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Long-term variations of zooplankton community in Lake Edku, Egypt

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ABSTRACT

Lake Edku receives huge amounts of waste waters discharged from various effluents that could be affecting on its ecological and biological features. Samples were collected seasonally for seven subsequent years (2009 - 2015) from 9 stations represent the different habitats in Lake Edku to assess the ecological status of the lake through long-term variations of zooplankton community. The data of physico-chemical parameters indicated that some parameters had wide variations in yearly average and others changed within narrow range. Lake Edku is considered among the highly eutrophic lakes as the average values of Chlorophyll- a concentrations all over the study period always higher than the eutrophication level. Zooplankton community in the lake comprised 77 species. Rotifera and Copepoda were the most abundant and diversified groups. Long-term variations of zooplankton abundance and diversity indicated that the lake is in continuous degradation. This also confirmed by the dominance of rotifer species belonging to genera *Brachionus*, *Polyarthra*, *Keratella* and *Filinia* which were considered as bio-indicators of organic pollution. However, it would be concluded that Lake Edku is highly eutrophic basin, under severe conditions and their ecological status is too bad and needs repair.

INTRODUCTION

Zooplankton is one of the most important biotic components in aquatic environment. It plays an important role in the pelagic food web as a food source for larval and juvenile fish. Zooplankton relationships with physico-chemical parameters are important for the management strategies of aquatic ecosystems (Edward and Ugwumba, 2010). The community structure of zooplankton was significantly influenced by different water quality parameters (Sousa *et al*., 2008). Zooplankton is a well-suited tool for understanding the state of environment and as a bio-indicator of aquatic environmental perturbation (Contreras *et al*., 2009, El-Naggar, 2016). For instance, rotifers are known to be excellent indicators of organic pollution as they thrive better in organically polluted environments (Paleolog *et al*., 1997; El-Naggar, 2016) as well as some protozoan species are considered as indicators of pollution with sewage pathogens (Froneman, 2004).

Lake Edku lies in the southeastern Mediterranean, northwest of the Nile Delta and is connected to Abu Qir Bay through Boughaz El Maadiya. The lake receives huge amounts of drainage water discharged from two main drains namely El-Khairy Drain (annual inflow 592×10^6 m^3) and Berseq Drain (annual inflow 348×10^6 m^3). El-

Khairy Drain transports domestic, agricultural and industrial wastes discharged from El-Bousely, Edku and Damanhour sub-drains as well as effluents from more than 300 fish farms. However, the lake is subjected to various kinds of pollution which influenced on its water quality (Masoud *et al*., 2004). Beside large quantities of floating, aerial and submerged plants or hydrophytes cover about 50% of the lake area and decrease the surface area of the lake. Therefore, the present study is aimed to assess the ecological status of Lake Edku through long-term variations of zooplankton community.

MATERIALS AND METHODS

Lake Edku is the third largest Northern Nile Delta Lakes. It lies at latitude 31° 11′, 31° 18′ N and longitudes 30° 8′ 30″, 30° 23′ E. It is a shallow water basin connected to the Mediterranean Sea by a narrow passage (Boughaz El-Maadiya) that opens at its northern margin. The lake has an average depth of about 1 m and surface area of about 85 km^2. Samples were collected seasonally for seven subsequent years (2009-2015) from nine stations represent the different habitats in Lake Edku. Figure 1, illustrates the area of investigation and locations of sampling stations.

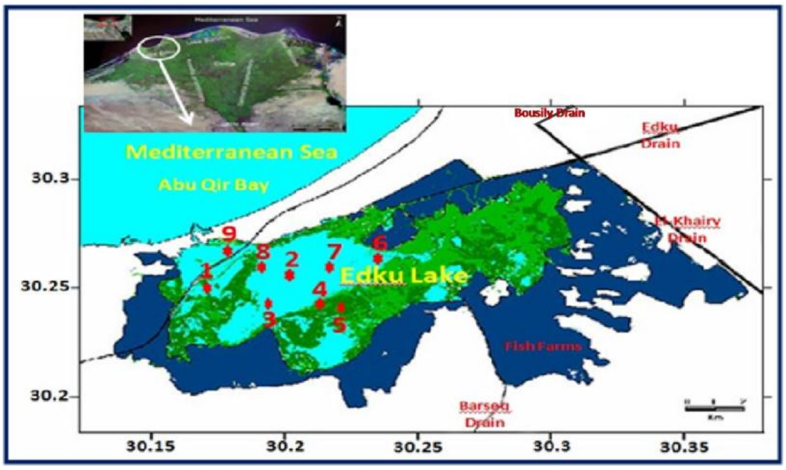

Fig. 1: Lake Edku and the locations of sampling stations.

