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Environmental Determinants of Zooplankton Community in the Damietta Estuary of the Nile River, Egypt

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WSE-T designed the study, drafted the main text and prepared figures. RRH helped in the manuscript preparation and editing. WSE-T and NEMAA did field investigations and sampling .

Key words
Zooplankton community, Environmental variables, Damietta estuary, Nile River, Salinity gradients.

ABSTRACT

Zooplankton community and eleven environmental variables were investigated seasonally during 2014 through nine stations in the Damietta estuary of the Nile River. Meroplanktonic larvae were the major component representing 39.4% of the total zooplankton abundance. Copepods and their larval stages contributed 36.2%. Rotifers ranked the third important group (12.6%). Protozoa contributed 10.6% of the total community. According to the Canonical Correspondence Analysis (CCA), the variations in the species data were significantly ($P < 0.05$) related to salinity, temperature, phosphate concentration and phytoplankton biomass. The main spatial gradients along the estuary were associated with salinity. The high salinity zone in the estuary downstream was dominated by the calanoid paracalanidae and the harpacticoid *Euterpina acutifrons*. In the lower salinity transects, the tintinnid *Favella serrata* dominated the estuary midstream, together with several rotifer species in the estuary upstream. The juvenile copepods and the cyclopoid *Oithona* spp. together with the numerically dominant polychaete and cirriped larvae seemed little affected by salinity gradients.

INTRODUCTION

The ecological importance of estuaries arises from being a habitat where freshwater and marine organisms exist together and can tolerate a wide range of salinity variations. Such areas are usually rich in the elements essential for the growth of primary producers, which directly or indirectly attract organisms from higher trophic levels. Estuaries also serve as important nursery areas for many economic fish and shellfish species (Park and Marshall, 2000; Janakiraman *et al*., 2013; Champalbert *et al*., 2014). The estuarine and brackish-water biotas represent a unique setting for intimate collaboration between the fresh water biologists and oceanographers (Little, 2000). The Damietta estuary is a shallow temperate estuary on the Egyptian Mediterranean coast that provides critical habitat for fish and migrating birds (Hamza, 2006). This estuary ecosystem is subjected to direct or indirect human effects related to intensive agriculture, increasing industrial activities, maritime activities, and pollution (Saad and Abdel-Moati, 1984), all of which, in a particular, affect most of the estuary parts.

Spatiotemporal variations and habitat types are among the most important factors affecting patterns of species abundance and composition of estuarine plankton (Marques *et al*., 2006). The relation between distribution of zooplankton and environmental variables has been studied in several estuaries, and frequently salinity and temperature have been shown to be the most important parameters affecting the distribution and abundance of estuarine zooplankton (Graham and Bollens, 2010; Bollens *et al*., 2011). The continuous mixing processes in estuaries cause changes in the environmental conditions particularly salinity, while temperature changes are usually driven by weather and climate (Costello *et al*., 2006; Allen *et al*., 2008; Winder and Jassby, 2011; Champalbert *et al*., 2014). Horizontal gradients of salinity affect the spatial distribution of estuarine zooplankton and the species distribution is almost determined according to salinity tolerance (Lawrence *et al*., 2004).

The seasonal changes and the input of fresh and marine play a large role in the structuring of estuarine communities (Kimmel *et al*., 2009). The Damietta estuary is now isolated from the Damietta branch of the Nile River by tight and permanent closure of the Faraskour's Dam, such that no river water is any longer released to the estuary. The estuary is now filled with Mediterranean seawater mixed with irrigation water and water effluents from Manzalla Lake that allow it to maintain its estuarine status (Cameron and Pritchard, 1963).

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Currently, no studies have examined the zooplankton community in the Damietta estuary. For this reason, the current status of Damietta estuary, its plankton community, and the mechanisms affecting their dynamics are important to understand. This study examined the zooplankton community of Damietta estuary with two objectives. The first was to measure the composition, distribution, and abundance of zooplankton in the estuary. The second objective was to correlate community variations to physicochemical parameters including chlorophyll *a* concentration.

MATERIALS AND METHODS

Study area

The Nile River flows from Tanganyika Lake in Tanzania (4° S) to the Mediterranean Sea (31°31'N) over a distance of 6625 km (Khedr, 1998). About 23 km North of Cairo, the river bifurcates into two branches, the Rosetta and the Damietta. In 1989, Damietta branch was blocked by a permanent earth dam at the south of Damietta city, known as Faraskour Dam (Fig. 1); forming a completely isolated area of the Nile called the Damietta estuary. It's a long stretch of water with an average length of about 13 km. The estuary is connected to the Damietta harbor by a navigational canal (Barge canal, 4.5 km long). Thus the water properties in the estuary are mainly controlled by the land runoff and by the tidal regime. Generally, the freshwater flows mainly due to the irrigation water and water effluents from Manzalla Lake which are relatively low when compared with the volume of seawater entering the estuary.

Samples collection and analysis

Zooplankton samples were collected seasonally during 2014, with surface water samples collected concurrently for the measurement of environmental parameters. The collection of samples was carried out at a fixed daytime (9.00-9.30am), at nine stations to represent the salinity gradients (Fig. 1), each with different anthropogenic influences (Table I).

Chlorophyll *a* and hydrographic parameters (temperature, salinity, transparency, dissolved oxygen , pH) and nutrients (PO_4, NO_3, NO_2, NH_4 and SiO_3) were measured. The surface water temperature was measured to the nearest 0.5 °C with a mercury thermometer, and salinity to the nearest part per thousand with a refractometer. Water transparency was estimated by a standard secchi disc (25 cm in diameter) and pH with a digital pH meter. Dissolved oxygen, nutrients and phytoplankton biomass (chlorophyll *a*) were determined according to the methods described by Strickland and Parsons (1972).

Zooplankton collections were taken using a 54-µm mesh plankton ring-net of 45 cm mouth diameter hauled vertically slowly from the bottom to the surface at each station. Samples were preserved in 5% formalin. Zooplankton samples were identified to species using a combination of Rose (1933), Edmondson (1959), Marshall (1969), Cosper (1972), Newell and Newell (1979), Nishida (1985), and Boltovskoy (1999). Abundance was determined from the average counts of three aliquots of 5ml and expressed in number/ m^3.

Statistical analysis

For zooplankton samples, the dominance of species was calculated according to Zhao and Zhou (1984). One-way ANOVA with Tukey's-b test was employed to test the spatial and temporal differences between the environmental variables. Simple correlations were determined to define the relationship between some selected parameters . The data were tested for normality prior to analysis, and transformed to natural logarithms where necessary to satisfy the homogeneity of variances and normality of analysis. ANOVA and Correlations were performed using SPSS 18.

