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Monitoring of the Ecological Status of the Phytoplankton Dynamics, Water Quality, and Water Types in the Egyptian Mediterranean Coastal Estuary over Two-Decade Intervals

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ABSTRACT

El Mex Bay is an estuarine area; it is one of the "hot spots" on the Egyptian Mediterranean Coast. It is located west of Alexandria City. It is influenced by different pollutants from the El Umum Drain water, impacting the water quality. Phytoplankton community structure was monitored as well as different water types over two-decade intervals. The first was recorded monthly from April 2003 to April 2004, while the second was recorded seasonally from winter 2020 till spring 2021 to monitor the changes that have occurred in this region. The phytoplankton abundance in El Mex Estuary showed significantly higher eutrophication during the first period ($1.243x10^6$ units l^{-1}, 82 genera, and 201 species) than the second one ($0.946x10^6$ units l^{-1}, 70 genera, and 123 species); moreover, the community structure differs in terms of phytoplankton class abundance. Baccillariophyceae dominated the phytoplankton community in the two periods, representing 87.18 (39 genera & 96 species) and 77.0% (36 genera & 69 species), respectively. However, Dinophyceae contributed 3.41 (10 genera & 30 species) and 9.2% (12 genera &16 species), respectively. Cyanophyceae are shared by 0.7 (10 genera & 18 species) and 4.47% (8 genera & 10 species), respectively. The phytoplankton abundance at El Umum Drain recorded remarkably higher eutrophication during 2020– 2021 ($1511.3x10^3$ units l^{-1}, 64 genera & 147 species) than that in 2003– 2004 ($0.352x10^3$ units l^{-1}, 70 genera & 123 species); furthermore, the community structure differs. The trophic status was ascertained and discussed using a variety of metrics, including phytoplankton abundance, diversity indices, and others. Based on these measurements, El Mex Estuary was found to be highly eutrophic and significantly contaminated to differing degrees.

INTRODUCTION

The Mediterranean Strategy Plan has identified a number of "hot spots" and susceptible areas on Egypt's northern shore **(EEAA, 2009)**. For many years, these areas have been plagued by development, population growth, and environmental deterioration. Located west of Alexandria City, the El Mex Estuary's industrial zone is one of these "hot spots." It receives massive amounts of untreated industrial water due to the growing heavy industries (petrochemicals, pulp, metal planting dyes, textiles), uncontrolled wastewater disposal, and enormous volumes of untreated industrial water.

Chemical-physical analysis was most often utilized to identify and assess the water quality. However, phytoplankton monitoring is required in dynamic environments since phytoplankton community analysis will give a clearer image of how the pollutant's presence impacts the waters' community structure **(Mathivanan *et al*., 2007; Shashi Shekhar *et al*., 2008)**.

Phytoplankton is a diverse and globally distributed organism that serves as the basis for the majority of marine food webs. They contribute around half of the world's primary productivity **(Hamer *et al*., 2022)**. Phytoplankton uses the inorganic and/or organic materials found in their surroundings. The species' richness, diversity, density, and distribution all reflect the nutritional state of the surrounding ecosystem. Phytoplankton is a great indication of environmental pollution since it is unable to control its movements, which means that pollution cannot escape from it **(Davies & Jaja, 2014)**. The base of the food chain, primary producers, or phytoplankton, can serve as biological indicators of the condition of the environment, the water's quality, and the degree of eutrophication **(Paerl, 2009)**. Different physicochemical and biological parameters influence the amount of primary production, variety, and community organization of phytoplankton. The species composition, abundance, and spatiotemporal distribution of these aquatic creatures can be utilized as indicators of the biological integrity or environmental health of an aquatic system owing to their sensitivity and quick response to environmental changes **(Paerl *et al*., 2003)**. Therefore, monitoring the relationship between primary producers and coastal water quality is essential.

Since phytoplankton diversity is essential to the structure of marine ecosystems, the spatial mapping of phytoplankton helps identify hotspots based on abundance and diversity. The primary metric used to assess the ecological environment and water quality of the research area is this index. A few studies looked at the diversity and spatial distribution of plankton **(Badsi *et al*., 2012)**. Analyzing the relationship between phytoplankton dispersion and regional patterns is crucial to determining the ecosystem's structural and functional integrity. Diversity indices are frequently used to evaluate ecological systems' general health. Additionally, ecological productivity and phytoplankton diversity are correlated **(Newall *et al*., 2011;Newall *et al*., 2014)**. Furthermore, habitat characterization might be carried out using the diversity index **(de Domitrovic *et al*., 2007; Cardoso *et al*., 2012)**.

El Mex Estuary has attracted researchers to study the phytoplankton distribution and its ecology. Studies covering one-year have been conducted by **Dorgham *et al.* (1987)**, **El-Sherif (1989)**, **Samaan *et al*. (1992)**, **Mikhail (1997)** and **Gharib (1998)**. Additionally, the plankton of El Umum Drain was also discussed by **Gharib (1998)** and **Hussein and Gharib (2012)**. The current study aimed to investigate phytoplankton, focusing on species composition, standing crop, dominance pattern, diversity in relation to the surrounding environmental conditions, and identification of indicator species. It also calls attention to the water mass in order to illustrate the purity of the estuary's water. To emphasize the changes brought about by the increase in water discharged from El Umum Drain to the Estuary during the past few years, a comparison with earlier configurations was conducted. This study establishes baseline data for future research and offers preliminary findings of notable pollution hotspots in the Mediterranean coastal water.

MATERIALS AND METHODS

1. Study site

One of the most popular fishing spots west of Alexandria is the El Mex Estuary. It extends across around 7km parallel to the shore. It can stretch for around 15 kilometers, from the Western Harbor to the east reaching the El-Agami headland to the west, with an average depth of 10 meters and a surface area of roughly 20km^2. It reaches a depth of around 30m from the coast (Fig. 1). On average, it is three kilometers wide.

The El Mex region receives trash from multiple sources. El Umum Drain, which is 41km long, discharges a massive amount of brackish water (7.7x10^6 m^3 day^{-1}, according to the Egyptian Drainage Research Institute, EDRI) **(Nagy & Salem, 2003)**. El Mex pumping station, located approximately 1km upstream on El Umum Drain, collects overflow from Lake Maruit in addition to agricultural drainage water **(Masoud *et al.*, 2001)**. Its water is mixed with the water effluent of Lake Maruit, a nearby sewage-polluted lake (Fig. 1). The contaminants from industry, agriculture, and residential areas that are poured into these regions are not sufficiently treated. The chloro-alkali plant drain (CAP) of Misr Chemicals Industries Company is the direct source of industrial waste for El-Mex Estuary's western edge. Other waste sources include tanneries and slaughterhouses, as well as the effluent from the Sodium Bicarbonate Factory.

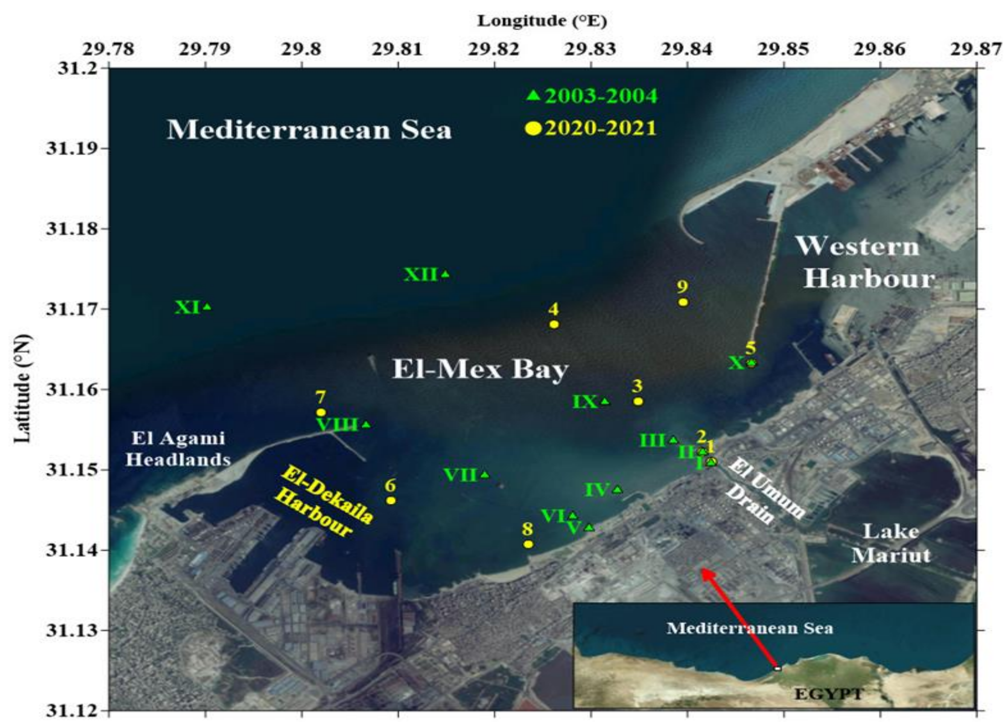


Fig. 1. Map showing sampling stations from El Mex Estuary during the two periods of investigation

2. Sample collection and processing

The recent study was divided into two phases. The first involved collecting the data from El Umum Drain and El Mex Estuary on a regular monthly basis. Water samples were collected from the surface layer from April 2003 to April 2004 at 12 sites (I-XII), as indicated in Fig. (1) in addition to one sample from El Mex pumping station (0). The first three samples (Sts. I, II, and III) represented El Umum Drain, and stations IV–XII represented El Mex Estuary. During the second period, surface water samples were taken seasonally between winter 2020 and spring 2021. Nine sites were selected to cover the various habitats of the estuary; stations 1 and 2 are situated at the El Umum Drain outlet, while the remaining seven stations cover the entire estuary. This is due to the COVID-19 events and how they have affected life in general.

Two-liter surface water samples were collected at each site, one for phytoplankton samples and the others to measure environmental factors. The water's temperature was measured on-site using a thermometer that had been calibrated. Immediately following the collection, the pH was measured using a portable digital pH meter (HACH EC10), with an accuracy of ± 0.02. Water salinity was determined by measuring the electrical conductivity ratio using a Bekman induction salinometer (Model RS-7C). Samples for the measurements of dissolved oxygen were fixed on board according to the modified Winkler method, following the completion of all necessary safety procedures. The output of O_2 is expressed in milliliters (ml). Dissolved inorganic nutrients (NO_2, NO_3, NH_4, PO_4, and SiO_4) were measured spectrophtometrically according to **Grasshoff *et al*. (1999)**. Phytoplankton species were identified and counted after the sedimentation of a one-liter sample and preservation with 4% neutral formalin and a few drops of lugol iodine solution **(Utermöhl, 1958)**. In order to assure measurement accuracy, each sample was examined in triplicate; the different species were identified according to **Péragallo and Péragallo (1897)**, **Cupp (1943)** and **Anagnostidis (1988)**, counted, and estimated as a units per liter.

3. Statistical analysis

The three diversity indices are used to calculate community metrics for phytoplankton. These are the Shannon-Wiener diversity index (H^0) **(Shannon & Weaver, 1963)**, the Pielou evenness index (J) **(Pielou, 1969)**, and the Margalef richness index (d) **(Margalef, 1978)**. Using correlation matrices, the phytoplankton standing crop, its major groups, and environmental parameters were connected. A principal component analysis (PCA) was also utilized to assess each water quality indicator's relative relevance.

4. Trophic status

4.1. Trophic status based on phytoplankton abundance

According to the criteria of **Kitsiou and Karydis (2001)**, to assess the water status based on phytoplankton abundance, oligotrophic waters have up to $6x10^3$ units. l-1, mesotrophic waters range from $6x10^3$ units. l-1 to $1.5x10^5$ units. l- 1, and eutrophic waters exceed > $1.5x10^5$ units. l- 1.

