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Environmental Impact Assessment of Aquaculture Practices Using Zooplankton in Lake Mariout, Alexandria, Egypt

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ABSTRACT

Over time, aquaculture has been able to fill the gaps in global national fish output, but the deficient management in aquaculture facilities caused huge negative effects on the environment. For this reason, the present work aimed to conduct an environmental assessment of the impacts of aquaculture practices on the ecosystem and water quality of Lake Mariout. This target was achieved by evaluating the aquaculture impacts on the zooplankton communities and describing the environmental aspects of zooplankton in relation to aquaculture. Seven stations were chosen to cover all major aquaculture features in the lake. Seasonal field scurvies were performed during the period from summer 2020 to spring 2021. A total of 63 zooplankton species and other immature forms were recorded during the current study. Rotifera was the main diverse (44 species) and quantitative (91.28 % of the total count of zooplankton) group. Copepoda come second then Protozoa and other groups that were rare and low in diversity. The rotifer *Brachionus angularis* was the most dominant zooplankton species. Zooplankton flourished in spring and low during winter. The results revealed that species richness ranged between 0.65 and 3.09, which means that the lake tends from moderate to high pollution. Moreover, the Shannon index ranged between 0.46 and 2.93, indicating that the lake is moderately polluted. The Evenness index showed clear effects of aquaculture activities on the equitability of the zooplankton distribution within the lake. In the same context, the total zooplankton density only negatively correlated with the salinity and ammonia concentration; rotifers density also showed the same; copepods were weakly negatively correlated with temperature; protozoans density showed significant correlation with water temperature and negative correlation with hydrogen ion concentration. On the other hand, zooplankton showed no significant correlation with any measured heavy metals. In conclusion, all human activities produce some impact on the surrounding environment, and aquaculture is not an exception, as it utilizes natural resources and releases waste into the environment. The present study indicated that the unmanaged practices of aquaculture can negatively impact the environment. Regulation of aquaculture can create better products for human consumption, and making sure it runs properly for the safety of our environment is a must.

INTRODUCTION

The anthropogenic activities have many impacts on the environment, and aquaculture is not an exception, as it utilizes natural resources and releases waste into the environment. Given the development of aquaculture sector, environmental aspects

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became of an increasing concern, in parallel with the maximum public environmental concern developed during the second half of the 20th century. Up till now, most aquaculture practices have produced little negative effects on the ecosystems, even being beneficial in some cases. However, frequently a deficient management or accidents in aquaculture facilities have been reported to cause negative effects. Potential effects of aquaculture activities include water and sediment quality, and negative impacts on natural populations, landscape and other pre-existing economical activities. To a great extent, these effects depend on factors such as type of facilities, geographical location and produced species. The varying effects are originated from a small number of sources, including feeds offered, chemicals, animal's excretions, dead animals, and the interactions between cultured and wild animals **(Domínguez & Martín, 2004; El-Sadek *et al*., 2022a)**.

Aquaculture, over the years, has been able to offset the deficits in national fish production all over the world. There have been substantial socio-economic benefits arising from the expansion of aquaculture. Previously seen as a solution to capture fisheries which have over the years caused significant ecological changes to the environment, aquaculture has now been identified to pose equally the same problems, or even worse in some cases. The study reviews some deleterious effects of aquaculture and assesses the impact of the increasing practice of aquaculture on the surrounding habitats. Recommendations are made in line with good aquaculture practices seen elsewhere around the world **(Dabi & Dzorvakpor, 2015)**. Fish farms are maintained by complex physical and chemical factors and by biological interactions, which directly depend on water quality. Framing activities can cause important impacts on the environments due to the discharge of waste water into streams, rivers and lakes. These farms are normally commercial and associated with high intensification (increased inputs) and astute entrepreneurial management to meet market demands. Such intensification may increase the risk of environmental pollution **(Iliyasu *et al*., 2016)**. Water quality is the first most important limiting and difficult factor in fish farm production to understand, predict and manage. Thus, fish farm production has risen to be planned within the context of minimizing environmental impact and optimizing resource utilization through the management of the water quality **(Tavares & Santeiro, 2013)**

In Egypt, aquaculture has become an increasingly important activity as an instantaneous source of fish protein required for the increase population (**Ahmed *et al*., 2011)**. Most aquaculture activities are generally located in the northern Nile Delta region, with fish farms usually found clustered in the areas surrounding the four Delta lakes (Mariout, Edku, Buroullus and Manzalla) **(FAO, 2005)**.

Lake Mariout is located on the western Mediterranean coast of Egypt **(Khairy, 2013)**. It is a brackish water lake, receiving its water from agricultural drains, which collect drainage water from the Delta region and flow by gravity to El-Umum drain which in turn, discharges to the lake. The lake water level is maintained at a relatively constant level by means of the El-Mex pumping station, where water is discharged through a dug canal to the Mediterranean Sea. Numerous works have studied the different pollution conditions in the lake resulting from human activities. The lake is affected by many human activities including fish farming. The study reviewed some deleterious effects of aquaculture and assessed the impact of the increasing practice of aquaculture on the surrounding habitats. The present work aimed to introduce an environmental impacts' assessment of aquaculture practices on Lake Mariout environment including the detection of aquaculture's impacts on water quality and zooplankton communities of the lake, as well as describing the environmental aspects for zooplankton in the lake under study in relation to aquaculture.

MATERIALS AND METHODS

1. Study Area and sampling sites

Lake Mariout is a brackish lake of about 250 km^2 in northern Egypt, lying between Latitude 31º 01' 48” and 31^o 10' 30” N and Longitude 29º 57' 00” E along the Mediterranean coast of Egypt. It is separated from the Mediterranean Sea by the narrow isthmus on which Alexandria City was built. It is considered a major coastal lagoon, which actually forms the southern border of Alexandria City. The lake is divided into artificially four main basins; namely, the main (6000 acres), the South West (5000 acres), the North West (3000 acres), and aquaculture or fisheries (1000 acres). The lake is fed by canals from the Rosetta branch of the Nile. The main canals are al Kalaa drain, Omum drain and Nubaria canal. The outflow from the lake is only released by El-Max pumping station. Seven stations were chosen coverng all major aquaculture features in the lake (Fig. 1).

2. Collection and treatment of zooplankton samples

Zooplankton samples were seasonally collected during the period from summer 2020 to spring 2021 by filtering 50 liters of lake water at each station using standard plankton net of 55µm mesh size. After collection, zooplankton samples were preserved immediately in 5 % neutral formalin solution. In the laboratory, the sample volume was concentrated to 100ml, and the whole sample was examined in Petri dish to identify all species. Three separated homogeneous samples (each of 1ml volume) were separately examined in a counting Sedgwick Rafter cell under the ordinary binocular microscope **(Zakaria & El-Naggar, 2019)**. The identification of zooplankton species was done using the keys of **Jorgensen (1924)**, **Rose (1933)**, **Tregouboff and Rose (1957)**, **Newell and Newell (1979)**, **Marshall (1969)**, **Santhanam and Srinivasan (1994)**, **Boltovskoy (1999)**, **Conway *et al*. (2003)** and **EL-Naggar (2014)**.