Hierarchical and non-metric Multidimensional Scaling (MDs) analysis of similarity between stations were computed on the basis of the Bay-Curtis similarity index. Stations groups were statistically identified and groupings were subjected to SIMPER (similarity percentages) routine to identify species contributing to similarity within and differences between groups [CAP v3.0 (Seaby et al., 2004)].

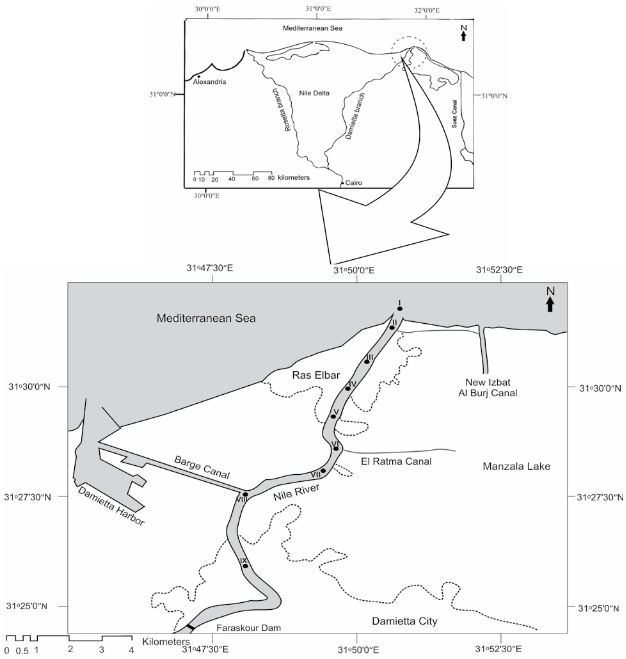

Fig. 1. Map of the study area showing the positions of the sampling stations.

Table I.- Description of the sampling stations in the Damietta Estuary of the Nile River.

Stations	Names	Descriptions	Position
I	Al Boghaz	At the mouth of the estuary. -Average depth: 4.3m	**Lat.** 31°31′.62N, **Long.** 31°50′.74E
II	Al Sohpara Canal	At the canal front, receives water effluents from Manzalla Lake. -Average depth: 3.5m	**Lat.** 31°31′.196N, **Long.** 31°50′.517E
III	Izbat Al Burj	-Housing estate (point source of industrial and domestic discharge). - Maritime activities of the fisheries fleet -Average depth: 3.5m	**Lat.** 31°30′.43N, **Long.** 31°50′.15E
IV	El Gerbe Ras El Bar	-Housing estate. - Maritime activities of the fisheries fleet. -Average depth: 3.9m	**Lat.** 31°29′.55N, **Long.** 31°49′.56E
V	El Sheikh Dorgham	- Housing estate and Agricultural wastes. - Maritime activities of the fisheries fleet. -Average depth: 4.63m	**Lat.** 31°29′.11N, **Long.** 31°49′.39E
VI	El Ratma Canal	-Housing estate and Agricultural wastes. - At the front of the Ratma Canal, receives water effluents from Manzalla Lake. -Average depth: 5.5m	**Lat.** 31°28′.34N, **Long.** 31°49′.39E
VII	Izbt Tabl	- Housing estate and Agricultural wastes. -Average depth: 5.8m	**Lat.** 31°27′.56N, **Long.** 31°49′.18E
VIII	Damietta Harbor Barge Canal	At the front of the Barge canal and in addition to house estate and agricultural wastes, this site receives wastes of the Damietta port -Average depth: 5.3m	**Lat.** 31°27′.32N, **Long.** 31°48′.9E
IX	Damietta City	-Housing estate. -Average depth: 4.3m	**Lat.** 31°26′.29N, **Long.** 31°48′E

Lat., Latitude; Long., Longitude.

Table II.- Seasonal variations and average values of different physico-chemical parameters and chlorophyll *a*. Different letters denote significant differences between values based on One Way ANOVA with Tuckey's-b test where a>b.

	Win	Spr	Sum	Aut	ANOVA	
					F	P
Temp (°C)	17.02^c	20.7^b	27.1^a	21.6^b	60.7	<0.001
Tran (cm)	139^{a,b}	195.4^a	140.1^{a,b}	110.2^b	3.21	<0.05
Salinity (PSU)	32.9	33.6	35.8	33.7	0.78	0.423
pH	8.1^b	8^b	8.3^a	8.1^b	2.99	<0.05
DO (mgl^{-1})	8	7.9	7.7	8.2	1.11	0.214
NO_3 (µml^{-1})	0.61	0.86	1.12	0.91	1.15	0.208
NO_2 (µml^{-1})	0.37	0.42	0.56	0.33	0.82	0.483
NH_4 (µml^{-1})	3.42	10.6	13.1	12.61	0.461	0.721
PO_4 (µml^{-1})	0.02^b	0.01^b	0.13^a	0.013^b	17.5	<0.001
SiO_3 (µml^{-1})	1.8	2.26	9.87	10.45	1.75	0.18
Chlorophyll *a* (µgl^{-1})	12.32	19.1	20.1	17.6	1.047	0.385

Tran, transparency; Win, winter; Spr, spring; Sum, summer, Aut, autumn.

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.

To examine the relationship between zooplankton community structure and the environmental variables, abundance-weighted averaging was used to calculate taxon-specific optima along gradients of chlorophyll *a* and salinity (Ter Braak and Smilauer, 1998). Calculations of weighted average optima (WAopt) of zooplankton taxa were carried out using the following equation:

$$WAopt = \frac{\sum_{i}^{n}(A_i \times V_i)}{\sum_{i}^{n} A_i}$$

Where, A_i is the taxon's abundance in sample *i*, V_i is the abundance/concentration of the environmental variable in sample *i* and *n* the number of samples.

Table III.- The average values of different physico-chemical parameters and chlorophyll *a* at the sampled stations. Different letters denote significant differences between values based on One Way ANOVA with Tuckey's-b test where a>b>c>d.

