska, 1976)

In the Egyptian waters the widespread use of fine plankton nets (55 µm or even lower) has led to a comparatively low diversity and abundance of mesozooplankton (adult copepods and cladocerans), as the fine nets are clogged easily which allowing the mesozooplankton to escape during the filtration process (Buskey *et al.*, 2002). As a result, most of the zooplankton samples collected previously in the Nile River using fine nets showed an overwhelming increase in diversity (richness and quantities) of small taxa over the larger species. As pointed out by Riccardi (2010), the coarse nets (≈200µm) is providing reliable descriptions of the mesozooplankton assemblages than that of the finer nets. Also, Hopcroft and other (1998) mentioned that the use of coarse nets (180-300 µm) yields an adequate representation of the community structure and its dynamics. During the present study, we assumed that the used coarse net (180 µm) should display a reliable description of the mesozooplankton assemblage and avoid the strong bias towards collecting of small animals in most freshwater zooplankton studies. The study was also aimed to examine of the mesozooplankton community of the Nile River Damietta Branch with three objectives. The first was to determine the composition, distribution, and abundance of mesozooplankton in the Damietta Branch through monthly sampling over a one-year round. The second objective was to analyze the impact of some physicochemical factors on community variations. The third was to clarify the relationship between species and their environment within the study area.

MATERIALS AND METHODS

Study area and stations

The study area (Fig. 1) extended about 78 km in Damietta Branch. The field data used in this paper were collected at seven stations every month from October 2013 to September 2014. Pollutants slightly stressed the station I was located at the water inlet of water planet station. Staions II and VI near the hot water outlet of thermal power generations plants. Station III near the drainage canal of inorganic fertilizer factory receiving industrial sewage. Stations IV, V, and VII near some villages receiving domestic sewage.

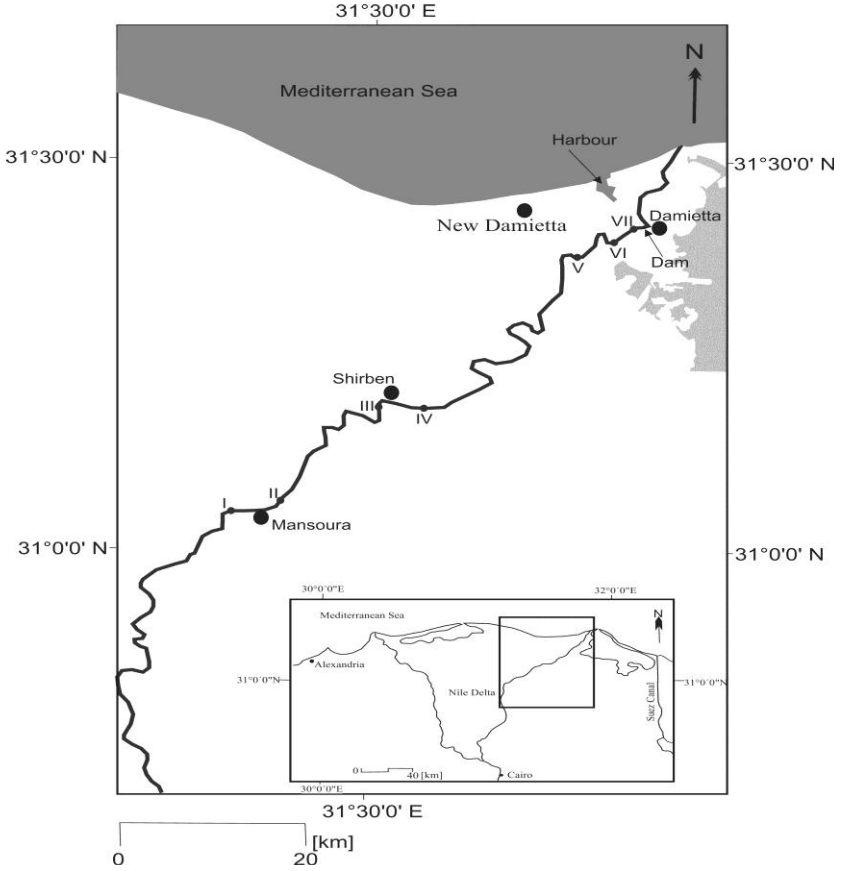

Fig. 1. Map of the study area showing the location of sampling staions.

Sampling and analysis

Surface water samples were collected concurrently with zooplankton samples for the measurement of physicochemical parameters. Temperature, water transparency, pH, electrical conductivity (*EC*), total dissolved solids (*TDS*), and dissolved oxygen (*DO*) were measured in-situ. In the lab, the analysis of physicochemical parameters namely, chloride (Cl^-), alkalinity ($CaCO_3$), nitrate (NO_3^-), nitrite (NO_2^-), ammonium (NH_4^+), and inorganic dissolved phosphorus (PO_4^{3-}) was done by standard methods (Clesceri *et al.*, 1999). The phytoplankton biomass (Chlorophyll-a) was determined according to the methods described by Wetzel and Likens (2000).

