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Impacts of Water Quality, Excessive Fishing Effort and Sediment Composition on Some Edible Bivalves in Suez Canal Lakes, Egypt

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ABSTRACT

Fish production from natural resources has been facing countless challenges, primarily pollution, excessive fishing effort, unlawful gathering of fish fry in addition to food accessibility. Suez Canal lakes, Bitter and Timsah lakes are among the essential lakes in Egypt, producing commercial species with a mean annual fish production of 4000 tons (2005- 2021). In the last 17 years, a severe decline in the fish production from the Suez Canal lakes was recorded. Fishery statistics of the Suez Canal lakes were collected from 2005 to 2021 to track the total catch, bivalve catch, and fishing effort during that period. Sediment and water samples were collected at 24 stations around the Great Bitter and Timsah lakes during 2022 and 2023. The grain size analyses designated that the bottom sediments of the Suez Canal lakes were principally composed of sand, with minor ingredients of gravel and mud. The concentration of heavy metals revealed that Fe has the highest concentration in the water and sediments of both lakes, while that of Cd was the lowest. The soft tissues of 105 individuals of *Paphia undulata* (Born, 1778), 100 individuals of *P. textile* (Gmelin, 1791) and 200 individuals of *Donax trunculus* (Linnaeus, 1758) from Lake Timsah were used for assessing heavy metal concentrations. Results showed that the concentration of all metals in the soft edible parts of the considered bivalve species were within the safe levels, except for lead (Pb) and zinc (Zn) that recorded higher levels than the permissible ones. A production model was used to evaluate the fishery status of the studied species in the Bitter and Timsah lakes. Based on the results, the main reasons for the production depletion of the studied species in the Suez Canal lakes are the overfishing and pollution. Therefore, the fishing effort control and pollution mitigation are strongly recommended in the lakes.

INTRODUCTION

Egyptian fisheries, including marine, inland and aquaculture sectors, are considered essential sources of nutrition, employment, profits, and recreation for Egyptian inhabitants. Many Egyptians rely on fish and fishery industries for their livelihoods **(Mehanna, 2020, 2021; Mehanna *et al.*, 2023)**.

The Suez Canal serves as a route for the immigrant animals moving between the Red Sea and the Mediterranean, providng a suitable habitat for these animals to establish themselves. Three lakes were identified along the Suez Canal, namely the Timsah and the

Great and small Bitter Lakes (Fig. 1). These lakes are one of the important fish production sources in Egypt, where they yield high marketable fish species, such as the grey mullets, the prawns, the crab, the molluscs, the tilapia, *Pomadasys stridens*, the seabream, and *Siganus rivulatus*, with a mean value of about 4000 tons from 2005 to 2021 **(GAFRD, 2005- 2021)**. There are about 820 sailing non-motorized boats (Fig. 2) operating in the Suez Canal lakes using numerous fishing techniques, such as gillnets, trammel nets, shrimp nets, beach dredge, hattata, crab nets, and beach seine **(Eid, 2019; Mehanna *et al.*, 2019a, b; GAFRD, 2021)**

Lake's sediments are considered as chief sources of heavy metals and act as a source of the pollutants for aquatic animals, plants, and the surrounding water. The bottommost sediments are sensetive to heavy metal accumulation since they are mid or/and long-term integrators of metal input. Increased population, industries' expansion, speedy urbanization, over-use of pesticides and herbicides, detergents and agricultural chemicals, sewage treatment plants, waste dumps, and the discharging of municipal wastes are the key pollutant sources of heavy metals in the natural water bodies **(Baruah *et al.*, 2011)**. The closed and semi closed lakes that face this type of polluted water discharge led to greatly high accummulations of heavy metals and other pollutants in the bottom sediments and benthic animals. The extraordinary volumes of the metals and metallic compounds amassed in the natural water bodies form huge risks to humanoid health through the intake of fish products and seafood. Some elements are needed but in small amounts, they can be toxic to organisms if it exceeds certain threshold concentrations. Thus, for the aquatic biota health, it is vital to keep these metals under the toxic limits in aquatic ecosystems **(Brown & Depledge, 1998)**. Amongst the filter-feeders and deposit feeders, the mollusks are seeming to be more suitable for reflecting the heavy metal contents in the marine and fresh water bodies. Consequently, the molluscs, especially the bivalves, are among the greatest used animals as bio-indicators for the pollution by heavy metal **(Conti & Finoia 2010)**.