	I	II	III	IV	V	VI	VII	VIII	IX	ANOVA	
										F	P
Temperature (°C)	20.5	20.9	21	21.8	21.7	22.1	21.9	22.4	22.3	0.336	0.944
Transparency (cm)	160.5	91	130.5	118.8	150	130.5	137.5	221.8	130.5	1.171	0.352
Salinity (PSU)	38.8^{a}	$36.9^{a,b}$	$36.7^{a,b}$	$34.5^{b,c}$	$34.5^{b,c}$	$33.9^{b,c}$	32.6^{c}	29.5^{d}	29^{d}	20.47	<0.001
pH	8.1	8.1	8.2	8.3	8.3	8.3	8.3	8.4	8.3	2.187	0.061
DO (mgl^{-1})	6.3^{c}	6.2^{c}	6.5^{c}	$9.5^{a,b}$	$9.7^{a,b}$	$9.2^{a,b}$	$8.7^{a,b}$	10.1^{a}	10.1^{a}	3.848	0.002
NO_3 (μml^{-1})	$1.1^{a,b}$	$0.74^{a,b}$	$0.66^{a,b}$	0.28^{b}	$0.52^{a,b}$	$0.45^{a,b}$	$1\pm0.94^{a,b}$	3.83^{a}	0.25^{b}	2.66	0.026
NO_2 (μml^{-1})	0.3^{b}	$0.55^{a,b}$	0.33^{b}	0.08^{c}	0.35^{b}	0.36^{b}	0.062^{b}	1.88^{a}	0.06^{b}	3.62	0.006
NH_4 (μml^{-1})	$10.23^{a,b}$	61.6^{a}	7.22^{b}	0.064^{c}	2.1^{b}	$1.47^{b,c}$	$0.6^{b,c}$	$1.5^{b,c}$	$2.2^{b,c}$	7.91	<0.001
PO_4 (μml^{-1})	10.23	0.07	0.014	0.03	0.03	0.044	0.041	0.048	0.06	0.25	0.977
SiO_3 (μml^{-1})	10.23	20.09	6.55	1.77	3.05	2.42	3.79	6.22	5.75	1.512	0.179
Chlorophyll *a* (μgl^{-1})	$10.23^{a,b}$	$10.8^{a,b}$	$19.8^{a,b}$	$23.6^{a,b}$	$19^{a,b}$	29.1^{a}	$13^{a,b}$	$9.2^{a,b}$	$13.5^{a,b}$	2.589	0.019

RESULTS

Environmental variables

Estuaries are characterized by their environmental gradients, both temporally and spatially. Salinity showed the most noticeable spatial gradient in the Damietta estuary with a trend of decreasing toward the estuary upstream. Surface water temperatures (Table II) showed temporal variations between the minimum in winter (17.02°C) and the maximum in summer (27.1°C), but little difference between stations was noticed (Table III). Secchi disk transparency (SDT) varied significantly between seasons with values ranging between 110 cm in autumn and 195 cm in winter. Surface dissolved oxygen ranged from oversaturation at stations form IV to IX to considerably lower levels toward the estuary downstream. The pH displayed a little variation, with an average between 8.1 and 8.4 at the different stations (Table III). Nutrients (NO_3, NO_2, NH_4, PO_4, and SiO_3) concentrations were generally high, consistent with the pronounced eutrophication of Damietta Estuary. ANOVA and statistical test (Tukey's-b test) on nutrients concentration by seasons showed only significant differences in phosphate concentrations, with considerably higher value in summer versus the other seasons (Table II). Spatially, there were negligible differences in phosphate concentrations except at station 1 which showed the highest values. The concentrations of NO_3 showed spatial significant differences, while NO_2 was the highest at station VIII and the lowest at stations IV and IX. Also, ammonia concentrations were considerably higher at stations I and II versus the other stations (Table III). Silicate concentrations ranged from lowest values at station IV to the highest at station II. The high nutrient levels promoted the intensive growth of phytoplankton (always > 2 $\mu g\ l^{-1}$), causing acute level of eutrophication along the estuary indicate the large influence of freshwater discharge in this region. Chlorophyll *a* demonstrated clear differences between the sampled stations, with the markedly high value (29.1 $\mu g\ l^{-1}$) at station VI to much lower value (9.2 $\mu g\ l^{-1}$) at station VIII; however temporal variations were not significant.

Zooplankton composition and abundance

In total, 61 holoplankton taxa belonging to 7 categories: Protozoa, Cnidaria, Rotifera, Crustacea (Copepoda, Cladocera, Ostracoda, Amphipoda and Mysidacea), Chaetognatha, Mollusca, Larvacea, and 8 different types of meroplankton were also recorded (Table IV). The highest diversified communities (34 taxa) were reported at station V in autumn, while the lowest (10 taxa) occurred at station IX in summer (Fig. 2). Total zooplankton abundance averaged over all stations varied from < 1.5×10^{3} individual m^{-3} in winter at the stations VII, VIII, and IX, to > 15×10^{3} individual m^{-3} in spring at the station VI (Fig. 2). The meroplanktonic larvae dominated the community structure, representing > 39% of the total abundance. Dominant taxa were the larvae of Annelida and Cirripedia. Crustaceans were the most abundant component among the holoplankton, representing > 36 % and 39 % of the total abundance and species richness respectively. Copepods were the dominant organisms (17 taxa, mean abundance 1975 individual m^{-3}). The three major orders of planktonic copepods (calanoida, cyclopoida and harpacticoida) demonstrated different roles along the estuary. Although all three orders of copepods had similar diversity, cyclopoida numerical density was considerably higher (Table IV). Rotifers were the third important group, comprising 6 species and contributed

13.37% of the total abundance. Although, there was high diversity of protozoans (26 taxa), they contributed only 10.55 % of the total abundance. They were represented by three groups; Tintinnids, non-Tintinnid ciliates and Foraminifera. Tintinnids were the most diversified groups (14 species), followed by non-Tintinnid ciliates (8 species) and Foraminifera (4 species). Other occurring taxa included Cnidaria, Cladocera, Ostracoda, Amphipoda, Mysidacea, Pteropoda, Larvacea, and Chaetognatha were represented by a small number of species (Table IV), contributed collectively 19.68% and about 1% of the species richness and total abundance, respectively.