Mesozooplankton collections were taken using a 180 μm mesh plankton ring-net of 65cm mouth diameter hauled vertically from the bottom to the surface at each station. Samples were preserved in 4% buffered formaldehyde. Zooplankton taxa were identified (Balcer *et al.*, 1984; Edmondson, 1959; Koste and Shiel, 1986; Koste and Shiel, 1987) and taxon abundance per cubic meter was determined from a 5 ml subsample, taken with a pipette of the entire sample (100 ml).

Statistical analysis

Canonical Correspondence Analysis (CCA) was performed to assess the association of mesozooplankton species with physicochemical parameters using the CANOCO 4.5 package (Ter Braak and Smilauer, 2005). A Monte Carlo test was used to evaluate the significance of the environmental factors (El-Tohamy *et al.*, 2018b).SIMPER analysis of similarity percentages between sampling stations was applied to identify species contribution in the sampling area [CAP v3.0 (Seaby *et al.*, 2004)]. The TWINSPAN "Two Way Indicator Species Analysis" (Hill *et al.*, 1975) was run using the default options to the second cut level. The significance of variations in environmental factors was assessed by ANOVA with tukey's-b test to determine the significant difference between TWINSPAN groups. One way ANOVA analysis was carried out using the statistical program SPSS v18.0.

RESULTS

General water quality

Water temperature varied temporally between a minimum of 19 °C in January and a maximum of 34.5 °C in June. The water was slightly alkaline; the pH range was 7.6-8.72 (Table 1). The water transparency varied significantly between station with values ranged between 39.3 cm at station IV and 390.8 cm at station VII. The total dissolved solids (TDS), ranged from 268 $mg{\cdot}l^{-1}$ at station VI in July to 686 mgl^{-1} at station II in October with an average of 435 $mg{\cdot}l^{-1}$. Throughout this study, the EC values ranged from 398 at station III in January to 1434 $\mu S{\cdot}cm^{-1}$ at station IV in November with an average of 830 $\mu S{\cdot}cm^{-1}$. Chlorinity (Cl^-) values varied between 144 to 210 $mg{\cdot}l^{-1}$ at the station I in October and August respectively, with an average of 163 $mg{\cdot}l^{-1}$. Dissolved oxygen (DO) levels exhibited variable results regarding the site nature. The values ranged from 3.7 to 7.8 $mg{\cdot}l^{-1}$ with an average of 5.9 $mg{\cdot}l^{-1}$. Nutrient concentrations were considerably high most of the year. Nitrate concentrations showed spatial differences, and in a parallelization with nitrite, the values were highest at station VI and lowest at station I. Ammonium ranged 5 to 550 $\mu g{\cdot}l^{-1}$ (Table 1). Generally, the concentrations were higher at stations I and II compared to other stations. Phosphate concentrations ranged from undetectable limits at stations V during winter to >90 $\mu g\ l^{-1}$ at the station I in March. The chlorophyll-a values ranged between 3.2 and 19.6 $\mu g{\cdot}l^{-1}$ with an average of 11.13 $\mu g{\cdot}l^{-1}$ (Table 1).

Table 1: Summary of basic descriptive statistics of different physicochemical parameters, and chlorophyll-a.

Component	Mean	Stand.dev.	Minimum	Maximum
Temperature (°C)	28.01	4.68	19	36.33
Transparency (cm)	179.72	155.71	30	545
pH	8.21	0.35	7.6	8.72
DO (mgl^{-1})	5.91	0.78	3.68	7.83
Alkalinity (mgl^{-1})	825.3	182.9	672.7	1438
EC (μscm^{-1})	829.83	342	397.67	1433.67
TDS (mgl^{-1})	435.26	117.17	276.67	686.33
Cl^- (mgl^{-1})	163.26	15.28	143.92	209.64
NO_2^- (μgl^{-1})	40	20	17	95
NO_3^-(μgl^{-1})	100	47	35	200
NH_4^+(μgl^{-1})	270	130	3	550
PO_4^{3-}(μgl^{-1})	19	25	0	93
Chlorophyll-a (μgl^{-1})	11.13	4.32	3.25	19.57

Zooplankton community and abundance

A total of 36 mesozooplankton species were identified during the present study along the Nile River Damietta Branch, including 12 rotifers, 1 nematode, 8 cladocerans, 10 copepods, and 5 ostracodes. The highest diversified communities (12 taxa) were reported at station V in winter, while the lowest (7 taxa) occurred at station VI during autumn and winter (Fig. 2). The present results reported pronouncedly high variations of mesozooplankton standing crop, whereas the total count over the study area varied from < 300 individual m^{-3} at stations V and VI during winter and summer respectively to > 2300 individuals m^{-3} in winter at the station VII (Fig. 2), with an annual average of 931.7 individuals m^{-3}.

