Zooplankton Community Structure of Lake Edku, Egypt

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ABSTRACT

This research was designed to assess the impact of water quality on zooplankton community structure of Edku Wetland, Egypt. Zooplankton and water samples were collected seasonally from January to November 2004. Seven sampling stations were selected to represent different habitats of the Lake that were classified in this study to three distinct habitats; Body of the lake (BL), Drainage (D) and Lake- Sea Connection (LSC). Several physical and chemical parameters were studied, such as temperature, transparency, alkalinity, water pH, chlorosity, electrical conductivity, water depth, dissolved oxygen (DO), chemical oxygen demand (COD), biological oxygen demand (BOD) and water hardness. Zooplankton community is composed of 72 species dominated by three groups; Rotifera, Copepoda and Cladocera. These groups were representing 89.5%, 6.8% and 2.3% of total zooplankton density, respectively. The index of species abundance (ISA) and modified index of species abundance (MISA) showed that the small sized animals, such as Rotifera became the most dominant especially, genus *Brachionus*, which is considered as an indicator for organic pollution and eutrophication. Community ordination, trellis diagram and other biostatistical and multivariate analyses techniques showed that within the lake, similar ecological habitats have similar community structures for zooplankton and differ among different habitats. Comparing the present results with previous data of other researchers showed that zooplankton community shifted from dominance of Cladocera and large zooplankton species to rotifers and small zooplankton by increasing eutrophication.

INTRODUCTION

The fish production of Lake Edku may reach 19,000 tons, which is approximately a value added of 6000000£ to the Egyptian economy. There are about

1700 fishing boats and more than 4000 fishermen working in the lake. It is subjected to various kinds of water pollution (Abdel-Moati and El-Sammak, 1997; Adham *et al.*, 1999; Zaghloul and Hussein, 2000, Fathi *et al.*, 2000 and Masoud *et al.*, 2004) which influenced the water quality and biotic community especially eutrophication. The effect of increased nutrients in the freshwater has resulted in deterioration of the ecosystems worldwide. Changes in nutrient contents of the water also result in changes in community structure at each trophic level or within different taxonomic groups (Jeppesen et al., 2000). Eutrophication is defined as "the enrichment of water by nutrients causing an accelerated growth of algae and higher forms of plant life to produce an undesirable disturbance of the balance of the organisms present in the water and to the quality of the water (Jeppesen *et al.*, 2007).

On the other hand, the importance of zooplankton as a heterogeneous assemblage of microscopic animals, in the trophic dynamics of freshwater ecosystems has long been recognized. These organisms, not only regulate the aquatic productivity, by occupying almost middle position in food chain, but also indicate environmental status in a given time as bioindicators (Ismail and Zaidin, 2015 and Sarkar and Saha, 2016). In addition, their diversity has assumed added importance during recent years due to the ability of certain species to indicate the deterioration in the water quality caused by pollution and eutrophication (Khan, 2003). Zooplankton organisms contribute significantly to the recycling of nutrients and provide a food base for predatory invertebrates and vertebrates (Sautour and Castel, 1997; Bedir, 2004).

Therefore, the objective of this study is to assess the impact of water quality changes on zooplankton community structure of Lake Edku.

MATRIALS AND METHODS

1- Lake Description and Characteristics

Lake Edku is a coastal wetland in the eastern Mediterranean and is located about 40 Km eastern of Alexandria city and 18 Km western of Rosetta branch of the River Nile. It is located west of the River Nile delta between longitudes 30°8'30 " and 30 ° 23' E and latitudes 31°10 ' and 31 018 ' N. (Fig.1). The lake is connected to the adjacent Abu Qir Bay through Boughaz El Maadia.

There are two main drains discharge their wastes into the lake; namely El-Khayry and Barsik drains. The first drain is joined to three sources of drainage water coming from El-Bosely, Edku and Damanhour subdrains, which transport domestic, agriculture, and industrial wastewaters as well as the drainage water of more than 300 fish farms. The second drain transports mainly agricultural drainage water into the lake.

There are large quantities of the floating, aerial and submerged plants or hydrophytes covering about 50% of the lake surface area. These plants are *Phragmites communis* Trin. *Ceratophyllun demersum*, *Potamogeton pectinatus* and *Eichormia crassipes* (Mart.). The hydrophyte *C. demersum* and *P. pectinatus* represent the most abundant plants in the lake. This vegetation resist the movement of the fishing boats causes many problems to the fishermen and decreasing the surface area of the lake. After the mechanical control, it reaches now less than 30% of the total area where the mechanical excavators make roads of 25 m wide by cutting the plants under the surface of water.
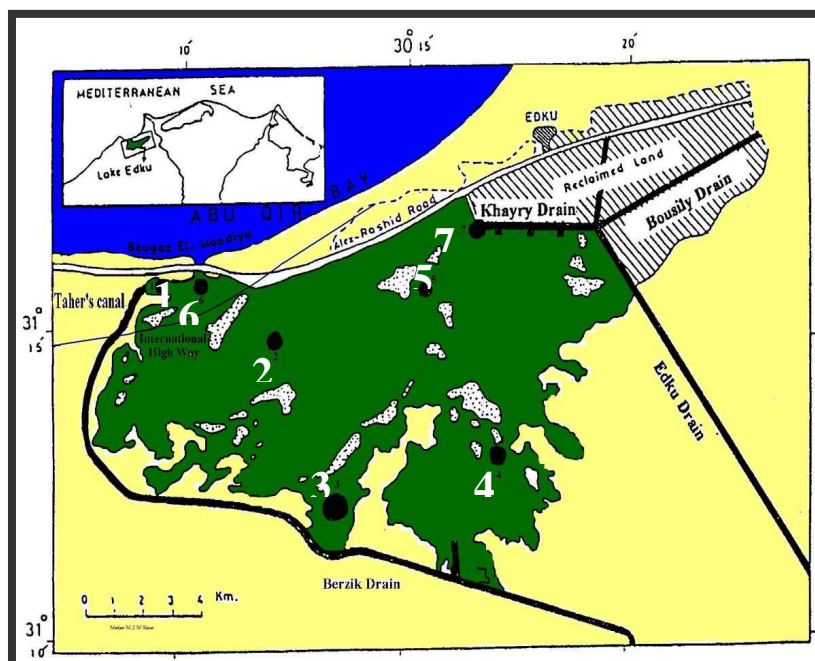
Fig. (1): Lake Edku showing the locations of different stations.

2- Sampling Locations and Period of Investigations

Water and zooplankton were collected seasonally all over one year from January 2004 to November 2004 from seven stations representing the different habitats of the lake (Fig. 1). These stations are:

1. Taher's canal at the end of Barzik Drain (St. 1)
2. Gezeret Al kotala (St. 2)
3. Bab Hassan (St. 3)
4. Gezeret El-Diyab in front of Bab Abdel Rahman (St. 4)
5. Gezeret El-Shalashel at the entrance of Bab Basala (St. 5)
6. Boughaz El Maadia (St. 6)
7. El-Khairy Drain (St. 7)

3- Physico-chemical Parameters

Hydrogen ion concentration (pH), alkalinity, water hardness (Ca^{++} and Mg^{+}), dissolved oxygen (DO), primary productivity, chemical oxygen demands (COD), biological oxygen demands (BOD) and salinity were seasonally measured during the year 2004 according to Standard Methods for examination of water and waste water, (APHA,1996). In the field, pH was measured immediately by 3070 Jen Way pH device. Water salinity and conductivity were measured by 4205 Jen Way salinity meter.