4.2. Trophic status based on freshwater species

The Euglenophycean index was used to determine the trophic status; it shows numerically whether a system is oligotrophic, mesotrophic, or eutrophic. The index was calculated according to the method of **Toma (2019)**, as follows:

The Euglenophycean index = number of Euglenophyta / number of Cyanophyta + Chlorophyta

If the Euglenophycean index is < 1, the system is oligotrophic; if it is 1– 2.5, the system is mesotrophic; if it is 3- 5, the system is eutrophic, and if it is 5– 20, the system is hypertrophic.

5. Diversity index method

The phytoplankton community structure of the research region was evaluated using the following ecological indices: abundance and relative frequency of species, as well as the Shannon-Wiener diversity index (H^0) **(Shannon & Weaver, 1963)**, the Pielou evenness index (J) **(Pielou, 1969)**, species equitability or evenness, and the Margalef richness index (d**) (Margalef, 1978)**.

Table 1. Water quality and ecological standards **(Yi Xu Liang *et al*., 2021)**

Diversity index	Serious pollution	Heavy pollution	Medium pollution	Light pollution	Oligosaprobic (clean)
H′	0- 1	<1	1-2	2-3	>3
D		1- 2	2-3	3-4	> 4
J		0.1-0.3	0.3-.5	0.5-0.8	0. 8-1

Water quality was assessed using phytoplankton density **(Kitsiou & Karydis, 2001)**. While, phytoplankton species diversity (H0) was estimated using the method of **Shannon and Wiener (1963)**. A correlation matrix was conducted separately for El Umum Drain and El Mex Estuary during each period, and the results were subsequently analyzed and discussed.

6. Nitrogen–phosphorus ratio

Rolff and Elfwing (2015) proposed an estimation method for assessing phytoplankton growth limitation by calculating the ratio between dissolved inorganic nitrogen (DIN) to 16 times the concentration of dissolved inorganic phosphate (DIP), both measured in μ M. l^{-1}. The variable was called Ø (Ø = (NO_2 + NO_3 + NH_4) – 16 x PO_4). Ø is a difference with the same concentration unit as DIN and DIP that can be quantitatively interpreted as a nitrogen surplus or deficit. When Ø> 0, nitrogen occurs in excess, and production is phosphorous- limited; when Ø = 0, nutrients are balanced, and when Ø < 0, nitrogen availability limits production.

3. RESULTS

1. First period (2003- 2004)

1.1. Physicochemical and nutrient variables

Environmental factors of stations (Sts. I, II, and III) at the El Umum Drain sample varied greatly during the study period (Table 2) following the changes in volume and water quality of discharged brackish water. The measured water temperature ranged between 15°C in January 2004 and 29°C in August 2003. It attained an annual average of 22°C. Water salinity fluctuated from 2.9' in December 2003 at station I to 6.66' in May at station III, with an annual average of 3.94'. Dissolved oxygen (DO) ranged between 0.64mg $O_{2.}$ l^{-1} and 7.0mg $O_{2.}$ l^{-1} in August at station II, with an annual average of 2.05mg $O_{2.}$ l^{-1}.

El Umum Drain attained high nutrient values as recorded: ammonium (NH_4) ranged from 6.32µM.l^{-1} (June, St. I) to 255.9µM.l^{-1}, showing a very high annual average concentration of 135µM.l^{-1}. Nitrite (NO_2) fluctuated between 2.86 (Dec. St. II) and 24.03µM.l^{-1} (Oct. St. II), recording an annual average content of 11.86µM.l^{-1}. While, nitrate (NO_3) showed a high value from 10.71 (May, St. II) to 106.2µM.l^{-1} (Feb., St. II); the annual average attained was 55.73µM.l^{-1}. Reactive phosphate (PO_4) ranged from 3.92 (June, St. II) to 28.27µM.l^{-1} (Oct., St. I), with an annual average of 14.66µM.l^{-1}. Reactive silicate (SiO_4) fluctuated from 28.2µM.l^{-1} (June, St. III) to a very high concentration of 284.9µM.l^{-1} (Oct., St. I). It reached an annual average of 123.16µM.l^{-1}.

The spatial distribution of environmental parameters in the El Mex Estuary (Sts. IV–XII) is displayed in Fig. (2). The water temperature showed a very typical seasonal variation from 15°C during the winter months, particularly in February, to 30°C during the summer months, especially August (Fig. 2). Recorded water salinity increases gradually according to water mixing with sea water. It ranged from diluted sea water (Sts. IV, V, VI, and VII) to nearly the proper Mediterranean Sea water salinity in the remaining stations (Fig. 2). Lower values of salinity were recorded in station IV (14.13' during June), while the highest value was attained in the water of station XII (36 in March). El Mex Estuary was well oxygenated, particularly during June and August, and low values were recorded during November and April 2004. Stations VIII–XII attained higher DO. However, lower values were recorded for the remaining stations (Fig. 2). NH_4 attained the height values in stations IV, V, and VI and decreased toward the open sea stations. While, lower values were observed in the periods of April, May, and June. There were abnormal readings in station V during both December 2003 and April 2004 (Fig. 2). Nitrite (NO_2) showed the same distribution of NH_4, since the highest concentration was recorded in stations IV, V, and VI and decreased gradually toward the open sea stations. The periods of July, August, and October attained the highest concentration (Fig. 2). Moreover, nitrate (NO_3) showed a similar distribution to NH_4 and NO_2; however, its highest concentration was recorded for stations IV, V, VI, VII, and IX during the periods of January, February, and March. The same trend was observed for both PO_4 and SiO_4 in their distribution, since the highest concentration was recorded during the period from January to March, as well as in stations IV to VIII, and decreased in the rest of the stations lying near the open sea.

1.2. Distribution and composition of phytoplankton structure

The community composition of phytoplankton in El Mex pumping station (St. 0) attained an annual average of 352×10^3 unit l^{-1} and represented 68 species. Bacillariophyceae (174×10^3 unit 1^{-1}) formed the main bulk of the standing crop since it consisted of 49.26% (11 genera, 21 species). The freshwater Chlorophyceae (16 genera, 25 species), Cyanophyceae (11 genera, 12 species), and Euglenophyceae (2 genera, 10 species) were represented by 29.18, 13.6, and 7.91% of the total standing crop, respectively. The most dominant species are *Melosira variance* (22.65%), *Chlorella vulgaris* (11.33%), *Cyclotella glomerata* (11.13%), *Lyngbya limnetica* (8.5%), and *Cyclotella meneghiniana* (3.28%). Dinophyceae were not recorded in station 0.

The phytoplankton community composition in El Umum Drain (Sts. I, II, and III) attained an average of $352x10^3$ unit.1^{-1} and represented 147 taxa. The number of species in stations showed variations ranging between 94 (St. II) and 111 (St. I). The Chlorophyceae represented the dominant group, forming 42.7% of the total phytoplankton abundance, followed by the Bacillariophyceae at 39.0%. However, Cyanophyceae and Euglenophyceae formed 10.1 and 8.0%, respectively. The dominant genera were recorded to be *Cyclotella* (20.87% by number of the total phytoplankton standing crop), *Scendesmus* (12.7%), *Crucigenia* (12.5%), and *Ankistrodesmus* (4.5%).

Regarding the distribution of the standing crop, it increases gradually from station I ($237x10^3$ units. l^{-1}) to station III ($440x10^3$ unit l^{-1}), as shown in Fig. (3), with an annual average of $353x10^3$ units. l^{-1}. This is similar to that recorded in El Mex pumping station.

With regard to the distribution of phytoplankton standing crop at the surface layer of El Mex Estuary (Sts. IV to XII), a total of 82 genera and 201 phytoplankton species were recorded over the study period. It corresponds to an annual average of $1243x10^3$ units. l^{-1}.

The number of species varied from one station to another. It showed variations ranging between 57 (St. V) and 104 species (St. VII). Bacillariophyceae made up the highest number (39 genera, 96 species). It shared 87.18% of the total phytoplankton counts. It attained the highest counts in stations VIII and X (Fig. 3). There was a remarkably low number of Euglenophyceae (4 genera, 17 species), with about 2.35%. Additionally, there were 18 genera and 39 species (7.58%) of freshwater Chlorophyceae, 10 genera, and 18 species (0.7%) of Cyanobacteria, respectively. Dinophyceae included 10 genera and 30 species (3.41%). Total phytoplankton abundance showed high variability, with average values ranging from 218 (St. XII) to $2993x10^3$ unit l^{-1} (St. X), as shown in Fig. (3). Bacillariophyceae attained the highest percentage frequency in both stations VIII and X (95.0 & 93.%, by the total phytoplankton counts, respectively). It is mainly represented by *Skeletonema costatum* (90.6 & 61.3% for the two stations, respectively), followed by *Chaectocers* (29.6%, St. X).

Table 2. Range and mean values of environmental parameters at El Umum Drain during the first period of investigation (2003- 2004)

El Umum Drain	**Range**	**Average**
Temperature °C	15 (Jan.2004)- 29 (Aug. 2003)	22
Salinity	2.9 (Dec. 2003, St. I)- 6.66 (May 2003, St.III)	3.94
DO mg O_2 /l	0.64 (April 2004, St. III)-7.0 (Aug.2003, St.II)	2.05
NH_4 µM/l	6.32 (Jun, St. I)- 255.9 (March, St.III)	135
NO_2 µM/l	2.86(Dec., St.II)- 24.03(Oct.St.II)	11.86
NO_3 µM/l	10.71 (May, St.II)- 106.2 (Feb., St.II)	55.73
PO_4 µM/l	3.92(June, St.II)- 28.27 (Oct., St. I)	14.66
N/P	3.46 (May, St.I)- 42.25 (Dec., St.II)	15.76
SiO_4 µM/l	28.2 (June, St. III)-284.9 (Oct., St. I)	123.16

