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Impact of Umum Drain on zooplankton community structure in Max Bay, Alexandria, Egypt

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Abstract

Zooplankton standing stock and diversity cycle were studied bimonthly during 1995 and discussed in relation to the most effective environmental physico-chemical parameters in both Umum Drain and Max Bay. This bay is located west of Alexandria is an estuarine zone of a huge agricultural drain (Umum Drain).

The average counts of zooplankton standing stock in Umum Drain were higher than that recorded in Max Bay ($408x10^3$ and $196x10^3$ organisms m^{-3}).

Generally, zooplankton population was dominated by three main groups namely; Rotifera, Protozoa and Crustacea (copepods). They respectively contributed 69.4, 17.8 and 7.0% by number to the total zooplankton in Max Bay and 84.6, 10.7 and 2.0% in Umum Drain. A total number of 80 zooplankton taxa were recorded and characterized by different ecological affinities. Few species were responsible for the main bulk of the community namely; the rotifers *Brachionus angularis* and *B. calyciflorus*, beside *Filinia brachiata* and the Ciliophora *Paramecium caudatum* in Umum Drain, while *Synchaeta pectinata*, the Ciliophora, *Euplotes patella* and *Favella adriatica* in Max Bay.

The species diversity showed irregular pattern ranging from 0.92 to 2.04 in Umum Drain and from 0.29 to 2.52 in Max Bay. The effects of the most ecological parameters on the standing stock and diversity index were established and discussed according to the regression models.

Key words: Max Bay, zooplankton, Diversity Index.

INTRODUCTION

Max Bay extends for about 7 km, between El-Agamy head land in the west and the Western Harbor in the east. It has a total area of about 20 km^2 and average width of 3 km [1] with average depth of 15 m. The bay receives a heavy load of wastewater from Umum Drain and the main basin of Lake Mariut. These waters are grossly contaminated with industrial, agricultural and domestic wastes. Umum Drain is 45.8 km long with a width of 20 m and an average depth of 3-4 m.

The configuration of the bay, its hydrology and chemical characteristics have been studied by several authors [2-8]. The distribution and ecology of the phytoplankton were studied [9-12]. Neverthless, the studies on zooplankton standing stock were rather limited [13,14].

The present investigation deals with the enfluence of Umum Drain on the quantity and quality of zooplankton community composition and its species diversity (February-December 1995) in correlation with the most abiotic factors to evaluate the productivity of Max Bay water.

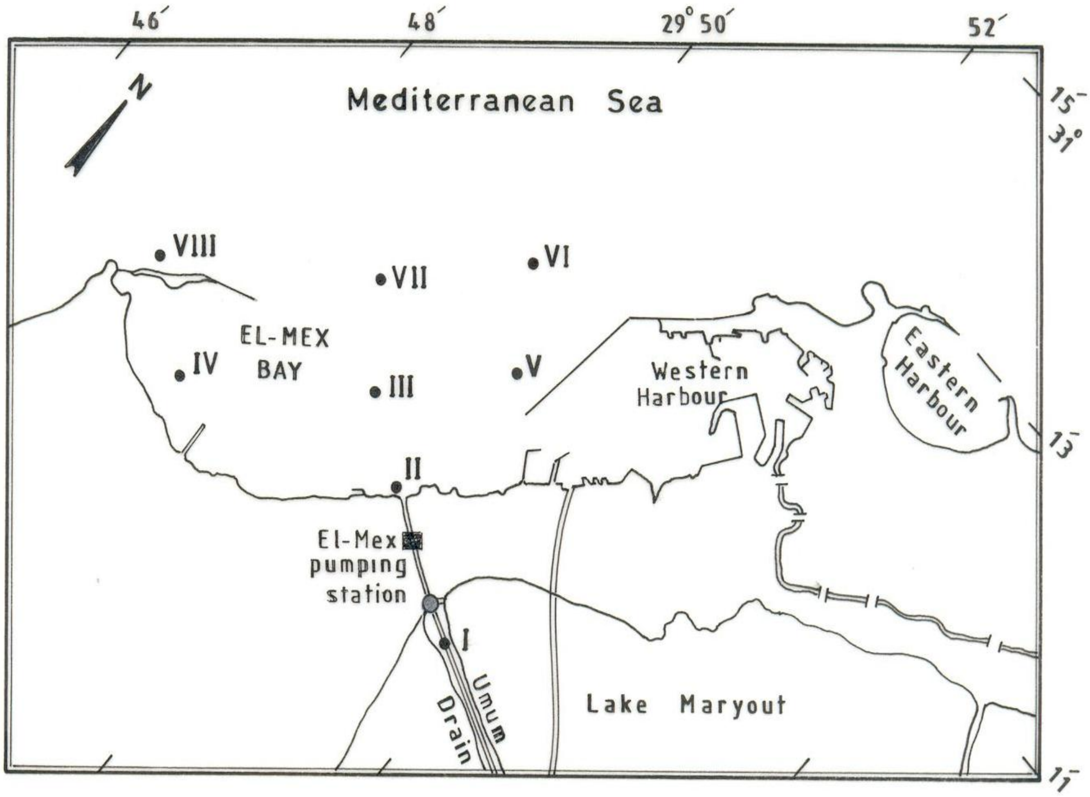

Figure 1: Area of investigation.

MATERIAL AND METHODS

Zooplankton samples were collected bimonthly at seven hydrographic stations in Max Bay and one in Umum Drain (Fig. 1) during the period from February to December 1995. Sampling occurred in the surface water and in the near bottom layer by filtering 50 liters of water, using plankton net of 25µm.

Ninety zooplankton samples were collected. The collected samples were preserved in 4% neutral formalin solution. In laboratory, the volume of each sample was standardized to 100 ml and triplicate subsamples{5ml each} were removed for identification and counting under 300X research microscope. The standing stock of zooplankton community was calculated as their total number per cubic meter. The identification of zooplankton organisms was done [15-20].

