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Effect of Environmental Conditions on Biodiversity of Benthic Fauna Inhabiting El-Max Bay, Mediterranean Sea, Alexandria, Egypt

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ABSTRACT

The present study explored the impact of water physical parameters, nutrients and heavy metals on the abundance and diversity of macro-benthic invertebrate communities at El-Max Bay, Alexandria, Egypt. Water physical parameters were recorded at the bay, whereas water samples were collected and analyzed for various chemical parameters, such as nutrients and heavy metal concentrations. Macro-invertebrates were also collected and identified. Subsequently, abundance and diversity were estimated. The results revealed that the abundance of benthic invertebrates showed a positive correlation with water temperature, total dissolved solids, electrical conductivity, alkalinity, ammonia, nitrites, nitrates, cadmium, copper, lead, iron and zinc. In contrast, benthic invertebrate abundance was negatively correlated with pH, dissolved oxygen concentration, transparency and phosphates. The diversity of benthic invertebrates, on the other hand, was positively correlated with water temperature, pH, dissolved oxygen concentration, electrical conductivity, alkalinity, ammonia, nitrites, nitrates, cadmium, copper, lead, iron, and zinc. In addition, it was negatively correlated with total dissolved solids, transparency and phosphates. These findings suggest that the anthropogenic activities that led to increasing nutrients and heavy metal pollution in El-Max Bay had negative impacts on the health and diversity of the macro-benthic communities, which could have implications for the wider marine ecosystem. Therefore, measures should be taken to reduce nutrient and heavy metal pollution in the bay to protect the macro-benthic community and the marine ecosystem.

INTRODUCTION

Egypt's Mediterranean Sea coastline stretches for about 1,018 kilometers in addition to Alexandria, Port Said, Damietta, Rosetta, Matruh and Al-Arish. The coastal region is notable for a variety of activities, including fishing, manufacturing, tourism, trade, agriculture, transportation in addition to the production of oil and gas **(Abo-Taleb *et al.*, 2016)**. El-Max Bay is a relatively large coastal bay west of Alexandria. The bay is an important fishing and recreational area. It includes the ports of Westport and Dekhalia.

It is one of the most polluted areas on Egypt's Mediterranean coast, receiving large quantities of agricultural, industrial and sewage waste from the neighboring Mariut Lake through the El-Umoum Drain. According to different estimates in the literature, the volume of sewage fluctuates between 7 × 106 and 8 × 106m^3day-1 **(Dorgham, 2010).** Moreover, it is expected to increase with the increase in the population density of the city of Alexandria. These conditions lead to marked eutrophication and dramatic changes (**Abo-Taleb *et al*., 2015)**.

These problems are caused by the continuous accumulation of nutrients from various sources, including offshore activities, various land-based wastewaters consisting of stored fertilizer, mixed industrial domestic and agricultural wastes,. Nutrient loads are directly related to human activities, which in turn are related to world population growth. Therefore, human-caused eutrophication has a certain relationship with population increase **(De Jonge *et al*., 2002)**. Alexandria's population has nearly doubled since 1985, when eutrophication was first documented in El-Max Bay **(Dorgham, 2010).** Over the past 20 years, the rapid expansion of human activities, both directly and indirectly contributing to nutrient enrichment, has increased eutrophication levels in the bay. This expansion has occurred in tandem with population growth. Numerous studies have been conducted on El-Max Bay's physical, chemical and biological characteristics **(Dorgham *et al*., 2004; Hussein & Gharib, 2012; Hendy, 2013)**. It showed that the continuous discharge of sewage into the bay caused a gradual deterioration for algal blooms and water quality **(Zakaria, 2007; Mahmoud *et al*., 2009)**.

The problem of increasing trace metal concentrations in the marine environment is a global one. Discharges of trace metal wastes have numerous, visible effects on water, sediments and organisms, which lower productivity and increase exposure to pollutants in humans. The shape and type of the chemical affect toxicity, bioavailability, bioaccumulation, biodegradability, persistence, flow ability, solubility, extractability, among other important qualities **(Lores & Pennock, 1998)**.

Since macroinvertebrates are highly sensitive to pollution and relatively long-lived, they are also commonly used as indicators of the integrity of aquatic ecosystems **(Richman & Somers, 2010; Selvanayagam & Abril, 2016; Du *et al*., 2021)**. Natural phenomena and human actions have a significant impact on the distribution of macroinvertebrate communities in aquatic systems **(Yu *et al*., 2020).** Hence, biota respond to stressors on various spatial or temporal scales; biological techniques are useful in many studies for identifying natural and anthropogenic influences on water resources and habitats **(Weigel & Robertson, 2007; Resende *et al*., 2010; He *et al*., 2020; Kurthen *et al*., 2020)**. The use of aquatic species in ecological research has proven to be more successful than relying solely on environmental variables due to the integration of structural and functional traits within the aquatic community, which reflects the health of the studied streams **(He *et al*., 2020)**. Environmental elements are also crucial, for instance, water temperature has an impact on the development and survival of organisms **(Hall & Burns, 2001).** Due to their increasing prevalence, chemical stressors and resource enrichment serve as important case studies for environmental stressors (**Bernhardt *et al*., 2017)**, and it is anticipated that they would have negative consequences on biodiversity (**Mazor *et al*., 2018).** Heavy metal pollution from household and industrial sources causes extreme changes in the aquatic environment, causing the loss of biological variety as well as the amplification and bioaccumulation of harmful substances that are found in food chains. Metals are an important environmental pollutant (**Souza *et al*., 2012).** Marine biodiversity is crucial for maintaining ecosystem processes and for a variety of ecosystem services, including social, economic, and ecological ones **(Luypaert *et al*., 2020).** In addition to its essential significance, biodiversity also plays a significant role in fostering ecological services that support human communities and economies, which has led to the global recognition of the value of biodiversity **(MEA, 2005)**.