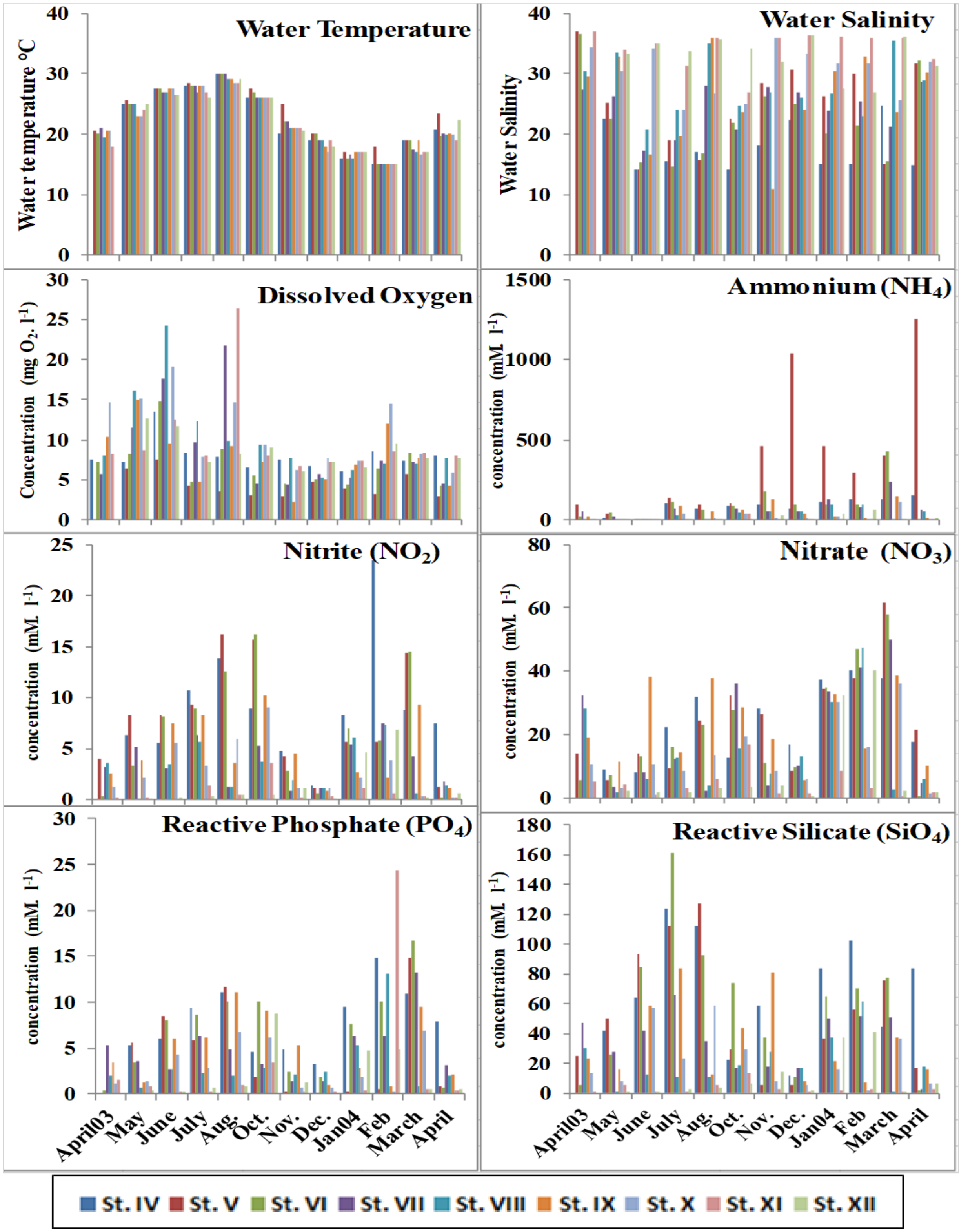


Fig. 2. Monthly variations of the environmental parameters at the different stations of El Mex Estuary during the first period of investigation (2003- 2004)

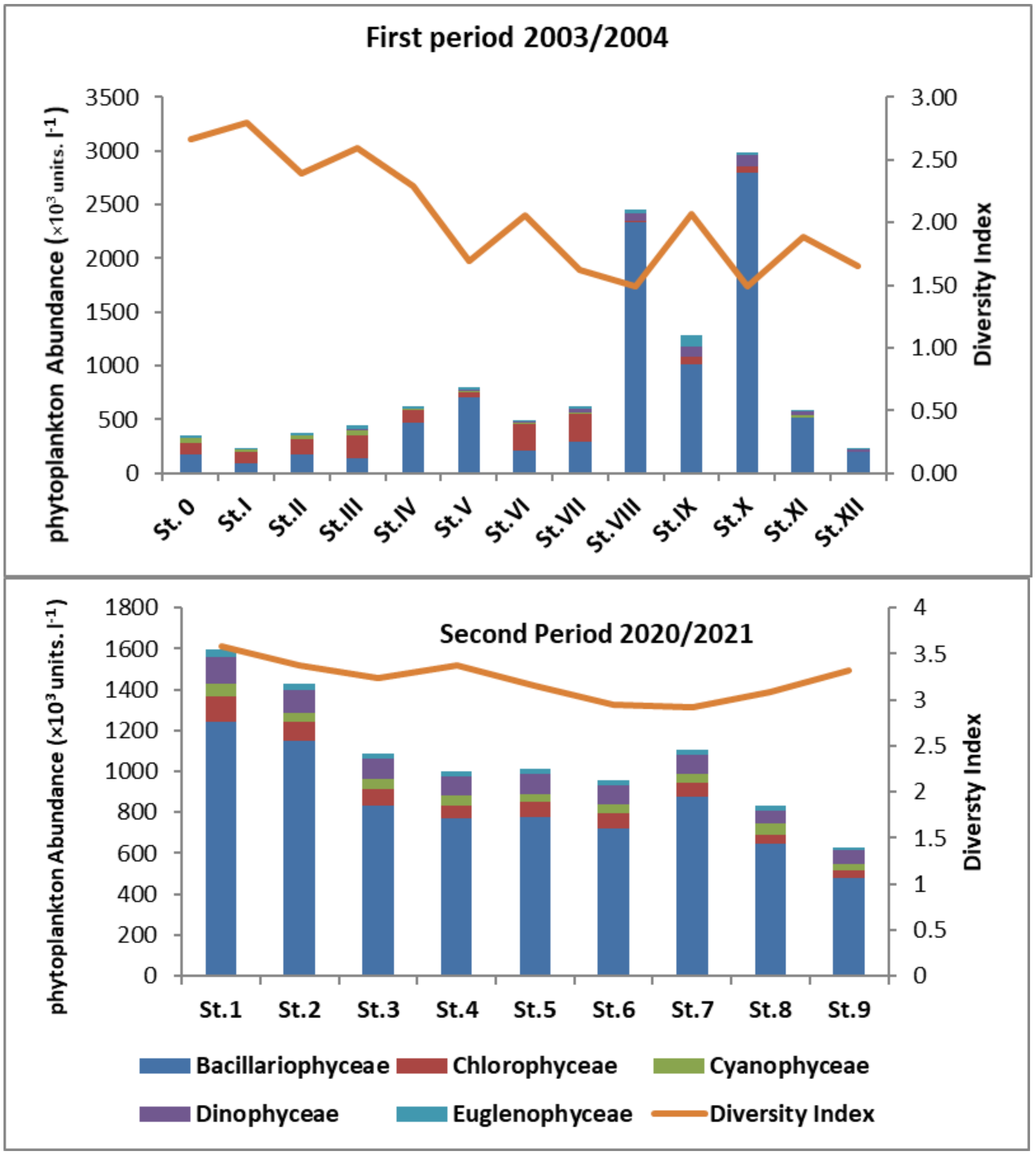


Fig. 3. Distribution of the phytoplankton groups and their diversity index in the different stations during two periods of investigation

1.3. Monthly variations

Regarding the monthly abundance of phytoplankton in both El Mex pumping station (St. 0) and El Umum Drain (Sts. I, II, and III), it fluctuated significantly between stations and in the following months.

For station 0, the phytoplankton abundance attained a high value during the period from April 2003 until August, with an exception in July (Fig. 4a). All of these increases are mainly due to Bacillariophyceae and less to Chlorophyceae and Cyanophyceae. The August bloom was mainly due to *Melosira varians* and less to *Planktolyngbya limneticain.* In April, the top two species were *Chlorella vulgaris* and *Melosira varians*; the two species that followed made up the June peak. The genus *Cyclotella* was dominant in the May peak.

Regarding El Umum Drain (Sts. I, II, and III), at station I, there are two outstanding blooms in April and May. The first one is mainly due to Bacillariophyceae (*Cylindrotheca closterium* and *Cyclotella glomerata)* and less to Chlorophyceae (*Chlorella vulgaris* and *Ankistrodismus spp.).* While, the slight increase in May is due to *Cyclotella* spp. and *Scenedesmus bijugus.*

On the other hand, two high peaks were recorded in station II in March 2004 and a lesser one in April 2003. In March, the Chlorophyceae were represented mainly by *Scenedesmus quadricauda*. The April bloom was mainly for Bacillariophyceae (*Cyclotella glomerata*, *Melosira varians*).

For station III, the blooms were recorded in April– May 2003 and February 2004. The blooms in April– May were mainly attributed to Bacillariophyceae and less to Chlorophyceae. The February blooming was mainly in the Cyanophyceae: *Planktolyngbya limnetica* and *Anabaena circularis* dominate (Fig. 4a).

Regarding El Mex Estuary (Sts. IV-XII), stations IV and V, the outstanding peak was recorded during May and less in June, beside a slight increase during March in station IV only (Fig. 4a). All of these increases are due to Bacillariophyceae; *Skeletonema costatum*, except in March due to *Crucigenia* from Chlorophyceae.

The standing crop in stations VI and VII increased in value during May and June 2003. This was mostly ascribed to Bacillariophyceae; *Skeletonema costatum* was recorded in both stations, and less so for Chlorophycea, *Carteria*, and *Chlorella*, which were present in station VI only. In March 2004, Station VI exhibited the highest peak, primarily due to increased counts of Chlorophyceae, specifically *Scenedesmus* spp. This increase was also observed, albeit to a lesser extent, in April. Additionally, there was a notable increase in the abundance of the diatom *Skeletonema costatum*, particularly in April. However, the standing crop in station VIII reached higher counts during the period from April to July, with a peak recorded in July. All these increases are due to Bacillariophyceae, *Skeletonema costatum.* Station IX attained the highest counts during April 2003, as the numbers of Bacillariophyceae increased, including *Skeletonema costatum.* Moreover, a slight increase was recorded in March 2004 in the counts of Euglena spp., Bacillariophyceae, Chaetoceros spp., and Chlorophycea, *Scenedesmus* spp.

The phytoplankton abundance at station X showed a high value during April and the highest counts in May, with an additional increase in March 2004. All of these increases are due to the Bacillariophyceae, *Skeletonema costatum*, and *Chaetoceros* spp. However, the standing crop at station XI recorded three increases, the first was during May– June and the second was in March. Bacillariophyceae are responsible for all these increases, but with different species: *Skeletonema costatum* for the first one, *Nitzschia* spp. for the second, and *Thalassiosira* spp. for the third one.

Station XII attained a high abundance in May, the highest one in October, and a low count in February 2004. All of these are due to Bacillariophyceae, *Skeletonema costatum*, *Nitzschia* spp., and *Thalassiosira* spp. in the three increases, respectively.