The molluscs (bivalve, gastropod and cuttlefish) constitute the bulk of catch in the Suez Canal lakes with mean values of 1500, 13, and 118 tons, respectively (40.8% of the total lakes' production). The molluscs in the Suez Canal area are of commercial importance for people inhabiting the area, and there is a continuously increasing demand on molluscus. Therefore, the present work was conducted to evaluate the fishery status, heavy metals concentrations, and the healthy status of the most common bivalve species in the Suez Canal lakes; *Donax trunculus* (Linnaeus, 1758), *Paphia undulata* (Born, 1778), and *P. textile* (Gmelin, 1791) to insure that there is no risk in their consumption in the region under study.

MATERIALS AND METHODS

1. Study area

Timsah Lake (Fig. 1) is a minor shallow lake with a surface area of around 14km^2 between 30° 34' 0.01" N and 32° 16' 59.99" E nearby the central of the Suez Canal at a point of 80km south of Port-Said City. The lake's depth ranged between 4 and 13m. Lake Timsah receives saltwater primarily from the Suez Canal and freshwater from various sources, including the Ismailia sweet freshwater canal. It also receives partially treated wastewater from numerous agricultural, industrial, and domestic sewage drains such as Al-Mahsama, Al-Wadi, Al-Bahtimi, Al-Dabiaia, and Al-forsan drains **(EEAA, 2010, 2011)**.

The Bitter Lakes are the biggest water bodies along the Suez Canal (Fig. 1), comprising around 85% of the system's water. The Little and Great Bitter Lakes are hypersaline water bodies located between 30° 13′ 15″ and 30° 24′ 55″ N and 32° 18′ 15″ and 32° 28′ 31″ E. The surface area of the Bitter Lakes is around 250km^2, and performing as a buffer for the canal, which reduces the influence of tidal currents **(Mehanna *et al.*, 2019a, b; Mehanna *et al.*, 2023)**. Since the canal has no locks, seawater easily flows into the lakes from both the Mediterranean and Red seas, replenishing water lost due to evaporation. The surface area of the Great Bitter Lake is approximately 194km^2, with depths varying between 18 and 28 meters.

Collection of fishery statistics and MSY estimation

Data regarding the yearly catch, bivalve catch, and fishing effort of the Suez Canal lakes were attained from the General Authority for Fish Resources Development office in Ismailia and from the annual statistical book **(GAFRD, 2005 - 2021)**. The gathered data were investigated to calculate the catch per unit of fishing effort (CPUE), which acts as a function of stock biomass.

The logistic surplus production model of **Schaefer (1954)** and **Schaefer (1957)** as realized in ASPIC 5 computer software was used to evaluate the fishery status of bivalves in the Suez Canal lakes. The maximum sustainable yield (MSY) and the optimum level of fishing effort (f_{opt}) were valued based on the formula of $dB_t/dt = rB_t – r/K*B_t^2$, where B_t is the biomass of the stock at time t; K is the carrying capacity of the habitat where the stock lives, and r is the intrinsic growth rate of the stock. Schaefer's model has K= -a/b, B_{MSY} (the equilibrium biomass for MSY)= K/2, MSY= aK/4, and f_{MSY}= a/2.

2. Samples collection and preparation

Samples of water, sediment, and bivalve specimens were collected from the Suez Canal lakes from 24 stations covering the whole area of the lakes (12 stations in Lake Timsah and 12 stations in the Great Bitter Lake) in seasonal basis during 2022- 2023 (Fig. 3). Sediment samples were gathered from sampling sites using a grab sampler, then stowed in plastic containers and frozen at -20ºC until examination. In the laboratory, sediment samples were washed and dehydrated. About 100 grams of each sediment sample were filtered at each one phi (Ø) interval using a mechanical shaker to approximate the main sediment constituents, following the method described by **Folk (1974)**.