The data on physico-chemical parameters were studied at the same sites and times and published [13]. The diversity index was estimated [21]. The correlation coefficient between biological (zooplankton standing stock and diversity index) and physico-chemical parameters[13] were done for the surface and near bottom layers (n= 48 and 42 for surface and near bottom layers, respectively). Multiple regression equation at confidence limit 95% ($p \geq 0.05$) was calculated at each layer separate to quantify the standing stock and diversity index in relation to the most correlative environmental factors. The statistical analysis was performed using Number Gruncher Statistical System [22].

RESULTS AND DISCUSSION

Zooplankton standing stock

Species composition and distribution

Zooplankton composition of the present investigation includes 80 species of which 34 were specific to Umum Drain (Table 1). The richest division in number of species was Protozoa (13 and 26 species), followed by Rotifera (11 and 22 species) and Copepoda (6 and 22 species) in Umum Drain and Max Bay, respectively. The other 10 species were infrequently or rarely encountered; these comprised Nematoda, Annelida, Mollusca and Crustacea (Cladocera, Ostracoda and Cirriped larvae).

Table 1: Zooplankton species recorded in Umum Drain and Max Bay (Fbruary – December 1995).

Table (1): Zooplankton species recorded in Umum Drain and Max Bay (February-December 1995).

		Umum Drain		Max Bay	
		S	**B**	**S**	**B**
Rotifera					
Brachionus calyciflorus	Pallas	+	+	+	+
B. angularis	Gosse	+	+	+	+
B. plicatilis	Muller	+	+	+	+
B. quadridentata	Herman			+	
Keratella quadrata	Muller				+
K. cochlearis	Gosse				+
Manfridium eudactylotum	Beauchamp			+	+
Colurella obtusa	Hauer				+
Lepadella patella	Muller	+	+	+	+
Lecane luna	Muller			+	
L. elasma	Muller			+	
L. depressa	Muller	+		+	
Monostyla lunaris	Ehr.	+	+	+	+
M.bulla	Gosse		+	+	+
M. closterocerca	Schmarda			+	+
Proales daphnicola	Thompson	+		+	+
Trichocerca cylindrica	Imhof	+	+	+	
Synchaeta pectinata	Ehr.			+	+
S. oblonga	Ehr.			+	+
Filinia longiseta	Ehr.	+	+	+	+
F. brachiata	Rouss.	+	+	+	+
Testudinella sp.			+	+	+
Protozoa					
Ammonia beccarii	Linn	+	+	+	+
Elphidium crispum	Linn			+	+
Textularia agglutinans	ORB.			+	+
Cycloforina contorta	Norvang			+	+
Globigerina inflate	ORB.			+	+
G. bulloides	ORB.	+			
Orbulina universa	ORB.		+	+	+
Centopyxis aculeate	Ehr.		+	+	+
Euplotes patella	Muller	+	+	+	+
Oxytricha fallax	Stein	+	+	+	+
Paramecium caudatum	Ehr.	+		+	
Plagiophyta nasuta	Stein	+		+	
Liontus fasciola	Ehr.		+	+	+
Askenasia volvox	Clap.			+	+
Trachelius ovum	Ehr.	+		+	+
Trachelophyllum apiculatum	Clap.	+	+		+
Teuthophrys trisulca	Chatton & Beauch.	+	+	+	
Amoeba radiosa	Ehr.			+	

Favella adriatica	Imhof			+	+
F. serrata	Mobius			+	
F. brevis	Kofoid & Camp.				
F. ehrenbergi	Clap.				
Helicostomella subulata	Ehr.			+	+
Xystonella longicauda	Brandt			+	
Eutintinnus fraknoi	Kofoid & Camp.			+	
Tintinnopsis campanula	Ehr.			+	
Crustacea				+	
1- Copepoda				+	
Acanthocyclops americanus	March		+	+	+
Halicyclops magniceps	Sars	+		+	+
Mesocyclops leuckarti	Claus	+			+
Thermocyclops crassus	Fischer	+		+	+
Th. Sp.		+		+	+
Paracyclops fimbriatus	Claus	+		+	+
Oithona nan	Giesbrecht	+			+
O. plumifera	Baird	+		+	+
Oncaea minuta	Giesbrecht	+		+	+
On. Media	Giesbrecht	+		+	+
Canthocamptus gracilis	Sars	+			+
Microsetella norvegica	Doeck	+		+	+
Euterpina acutifrons	Dana	+			+
Nitocera lacustris	Schm.	+		+	+
Paracalanus parvus	Claus	+		+	+
Clausocalanus arcuicornis	Dana	+			+
Diaptomus sp.					
Centropages typicus	Kroyer	+		+	+
Acartia clausi	Giesbrecht	+	+	+	+
A. grani	Sars	+		+	+
Nuplii of Copepoda		+		+	+
2- Ostracoda					
Cypridina Mediterranean	Costa	+	+	+	+
Cypria pellucida	Sars	+		+	+
3- Cladocera					
Podon polyphemoides	Leuckart				
Moina micrura	*Kruz.*	+	+	+	+
4- Cirriped larvae					
Nedmatoda					
Free living nematode		+	+	+	+
Annelida					
Polychaete larvae					+
Spionid larvae					+
Oligochaete larvae				+	+
Mollusca					
Veligers of lamellibranche			+	+	+

In Max Bay, a total of 80 species out of them 21 and 11 species were specific to the surface and near bottom layers, respectively, whereas 48 species (15 Rotifera, 17 Protozoa, 8 Copepoda and 8 others; 2 Ostracoda, 2 Cladocera, 1 Nematoda, Annelida, Mollusca and Cirriped larvae were common to both surface and near bottom layer.