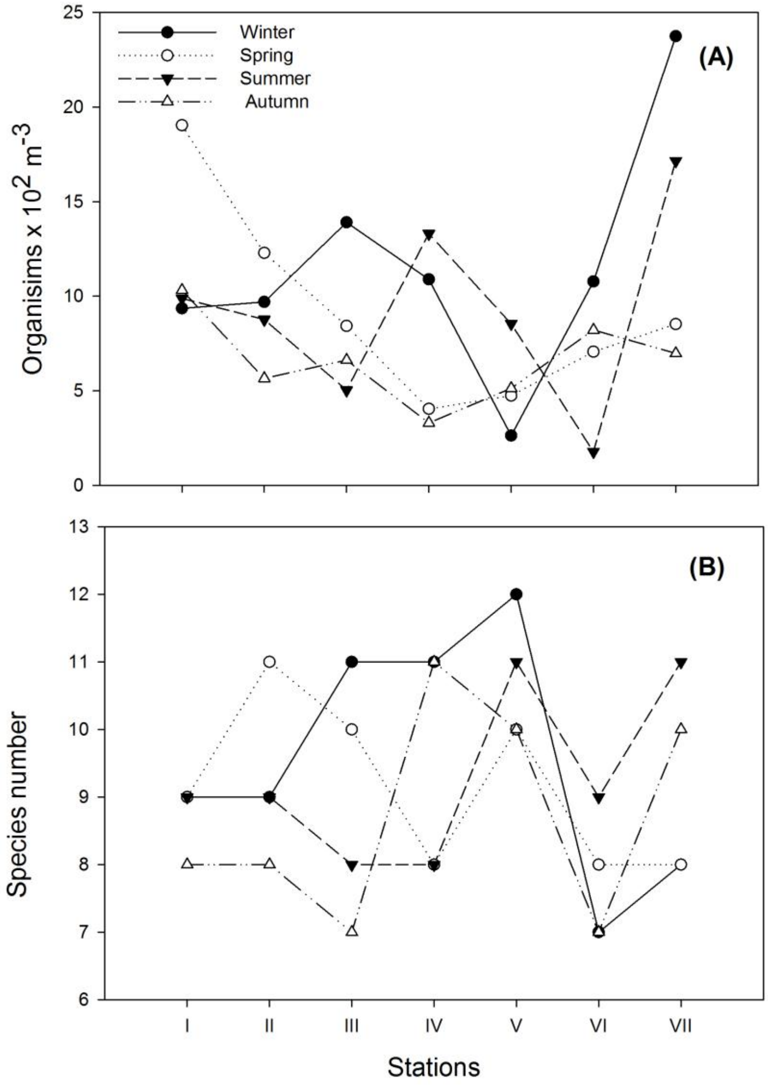

Fig. 2: Seasonal variations of mesozooplankton abundance (A) and species number (B) at the sampled stations.

Crustaceans were the most abundant component, representing 84.62% and 63.9 % of the total abundance and species richness respectively. Cladocerans dominated the Crustacea community structure, representing > 49 % of their total abundance. On the temporal scale, the cladocerans had the maximum role in winter at stations II and IV, in spring at stations II, V, and VI (Fig. 3). According to SIMPER analysis; *Bosmina longirostris*, *Ceriodaphnia reticulate*, *Moina micura*, and *Chydours sphaericus* were the dominant cladocerans and demonstrating the highest active contributors to the total mesozooplankton count between the sampling stations (Table 2). The former three dominant species contributed collectively about 8-19% and 8-22% of total crustaceans and total mesozooplankton respectively. Copepods represented the second predominant group, accounting for 35.3% and 29.9% of the total crustaceans and the total mesozooplankton respectively over the whole study area.

Table 2: Species list in the study area which is ranked according to SIMPER analysis. Abbrev.= Species abbreviation, Cont.% = the percentage of species contribution to the total mesozooplankton abundance.