The dissolved nutrient salts such as ammonia NH_3, nitrate NO_3, nitrite NO_2, phosphorous PO_4 and reactive silicate SiO_3 also were measured by spectrophotometric method according to Methods for examination of water and waste water, (APHA,1996) using Carl Zeiss spectrophotometer, Spicol. The water samples taken for analysis of nutrient salts were filtered through a Whatman glass microfiber filters "GF/C" using Bouchner device and a suction bump. The filtrate was stored at -80 °C until processing.

4- Zooplankton Samples

Zooplankton samples were collected vertically and horizontally by 55 µm mesh size 30 cm diameter plankton net. The net was lowered to 1 meter depth from the ring of the net to the water surface, and then hauled vertically to the surface at a uniform speed. Another horizontal swap was taken by towing the net under the surface of the

water for 10 meters distance at slow speed. Each sample was immediately preserved in 10% neutral formalin. Zooplankton was counted in 1ml using Carl Zeiss binocular stereomicroscope. This process was repeated three times. Zooplankton species were subjected to detailed examination and identification according to the following guides: Rutter-Kolisko (1974), Koste (1978), Sheil (1995), Einsle (1996) and Smirnov (1996).

5- Data Treatment

A. Absolute and Relative Importance values (AIV and RIV):

Data of zooplankton such as density (PD), biomass (BM), absolute frequencies (AF) and relative frequencies (RF) for each species were determined. These parameters were synthesized into the importance value indices (AIV and RIV) as calculated by Ghabbour and Shakir (1982), Shakir and Dindal 1997.

B. Diversity Indices and Multivariate Community Analysis:

In order to evaluate the diversity of zooplankton in different influence habitats in the lake, several indices were calculated according to Shannon and Weaver, Simpson, Menhinick's Index, Equitability and Richness were calculated and compared with Community Structure Diversity (CSD) Index (Shakir, 1989, and Shakir Hanna 2004). Trends in zooplankton community in Lake Edku and studied habitats were illustrated by using a modification of dissimilarity ordination (Bray and Curtis 1957) for each sampling. Similarity trellis diagram was calculated as described by Mountford (1962).

C. Similarity and Abundance of Zooplankton Taxa:

Two types of similarity coefficients were used; Sorenson's index (Wallwork, 1976) is quantitative and used on presence or absence of species or taxa, and Gleason's formula is a quantitative method that utilizes the importance values (AIVand RIV) by equation (1) as follows:

$$C_s = \frac{2W}{A+B} \qquad (1)$$

Where C^s is the similarity coefficient, A + B is the sum of the quantitative measure of the two seasons (AIV and RIV), and W is the sum of the shared (lesser) values of the two seasons or two sites or habitats.

A further analysis of the zooplankton data of the different habitats in Lake Edku in Egypt was carried out by using an index of species abundance (ISA) (Roberts and His 1979). This method has the advantage of assessing the values of absence as well presence occurrences of species. It has an advantage in comparing of the faunal composition of the different habitats in the lake that have been formed or affected by different stresses through the course of human activities in the lake. This method provided an analysis of the most abundant species in the lake. Further, it can be of important in monitoring the structure of species composition changes in the lake.

The original ISA was calculated from equation (2) as the following:

$$\frac{a + R_s}{K} \qquad (2)$$

1. Ranking of species abundance giving the lower rank to the most abundant species and highest rank to the rare species
2. If two or more species were having the same rank, everyone would take the average rank as if they were arranged in serial manner.
3. The maximum rank will be selected, this represent the minimal abundant species.
4. The number of blank cells for each species will be counted, this represents its absence.
5. Calculate C= maximum rank+ 1

6. a= number of blank cells for each species * C
7. R_s = Sum of the ranks for each species
8. ISA = a +R_s/K "K= number of columns"

The original ISA has some weak points where, the most abundant species will take the minimum ISA value furthermore; the rare species will get higher value. Additionally, the absent species will get the value of "C" which is the highest ISA value. Therefore, if we are comparing some communities to each other, the absent species will get closely approximated ISA values, thus it will cause a problem.
The modification of ISA will be achieved as following:

1. Ranking of the species where the most abundant species will get the highest rank.
2. The maximum rank in the table will be selected, representing the most abundant one.
3. Counting of the non-zero cells for each species, which represent the presence of that species.

By doing these steps in addition to the steps mentioned above (i.e. the remaining steps of the ISA), then the most abundant species will get the highest Modified Index of Species Abundance "MISA" value and the value will decrease as the density of the species decrease. Furthermore, the MISA value for the absent species will be zero.

6- Statistical analysis

Most dependent variables, that is, density and biomass, were analyzed separately by means of a factorial design (ANOVA) (Sokal and Rohlf 1981). Main effects were the environmental variables such as pH, water temperature, salinity, and other elements that were studied as described in the data collected. These factors were used for determination whether or not differences between the physical-chemical characteristics of the stations and habitat classifications were significant. Therefore, general linear model (GLM) of multivariate analysis of variance (MANOVA) was carried out using the STATGRAPHICS (1986) and SAS 9.1.3 (2007) for Windows software programs on PC as an authorized license of Texas A & M University to Prairie View University. Statistical significance was implied at the probability of 0.05 or less in this dissertation.

Results of regression and correlation analyses were used for explaining the relationship between the environmental, parameters and zooplankton. Most of regression and correlation analyses were done on transformed data.

RESULTS AND DISCUSSION

Zooplankton Density and Biomass
- Zooplankton Community Structure

Seventy-two species of zooplankton were identified in the present survey. The zooplankton community was dominated by three main groups; Rotifera, Copepoda and Cladocera (Fig. 2). Their annual average densities were 295275, 19465.18 and 8205.357 ind/m^3 with percentages 90.35%, 5.96% and 2.51%, respectively, (Table 1). Protozoa and meroplankton groups were represented only by 26.78 ind/m^3 and 3855.357 ind/m^3 with a percentage of 0.01% and 1.17% of the total number of zooplankton. As indicated in Table (2), although Cladocera group is less represented than copepods but they have higher biomass. On the other hand, dominance of rotifers may be due to the habitat preference where favorable ecological parameters are present and their food requirements (phytoplankton) are available in excess. The other factor that makes certain group or species dominating the other is the absence of

invertebrate predators of such organisms (Aboul Ezz and Soliman, 2000; Abdel Aziz and Dorgham, 2005).
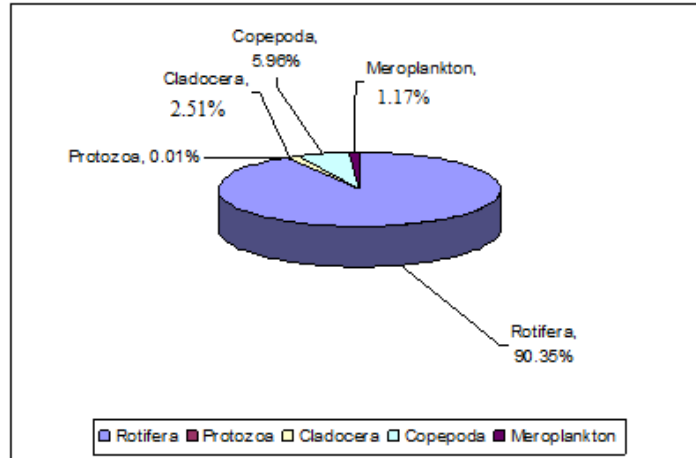

Fig. (2): Community structure of zooplankton in Lake Edku during the period of the study

Table (1): Percentages of important species to the total population density, total biomass, and total density of each group and functionality of the species.