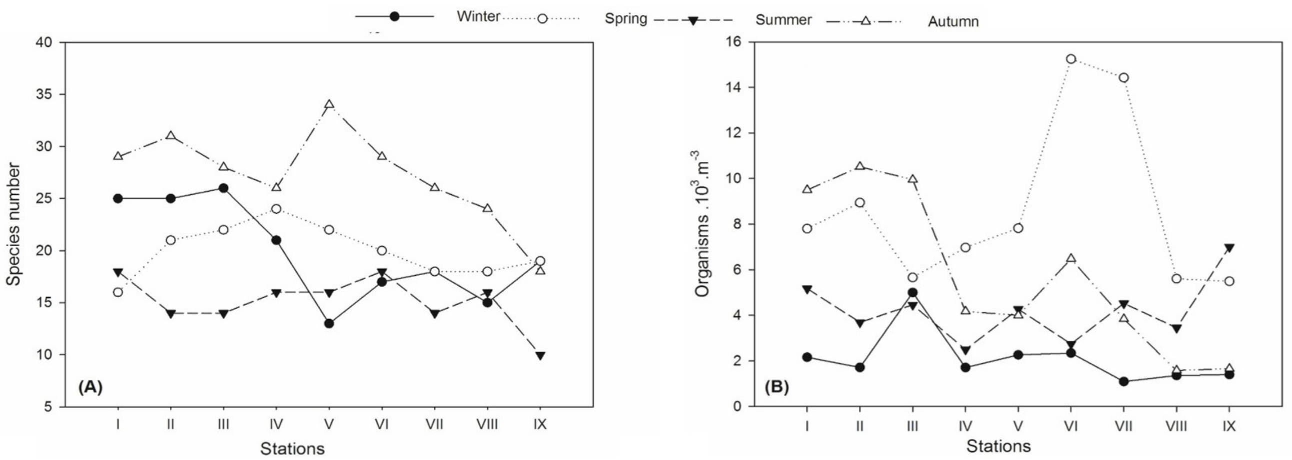

Fig. 2. Seasonal variations of zooplankton species number (A) and abundance (B) at the sampled stations.

Table IV.- Zooplankton species, richness, and average abundance (Ind.m^{-3}) of each category.

Category		Species		Mean Abundance	
		Number	%	Ind.m^{-3}	%
Protozoa	Foraminiferida	4	6.56	3.99	0.07
	Non Tintinnid ciliates	8	13.11	32.22	0.59
	Tintinnida	14	22.95	542.37	9.89
Cnidaria		1	1.64	1.67	0.03
Rotifera		6	9.84	733	13.37
Crustacea	Cladocera	3	4.92	6.66	0.12
	Ostracoda	1	1.64	3.03	0.06
	Copepod calanoida	5	8.20	136.47	2.49
	Copepod cyclopoida	5	8.20	414.03	7.55
	Copepod harpacticoida	7	11.48	122.14	2.23
	Copepod nauplii	-	-	403.3	7.35
	Copepod copepodites	-	-	899.23	16.40
	Amphipoda	1	1.64	0.11	<0.01
	Mysidacea	2	3.28	0.34	<0.01
Chaetognatha		1	1.64	6.87	0.13
Mollusca		1	1.64	31.5	0.57
Larvacea		2	3.28	8.99	0.16
Meroplankton	Medusa of *Obelia* spp.	-	-	138.62	2.53
	Polychaeta larvae	-	-	1134.3	20.68
	Cirripeda larvae	-	-	825	15.04
	Decapoda larvae	-	-	6.04	0.11
	Molluscs lamellibranch veligers	-	-	27.76	0.51
	Ascidiacea larvae	-	-	0.028	<0.01
	Crustacea eggs	-	-	5.79	0.11
	Fish eggs and larvae	-	-	0.58	<0.01