Name	**Classification**	**Abbrev.**	**Cont. %**
***Bosmina longirostris* (O.F. Müller, 1785)**	Cladocera	Boslo	8.4
***Ceriodaphnia reticulata* (Jurine, 1820)**	Cladocera	Cerre	5.4
***Moina micrura* (Kurz, 1875)**	Cladocera	Momi	6
***Acanthocyclops americanus* (Marsh, 1893)**	Copepoda-Cyclopoida	Acam	3.9
***Brachionus calyciflorus* (Pallas, 1766)**	Rotifera	Brca	4
Copepodites	Copepoda	Copd	3.7
***Candona subgibba* (G. O. Sars, 1926)**	Ostracoda	Casu	5.4
***Chydorus sphaericus* (O.F. Müller, 1776)**	Cladocera	Chsp	3.1
***Brachionus quadridentatus* (Hermann, 1783)**	Rotifera	Brqu	3.2
Ephippium of Cladocera	Cladocera	Ephcl	2.9
***Trichocerca* sp.**	Rotifera	Trsp	2.5
Nauplii larvae	Copepoda	Naup	2.7
***Synchae*ta sp.**	Rotifera	Sysp	1.2
***Alona rectangula* (G.O. Sars, 1862)**	Cladocera	Alre	2.9
***Mesocyclops leuckarti* (Claus, 1857)**	Copepoda-Cyclopoida	Mele	2.9
***Brachionus plicatilis* (Müller, 1786)**	Rotifera	Brpli	2.6
***Halicyclops magniceps* (Lilljeborg, 1853)**	Copepoda-Cyclopoida	Hama	3.1
***Eothinia elongata* (Ehrenberg, 1832)**	Rotifera	Eoel	2.5
***Asplanchna priodonta* (Gosse, 1850)**	Rotifera	Aspr	2.3
***Eucyclops speratus* (Lilljeborg, 1901)**	Copepoda Cyclopoida	Eusp	2.7
***Diaphanosoma excisum* (G.O. Sars, 1885)**	Cladocera	Diexc	1.9
***Proales similis* (de Beauchamp, 1907)**	Rotifera	Prsi	1.9
***Potamocypris variegata* (Brady & Norman, 1889)**	Ostracoda	Pova	4.4
***Oithna* sp.**	Copepoda-Cyclopoida	Oisp	1.9
***Onychocamptus mohammed* (Blanchard & Richard, 1891)**	Copepoda Harpacticoida	Onmo	3
***Monostyla bulla* (Gosse 1886)**	Rotifera	Mobu	0.3
***Cypria pellucida* (G. O.Sars, 1901)**	Ostracoda	Cypel	2.1
***Colurella* sp.**	Rotifera	Cosp	1.5
***Lecane depressa* (Bryce, 1891)**	Rotifera	Lede	1.5
Insect larvae	Hexapoda	Inla	1.8
***Macrothrix hirsuticornis* (Norman & Brady 1867)**	Cladocera	Mahir	1.7
***Limnocythere inopinata* (Baird, 1843)**	Ostracoda	Liino	1.5
***Platyias quadricornis* (Ehrenberg, 1832)**	Rotifera	Plqu	0.3
***Cypria obesa* (Sharpe, 1897)**	Ostracoda	Cyobe	1.1
***Diacyclops bicuspidatus odessanus* (Schmankevitsch, 1875)**	Copepoda-Cyclopoida	Dibi	1
***Oxyurella longicaudis* (Birge, 1910)**	Cladocera	Oxlo	0.8
***Nitokra lacustris* (Shmankevich, 1875)**	Copepoda- Harpacticoida	Nila	0.7
***Diaptomus minutus* (Lilljeborg & Richard, 1889)**	Copepoda-Calanoida	Dimi	0.4
***Dorylaimus* sp.**	Nematoda	Dosp	0.7

Copepods reported their greatest role in autumn at stations V, VI, and VII, in summer at station III. According to SIMPER analysis; *Acanthocyclops americanus*, *Mesocyclops leuckartii*, and *Halicyclops magniceps* were the most important species, contributing on average 8, 3.4 and 2 % to the total crustacea community respectively, and 1.7-6.7 % to the total mesozooplankton. Ostracodes accounted for 13.2% of the total mesozooplankton and 15.55% of total crustaceans. They reported their maximum role in spring at station IV, in winter at station VII (Fig. 3). *Candona subgibba* and *Potamocypris variegata* were numerically abundant among the ostracodes, and on average they contributed 8.2 and 3.2% of the total mesozooplankton abundance respectively. Although, the high diversity of rotifers (13 taxa), they contributed only 14.8% of the total abundance. According to SIMPER analysis (Table 2), *Brachionus calyciflorus*, *B. quadridentatus*, and *Trichocerca* sp. were the most abundant species, contributing on average 29.6, 17, and 6.4% of the total rotifers abundance respectively, and 4, 2.5 and 1.9% of the total mesozooplankton abundance respectively. Other taxa encompassed only the nematode *Dorylaimus* sp. in addition to the meroplanktonic insect larvae (Table 3), contributed collectively < 1% of the total abundance.

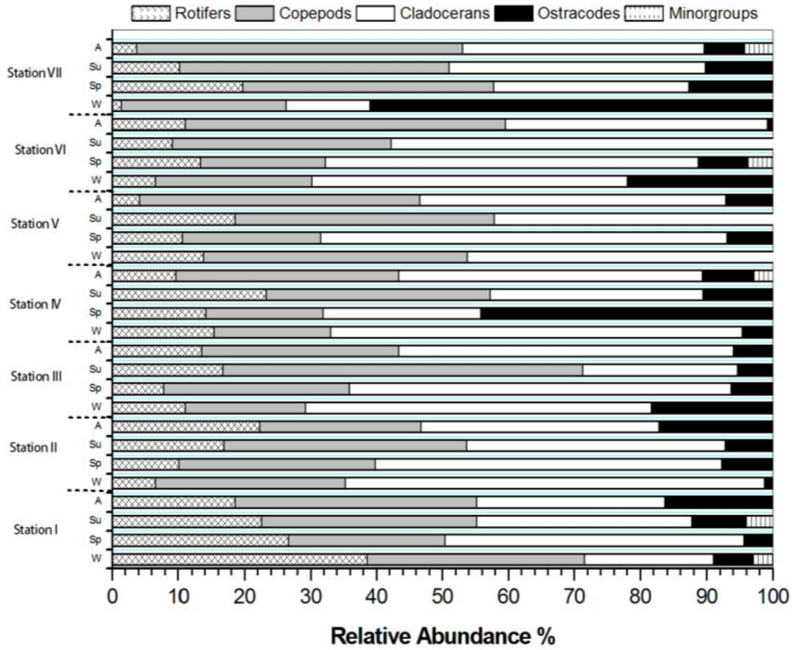

Fig. 3: Seasonal relative abundance of the major zooplankton groups at the sampled stations.