Species	Function	% to the group	% to TZD	Species	% to TZB	BM per ind.
B. calyciflorus	Herbiv.	36.8%	33.22%	*B. calyciflorus*	14.60%	0.45
B, angularis	Herbiv.	30%	27.08%	*B. angularis*	10.58%	0.4
B. plicatilis	Herbiv.	9.2%	8.32%	*M. micrura*	10.26%	11.6
P. vulgaris	Herbiv.	8.1%	7.34%	*A. tragani*	9.50%	18.24
K. quadrata	Herbiv.	5.5%	4.96%	*B. plicatilis*	5.04%	0.62
Nauplius larva	Deteriv.	66.2 %	3.95%	*B. longirostris*	4.38%	5.2
B. urceolaris	Herbiv.	2.2%	2.02%	Nauplius larva	2.85%	0.74
Cyclopoide Copipodid	Herbiv.	16%	0.97%	Cyclopoid copipodid	2.56%	2.7
M. micrura	Herbiv.	34.7 %	0.91%	*D. excisum*	1.52%	6.2
B. longirostris	Herbiv.	33.1 %	0.86%	*K. quadrata*	1.45%	0.3
A. tragani	Predator	9%	0.53%	*C. reticulata*	1.43%	11.16
D. excisum	Herbiv.	9.62 %	0.25%	*B. urceolaris*	0.83%	0.42
A. rectangula	Herbiv.	8.58%	0.22%	*A. rectangula*	0.77%	3.5
C. reticulata	Herbiv.	5.02 %	0.13%	*P. vulgaris*	0.29%	0.04

Table (2): The importance indices and ISA of the most important zooplankton species in the studied habitats of Lake Edku

Species	AF	RF	AIV	RIV	ISA	MISA
B. calyciflorus	100	3.85	11.7	53.0	1.50	144.50
B. angularis	100	3.85	11.4	41.3	1.50	144.50
M. micrura	75.00	2.88	9.7	13.3	13.25	132.75
A. tragani	67.86	2.64	8.3	9.7	15.38	130.63
B. plicatilis	96.43	3.71	10.1	15.5	5.75	140.25
B. longirostris	67.86	2.61	9.3	8.1	11.25	134.75
Nauplius larva	100	3.85	10.0	10.8	5.50	140.50
Cyclopoid copipodid	96.43	3.71	9.4	7.4	10.13	135.75
D. excisum	39.29	1.53	6.3	3.2	29.75	94.88
K. quadrata	82.14	3.18	8.6	10.5	16.00	129.88
A. rectangula	46.43	1.77	7.7	2.7	25.63	120.38
C. reticulata	32.14	1.22	6.0	2.9	35.36	89.00
B. urceolaris	100	3.85	9.2	6.8	6.75	139.25
P. vulgaris	96.43	3.72	9.2	10.9	4.25	141.75

- Species Composition of Zooplankton Community

Rotifera was represented by 36 species in the present survey. It was dominated by six species namely, *Brachionus calyciflorus* (108571.4 ind/m^3), *B. angularis* (88500.0 ind/m^3), *B. plicatilis* (27178.6 ind/m^3), *Brachionus urceolaris* (6589.3 ind/m^3), *Polyarthra vulgaris* (23982.1 ind/m^3) and *Keratella quadrata* (16214.3 ind/m^3) (Table 1). In addition, *K. quadrata* attained higher biomass (29 µg/m^3) than *P. vulgaris* (959.28 µg/m^3) (Table 2). As indicated in the density and biomass matrix, the genus *Brachionus* is the most abundant one in the studied ecosystem. The species, *B. calyciflorus* and *B. angularis* contributed together about 60 % of the total zooplankton density. Additionally, they have the highest AIV, RIV, AF, RF and MISA values which indicated their importance in the lake ecosystem as most dominant, frequent and abundant species. The dominance of this genus could be due to its high reproduction rate and habitat preference since their food such as phytoplankton or plant detritus are highly available. Zooplankton community was dominated by the herbivorous rotifers, *B. calyciflorus, B. angularis, B. urceolaris* this may be attributed to their special characteristics, high availability of phytoplanktonic food due to the increased eutrophication (Lijing et al., 2012 and Bielan´ska-Grajner et al., 2014) and absence of their predators. Aboul Ezz and Soliman (2000), Zaghloul and Hussein (2000), Hobaek *et al*. (2002) and Ali *et al*. (2007) reported similar results. They illustrated that, the gut contents of these species were dominated by *Certeria* and *Euglena*; which are more common in Lake Edku (Gharib, 1999). Further, Dunn (1985) and Uku and Mavuti (2001) established that, rotifers are less preferred than Cladocera and Copepoda by *Oreochromis,* which represent 82% of the total fish in Lake Edku (Sainty, 1985). Furthermore, the dominance of rotifers may be due to the decreased heterogeneity of the studied ecosystem and its dominance by organically polluted water. Hrodey *et al.* (2008) stated that, decreased habitat heterogeneity could lead to an increased abundance of highly adaptive taxa, which out-compete individuals that are more sensitive and dominate community composition.

Copepoda (Arthropoda, Crustacea) was represented by fourteen species. It was dominated by nauplius larvae (12894.643 ind/m^3), 66.2 %, of the total copepods Table (1) and immature cyclopoide copepodid, (3167.9 ind/m^3), 16% whereas, the adult, *Acanthocyclops tragani* contributed 1742.86 ind/m^3, 9 % of the total copepods. Dominance of immature stages may be due to the influence of eutrophication however, the low abundance of adults may be due to some predator fish that attracted to the large-sized adults than small-sized immature stages. This could be illustrated by the lower density and higher biomass of the large-sized adults. Additionally, the higher AF, RF and MISA values of the immature stages may confirm this observation. Furthermore, the ISA of immature stages was lower than that of the adult stages.

Cladocera or water fleas (Arthropoda, Crustacea) are considered biological indicators for water quality and pollution. In the studied ecosystem, Cladocera was represented by only eight species. Two species were the most dominant in the group namely, *Moina micrura* (2960.71 ind/m^3), comprising 34.68 % of the total Cladocera Table (1) and *Bosmina longirostris* (2821.43 ind/m^3), 33.05 %. These are small-sized Cladocera however, the large-sized species such as *Diaphanosoma excisum*, *A. rectangula* and *Cirrodaphnia reticulata* are less dominant and consequently; they have lower values for AIV, RIV, AF, RF and MISA. Accordingly they contributed the highest ISA. Larger size species (e.g. *Daphnia)* are no longer found in the lake although they were the most dominant group several years ago. This was confirmed by El-Hawary (1960) and Samaan (1976). Furthermore, the low number of Cladocera in the community could be attributed to the predation, eutrophication or pollution of the water body, where Cladocera cannot survive in polluted waters and change of

water characteristics led to corresponding changes in the zooplankton community (Flower, 2001)., additionally; more predators are attracted to them (Forneman *et al.*, 2002; Gaudy *et al.*, 2004).