The physico-chemical parameters of the stations sampled in Lake Edku were estimated at the same time of zooplankton samples collection as reported in the site of Environmental monitoring program for the North lakes (E.M.P.N.L.). Zooplankton samples were collected at each station by filtering 50 liters of lake water using standard plankton net of 55µm mesh size. The collected samples were preserved in 5% neutral formalin solution and their volumes were concentrated to 100ml. Quantitative and qualitative investigations were done by using a binocular research microscope and zooplankton abundance was expressed as ind./m^3. Zooplankton identification was done according to Edmondson *et al*. (1959), Berzins (1960), Harding and Smith (1960), Hutchinson (1967), Dussart, (1969) and Bick (1972).Species richness (Margalef, 1968), Diversity index (Shannon and Weaver, 1968), Evenness (Pielou, 1975) and Simpson index (Simpson, 1949) were calculated to estimate the stability of zooplankton community in Lake Edku. Moreover a similarity index was estimated between the stations sampled in the study area. The similarity was measured using Multivariate Methods; species analysis (species clustering) using Primary Program which is used to define species assemblages (species co-occur at the sites) using the Bray-Curtis similarity matrix with the aim to find" Natural grouping" of the samples more similar (Cormack, 1971).

RESULTS

Hydrographic conditions

The data of physico-chemical parameters in Lake Edku during 2009-2015 indicated that some parameters had wide variations in yearly average and others changed within narrow range (Table 1). The lowest average value of water temperature (22.47±7.85°C) was recorded during 2011 while the highest one (28.84±0.07°C) occurred in 2014. On the other side, the highest average value of water transparency (35.5±7.5) was recorded during 2009 and 2010 while the lowest one (21.96±11.4) was found in 2014. The pH values indicated that, the lake water lies in the alkaline side (varied between 8.09± 0.42 and 8.56±0.16). The average salinity values changed without definite trend and varied between 1.52± 0.37‰ and 4.07±4.26‰. The annual average of dissolved oxygen concentration showed that, the lake water well oxygenated all over the study period and reached its highest average value (10.81±1.94 mg/l) during 2015. However, Lake Edku is considered among the eutrophic lakes as the average values of Chlorophyll- a concentrations all over the study period always higher than the eutrophication level (Table 1).

Table 1: Physico-chemical parameters in Lake Edku during 2009-2015.

Parameters	2009/10	2011	2012	2013	2014	2015	Reference
Temp. (°C)	23.6±6.0	22.47±7.85	22.67±6.22	22.71±5.85	28.84±0.07	23.63±8.34	**Enironmental Monitoring Program for the North Lakes. (http://www.eeaa.gov.eg/ar-eg)**
Transparency (cm)	35.5±7.5	22.21±6.61	26.65±9.0	28.9±8.3	21.96±11.4	30.28±5.11	
pH	8.09±0.42	8.23±0.46	8.5±0.24	8.51±0.23	8.51±0.23	8.56±0.16	
Salinity (‰)	2.35±1.7	4.07±4.26	1.52±0.37	2.35±1.28	1.74±0.35	1.92±1.15	
Dissolved oxygen(mg/l)	8.62±0.84	10.36±1.11	7.26±2.3	10.43±1.42	9.57±0.73	10.81±1.94	
Chlorophyll-a (mg /l)	61.09±15.53	110±93.65	85.87±38.4	126.59±53.6	67.16±15.15	67.14±15.13	

Zooplankton community composition

Zooplankton community in Lake Edku was represented by 77 species as well as the meroplanktonic larvae of benthic forms. Rotifers came in the first rank of abundance and diversity; they comprised 34 species represented 74.24% of the total zooplankton count (Table 2). The second rank of zooplankton abundance occupied by copepods with their immature stages (nauplii and copepodite stages) contributed 13.99 % of the total zooplankton count. They were represented by 11 species. The third abundant group was Ostracoda constituted 8 % of the total zooplankton count. Cladocerans were less frequent, represented by 7 species forming 2.47 % of the total zooplankton count. Other groups such as Protozoa, Nematoda, Trematoda and Appendicularia as well as the meroplanktonic larvae of Polychaeta, Cirripedia and Mollusca were rare and constituted collectively about 1.29 % of the total zooplankton count.

Table 2: Relative abundance (RA) of the different zooplankton groups recorded in Lake Edku during the study period (2009-2015).