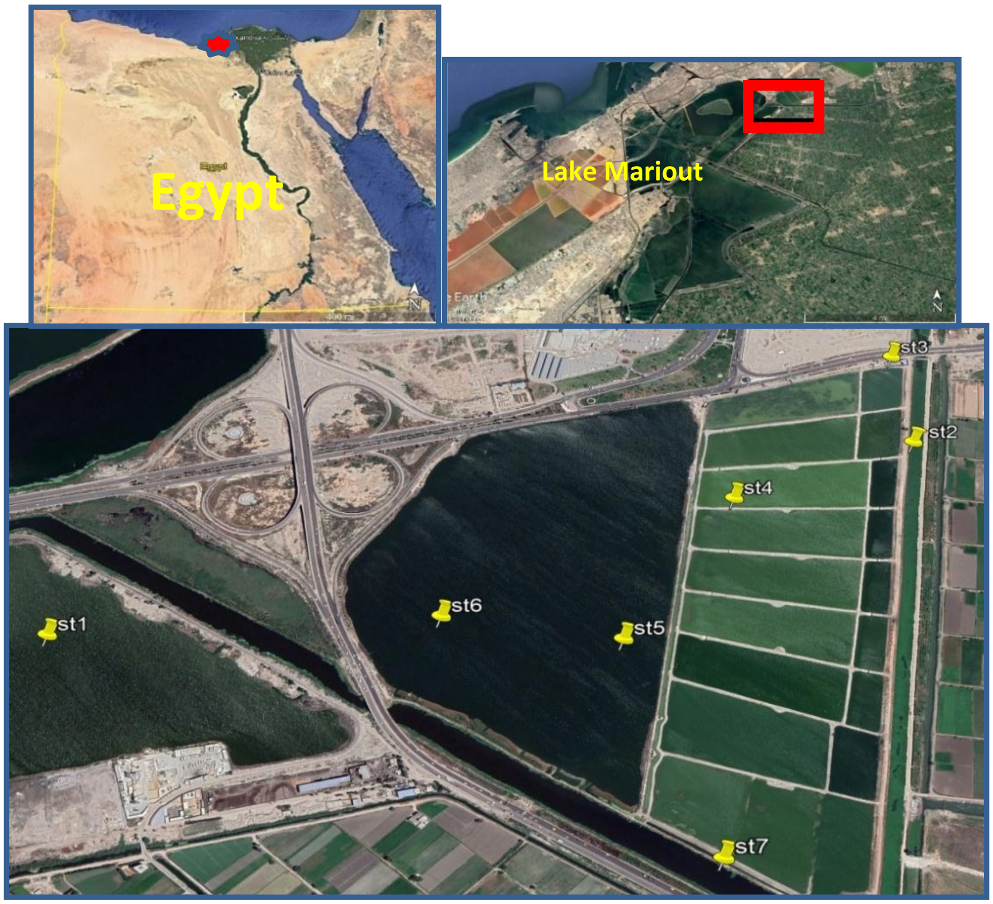

Fig. 1. Satellite map showing the location of the studied sites at Mariout Lake

3. Physico-chemical parameters and heavy metals determination

The physical and chemical parameters were simultaneously measured at each station through zooplankton sampling. Eight parameters were determined, including water temperature, salinity (‰), hydrogen ion concentration (pH), the dissolved oxygen (DO) which was measured depending on Winkler's method **(Strickland & parsons, 1972)**. Whereas, the biological or biochemical oxygen demand (BOD) and chemical oxygen demand (COD) were assessed using the method described in **APHA (1995)**. On the other hand, ammonia was spectrophotometrically detrmined using Indophenol blue technique **(Intergovernmental Oceanographic Commission, 1983)**. For the evaluation of heavy metals, the method used in the study of **Abdullah and Royle (1974)** was used.

4. Data analysis

All data were represented as Mean ± SD unless otherwise indicated. Normality of the data was tested with the Kolmogorov-Smirnov test. Stepwise regressions and combined correlation coefficient were selected to determine the relationship of species richness to environmental variables. Diversity indices {species richness, Shannon–Wiener index, evenness or equitability, and Simpson index} were calculated. Bray-Curtis similarity index for abundance data was used to calculate the degree of similarities between different sites. ANOVA was applied to test the changes of different parameters at different stations along the four seasons. CCA was used as correspondence analysis of a station/species matrix, where each site recoreded its own values or those of the environmental variables.

All the previous analyses were done using several computer software including MINITAB Release 18, Primer Ver.7.0.12.0, PAST (PAleontological STatistics) Ver. 3.25, Excel 2016 program and statistical for windows ver.7.0., Borland international, Inc. computer program.

RESULTS

1. Physical and chemical conditions of fish farms in Mariout Lake

The average concentrations of different physico-chemical parameters in the studied area are illustrated in Table (1). Water temperature fluctuated between 18±0.1ºC and 32.7±0.3ºC; it recorded high significance in different seasons and stations ($P< 0.001$). Water temperature was almost similar in the investigated stations, with a little increase in St2 and St3. Water salinity varied by season and station ($P< 0.001$). Water salinity recorded the highest average during spring 2021 (4.77±1.89‰) and the minimum during summer (4.53±1.71‰). Hydrogen ion concentration tended to the alkaline side, with the highest average (8.5±0.1) at St. 6 during spring and the lowest (7.7±0.1) at St. 2 during summer. The study area showed poor aeration; the dissolved oxygen concentrations were low and fluctuated from 8.4 ± 3.5ml/L in autumn to 6.86±3.18ml/L in spring. Biological oxygen demand fluctuated between 27.6±0.1 mg/L at St. 3 in spring and 2.4±0.1 mg/L at St. 2 in autumn. No significant difference was detected during the seasons and at stations ($P< 0.05$). Additionally, chemical oxygen demand showed no significant difference during all seasons and at stations under study ($P< 0.05$). It varied between 122.6±0mg/L at St. 7 in autumn and 9.8±0.1mg/L at St. 2 in winter. The maximum average of ammonia concentration was registered at St.7, while the minimum was measured at St.2. Spring recorded the highest ammonia concentration, followed by autumn, summer and winter.

2. Heavy metals pollution

The data in Table (1) show the heavy metals concentration in the lake's water. Copper conc. in summer was highly significant than the other seasons, followed by winter, spring and finally autumn ($P< 0.05$). Its concentrations recorded a high significance value at stations and during seasons ($P< 0.001$) using the analysis of variance. Zinc differed from 4±0.1ppm at St. 1 during spring to 111.8±0.8ppm at St.7 during summer. The analysis of variance showed a high significant value of zinc concentration throughout the stations and seasons ($P < 0.001$); in addition, summer average value was highly significant than the other seasons, followed by winter, spring and autumn ($P< 0.05$). While, chrome concentration in summer was highly significant compared to the other seasons, followed by winter, spring and autumn ($P< 0.05$). It recorded its maximum average at St. 5, and the minimum average was recorded at St. 1. Iron concentrations were fluctuated between 18.2±0.2 ppm during autumn at St.3 and 304.8±0.8 ppm during summer at St. 5. There is a high significant value of iron concentration at all stations and during seasons ($P< 0.001$).

Table 1. Variations of the physico-chemical parameters and heavy metals recorded in fish farms of Lake Mariout from summer 2020 to spring 2021*