The aim of this study was to investigate the abundance and diversity of marine benthic invertebrate communities, along with exploring various biological aspects of dominant invertebrate species. Additionally, the research aimed to assess the impact of environmental factors on the diversity and abundance of invertebrates along the Mediterranean Sea coast in Alexandria, Egypt.

MATERIALS AND METHODS

1. Area of study

El- Max Bay is located in the west of Alexandria between the longitudes of 29°48′ and 29°54′E and the latitudes of 31°07′ and 31°15′N. It is a sizeable coastal embayment having a surface area of about 19.4km^2 and an average depth of 10m **(El- Sherif, 2006)**. The bay is one of the most polluted areas along the Egyptian Mediterranean coastline as a result of the discharges of a sizeable amount of industrial, agricultural and sewage pollutants into the bay through the El-Umoum Drain from the neighboring Lake Mariut. According to various estimates found in the literature, the wastewaters' volume ranged between 7× 106 and 8 × 106 m^3 day-1 **(Dorgham, 2010).**

Fig. 1a. Map of El-Max Bay, Alexandria, Egypt

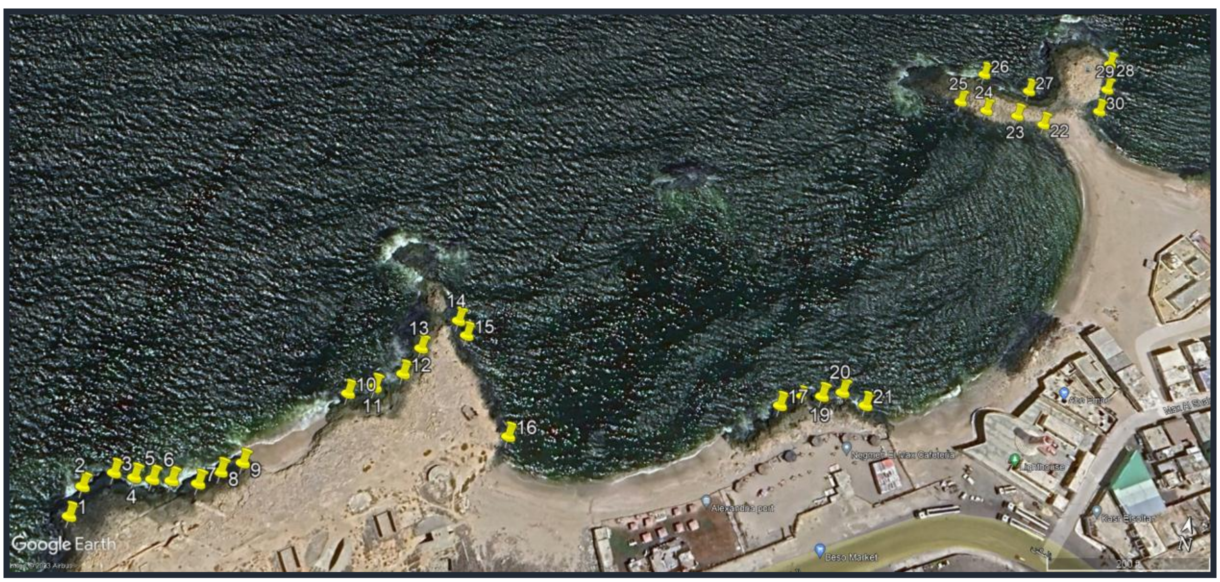

Fig. 1b. Map of El-Max Bay showing the collection sites

2. Physicochemical parameters

2.1. Water temperatures and hydrogen ion concentrations

Water temperatures °C and pH (hydrogen ion concentrations) were determined by standard professional pH-TEMP portable meter model: AD110; brand name: Adwa instruments.

2.2. Electrical conductivity and total dissolved solids

Electrical conductivity (EC) mg/l and total dissolved solid (TDS) mg/l were measured by waterproof EC/TDS meter model: H.I. 9835N; brand name: Hanna instruments.

2.3. Dissolved oxygen concentrations

The modified Winkler method **(APHA, 1985)** was used to estimate dissolved oxygen concentrations according to the following formula:

$$\textbf{Dissolved oxygen (mg/l)} = \frac{N \times V \times 8}{MI\ \ of\ sample} \times 1000$$

Where,
N = Sodium thiosulphate is normal.
V = Quantity of sodium thiosulphate.

2.4. Transparency

Secchi disk with a diameter of 25cm was utilized to study water transparency.

2.5. Alkalinity

Alkalinity was immediately determined after collecting water samples according to **APHA (1985)** adopting the succeeding formula:

$$\textbf{Total alkalinity is measured as calcium carbonate} = \frac{N \times A \times 50}{MI\ \ of\ sample} \times 1000$$

Where, N = Normality of acid.

A = Volume of titrate.

3. Determination of nutrients in the water

3.1. Dissolved inorganic phosphates (PO_4-P)

Total phosphorus was determined according to **APHA (2005)**.

3.2. Nitrites (NO2-N)

Nitrites were determined based on the Griess reaction using the colorimetric method according to **Griess (1858)**.

3.3. Nitrates (NO3-N)

Determination of nitrates was carried out by reducing it to nitrite in a powerful alkaline medium (pH 12) through hydrazine sulfate in the presence of copper as a catalyst according to **Mullin and Riley (1955)**.