The four species, *B. calyciflorus, B. angularis*, *Moina micrura* and *Acanthocyclops tragani* comprised together about 45 % of the total zooplankton biomass. Although rotifer species are small in size but they have the highest biomass. On the contrary, *A. tragani*, *M. micrura* and *B. longirostris* have higher biomass per individual and lower population density than the rotifers, *B. angularis* and *B. plicatilis*. This may indicate their importance in the food web, where, larger species with higher biomass are more satisfactory for predators than the smaller rotifer species. These may explain the higher predation impact on cladocera and adult copepods and their role in the food web. Similarly, the biomass of Cladocera was higher than that of copepods, which may indicate that Cladocera are more attractive to predators than copepods and consequently they have more important role in the food web (Lair, 2005; Ali *et al.*, 2007).

- Seasonal Distribution of Zooplankton

The average total density of zooplankton started to increase during spring and reached its peak in summer; then started to decrease during autumn until reaching its minimum level in winter. Rotifera followed the same pattern of seasonal variation of zooplankton where, summer was the season of highest production of these organisms with an average standing crop, 383942.9 ind/m^3. The lowest population density was recorded during winter, 211514.29 ind/m^3. This may be due to the increased water temperature during summer, which accelerated the egg development and hatching rate of most zooplankton such as rotifers (Froneman *et al.*, 2002; El-Shabrawy and Dumont, 2004; Bedir, 2004; Mageed, 2005; Lair, 2005; Ali *et al.*, 2007). They attributed this increase to the increased rate of egg hatching and development of the planktonic groups especially Rotifera. However, they attributed the decrease in winter to the increased salinity, water current and turbidity due to the wind action. These are known to affect zooplankton populations through several mechanisms including decreased assimilation efficiency and filtering rates.

The average standing crop of copepods showed its peak, 29975.0 ind/m^3 during winter, followed by summer, 21114.29 ind/m^3. The minimum density was 12985.71 ind/m^3 during autumn. Similar fluctuations were observed for the biomass. This may be due to the adult copepods entered with seawater then decreased gradually due to decreased salinity. The increase during summer may be related to egg hatching and increase of immature stages. Wolfnbarger (1999) and Bedir (2004) supported this result. In addition, this is confirmed by the positive correlation between temperature and zooplankton density and biomass. Froneman (2004), Bedir (2004) and Mageed and Heikal (2006) agreed with these results. Furthermore, Mageed and Heikal (2006) established the dominance of nauplii and immature stages over the adults. Williamson and Bulter (1986) and Williamson (1987) mentioned that, dominance of immature stages of copepod community is caused by eutrophication of the water body.

Cladocera displayed more or less different pattern of distribution from that observed for total zooplankton. The average standing crop of Cladocera reached its peak in winter, 11421.0 ind/m^3 followed by summer (9929.0 ind/m^3) while the lowest density was in autumn, (5114.0 ind/m^3). The increase of Cladoceran density in winter could be due to the increased oxygen content of the water because of decreased temperature and increased water movement. This increase was in the sites far from the sea in the center of the lake. Additionally, some species might prefer cold weather for their egg hatching. This was in agreement with the results of Ropert *et al.* (1983), Wolfnbarge (1999), Fathi *et al.* (2000), Abdel Aziz and Dorgham (2005), Kuczynska-

Kippen and Nagengast (2006) and Martinez-Jeronimo and Martinez-Jeronimo (2007). They attributed this increase to *M. micrura* and *B. longirostris*, which are the most dominant cladoceran species in this study and they increase during winter. They clarified that, large cladocerans are usually restricted to freshwater environment; however, those inhabiting brackish waters are smaller in size and have reduced reproduction. This was confirmed by El-Hawary (1960) and Samaan (1976) where the large caldoceran species *Daphnia* was dominating the lake but it is not found now. Abul Ezz and Soliman (2000) and Flower (2001) established the former freshwater nature of Lake Edku water and change of water characteristics led to corresponding changes in the zooplankton community.

- The Role of Inter-Specific Interactions in Shaping Zooplankton Community Structure

Not only physico-chemical variables influenced zooplankton community structure, but also there is a strong effect from the biotic component of the aquatic ecosystem upon each other (e.g.) grazing of herbivorous zooplankton upon the phytoplankton and predation of vertebrate and invertebrate predators on the herbivorous zooplankton. These interactions strongly influence the community composition (Zhao *et al*. 2008). In Lake Edku, small-size Rotifera dominated the zooplankton community. This may be due to that most fishes and other vertebrate predators do not prefer them. Furthermore, the larger zooplankton species such as copepods and Cladocera are limited as they are preferable by the predators. This was confirmed by Vinebrooke *et al*. (2004) and Uku and Mavuti (1999), who illustrated that, gut content of *Oreochromis* spp., indicated that Copepoda and Cladocera are more preferable than Rotifera. Some predators are selective, however others may feed on another prey if their favorable food is not present (Bogdan and Gilbert, 1984). Additionally, many of the rotifer species possessed morphological and behavioral characteristics that drastically reduced their vulnerability to predation, such as genus *Brachionus* that has lorica with long spines. This genus is the most common in Lake Edku, whereas soft-bodied species are less dominant as they are more vulnerable to predation. This agreed with the results reported by Ruttner-Kolisko (1974), Williamson (1987), Lair (2005) and Ali *et al.* (2007). In addition, the most widespread predators of planktonic rotifers especially *Brachionus*, is the copepod *Mesocyclops edax*, (Williamson, 1983 and 1984; Williamson and Bulter, 1986); this predator is not found in Lake Edku. The present study revealed that copepod community was dominated by small sized immature stages and nauplii. This may illustrate the high predation rate on the large sized adult planktonic species, where many species of fish select the largest prey that they can see. The rotifers and nauplii can escape because they are too small in size or because they provide negligible meal if compared with the effort of catching it (Jeppesen *et al*., 2007; Zingel and Haberman, 2008). The same for Cladocera where Bedir (2004), Abdel Aziz and Dorgham (2005), & Mageed and Heikal (2006) postulated that Cladoceran species are exclusively filter feeder and algae user, as well as it is the favorite prey for both invertebrate and vertebrate predators. Therefore, predation may limit the species composition in the community and may illustrate the dominance of Rotifera. Furthermore, this was confirmed by the strong significant correlation between total Copepoda and total Cladocera in the present work. This may illustrate predation effect from copepods on adult cladocerans or their eggs (Wolfnbarger, 1999; Forneman *et al*., 2002; Gaudy *et al*., 2004; Costa *et al*., 2006). Williamson and Bulter (1986) established that, copepods were feeding on the cladoceran eggs inside their brood pouches. Accordingly, the zooplankton functionality has an important role in shaping zooplankton community structure (Thebault and Loreau, 2006).