The average annual standing stock of zooplankton of Umum Drain reached 484 x 10^3 organisms m^{-3} in the near bottom layer. This value decreased to 332 x 10^3 organisms m^{-3} in the surface water as a result of the direct effect of the pollutant effluents. Max Bay attained lower averages standing stock than Umum Drain (254 x 10^3 and 139 x 10^3 organisms m^{-3} in the surface and near bottom layers, respectively). These values were much higher than those recorded by Guerguess [14]during 1987 at the same site. This is attributed to increase in the fertility of the water as a result of the eutrophication effect of Umum Drain water [11].

Generally, Rotifera were the most important group; formed 89.35 and 80.11% to the total zooplankton in the surface water in Umum Drain and Max Bay, respectively (Table 2). In the near bottom layer, Rotifera formed 81.34% in Umum Drain, decreased to 49.76% in Max Bay. The association of Rotifera with organically rich water was previously recorded [23,14].The dominant species were *Brachionus angularis, B. calyciflorus* and less so *Filinia brachiata* with different percentage frequencies in Umum Drain and Max Bay (Table 3). *Synchaeta pectinata* contributed a significant part in Max Bay particularly in the near bottom layer.

Protozoa ranked the second group constituting 7.49 and 12.84% to the total zooplankton in the surface water in Umum Drain and Max Bay, respectively then increased to 12.88 and 26.96%, respectively in the near bottom layer.*Paramecium caudatum, Oxytricha fallax* and *Euplotes patella* were the major species in both Umum Drain and Max Bay, beside *Favella adriatica* in the near bottom layer in Max Bay (Table 3). . In the surface water Copepoda and their larvae attained 1.05% to the total zooplankton in Umum Drain increased to 4.08% in Max Bay. The same trend was observed in the near bottom layer (2.68 and 12.44%, respectively).

Due to mixing between Umum Drain water and seawater in Max Bay the zooplankton standing stock increased from 332 x 10^3 organisms m^{-3} in the Umum Drain to 1166 x 10^3 organisms m^{-3} at station II and the number of species increased from 23 to 36, respectively. Also the effect was slightly extended to station III (averages 274 x 10^3 and 327 x 10^3 organisms m^{-3} in the surface and near bottom layers, respectively) with 32 species in the surface water and 37 species in the near bottom layer compared to 28 in the Umum Drain. The lowest densities were restricted to the west in both layers at stations IV and VIII (Fig. 2).

Table 2: The annual average numbers of the different groups of zooplankton, their frequencies and number of species at Umum Drain and Max Bay.

	Umum Drain						Max Bay					
	Surface			Near Bottom			Surface			Near Bottom		
	org. m^{-3} x10^3	%	No. of Sp.	org. m^{-3} x10^3	%	No. of Sp.	org. m^{-3} x10^3	%	No. of Sp.	org. m^{-3} x10^3	%	No. of Sp.
Rotifera	296.0	89.35	9	394.0	81.34	11	204.0	80.00	19	69.0	49.76	18
Protozoa	25.0	7.49	9	62.0	12.88	8	33.0	13.00	24	37.0	26.96	19
Copepoda	4.0	1.05	3	13.0	2.68	4	10.0	4.00	18	17.0	12.44	13
Nematoda	6.8	2.04	1	12.0	2.48	1	2.0	0.80	1	2.4	1.64	1
Cirripede larvae	0.0	0.00	0	0.3	0.07	1	2.6	1.00	1	7.3	5.20	1
Ostracoda	0.2	0.07	1	2.0	0.41	2	0.4	0.20	2	0.8	0.48	2
Cladocera	0.0	0.00	0	0.0	0.00	0	0.6	0.30	2	0.9	0.68	2
Annelida	0.0	0.00	0	0.0	0.00	0	0.9	0.40	1	4.1	2.62	2
Mollusca	0.0	0.00	0	0.7	0.14	1	0.5	0.20	1	0.3	0.16	1
Total	332.0	100.00	23	484.0	100.00	28	254.0	99.90	69	138.8	99.94	59