Table 3: The relative richness and abundance of the main mesozooplankton groups.

Category		Species		Mean Abundance	
		Number	%	Ind.m^{-3}	%
Rotifera		12	33.3	137.9	14.8
Nematoda		1	2.8	1.5	0.2
	Cladocera	8	22.2	387.4	41.6
Crustacea **Crustacea**	Ostracoda	5	13.9	122.6	13.2
	Copepod	10	27.8	278.4	29.9
Insect Larvae		-	-	3.6	0.4
Total		36		931.7	

ROT: CLA: COP ratio

The ROT:CLA:COP ratio in the study area, which constituted 0.16:0.52:0.32 in the Winter, achieved 0.19:0.49:0.31 in the Spring during the eutrophication development and changed to be 0.17:0.45:0.39 and 0.17:0.46:0.37 in summer and autumn respectively. These ratios are suggesting an increase in the eutrophication with increasing temperature values from spring to autumn. Also, the ratios indicated a relative decrease in the density of rotifers when compared with that of copepods or cladocerans.

The TWINSPAN analysis

A data set of 84 samples that contains zooplankton species in the study area was analyzed using two-way indicator species analysis (TWINSPAN). The results classify mesozooplankton samples to four groups or clusters labeled A-D (Fig. 4). Each group includes a set of samples with higher similarity of species as compared to other groups. Each cluster is characterized by indicator species identified by TWINSPAN at each level of hierarchical classification. In the following description, the groups are characterized in terms of their indicator species.

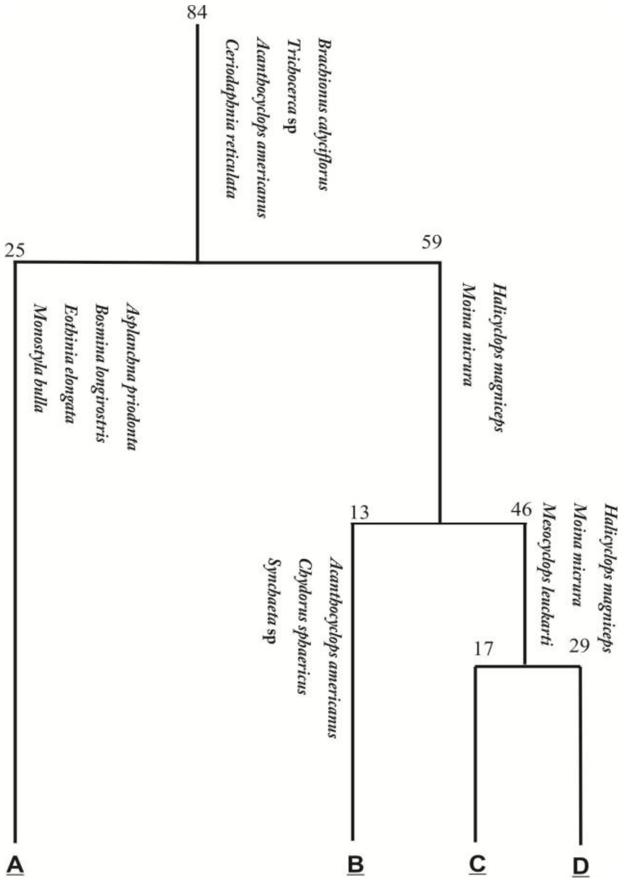

Fig. 4: TWINSPAN dendrogram of 84 samples based on the density of zooplankton species in the study area. Indicator species are shown at each level of classification. Four groups (A-D) are shown at level 2.

Group A: including 25 samples from stations II and VI; the group is characterised by *Asplanchna priodonta*, *Bosmina longirostris*, *Eothinia elongate*, and *Monostyla bulla as indicator species*.

Group B: comprises 13 samples mostly from the station I and indicated by *Acanthocyclops americanus*, *Chydorus sphaericus*, and *Synchaeta* sp..

Groups C and D: 46 samples including the sample units from stations III, IV, V, and VII with *Halicyclops magniceps*, *Moina micrura*, and *Mesocyclops leuckartii* as indicator species.

As shown in Table 4, group A is associated with the highest values of temperature, alkalinity, phytoplankton biomass, and the lowest phosphate values, while group B was associated with the highest values of pH, dissolved oxygen, and the lowest values of temperature and phytoplankton biomass. On the other hand, groups C and D appeared to be in accordance with relatively higher values of nutrients and chlorophyll-a.