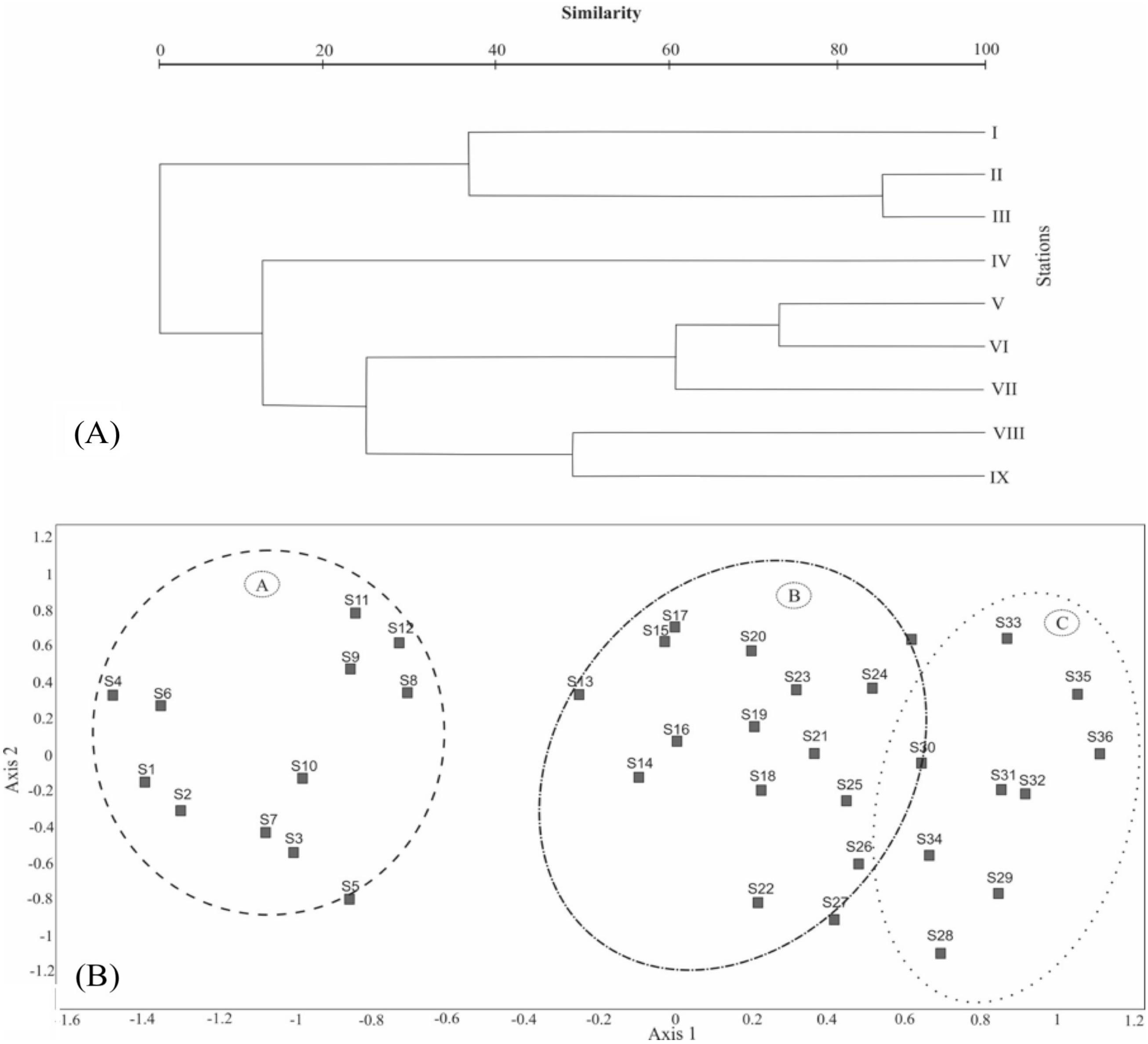

Fig. 3. Identification of station groups based on the results of (A) Bray-Curtis clustering and (B) non-metric MDS ordination both using data from station matrix. Letters from S1 to S36 denote for the sampling stations in the four seasons. A, B and C are estuary downstream, midstream, and upstream, respectively.

Community structure

All the recorded taxa were used for multivariate analysis. Results of hierarchical cluster analysis and multi-dimensional scaling are shown in Figure 3A and B. The cluster analysis and two-dimensional MDS plots divided the stations into three sectors (A, B, and C). The relative position of some stations within each sector reflects similarities in species composition among stations and also shows the anthropogenic influences. Sector A occupied the lower estuary stations (I, II, and III) and was influenced largely by seawater intrusion. Stations belonging to sector B were found in the middle region of the estuary and include most of sampling events from stations IV, V, VI, and VII. This sector being affected by maritime activities of the fisheries fleet and land runoff from the surrounding villages and Manzalla lake. Sector C at the upper estuary includes station VIII and IX; being affected directly by domestic and agricultural wastes. Mean zooplankton abundance in sector A was higher than the other 2 sectors (Table V).

Table V.- zooplankton abundance (ind.m^{-3}) at different sectors.

Sector	Mean abundance	Standard deviation
A	6211.8	3050.2
B	5897.4	5996.8
C	3439.4	4538.6

According to the analysis of similarity (SIMPER), the mean densities and occurrence frequencies of the taxa that contributed ≥ 1% within sector similarity or between sector dissimilarity are summarized in Table VI. The listed taxa accounted more than 67% of within-group similarity across the three sectors. Some widely distributed taxa dominated the zooplankton community in the three sectors, such as polychaete larvae, cirriped larvae, the larval stages of copepods, and the copepod *Oithona* spp. The other taxa demonstrated different roles along the estuary. The copepod *Euterpina acutifrons* and the species of Paracalanidae dominated the community at the estuary downstream. The tintinnid *Favella serrata* dominated the estuary midstream, together with the rotifer *Synchaeta okai*, and *Synchaeta pectinata* was the only species that dominated the community in the estuary upstream (Table VI). Note: a large number of species (*e.g. Leprotintinnus nordgvistii*, *Acartia clausi, Mesochra rapiens*, *Microsetella norvegica*, *Cypridina mediterrianea*, *Sagitta friderici*, Medusa of *Obelia* spp., and Molluscs Lamellibranch veligers) were recorded in high frequencies at sector A. Overall, the estuary midstream and upstream supported the highest densities of protozoans, rotifers, and most meroplanktonic larvae, whereas the estuary downstream supported the highest densities of copepods, cladocerans, ostracods, molluscs, chaetognths, and larvaceans.

Table VI.- Mean abundance (ind. m^{-3}) and Frequency of occurrence (%) averaged across all sectors by station grouping of those species/taxa that contributed ≥ 1% to within-group similarity or between-group dissimilarity. The values with asterisk indicate the dominancy.

Taxa	Abb.	Sector A Stations I, II and III	Sector B Stations IV, V, VI and VIII	Sector C Stations VIII and IX	WAopt	
					Chl a (µgl^{-1})	Salinity (gl^{-1})
Polychaeta larvae	Plar	954.6 (100)*	1157.6(100)*	1357.4(100)*	16.4	33.6
Cirripeda larvae	Crlar	364.5 (100)*	1118.3(100)*	929.4 (100)*	16	33.5
Copepodite stages	Cstag	1899.5 (100)*	493.1 (100)*	211.1 (100)*	14.2	36.6
Nauplii	Nlar	771.8 (100)*	245.8 (100)*	165.7 (100)	14	36.1
Synchaeta pectinata (Ehrenberg)	Spec	215.8 (25)	912.2 (100)*	304.8 (100)*	16.5	33.9
Oithona spp.	Oisp	868.3(100)*	241.5(100)*	201(100)*	16	36.9
Paracalanidae	Para	291.12 (100)*	57.7 (56.25)	20.7 (25)	9.1	37.83
Medusa of *Obelia* spp.	Mobe	137.4 (100)	203 (100)	11.7 (87.5)	18.6	34.8
Euterpina acutifrons (Dana)	Eacu	254.6 (100)*	21.4 (100)	24.5 (87.5)	11.6	36.9
Lamellibranch veligers	Lbve	50.9 (83.3)	14 (87.5)	21 (87.5)	11.3	35.7
Synchaeta okai (Sudzuki)	Soka	16.2 (41.7)	246.3 (93.8)*	61.4 (62.5)	20.4	33.4
Favella ehrenbergii (Claparéde and Laachmann)	Fehr	4.8 (16.7)	192.2 (50)	106.5 (75)	17.5	33.6
Decapoda larvae	Delar	8.3 (83.3)	4.8 (37.5)	5.2 (62.5)	14.2	36.1
Acartia clausi (Giesbrecht*)*	Acla	27.04 (75)	9.2 (87.5)	2.8 (62.5)	14.4	35.2
Synchaeta oblonga (Ehrenberg)	Sobl	4 (8.3)	80.2 (56.3)	43.7 (62.5)	23.1	33.7
Paramecium sp.	Pasp	1.9 (16.7)	11.64 (25)	37.7 (12.5)	20.9	31.9
Tintinnopsis campanula (Ehrenberg)	Tcom	9.2 (41.7)	10.3 (43.8)	2.4 (12.5)	18.4	35.3
Acartia discaudata (Giesbrecht*)*	Adis	4.4 (33.3)	13.4 (75)	3.4 (50)	15.7	34.4
Oikopleura dioica (Fol)	Odio	16.7 (66.7)	1 (18.8)	10.7 (25)	9.6	36.9
Halicyclops magniceps (Lilljeborg)	Hmag	5.1 (25)	2.1 (50)	4.2 (50)	11.5	32.5
Nitokra lacustris lacustris (Schmankevich)	Nlac	1.3 (16.7)	7.36 (56.3)	7.34 (75)	17	32.8
Podon intermedius (Lilljeborg)	Pinte	14.8 (50)	2 (31.3)	2.5 (12.5)	9.6	36.9
Synchaeta stylata (Wierzejski)	Ssty		154.9 (68.8)	65.8 (37.5)	18.9	32.2
Cypridina mediterrianea (Claus)	Cmed	6.1 (83.3)	1.7 (56.3)	1.1 (37.5)	13.8	35.8
Mesochra rapiens (Schmeil)	Mrap		9.7 (68.8)	8.8 (87.5)	16.6	32.8
Leprotintinnus nordqvistii (Brandt)	Lnor	138.6 (100)	0.3 (6.3)	4.9 (12.5)	5.5	38.4
Sagitta friderici (Ritter.Zàhon)	Sfri	18.7 (91)	5.4 (43.8)	1 (25)	14.3	37.1
Acanthocyclops americanus (Marsh)	Aamer		16.8 (50)	15.3 (56.3)	21.4	32.1