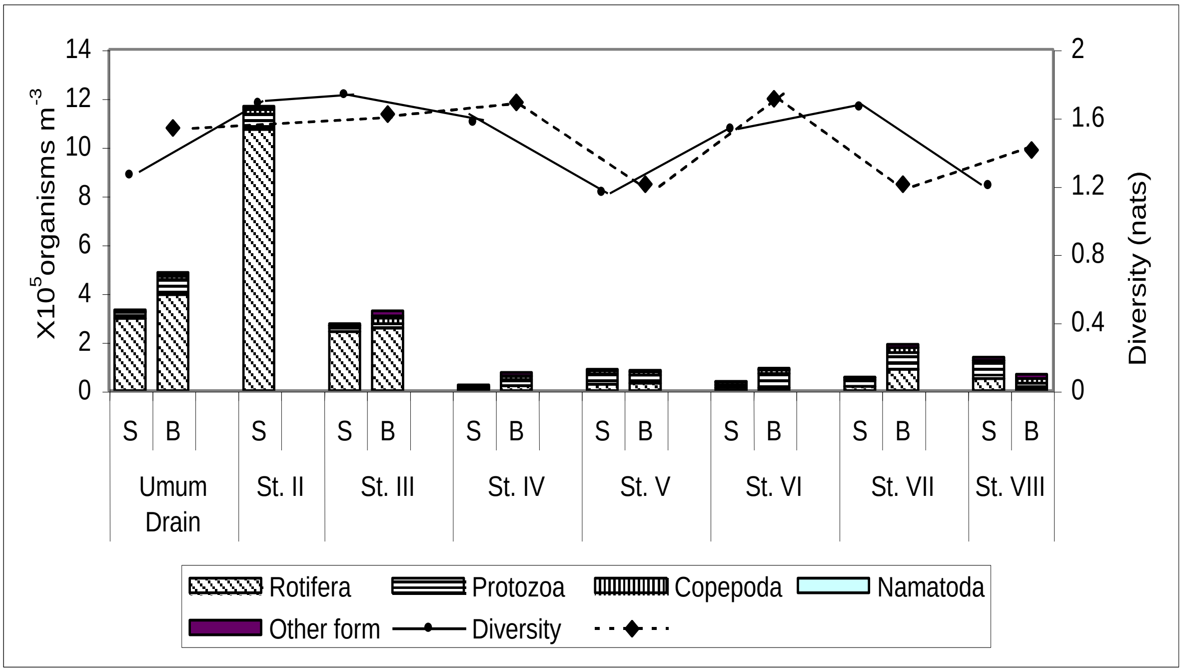

Figure 2: Distribution of zooplankton, its main components and diversity index (S=surface water B=near bottom layer) at max Bay and Uman Drain.

Figure (2): Distribution of zooplankton, its main components and diversity index (S= surface water, B= near bottom layer) at Max Bay and Umum Drain.

Table 3: The dominant species and their percentage frequencies at Umum Drain and Max Bay.

Species	**Umum Drain**		**Max Bay**	
	Surface	**Bottom**	**Surface**	**Bottom**
Brachionus angularis	57.30	48.80	35.10	18.80
Brachionus calyciflorus	29.70	21.30	32.70	11.10
Synchaeta pectinata	0.00	0.00	3.20	11.40
Filinia brachiata	1.10	7.20	1.90	1.40
Paramecium caudatum	2.90	7.00	1.30	0.32
Euplotes patella	1.90	2.00	6.10	3.11
Oxytricha fallax	2.30	2.20	1.50	0.60
Favella adriatica	0.00	0.07	1.70	14.50
Nematoda	2.00	2.50	0.80	1.60

Bimonthly variations of the total zooplankton

Umum Drain represents the major source of waste water into the Max Bay. It was characterized by a salinity lower than 10 and low concentration of dissolved oxygen owing to a steady increase in the concentration of oxidizable organic matter and ammonium [13]. The community was comprised mainly by brackish and freshwater forms transferred from Lake Mariut. Max Bay showed a marked variability of zooplankton standing stock in space and time, as well as in community structure as follows:

- **February**

The diluted water mass was dominated [13]. The zooplankton counts showed a marked variations between surface and near bottom layers in Umum Drain (12 x 10^3 and 80 x 10^3 organisms m^{-3}, with 7 and 9 species, respectively). Also, in Max Bay the averages were 63 x 10^3 and 120 x 10^3 organisms m^{-3} ,with 22 and 23 species, respectively having the highest density in the east and decreased westward (Fig. 3). In Umum Drain, *Halicyclopos magniceps* and the free living Nematoda formed the main bulk of the zooplankton community with 35 and 29% to the total count in the surface water and 37.5% for each in the near bottom layer. In Max Bay they formed 7.0% for each in the surface water decreased to 3.3 and 5.6%, respectively in the near bottom layer and they were completely absent in the northern (offshore) stations. In Umum Drain, Protozoa formed 6.0% to the total count in the surface water, with a single one species (*Ammonia beccarii*), while in the near bottom water layer it attained 15% with 3 species dominated by *Favella adriatica.* In Max Bay, Protozoa formed about 82% in both layers with 13 and 11 species, respectively. The tintinnid; *Favella adriatica* was the dominant in the two layers beside *Euplotes patella* in the surface layer. Rotifera attained 18 and 5% in the surface and near bottom layers, respectively in Umum Drain with the dominance of *Trichocerca cylindrica*. *Lepadella* *patella* and *Proales daphnicola* were less recorded in the surface and near bottom layers. In Max Bay, Rotifera constituted 2 and 4%, respectively in the two layers where *L. patella* appeared at station III in both layers and *Keratella quadrata* was recorded at station VI in the near bottom layer.

- **April**

Water temperature showed a slight increase (Table 4) accompanied with a rise in salinity. In consequence, the zooplankton standing stock in Umum Drain and Max Bay developed to its highest density of the all year round particularly at stations II and III. Another small increase was observed at station V (Fig. 3). This was accompanied with high values of oxidizable organic matter, nutrients and low salinity, which indicate the direct effect of drainage water. This was confirmed with the dominance of brackish and freshwater forms. Rotifera constituted the main bulk of zooplankton in Umum Drain and Max Bay (Fig. 3). In the surface water, they attained 93.0% to the total standing stock for both and in the near bottom layer they formed 89 and 82%, respectively . *Brachionus* species and *Filinia brachiata* predominated in Umum Drain while in Max Bay they were restricted to the middle and east stations but *Testudinella sp*. appeard in the west. In Umum Drain and Max Bay Protozoa were frequently recorded constituting 5.2 and 3.3% at the surface waters and 9.5 and 5.6% in the near bottom layers, respectively. The ciliates; *Oxytricha fallax* and *Paramecium caudatum* dominated in Umum Drain and middle and east of the bay, while the Foraminifera; *Globigerina bulloides* appeared at stations VI and VII. Copepoda attained 0.9 and 1.5% in the surface and near bottom layers in Umum Drain, respectively, increased to 2.5 and 9.1%, respectively in Max Bay with the prevailing of nauplii.