3.4. Ammonium (NH4+-N)

Ammonia was determined by using the phenate method **(APHA, 1995)**.

4. Determination of heavy metals in water

Since the level of heavy metal concentrations in seawater sensitivity levels for atomic absorption spectroscopy are below those of seawater, a pre-concentration step was necessary before measurement using the cationic exchange chelex-100 method **(Riley &Taylor, 1968; Abdullah & Royle, 1974)**.

5. Sample collection and species identification

Through a number of field trips (12 trips), macro-benthic invertebrates occupying various sites throughout the study region were seasonally sampled from November 2020 to November 2021. By using the Permanent Quadrat Method (**English *et al.*, 1997)**, the quantitative information about the macrobenthic invertebrates was gathered. The average was computed by thirty quadrates (1m x 1m), with 1m^2 quadrates in each intertidal zone at each surveyed location during each season. Walking carefully through the surveyed areas allowed us to examine a qualitative sample of the benthic biodiversity. Seasonally, samples of a few marine benthic invertebrates—the study's target populations—were gathered from the several study sites (thirty quadrates). The specimens were preserved in 10% neutral formalin solution and stored in labeled plastic jars for later analysis and identification. Date, time, shore type, human activity (fishing or diving) and substrate type were noted at each site. Five ecological intertidal zones were used for data gathering at each site. The macro-benthic invertebrate samples were collected, and their identities were determined using the suggested identification keys **(Riley, 2002; White, 2008; Bariche, 2012; Abdel-Salam *et al.*, 2017; Giacobbe, *et al.*, 2018)**, whereas the description of diversity indices methods (Simpson index, Shannon index, Pielou index, ….) were determined by PAST (PAleontological STatistics).

Data analysis and statistics

In the current study, all obtained data were tabulated, and suitable graphs were created. Several computers were used to statistically evaluate the data software including PAST (PAleontological STatistics), Ver. 4.13, R studio Ver. 3. 3.0., and Excel 2010.

Shannon-Weaver index

According to **Shannon (1948)**, the Shannon weaver index was calculated from the following equation:

$$H' = -\sum_{i=1}^{n} p_i \ {}_{log2Pi}$$

Where,

Pi is calculated as the total number of species in the sample divided by the number of individuals in each species (n), and **(N) = n/N**.

Log: natural logarithm of $\boldsymbol{p_i}$., and

n: species present in the community.

Pielou evenness index

According to **Pielou (1966)**, the following formula was used to determine the evenness index:

$$J' = \frac{H'}{H'_{max}} = \frac{H'}{LnS}$$

Where,

H': the Shannon wiener index value**;**

H' max: the highest Shannon wiener index value**, and**

Max S: the number of taxa in samples species richness.

Margalef's diversity index (Margalef, 1968)

It calls the species richness and calculated by the following equation:

$$R_i = S - 1Ln(N)$$

Where,

S: Total number of species, and

N: Total number of individuals in the sample.

Simpson index (Somerfield *et al.*, 2008).

It was calculated according the following formula:

$$D = \sum_{i=1}^{n} P_i^{\,2}$$

Where,

pi: a proportional abundance of ecosystem *i*, i.e. the total surface of ecosystem *i* divided by the total surface sum: pi = ni/N.

Menhinick's index (Whittaker, 1977)

It was calculated by the following formula:

$$D_{Me=} \frac{S}{\sqrt{N}}$$

Where,

S: total groups that have been identified**, and**

N: the total number of individuals counted.

The Berger-Parker index (Berger & Parker, 1970)

This index was calculated by the following formula:

$$D = \frac{n_{max}}{N}$$

Where,

n_{max}= the maximum number of identified species max and

N: the total number of individuals**.**

Correlation matrix

Stepwise regressions and combined correlation coefficient using statistics for windows Ver. 10.0. and R studio Ver. 3. 3.0.

ANOVA test

The obtained results were presented as mean ± S.D. in Tables. Correlations were analyzed using Microsoft Excel 2010, Windows 10. Analysis of variance (ANOVA) was assumed according to **Bailey (1981).** Canonical correspondence analysis **(C.C.A.)** was assumed according to **Ter Braak (1986)**.

RESULTS

1. Physico-chemical parameters

Physico-chemical parameters at El-Max Bay were significantly varied between investigated stations (Table 1 & Fig. 2**)**. Seasonally, the highest water temperatures (30.1±0.93°C) were recorded during summer, while the lowest (17.0±1.25°C) was recorded during winter. The highest transparency (180.8±19.25cm) was recorded during autumn, while the lowest (77.19±15.94cm) was recorded in summer. The highest electrical conductivity averaged 53.8±12.73mS/ cm during summer, while the lowest (43.3±9.88[a]mS/ cm) was recorded during winter. The highest total dissolved solids averaged 38.7±3.25mg/ L during summer, while the lowest (22.4±2.79mg/ L) was recorded during winter. The highest hydrogen ion values averaged 8.5±1.05 during autumn, while the lowest (7.6±1.20) was recorded in winter. The highest values of dissolved oxygen concentrations was recorded during winter (7.25±0.50mg/ L), and the lowest average (3.8±0.55mg/ L) was recorded during autumn. In this context, the highest alkalinity average (200±32.80mg/ L) was registered in summer, while the lowest (130±37.78mg/ L) was recorded during autumn.