S.	St.	Parameters							Heavy metals				
		Tem.	Sal.	pH	Do	BOD	COD	Amm.	Copper	Lead	Zinc	Chrome	Iron
Summer	St.1	29.3 ± 0.2^{d}	3.2 ± 0.2^{e}	7.8 ± 0.2^{b}	11.2 ± 0.1^{a}	18.2 ± 0^{a}	18.5 ± 0.2^{f}	$0.13 \pm 0.04^{e,f}$	6.9 ± 0.1^{f}	28 ± 0.1^{d}	66 ± 2.6^{e}	5.1 ± 0.1^{e}	155 ± 1.7^{f}
	St.2	32.5 ± 0.2^{a}	1.9 ± 0.1^{f}	7.7 ± 0.1^{b}	4.1 ± 0.1^{f}	2.6 ± 0.1^{f}	12.5 ± 0.1^{g}	0.07 ± 0.01^{f}	5.2 ± 0.1^{g}	22 ± 1.7^{e}	68 ± 1.7^{e}	$6.3 \pm 0.2^{c,d}$	105 ± 1.3^{g}
	St.3	32.7 ± 0.3^{a}	6.6 ± 0.2^{a}	$8 \pm 0.2^{a,b}$	7.4 ± 0.2^{c}	5.7 ± 0.1^{e}	42.7 ± 0.1^{d}	0.33 ± 0.1^{c}	8.5 ± 0.2^{e}	38 ± 0.3^{a}	85 ± 1.7^{d}	$6.8 \pm 0.3^{b,c}$	274 ± 2.6^{b}
	St.4	30 ± 0.4^{c}	6.5 ± 0.1^{a}	7.8 ± 0.2^{b}	7.1 ± 0.1^{c}	5.5 ± 0.1^{e}	46.5 ± 0.1^{c}	$0.31 \pm 0.02^{c,d}$	9.2 ± 0.2^{d}	35.9 ± 0.4^{b}	97.8 ± 0.3^{c}	6.2 ± 0.3^{d}	259.7 ± 2.5^{c}
	St.5	$30.6 \pm 0.2^{b,c}$	5.1 ± 0.4^{b}	$8 \pm 0.1^{a,b}$	8.6 ± 0.3^{b}	12.5 ± 0.1^{b}	50.1 ± 0.1^{b}	0.78 ± 0.02^{b}	22 ± 0.1^{a}	38.2 ± 0.1^{a}	103.8 ± 1.3^{b}	7.8 ± 0.2^{a}	304.8 ± 0.8^{a}
	St.6	30.9 ± 0.3^{b}	3.9 ± 0.1^{d}	8.3 ± 0^{a}	6.4 ± 0.1^{d}	10.5 ± 0.1^{d}	39.5 ± 0.2^{e}	$0.22 \pm 0.03^{d,e}$	14.2 ± 0.1^{c}	30.3 ± 0.1^{c}	49.7 ± 0.6^{f}	7.1 ± 0.1^{b}	230 ± 2^{d}
	St.7	30.7 ± 0.1^{b}	4.5 ± 0.2^{c}	$8.1 \pm 0.2^{a,b}$	4.9 ± 0.1^{e}	11.4 ± 0.1^{c}	85.2 ± 0.2^{a}	0.9 ± 0.05^{a}	16.8 ± 0.2^{b}	$29 \pm 0.3^{c,d}$	111.8 ± 0.8^{a}	$6.6 \pm 0.1^{b,c,d}$	205 ± 1.7^{e}
Autumn	St.1	18.7 ± 0.2^{d}	2.3 ± 0.3^{d}	$7.9 \pm 0.1^{b,c}$	11.8 ± 0.1^{a}	18.9 ± 0^{d}	21.5 ± 0.3^{g}	0.34 ± 0.03^{c}	1.8 ± 0.1^{e}	4.9 ± 0.2^{f}	7.5 ± 0.1^{e}	$1.8 \pm 0.1^{c,d}$	26.4 ± 0.2^{c}
	St.2	21.3 ± 0.1^{a}	2.1 ± 0.1^{d}	$8 \pm 0^{b,c}$	1.8 ± 0.1^{f}	2.4 ± 0.1^{e}	22.5 ± 0.2^{f}	0.11 ± 0.02^{d}	1.9 ± 0.1^{e}	3.2 ± 0.1^{g}	9.2 ± 0.3^{d}	$1.4 \pm 0.1^{d,e}$	20.5 ± 0.5^{f}
	St.3	20 ± 0.3^{b}	5.8 ± 0^{a}	8.2 ± 0.1^{a}	6.3 ± 0.1^{e}	21.2 ± 0^{b}	77.6 ± 0.1^{d}	0.43 ± 0.01^{c}	2.6 ± 0.1^{c}	7.6 ± 0.1^{c}	13.8 ± 0.3^{c}	1.2 ± 0.3^{e}	18.2 ± 0.2^{g}
	St.4	$19.2 \pm 0.3^{c,d}$	5.6 ± 0.1^{a}	7.8 ± 0^{c}	8.2 ± 0.1^{d}	20 ± 0.5^{c}	81.2 ± 0.1^{c}	0.4 ± 0.03^{c}	2.8 ± 0.1^{b}	7.1 ± 0.1^{d}	15 ± 0.5^{b}	$2 \pm 0.1^{b,c}$	22.4 ± 0.2^{e}
	St.5	$19.6 \pm 0.3^{b,c}$	5 ± 0.1^{b}	$8.1 \pm 0.1^{a,b}$	8.9 ± 0.1^{c}	22.2 ± 0.1^{a}	85.3 ± 0.1^{b}	0.9 ± 0.04^{b}	$2.6 \pm 0.1^{b,c}$	8.9 ± 0^{a}	19.2 ± 0.3^{a}	$2.3 \pm 0.1^{a,b}$	46.1 ± 0.5^{b}
	St.6	20.1 ± 0.1^{b}	4 ± 0.1^{c}	$8.1 \pm 0.1^{a,b}$	10.2 ± 0.2^{b}	20.1 ± 0.1^{c}	60.2 ± 0.1^{e}	0.36 ± 0^{c}	2.3 ± 0.1^{d}	6.1 ± 0.1^{e}	13.1 ± 0.1^{c}	1.9 ± 0.1^{c}	34.9 ± 0.4^{d}
	St.7	19.8 ± 0.1^{b}	4.6 ± 0.3^{b}	$8 \pm 0^{b,c}$	11.6 ± 0.2^{a}	22.3 ± 0.1^{a}	122.6 ± 0^{a}	1.1 ± 0.1^{a}	3.6 ± 0.1^{a}	8.2 ± 0.1^{b}	18.5 ± 0.5^{a}	2.6 ± 0.1^{a}	48.2 ± 0.3^{a}
Winter	St.1	18 ± 0.1^{d}	2.6 ± 0.2^{c}	7.8 ± 0^{d}	9.9 ± 0^{b}	4.2 ± 0.3^{d}	12.2 ± 0.1^{f}	0.08 ± 0.01^{b}	1.6 ± 0.1^{e}	2.9 ± 0^{f}	21.9 ± 0.4^{f}	$3.9 \pm 0^{c,d}$	50 ± 2.6^{f}
	St.2	19.6 ± 0.2^{a}	2 ± 0.1^{d}	$7.9 \pm 0.1^{c,d}$	2.2 ± 0.1^{e}	4.2 ± 0.1^{d}	9.8 ± 0.1^{g}	0.02 ± 0.01^{c}	1.3 ± 0.1^{f}	2.5 ± 0.1^{g}	17.9 ± 0.4^{g}	3.5 ± 0.9^{d}	56.1 ± 0.1^{e}
	St.3	19.3 ± 0.1^{a}	5 ± 0.1^{a}	$8.1 \pm 0.1^{b,c}$	7.3 ± 0.1^{d}	$5.5 \pm 0^{b,c}$	26.2 ± 0.2^{d}	0.08 ± 0.0^{b}	4 ± 0.1^{c}	4.8 ± 0.1^{e}	28.1 ± 0.1^{d}	$4.6 \pm 0.1^{c,d}$	$70 \pm 3^{c,d}$
	St.4	$18.1 \pm 0.1^{c,d}$	4.8 ± 0.2^{a}	$8 \pm 0^{c,d}$	8.7 ± 0^{c}	4.3 ± 0.1^{d}	26.9 ± 0^{d}	$0.06 \pm 0^{b,c}$	4.9 ± 0^{b}	5.1 ± 0^{d}	30.6 ± 0.1^{c}	$4.9 \pm 0.4^{c,d}$	72.2 ± 0.2^{c}
	St.5	18.4 ± 0.1^{c}	4.6 ± 0.3^{a}	$8.3 \pm 0^{a,b}$	9.7 ± 0.1^{b}	5.9 ± 0.1^{b}	35.3 ± 0.1^{b}	$0.05 \pm 0.01^{b,c}$	5.2 ± 0.1^{a}	6.9 ± 0.1^{a}	34.2 ± 0.1^{b}	6.9 ± 0.1^{a}	85.3 ± 0.2^{a}
	St.6	18.8 ± 0.2^{b}	3.3 ± 0^{b}	8.5 ± 0.2^{a}	10.5 ± 0.2^{a}	5.1 ± 0.1^{c}	30.8 ± 0.2^{c}	$0.04 \pm 0^{b,c}$	2.9 ± 0^{d}	5.4 ± 0.1^{c}	26.2 ± 0.1^{e}	5.1 ± 0.1^{c}	66.2 ± 0.3^{d}
	St.7	$18.3 \pm 0.1^{c,d}$	4.6 ± 0.3^{a}	8.4 ± 0.1^{a}	9.9 ± 0^{b}	13.2 ± 0^{a}	55 ± 0.1^{a}	1.55 ± 0.03^{a}	3.8 ± 0.2^{c}	6.3 ± 0.1^{b}	43.6 ± 0.2^{a}	6.2 ± 0.3^{b}	80.6 ± 0.1^{b}
Spring	St.1	24.7 ± 0.1^{d}	2.4 ± 0.1^{e}	8.1 ± 0.1^{c}	10.9 ± 0.1^{a}	8.2 ± 0.1^{f}	45.4 ± 0^{f}	0.57 ± 0.02^{d}	3 ± 0.1^{d}	3.2 ± 0^{f}	4 ± 0.1^{d}	2.2 ± 0.3^{e}	55 ± 3.5^{e}
	St.2	26.2 ± 0.1^{a}	2.1 ± 0.1^{e}	$8.3 \pm 0.2^{a,b,c}$	2.1 ± 0.1^{g}	6.3 ± 0.1^{g}	30.7 ± 0.1^{g}	0.35 ± 0.02^{e}	1.3 ± 0.1^{f}	1.2 ± 0.1^{g}	6 ± 0.5d	$2.4 \pm 0.4^{d,e}$	45 ± 2.6^{e}
	St.3	25.5 ± 0.2^{c}	6.7 ± 0.3^{a}	$8.4 \pm 0.2^{a,b,c}$	9.5 ± 0^{b}	27.6 ± 0.1^{a}	70.2 ± 0^{c}	0.4 ± 0.03^{e}	2.6 ± 0.1^{e}	6.9 ± 0^{e}	$19 \pm 5.6^{b,c}$	$3.2 \pm 0^{b,c}$	160 ± 5^{c}
	St.4	25.3 ± 0.1^{c}	$6.5 \pm 0.3^{a,b}$	$8.2 \pm 0.1^{b,c}$	4.1 ± 0.1^{f}	26.9 ± 0.1^{b}	71.4 ± 0.1^{b}	0.38 ± 0.03^{e}	3.2 ± 0.1^{d}	7.2 ± 0^{d}	$23 \pm 0.6^{a,b}$	$2.8 \pm 0.1^{c,d}$	$170 \pm 4.4^{b,c}$
	St.5	25.8 ± 0.1^{b}	6.1 ± 0.1^{b}	$8.5 \pm 0.1^{a,b}$	5.1 ± 0.1^{e}	24.9 ± 0^{c}	67.2 ± 0.2^{d}	1.2 ± 0.04^{a}	5.1 ± 0.1^{a}	9.8 ± 0.1^{b}	26 ± 0.5^{a}	3.6 ± 0^{b}	185 ± 2^{a}
	St.6	$25.6 \pm 0.1^{b,c}$	4.5 ± 0.2^{d}	8.6 ± 0.1^{a}	8.7 ± 0.1^{c}	19.5 ± 0.2^{e}	60.2 ± 0.1^{e}	0.77 ± 0.08^{c}	3.5 ± 0.1^{c}	9.1 ± 0.1^{c}	$18 \pm 0.5^{b,c}$	3.1 ± 0.1^{c}	115 ± 2.6^{d}
	St.7	25.8 ± 0.1^{b}	5.1 ± 0.1^{c}	$8.2 \pm 0.1^{b,c}$	7.6 ± 0^{d}	23 ± 0.1^{d}	98.7 ± 0.1^{a}	0.9 ± 0.02^{b}	4.2 ± 0.1^{b}	12 ± 0.1^{a}	16 ± 1.3^{c}	4.5 ± 0.1^{a}	$180 \pm 7.5^{a,b}$
		23.74±5.1	4.34±1.54	8.1 ± 0.24	7.67 ± 2.9	13.3 ± 8.4	50.21±28.9	0.46±0.41	5.25±4.9	12.53±11.81	35.46±31.17	4.14±1.99	112.2±84.78