- long-Term changes of Zooplankton Community Structure

Aquatic ecosystems are considered as the most impacted habitats as a result of human activities; these stresses represent one of the most important factors in shaping and limiting the density, diversity and community structure of zooplankton (Xiong *et al*., 2016). Historical long-term studies revealed that Lake Edku was poor in zooplankton due to its mesotrophic properties (Samaan, 1976). After that, the density of rotifers increased from 248300 to 295275 ind/m^3, percentage from 76 to 89.42% in the last four years, however species number decreased from 49 to 36 species. This may be due to increase of drainage water, nutrients and eutrophication. This was supported by Odum (1997), Aboul Ezz and Soliman (2000), Bedir (2004) and Yildiz *et al*. (2007); they stated that in freshwater systems zooplankton abundance increase by increasing eutrophication especially rotifers which are characteristic for eutrophic and organically polluted waters. Additionally, Rogozin (2000) pointed that the trophic status of the water body is closely related to the structure of zooplankton community. They are sensitive for pollution and eutrophication (Ismail and Zaidin, 2015). Further, Zingel and Haberman (2008) added that, fundamental changes have recorded in zooplankton composition of Lake Edku due to the increased eutrophication, where oligo-mesotrophic species have almost totally disappeared. In addition, Ruttner-Kolisko (1974) advocated that the number of species at first increase with the eutrophication of the water up to certain point and then decrease again. Fisher *et al*. (1943) stated that in the healthy ecosystem, the number of species increases over the long period, however in the present case eutrophication led to poor and degraded ecosystem in which the number of species decreased with time. Moreover, Vaughn and Hakenkamp (2001) and Saad (2003) found that increased eutrophication may cause sudden mass mortality of aquatic organisms due to high oxygen consumption by increased phytoplankton and aquatic vegetation. This may indicate the declining of fish in the Lake Edku due to its pollution, therefore Rotifera still the most dominant group. This was supported by Abdel-Aal and Talaat (2000) and Nafea (2005); who reported that the predominance of small sized fish over older age group which were represented in small proportions or even absent, reflecting decreasing and the higher mortality of fish. Therefore, Lake Edku has the lowest species number of fish among the Delta lakes. In addition, Aboul-Ezz and Soliman (2000) reported that changes occurred in zooplankton community was attributed to the increased densities of hydrophytes, diatoms, phytoplankton, and bacterial growth, leading to oxygen consumption which hinders the growth of zooplankton.

Increased human activities in the aquatic habitats influence the species composition of the local communities or species sorting (Xiong *et al*., 2016). Cladocera was dominating Lake Edku in late seventies and early eighties followed by copepods, while Rotifera was rare group or even absent as indicated by El-Hawary (1960) and Samaan (1976). After that, rotifers highly increased and became the most dominant group until now. El-Shabrawy and Dumont (2004) stated that, at times and places where cladoceran densities were high, rotifer density tended to be low. This may indicate the control effect of cladocera on rotifera. Additionally, Williamson (1987) found crushed rotifers in the food chamber of *Daphnia*. On the other hand, Cladocera showed a very minute increase in density. Figures (3 and 4) reflecting parallel increase of total rotifers density by increasing the nutrient salts. This was accompanied by a parallel decrease of cladocerans density indicating that they can hardly survive under the present stressors such as suspended sediments that decrease their filtering ability and assimilation rates. This agreed with the results reported by Wolfinbarger (1999) and Yildiz *et al*. (2007). Moreover, El-Hawary (1960) reported that, large sized Cladocera, especially *Daphnia,* were characteristic for Lake Edku,

however, genus *Brachionus* was not found in Edku as it is highly increases in eutrophic and organically polluted water bodies. These results agreed with those reported by Ruttner-Kolisko, (1974), Sladecek (1983), Aboul-Ezz and Soliman (2000), Vinebrooke *et al.* (2004), Bedir (2004), Mageed (2005) and Jeppesen *et al.* (2007). Similarly, Williamson and Bulter (1986), Williamson (1987), Zingel and Haberman (2008) and Ismail and Zaidin (2015) established that small size zooplankton organisms (e.g. Rotifera, *Chydorus*, *Bosmoin*, etc.) are known to be eutrophication indicators and they can assess the condition and changes in the aquatic ecosystem.
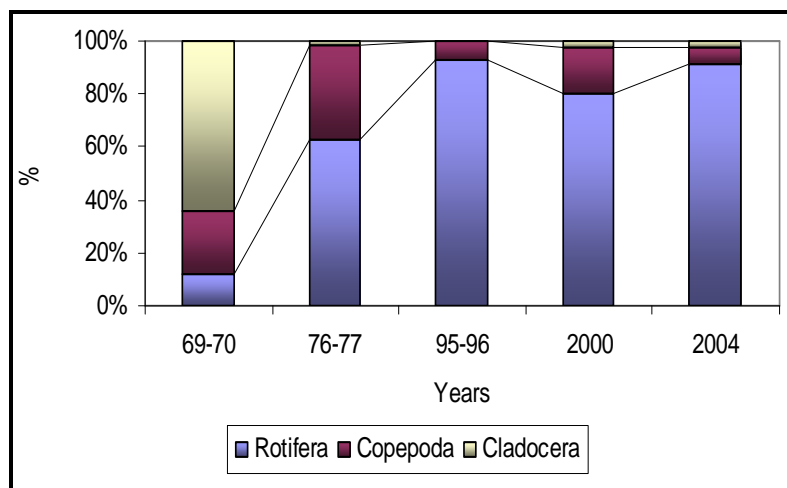

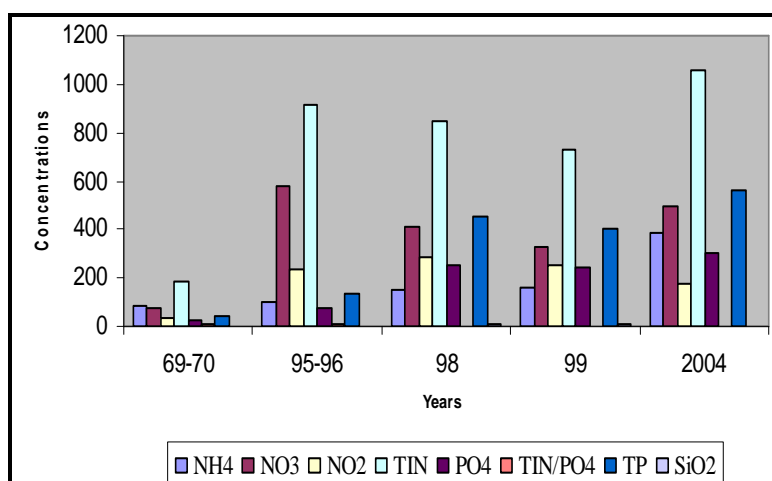**Fig. (3): Long-term changes of zooplankton community in Lake Edku.**

Fig. (4): Long-term changes of nutrient salt concentrations in Lake Edku.

Nematode plankters showed a remarkable increase from 2650 to 7103 ind/m^3 and from 0.8 to 2.15%. This may be attributed to the increase of hydrophytes due to increased nutrients and plant detritus as indicated by El-Hawary (1960), Samman (1977), Fahmy *et al.* (1996), Gharib (1999), Gharib and Dorgham (2000) and Ali *et al.* (2007), moreover, aquatic vegetation influences the distribution of nematode community in coastal wetlands (Du *et al.*, 2014).

Effect of Physico-Chemical Parameters on Zooplankton

According to analysis of ecological parameters, the most important factors affecting the lake water environment are temperature, pH, ammonia, BOD, Mg, SD, SiO$_3$ and salinity. These factors are affecting the zooplankton density, biomass and species composition.