For bivalve samples, all specimens were morphologically identified, and the whole soft tissues of the three species of bivalve under study were frozen for heavy metals evaluation. The preparation of samples of bivalve soft tissues to determine the heavy metals concentration was conducted according to **FAO (1976)**, and analyzed using the flame atomic absorption spectrophotometer. The measurements were performed using Perkin Elmer A Analyst 100 Atomic Absorption Spectrophotometer.

Water samples were collected and the total metal content in the marine water was assessed according to the methods of **APHA (1989)**. The metals were preconcentrated from water using ammonium pyrrolidine dithiocarbamate (APDC) as a chelating agent, and after extraction, they were dissolved in methyl isobutylketone (MIBK). The organic extract was then aspirated directly to a flame atomic absorption spectrophotometer to determine the metal concentration.

To compare the total amount of metals in the three diverse bivalves species, the metal pollution index (MPI) was estimated by the equation **(AMA, 1992; Usero *et al.*, 1997)**: $MPI = (Cf_1, x\ Cf_2, \ldots Cf_n)^{1/n}$. Where Cfi = concentration of metal i in the sample and n= number of metals.

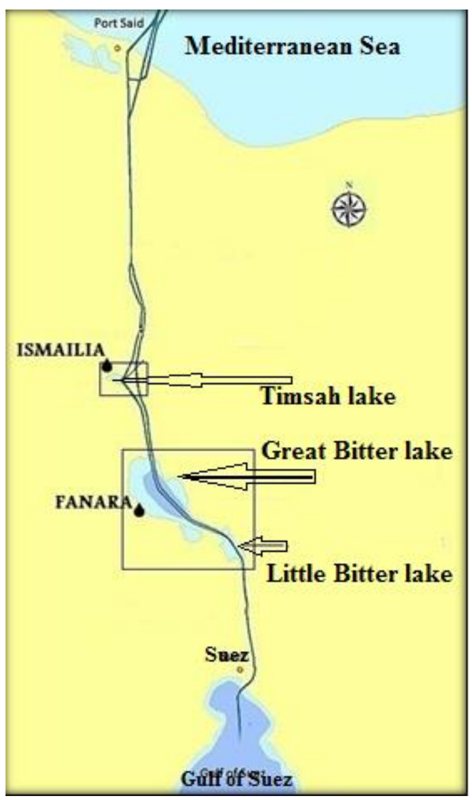

Fig. 1. Suez Canal and its lakes

Fig. 2. Sailing boats and fishing methods in Suez Canal lakes **(after Mehanna *et al.,* 2023)**

Fig. 3. Chosen 24 stations in Suez Canal lakes

RESULTS AND DISCUSSION

1. Catch, fishing effort, relative abundance and MSY

Catch and fishing effort data have an essential role in assessing the status of different exploited fish stocks. The catch per unit fishing effort (CPUE) is a good measure for the relative abundance of the exploited stocks. In addition, information about effort and catch per unit effort is fundamental data for the estimation of maximum sustainable yield (MSY) and the corresponding level of fishing effort (f_{MSY}) by means of surplus production models **(El-Gammal *et al.*, 1994; Mehanna & El-Gammal, 2007; Mehanna *et al.*, 2021)**.

The number of fishing effort represented by the standardized number of fishing boats in the Suez Canal lakes fluctuated between 776 (2012) and 829 (2020) small wooden sailing and oaring boats. The fishing boats never exceed 7m in length and have an average width of about 1.8m, with two or three fishermen for each boat. Both trammel (three layers nets) and gill nets (one layer nets) are used in different ways.