- **June**

Water temperature was remarkably increased (Table 4). A sharp drop in the total community occurred (Fig. 3); Umum Drain attained its lowest density in the surface water (8 x 10^3 organisms m^{-3}) where Protozoa and Nematoda equally shared the zooplankton community. Ciliates and Nematoda are classified with the polysaprobes characteristic for strongly polluted waters [24,25]. Protozoa increased forming 8.2 and 28.1% to the zooplankton density, with 4 species in both layers of Max Bay. *Oxytricha fallax* was the dominant species in the drain and stations II and III of the bay, while the eurytopic, *Euplotes patella was* restricted to stations VII and VIII. In the surface water ,Rotifera were completely disappeared in Umum Drain but still dominant in Max Bay forming 82.4%, with 13 species. In the near bottom layer Rotifera formed 45 and 33.8% in Umum Drain and Max Bay, with 4 and 6 species respectively. *Lecane depressa, Proales daphnicola* and *B. calyciflorus* were the dominant species at stations II, III and IV, while the marine form, *Synchaeta* species dominated at other stations. Copepoda attained 5.7 and 7.9% at the two layers, respectively in Max Bay with also the dominance of nauplii.

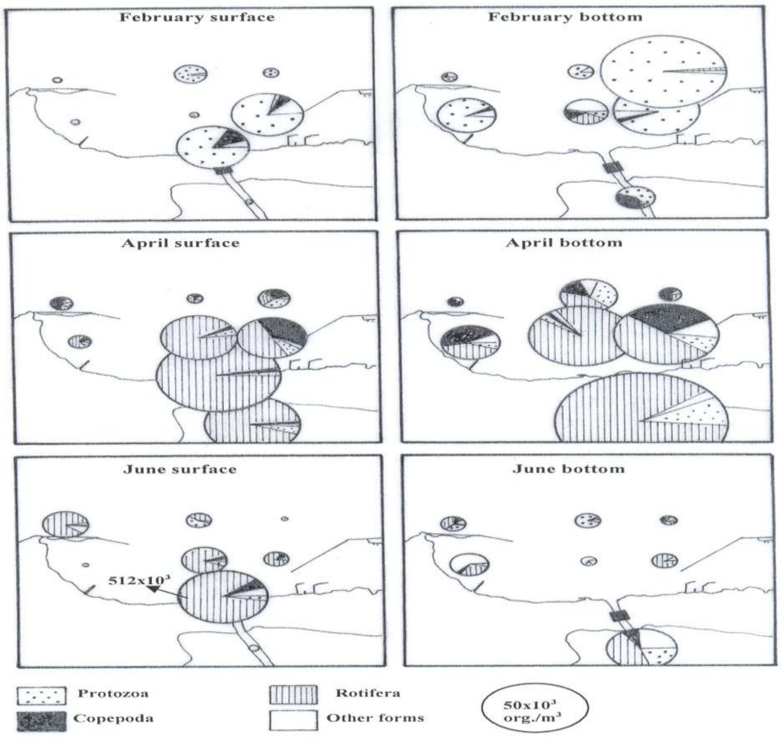

Figure 3: Spatial and monthly abundance and percentage composition of zooplankton in Max Bay and Umum Drain during February, April and June.

Table 4: Range and mean values of some hydrographic parameters in the surface (S) and near bottom (B) water layers of Umum Drain and Max Bay (after Soliman & Gharib 1998).

		Secehi deapth cm		Water Temperature C°		pH	Oxidizable organic matter ml O_2. l^{-1}		Dissolved oxygen ml O_2. l^{-1}		Silicate µg.-at. l^{-1}		Phosphate µg.-at. l^{-1}		Nitrite µg- at. l^{-1}		Nitrate µg- at. l^{-1}		Ammonia µg- at. l^{-1}		Salinity	
		Range	Mean	Range	Mean	Range	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
February	S	56-600	430	17.0-21.0	18.8	7.92-8.70	0.5-15.20	4.69	1.0-6.00	3.88	3.64-128.4	48-33	0.0-17.24	5.68	0.0-4.36	2.93	9.38-33.4	26.00	0.47-135.02	58.94	3.68-21.94	15.16
	B	-		16.0-18.5	17.7	8.48-8.84	0.0-2.50	1.46	5.3-6.40	5.93	1.44-81.68	21.38	0.0-7.21	1.20	0.12-80	0.82	5.53-34.83	14.35	0.04-71.81	14.47	13.73-33.12	23.20
April	S	40-485	250	18.2-18.5	18.8	8.88-9.40	1.0-13.21	3.77	3.5-8.20	5.85	13.12-122.32	53.91	0.28-16.10	4.72	2.0-10.36	5.89	0.95-28.57	13.08	7.01-60.85	21.88	7.75-32.74	21.54
	B	-		18.1-19.4	18.5	8.80-9.70	0.0-5.41	1.06	3.9-7.90	6.25	2.24-112.32	25.24	0.0-6.69	1.61	0.24-10.44	2.89	1.69-14.69	4.38	4.3-26.7	10.13	12.42-35.28	29.57
June	S	61-129	86	26.0-30.0	28.0	7.91-9.66	0.0-16.00	8.45	1.2-8.50	5.25	6.4-158	82.46	0.46-10.96	3.95	0.0-18.24	4.63	4.45-29.28	13.85	0.0-64.67	13.63	7.22-33.82	26.77
	B	-		26.0-30.0	27.6	8.14-8.80	0.0-14.40	7.70	1.1-7.00	4.91	7.52-61.36	28.49	0.18-5.15	1.57	0.0-3.36	0.95	4.69-13.20	7.01	0.0-27.48	5.41	23.47-38.21	28.18
August	S	55-125	127	28.8-29.1	29.0	7.52-8.34	0.0-14.40	5.60	0.45-6.33	3.17	0.72-157.6	64.55	0.49-13.51	4.39	0.04-11.44	4.29	0.04-45.37	16.51	0.0-60.42	17.12	4.9-39	29.84
	B	-		28.5-28.8	28.6	7.64-9.40	0.8-4.00	2.40	1.47-5.65	3.8	0.0-155.84	27.37	0.46-4.13	1.25	0.08-5.16	1.72	0.0-14.22	5.53	0.0-20.51	3.92	30.47-38.68	35.29
October	S	125-375	229	24.8-26.0	25.2	7.61-7.96	0.8-11.20	5.71	0.23-4.07	2.35	24.8-159.76	131.30	1.4-10.33	7.03	2.48-13.64	9.06	11.4-58.01	34.70	0.0-18.92	10.80	5.51-38.08	20.55
	B	-		24.5-25.7	24.9	7.76-8.00	0.0-5.60	1.46	1.7-4.52	2.97	20.16-159.92	64.01	0.7-10.15	3.54	1.24-9.48	4.52	7.76-31.96	18.70	0.0-33.71	7.54	6.12-39.21	31.57
December	S	100-450	254	20.0-21.5	20.9	7.89-8.34	0.0-7.20	1.94	2.03-4.18	3.13	56.96-155.44	125.26	2.35-13.48	8.50	1.36-5.00	3.15	11.02-21.97	15.57	3.4-16.21	9.94	5.51-34.12	18.51
	B	-		20.0-21.5	21.0	8.10-8.39	0.0-1.60	0.83	0.0-4.29	2.22	26-129.36	89.80	1.72-7.35	4.47	0.84-2.48	1.69	8.54-15.33	12.18	1.12-8.82	6.25	22.25-37.13	28.74
Umum Drain	S	40-100	75.5	20.0-29.0	23.8	7.55-8.50	6.4-16.80	13.07	0.68-2.90	1.73	121.44-159.92	146.15	10.61-14.00	12.50	3.04-21.00	10.75	18.34-39.83	30.60	13.98-134.93	48.49	3.55-5.84	4.78
	B	-		19.0-29.5	24.3	7.58-8.66	5.6-13.60	8.66	0.57-3.50	2.35	47-159.36	127.17	0.88-13.97	9.26	0.52-11.28	9.09	6.98-30.94	27.62	0.0-129.26	44.40	4.29-10.28	6.98