*** Data represented as means ± standard deviation (SD). Means that do not share a letter are significantly different (Tukey's test; *P*< 0.05).**

3. Community Structure of zooplankton

A total of 63 zooplankton species and other immature forms were recorded during the present study. The recorded species belong to 36 genera, 27 families and 9 classes. The most diverse group was Rotifera (44 species); it is quantitatively (91.28 %) the first dominant group. Copepoda come the second in diversity with remarkably low numbers (8 species) but with relative abundance of 3.31% of the total zooplankton count, while Ciliated Protozoa (3 species) was the second abundant group (5.11%); other groups were rare and low in diversity.

Rotifera were represented by 44 species; *Brachionus angularis* was found to be the most dominant rotifer species, followed by *Brachionus calyciflorus*, *Filinia longiseta*, *Brachionus caudatus*. Genus *Keratella* was represented by 4 species (*Keratella tropica*, *K. cochlearis, K. valga* and *K. luna*). Six species were recorded from genus *Lecane* (*L. bulla*, *L. elasma*, *L. depressa*, *L. colesterocerca*, *L. lunaris* and *Lecane* sp.). Protozoa was the second abundant group in the present study; it was represented by 2 identified species (*Euplptes patella*, *Vorticella* sp.) while others were unidentified. Eight species and other immature stages represented the copepods group. Copepod Nauplii were found to be 82.33% of the total copepods density, while Copepodite stages represented 15.47% of the total copepods density. *Cyclops* sp. was the most abundant adult copepod species, followed by *Oithona nana*, *Acathocyclops americanus*, which was the only copepod species recorded in the whole year. On the other hand, *Diaphanosoma* sp. was the most dominant Cladocera species, *Monia mircura* was the second, while *Daphnia* sp. was recorded only in spring. Ostracoda was represented by two species, *Cypricercus affinis* and *Cypridina* sp. Tintinnina was represented by *Favella* sp. and Cercaria of *Fasciola* was the only trimatod species recorded in this study.

Table 2. The annual abundance, relative abundance and number of species recorded for each recorded zooplankton groups

Group	Average	Relative abundance (%)	No. of species	No. of species (%)
Rotifera	89396.4±728.85	91.28	44	69.8
Copepoda	3244.6±121.85	3.31	8	12.7
Protozoa	5001.8±11.29	5.11	3	4.7
Cladocera	130.4±2.81	0.13	4	6.3
Tintinnida	42.9±1.25	0.04	1	1.6
Trimatoda	42.9±1.25	0.04	1	1.6
Ostracoda	75±1.0	0.08	2	3.2
Total Zooplankton	**97933.9**	**100**	**63**	**100**

4. Zooplankton distributions

Zooplankton flourished in spring (271135.7ind./m^3), followed by winter, autumn and summer (9871.43ind./m^3). Rotifera showed higher abundance during spring and low during summer. Ciliated protozoa were high during winter and low during summer, while Copepoda was high during spring and low during winter.