The total catch of the Suez Canal lakes fluctuated between a maximum of 6289 tons in 2005 and a minimum of 2894 tons in 2012, while the catch of bivalve ranged between 2088 tons in 2006 and 836 tons in 2012 (Fig. 4). Accordingly, the catch per unit of fishing effort CPUE (catch/ standardized number of fishing boat) fluctuated between 7.98 (2005) and 2.80 ton/boat (2018) for the total catch and between 2.63 (2006) and 1.06 ton/boat (2018) for the bivalve (Fig. 5).

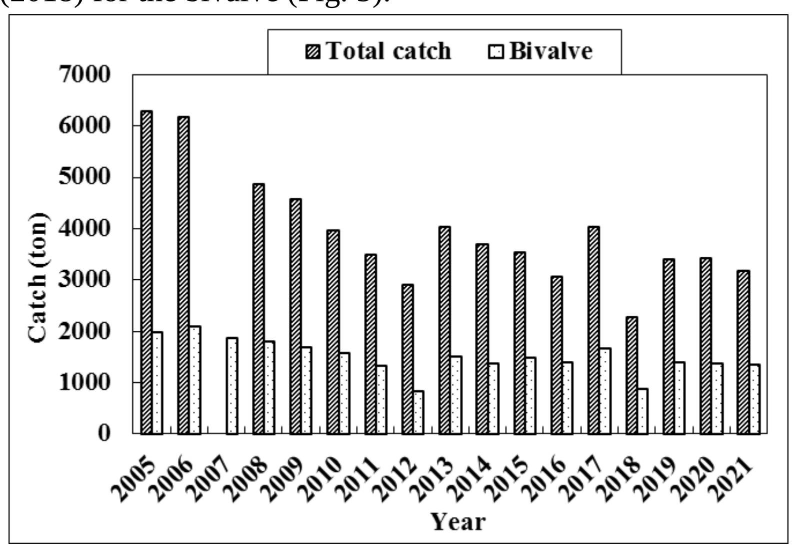

Fig. 4. Total catch and bivalve catch from the Suez Canal lakes

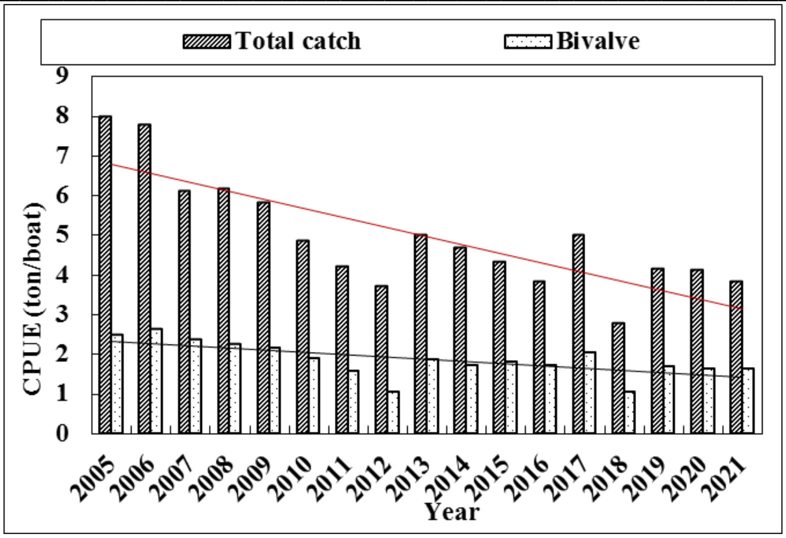

Fig. 5. Total catch and bivalve catch per standardized unit of fishing effort from the Suez Canal lakes

The catch composition of the Suez Canal lakes during the period from 2005 until 2021 revealed that molluscs are the main component of the catch contributing 38.23% for the bivalves, 3% for the cuttlefish and 0.32% for the gastropods. Commonly, the fishery production in the Suez Canal lakes demonstrate a declining tendency during the study period, and a similar tendency is detected for the bivalve catch. On the other hand, there is a severe failure in the relative richness of fish stocks in the Suez Canal lakes as the CPUE decrease for both the total catch and the bivalve catch through the last 17 years.