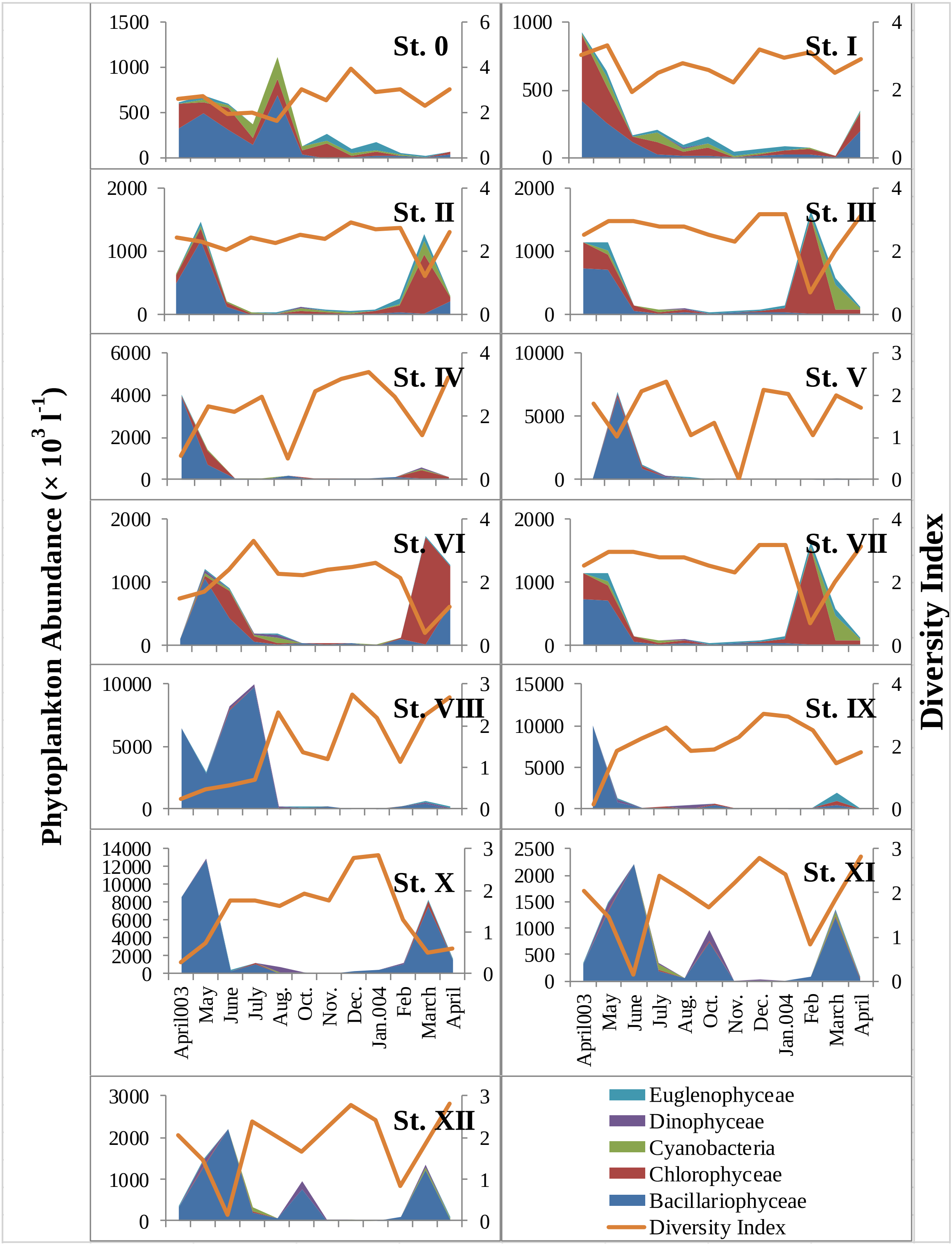


Fig. 4a. Monthly variations of phytoplankton groups and their diversity index in the different stations of El Umum Drain and EL Mex Estuary during the first period of investigation (2003-2004)

1.4. Diversity index

Rich phytoplankton diversity was recorded in the El Mex Estuary (202 taxa). The maximum number of phytoplankton taxa was observed at El Umum Drain (111 spp., St. 1) due to the presence of fresh water forms. The minimum number (66) was found in station XII (mainly marine forms).

Generally, the diversity index showed higher values in El Umum Drain than those recorded in El Mex Estuary (Fig. 3). This may be traced back to the community composition in drain stations (St. I, II, and III) being mainly freshwater. While in the estuary, it constitutes fresh, brackish, and marine forms as a result of the water salinity gradient in the estuary. The highest absolute diversity values in El Umum Drain were attained at 3.62 and 3.2 (Sts. I & III), with a number of species of 110 and 95 , respectively. The lowest one was recorded in stations VII and VIII (1.50 and 0.89), with 104 and 93 species, respectively. The higher diversity values in station I indicate a greater number of species in the community composition, such as *Cyclotella glomerata* (9.80% of the phytoplankton density), *Cyclotella meneghiniana* (8.03%), *Nitzschia closterium* (5.8%), *Ankistrodesmus falcatus* (6.1%), and *Chlorella vulgaris* (9.5%). Meanwhile, in station II, *Cyclotella glomerata* comprised of 5.6% of the phytoplankton density, followed by *Cyclotella meneghiniana* (3.4%), *Ankistrodesmus falcatus* (3.6%), and *Crucigenia quadrata* (27.4%).

Although the phytoplankton standing crop was high in stations VII and VIII, the diversity value was lower (1.50 and 0.89), as well as species richness (104 and 93.). This is due to the dominance of one species, *Skeletonema costatum*, since it shared by 67.0 and 85.9%, respectively.

Species richness ranged between 66 (St. XII) and 111 (St. I). Margalef richness index (d) values varied between 4.171 (St. V) and 8.925 (St. I). Pielou's evenness index (J') ranged from 0.197 in St. VIII to 0.769 in St. 1.

1.5. Trophic state based on phytoplankton abundance

Based on phytoplankton counts, water bodies with less than $6x10^3$ units l^{-1} are categorized as oligotrophic waters, those with counts ranging from 6 to $1.5x10^5$ units l^{-1} are considered mesotrophic waters, and > $1.5x10^5$ units l^{-1} are classified as eutrophic waters. The result in El Mex Pumping Station (St. 0) revealed that, about 46% of the cases are considered mesotrophic and 54% are eutrophic (n = 13), while El Umum Drain (Sts. I, II, & III) represents 59% being mesotrophic and 41% being eutrophic (n = 39). With respect to El Mex Estuary (Sts. IV- XII; n = 115), 56.5% is eutrophic, 40% is mesotrophic, and only 3.5% is oligotrophic, particularly in station V during the period from September 2003 until January 2004.

1.6. Trophic state based on fresh water species

During the first period, the Euglenophycean index explored the dominance of the oligotrophic condition all year round in El Mex Pumps station (St. 0), except during December 2003 and January 2004, which represented mesotrophic states. However, El Umum Drain water (Sts. I, II, & III) represented an oligotrophic state (95%) during most of the year. In El Mex Estuary, the Euglenophycean index explored the dominance of the oligotrophic state condition, which represented 81% of all readings and 19% of the mesotrophic state.

2. Phytoplankton structure and environmental parameters

According to the present data, El Umum Drain attained lower values of both dissolved oxygen (2.9ml $O_2.1^{-1}$) and water salinity (4.07'). However, the highest nutrient concentration was 125.5µM. $l^{-1}$of ammonium (NH_4-N), 14.7µM. l^{-1} of phosphate 44.3µM. l^{-1} of nitrate, 12.3µM. l^{-1} of nitrite, and 123.2.µM. l^{-1} of silicate.

As shown in Table (3) and Fig. (5a), El Umum Drain recorded a positive correlation between water temperature and water salinity and a negative one with each of NH_4, NO_3, and N/P. pH is positively correlated with NH_4 and NO_3. N/P is negatively correlated with salinity. Silicate content is positively correlated with NO_2 and NO_3.

The total standing crop is positively correlated with water salinity, while being negatively correlated with N/P. Bacillariophyceae recorded negative correlations with pH, NH_4, and NO_3, while recording a positive correlation with water salinity. However, Chlorophyceae are solely positively correlated with $PO_{4.}$ Euglenophyceae recorded a positive one with both water salinity and $PO_{4.}$ While, Dinophyceae recorded a positive correlation only with water temperature. The diversity value is significantly positively correlated with Bacillareiophyceae and phytoplankton. While, it negatively affects pH.

However, the El Mex Estuary region is characterized by high nutrient concentrations, with an average of 18.9µM. l^{-1} of ammonium (NH_4-N), 4.4µM. l^{-1} of phosphate, 4.2µM. l^{-1} of nitrate, 1.8µM. l^{-1} of nitrite, and 34.1µM. l^{-1} of silicate. 7.0ml $O_2.1^{-1}$ dissolved oxygen (DO), and 33.7' of water salinity. Such high nutrients are attributed to the huge amounts of wastewater, which creates an eutrophication state in the estuary.

With respect to El Mex Estuary (Table 3 & Fig. 5a), water temperature was positively correlated with dissolved oxygen. The fluctuation in nutrient concentration depends on its sources, including agro-industrial activities and biological activity. Negatively significant differences were noticed for the studied nutrients: Salinity with NO_2, NO_3, PO_4, and SiO_4. While, SiO_4 positively correlated both NO_2 and NO_3,

The significant correlation coefficient of the phytoplankton standing crop and its main groups in the El Mex Estuary (n = 156), along with some physicochemical parameters (Table 4 & Fig. 5a), showed that, Bacillariophyceae are positively correlated with DO and negatively correlated with diversity. Chlorophyceae affect water, salinity, and diversity negatively, while, a positive effect was recorded for NO_3 and PO_4. Cyanophyceae recorded positive correlations with water temperature, NO_2, and SiO_4. Dinophyceae are positively correlated with water temperature. The phytoplankton standing crop recorded a positive correlation with DO and a negative correlation with diversity. However, diversity is only negatively correlated with DO.

Table 3. Significant correlations during 2003- 2004

El Umum Drain	T°C	Salinity	pH	NH_4	NO_2	NO_3	PO_4	N/P	SiO_4	Diversity
Salinity	0.40									
NH_4	-0.63		0.38							
NO_3	-0.57		0.37							
PO_4										
N/P	-0.41	-0.37								
SiO_4					0.47	0.54				
Bacillariophyceae		0.37	-0.53	-0.47		-0.43		-0.39		0.54
Chlorophyceae							0.36			
Cyanophycea		0.31			0.30		0.42			
Dinophyceae	0.37									
Euglenophyceae		0.38					0.37			
Phytoplankton		0.39						-0.42		0.42
Diversity			-0.37						-0.35	

El Mex Estuary	T°C	Salinity	DO	NO_2	NO_3	PO_4	SiO_4	Diversity
DO	0.35							
NO2		-0.72						
NO3		-0.50						
PO4		-0.56						
SiO4		-0.80		0.78	0.50			
Bacillariophyceae			0.37					-0.56
Chlorophyceae		-0.23			0.32	0.35		-0.29
Cyanophycea	0.31			0.25			0.31	
Dinophyceae	0.34							
Phytoplankton			0.38					-0.59
Diversity			-0.33					