Spatially, the abundance of zooplankton was high at St.1 with an annual average of 1172950 ind./m^3, while, it was recorded the lowest at St.7 (77350 ind./m^3). Moreover, Rotifera was high at St1 and low at St.7. Copepoda and Protozoa abundance was high at St.6, and their low abundance was recorded at St.7. While, Cladocera was high abundant at St.2 and low at St.7

Tukey wise analysis results showed that the zooplankton abundance differed significantly (P< 0.0001) among stations during seasons. Dunn's multiple comparisons test clarified that the total abundance of zooplanktons was significant in spring (P<0.05), while the other seasons sharing the same letters were considered non-significant ($P \geq 0.05$).

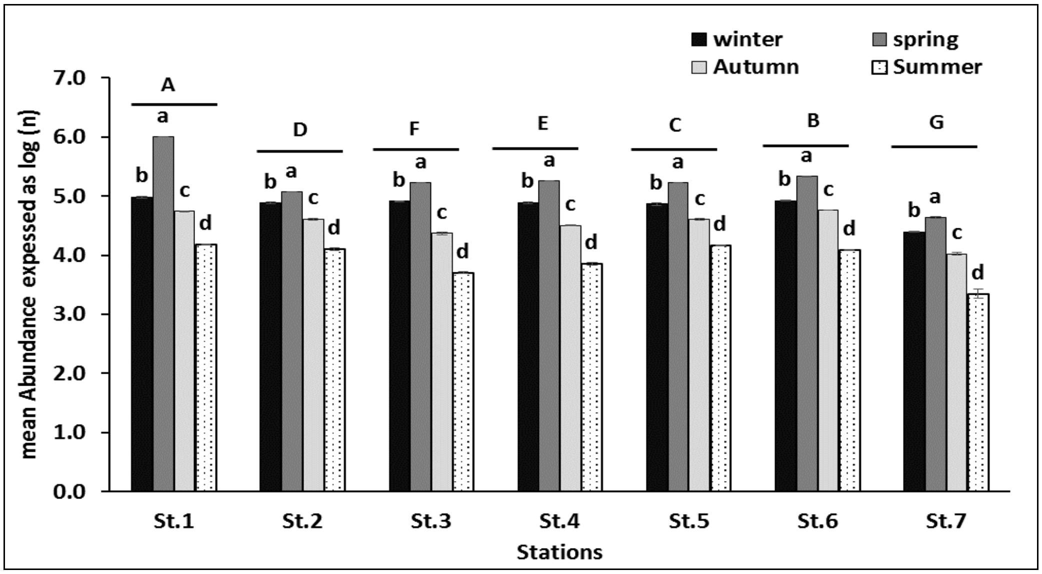

Fig. 2. The mean abundance of the zooplankton recorded in Lake Mariout during different seasons from summer 2020 to spring 2021

Means with different letter are significantly different (Tukey post- hoc comparisons; $P<0.05$). Capital letters indicate significant differences between sites, and small letter are those between seasons within each site.

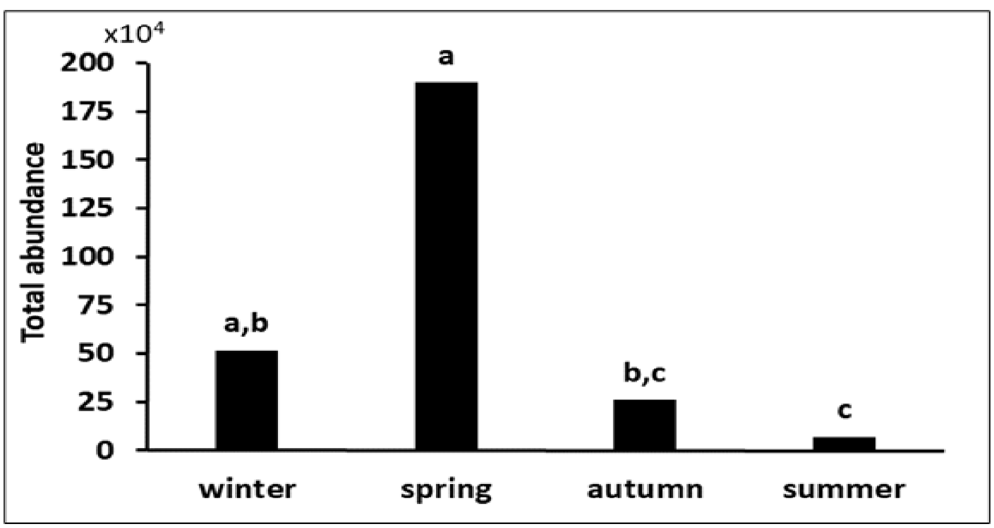

Fig. 3. The total Abundance of the zooplankton recorded in lake Mariout during different seasons from summer 2020 to spring 2021

Means with different letter are significantly different (Dunn's multiple comparisons test; *P*- values <0.05.

5. Diversity indices of zooplankton distribution in Lake Mariout

The ecological diversity indices were widely ranged among investigated stations during the four seasons. The species richness recorded its highest value (3.088) at St.6 during spring and the lowest value (0.6478) at St.7 during winter. Concerning the Shannon-Wiener index, the highest value (2.931) was calculated at St.4 during autumn, while the lowest value (0.4642) was measured at St.7 during spring (Fig. 4). The highest evenness values were 0.774 in St.3 during autumn, while the lowest (0.1317) was at St. during summer. The Simpson index fluctuated from 0.8723 at St.2 during winter to 0.1694 at St.1 during summer (Fig. 5).

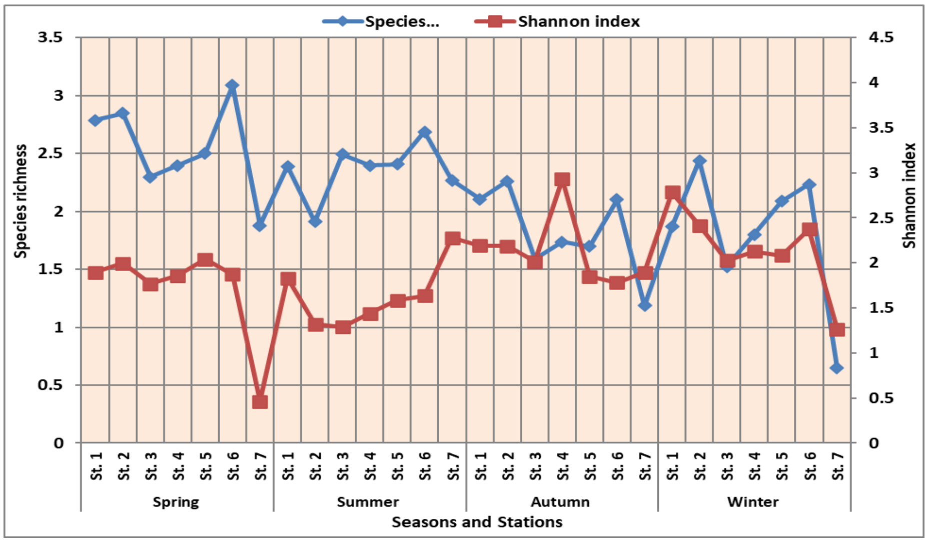

Fig. 4. Species richness and Shannon index of zooplankton inhabiting Lake Mariout