Zooplankton groups	Relative abundance (ind./m^3)	R. A. (%)
Protozoa	3341.9	0.552
Nematoda	4081.2	0.674
Trematoda	17.1	0.003
Rotifera	449636.8	74.237
Polychaeta	265.0	0.044
Cladocera	14978.6	2.473
Ostracoda	48465.8	8.002
Copepoda	84751.3	13.993
Cirripedia	64.1	0.010
Mollusca	59.8	0.010
Appendicularia	12.8	0.002
Total	605674.4	100

Spatial distribution of zooplankton

The abundance and the number of zooplankton species recorded in Lake Edku showed spatial variations all over the study period (Fig. 2). It would be noticed that, St. 3 attained the highest zooplankton abundance (779038.46 ind./m^3). Rotifera was the most abundant (585038.46 ind./m^3) and diversified group (21 species). It was dominated by *Brachionus calyciflorus* and *Brachionus angularis*.

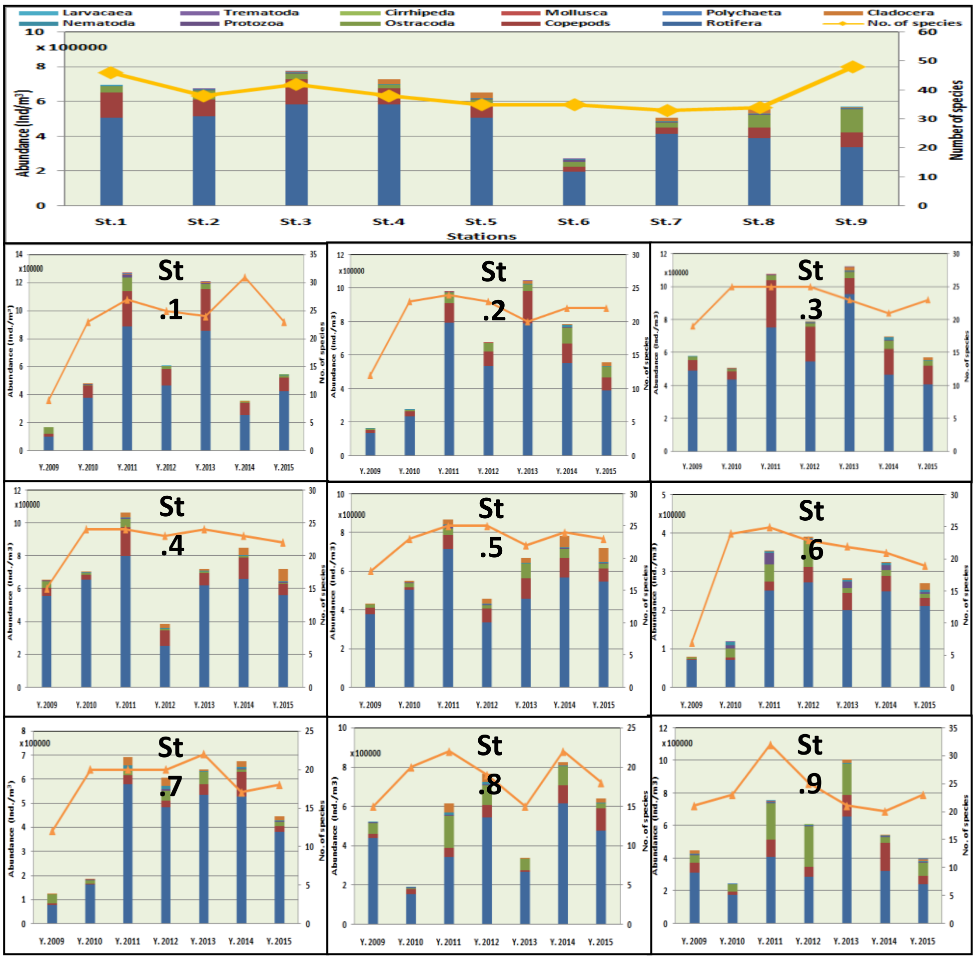

Fig. 2: Long-term spatial distribution of zooplankton in Lake Edku.

Copepoda was the second abundant group (146038.46 ind./m^3). It was represented by 5 species dominant by *Acanthocyclops americanus* and *Thermocyclops crassus.* On the other side, the lowest zooplankton abundance (274307.69 ind./m^3) was recorded at St. 6 where Rotifera was the most abundant group (198615.38 ind./m^3) followed by Ostracoda (27730.77 ind./m^3). The spatial variations of zooplankton diversity indicated that, the highest number of species was recorded at St. 9 (48 species) while the lowest one was found at St. 7 (33 species).