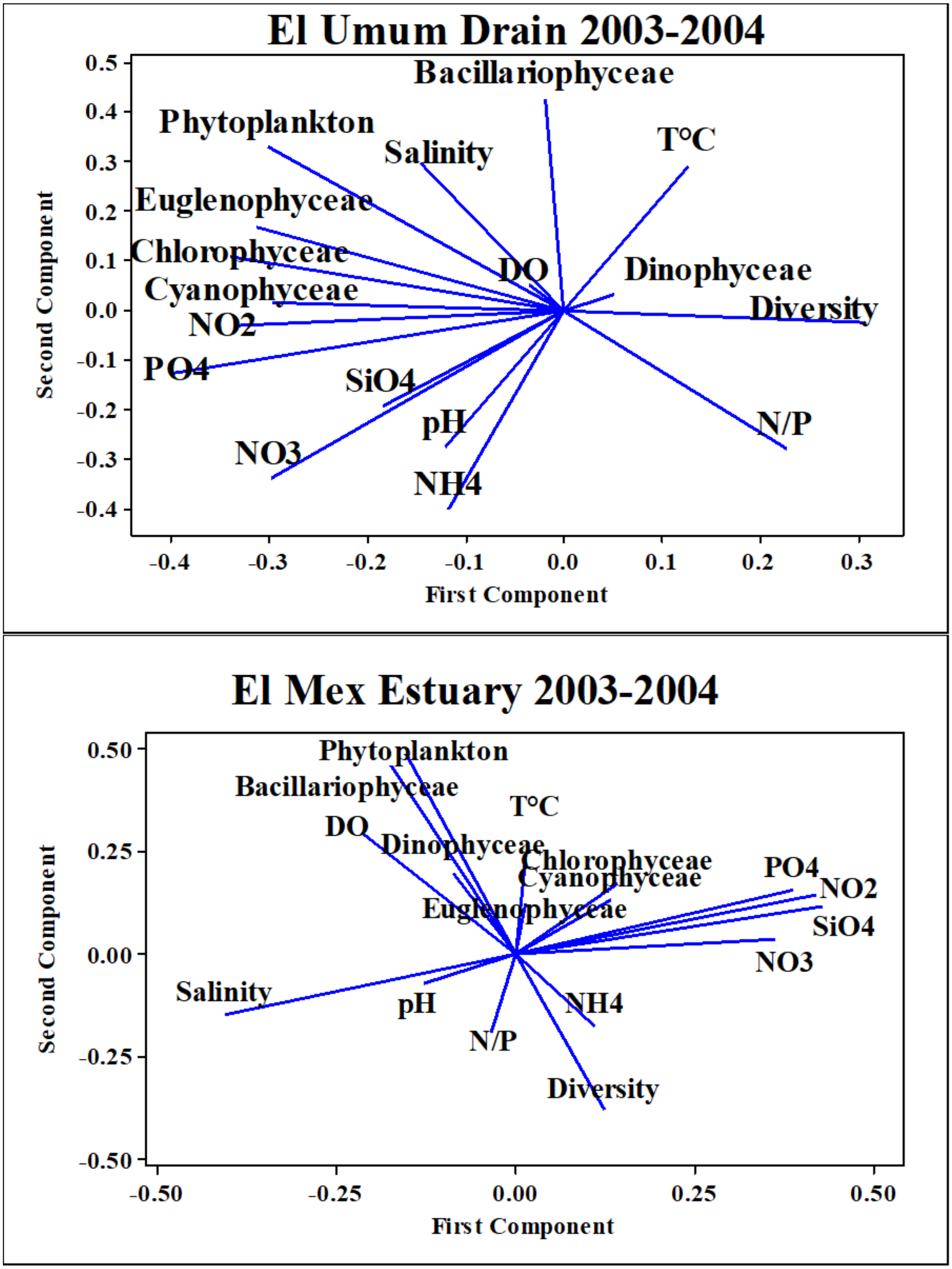


Fig. 5a. PCA analysis illustrating the relationship between phytoplankton groups and environmental conditions during the first period

2.1. Second period (2020- 2021)

2.1.1. Physicochemical and nutrient variables

The environmental parameters were estimated and published by **Zaghloul *et al*. (2023)**, and the data were used for statistical analysis, evaluation, and comparisons (Table 4).

Table 4. Range and mean values of environmental parameters during 2020- 2021 **(Zaghloul *et al.*, 2023)**

El Umum Drain	Range	Average
Temperature °C	16.4 (summer 20)-2832 (autumn 20)	21.6
Salinity	2.67 (winter 20)-4.87 (autumn 20)	4.05
DO mg O_2 /l	4.54 (spring 21)-11.34 (winter 21).	7.55
OOM mgO_2/l	8.16 (winter 21)-13.96 (spring 21)	11.96
NH_4 µM/l	2.39 (autumn 20)-173.6 (spring 21)	100.2
NO_2 µM/l	6.9 (winter 21)- 30.2 (autumn 20)	19.8
NO_3 µM/l	19.6 (spring 21)- 64.4 (autumn 20)	38.9
PO_4 µM/l	042 (summer 20)- 19.03 (spring 21)	10.95
SiO_4 µM/l	28.2 (winter 21) - 250.6 (spring 21)	130.4

El Mex Estuary	Range	Average
Temperature °C	17.2 (winter 20)- 27.9 (autumn 20)	22.14
Salinity	11.3 (winter 20) - 39.06 (summer 20)	34.96
DO mg O_2 /l	3.89 (autumn 20)-20.4 (summer 20)	9.00
OOM mgO_2/l	0.64 (summer 20)- 31.04 (spring 21)	6.25
NH_4 µM/l	1.3 (winter 21)- 101.5 (winter 20)	32.12
NO_2 µM/l	0.17(winter 21)- 23.5 (spring 21)	5.5
NO_3 µM/l	1.61 (winter 21)- 41.7 (summer 20)	20.6
PO_4 µM/l	016 (summer 20)- 10.04 (winter 20)	2.15
SiO_4 µM/l	26.9 (summer 20)- 92.8 (winter 20)	26.9

2.1.2. Distribution and composition of phytoplankton structure

The phytoplankton standing crop in El Umum Drain attained an average of $1511x10^3$ units.l^{-1} and represented 70 genera and 123 species. It comprised five groups, dominated by Bacillariophyceae (36 genera, 69 species), which constituted about 79.14% of the total phytoplankton abundance. Chlorophyceae (11 genera, 18 species) formed 7.09%. Euglenophyceae (3 genera, 16 species) shared 8.2%. Cyanophyceae (8 genera, 10 spp.) formed 3.47%. Dinophyceae (12 genera, 10 species) represented 2.1%. The dominant genera were *Pseudonitzschia* (8.2% by total of the phytoplankton standing crop), *Cyclotella* (5.7%), *Nitzschia* (5.7%), *Thalassiosira* (4.6%), and *Rhizosolenia* (3.3%).

With respect to the phytoplankton standing crop community composition at El Mex Estuary's surface layer (Sts. 3 to 9), 123 species and 70 genera were recorded throughout the study. It attained an annual average of $946x10^3$ units. l^{-1}. The number of species varied by station. It showed variations ranging between 104 (St. 6) and 115 species (St. 3). Bacillariophyceae made up the highest number (36 genera, 69 species). It shared

76.95% of the total phytoplankton counts. Dinophyceae (12 genera, 16 species) formed 9.17%. Chlorophyceae (11 genera, 18 species) formed 6.87%, and Caynophyceae (8 genera, 18 species) represented 4.5%. There was a remarkably low number of Euglenophyceae (3 genera, 10 species), with about 2.54%. The dominant genera were represented mainly by *Skeletonema costatum* (36.2% by number of the total phytoplankton standing crop), *Pseudnitzschia* (7.33%), *Rhizosolenia* (5.3%), *Cyclotella* (4.7%), *Nitzschia* (4.2%), *Alexandrium minutum* (2.6%), *Thalassiosira* (2.4%), and *Chaetocros* (2.0%). Total phytoplankton abundance attained the highest counts in El Umum Drain (Sts. 1 & 2). However, it showed high variability in El Mex Estuary, with average values ranging from 630 (St. 9) to 1103x10^3 units. l^{-1} (St. 7), as shown in Fig. (3). Additionaly, Bacillariophyceae ranked the main components for all stations in both the drain and the estuary.

2.1.3. Seasonal variations

As displayed in Fig. (4b), the total counts of phytoplankton standing crop in El Umum Drain (Sts. 1, & 2) recorded higher values during all seasons, with a slight decrease during winter 2021. Particularly in station 2. Bacillariophyceae formed the most dominant group.

With respect to El Mex Estuary (Sts. 3– 9), station 3 recorded the same seasonal variation as station 2. Generally, the phytoplankton standing crop decreased toward the open sea stations (Fig. 4b). Stations 5, 7, 8, and 9 were similar in their distribution since the standing crop recorded a slight decrease in summer. Along with another decrease in station 9 during winter 2021, Bacilariophyceae were the most dominant for all stations.

2.1.4. Diversity index

The value of the diversity index during 2020– 2021 attained a minimum of 2.95 at station 7, with a number of species of 106. The highest one was recorded in stations 1 and 9 (3.58 and 3.32), with 115 and 107 species, respectively. The phytoplankton counts were the highest in station 1, whereas the lowest one was recorded in station 9.

The higher diversity values recorded in station 9 were attributed to the many species represented in the community composition: *Skeletonema costatum* (33.0% of the total phytoplankton abundance), *Rhizosolenia* (7.0%), *Pseudonitzschia* (6.0%), *Nitzschia* (4.5%), *Melosira* (3.9%), *Cyclotella* (3.7%), *Asterionella* (3.1%), and *Chaectoceros* (2.0%). However, the lowest diversity values in stations 7 means that one or two dominant species are *Skeletonema costatum* (41.7%) of the total standing crop and *Pseudonitzschia* (6.9%).

Margalef richness index (d) values varied between 7.48 (St. 6) and 8.20. (St. 3). Pielou’s evenness index (J’) ranged from 0.625 in St. 7 to 0.755 in St. 1.

2.1.5. Trophic state based on phytoplankton abundance

Based on phytoplankton counts, it was less than 6x10^3 units.’ l^{-1} for oligotrophic waters, from 6x10^3 units l^{-1} to 1.5 x10^5 units.l^{-1} for mesotrophic waters, and > 1.5x10^5 units l^{-1} for eutrophic waters. Regarding the second period, 2020- 2021, the trophic status was reported as 100% eutrophic in both El Umum Drain (n = 10) and El Mex Estuary (n = 35).

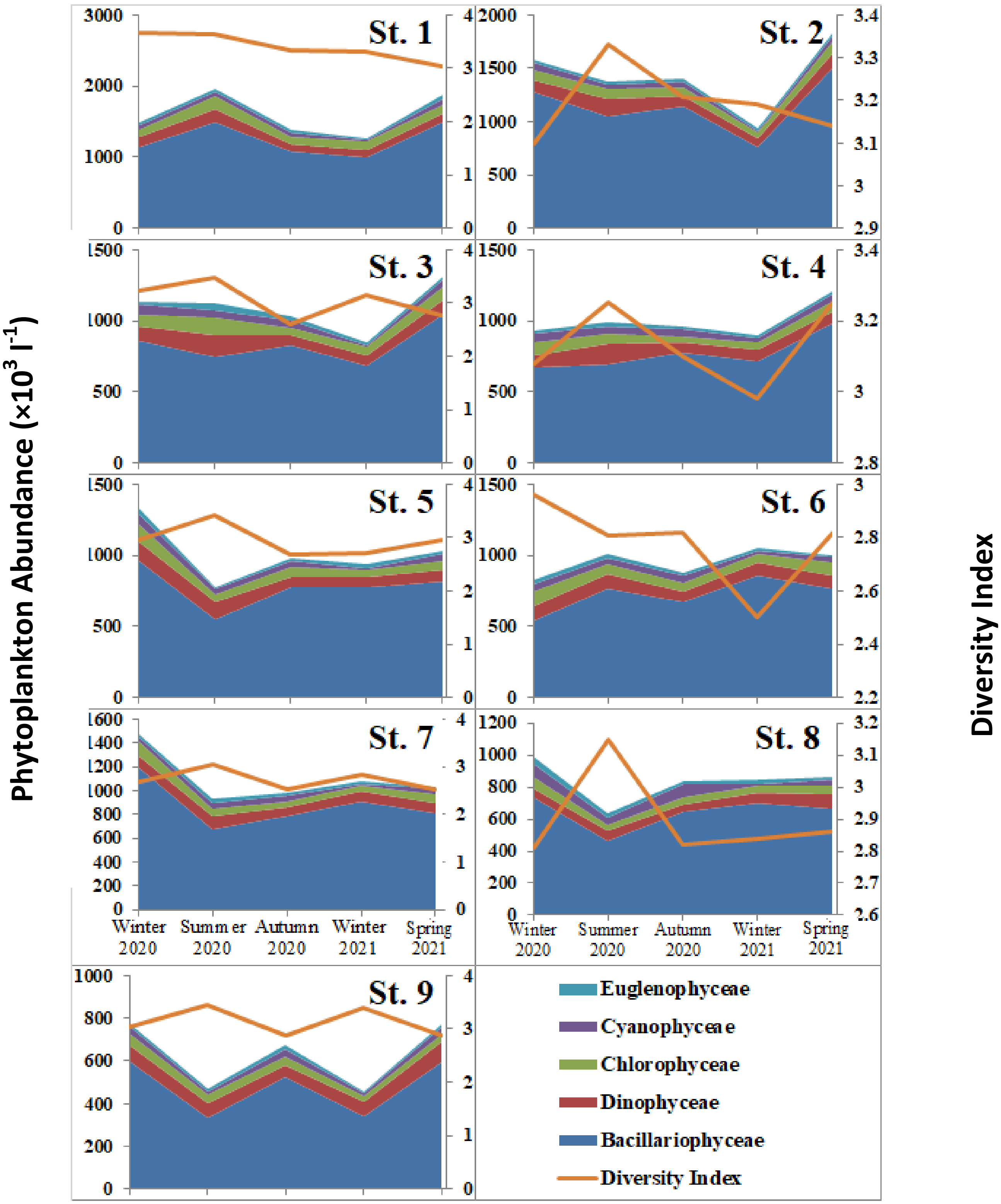


Fig. 4b. Seasonal variations of phytoplankton groups and their diversity index in the different stations of El Umum Drain and EL Mex Estuary during the second period of investigation (2020- 2021)

2.1.6. Trophic state based on freshwater species

The Euglenophycean index showed the dominance of an oligotrophic state (100%) in both El Umum Drain and El Mex Estuary, as a result of more water entering El Mex Estuary from El Umum Drain.