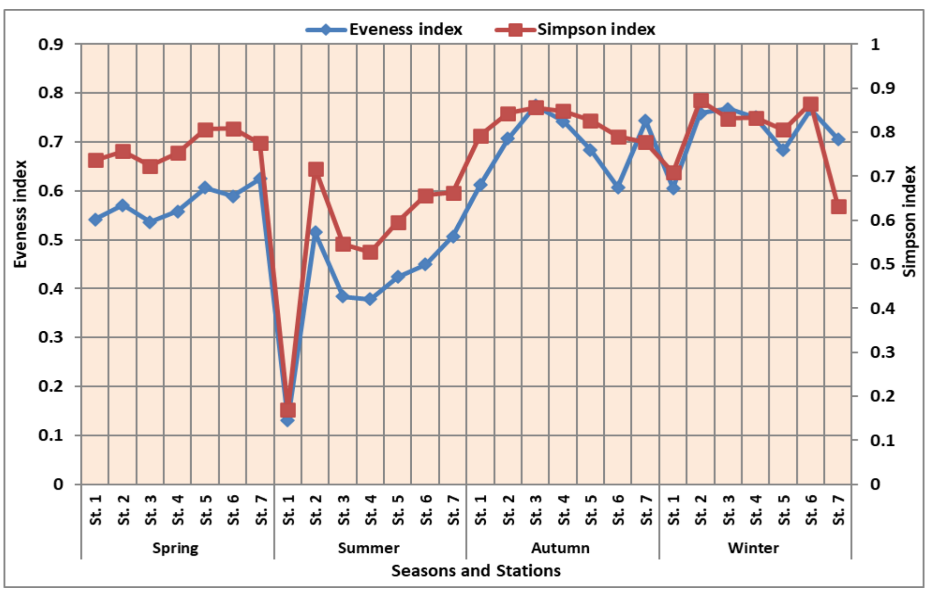

Fig. 5. Eveness and Simpson indices of zooplankton inhabiting Lake Mariout

6. Associations among all sets of variables

CCA models identify the associations among all sets of variables as follows: the intercorrelated species with seasons for intense, winter's most dominant species (13, 14, 17, 28, 31, 63) at stations (1,2,3,4,5,6), then spring's dominant species (5, 20, 32, 37, 54) at stations (1,3,4,7), followed by summer's dominant species (8, 15, 24, 55) at St1 to St7, finally comes autumn dominant species (41) at stations from 1- 6. There was inverse relationship between pH value and Pb & Cu concentrations in addition to a relation between (Cr & Do) and (BOD, COD, Temp, ammonia and CO_2). Data revealed that there's a high correlation between Cu, Pb conc. and the dominancy of species (48, 47, 10, 3, 45, 26, 23,55, 16), while species 9 in spring were strongly correlated to ammonia.

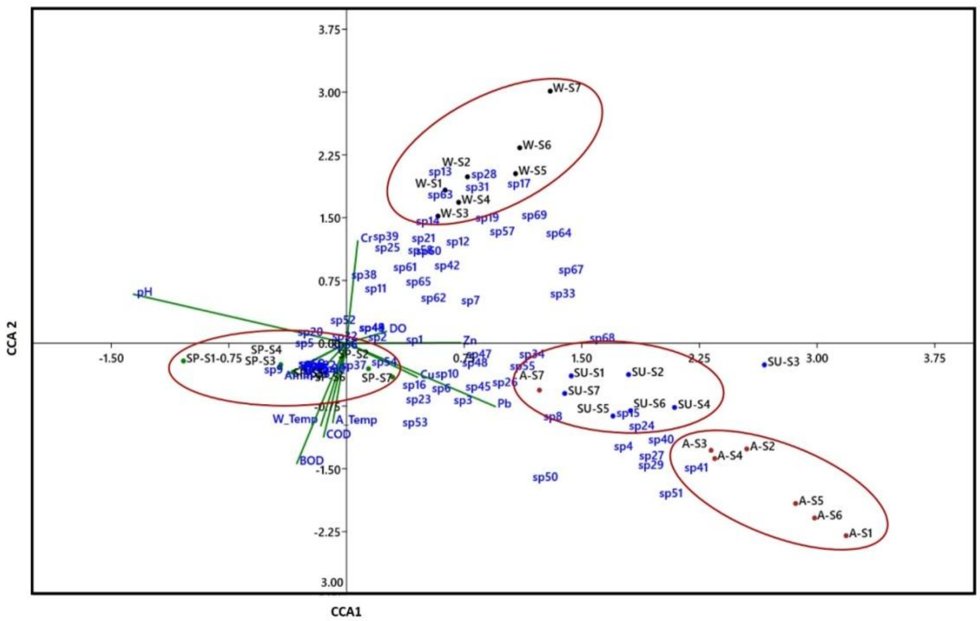

Fig. 6. Biplots of the CCA models for the species abundance matrix: species and (A) station (7 stations) (B) seasons
(W = winter, SP= spring, A= autumn and SU = summer) (C) Abiotic Variables are: water and air temperature, salinity, pH, DO, BOD, COD, Ammonium, Cu, Pb, Zn, Cr and Fe.

7. Effect of physic-chemical parameters and heavy metals on zooplankton communities

The correlations between zooplankton communities and physicochemical parameters showed that the total zooplankton density was only negatively correlated with the salinity and ammonia concentrations (r= -0.613 and -0.557, respectively) (*P*< 0.05). Consecutively, rotifers density was the same as that of the total zooplankton density (r= -0.643 and -0.511 for salinity and ammonia, respectively) (*P*< 0.05). In this context, the copepods were weakly negatively correlated with temperature (r= -0.382) (*P*< 0.01). Whereas, protozoans' density showed significant correlation with water temperature (r= 0. 759) (*P*< 0.01) and negatively correlated with hydrogen ion concentration (r= -0.434) (*P*< 0.05). On the other hand, Cladocera was positively correlated with water temperature (r=

0.496) (*P*< 0.01), and it showed negative correlation with hydrogen ion concentration (r= -0.447) (*P*< 0.05).

On the other hand, zooplankton showed no significant correlation with any measured heavy metals. Moreover, rotifers' density showed the same value of zooplankton density. Copepoda recorded a moderate negative correlation with copper (r= -0.517) (*P*< 0.01) and iron (r= -0.627) (*P*< 0.01). Protozoa density showed significant correlation with all measured heavy metals, but it recorded a strong negative correlation with iron (r= -0. 612), copper (r= -0. 683), lead (r= -0. 898), zinc (r= -0. 785) and chromium (r= -0. 604) (*P*< 0.01). Cladocera showed significant moderate positive correlation with lead (r= 0.499) (*P*< 0.01) and zinc (r= 0.404) (*P*< 0.05).

Key species, such as *Brachionus angularis* was the main eudominant and common species during the whole study period. *B. angularis* showed no significant correlation with all parameters and heavy metals, except for water salinity and ammonia, where it showed a moderate negative correlation with them (r= -0.532 for salinity and -0.622 for ammonia) (*P*< 0.05). The second key species was *B. calyciflorus* which recorded the second dominant species, showing moderate negative correlation with water salinity, iron and chromium (r= -0.490, -0.434 and -0.404, respectively) (Table 3)

Table 3. Correlation coefficient (r) between zooplanktonic communities and physicochemical parameters with heavy metals recorded in Lake Mariout