Table 1. Physicochemical parameters recorded at El-Max Bay during the period from November 2020 to November 2021

Physical parameter	Autumn	Winter	Spring	Summer	Annual average
Temp. (°C)	26.17±1.31[b]	17.00±1.25[c]	28.80±0.93[ab]	30.10±0.93[a]	25.52±1.11
Transparency (cm)	180.83±19.25[a]	150.17±20.75[ab]	120.17±16.97[b]	77.19±15.94[c]	131.75±18.23
E.C (mS/cm)	50.11±9.44[a]	43.30±9.88[a]	44.40±8.08[a]	53.80±12.73[a]	47.90±10.03a
T.D.S (mg/L)	30.00±3.50[a]	22.40±2.79[ab]	26.00±2.12[bc]	38.70±3.25[c]	29.28±2.91
pH	8.50±1.05[a]	7.60±1.20[a]	7.99±1.55[a]	7.81±1.04[a]	7.98±1.21
D.O (mg/L)	3.75±0.55[a]	7.25±0.50[a]	5.70±0.67[a]	6.12±0.95[b]	5.71±0.67
Alk. (mg/L)	130±37.78[a]	170±48.58[a]	150±22.06[a]	200±32.80[a]	162.50±35.30

***Means that share the same letter within a row differ significantly.**

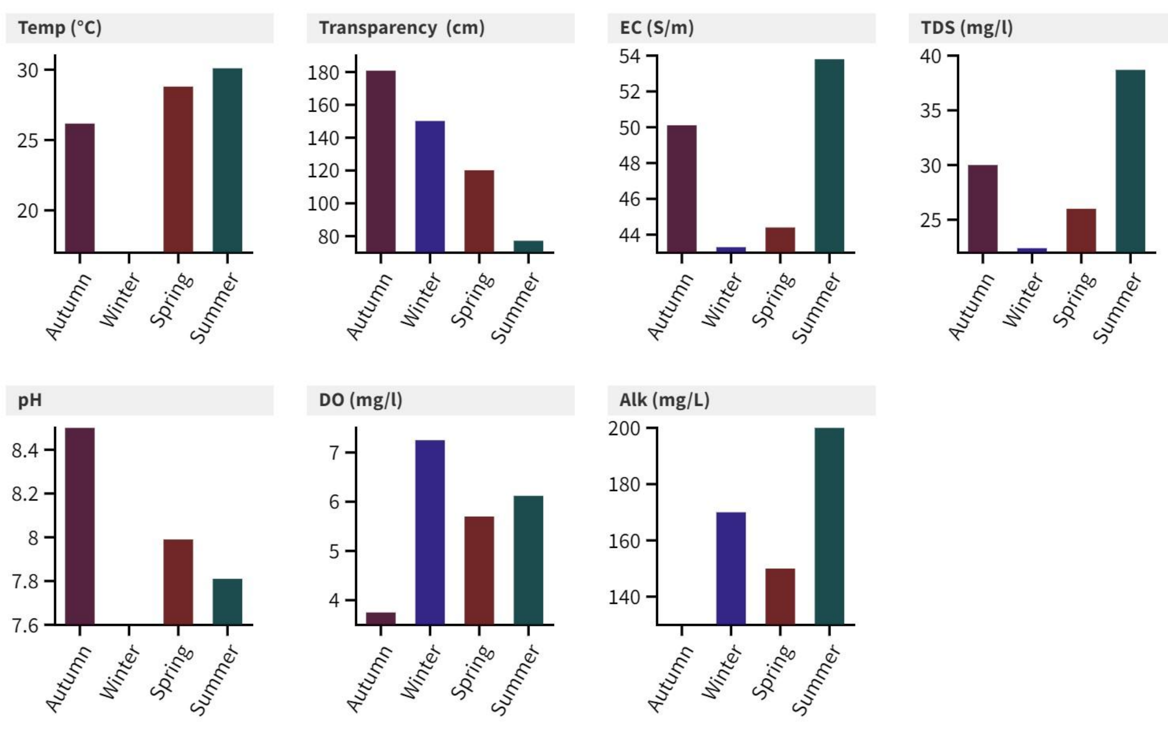

Fig. 2. Column chart representing physicochemical parameters during this study recorded at El-Max Bay from November 2020 to November 2021

2. Nutrient parameters

Nutrient parameters were significantly varied between different seasons, as shown in Table (2) and Fig. (3). Seasonally, autumn had the highest level of phosphates (4.89±0.98), while spring had its lowest level at 1.16±0.13. The summer months had the highest levels of nitrite (4.22±1.00c), while the winter months had the lowest (0.2±0.04). Nitrate levels ranged from the greatest (11.55±0.51) during summer to the lowest (3.48±0.87) during winter. Autumn, spring, and summer recorded the greatest ammonia concentrations (1.0±0.50), while winter recorded the lowest (0.1±0.15).

Table 2. Nutrients parameters recorded at El-Max Bay from November 2020 to November 2021

Nutrient	Autumn	Winter	Spring	Summer	Annual average
PO_4 (mg/L)	$4.89{\pm}0.98^{a}$	$2.50{\pm}0.77^{b}$	$1.16{\pm}0.13^{b}$	$2.40{\pm}0.51^{b}$	2.74±0.60
NO_2 (mg/L)	$1.88{\pm}0.76^{a}$	$0.20{\pm}0.04^{ab}$	$3.44{\pm}0.41^{b}$	$4.22{\pm}1.00^{c}$	2.44±0.55
NO_3 (mg/L)	$7.38{\pm}0.97^{a}$	$3.48{\pm}0.87^{b}$	$4.48{\pm}0.41^{c}$	$11.55{\pm}0.51^{c}$	6.72±0.69
NH_3 (mg/L)	$1.00{\pm}0.50^{a}$	$0.10{\pm}0.15a^{b}$	$1.00{\pm}0.10^{ab}$	$1.00{\pm}0.40^{b}$	0.78±0.29