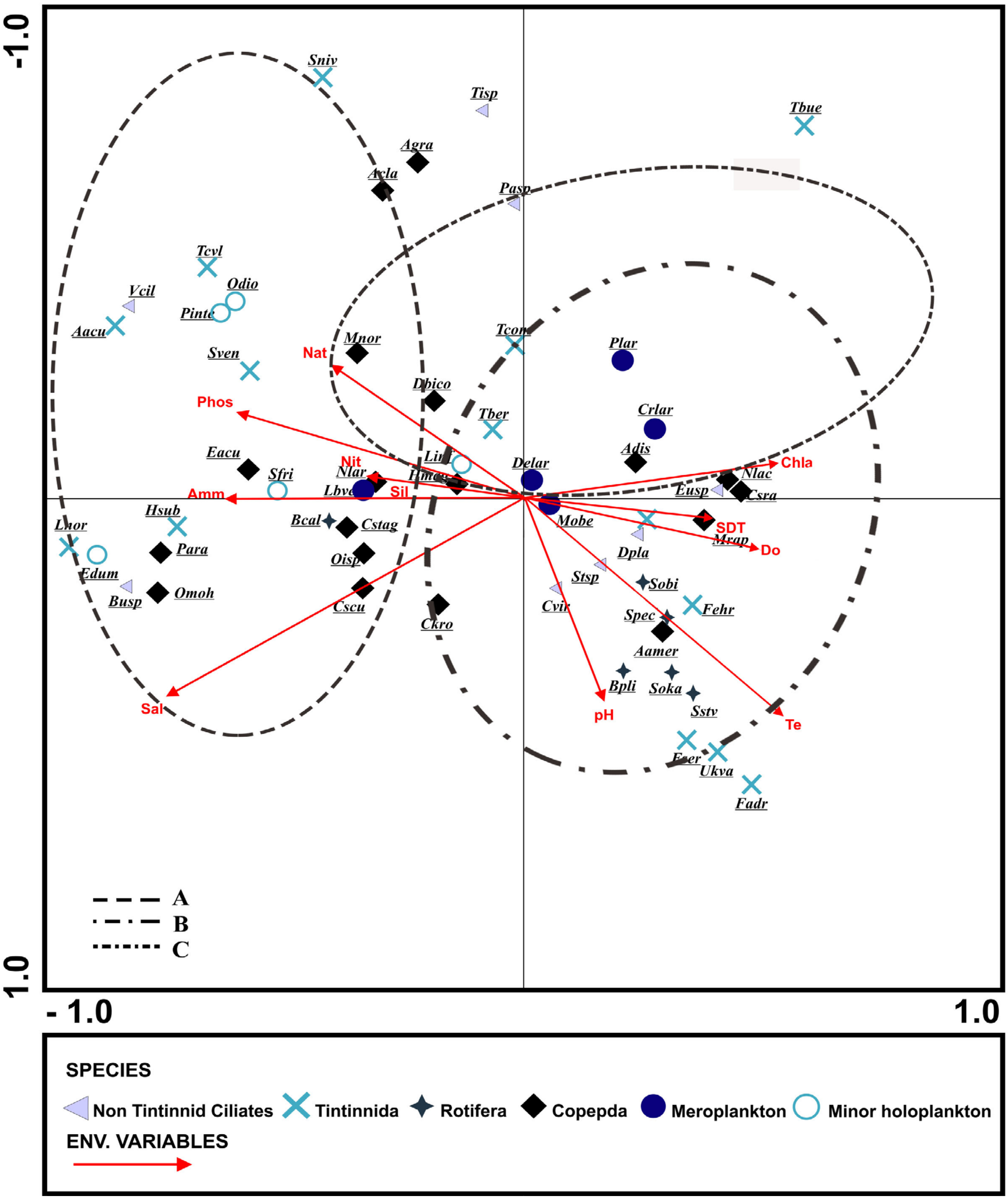

Fig. 4. Ordination diagram by CCA analysis of the important zooplankton taxa as a function of environmental variables (See **Table** VI for some abbreviations, other abbreviations are *Amphorellopsis acuta* (Aacu), *Bursaridium* sp.(Busp), *Climacostomum virens* (Cvir), *Euplotes* sp. (Eusp), *Dichilum platessoides* (Dpla), *Favella adriatica* (Fadr), *Helicostomella subulata* (Hsub), *Stenosemella nivalis* (Sniv), *S. ventricosa* (Sven), *Strobilidium* sp. (Stsp), *Tillina* sp. (Tisp), *Tintinnopsis beroidea* (Tber), *T. cylindrica* (Tcyl), *Vasicola ciliata* (Vcil), *Undella hyalina* (Uhya), *Brachionus calyciflorus* (Bcal), *B. plicatilis* (Bpli), *Ectopleura dumortierii* (Edum), *Acartia grani* (Agra), *Centropages kroyeri* (Ckro), *Clytemnestra scutellata* (Cscu), *Diacyclops bicuspidatus odessanus* (Dbico), *Microsetella norvegica* (Mnor), *Onychocamptus mohammed* (Omoh), *Evadne tergestina* (Eter), and *Limacina inflata* (Linf)). Temp (temperature), SDT (Sechi disk Transparency), Sal (salinity), Sil (SiO_3), Amm (NH_4), Nit (NO_2), Nat (NO_3), Phos (PO_4), and Chla (chlorophyll *a*). A, B, and C are estuary downstream, midstream, and upstream, respectively.