Aquatic organisms are indirectly affected by air temperature through its effect on water temperature, the later can directly influence aquatic organisms especially plankton. Figure (5) illustrates the positive correlation between both air temperature (AT), water temperature (WT) and total zooplankton density (TZD), (AT ($r = 0.36$ and $P < 0.05$) and WT ($r = 0.33$ and $P < 0.05$)). This is due to the direct effects of water temperature on the physiological activities of zooplankton such as metabolism, egg development and hatching. Water temperature was following that of the air. There were no abnormal thermal changes in the lake. Samaan (1974, 1976) and Saad (2003) supported this result and indicated that Lake Edku has a uniform water temperature due to the shallowness and continuous water flow. These results came in harmony with that recorded by Froneman *et al*. (2002) and Telesh (2004) who advocated that these ecosystems are characterized by the virtual absence of horizontal gradient in temperature; this is due to the low depth, which facilitates horizontal and vertical mixing of the water column.
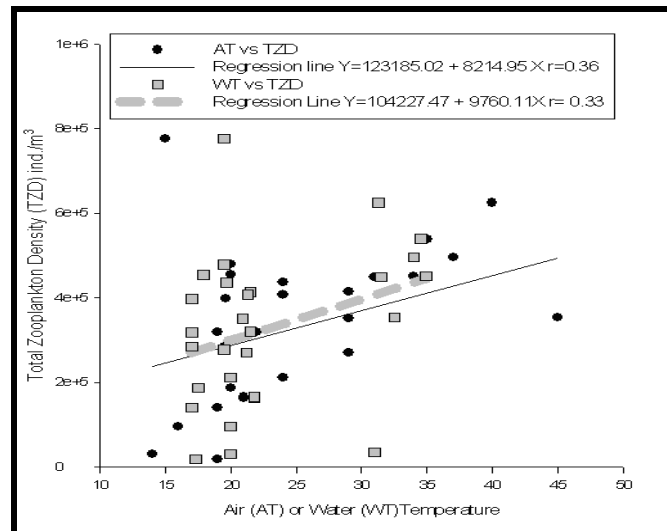

Fig. (5): Relationship between total zooplankton density (TZD), air temperature (AT) and water temperature (WT).

A significant positive influence of water pH on total zooplankton and total rotifers densities was found in Figure (6), ($r = 0.54435$ $p < 0.0027$ and $r = 0.5249$ $p < 0.0041$ respectively). This may be explained by the preference of alkaline medium by rotifers where most of them have a lorica and lower pH may affect this lorica and consequently their life. The lowering in pH value in station 5 is due to the water discharge from El-Khairy drain. This result agreed with those reported by Abbas *et al*. (2001) and Shakweer (2006). El-Khairy Drain was having lower pH than Taher Drain because the later carries agriculture discharge with high nutrient load and phytoplankton that make photosynthesis consuming the CO_2, while the other is carrying mainly industrial and domestic wastes, which decrease the pH values This was supported by Shakweer and Abbas (2005). The low pH in the lake-sea connection, especially in the winter, is attributed to the entrance of seawater from Abu Qir Bay carrying industrial pollutant. These results matched with those reported by Moore (1989) and Youssef (2003). The increased pH during summer was explained by Samaan (1974), Moore (1989) and Michaud (1991) who reported that the peaks of pH were recorded during spring and summer due to increased photosynthesis, primary production of phytoplankton and growth of hydrophytes.
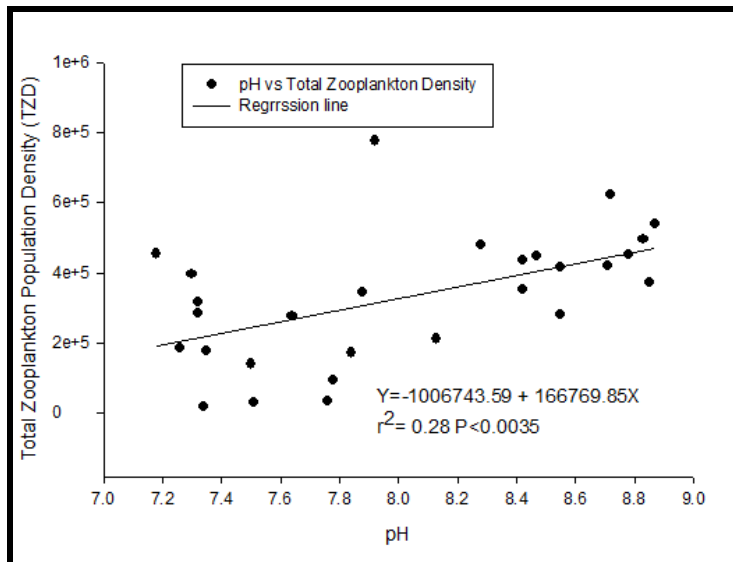
Fig. (6): Relationship between total zooplankton density (TZD) and pH.

The total zooplankton density has a significant relationship with pH and water temperature. The density increased with increasing pH and increasing water temperature. Figures 5& 6 graph can explain that the highest density of zooplankton can be of importance for both highest temperature and highest values of pH (i.e. the regression line was significant r^2 =0.48 and P<0.01). The regression line for this three dimensional graph can show the impact of environmental parameters on the zooplankton. It is clear that zooplankton has significant temperature sensitive association with pH that can be of importance in affecting population growth activities.

The biological oxygen demand (BOD) indicates the presence of microbial activities and organic matter on which microbes can feed. Therefore, BOD is directly linked with decomposition of dead organisms in the aquatic ecosystem and hence, the higher values of (BOD) can be considered as an indicator for the pollution status of the water body. The more oxygen consumed, the hardly organisms can survive. Therefore, in the present study BOD was negatively correlated to the total zooplankton density and biomass (Fig. 7). This is attributed to the increased oxygen consumption required for oxidation of the organic matter in the water body. The total zooplankton density showed lower density when BOD has the lowest values.
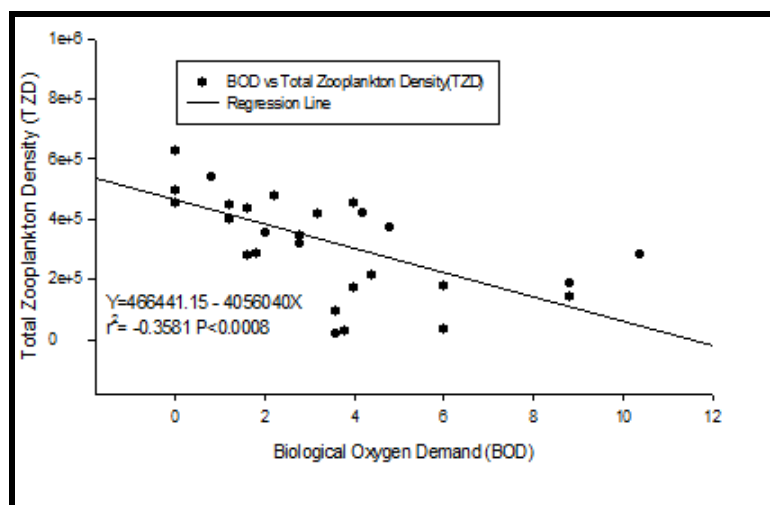

Fig. (7): Relationship between biological oxygen demand (BOD) and total zooplankton density (TZD).

The present results clarified that DO concentration is high during winter; however it was low during summer. This is in agree with Khalil *et al*. (2000), Jacob (2002), Telesh (2004), Mogias and Kevrekidis (2005) and Mageed (2005). They attributed it to the effect of high wind action and water current during winter that increases the DO. On the other hand, stagnation period and high temperature during summer decreased the dissolved oxygen concentration in the water. Furthermore, Comita (1968) and Bishop (1968) explained that, oxygen consumption rate increases during summer, and decreases DO concentration. On the contrary, Fathi *et al*. (2000) disagreed with the present results and reported that the maximum dissolved oxygen was during summer while the lowest was in spring. Generally, dissolved oxygen concentration in the drainage water was low if compared to that in the lake due to its consumption in oxidation of chemical compounds and organic matter found in the water. The chemical oxygen demand (COD) was higher in the drains than that of the lake due to their higher contents of oxygen demanding chemicals and organic matters in their waters. Abbas *et al*. (2001) supported these results. The average value of COD in all habitats was above 40 mg/l, therefore the lake is considered as polluted water body according to Musa and Hector (2005), who stated that water bodies having COD > 40 mg/l are considered as contaminated waters, while those having COD > 120 mg/l are highly contaminated.