***Means that share the same letter within a row are significantly different**.

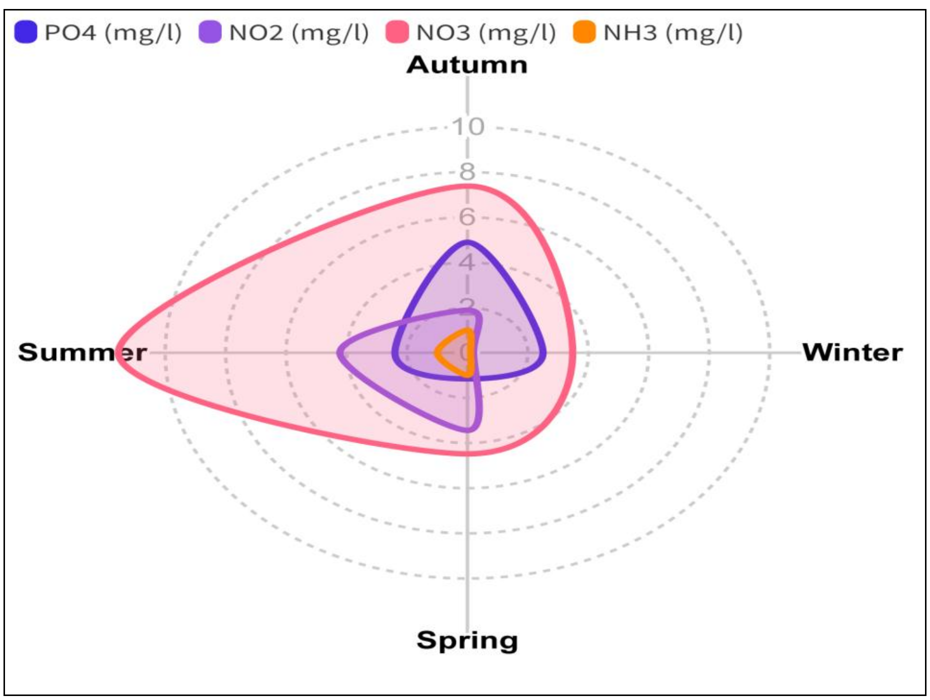

Fig. 3. Radar chart representing nutrients parameters recorded at El-Max Bay during the period extending from November 2020 to November 2021

3. Heavy metals

El-Max Bay's heavy metals characteristics were significantly different between different seasons, as presented in Table (3) and Fig. (4). The present results showed that, all recorded heavy metals have the highest levels of concentrations during summer, moderate in spring and the lowest ones are in winter, except for iron that show its lowest values in autumn (Table 3 & Fig. 4). With the exception of iron, all other metals were unavailable during autumn.

Table 3. Heavy metal concentrations recorded at El-Max Bay during the period extending from November 2020 to November 2021

Heavy metal	Autumn	Winter	Spring	Summer	Annual average
Cd (mg/L)	N.A.	0.03 ± 0.02^{ab}	0.05 ± 0.02^{bc}	0.07 ± 0.02^{c}	0.04 ± 0.01
Pb (mg/L)	N.A.	0.38 ± 0.05^{ab}	0.41 ± 0.04^{b}	0.59 ± 0.12^{c}	0.35 ± 0.05
Cu (mg/L)	N.A.	0.30 ± 0.06^{a}	$0.50\pm0.36a^{b}$	0.70 ± 0.19^{b}	0.38 ± 0.15
Fe (mg/L)	0.12 ± 0.02^{a}	0.33 ± 0.04^{a}	0.55 ± 0.35^{ab}	0.60 ± 0.23^{b}	0.40 ± 0.16
Zn (mg/L)	N.A.	0.12 ± 0.03^{a}	0.13 ± 0.03^{a}	0.16 ± 0.02^{b}	0.10 ± 0.02

***Means that share the same letter are significantly different; **Note: N.A. = Not available.**

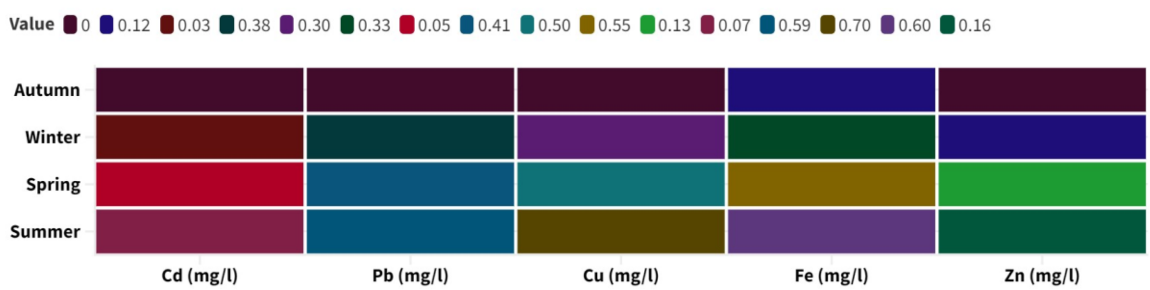

Fig. 4. Heat map showing heavy metal values recorded at El-Max Bay during the period that extended from November 2020 to November 2021.

4. Macrobenthic invertebrate communities

During the study period, 17 species were discovered along the study area at El-Max (Table 4). Recorded species belong to five phyla comprising: Cnidaria (Anthozoa, and Scyphozoa), Bryozoa (Gymnolaemata), Annelida (Polychaeta), Mollusca (Gastropoda and Bivalvia), and Arthropoda (Hexanauplia and Malacostraca).