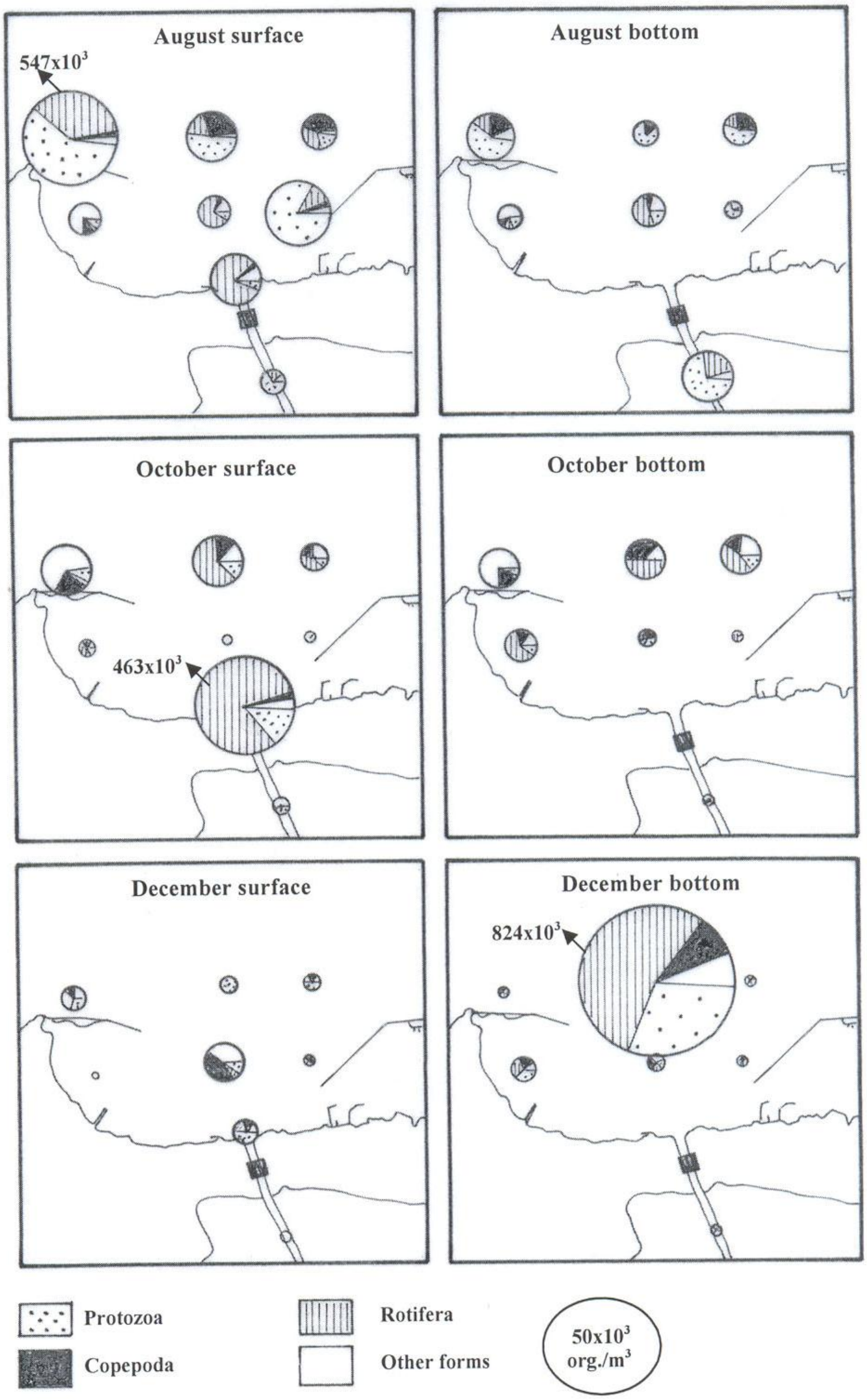

Figure 4: Spatial and monthly abundance and percentage composition of zooplankton in Max Bay and Umum Drain during August, October and December.