Table 4: Means of 13 environmental parameters recorded in different TWINSPAN groups. Mean of the variables have the Latin letters of the groups which are significantly different according to the Tuckey's-b test.

	TWINSPAN groups				***ANOVA***	
	A	***B***	***C***	**D**	**F**	**p**
Temperature	34.3$^{\mathbf{I}}$	21$^{\mathbf{III}}$	26.5$^{\mathbf{II}}$	28.2$^{\mathbf{II}}$	29.8	<0.001
Transparency	269.6	195	166.3	132.1	1.7	0.177
pH	8.1$^{\mathbf{II}}$	8.6$^{\mathbf{I}}$	8.2$^{\mathbf{II}}$	8.0$^{\mathbf{II}}$	5.5	0.002
DO	7.5$^{\mathbf{II}}$	9$^{\mathbf{I}}$	8.2$^{\mathbf{I}}$	7.5$^{\mathbf{II}}$	6.21	0.001
Alkalinity (*ALK*)	976.7$^{\mathbf{I}}$	747.9$^{\mathbf{II}}$	817.9$^{\mathbf{I}}$	757.7$^{\mathbf{II}}$	4.42	0.006
EC	902.4	648.2	759.6	866.8	1.2	0.344
TDS	461.5	403.7	383.2	454.5	1.7	0.18
Cl^-	162.2	176.5	162.3	160.6	1.14	0.34
NO_2^-	37.7	51.7	35.6	40.5	0.6	0.6
NO_3^-	71.2$^{\mathbf{II}}$	79.3$^{\mathbf{II}}$	129.9$^{\mathbf{I}}$	132.4$^{\mathbf{I}}$	2.84	0.04
NH_4^+	156.7	226.8	259.0	256.4	1.8	0.1
PO_4^{3-}	3.9$^{\mathbf{III}}$	44.7$^{\mathbf{I}}$	18.4$^{\mathbf{II}}$	24.3$^{\mathbf{II}}$	2.61	0.05
Chlorophyll-a	14.5$^{\mathbf{I}}$	5.2$^{\mathbf{II}}$	10.8$^{\mathbf{I}}$	12.0$^{\mathbf{I}}$	10.26	<0.001

The multivariate analysis

The DCA results showed that the maximum length of gradients was 2.66, suggesting a linear or unimodal relationship between zooplankton species and environmental parameters. Therefore, both Redundancy analysis (RDA) and Canonical Correspondence analysis (CCA) were performed. The CCA was chosen because it explains more variance in the species distribution than the RDA in the first four axes (RDA: 12.5 %, CCA: 15.1%). The results of CCA indicated that the environmental parameters had a significant influence on mesozooplankton distribution (F-ratio = 3.02, P-value = 0.005), explaining 56.7% of the total variance. By using the Monte Carlo permutations test, six environmental parameters had significant influences on the species distribution, among them temperature, conductivity, nitrate, and pH were the most powerful (Table 5). The ordination diagram produced by CCA shows the distribution pattern of mesozooplankton species along the environmental gradients. As shown in figure 5, more than 65% of rotifers and cladocerans were found in the right half of the ordination diagram where the gradients of temperature and phytoplankton biomass in opposition with the vectors of dissolved oxygen, pH, and nutrients, especially at stations II and VI. On the other hand, at the other stations, ostracodes and 90% of copepods were associated mainly with the gradients of pH, dissolved oxygen, TDS, and nutrients opposite to the vectors of temperature and phytoplankton biomass. The cladocerans *Bosmina longirostris* and *Ceriodaphnia reticulate*, and the rotifers *Asplanchna priodonta* and *Brachionus plicatilis* were associated with gradients of temperature and phytoplankton biomass, especially at stations II and VI. The vectors of chloride and conductivity found mostly between the sample units from station VII. The rotifer

Brachionus calyciflorus, the ostracod *Cypria pellucida*, the harpacticoide *Onychocamptus mohammed*, and the cladoceran *Diaphanosoma excisum* were associated with these vectors (Figure 5). The cladocerans *Alona rectangula* and *Chydorus sphaericus*, the copepods *Acanthocyclops americanus*, *Nitokra lacustris*, and the rotifer *Synchaeta* sp. were associated with the highest values of pH and dissolved oxygen at station I. The genera which close to the point of diagram origin (0-0) as *Candona subgibba*, *Trichocerca Sp*, the copepod nauplii and copepodites indicated the homogonus distribution of these species at all sampled stations.The other species as *Lecane depressa*, *Halicyclops magniceps*, *Mesocyclops leuckartii*, *Diaptomus minutus*, *Moina micrura*, and *Limnocythere inopinata* were associated with the vectors phosphate and opposite to the vectors of temperature transparency at stations IV and V (Figure 5).

Table 5: Results of forwarding selection and Monte Carlo permutation tests from CCA.