S.	St.	Parameters							Heavy metals				
		Tem.	**Sal.**	**pH**	**Do**	**BOD**	**COD**	**Amm.**	**Copper**	**Lead**	**Zinc**	**Chrome**	**Iron**
Zooplankton	Pearson C.	-0.240	-0.613*	-0.270	0.289	0.152	-0.166	-0.557*	-0.272	-0.145	-0.089	-0.180	-0.312
	Sig.	0.219	0.023	0.164	0.137	0.439	0.400	0.032	0.162	0.462	0.652	0.360	0.108
Rotifera	Pearson C.	-0.258	-0.643*	-0.256	0.293	0. 157	-0.163	-0.511*	-0.282	-0.161	-0.112	-0.197	-0.322
	Sig.	0.186	0.022	0.189	0.130	0.425	0.407	0.043	0.146	0.414	0.572	0.314	0.095
Copepoda	Pearson C.	-0.382*	-0.077	-0.183	0.017	0. 286	0.220	-0.018	-0.517**	-0.316	-0.275	-0. 390*	-0.627**
	Sig.	0.045	0.697	0.350	0.933	0.140	0.261	0.929	0.005	0.101	0.157	0.040	0.000
Protozoa	Pearson C.	0.759**	-0.002	-0.434*	-0.066	-0.274	-0.257	-0.220	-0.612**	-0.683**	-0.898**	-0.785**	-0.604**
	Sig.	0.000	0.990	0.021	0.739	0.158	0.187	0.261	0.001	0.000	0.000	0.000	0.001
Cladocera	Pearson C.	0.496**	-0.312	-0.447*	-0.290	-0.316	-0.299	-0.276	-0.205	0.359	0.499**	0.404*	0.274
	Sig.	0.007	0.106	0.017	0.135	0.102	0.122	0.154	0.295	0.061	0.007	0.033	0.159
Brachionus angularis	Pearson C.	-0.235	-0.622*	-0.228	0.286	0.181	-0.127	-0.532*	-0.258	-0.156	-0113	-0.193	-0.312
	Sig.	0.228	0.031	0.244	0.140	0.356	0.521	0.041	0.185	0.428	0.568	0.324	0.106
Brachionus calyciflorus	Pearson C.	-0.289	-0.490*	-0.351	0.223	-0.057	-0.095	-0.220	-0.434	-0.154	-0.050	-0.181	-0.404*
	Sig.	0.135	0.039	0.067	0.254	0.772	0.630	0.261	0.045	0.432	0.801	0.357	0.033
****. Correlation is significant at the 0.01 level (2-tailed).**													
***. Correlation is significant at the 0.05 level (2-tailed).**													

DISCUSSION

Human activities cause disturbance to waterbodies, leading to the deterioration of water quality affectting the aquatic communities **(Mona *et al*., 2019; Darweesh *et al*., 2021a; El-Naggar *et al*., 2022)**. Water quality depends not only on natural processes such as precipitation inputs, erosion and weathering of crustal material but also on anthropogenic influences like domestic, industrial and agricultural activities **(Shaban *et al*., 2020)**. Lake Mariout water quality has been changed by several factors in the last decades because of anthropogenic activities **(Saad *et al*., 2017)**. It has been subject to multiple changes and intensifying human activities such as domestic, fishing, fish farm, industrial and agricultural activities.

One of the most important aspects of the aquatic ecosystem in the lake is the zooplankton communities. They act as major link in the food chain and occupy an intermediate position in aquatic food webs **(Raut & Shembekar, 2015)**. In addition, zooplankton has been used as a key for determing water quality for a long time. Some species flourish in highly eutrophic waters, while others are very sensitive to organic or chemical wastes **(El-Enany, 2009; Zakaria *et al*., 2018a, b)**.

Zooplankton in closed and semi-closed waterbodies such as Lake Mariout is considerably affected by water quality as determined by certain variables such as temperature, pH, dissolved oxygen, salinity, BOD and ammonia. These variables are thought to be the most critical variables affecting zooplankton composition, distribution, abundance and diversity **(Zakaria *et al*., 2016)**. Therefore, it has become mandatory to analyze at least the important water parameters upon conducting ecological studies. Such studies when done from time to time can indicate the favorable or unfavorable changes occurring in the ecosystem **(Shinde *et al*., 2011; Heneash *et al*., 2022)**.

The fluctuation of water temperature is mainly dependent upon the changing of air temperature in seasons and time of collection; this is in congruence with that reported by **El-Enany (2009)** and **Hegab (2015)**. High water temperature increases the biological activity; however, if it exceeds the organisms range of tolerance, it turns to be lethal **(Mansour *et al*., 2008)**. The correlation coefficients between temperature and zooplankton groups appeared positively correlated with Protozoa and Cladocera, and negatively with Copepoda; this means that Copepoda prefer low temperature. The variance in correlation coefficients between temperature and zooplanktonic groups are due to the difference of dominant species at each site. Each species has an optimum temperature at which its growth rate and health are at their best condition **(Lazur. 2007; Volkoff & Rønnestad, 2022)**.

Salinity was negatively correlated with total zooplankton and rotifers only. The variance in correlation coefficients between salinity and rotifers are due to the difference of species tolerance to salinity, especially the dominant ones. Similar findings are those recorded in the study of **Williams (1998)** who reported that the salinity has long been considered an important influence on the composition and dynamics of aquatic ecosystems. **Zakaria *et al.* (2007)** stated that, Copepoda and their larval stages were the most dominant group in the high-water salinity.

The correlation coefficients between pH and zooplankton groups elucidated that some groups can tolerate low pH. It showed negative correlation with Protozoa and Cladocera. In contrast, **Khater (2017)** found that protozoa was positively correlated with pH values. pH has a very minor ecological role since sea water is highly buffered, and the pH remains relatively constant **(Michael, 1984)**. Biological conditions are usually better when the pH values lie on the alkaline side; with the exception of certain species of protozoa that prefer a particular pH for growth, the value should always be maintained at 7 to 9. The alkaline waters are considered more productive than the acidic ones **(Hickling, 1962)**.

According to the present result, dissolved oxygen wasn't correlated with all zooplankton groups. This means that these groups can live in any DO level, which may conflict with many investigators who found that dissolved oxygen act as a limiting factor affecting zooplankton abundance and diversity. The dissolved oxyge in water is one of the most important factors involved in the metabolic activity of any aquatic system. It serves as an indicator of water conditions **(Huet, 1973)**. **El-Naggar (2008)** emphasized that the diversity of rotifers in the Nile delta habitats was controlled by transparency and dissolved oxygen as limiting factors.

The BOD test is the most useful method in estimating the amount of biodegradable organic matter present in the aquatic environment **(Tayel, 2003)**. The BOD value recorded in the current study is higher than those of **Abdel-Aziz and Aboul-Ezz (2004)** and **Khater (2017)** in Lake Mariout. The high BOD values are attributed to the increase in the amount of biodegradable organic matter, which agrees with that postulated in the study of **El-Bourie (2008)** who showed that the high BOD values indicate excessive export of biodegradable organic matter decreasing the oxygenation of water. The results showed that there are no correlation coefficients between BOD and zooplankton groups.

Ammonia more than 1mg/ L is an indicator of organic pollution and can be toxic to aquatic species in a concentration over 2.5mg/ L **(Lin *et al*., 2022)**. During this work, ammonia fluctuated between .02±0.01mg/L and 1.55±0.03 mg/L. These values are higher than the results of **Khater (2017)**. The high values of ammonia is related to the denitrification process. This result coincides with that of **(Metawea, 2009)** who reported that ammonia levels are directly related to pH, and added that the percentage of ammonia increases with higher pH values. The correlation coefficients between ammonia and rotifers were negative, and no correlation coefficient was detected between ammonia and other zooplankton groups.

Several studies concluded that Lake Maryout is considered the most heavily polluted lake among the northern delta lakes **(Saad & Safty, 2004)**. According to the present data, the lake is heavily productive for zooplankton, regardless of this pollution. As a result of the shallowness of Lake Maryout, the dominant species are eurythermic and euryhaline species **(Mateoea, 2009)**. Among 63 species recorded in the present study, only about five species were relatively abundant. This indicates that only a few species constitute the majority of the zooplankton abundance, which may result from the polluted and eutrophic condition.

The examination of zooplankton composition in the present work indicated that there are 4 groups dominating Zooplankton community, viz., Rotifera, Copepoda, Protozoa and Cladocera in addition to sporadic groups; namely, Ostracoda, Tintinnida and Trematoda. This finding matches the results of **Abdel- Aziz and Aboul-Ezz (2004)** and **Khater (2017)** who also showed the main zooplankton groups in Lake Mariout are Rotifera, Cladocera, Copepoda and Protozoa.