Total zooplankton density and biomass showed significant negative correlation with the concentration of ammonia in the water (Fig. 8). Increased ammonia is considered as a kind of toxins for the aquatic organisms therefore, (TZD) and consequently (TZB) decreased as ammonia increased. Ammonia consumes dissolved oxygen (DO) to be oxidized to nitrate by the microorganisms that in turn decreases the available oxygen for aquatic organisms and consequently their density and biomass decreases. This was confirmed by the negative influence of the increase of NH_4 and PO_4 on the (TZD).
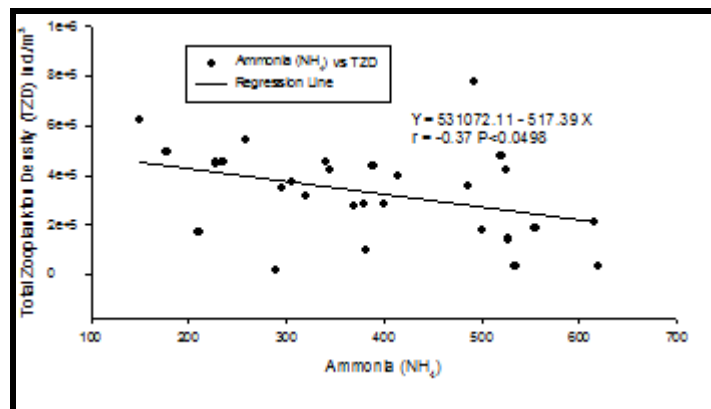

Fig. (8): Relationship between ammonia concentration and total zooplankton density (TZD).

A strong negative correlation was observed between WD and total cladoceran density (r= -0.697 p< 0.0001) this is may be because most of cladoceran organisms do not prefer to be near the bottom except *Chidorus* because (DO) may decrease near the bottom due to oxygen consumption by decayed plant detritus and dead organisms. Furthermore, cladoceran density was found to be negatively influenced by ammonia concentration and water clarity (SD). This is probably due to the increased predation impact on cladoceran species with increasing water clarity.

Water clarity was negatively correlated to total copepod density (r= -0.48 p< 0.01). This is because increased water clarity (SD) may increase the predation impact on the copepods and make them more visible to the predators.

These results disagree with Fathi *et al.* (2000) who stated that the maximum transparency was during winter while the minimum was in autumn. On the other side, the present results agreed with those reported by Soliman (1983), Wissa (2002), Fishar *et al.* (2003), Telesh (2004) and Mageed (2005). The lowest transparency of the drainage waters were in agreement with the results that postulated by Telesh (2004) and Shakweer (2006) and explained that heavy growth of the phytoplankton has an important role in decreasing the transparency of the lake. In addition, Shakweer (2006) found that Barzik Drain has higher TDS concentration than El-Khairy Drain and the later has lower TDS value than the body of the lake; which in turn greatly affect the water clarity. Wissa (2002), Fishar et al. (2003) and Mageed and Heikal (2006) mentioned that, water turbidity is either from the suspended silt and clay or from the heavy growth of the phytoplankton. In addition, the positive correlation between pH and TR was supported by Moore (1989), Michaud (1991) and Masoud *et al.* (2004). They clarified that $CaCO_3$ is precipitated at high pH during photosynthesis in relatively Ca rich water.

The diatom phytoplankton (Bacilariophycae) is the main consumer of silicate in aquatic ecosystems. Since nutrient compounds and silicate are abundant in the water, they will increase in number. Their increase will be met by high oxygen consumption and accordingly, decrease in total zooplankton density. Therefore, increased silicate was negatively correlated to zooplankton density (Fig. 9). Additionally, decomposition of dead diatoms by microorganisms will consume more oxygen.
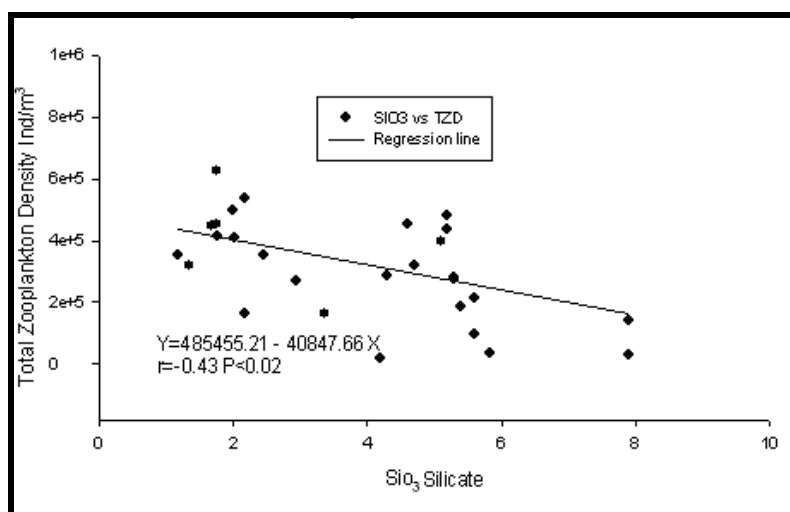

Fig. (9): Relationship between total zooplankton density (TZD) and reactive silicate (SiO₃).

SPECIES DIVERSITY OF ZOOPLANKTON

Species diversity, dominance, evenness and species richness can be influenced by several factors such as fluctuations of water characteristics, climate changes, pollution, eutrophication and habitat characteristics.

1. Analysis of Zooplankton Diversity in Lake Edku

The lowest number of species (40 species) was recorded in the lake-sea connection, while the highest (53species) was at station 2, in the body of the lake Table (3) whereas, 44 species were recorded in El-Khairy Drain (St. 7). The low number recorded in station 5, could be due to the influence of water discharged from El-Khairy Drain into the lake near this station.

The species number and species richness for both the drainage and the lake habitats was close to each one which indicates the impact f the drainage discharge on the lake characteristics and more or less the water homogeneity Table (4). The

community dominance index increased in the lake habitat and lake-sea connection which in turn decreased their diversity.

Table (3): Average of Zooplankton major diversity indices in the studied locations of Lake Edku.

Stations	Habitat	Sp. No.	Sp. Rich.	Shannon*	Margalef	Community Dominance CDI	Evenness
ST1	D1	52	31.75	0.909	2.475	56.94	0.605
ST2	BL2	53	32.75	0.8765	2.44	60.48	0.576
ST3	BL3	49	28.25	0.822	2.09	59.705	0.57
St4	BL4	47	26.25	0.772	1.94	64.05	0.546
St5	BL5	39	22.00	0.7764	1.65	62.96	0.579
ST6	LSC6	40	17.5	0.704	1.49	70.807	0.571
ST7	D7	44	23.5	0.933	2.01	56.017	0.687
Average		46	26.000	0.828	2.01	59.433	0.591
SE			±2.060	±0.031	±0.138	±2.983	±0.017

BL= Body of the lake   *used the $\log_{10}$ D = Drainage   LSC = Lake Sea Connection

Table (4): Matrix of Diversity Indices for the Studied Habitats

Index	D	BL	LSC
Sp. No.	48	47	40
Sp. Rich.	27.63	27.31	18
Shannon	0.92	0.81	0.70
Evenness	0.65	0.57	0.571
Margalef	2.24	2.03	1.492
CDI	56.48	61.8	70.81

Seasonal changes can influence zooplankton diversity, reproduction and distribution. The zooplankton diversity indices increased during winter and summer; however, they decreased during autumn. In addition, the species number was high in winter (Table 5) due to the entrance of some marine species into the lake. This number decreased during spring due to the decreased salinity that led to death of marine species, or increased phytoplankton that led to high oxygen consumption and consequently decreased zooplankton species number.