Figure 2, illustrates long-term variations of zooplankton abundance and the number of species recorded at each station in Lake Edku during the study period. The highest zooplankton abundance was recorded during 2011 at St.1, St.4, St.5 & St.7 (1272500 ind./m^3, 1061500 ind./m^3, 864250 ind./m^3 and 692250 ind./m^3 respectively) and during 2013 at St.2, St.3 & St.9 (1048000 ind./m^3, 1125500 ind./m^3 and 1004000 ind./m^3 respectively) while the lowest one was recorded during 2009 at most stations (St.1, St.2, St.3, St.5, St.6 & St.7). On the other hand, the highest number of zooplankton species was recorded during 2011 at St.2, St.3, St.4, St.5, St.6 & St.8 and during 2013 at St.7 & St.9 while the lowest one was recorded during 2009 at nearly all st.

Temporal distribution of zooplankton:

Zooplankton abundance and diversity in Lake Edku varied seasonally all over the study period (Fig. 3). Spring was the most abundant (777203.70 ind/m^3) but less diversified season (38 species) while winter was the less abundant (472777.78 ind/m^3) but high diversified season (51 species). Figure (3) illustrates long-term variations of zooplankton abundance and the number of recorded species during the study period. It would be noticed that, zooplankton community in 2011 was the highest abundant and diversified (853000 ind/m^3, 44 species) while in 2009, it was less abundant and less diversified (310111.11 ind/m^3, 30 species). However, zooplankton abundance and the number of recorded species varied seasonally from year to another (Fig. 3). At the end of 2009, zooplankton abundance was decreasing from summer (360444.44 ind./m^3) to autumn (259777.78 ind./m^3), *Brachionus calyciflorus* and *Brachionus angularis* constituted the main bulk of zooplankton community. With starting of 2010, zooplankton abundance reached its lowest value (213555.56 ind./m^3), *Keratella quadrata* was the most abundant species (46.31% of the total zooplankton count) followed by *Brachionus calyciflorus* and *Brachionus angularis*. From spring 2010, the zooplankton abundance was starting to increase (352888.89 ind./m^3) until reached its highest value during spring 2011 (1192888.89 ind./m^3), *Brachionus calyciflorus*, *Brachionus angularis* and *Keratella quadrata* as well as ostracods were the major zooplankton components during this period. From summer 2011, the zooplankton abundance decreased (721888.89 ind./m^3) and reached its lowest value in winter 2012 (149555.56 ind./m^3) when *Brachionus calyciflorus* and *Brachionus angularis* attained their lowest abundances (5444.44 ind./m^3 and 16555.56 ind./m^3, respectively). In spring 2012, zooplankton abundance increased (1095444.44 ind./m^3) with the increasing the abundances of *Brachionus calyciflorus, Brachionus angularis* and *Keratella quadrata*. The zooplankton abundance decreased during summer and autumn 2012 (533444.44 ind./m^3 and 573000 ind./m^3, respectively). With starting of 2013, zooplankton abundance increased and reached its highest value during autumn (1234111.11ind./m^3). The sudden blooming of *Keratella cochlearis* and copepod nauplii were the main reasons of increasing of zooplankton abundance in winter 2014. In summer 2014, the zooplankton abundance was low (292222.22 ind./m^3) because of the decreasing in rotifer and copepod abundances to their lowest levels. From autumn 2014 to the end of study period, zooplankton abundance attained alternative increase and decrease with the different seasons. It would be noticed that, the zooplankton abundance appeared three peaks; spring 2011 (1192888.89 ind./m^3), 2012 (1095444.44 ind./m^3) and autumn 2013 (1234111.11 ind./m^3).

Meanwhile, the lowest zooplankton abundances occurred during winter 2010, 2012 and 2015 (213555.56 ind./m^3, 149555.56 ind./m^3 and 195111.11 ind./m^3 respectively). On the other side, the highest number of zooplankton species was recorded during winter 2010, 2014 and spring 2011 while the lowest one occurred during summer 2014 (Fig.3).