The highest zooplankton average density was collected during spring but the lowest occurred in summer. This is because of water discharge rich in nutrients during spring and winter, which increases zooplankton density and also due to the increase of fish larvae in summer, tending to consume a great proportion of zooplankton. These results coincide with those observed in the studies of **Mageed (2008)** and **Hegab (2015)**. Furthermore, the beginning of the culture cycle is in March for a period of six months, which means that the highest effect of the aquaculture cycle is aligned with the increase of zooplankton density; this may be due to the increase in nutrients from fish faces and feed added to the aquaculture ponds.

Rotifera formed 91.28% of the total zooplankton density; its maximum density was recorded during spring, and this is due to the increasing trophic status. Similar observation was reported in the studies of **Vasconcelos (1994)** and **Abdel Aziz and Aboul Ezz (2004)** who mentioned that, the availability of phytoplankton is considered to be the main reason for the fluctuation of rotifer density. Moreover, the current finding coincides with the report of **Paturej (2008)** who showed that the density of rotifers increases significantly with increasing trophic state elsewhere. In this respect, **Khater (2017)** found that the maximum rotifer density in Lake Mariout occurred during winter. The present abundant rank of rotifers is in conformity with that observed by **Abdel Aziz (1987)**, **Guerguess (1988)** and **Abdel-Aziz and Aboul-Ezz (2004)**. The high relative abundance of Rotifera with the low one of Protozoa is due to the feeding habits of rotifers which feed on Protozoa, including ciliates and heterotrophic flagellates **(El-Damhougy *et al*., 2019)**.

Rotifers are known to be an excellent key of organic pollution as they thrive better in organically rich environment. Rotifer populations indicate pollution that direct entry of untreated domestic sewage and industrial effluents into the lake **(El-Naggar, 2015; Solanki *et al*., 2015)**. The dominance of rotifers over the other zooplankton group ie related to the polluted condition of the lake and not just the lake eutrophication. The presence of *Brachionus* spp. as a dominant zooplankton in Lake Maryout indicates the polluted nature of the lake. Remarkably, the occurrence of *Brachionus* spp. is an important indicator for the status of aquatic ecosystem. **El-Damhogy *et al*. (2016)** has concluded that the characteristic type of zooplankton in Lake Maryout was *Brachionus* spp. The high concentration of rotifer *Brachionus* species in the waterbody is due to the alkaline nature of water **(Santha, 2022)**. The abundance of such species is considered a biological indicator for pollution **(Sousa *et al*., 2008; Najeeb, 2014)**. Rotifers, especially *Brachionu plicatilis* formed the most dominant species in the eutrophic waterbodies **(Ahamed *et al*., 2011)**.

Protozoa is the second abundant zooplankton group. The low densities of protozoans may be due to the low concentrations of ammonia and BOD and also to high rotifer and copepods abundance which feed on protozoans. Similar observation was noticed in the study of **Zakaria *et al*. (2018b)** who reported that protozoans constitute a considerable part of rotifer food.

Copepoda is the third abundant zooplankton group during the present study; the highest copepod density during spring is assumed to control the abundance of rotifers density, while the decline of the copepod production during winter is accompanied by higher rotifer production. This agrees with the results of **Lignell *et al*. (1993)** and **Koski *et al*. (1999)**.

It is noteworthy that, aquaculture activities have negative impact on Rotifera and Copepoda, but each one has positive impact on Cladocera, without any impact on Protozoa **(Nguyen *et al*., 2020)**.

The present data of diversity indices revealed that the study area has a great variety of zooplankton species (high diversity), but there are disturbance in species distribution and richness. The species indices values were typically estimated by the species diversity and abundance variation among investigated sectors. **Bojanic *et al*. (2012)** found that the species richness (S) was positively related to overall zooplankton abundance on a temporal scale, but the strength of that relation was negatively related to increased trophic state. The species diversity index can increase without an increase in taxon number if evenness increases **(Wen *et al*., 2011)**. Zooplankton species richness in lakes is a key measure not only for biological status but also for ecosystem stability **(Walsing *et al*., 2006; Faqihi *et al*., 2023)**.

Patra *et al*. (2011) showed that the species richness with ranges between 1 and 5 indicates a moderate pollution, whereas larger index indicates more healthy water body, but when it tends towards 1, it would mean an increased pollution, and hence damage should be suspected. The present work revealed that species richness index ranged in all stations between 0.65 and 3.09; this means that the study area tends from moderate to high pollution. Moreover, Shannon index ranged between 0.46 and 2.93, which means that the lake is polluted at a moderate side. The results of evenness index showed that human activities affect the equitability of the zooplankton distribution within the lake environment; this is in congruence with that reported by **Hosam (2006)** and **Farrag *et al*. (2019)**.

The investigated sites in Lake Mariout are exposed to different synergetic factors. Each basin in turn may act as a mirror for the impact of environmental conditions at the lake. Zooplankton have been used as a key of water quality for a long time. Some species flourish in highly eutrophic waters, while others are very sensitive to organic or chemical wastes **(El-Enany, 2009; Mola, 2011)**. St.1 that represents the control station was the highest abundant station with zooplankton because it is located in 1000 acres' basin and far from aquaculture activities. Basin1000 is considered the purest site in Lake Mariout and is characterized by high transparency water. This area is relatively very low with respect to the negative impact posed on it; thus it has been selected as control site; **Khater (2017)** confirmed this situation. On the other hand, St.7 that is located in El Qalaa drain was the lowest abundant station with zooplankton. Eminently, El Qalaa drain is one of the important drains in the Alexandria City. It receives the sewage and agricultural wastewater of the entire governorate, with an estimated capacity of about 1,300,000 cubic meters per day.

The studies on Lake Maryout recorded that zooplankton community composition is unstable; it changes in accordance to water quality. **Zakaria *et al*. (2019)** showed that the zooplankton density in Lake Maryout exhibited considerable decreasing trend with time. The results obtained by **Abdel Aziz and AboulEzz (2004)**, **Khater (2017)** and **Zakaria *et al*. (2019)** as well as the present study gave further evidence about gradual degradation in zooplankton density and abundance. This degradation in diversity and density is accompanied by serious changes in the community structure.

Aquaculture can negatively impact the environment through overfeeding fish and marine life. Lack of regulation combined with a lackluster feed plan can result in numerous negative influences on the environment. Nutrients that are not absorbed by the marine life are released out into the environment, and the ecosystem must adapt to this pollution **(White, 2013; El-Naggar *et al*., 2019)**. Another negative impact aquaculture has on the environment is through discharge. Just like any other animal production system, aquaculture generates waste throughout the process. Aquaculture waste can be separated into solid and dissolved waste, specifically carbon, nitrogen and phosphorous. Moreover, solid waste is derived from uneaten and/or spilled feed and from fish feces. Meanwhile, the dissolved waste comes mostly from metabolites excreted by fish **(Amirkolaie, 2011)**. These two types of pollutants grow in a location and eventually will reduce the water quality of that particular system, while also leading to an influx of disease-carrying fish. In order to have a system with sufficient and healthy water quality, waste must be discharged in unison with effluent water **(Amirkolaie, 2011)**.

The emissions of marine animal waste from aquaculture facilities into the ecosystem will not only affect other fish but will also result in nutrient pollution. This waste can contain antibiotics, pesticides and fish feces, which pollute the open water and make it unsafe for human drinking, recreational use and other wildlife **(Abd El-Aziz *et al*., 2022)**.

CONCLUSION

In conclusion, all human activities affect the surrounding environment, and aquaculture is not an exception, as it utilizes natural resources and releases waste into the environment. Although aquaculture has offset the deficits in national fish production all over the world, the deficient management or accidents in aquaculture facilities caused huge negative effects. The present study proved that aquaculture can negatively impact the environment if it was incorrectly managed.

Regulation of aquaculture can create better products for human consumption and benefit the economy by creating jobs in all fields. For the sake of our country, management of fisheries should be properly run to attain the safety of our environment.

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