Table (5) Average of Seasonal Zooplankton Major Diversity Indices In Lake Edku.

Season	Species No.	Sps. Rich.	Shannon*	Margalef	CDI	Evenness
WI	60	26.71	0.86	2.14	56.44	0.61
SP	46	24.29	0.80	1.85	66.29	0.59
SU	53	27.14	0.85	2.05	58.00	0.60
AU	48	25.86	0.79	2.01	65.54	0.57
Average	51.75	26.00	0.83	2.04	61.57	0.59
SE	1.502	1.207	0.029	0.095	2.35	0.019

*used the $\log_{10}$

The aquatic organisms seem to be affected by increased acidity because most of them may have chitinus, calcareous or siliceous exoskeleton and these protective

structures might be damaged by decreasing the water pH. In the studied ecosystem, rotifer species only increase by increasing water pH therefore the evenness and diversity will decrease and dominance index will increase; where they are mostly dominated by one genus, *Brachionus*. Figure (10) shows the negative correlation between water alkalinity and Shannon and Weaver diversity index.
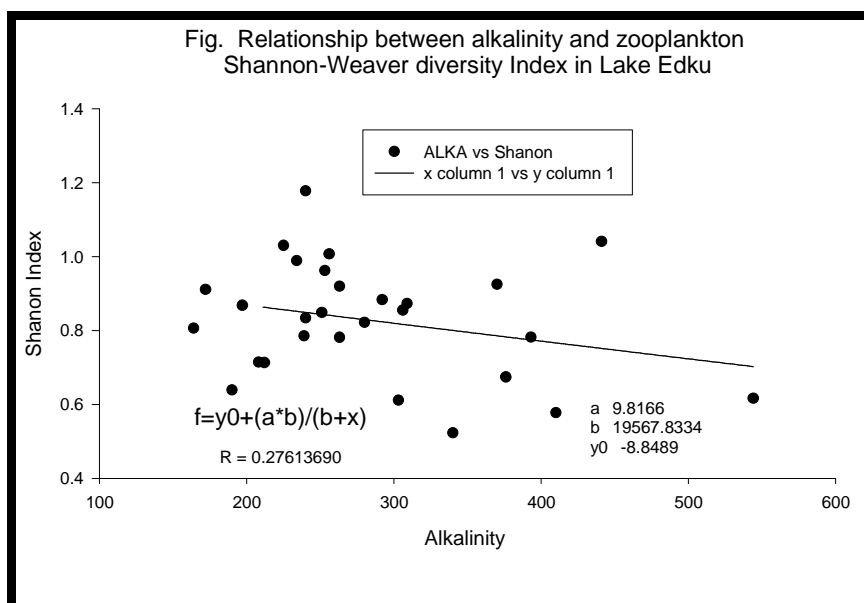

Fig. (10): The relationship between water alkalinity and zooplankton Shannon-Weaver diversity

The diversity index would be higher when two different communities mix together (Margalef, 1958; Gharib, 1999). This may support the increased species number in station 2 due to its location between Taher Drain and the body of the lake. Moreover, the low species richness and species number in station 5 may be attributed to the effect of El-Khairy Drain. These results came in agreement with those reported by Martin *et al*. (2000) and Abdel-Aziz and Dorgham (2004).

The decrease of the diversity index in the lake-sea connection may be due to the pollutants coming from Abu Qir Bay or due to the continuous fluctuation of salinity and the pollutant coming from Abu Qir Bay which may bring different species. This observation was supported by Odum (1971) and Ostfield and LoGiudice (2003) who stated that loss of biodiversity occurred in communities subjected to seasonal or periodic perturbations by man or nature. Furthermore, youssef (2003) and Abdel-Aziz and Dorgham (2004) explained that estuarine area is characterized by variable and unpredictable environmental conditions, which in turn influence the biodiversity. However, they supported the increase of species number in this habitat during winter and attributed this to the entrance of some marine species. Moreover, Flower (2001) encouraged these results as she postulated that, Delta lakes are rich in phytoplankton diversity but not so for zooplankton diversity. Samaan (1976) illustrated that increased density of submerged hydrophytes was met by a decrease in the number of zooplankton organisms.

In conclusion, comparing the present results with previous data of other researchers showed that zooplankton community in Lake Edku shifted from dominance of Cladocera and large zooplankton species to rotifers and small zooplankton by increasing eutrophication.

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تركيب مجتمع هائمات المياه العذبة الحيوانية في بحيرة ادكو- جمهورية مصر العربية

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لقد تم تصميم هذه الدراسة لتقييم تركيب مجتمع الهائمات الحيوانية ببحيرة ادكو بمصر؛ و للوقوف على الحالة الراهنة لهذه الكائنات و تقييم التأثير البيئي وجودة وحالة المياه علىهذه الكائنات.

جمعت عينات الهائمات و المياه موسميا خلال عام ٢٠٠٤ من سبع محطات تم اختيارها لتمثل المسطح المائي والبيئات الموجودة به؛ حيث قسم المسطح المائي الي ثلاث بيئات مختلفة هي جسم البحيرة (BL)و المصارف (D) و بيئة البرزخ (LSC). تم قياس بعض العوامل البيئية الفيزيائية و الكيميائية مثل درجة الحرارة و شفافية الماء و قلوية الماء و حموضة الماء و تركيز الكلور و التوصيلية الكهربية للماء و عمق الماء و الأكسجين المذاب و الأكسجين المستهلك حيويا و كيميائيا و عسر الماء.

أوضحت الدراسة ان مجتمع الهائمات الحيوانية يتكون من اثنان و سبعون نوعا موزعة علي ثلاث مجموعات اساسية؛ هي العجليات و مجدافيات الأرجل و براغيث ، حيث مثلت كل مجموعة ٨٩.٥% و ٦.٨% و ٢.٣% علي التوالي من مجموع الكثافة الكلية للهائمات الحيوانية. اوضح حساب معامل وفرة الأنواع (ISA) و معامل وفرة الأنواع المعدل (MISA) ان الحيوانات ذات الحجم الصغير مثل العجليات سادت البيئة في المسطح المائي محل الدراسة وبخاصة نوع براكيونس الذي يعتبر من مؤشرات زيادة التلوث العضوي للماء و الإثراء الغذائي الزائد.

اثبتت التحليلات الاحصائية المستخدمة في الدراسة ان البيئات المتشابهة تحتوي على مجتمعات متشابهة من الهائمات. كما اثبتت المقارنات ان مجتمع الهائمات الحيوانية في بحيرة ادكو تحول علي المدى البعيد من سيادة الأنواع الحساسة كبيرة الحجم مثل الدافنيا الى سيادة الأنواع صغيرةالحجم المحبة للتلوث و الاثراء الغذائي.