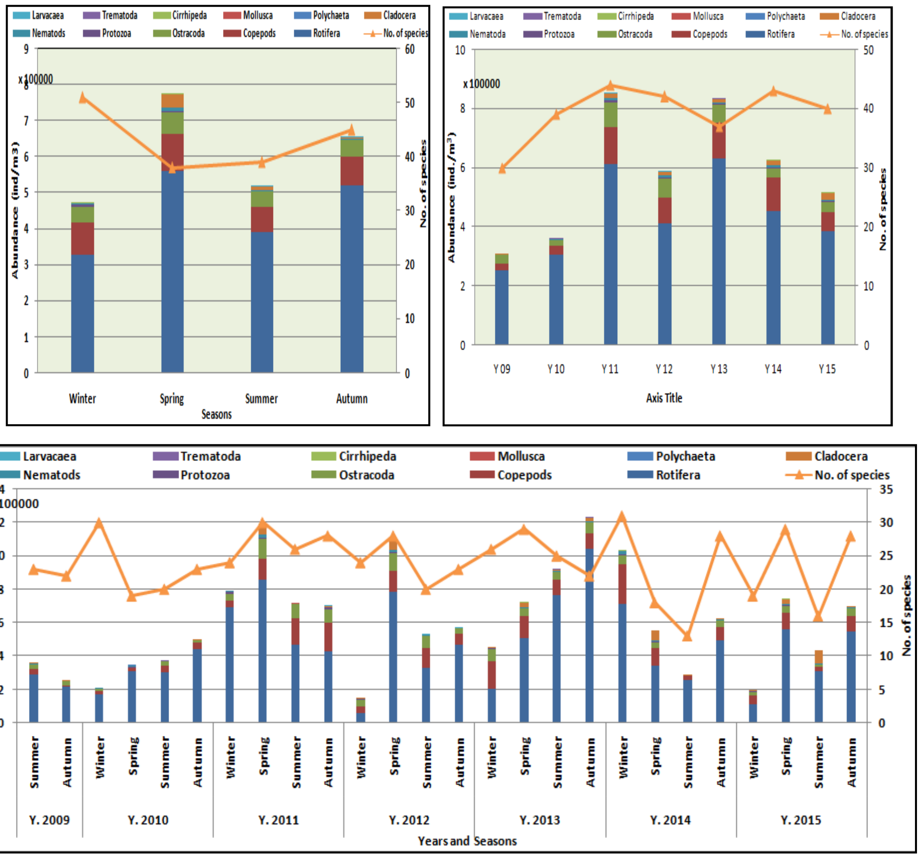

Fig. 3: Temporal variations of the different zooplankton groups recorded in Lake Edku during the study period

The dendrogram illustrates the similarity level of the nine stations sampled in Lake Edku during the study period is shown in Fig. 4. According to the similarity level between stations, the cluster analysis classified them into two categories; homogenous stations and non-homogenous stations. It would be noticed that St.4 and St.5 were homogenous stations with the similarity of 82.3% during 2009, 79.15% in 2010, 83.46% in 2011, 84.73 in 2012, 81.77% in 2013, 84.07% in 2014 and 86.38% in 2015. On the other side, St.6 and St.9 were non-homogeneous with other stations. They separated from the other stations during most of the study period. Over all the study period, the highest similarity (86.86%) was recorded between St.7 and St.8 followed by 86.38% between St.4 and St. 5 during 2015 (Fig.4).

The diversity indices of zooplankton community in Lake Edku varied all over the study period (Fig.5). The highest value of species richness (2.808) was recorded at St. 9 during 2011 while the lowest value (0.887) occurred at St.6 during 2009. On the other hand, the highest value of Shannon index (2.436) was recorded at St. 4 during 2012 while the lowest (1.246) was found at St. 9 during 2009. The highest value of evenness index (2.7394) was recorded at St. 9 during 2014 while the lowest (0.431) was recorded at the same station during 2009. Simpson index attained its highest value (0.8858) at St.2 during 2012 while the lowest (0.5576) occurred at St. 9 during 2009.