3. Phytoplankton structure and environmental parameters

Based on the data of **Zaghloul *et al*. (2023)**, the El Umum Drain region during 2020–2021 was characterized by high nutrient concentrations, averaging 100.2µM. l^{-1} of ammonium (NH_4-N), 11.0µM. l^{-1} of phosphate, 39.9µM. l^{-1} of nitrates, 19.8µM. l^{-1} of nitrite, 130.4µM. l^{-1} of silicate, and 7.55ml O_2. l^{-1} dissolved oxygen and 4.05 of water salinity.

The standing crop recorded a positive correlation with silicate content (Table 5 & Fig. 5b). In addition, Bacillariophyceae showed a negative correlation with DO and a positive correlation with SiO_4. Chlorophyceae recorded a positive correlation with each of N/P and diversity. There is a negative correlation between Cyanophyceae and DO, while a positive one was recorded with water temperature, dissolved organic matter (OOM), NO_2, PO_4, and SiO_4. Dinophyceae recorded a positive correlation only with PO_4 concentration, and Euglenophyceae showed a negative correlation with PO_4 and a positive one with both N/P and diversity. Whereas, the diversity index demonstrated a significant negative association with water temperature and a positive one with N/P.

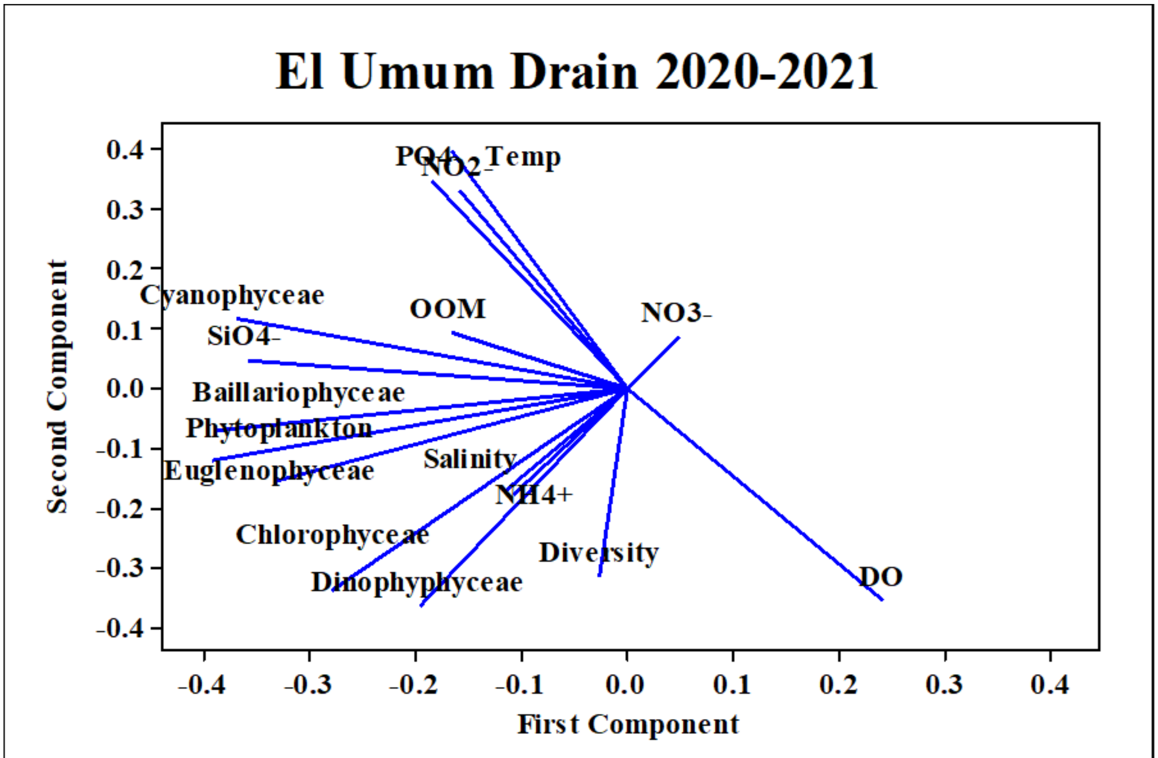
El Mex Estuary was characterized by higher average values of nutrient concentration: 32.12µM. l^{-1} of ammonium (NH_4-N); 2.15µM. l^{-1} of phosphate; 20.57µM. l^{-1} of nitrate; 5.52µM. l^{-1} of nitrite; and 26.9µM. l^{-1} of silicate, 9.0ml of O_2. l^{-1} dissolved oxygen, and 35' of water salinity **(Zaghloul *et al.*, 2023)**.

Regarding El Mex Estuary (n = 35), as shown in Table (5) and Fig. (5b), the phytoplankton standing crop recorded only a positive correlation with DO. Dinophyceae showed a positive correlation with NH_4, NO_2, NO_3, and PO_4. However, the diversity index recorded a negative correlation with Chlorophyceae and a positive one with Bacillariophyceae and DO.

Table 5. Significant correlations during 2020- 2021

EL Umum Drain	T°C	DO	OOM	NO_2	PO_4	SiO_4	N/P	Diversity
Bacillariophyceae		-0.38				0.78		
Chlorophyceae							0.68	0.58
Cyanophycea	0.44	-0.64	0.61	0.44	0.51	0.63		
Dinophyceae						0.52		
Euglenophyceae					-0.50		0.83	0.49
Phytoplankton						0.75		
Diversity	-0.45						0.45	

El Mex Estuary	DO	NH_4	NO_2	NO_3	PO_4	SiO_4	Diversity
Bacillariophyceae							0.40
Chlorophyceae							-0.47
Dinophyceae		0.40	0.32	0.56	0.32	0.44	
Phytoplankton	0.56						
Diversity	0.43						



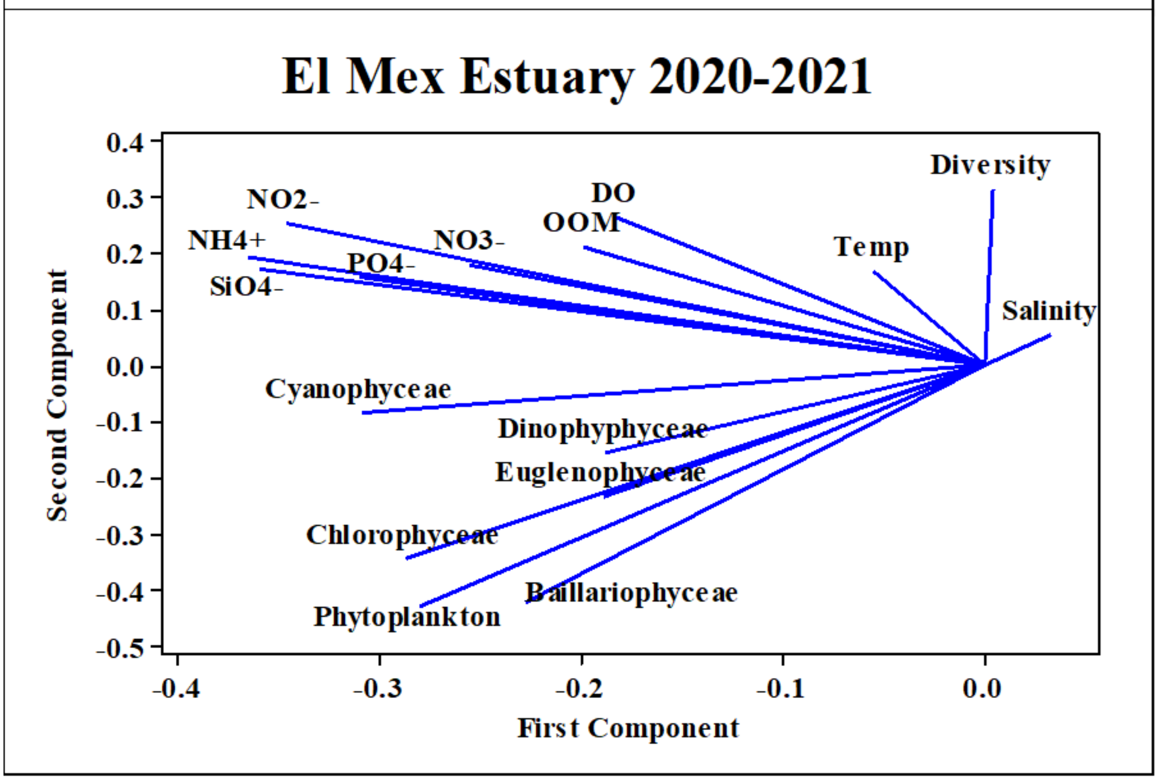


Fig. 5b. PCA analysis illustrating the relationship between phytoplankton groups and environmental conditions during the second period

DISCUSSION

El Umum Drain transports the Estuary enormous amounts of industrial, sewage, and agricultural waste from the neighboring Lake Mariut. These discharges resulted in identifying El-Mex Bay as one of the most polluted coastal areas on Egypt's Mediterranean Coast. According to the **Egyptian Drainage Research Institute (EDRI) (1982- 2021)**, wastewater production varies annually and is gradually increasing. In addition to the El Umum Drain discharge (Table 6), the estuary also gets industrial pollutants from the neighboring businesses, such as cement, petroleum, tanneries, chemicals, and chloro-alkali. These conditions result in a substantial eutrophication and significant environmental impacts. Regional variations were observed in El Mex Estuary's surface salinity with respect to the discharged waste fluids' distribution pattern. The distribution of nutrients, salts, and dissolved oxygen content is highly consistent with salinity, as their content is mainly dependent on the volume and quality of discharged water from different drains and water currents in El Mex Bay. The water quality parameter distribution exactly reflects the brackish water–sea water mixing pattern. The amount of discharged water from El Umum Drain to El Mex Estuary increases from one year to the next (Table 6).

Table 6. The amount of El Umum Drain water ($x10^6$ m^3) discharged to El Mex Estuary as reported by the Egyptian Drainage Research Institute (EDRI) **(Zaghloul *et al*., 2023)**

Season	Previous study			Present study	
	1982- 1983	**1988**	**1995- 1996**	**2003- 2004**	**2020- 2021**
Summer	230	520.978	207	588.73	816.36
Autumn	257	450.704	207	705.44	647.76
Winter	222	744.381	205	658.98	816.16
Spring	246	490.528	185	510.45	504.1
Total /year	2865	2206.591	2412	2452.65	2784.38

Phytoplankton patterning exhibits variation among habitats, a significant year-to-year alternation, and yearly cycles of abundance fluctuation and habituation. In comparison with the first period of El Umum Drain during 2003– 2004 ($0.333x10^6$ unit l^{-1}), the phytoplankton abundance admitted a remarkably high level of eutrophication during the second period ($1.511x10^6$ unit l^{-1}). The community structure also differs (Fig. 6), with Chlorophyceae and Cyanophyceae recording higher percentage frequencies during the first period (42.4 & 10.4%, respectively). In contrast, it only formed 7.1 and 3.5% in the second one. In the first period, Cyanophyceae was abundant at high temperatures in summer (July- October, 2003) and minimum at low temperatures during winters (January- February, 2004); this agrees with the finding of **Jindal *et al.* (2014)**.