- **August**

A pronounced zooplankton increase was observed in Umum Drain and Max Bay. Water temperature was raised up to 29.1ºC associated with higher salinity (Table 4). As a result, Rotifera decreased to form about 24% (for both layers) in Umum Drain and 35.6 and 19.5% to the total counts in the surface and near bottom layers, respectively of Max Bay, but with the highest number of species 15 and 9 respectively). *Filinia* species predominated the community in Umum Drain and stations II, III in Max Bay. *Synchaeta* species, were the only recorded rotifers in the rest of the bay. Protozoa were the dominant group with about 67.0 and 72.0% in the surface and near bottom layers in Umum Drain and 52.0 and 50.0% in Max Bay, respectively (Fig. 4). *Euplotes patella* was the leading protozoan, beside the ciliates *Paramecium caudatun* and *Oxytricha fallax* in the drain and at stations II and III, while the marine tintinnids were prevailing at the remaining stations. Copepoda were restricted to Max Bay contributing 6.2 and 16.8%, with 4 and 3 species, respectively. Polychaete larvae began to appear, in the surface layer forming 3.7%, while they were more frequent in near bottom layer (10.1%). Polychaete larvae typically dominated in many estuaries [26].

- **October**

Water temperature began to decrease and salinity has slightly decreased. This was accompanied with decrease in zooplankton standing stock in both Umum Drain and Max Bay (Figure 4). Rotifera flourished again except in the surface water of the drain (5% to the total count) while in the near bottom it reached 29.0%. In Max Bay, it formed 64.9 and 37.3% with 14 and 8 species respectively, *Brachionus angularis* and *Filinia brachiata* were well represented in Umum Drain beside *B. calyciflorus* predominated the whole bay except at stations III and VIII. Protozoa formed about 30% in Umum Drain decreased to 11.9 and 9.2% in the surface and near bottom layers of Max Bay with 13 and 5 species respectively. The Protozoan ciliates, which dominated the eastern part of the bay changed into the marine tintinnids in the west.

Nematoda dominated the community in Umum Drain forming 65% in the surface water and 29% in the near bottom layer while it was rarely recorded at Max Bay. Copepoda appeared only in Max Bay with 7.6 and 21.8% to the total counts, with 6 and 4 species, respectively and were concentrated in the western part. Cirriped larvae constituted 8.3 and 21.8% to the total counts at station VIII, respectively in the two layers.

- **December**

A further temperature decrease was observed. Salinity was low in the near shore stations (Table 4) increased gradually northward. The zooplankton population was drastically reduced in Umum Drain and in the surface water of Max Bay with high counts and number of species at stations II, III (11 and 12 species, respectively). This is attributed to the mixing with drainage water, which was loaded with high oxidizable organic matter. Protozoa contributed 92% in the surface water and 80% in the near bottom layer in Umum Drain with 2 and 5 ciliate species, respectively. The community in Max Bay completely differed where the tintinnid, *Favella* occupied the whole bay except at station II. One single species of Rotifera, *Lecane depressa* appeared in the drain. In Max Bay, the marine form, *Synchaeta pectinata* shared at all stations except at station VII in the surface. Copepoda still disappeared in Umum Drain and their nauplii dominated at the bay stations. Cirriped larvae formed 17 and 12.3% in both layers, respectively.

Generally, the phytoplankton standing crop [13] showed an inverse relationship with zooplankton standing stock, resulting from the grazing effect most of the year, except in April since the two components were high.

Zooplankton and water quality relationship

In the surface water, a strong positive correlation existed between the zooplankton standing stock and each of Rotifera (r= 0.99) Protozoa (r= 0.35) and Copepoda (r= 0.52). Also, Copepoda were positively correlated with Rotifera (r= 0.55).

The significant correlation coefficient existed between total zooplankton standing stock and main groups with some physicochemical parameters (Table 5). Thus, in the surface water hydrogen ion concentration (pH), oxidizable organic matter (OOM) and phosphate (PO_4) appeared to be the main factors which are positively correlated with the development of zooplankton. Although phosphate was unlimiting factor, yet it is an essential element for growth of the dominant group. However, in the near bottom layer, nitrite (NO_2) and silicate (S_iO_4) were the main factors which were positively correlated with zooplankton. Phosphate also showed a positive correlation with Rotifera. Temperature (temp.) was negatively correlated with Protozoa.

Table 5: Correlation coefficient of total zooplankton, its main groups and diversity index at surface (S) and near bottom (B) water layers at Max Bay with some physico-chemical parameters.

	Temperature	pH	DO	OOM	NO_2	NO_3	PO_4	SiO_4
Zooplankton S		0.362		0.2884			0.3546	
B					0.4494			0.2879
Rotifera S		0.3596		0.2707			0.3585	
B							0.3024	0.3011
Copepoda S		0.4271						
B								
Protozoa S				0.3739				
B	-0.3129				0.5395			
Diversity S		-0.4754	-0.4435		0.6077	0.5588	0.4274	0.5538
B		-0.3119			0.3400		0.3222	0.3615
pH: Hydrogen ion concentration			**OOM:** Oxidizable organic matter				**DO:** Disolved oxygen	
NO_2: Nitrite		**NO_3:** Nitrate		**Po_4:** Phosphate		**SiO_4:** Silicate		

A series of statistical regression models were calculated. These models deal with the dependence of zooplankton standing stock (St. stock) and its main groups on the most effective abiotic factors in both surface water and near bottom layer as follows.

- Surface water

St. stock = -884 + 0.651 pH -0.249 DO + 0.197 OOM + 0.367 PO_4 (M.R= 0.66).