Variables	***Lambda-A***	***F-ratio***	***P-value***
Temperature	0.15	3.02	0.005
EC	0.1	2.06	0.005
NO_3^-	0.08	1.79	0.015
pH	0.08	1.75	0.04
Cl^-	0.08	1.74	0.02
PO_4^{3-}	0.07	1.38	0.04
Alkalinity	0.06	1.32	0.159
NH_4^+	0.05	1.14	0.328
Transparency	0.05	1.09	0.323
NO_2^-	0.05	1.03	0.388
DO	0.04	0.99	0.493
TDS	0.04	0.93	0.547
Chlorophyll-a	0.04	0.82	0.711

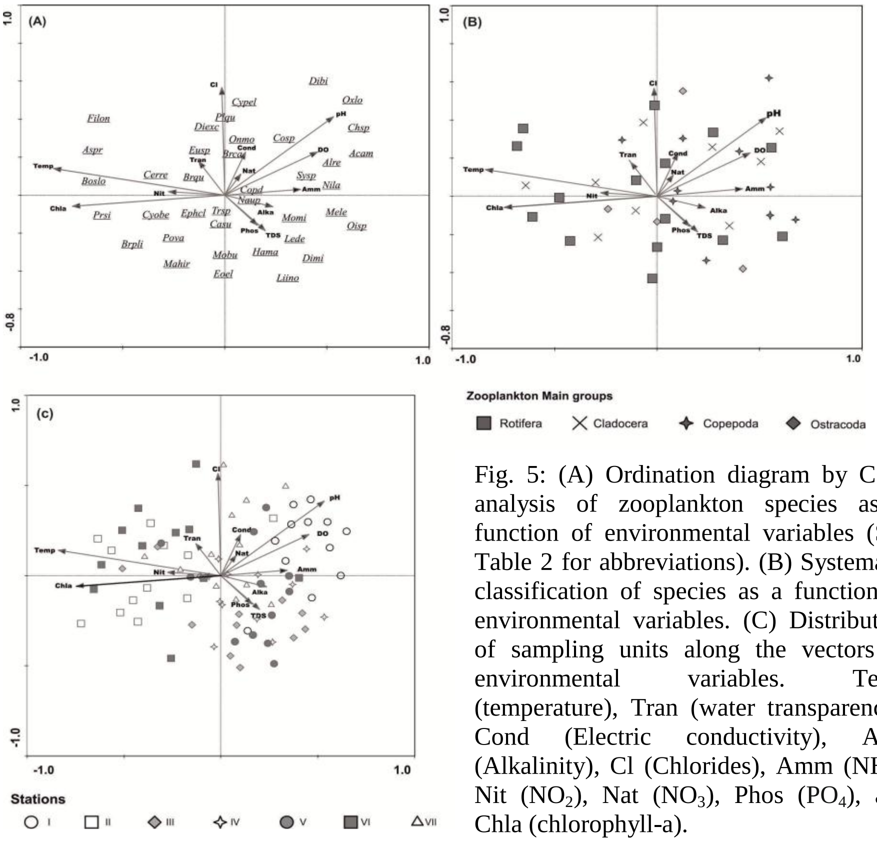

Fig. 5: (A) Ordination diagram by CCA analysis of zooplankton species as a function of environmental variables (See Table 2 for abbreviations). (B) Systematic classification of species as a function of environmental variables. (C) Distribution of sampling units along the vectors of environmental variables. Temp (temperature), Tran (water transparency), Cond (Electric conductivity), Alka (Alkalinity), Cl (Chlorides), Amm (NH_4), Nit (NO_2), Nat (NO_3), Phos (PO_4), and Chla (chlorophyll-a).

DISCUSSION

The available data existing in the literature on the Nile River Damietta Branch zooplankton community structure were provided by Helal (1981; 2006). However, the present study is limited by the large mesh size used (180 µm). The recorded pattern of zooplankton in this study reflects the use of coarse mesh size. This coarse mesh net causes the undersampling of small zooplankton specimens such as rotifers and small copepods, which probably lead to an underestimation of the total zooplankton abundances (Chisholm and Roff, 1990). Accordingly, zooplankton abundances in the present study were significantly lower than those found in other areas along the Egyptian part of Nile River, such as upper Egypt (El-Bassat, 1995; El-Otify and Iskaros, 2015; Rzoska, 1976), Rosetta Branch (Abdel-Halim *et al.*, 2013; El-Shabrawy and Khalifa, 2002; Hegab, 2010), and that studied previously in Damietta Branch by Helal (1981; 2006). On the other hand, most of the standard sampling protocols for zooplankton in the Egyptian waters are restricted only to mesh sizes < 60 µm. This reduction in mesh size may be inappropriate for mesozooplankton collection with the loss of many species through the filtration process (Tseng *et al.*, 2011). According to Sosnovsky and others (2016), the mesozooplankton community comprises mostly copepods and cladocerans. In the 1981 study (Helal, 1981), cladocerans were represented by six different species decreased to four species in 2006 study (Helal, 2006), whereas in the present study the group was represented by eight species. The copepods were represented by ten species in the current investigation, against eight species in 1981 study. Also, Abdel-Halim and others (2013) recorded only six different species of copepods in the Rosetta Branch. The significant increase in the number of mesozooplankton species, especially among copepods and cladocerans, is indicative of the advantages of coarse mesh in the collection of mesozooplankton.