The data presented in Table (4) revealed that Mollusca, which comprises three species from three families and accounts for 37.21% of the entire macrobenthic population, was the most abundant phylum. The majority of Mollusca were in class Gastropoda, which consisted of two species (33.14% of the total population) from two families. One species (4.06% of the total population) from one family makes up the Bivalvia. The second most prevalent phylum was the Annelida, which had two species (which made up 33.82% of the total count) and two families from a single class. Eight species (27.46% of the total count) from eight families and two classes of Arthropoda were present. The majority of Arthropoda were Hexanauplia, which consisted of three species (22.04% of all individuals) from three families. Malacostraca comprised 5 species (5.42% of the total population) from 5 families. Three species (1.04% of the total count) of Cnidaria from three families and two classes were present. The majority of the Cnidaria included Anthozoa, which consisted of two species (0.99% of the total number of individuals) from two families. Scyphozoa comprised of 1 species (0.05% of the total population), each of which belong to a single family. One species of Bryozoa made up 0.68% of the overall count, belonging to one family of one class.

Considering the data provided in Table (4), *Hydroides elegans* and *Echinolittorina punctate* were the dominant species, came in the first and second importance and were represented by 33.72% and 32.83% of the total count of macro-benthic invertebrates, respectively. *Chthamalus stellatus* and *Semibalanus balanoides* were also dominant, came in the third and fourth importance and were represented by 13.03% and 8.65%, respectively. Moreover, there were three subdominant species; namely, *Brachidontes rostratus* (4.06%), *Sphaeroma* sp. (2.97) and *Ligia italic* (2.19%). Six species were ranked as minor species (≤ 2.0% - ≥ 0.1% based on the total number of macrobenthic invertebrates counted), and the remaining species (4 species) that were recorded have been classified as uncommon species (≤ 0.1%).

Table 4. Macro-benthic invertebrate community observed at El-Max Bay during the period extending from November 2020 to November 2021

Phylum	Class	Family		Species	Relative abundance (%)
Cnidaria	**Anthozoa**	**Actiniidae**	**1**	*Actinia equine*	**0.05**
		Aiptasiidae	**2**	*Exaiptasia diaphana*	**0.94**
	Scyphozoan	**Rhizostomatidae**	**3**	*Rhopilema nomadica*	**0.05**
Bryozoa	**Gymnolaemata**	**Vesiculariidae**	**4**	*Amathia verticillata*	**0.68**
Annelida	**Polychaeta**	**Serpulidae**	**5**	*Hydroides elegans*	**33.71**
		Nereididae	**6**	*Nereis pelagica*	**0.10**
Mollusca	**Gastropod**	**Littorinidae**	**7**	*Echinolittorina punctate*	**32.82**
		Patellidae	**8**	*Patella caerulea*	**0.31**
	Bivalvia	**Mytilidae**	**9**	*Brachidontes rostratus*	**4.06**
Arthropoda	**Hexanauplia**	**Chthamalidae**	**10**	*Chthamalus stellatus*	**13.03**
		Archaeobalanidae	**11**	*Semibalanus balanoides*	**8.65**
		Balanidae	**12**	*Perforatus perforates*	**0.36**
	Malacostraca	**Ligiidae**	**13**	*Ligia italic*	**2.19**
		Sphaeromatidae	**14**	*Sphaeroma* sp	**2.97**
		Portunidae	**15**	*Charybdis helleri*	**0.05**
		Eriphiidae	**16**	*Eriphia verrucosa*	**0.05**
		Grapsidae	**17**	*Pachygrapsus marmoratus*	**0.16**

Total of relative abundance =100.

The different ecological diversity indices of the recorded benthic invertebrate species at El-Max Bay were presented in Table (5). The Simpson index (0.90) showed that diversity was higher. Shannon index (2.43) showed that the high diversity, the large number of species, and even the distribution of species are all indicators of high value. Pielou index measures species equality (0.87); high evenness is sometimes taken as an indicator of a healthy ecosystem. The higher the index, the greater the species richness, according to the Margalef index (3.29) and the Menhinick index (2.10). Berger-Parker Index (0.10) is more moderate, which indicates that the most common species dominating the community.

Table 5. Diversity indices calculated for macro-benthic invertebrates' communities at El-Max Bay during the period extending from November 2020 to November 2021

Diversity indices	Simpson index	Shannon index	Pielou index	Margalef index	Menhinick index	Berger-Parker index
Results	0.90	2.43	0.87	3.29	2.10	0.10
Theoretical index value range	0-1	0-1	0-1	0 - > 5	0-1	0-1

Canonical correspondence analysis (CCA) revealed the role effect of analyzed parameters on species community observed at El-Max Bay stations throughout the study, showing that transparency as physicochemical parameters was the most reliable on species dynamic, while NH_3 dominates other nutrients. In the same manner, Cd and Cu as heavy metals had the biggest impact on species dynamic throughout the study (Fig. 5a).

The tow cluster revealed that summer at El-Max Bay stations has a unique community over the remaining seasons. Hence, summer cladded on one node with divergent similarity to other seasons (Fig. 5b).