Rotifera = -903 + 0.688 pH – 0.300 DO + 0.215 OOM -0.183 NH_4 + 0.464 PO_4 (M.R= 0.67).

Protozoa = 7960 + 0.374 OOM (M.R= 0.37).

Copepoda = -107616 + 0.609 pH – 0.426 DO + 0.522 NO_2 – 0.315 NO_3 – 0.395 NH_4 + 0.795 PO_4 – 0.724 SiO_4 (M.R= 0.72).

- Near bottom layer

St. stock = 714232 – 0.425 Temp. – 0.003 pH + 0.215 OOM + 0.781 NO2 - 0.496 NO3 (M.R= 0.65).

Rotifera = 495087 – 0.367 Temp. + 0.251 OOM + 0.940 NO_2 – 0.600 NO3 (M.R= 0.74).

Protozoa = 149498 – 0.309 Temp. – 0.185 NO_2 (M.R= 0.36).

Copepoda = -65706 + 0.203 pH – 0.377 OOM – 0.287 NO_2 – 0.377 NO_3 + 0.810 PO4 (M.R= 0.57).

Oxidizable organic matter (OOM) was the most effective environmental factor controlling the zooplankton community in the two layers. Hydrogen ion concentration (pH) had a positive effect in the surface, while temperature showed a negative effect in the near bottom layer.

Diversity Index

Diversity cycle

Generally, species diversity of zooplankton in Umum Drain and Max Bay showed an irregular pattern (Fig.2). In Umum Drain, the lowest values (0.92 in the surface and 0.96 in the near bottom layer) were recorded during June and December, respectively. This was accompanied with the lowest number of species all over the year (3 species for each) and low standing stock of zooplankton (8×10^3 and 10×10^3 organisms m^{-3}, respectively). The dominant species was *Oxytricha fallax* with 42 and 60% to the total counts respectively in both layers. The highest values of diversity were 1.71 in the surface during February and 2.04 in the near bottom layer in June. This was met with species richness of 7 and 13 species, respectively. Also, the zooplankton standing stock in February ($12x10^3$ organisms m^{-3}) was much lower than that in June ($164x10^3$ organisms m^{-3}). Such increased diversity reflects the absence of distinct dominance of any definit species where the dominancy in February was shared by several species; Nematoda (35.3%) *Halicyclops magniceps* (23.5%), Ostracoda and the rotifer *Trichrocerca cylindrica* (11.7% to the total community for each). In June, it shared by the rotifers *Lecane luna* (24.3%) and *Proales daphnicola* (18.2%), Nematoda (20.6%) and the protozoans, *Oxytricha fallax* (10.9%) and *Paramecium caudatum* (9.7%).

In Max Bay, the surface diversity index ranged between 0.41 nats (station V in December) and 2.52 nats (station VI in October). This was parallel with the number of species (3 and 17 species respectively) and zooplankton standing stock (13×10^3 and 39×10^3 organisms m^{-3} respectively).

In the near bottom layer, diversity index showed wide range between 0.29 (station V in June) and 2.36 (station VI in October). The same trend was observed as that of the surface water; species richness was 2 and 12 species and zooplankton stock of 48×10^3 and 66×10^3 organisms m^{-3} respectively.

The low diversity values in both surface and near bottom layers were accompanied by high frequency of only one species; *Synchaeta pectinata* with 89.5% and 91.7% to the total counts respectively. However, the high diversities were corresponding to the dominancy of the same species in the surface and near bottom layers but with different percentage frequencies; Copepod larvae (16.9%), Nematoda (11.15%) and the rotifers, *Brachionus calyciflorus*, (11.9%), *B. angularis* (9.18%) and *Synchaeta pectinata* (14.9%).

Diversity and habitat structure relationship

Diversity index showed an inverse relationship with Protozoa in Max Bay (r= -0.32 & -0.35) in the surface and near bottom layers, respectively. This appeared clearly in October at station VI where diversity values were the highest (2.52 and 2.36, respectively) accompanied with low Protozoa. In the surface water, species diversity was negatively correlated with pH and dissolved oxygen but appeared positively correlated with nutrients. In the near bottom layer it was also negatively correlated with pH and positively correlated with nitrite, phosphate and silicate(Table 5).

The stepwise multiple regression equations describe the dependence of species diversity (H) on the most effective environmental factors as follows:-

$(H)S= 4.0534 + 0.502426\ NO_2 - 0.32392\ pH - 0.15588\ OOM$ (M.R=0.69).

$(H)B= 4.3312 + 0.455324\ S_iO_4 - 0.36345\ pH + 0.34306\ DO - 0.1894$

OOM (M.R= 0.48)

From these equations, it appeared that pH and oxidizable organic matter were the most effective environmental parameters in the two layers, nitrite had a positive effect in the surface water (S), while dissolved oxygen and silicate in the near bottom layer (B).

CONCLUSION

Max Bay continuously receives huge quantities of brackish water from Umum Drain causing the eutrophication of the water which created a massive development of zooplankton blooms. The zooplankton and Rotifera in the surface water of Max Bay showed a significant positive correlation with pH, oxidizable organic matter and dissolved phosphate. Copepoda were positively correlated only with pH and Protozoa with oxidizable organic matter. In the near bottom layer, zooplankton was positively affected by nitrite and silicate. Rotifera were affected with dissolved phosphate and silicate. Protozoa were negatively correlated with water temperature and positively with nitrite. According to the extention of Umum Drain effluent the freshwater forms such as, *Paramecium caudatum, Oxytricha fallax, Euoplotes patella, Brachionus calyciflorus, B. angularis, Filinia brachiata, Proales daphnicola,* Nematoda were sometimes found as codominant with marine forms in Max Bay.

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