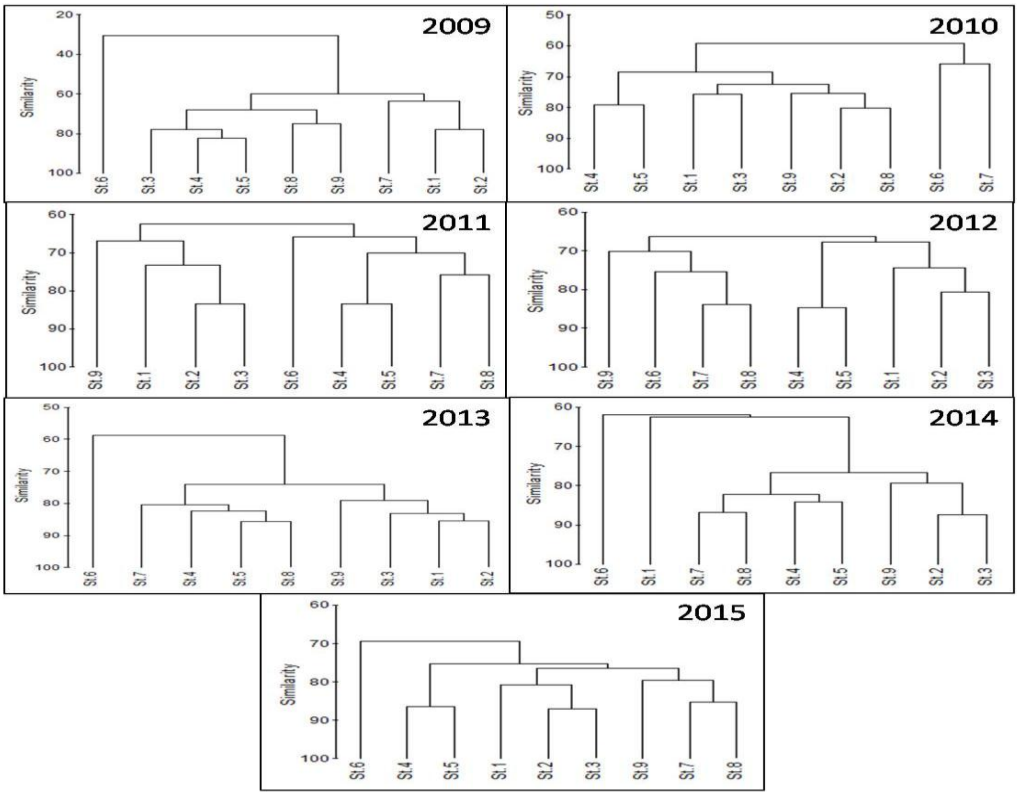

Fig. 4: Cluster analysis of zooplankton abundance between stations in Lake Edku during the study period.

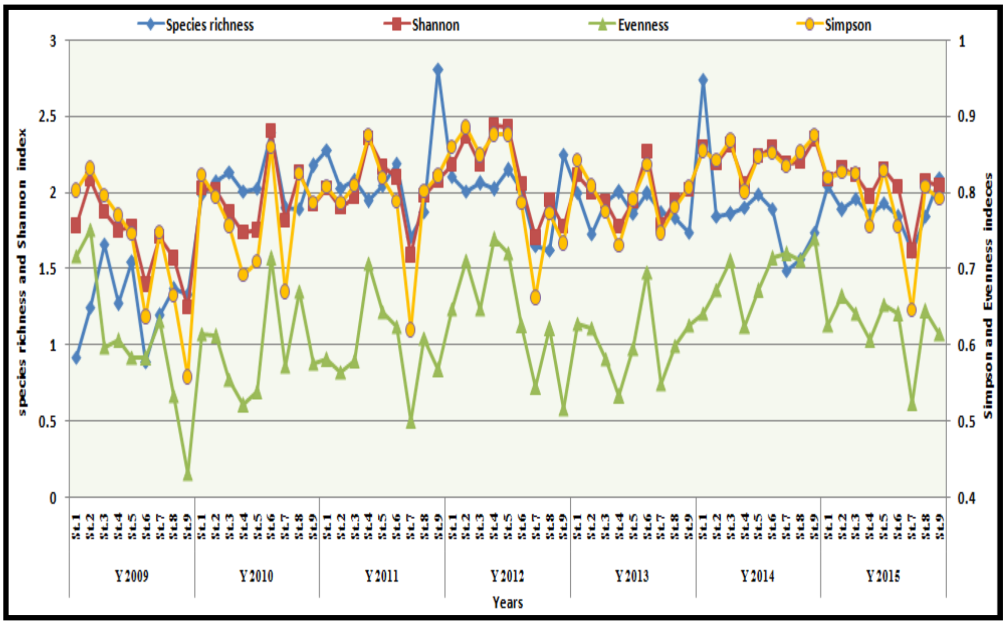

Fig. 5: The diversity indices of zooplankton community in Lake Edku during the study period.

Long-term variations of zooplankton abundance and diversity based on historical data as well as the present results are shown in Fig. 6. Zooplankton abundance exhibited a considerable decrease with time, attained its highest value (2664024 ind./m^3) during 1995-96 then gradually decreased until reached its lowest value (50355.1 ind./m^3) during 2015. On the other side, the number of zooplankton species also exhibited considerable decreasing trend with time (Fig.6).