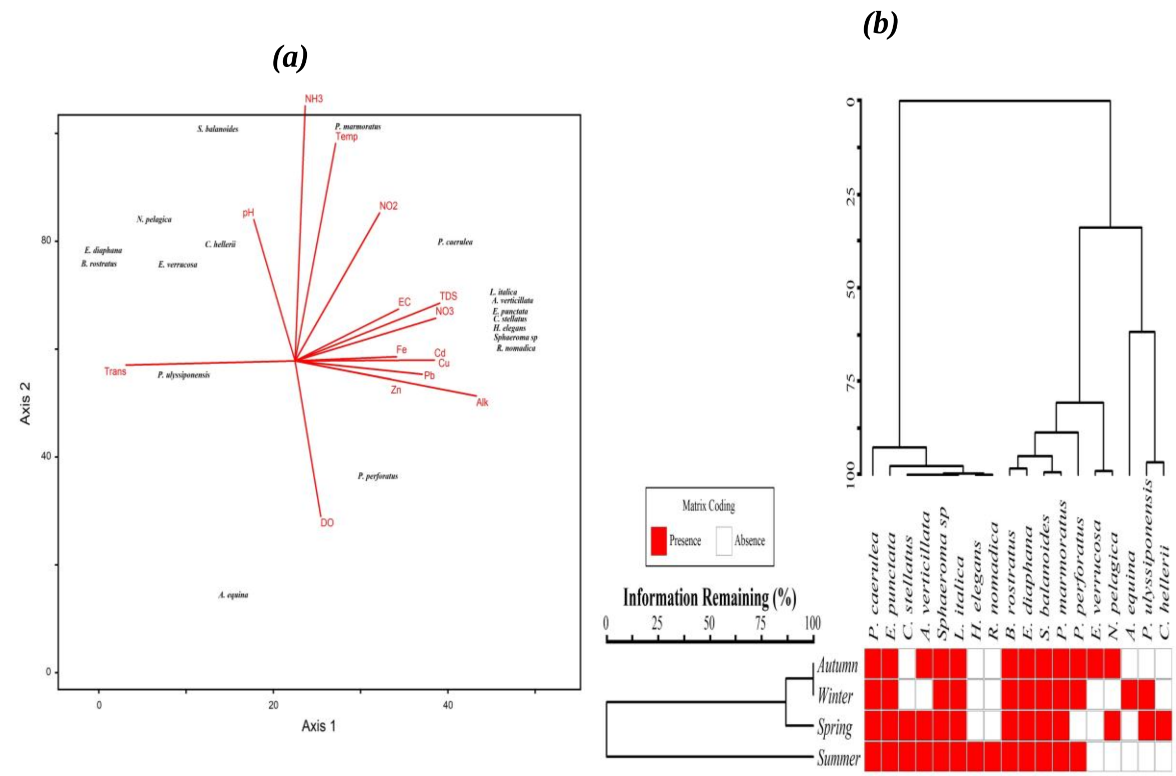

Fig. 5. a**.** Canonical correspondence analysis (CCA) of analyzed parameters and observed species diversity & abundance; *b.* Tow way cluster heat map represents the species dynamic over studied seasons at El-Max Bay stations**.**

DISCUSSION

Environmental aspects are crucial; for instance, water temperature affects an organism's growth and development as well as its survival (**Hall & Burns, 2001)**. Due to their increasing prevalence, environmental stressors with significant case studies include chemical stressors and resource enrichment **(Bernhardt *et al.*, 2017)**, and it is projected that they would have negative consequences on biodiversity (**Mazor *et al.*, 2018)**. They are important for communities of decomposers as well. Metals and pesticides are examples of chemical stressors that reduce decomposers' diversity, abundance, development, and activity in terrestrial and aquatic systems **(Pelosi *et al.*, 2014**; **Schäfer, 2019)**. Owing to their toxicity, long persistence, bioaccumulation and biomagnification in the food chain, the pollution of water and sediment by heavy metals and metalloids in greater quantities poses a serious danger **(Lamas *et al.*, 2007)**.

In the current investigation, summer recorded the highest water temperatures (30.10±0.93°C), while winter had the lowest temperatures (17.00±1.25°C). Similar findings were detected by **Abbas (2015)** and **Abo-Taleb *et al.* (2015)**. While, they differ with those of previous results **(Shreadah *et al.*, 2014; Okbah *et al.*, 2017)**. For transparency, autumn had the highest average (180.83 ± 19.25cm) and a decline was recorded to the lowest value (77.19±15.94cm) during summer. The current findings are higher than those recorded by **Shreadah *et al.* (2014**) and **Abbas (2015)**; however, they are similar to the outcomes recorded in the study of **Abo-Taleb *et al.* (2015).** The highest electrical conductivity (53.80±12.73mS/cm) was recorded during summer, while the lowest (43.30±9.88 mS/cm) was recorded during winter. The present findings are similar to what has been obtained by **Abbas (2015).** Summer had the greatest total dissolved solids concentrations (38.70±3.25mg/L), while winter showed the lowest value (22.40±2.79mg/L). The current findings are accepted according to the data reported in the study of **Abbas (2015).**

The highest hydrogen ion concentration was 8.50±1.05, recorded during autumn, while the lowest (7.60±1.20) was detected during winter. These results agree with those of previous research articles **(Abbas, 2015; Abo-Taleb *et al.*, 2015; Okbah *et al.*, 2017)** and disagree with the results of **Shreadah *et al.* (2014)**.

The highest dissolved oxygen was recorded during winter (7.25±0.50 mg/L), and the lowest (3.75±0.55mg/L) was recorded during autumn. The present findings coincide with those of **Abbas (2015)** and **Abo-Taleb *et al.* (2015).** On the other hand, the current findings disagree with those of **Shreadah *et al*. (2014)** and **Okbah *et al.* (2017).** In this context, the highest alkalinity (200±32.80mg/ L) was recorded during summer, while the lowest (130±37.78mg/ L) was during autumn. These results are in line with the findings of **Abbas (2015)**.