By applying Schaefer model, a maximum sustainable yield MSY of 2236.1 tons of the bivalve could be achieved at a fishing effort of 510 standardized fishing boats. This means that the current fishing effort (825 boat in 2021) should be decreased to only 510 boat (38.2% decreasing); this will be accompanied with an increase in the bivalve catch from 1354 to 2236.1 tons i.e an increase of 65.1% (Fig. 6).

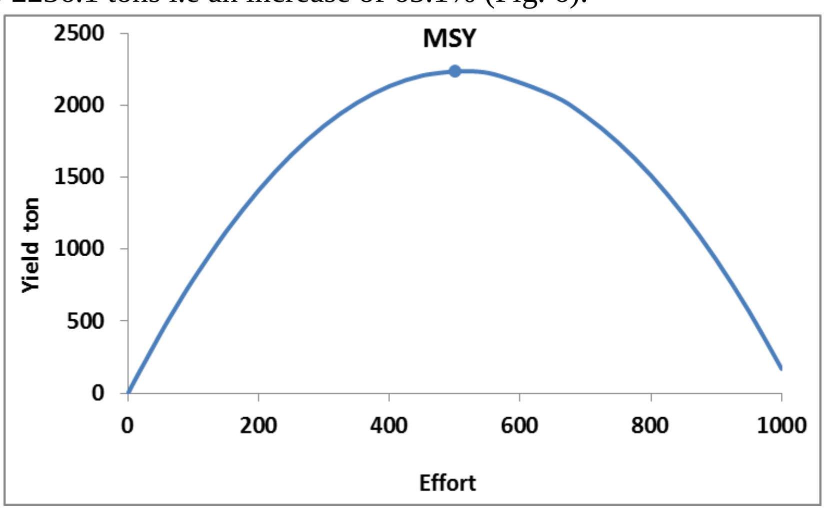

Fig. 6. Schaefer model for estimating MSY and f_{MSY} for bivalve in Suez Canal lakes

Although the relative abundance and MSY were estimated using the only available data obtained from GAFRD annual statistical books, it should be estimated for each lake separately and for each species. Therefore, the catch by species and fishing effort should be recorded more accurately, including the number of fishing days, trips, and fishing hours, rather than relying solely on the number of fishing boats. Nevertheless, the obtained results reflect the overexploitation status of Suez Canal lakes' fishery, highlighting an urgent need to reduce the fishing effort to conserve commercial fish stocks in these lakes.

2. Sediment characterization

Sand was the principal component in Lake Timsah, at all stations, while gravel was found in a low percentage at all stations, except 1, 9, and 11 (Fig. 7). This may be due to the unceasing heavy masses of the earthly contributions resulting from the different human activities. The coarse sediment group (CSG) showed the same trend of gravel, while the medium sediment group (MSG) recorded the highest average at Timsah Lake.

Additionally, sand was the principal sediment component at the Great Bitter Lake approved by the high averages of MSG and $Ø_3$, it recorded significantly high percentage exceeding 90% with very low gravel and mud percentages (Fig. 7). The coarse sediment group (CSG) showed low values at the different stations, except stations 9 and 10, owing to the influence of the natural wave actions and ship-generated waves. The noted extraordinary values of MSG and FSG in both lakes may be ascribed to the stagnant circumstances in these semi-closed circular shape basins that minimalize the wave action and stop the fine sediment spreading.

Sediments are the last location of both natural and anthropogenic constituents in the aquatic environment, and its superiority is an indicator for pollution. Sediments gather metals and other organic pollutants, thus the metal absorptions in the sediments are highly greater than that in the water column.