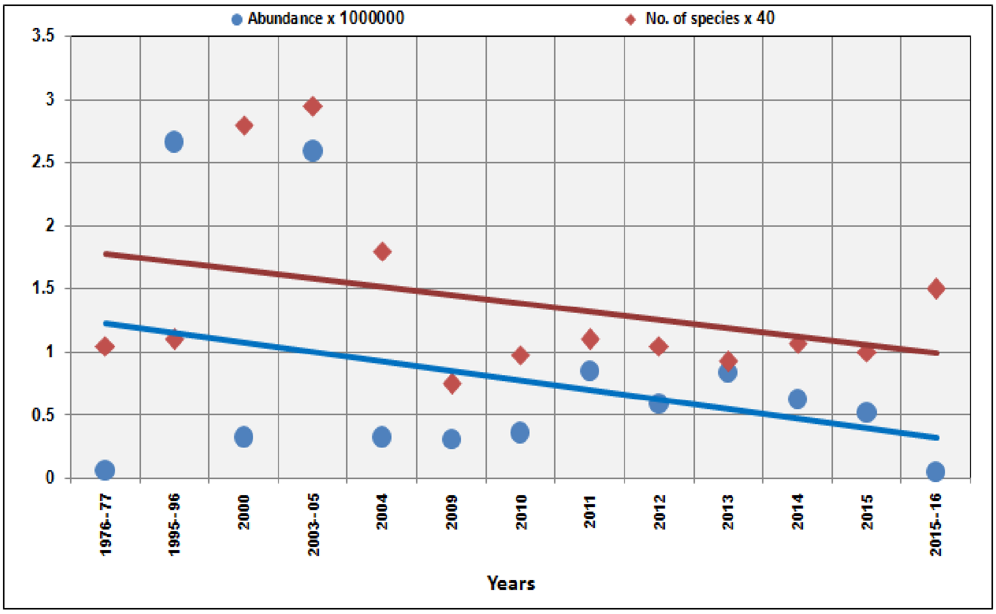

Fig. 6: Long-term variations of zooplankton abundance and diversity in Lake Edku [1976-77 (Soliman, 1983); 1995-96 (Gharib and Soliman, 1998); 2000 (Aboul Ezz and Soliman, 2000); 2003-05 (Aboul Ezz, 2008); 2004 (Hassan *et al.*, 2017) and 2009-15 the present study].

DISCUSSION

Aquatic ecosystems are considered as the most impacted habitats as a result of human activities that represent one of the most important factors in shaping and limiting the abundance, diversity and community structure of organisms (Mona *et al.* 2019). Lake Edku receives huge amounts of waste waters discharged from various effluents such as fish farms, agriculture and sewage discharges that could be affecting on its ecological and biological features. The data of physico-chemical parameters indicated that, the water temperature of Lake Edku changed within narrow range. Its changes depend on the sampling time and wind action. On the other side, the decrease in salinity values may be attributed to the increase in the amount of waters discharged into the lake. The expansion of agriculture and aquaculture farming as well as the industrial activities contributed to the increasing in the volume of waste waters discharged into the lake. Huge amounts of drainage waters discharged from the surrounding cultivated lands of El-Behaira Governorate provided a nutrient rich input to the lake with a salinity of about 2-3 ‰. The transparency of lake waters also decreased with time due to the increase in the rush of sewage and the strong mixing caused by waste disposal and intensive transit of fishing boats as well as the flourishing of phytoplankton. The annual averages of dissolved oxygen concentration indicated that the lake water was well oxygenated all over the study period. This could be attributed to the release of oxygen through photosynthesis of the intensive masses of large plants in the lake and flourishing of phytoplankton. On the other side, according to the trophic classification of inland waters based on chlorophyll-a concentration, Lake Edku is considered among the eutrophic lakes as the average values of Chlorophyll- a concentrations all over the study period always higher than the eutrophication level.

Based on the historical data, Lake Edku showed gradual increase in zooplankton diversity. It increased from 28 species in 1970 (Samaan, 1976) to 42 species in 1977 (Soliman 1983), 44 species in 1996 (Soliman, 2005), 112 species in 2000 (Aboul Ezz and Soliman, 2000) till reach its maximum, 118 species in 2003-05 (Aboul Ezz, 2008). On the other side, the present results indicated that the diversity of zooplankton community in the lake tended to decrease with time. The low diversity values always associated with the environments under stress. Also, zooplankton abundance had a decreasing tendency over time. It reached its highest value in 1995-96 and then gradually decreased with time till reached its lowest value in 2015. The abundance and diversity declined as the pollution effects are more severe (Abass *et al.*, 2001).