Table VII.- Monte Carlo test with 999 permutations for the selection of environmental parameters.

Variables	Variance explained	F-ratio	P-value
Salinity	0.23	6.42	0.001
Temperature	0.13	4.01	0.001
PO_4	0.09	2.32	0.01
Chlorophyll *a*	0.08	1.93	0.046
Dissolved oxygen	0.04	1.35	0.216
pH	0.04	1.32	0.207
NH_4	0.03	1.09	0.329
SiO_3	0.03	1.19	0.294
NO_2	0.02	0.78	0.619
Sechi disk transparency	0.02	0.58	0.795
NO_3	0.01	0.48	0.87

Linkage between zooplankton community and environmental variables

The Canonical Correspondence Analysis (CCA) ordination indicates that environmental parameters had significant influences on zooplankton species distribution ($P< 0.05$; Monte Carlo test), explaining 79.3 % of the total variance. Of the tested environmental variables, Monte Carlo permutations showed, in descending order, salinity (explained alone 23% of the variance), temperature, phosphate, and chlorophyll *a* had the major significant influences on the distribution of zooplankton species (Table VII). CCA ordination diagram for the two most important ordination axes (Fig. 4) showed the pattern of the variations in the community composition, which can be explained by the environmental variables, and also showed the distribution patterns of the species along each environmental gradient. From this, it can be inferred that salinity is the major factor that controlled the species distribution along the estuary. Sampling events from stations I, II, and III at the estuary downstream were positively correlated with salinity and distributed in the right hand side of the biplot. Meanwhile, most of sampling events from the other stations were negatively correlated with salinity and grouped in the left hand side of the biplot. Traditionally low salinity taxa (non tintinnid ciliates, rotifers, majority of freshwater copepods like the cyclopoid *Acanthocyclops americanus* and the harpacticoids *Mesochra rapiens* and *Nitokra lacustris lacustris*) and *Favella* spp. were mainly associated with the lowest values of salinity and the gradients of pH, temperature and phytoplankton biomass, indicating a great affinity of species for the terrestrial effluents and the high trophic conditions. Conversely, traditionally marine species were associated with the highest values of salinity and the low concentrations of phytoplankton biomass. Although, most meroplanktonic larvae were associated with the point of the diagram origin (0,0), shift toward sectors B and C can be noticed, indicating the distribution of these larvae along the estuary but their production increased with the decreasing of salinity and the increasing of phytoplankton biomass.

The abundance and distribution of the most important zooplankton taxa along the environmental gradients of eutrophication and salinity in the Damietta estuary can also be explored by calculating their abundance-weighted optima of chlorophyll *a* and salinity, respectively (Table VI). For example, the rotifers *Synchaeta oblonga,* and *S. okai*; the protozoan *Paramecium* sp.; and the copepod *Acanthocyclops americanus* showed their abundance weighted optima at the highest levels of algal biomass, whereas, *Leprotintinnus nordgvistii*; the larvacean *Oikopleura dioica*; and the cladoceran *Podon intermedius* were generally more abundant at the lowest concentrations of chlorophyll *a*. On the other hand, the results confirm that, the tintinnids *Leprotintinnus nordgvistii*; the chaetognath *Sagitta friderici*; and the species of Paracalanidae showed their optima at the highest levels of salinity, whereas *Paramecium* sp.; the copepod *Acanthocyclops americanus*; and *Synchaeta stylata* were more abundant in less saline water.

DISCUSSION

Increasing human population has a direct link with nutrient loading in freshwater and coastal ecosystems (Nilsson and Malm-Renöfält, 2008; Prasad *et al*., 2014). A high nutrient load deteriorates the water quality in Damietta estuary and cause eutrophication. The significant spatial variations in nitrogenous nutrients concentrations along the estuary may be attributed to the rate and volume of land water. Compared to the only two prior studies for the Damietta estuary done by Khedr (1998) and Saad and Abdel-Moati (1984), the present study showed that the general physical status of the water in the estuary has not changed significantly over the last 15 years, despite the expansion of the human activities.

In this study, the multivariate analysis revealed the presence of three well-defined regions along the Damietta estuary (downstream, midstream, and upstream). The variations in the zooplankton assemblages between these regions were mainly a function of variations of environmental conditions; in particular, salinity had the major effect on zooplankton, in addition to temperature, phosphate concentration, and food availability (*e.g.*

phytoplankton biomass). This is consistent with other studies that consider salinity the most important environmental variable determining spatial distribution of zooplankton in estuaries (*e.g.* Collins and Williams, 1982; Froneman, 2002; Kibirige and Perissinotto, 2003).

The zooplankton community in the Damietta estuary was characterized by low species diversity compared to that of the Nile's Rosetta estuary (Setaita and Montaser, 2010), suggesting high levels of eutrophication in the Damietta estuary. Uriarte and Villate (2004) indicated that the estuarine zooplankton communities in Bay of Biscay were controlled by levels of pollution and the physical properties of the water. In most estuaries the greatest species diversity occurred near the mouth of the river since the diversity is enhanced through the mixture of estuarine and coastal zooplankton, and characterized by the presence of large consumers (chaetognathas, copepods and veligers) (Lam-Hoai *et al*., 2006; Primo *et al*., 2009). This is consistent with the present results; where high species number at the estuary mouth indicating the prevalence of coastal zooplankton species while the much lower values toward estuary's upstream may be due to the high levels of pollutants and/or reduced salinity. Gray *et al*. (1979) stated that the pollution causes the loss of some sensitive species and leads to the dominance of the few most tolerant species. In most temperate estuaries, the freshwater flow at the upper estuary makes the freshwater zooplankton predominant (Primo *et al*., 2009). Although this wasn't the case in the Damietta estuary due to the obstructed flow by the Farskour dam, 20 fresh water species were still recorded and some of these species like *Acanthocyclops americanus* and *Nitokra lacustris lacustris* appeared in high frequencies particularly at the estuary upstream indicating that the zooplankton communities are shaped by salinity variations

Total zooplankton, copepods, cladocerans, appendicularians, veliger larvae and tintinnids showed higher densities at the estuary mouth where salinities were highest. This finding could be attributed to the rapid exchange with seawater, which improved water quality and lowered eutrophication. These observations supported higher abundance of zooplankton organisms with increasing salinity and subsequent improvement in water quality (Siokou-Frangou and Papathanassiou, 1991; Uriarte and Villate, 2004).