3. Heavy metals valuation

In respect to the sediment samples, the average values of six metals: Fe, Mn, Zn, Cu, Pb and Cd, were assessed, and it was found that there is no significant differences between the two lakes with slightly higher concentrations were observed in Lake Timsah (Fig. 8). The metals Fe, Cu, Mn, and Zn were the main metals in bulk sediment and the fine fractions in both lakes. The mean concentrations of metals in bulk sediment decreased in the following order: Fe > Cu > Mn > Zn > Pb > Cd for the Great Bitter Lake and Fe > Zn > Pb > Cu > Mn > Cd for the Timsah Lake. The stations 9, 10, and 12 in the Great Bitter lake displayed extraordinary concentrations of Fe, Mn, Zn and Cu; this may be due to the discharge of agricultural wastewater and pollutants from Abu-Rommanh drain and the domestic sewage from Kabreit and Shandoura areas. Lead (Pb) concentration was high in station 6, while Cd was high in station 1, which could be attributed to the agriculture overflow from Fanara and Defresoir, as well as navigation activities through the navigation channel of the Suez Canal. The concentrations of Mn, Cu, and Pb were high at station 8, which may be due to shipping activities, fixing, de-fouling, sustaining and constructing ships.

The same situation was noticed in the Timsah Lake where Fe, Zn, Pb and Cu were dominant at all stations with Zn recording the highest value, followed by Fe. Lead (Pb) was recorded in considerable concentrations indicating the risk of unhealthy situation of sidements where bivalve and other benthos live.

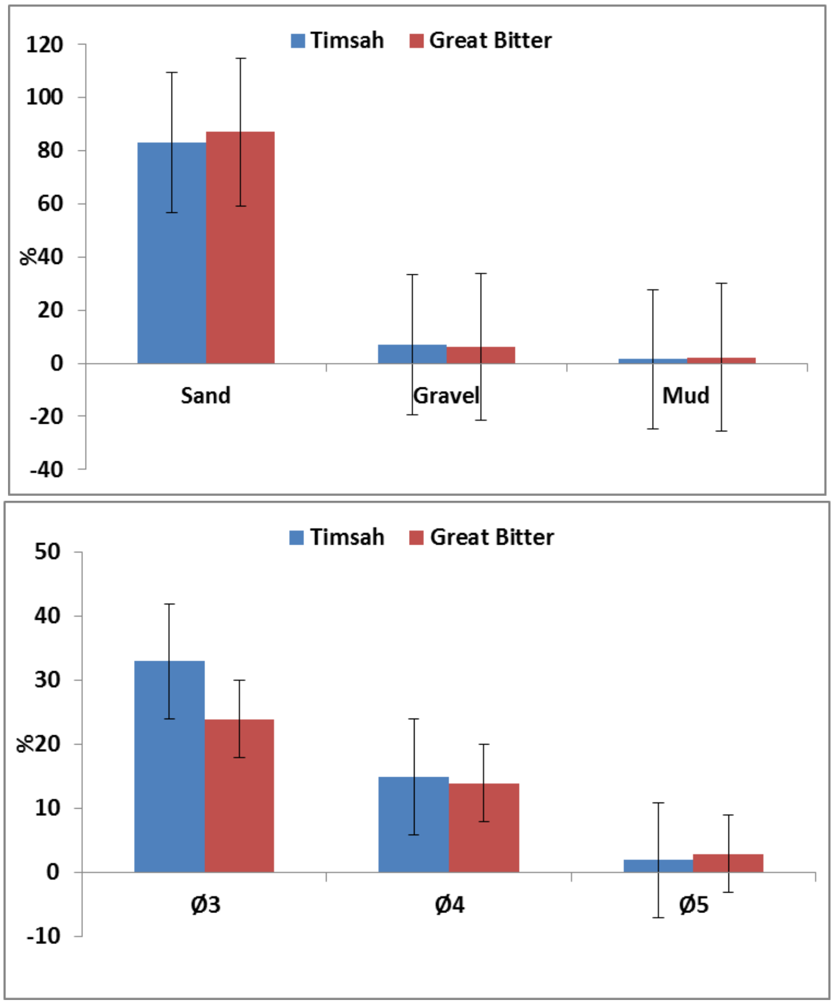

Fig. 7. The variation among gravel, sand, and mud, as well as the fine fractions ($Ø_3$, $Ø_4$ and $Ø_5$) at the Suez Canal lakes