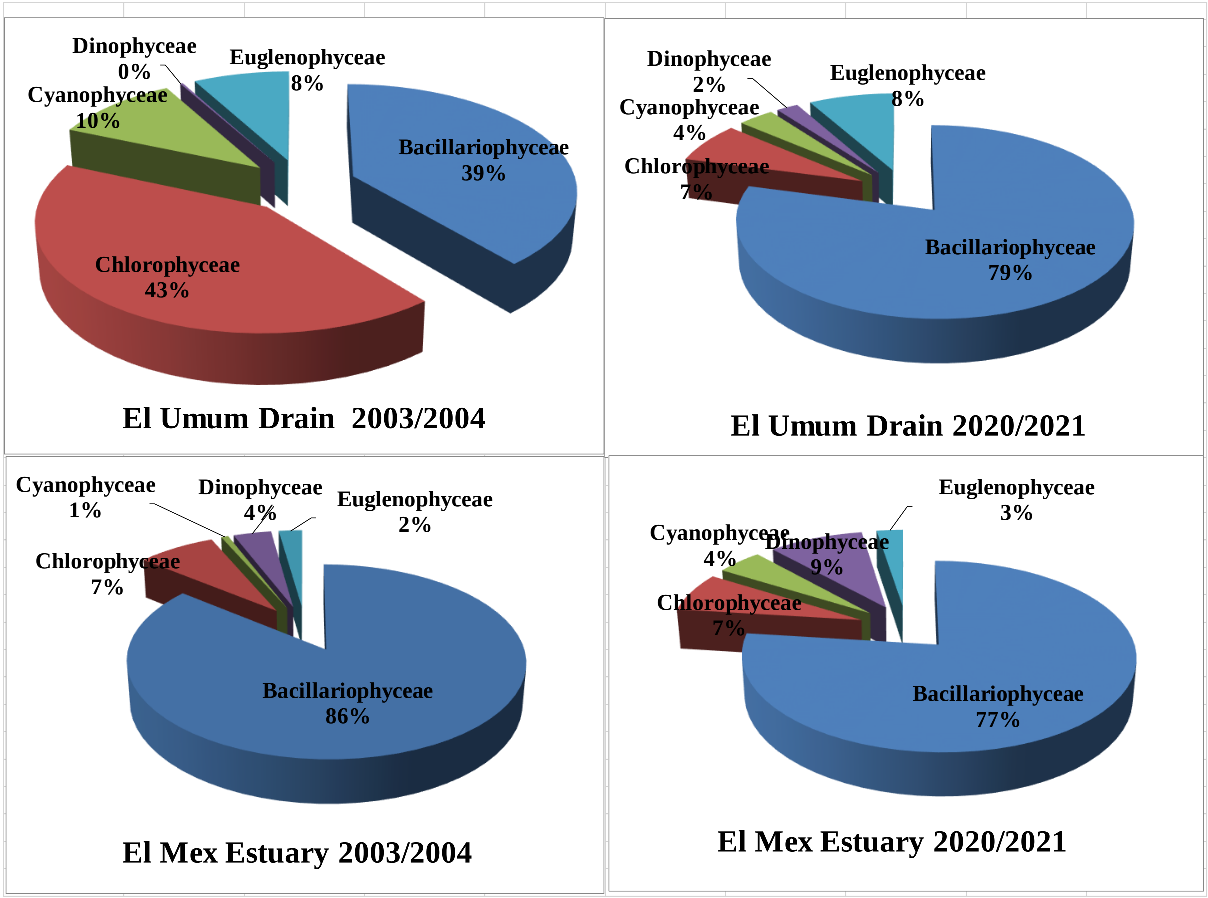


Fig. 6. Average percentage composition of different phytoplankton groups in both El Umum Drain and El Mex Estuary during the two periods of investigation

During 2003– 2004, El Umum Drain recorded a total of 147 species, representing 64 genera, and there were five phytoplankton groups, including Bacillariophyceae (39%), Chlorophyceae (42.7%), Cyanophyceae (10.4%), Dinophyceae (0.22%), and Euglenophyceae (7.94%). When there was an incidence of Cyanobacterial bloom during the period of July till October 2003 (the lowest diatom abundance), Cyanobacterial abundance was highest (33– 42%) in July, 15– 30.5% in August, and 15– 51% in October, i.e., it contributed collectively 35.5, 22.1, and 33.2% during July, August, and October, respectively. Diatoms had the lowest share, ranging from 10.8– 20.4% in July to 5.1– 32.3% in August and 7.8– 29.6% in October, or 14.8, 25, and 11% in July, August, and October, respectively. The prevalent Cyanophyceae bloom species were *Lyngbya* spp., *Oscillatoria* spp., *Microcystis aeruginosa*, and *Anabaena circularis*. This supports the result of **Akagha *et al.* (2020)**.

For the phytoplankton of the first period, El Umum Drain's recorded the genera *Cyclotella* (20.9%), *Scendesmus* (12.7%), *Crucigenia* (12.5%), and *Ankistrodesmus* (4.5%). *Cyclotella* was employed as a representative genus to indicate oligotrophic environments **(Tas *et al.*, 2002; Stoermer & Julius, 2003)**. It was also represented as dominant in the Egyptian waters in other studies **(Zaghloul, 1994, 1996; Ismael & Dorgham, 2003)**. However, the community composition in the second period was different and consisted of *Pseudnitzschia* (7.33%), *Rhizosolenia* (5.3%), *Cyclotella* (4.7%), *Nitzschia* (4.2%), *Alexandrium minutum* (2.6%), *Thalassiosira* (2.4%), and *Cheacticers* (2.0%).

Compared with the previous result, the standing crop in El Umum Drain increases with the years (Table 7). Regarding the standing crop of El Mex Estuary, it is the opposite case of El Umum Drain since it recorded $1.207x10^3$ units l^{-1} during the first period (2003– 2004). While it attained $0.946x10^6$ units l^{-1} in the second one, however, the percentage frequency of Dinophyceae increased in the second period compared to the first one (9.2 and 3.6%). According to **Devil and Kideys (2000**), it flourishes well at high temperatures; the current results clearly demonstrate the presence of Dinophyceae in summer and autumn. With respect to the first period, Bacillariophyceae were mainly represented by *Skeletonema costatum* (59% by number of the total phytoplankton standing crop), *Chaectocers* (7.8%), *Cyclotella* (6.3%), *Thalassiosira* (3.6%), and *Rhizosolenia* (1.3%). However, in the second period, the dominant genera were mainly *Skeletonema costatum* (36.2%), *Pseudnitschia* (7.3%), *Rhizosolenia* (5.3%), *Cyclotella* (4.7%), *Nitzschia* (4.2%), *Melosira* (3.0%), *Prorocentrum* (2.7%), and *Alexandrium minutum* (2.6%). The genus Pseudonitzschia was mainly recorded in the coastal waters, which are rich in nutrients, and this is considered an indication of eutrophication since it is recorded as a harmful alga **(Bates *et al*., 2018)**. The diatom species *Skeletonema costatum* and Chaectoceros dominated the phytoplankton population in the Egyptian waters **(Zaghloul, 1994, 1996; Dorgham, 1997, 2011)**. Compared to the previous result in the same region during different years (Table 7), the phytoplankton abundance showed different values according to sampling intervals and the quantity of El Umum Drain outfalls. The highest result occurred during 2005- 2006 **(Mikhail, 2008)**, as a result of the recorded red tide of Bacillariophyceae (60% of the total phytoplankton counts).

The overall mean phytoplankton density of El Umum Drain in the second period (2020– 2021) is mostly reported to have reached a high, outstanding peak during most of the year, with a slight decrease in winter 2021 (Fig. 3b). This is due to a low amount of El Umum Drain water discharge (Table 5), the lowest amount of OOM, nitrite concentration, and silicate, as well as a lower water temperature. This agrees with the findings of **Schuler *et al*. (1953)** and **Zaghloul *et al.* (2023)**. However, it attained its high abundance during spring, which was met with the highest concentration of nitrite and a high water temperature **(Zaghloul *et al*., 2023).**

Generally, the first period of the El Mex Estuary is characterized by the highest outstanding peak recorded from April 2003 till July, as mentioned previously. All of these are due to increased Bacillariophycea counts, mainly *Skeletonema costatum*, which contributed 73.5, 74% 76, and 79% to the total standing crop in April, May, June, and July, respectively. In addition, a slight increase was detected during March 2004; these increases were due to *Nitzschia* and *Chaectorces.*

Skeletonema costatum is considered a euryhaline and eurythermal species that can grow quickly under eutrophication conditions **(Pednekar *et al*., 2014)**. The outburst of *Sk. costatum* is a good indicator of water quality and pollution **(Ferdous *et al*., 2012)**.

This agrees with the present result. However, *Pseudo-nitzschia pungens* is considered a harmful alga **(Pednkar *et al*., 2014)**. In addition to *Cyclotella meneghiniana*, there is a euryhaline nature **(Zaghloul, 1996; Choudhury & Pal, 2010)**.

Table 7. Comparison of phytoplankton standing crop and its main groups (×10^6) in both El Umum Drain and El Mex Estuary with previous data

Study period	Annual average	Total NO. of species	Bacillariophyceae	NO. of species	Dinophyceae	NO. of species	Chlorophyceae	NO. of species	Cyanophyceae	NO. of species	Euglenophyceae	NO. of species	Reference
El Umum Drain													
Jan.1992-Jan.1993 (Monthly)	0.32	99	0.19	56	0.001	7	0.05	22	0.04	7	0.03	7	**Mikhail, 1997**
Feb.-Dec. 1995	0.71	100	0.46	50		3		25		16	0.14	6	**Gharib, 1998**
2003-2004 (Monthly)	0.353	147	0.137	64	0.008	9	0.151	40	0.036	18	0.028	16	Present work
2020-2021 (Seasonally)	1.51	123	1.196	69	0.124	10	0.107	18	0.053	10	0.124	16	Present work
El Mex Estuary													
1983 (Seasonally)	0.043	210		119		50		26		11		4	**Dorgham *et al*., 1987**
1988 (Seasonally)	0.097	159	0.023	83	0.003	5	0.058	41	0.004	26	0.007	4	**El-Sherif, 1989**
Jan.1992-Jan.1993 (Monthly)	0.836	226	0.79	133	0.22	29	0.009	35	0.004	10	0.012	17	**Mikhail, 1997**
Feb.-Dec. 1995 (Bimonthly)	0.94	158		83		17		30		20		8	**Gharib, 1998**
March-October, 1998	10.63		6.56		0.52	18				6	0.19		**Mikhail, 2003**
March,2005-Jan., 2006 (Bimonthly)	17.54	202	10.48	91	0.27	23	5.04	43	0.04	17	0.07	22	**Mikhail, 2008**
2003-2004 (Monthly)	1.243	201	1.071	96	0.042	30	0.093	39	0.008	18	0.029	17	Present work
2020-2021 (Seasonally)	0.946	123	0.728	69	0.087	16	0.065	18	0.042	10	0.24	10	Present work

3.1. Diversity cycle

Species diversity is an important indicator of water quality due to the strong relationship between species variety and the trophic status of a body of water. Additionally, some studies have shown that a high diversity index indicates a stable and healthy ecosystem, while a low value indicates an environment that is less healthy or damaged **(Mu *et al*., 2013)**. The Shannon species diversity index (H^0), Margalef richness index (d), and Pielous's evenness index (J') indicate the richness of species in a biological community. Generally speaking, the number of species is high in a healthy environment, and the number of species is low in a polluted environment.