The CCA ordination analysis revealed that the considerable variations in different mesozooplankton groups among sampling stations were significantly correlated with the variations of temperature, conductivity, and nitrate concentrations. This confirms with the observations in other areas, where the water temperature was a keystone element in the seasonal dynamics of mesozooplankton (Jerling and Weerts, 2018; Nakajima *et al.*, 2017), and may regulate most ecological mechanisms in temperate areas (Sellami *et al.*, 2010). As mentioned by El-Tohamy (2018a), the study area receives relatively high anthropogenic disturbance, directly or indirectly resulting in high values of nutrients and conductivity. According to Dorak (2014), the conductivity variation may regulate the structure of zooplankton assemblages, especially the spatial changes in species diversity and abundance.

The particular thermal and trophic conditions are shaping the occurrence and the spatial distribution of zooplankton in the study area. This is related to the quantity and quality of the post-cooling waters that discharged into the river system which resulted in the decrease in abundance and diversity of mesozooplankton particularly at stations II and VI in comparison to other stations. The impact of the discharge of thermal power generation plant post-cooling waters on zooplankton diversity, spatial distribution, and abundance have been stated in many studies (Gromova and Protasov, 2017; Hillbricht-Ilkowska and Zdanowski, 1989; Kulakov *et al.*, 2018; Tunowski, 2009; Zdanowski, 1988). According to Zdanowski and Prusik (1994), the changes in thermal regimes and chemical composition of waters have significant impacts on the metabolism of planktonic organisms.

Although the CCA ordination was explaining 56.7% of the total variations of the mesozooplankton community of Damietta Branch-Nile River, a significant amount of the total variations remains unexplained. Some portion of the unexplained variation in the recorded zooplankton data may be associated with the primary productivity (opposing the merely using of chlorophyll-a as a proxy for phytoplankton standing crop). According to Emerson and other (2015), the variations in chlorophyll-a concentrations were not strong explanatory of the zooplankton community, indicating the need for an effective way for the primary production determination. Other unexplained factors that may need future study include zooplankton predation by fishes and invertebrates and competition between zooplankton taxa.

TWINSPAN analysis demonstrated the tight relationship between the spatial distribution of zooplankton and the environmental characteristics in the study area. The analysis grouped the sampling points that are sufficiently similar into two main clusters. The first cluster (warm-water community of stations II and VI) seemed to be clearly separated from the other cluster groups (Fig. 4). The indicator species of each TWINSPAN group differed in relation to the prevalence of different environmental conditions. For example, the cladocerans *Bosmina longirostris* is a polythermal species (Di Genaro *et al.*, 2015) and their population growth usually increases at a temperature above 22 °C, which supports their rapid rise to dominance particularly at stations II and VI. Also, the distribution pattern of other indicator species found in the present study was clearly influenced by the combination of the influences of post-cooling waters and other environmental factors. In the first cluster, there were some warm-water species, such as the rotifers *Asplanchna* sp. and *Monostyla* sp., whereas there were some cold-water rotifer species indicated the second cluster such as *Keratella quadrata* and *Synchaeta* sp.. This is in agreement with Yin et al. (2018), who reported that the rotifers *Asplanchna* sp. and *Monostyla* sp. preferred the warm-water habitat, whereas *Keratella quadrata* and *Synchaeta* sp. preferred cold-water. The CCA biplot also showed that the abundance of *Bosmina longirostris*, *Asplanchna* sp. and *Monostyla* sp., were significantly correlated with temperature.

The ROT:CLA:COP ratio was applied to detect how the eutrophication process changes the contribution of rotifers, cladocerans, and copepods communities to the total zooplankton abundance (Adamczuk *et al.*, 2015). In the present study, we observed that Cladocera and Copepoda were contributed largely than Rotatoria in the process of eutrophication all year round. Also, the ratio of calanoid copepods to cladocerans and cyclopoids frequently used as a good indicator of trophic conditions in freshwater ecosystems (Gannon and Stemberger, 1978; Jeppesen *et al.*, 2011; Montagud *et al.*, 2019). Calanoids are more adapted to oligotrophic conditions while cyclopoids and cladocerans are usually more abundant with increasing eutrophication (Adamczuk *et al.*, 2015). That statement was confirmed by similar observations in the study area, the significantly decreased ratio of calanoid copepods (represented only by *Diaptomus minutus*) to cladocerans and cycloids copepods indicated the eutrophication process.

CONCLUSION

This study represented a comprehensive investigation of the mesozooplankton community of this poorly studied area in the Nile River. The main factor influencing the abundance and distribution of the mesozooplankton assemblages was the water temperature. The low species richness and density obtained at stations II and VI that are directly exposed to the discharge of heated waters. Lastly, but not less important, the present work identified that the studying of the mesozooplankton role in aquatic habitat could be better with relatively coarser nets, enabling us to avoid many factors that could affect sampling efficiency such as avoidance, escape and clogging.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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