Tintinnids frequently appeared along the estuary with relatively high diversity. They were mainly within genera classified as neritic (*Favella*, *Leprotintinnus*, *Stenosemella* and *Tintinnopsis*) or cosmopolitan (such as *Amphorellopsis* and *Undella*) (Dolan *et al*., 2006). Many factors typically control the spatial and temporal distribution of tintinnids including biological factors such as food supply and physicochemical factors as well as temperature and salinity (Sanders, 1987; Verity, 1987; Pierce andTurner, 1993). However, no clear correlations can be found between tintinnid abundance and chlorophyll *a* (Pearson's: r= 0.0.122, P=0.480) or temperature (Pearson's: r= 0.109, P=0.506) during the present study. Barría de Cao (1992) did not observe any correlation between the temperature and tintinnid abundance, while Kamiyama and Tsujino (1996) observed no correlation between tintinnids and chlorophyll *a*. The abundance of tintinnids during the present study seems to be affected primarily by salinity: the low salinity at the estuary upstream may have prohibited the tintinnids proliferation, while the three neritic species, namely *Leprotintinnus nordqvistii*, *Stenosemella ventricosa* and *Tintinnopsis cylindrical,* were frequently found at the mouth of the estuary potentially from mixing during the high tide. Similar observations were recorded by Rakshit *et al*. (2014) for some neritic tintinnids in Hooghly river estuary. On the other hand, the existence and dominance of *Favella* spp. along the estuary is evidence that these hyaline tintinnids can proliferate and survive in poor conditions. Non-tintinnid ciliates also showed low diversity and abundance during this study and similar to the pattern described by Rakshit *et al*. (2014) for the Hooghly river estuary, while contrasting with the pattern that usually described for tropical coastal waters (Pierce and Turner, 1994).

Rotifers showed significant contribution in both freshwater and estuarine systems may be attributed to their trophic status as major grazers of algae and small ciliates (Havens, 1991; Arndt, 1993; Tian et al., 2017). The dominant species of rotifer in Damietta estuary belonged to *Synchaeta*, a genus which is considered to be a marine rotifer (Wei and Xu, 2014) and is common in temperate estuaries (Townsend, 1984; Aboul-Ezz *et al*., 2014; Wei and Xu, 2014). *Synchaeta* were represented by 4 species and constituted more than 99% of the total rotifers abundance, likely due to relatively high salinity of the Damietta estuary. Heinbokel *et al*. (1988) reported the dominance of *Synchaeta* in Chesapeake Bay, while Aboul-Ezz *et al*. (2014) reported the significant contribution of *Synchaeta* to the rotifer community in the Egyptian Mediterranean water.

Although copepods dominated the holoplankton in Damietta estuary, only *Oithona* spp., *Euterpina acutifrons* and Paracalanidae were common; while the other species were recorded infrequently. Similar observations were found in both the Egyptian Mediterranean coast (Nour El-Din, 1987; Abdel-Aziz and Aboul-Ezz, 2004; Abdel-Aziz *et al*., 2007) and the Suez canal area (El-Serehy *et al*., 2001; El-Sherbiny *et al*., 2011). The dominance of the small Oithonidae and Paraclanidae is a characteristic of the inshore tropical waters (Stephen, 1978; Hopcroft *et al*., 1998; Abdel-Aziz and Aboul-Ezz, 2004; McKinnon *et al*., 2005; Duggan *et al*., 2008). Stephen (1978) claimed that, although the Paracalanidae were the dominant copepod family in Indian coastal waters, cyclopoid copepods were more represented as a consequence of the use of small mesh size net. In this study, a small mesh size net (54 µm) was used and the small cyclopoid copepods dominated the copepod community. The cyclopoid morphology or prey preferences may express a greater flexibility to environmental conditions than calanoides (Paffenhöfer, 1993).

Oithona spp. and *Euterpina acutifrons* are assumed from their distribution to be neritic, cosmopolitan and estuarine species (Dowidar, 1965; Hussein, 1977; Vieira *et al*., 2003). They are also eurytropic species tolerating a wide range of temperature and salinity (Dowidar, 1965; Nour El-Din, 1987). The copepod nauplii and copepodite stages dominated the zooplankton in Damietta estuary, as they do in other estuaries (Turner, 1982; Winder and Jassby, 2011). They formed the main bulk being 20.4% and 45.5% of the total copepod abundance respectively. Vieira *et al*. (2003), claimed that the neritic and estuarine plankton differ from the oceanic by the smaller size of organisms and by the higher abundance of larval stages.

The meroplankton abundance reflects the reproductive rates of the benthic adult forms with their high densities reflecting larval recruitments at the mouth of the estuaries (Raymont, 1983) where they sometimes dominated estuarine zooplankton (Fulton, 1984). This is consistent with the present results where the meroplanktonic larvae generally dominated the community structure during the study period. Among all the recorded meroplanktonic forms, cirriped larvae and polychaete larvae were consistently highly abundant at all stations of the estuary. A significant increase in density of polychaete larvae with decreasing salinity occurred along the estuary, while for cirriped larvae the effect of salinity was limited and their maximum abundance appeared at the estuary midstream. This suggests meroplanktonic populations may be more related to differences in benthic habitat or productivity than the pelagic environment (Sautour and Castel, 1995). Thus the large extent of mudflates toward the end of the estuary may provide an excellent habitat for polychaetes while the presence of hard substratum particularly at stations from IV to VIII at the estuary midstream can serve as habitat for barnacle populations.

Cnidarians were represented only by the coastal hydromedusae (*Ectopleura dumortierii* and *Obelia* spp.). It is known that cnidarian species can not flourish in estuaries due to difficulties with osmoregulation (Dumont, 1994). Therefore, low densities of cnidarians appeared only at the estuary's lower end where salinities were >30%.

CONCLUSION

In general, the obstruction of Nile River flow by Farskour dam changed the properties of Damietta estuary water, with seawater now mixed primarily with land-based effluents. It seems that the Damietta estuary is now under environmental stress, that has resulted in changes in the species dynamics within the estuary. The abundance and diversity of zooplankton community structure was relatively homogenous within the high salinity region at the downstream part of the estuary, while considerable gradients in abundance and diversity of both meroplanktonic and holoplanktonic groups were found within the acute eutrophic region in the upstream part of the estuary.

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Statement of conflict of interest

Authors have declared no conflict of interest.

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