The present results during the first period showed that diversity values in the drain water recorded 88.5% up to 2 of the total readings (light pollution); however, its value from one to two represented 9.5% (medium pollution). Only 2.0% of the data is less than one (heavy pollution), as mentioned by **Yi Xu *et al*. (2021)**. According to the study's diversity score, the water in the drain does not enhance phytoplankton growth or survival. There may be major repercussions from the deterioration in water quality.

Regarding El Mex Estuary, the diversity values were as follows: 18% less than one (serious pollution), 35% from 1- 2 (medium pollution), and 47% from 2- 3 (light pollution). The Mex Estuary is shown as a stable community. Still, a low species diversity index value indicated that there aren't many dominant species in the area **(Margalef, 1978)**. Future ecological research and the observation of coastal ecosystems may benefit from baseline data on the structure of the phytoplankton population.

The Pielou evenness index (J) gives a good representation of the distribution uniformity of the individuals of phytoplankton species. The value range of J is 0-1. When this value is large, it indicates that the distribution of individuals among the species is uniform; when this value is small, it suggests an uneven distribution of individuals among the species. In the El Mex Estuary, it varies from 0.324 (St. VII) to 0.567 (St. VI).

Regarding the second period, the results showed that diversity values in El Umum Drain water recorded 100% over 3.0 diversity values. According to **Yi Xu *et al.* (2021)**, drain water is polluted. However, El Mex Estuary recorded 63% from 2– 3 and 37% (H' >3); it ranged from a moderate to polluted region.

3.2. Nitrogen-phosphorus ratio

The DIN/ DIP ratio in the first period, according to **Rolff and Elfwing (2015)**, showed that phosphate is a limiting factor at most stations, except stations III and V, where nitrogen is a limiting factor.

With respect to the result of the second period, the DIN/ DIP ratio at El Umum Drain was recorded to be a limiting factor (Ø< 0) during winter 2020, autumn 2020, and spring 2021. El Mex Estuary attained the same phenomena in stations 8 during winter 2020; station 4 (autumn 2020 and spring 2021); and stations 3 and 6– 9 (winter 2021). Other than that, phosphate is the limiting factor during the rest of the year.

3.3. Water quality for each water type

During the first period, the water salinity recorded in the study area is directly related to the volume of water discharged from the El Umum drain, surface water current in the bay, and mixing with sea water. It varies regionally within a wide range from low-salinity brackish water in front of the El Umum outlet to diluted sea water in the north toward the open sea.

To better understand the extent to which the brackish water runoff is mixed with sea water and how it affects the water quality of the estuary, it is convenient to identify specific water types based on salinity.

Based on the recorded salinity distribution of estuary surface water during 2003–2004, the surface water layer can be divided into only three water types, identified as follows:

1: Mixed land drainage: waste water "L" with salinity< 10'.
2: Mixed sea water "M" with salinity 10'<salinity<30'.
3: Diluted sea water "D" with salinity ranged from 30'<salinity<35'.

1: Mixed-land drainage water (water type “L”) is brackish water. The water quality of water type L reflects the impact of these different sources of discharged water (a mixture of domestic, agricultural, and industrial waste water), as it showed a very low pH (7.77) and a low dissolved oxygen content (3.67mgO_2/ l). The brackish water was characterized by a very high nutrient content: ammonium (88.85µM. l^{-1}), nitrite (10.32µM. l^{-1}), nitrate (34.19µM. l^{-1}), phosphate (9.34µM. l^{-1}) and silicate (123.2µM. l^{-1}). The calculated N/ P ratio indicated that the phytoplankton yield varied with nitrogen speciation and concentration, as the phosphorous content was very high in the discharged brackish water from the drain. The phytoplankton abundance reached 352.5x10^3 units. l^{-1}; it represented 94 species; and the diversity values attained 3.0. Bacillariophyceae were the most dominant: *Cyclotella* (20.9% of total counts of standing crops), as well as Chlorophyceae: *Scenedesmus* (12.73%), *Crucigenia* (12.5%), and Euglenophyta: *Euglena* (5.5%).

2: Water type “M” is an intermediate stage between water types “L” and "D." The water quality of water type M is intermediate between water types L and D. The concentration of water quality parameters directly reflects water mixing, which depends on the volume of discharged water from the drain and the seawater current. Water type M showed a pH of 8.05 and a dissolved oxygen content of 4.99mgO_2. l^{-1}. The recorded nutrient salts were ammonium NH_4 = 51.91µM. l^{-1}, nitrite NO_2 = 5.87µM. l^{-1}, nitrate NO_3 = 19.02µM. l-1, phosphate PO_4 = 3.81µM. l^{-1} and silicate = 44.5µM. l^{-1}. The recorded N/P ratio revealed high nitrogen content in comparison with that of phosphorous and is mainly attributed to anthropogenic input through land-based sources. Based on the N/P ratio, it is concluded that phytoplankton yield in water type M is phosphorus-limited. The phytoplankton-standing crop attained high counts of 1235x10^3 units.’ l^{-1}. It represented 89 species, and the diversity values attained 1.87. Bacillariophyceae were mainly dominat: *Skeletonema costatum* with 65.5% of the total standing crop, followed by *Cyclotella* (9.1%), *Thalassiosira* (2.9%), *Nitzschia* (2.4%), Chlorophyceae: *Scenedesmus* (6.7%), and *Ankistrodesmus* (1.5%).

3: In water type "D," which is diluted sea water according to the salinity recorded, reflecting a pH of diluted sea water (8.14) and high dissolved oxygen content (5.88mg $O_{2.}$ l^{-1}). The recorded nutrient salt content was typical for enriched coastal water, with ammonium concentrations of 10.35µM. l^{-1}, nitrite 2.70µM. l^{-1}, nitrate 12.44µM. l^{-1}, phosphate 2.28µM. l^{-1} and silicate 12.1µM. l^{-1}. The calculated N/P ratio, according to **Rolff and Elfwing (2015)**, indicated high nitrogen availability, and phytoplankton yield is phosphorus limited. The phytoplankton standing crop attained 1257.5x10^3 units. l^{-1}; it represented 70 species; and the diversity values attained 1.68. Bacillariophyceae were dominated mainly by *Skeletonema costatum* (55% of the total standing crop), *Chaetoceros* (23%), *Thalassiosira* (6.0%), *Nizschia* (1.6%), Dinophyceae: *Prorocentrum* (1.7%), and Chlorophyceae: *Scenedesmus* (1.5%).

Regarding the second period (2020- 2021), based on the recorded salinity distribution of estuary surface water, it can also be divided into three water types, identified as follows:

1: Mixed-land drainage water (water type "L") is brackish water. It showed a very moderate value of dissolved oxygen content (7.55mg O_2. l^{-1}), and a high organic matter OOM (12mg O_2. l^{-1}). The low salinity of the brackish water was one of its characteristics (4.05'), and it's very high nutrient content: ammonium (100.2µM. l^{-1}), nitrite (19.8µM. l^{-1}), nitrate (38.9µM. l^{-1}), phosphate (10.95µM. l^{-1}), and silicate (130.4µM. l^{-1}). The calculated N/P ratio of 14.5 indicates high nitrogen availability, and phytoplankton yield is phosphorus-limited. The phytoplankton abundance reached 1511x10^3 units. l^{-1}, it represented 123 species; and the diversity values attained 2.85. Bacillariophyceae: *Skeletonema costatum* with 27.4% of total counts of standing crops, followed by *Pseudonitzschia* (8.2%), *Nitzschia* (5.7%), *Cyclotella* (5.7%), and *Thalassiosira* (4.5%).

2: Water type "M" is situated between water types "L" and "D. The concentration of water quality parameters directly reflects water mixing; it showed a dissolved oxygen content of 9.2mg O_2. l^{-1} and an OOM of 7.3mg O_2. l^{-1}. The recorded nutrient salts were ammonium NH_4 = 41.9µM. l^{-1}, nitrite NO_2 = 7.4µM. l^{-1}, nitrate NO_3 = 23.1µM. l^{-1}, phosphate PO_4 = 2.5µM. l^{-1}, and silicate = 47.1µM. l^{-1}. The recorded N/P ratio is 10. The phytoplankton-standing crop attained high counts of 973x10^3 units. l^{-1}. It represented 121 species, and the diversity value reached 2.27. Bacillariophyceae are mainly represented as follows: *Skeletonema costatum* with 36.7% of the total standing crop, followed by *Pseudonitzschia* (7.6%), *Rhizosolenia* (5.02), *Cyclotella* (4.9%), *Nitzschia* (3.9%), *Asterionella* (3.03%), and *Thalassiosira* (2.7%). Chlorophyceae: *Scenedesmus* (2.5%), *Ankistrodesmus* (2.2%). Dinophyceae: *Alexandrium minutum* (2.2%).

3: In water type "D," there is diluted sea water according to the recorded salinity and a reflected high dissolved oxygen content (8.7mg O_2. l^{-1}), and OOM (4.8mg O_2. l^{-1}). The nutrient concentrations were typical for enriched coastal water, with ammonium at 29.8µM. l^{-1}, nitrite at 4.1µM. l^{-1}, nitrate at 19.5µM. l^{-1}, phosphate at 2.9µM. l^{-1}, and silicate at 40.9µM. l^{-1}. The calculated N/P ratio was 18.7, which indicates high nitrogen availability and that phytoplankton yield is phosphorus-limited. The phytoplankton standing attained 911x10^3 units.l^{-1}; it represented 121 species; and the diversity values attained 2.44. Bacillariophyceae are dominated by *Skeletonema costatum* with 35.4% of the total standing crop, followed by *Pseudonitzschia* (7.0%), *Rhizosolenia* (5.6), *Nizschia* (4.6%), *Cyclotella* (4.4%), *Asterionella* (3.5%), *Chaetoceros* (2.4%), *Thalassiosira* (2.2%), Dinophyceae: *Alexandrium minutum* (3.1%), and *Prorocentrum* (2.6%).

CONCLUSION

The investigated area is characterized by receiving huge quantities of different land-based effluents carrying several types of pollutants. These effluents introduce large concentrations of nutrients into the surrounding environment, which leads to the eutrophication of the water. Significant temporal and spatial fluctuations were observed in salinity and nutrient levels with respect to the variances in the effluents' nature. The region of El Mex Estuary recorded the greatest concentration of nitrate and nitrite. The diversity and dominance of the phytoplankton species were clearly a reflection of the changes in their physicochemical properties. These conditions also significantly changed the dynamics of plankton communities, affecting species dominance, standing crops, seasonal cycles, and the role of various groups. Diatom diversity was higher. According to the El Umum Drain expansion, contaminants have occasionally been found in freshwater forms. Countlless types of phytoplankton have been recognized as indicators of ecology or hydrology. Therefore, in order to solve the issue of eutrophication, which affects aquatic environments everywhere including Egypt's beaches, it is imperative to restrict the use of chemical fertilizers in cultivated areas and reduce their discharge into the marine ecosystem.

The results demonstrated that the area is light to moderately polluted and proved the necessity of using the phytoplankton community as an indicator of water quality. Therefore, it is recommended that wastewater should be treated or recycled rather than being poured into this natural body of water.

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