Fractions ($Ø_3$, $Ø_4$ and $Ø_5$) were used to show the relationship between the grain size and metals concentrations in sediments. The obtained results showed that all the six measured metals in both lakes were reported for their highest values in $Ø_5$. The moderately high concentrations of Fe, Zn, Mn, Cu, Pb, and Cd in the mud fractions in the Suez Canal lakes demonstrate that the heavy metal accumulation in the fine sediment fractions is much more than the coarsest fractions. Despite the low contribution of mud fraction in comparison to the other sediment fractions in the Great Bitter and Timsah lakes, it was considered the main heavy metal's carrier and for the benthos, the easiest particle sizes to consume. Furthermore, the accumulative indices for heavy metals in sediment are relatively high.

In respect to the heavy metals concentration in the water samples, it was lesser than that in sediment. There is a significant difference between water and sediment in respect to the heavy metals' concentrations since the heavy metals are highly accumulated in sediments compared to water. The heavy metals in the Suez Canal lakes were decreased in the order Fe > Cu > Zn > Mn > Pb > Cd for the Great Bitter Lake and Fe > Zn > Pb > Cu > Mn > Cd for the Timsah Lake. The highest average value of all tested metals was recorded for iron (Fe) (71.15 and 59.83µg/ L) and the lowest for cadmium (Cd) (0.104 and 0.108 µg/ L) at Great Bitter and Timsah lakes, respectively. These high concentrations were due to industrial, agriculture and domestic wastes, as well as the discharges from ships and fishing boats passing or waiting transit through the Suez Canal, which contain antifouling paints **(ElAzim *et al.*, 2017)**.

On the other hand, the heavy metals assessing in the edible parts of the three investigated bivalve species revealed that the accumulative indices for heavy metals in bivalve tissues are reasonably high. Metals accummulation is highly noticeable in bivalve species than in sediment and water. The resultant order of heavy metals concentrations in the three studied species was sequenced as: Fe > Zn > Cu > Pb > Mn > Cd. In general, the metal pollution index (MPI) of the bivalve was high in the present study. The metal pollution index depends on a number of factors like the feeding habits of the animal, the way the animal takes metals from all the surrounding environmental compartments, and the extent to which the surrounding environmental components (water and sediment) are polluted.

Lead (Pb) is the second element on the top poisoning 20 heavy metals list, as it targets bones, brain, blood, kidneys, thyroid gland, reproductive and cardiovascular systems **(Homady *et al.*, 2002; Massadeh *et al.*, 2004)**. The Pb accumulation in the present study varied between 16.1 & 40.8µg g^{-1} in the three investigated bivaves, with values exeeding the maximum allowable levels of **FAO (1983)** (0.5 µg g^{-1}).

High levels of zinc cause pancreatitis, anemia, muscle pain and acute renal failure **(Pais & Jones Jr, 1997)**. The concentrations of Zn in the studied bivalves was 71.9 – 99.7µg g^{-1} dry weight, which exceeds the maximum allowable level of **FAO (1983)** (40µg g^{-1}).