Rotifera, Copepoda, Ostracoda and Cladocera dominated zooplankton community in Lake Edku during the present study. They were also dominated at all previous studies in the lake but with different frequencies (Hassan *et al.*, 2017). The dominance of Rotifera usually associated with organically polluted water. On the other side, the lowest density of Cladocera could be attributed to predation, eutrophication or water pollution as they are more sensitive to changes in the water quality. The zooplankton species recorded in Lake Edku are mainly fresh or brackish water forms. The herbivorous rotifers, *Brachionus calyciflorus*, *B. angularis* and *Keratella quadrata* dominated zooplankton community in the lake during the present study. *Certeria* and *Euglena*, the most common phytoplankton genera in Lake Edku were found in the gut contents of these species Gharib (1999). The dominance of genus *Brachionus* in the lake could be attributed to its high reproduction rate, absence of their predators (Hobaek *et al.*, 2002) and abundance of suitable food (Bielan´ska-Grajner *et al.*, 2014).

Not only physico-chemical variables influenced zooplankton community structure, but also there is a strong effect from the biotic components of the aquatic ecosystem upon each other, for instance, grazing of herbivorous zooplankton upon phytoplankton and predation of vertebrate and invertebrate predators on herbivorous zooplankton. These interactions strongly influence the community composition (Zhao *et al.*, 2008). Zooplankton community in Lake Edku was dominated by small-size rotifer species which are not preferable as food by many fishes and other vertebrate predators. Furthermore, many of the rotifer species recorded in the lake possessed morphological and behavioral characteristics that drastically reduced their vulnerability to predation, such as genus *Brachionus* that has lorica with long spines. This genus was the most common genera in Lake Edku. On the other side, the larger zooplankton species such as copepod species and cladoceran species are less abundant in the lake as they are preferable by many predators. Some predators are selective feeders, examination of gut contents of *Oreochromis* spp. indicated that copepods and cladocerans are more preferable than rotifers (Uku and Mavuti, 1999). The present study revealed that copepod community was dominated by nauplii and small sized immature stages. This may illustrate the high predation rate on the large sized adult planktonic species where many fish species select the largest prey that they can see (Bogdan and Gilbert, 1984). The rotifers and nauplii can escape from predators because they are too small or because they provide negligible meal when compared with the effort of catching them (Lair, 2005; Zingel and Haberman, 2008). On the other side, cladoceran species are favorite prey for both vertebrate and invertebrate predators, therefore, predation may limit their abundance in zooplankton community (Bedir, 2004).

The trophic state of the water body was classified by Oecd *et al.*, 1982 into five classes, high, good, moderate, poor and bad depending on the chlorophyll-a concentration. Consequently, Lake Edku is highly eutrophic basin, under severe conditions and their ecological status is too bad. This is also confirmed by the dominance of rotifer species belonging to genera *Brachionus*, *Polyarthra*, *Keratella* and *Filinia* which were considered as bio-indicators of organic pollution (El-Naggar, 2016).

CONCLUSION

Lake Edku receives huge amounts of waste waters discharged from various effluents such as fish farms, agriculture and sewage discharges which are influenced on its water quality and biotic community. As a result of many anthropogenic activities, the ecological and biological features of the lake are deteriorating. Other appearance of environmental deterioration level of the lake is the decreasing of the water transparency with time which is attributed to the increasing in the rush of sewage and the strong mixing caused by waste disposal and intensive transit of fishing boats in addition to the flourishing of phytoplankton. The effect of increased nutrients in the freshwater has resulted in deterioration of the ecosystems. Changes in nutrient contents of the water also result in changes in community structure at each trophic level or within different taxonomic groups. The increasing in human activities in the lake, the increasing in the rate of drainage water discharged into the lake, the expansion of agricultural, industrial and fish farming activities are the main reasons that impact on the lake ecosystem and degraded it. The decreasing of the lake area may have also played an important role in this degradation. However, long-term variations in zooplankton abundance and diversity indicated that the lake is in continuous degradation. It would be concluded that Lake Edku is highly eutrophic basin, under severe conditions and their ecological status is too bad and needs repair. This also confirmed by the dominance of rotifer species belonging to genera *Brachionus*, *Polyarthra*, *Keratella* and *Filinia* which were considered as bio-indicators of organic pollution. Actually, it is difficult to nominate one limiting factor controlling the biological processes takes place in the aquatic ecosystem as such processes are controlled mainly by combination of factors acting at different rates throughout the successive seasons and years.

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