In the aquatic environment, nutrient salts are crucial for maintaining the balance of the food chain and immediately affect the quality of the water **(Emam *et al*., 2013)**. During the present study, three types of nutrient salts comprising nitrites, nitrates and phosphates were studied. Autumn had the highest levels of phosphates (4.89±0.98mg/ L), while spring showed the lowest (1.16±0.13mg/ L). The present findings are less than what was recorded by **Shreadah *et al.* (2014)**, **Abo-Taleb *et al.* (2015)** and **Okbah *et al.* (2017)**. In contrast, summer months had the highest levels of nitrites (4.22±1.00mg/ L), while winter recorded the lowest (0.20±0.04); the present findings coincide with those of **Abo-Taleb *et al.* (2015)**. While, they disagree with the findings of previous studies **(Shreadah *et al.*, 2014; Okbah *et al.*, 2017)**. Nitrates levels ranged from the greatest average of 11.55±0.51mg/ L to the lowest of 3.48±0.87mg/ L throughout the summer and winter, respectively. The present results match the findings obtained by **Abo-Taleb *et al.* (2015)**. On the other hand, they are higher than the findings obtained by **Shreadah *et al.* (2014)** and **Okbah *et al.* (2017)**. Autumn, spring and summer had the greatest ammonia readings (1.00±0.50mg/ L), while winter had the lowest concentration (0.10±0.15mg/L). The present findings were similar to those obtained by **Shreadah *et al.* (2014)** and **Okbah *et al.* (2017)**.

Although heavy metals are naturally occurring as trace elements in the aquatic environments, their concentrations have increased as a result of industrial waste, geochemical structure, agricultural and mining activities **(Kalay & Canli, 2000)**. Heavy metals poisoning of soils, sediments, water resources, and biota is a serious issue due to their toxicity, persistence and bioaccumulative nature, notably in a number of industrialized countries (**Ikem *et al*., 2003)**. Some aquatic plants and animals depend on trace metals like copper and zinc for essential metabolic activities, but when these metals are present in large quantities, they can be hazardous (**Kotickhoff, 1983)**. Summer recorded the highest cadmium concentration (0.07±0.02mg/ L), while winter had the lowest (0.03±0.02mg/ L. These results disagree with those of some previous studies **(Abbas, 2015; Abdel-Halim *et al.*, 2019)**. It was noticed that, summer had the highest lead concentration (0.59±0.12mg/L), whereas the winter recorded the lowest (0.38±0.05mg /L), which are both higher than the findings obtained by **Okbah (2000)**, **Abbas (2015)** and **Abdel-Halim *et al.* (2019)**. The summer season had the highest concentration of copper (0.70±0.19mg/ L), while winter had the lowest concentration (0.30±0.06mg/ L). The present findings are higher than those obtained in previous studies **(Okbah, 2000; Abbas, 2015; Abdel-Halim *et al.*,2019)**. On the other hand, summer recorded the highest levels of iron (0.60±0.23mg/L), while autumn had the lowest levels; these findings are similar to the findings of **Okbah 92000)** and higher than the recorded values stated in earlier studies **(Abbas, 2015; Abdel-Halim *et al.*, 2019).** Winter was noticed to own the greatest zinc levels (0.12±0.03mg/ L), while spring recorded the lowest (0.13±0.03mg/ L) levels. The present results are higher than the findings obtained in the studies of **Abbas (2015)** and **Abdel-Halim *et al.* (2019)**.

Composition of associated fauna of intertidal zone at the study area comprised 17 species, belonging to 5 different systematic groups. These are Phylum: Cnidaria with 3 species (Anthozoa, and Scyphozoa), Phylum: Bryozoa with 1 species (Gymnolaemata), Phylum: Annelida with 2 species (Polychaeta), Phylum: Mollusca with 3 species (Gastropoda and Bivalvia), Phylum: Arthropoda with 8 species (Hexanauplia and Malacostraca). Results disagree with those obtained by **Hamdy and Dorgham (2018)** who recorded 26 species, which belong mainly to polychaetes (11 species) and crustaceans (9 species). In addition to 2 species of mollusks and one species for each of Cnidaria, Porifera, Bryozoa, and Sipuncula at the sampling sites along the study area in the Eastern Harbour. Results revealed that Mollusca were the most abundant (37.7%) of the total faunal count, followed by Polychaetes (33.7%) and Arthropoda (27.4%). Results differ from those reported by **Hamdy and Dorgham (2018)** who reported that polychaetes were the most abundant (45.2%) of the total faunal count, followed by crustaceans (35.2%) and mollusks (19.4%) at the sampling sites along the study area in the Eastern Harbour. On the other hand, they disagree with the results o**f El-Komi (2011)** who determined that polychaetes were the most abundant (40%), followed by amphipods (16%) and bivalves (17%) at the sampling sites along the study area in Abu Qir Bay.

Data indicated that Mollusca was the most abundant group and comprised 714 (37.2%) individuals in El-Max Bay. The range of theoretical index values for Simpson

Index, Shannon Index, Pielou Index, Margalef Index, Menhinick Index, and Berger-Parker Index were the six indices used to evaluate the site. Theoretical index value range was within the acceptable limits, which suggested greater high diversity, species richness, a healthy ecosystem, and demonstrated the most common species dominated the community. Similar finding are those recorded in the study of **Hamdy and Dorgham (2018)** who reported that, the Shannon diversity index was low and associated with low evenness.

Canonical correspondence analysis (CCA) showing that transparency as physicochemical parameter was the most reliable on species dynamic, while NH_3 dominates other nutrients. In the same manner, Cd and Cu as heavy metals had the biggest impact on species dynamic throughout the study. Results agree with those of previous studies (**Abbas, 2015; Abo-Taleb *et al.*, 2015; Okbah *et al.*, 2017)**.

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