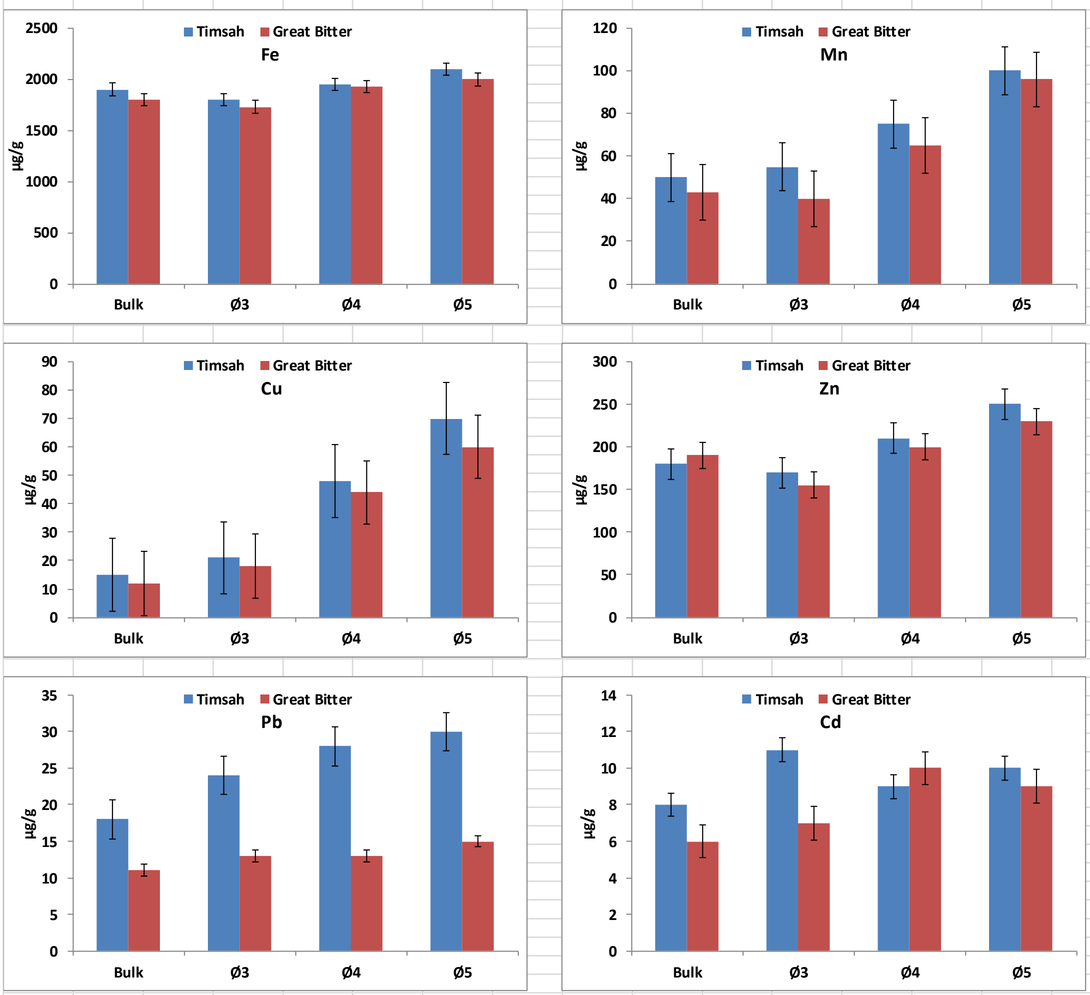

Fig. 8. Average values of heavy metal concentrations from the Suez Canal lakes

Mehanna *et al.* (2016) postulated that the fish production of the Timsah Lake has witnessed a serious drop in the recent years; beside the over-fishing and illegal mesh sizes, the severe pollution and the great fluctuation in salinity and temperature were another reasons. El-**Azim *et al.* (2018)** reported significantly higher concentrations of heavy metals in the north and west areas of Lake Timsah compared to the middle and western lagoon, which were identified as the primary sources of pollution, showing the highest levels of nearly all heavy metals in the lake.

CONCLUSION

The fish production in the Suez Canal lakes & the Bitter and Timsah lakes has experienced a sharp drop in the recent years, decreasing to about its half value. The main reasons behind this severe decline are overfishing, illegal mesh sizes, and uncontroled pollution. Catch and effort data are crucial for evaluating fishery status, making their consistency and availability urgent necessities to accurately assess the fishery's current state and provide a sound advice for fishery management. The accumulation of heavy metals, particularly in the bivalves followed by sediment and water, was considerable, with some levels exceeding the permissible limits in the edible parts. Pollution, especially from heavy metals, has significantly impacted water and fish quality, altering the physical and chemical characteristics of aquatic ecosystems and posing risks to human health. Therefore, urgent action is required to address the overfishing of the bivalve species in the Suez Canal lakes and to mitigate the sources of pollution including the reduction of the fishing efforts. Cleaning sediments and removing surface layers may help mitigate metal accumulation in benthic tissues, especially in the bivalves.

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