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A case study performed in Küçükçekmece Lagoon channel/Istanbul, Turkey: how the heavy metal contamination and the seasonal variations on phytoplankton composition influence water quality

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ABSTRACT

In this work, the experiments related to seasonal variations of phytoplankton composition and heavy metal contamination along with some water quality parameters were carried out throughout the channel, serving as a waterway between Lake Küçükçekmece and the Sea of Marmara. Considered as a Class B wetland, the lake has been stayed within the metropolitan area of Istanbul overtime. The samples from the surface water were taken monthly by using Nansen bottles at 5 sampling sites through the period of March–November. After experimental procedures, a total of 46 taxa were recorded belonging to Bacillariophyta (20), Charophyta (4), Chlorophyta (6), Cryptophyta (1), Cyanobacteria (4), Euglenozoa (3), and Miozoa (8) divisions. The phytoplankton densities were found to be varied from 76 individual cm^{-3} to 3,283 individual cm^{-3} throughout the channel and the variation for chlorophyll-a contents was between 0.99–55.32 mg m^{-3}. From our results, the heavy metal and nutrient concentrations were found to be as: 0.78–1.55 mg L^{-1} for Al, 4.28–13.88 mg L^{-1} for B, 1,201–1,693 mg L^{-1} for Ca, 45.20–120.40 μg L^{-1} for Cd, 432.40–1,398.40 μg L^{-1} for Cr, 232.00–1,043.00 μg L^{-1} for Cu, 663.40–2,315.60 μg L^{-1} for Fe, 626.20–1,435.20 mg L^{-1} for K, 738.00–1,113.00 mg L^{-1} for Mg, 1,882–6,084 mg L^{-1} for Na, 30.00–317.80 μg L^{-1} for Ni, 17.40–158.00 μg L^{-1} for Pb, and 440.20–1,186.20 μg L^{-1} for Zn. According to the data obtained in this study, the area where research conducted was determined as having eutrophic characteristics.

Keywords: Phytoplankton composition; Heavy metal pollution; Water quality; Küçükçekmece Lagoon; Istanbul

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1. Introduction

Coastal lagoons of which regulate the trophic structure and various biochemical cycles are complex systems that are highly affected by the inputs from land and/or marine origin [1]. Being critical habitats, they also are productive in terms of having exceptional ecological, recreational, and commercial value. As productive ecosystems, lagoons form transition zones between terrestrial and marine environments having nutrient richness; thereby, they create habitats for a wide variety of fauna and flora. Mainly operated for aquacultural, fishing and recreational purposes, lately lagoons are under pressure due to the negative impacts of physical, chemical, and biological changes [2–5].

Küçükçekmece Lagoon was formed due to a sandbank that caused the separation of the lake from the Sea of Marmara. The lake is located within the metropolitan area of Istanbul and is considered a Class of B wetland. According to the Ramsar Convention on Wetlands of International Importance Especially as Waterfowl Habitat, which is an international treaty supporting implementations for the conservation of biological diversity and sustainable use of wetlands, being signed in 1994 by Turkey, the wetlands are defined as Class A (First Class) are the regions that host and feed over 25,000 rare and/or unique internationally important plant and animal species at a time. And, wetlands considered as Class B (Second Class) regularly host and feed plant and animal species between 25,000 and 10,000 at a time [6,7].

The strong population growth in a fast manner during the last decades has led to unplanned urbanization and industrialization that has caused critical environmental problems in the area [8,9]. Discharges of pollutants from many sources including traffic and industrial facilities pose significant threats to water quality and aquatic life in lagoons [2]. In the past, Küçükçekmece Lagoon was known to be serving as host to many fish species, migratory birds, waterfowls, and a wide variety of endemic plant species. Because of the cancellation of the protection status, the vicinity of the lake was opened to the settlement with the decision taken in 1984. Due to the irregular migration and consequent excessive construction in the area, a high-level pollution load has been occurred in and around the lake in time. Besides, the extra discharge coming from the industrial facilities located in the area into the lagoon without any filtration has caused the pollution load to be even greater [10].

Heavy metal pollution in lagoon systems is an important issue that should be examined carefully and necessary cautions have to be implemented immediately. This is especially important for aquatic organisms living in the area that is sensitive to the accumulation of heavy metals. Also, this is one of the reasons for arising out of serious health risks for humans living around there [2,11].

Some heavy metals including Cu, Fe, Se, and Zn are essential for the organisms in certain amounts. On the other hand, some heavy metals including As, Cd, Hg, and Pb are having toxic effects even in minute amounts for the organisms [12,13]. The reasonings of heavy metal accumulation in aquatic environments could be due to natural processes, domestic and industrial wastes [14]. The large volume of heavy metal pollution occurred in the environment comes from discharges of fabric wastes because of their wide range of usage in various industries [15,16].

Being as a trend, the pollution load at Küçükçekmece Lagoon as well as in other locations in Istanbul is increasingly going on due to anthropogenic pressure mostly [17]. By earlier studies, contamination due to discharges of heavy metals, untreated industrial wastes and eutrophication was detected as a result of unplanned urbanization and industrialization around the lake. For example, the direct impact of the pollution because of domestic and industrial waste discharges in the vicinity of the lake on water quality was shown by Demirci et al. [18]. Also, the epipelic algal flora in Küçükçekmece Lagoon was investigated by Polge et al. [19] and the lake was declared as a mesotrophic one. Furthermore, the results of the first study carried out in the channel by Yilmaz [8] showed that the minimum and maximum water-quality parameters were found to be in normal ranges and eutrophication was defined for the study area through indication of the pollution level. The pollution level was estimated using the data obtained from the measurements of freshwater and marine species having high chlorophyll-a concentrations.

Phytoplankton reproduction as biomass increase is important because of being in the first step of the food chain and could be used as a bioindicator in aquatic systems because of reflecting changes immediately [9]. Therefore, periodically monitoring the algal flora as the natural biological source of the world in lagoon systems is a critical issue in terms of determining the quantitive levels. Being highly fragile ecosystems, lagoons play important roles related to providing the protection and maintaining of biological diversity [3,4]. In conjunction with this, as an important issue for monitoring the pollution level in lagoon systems, the determinations of the composition, trophic structure and productivity of phytoplankton community as well as heavy metal concentrations are required. Hence, this present study aims to perform an investigation on the composition of the phytoplankton community, some water quality parameters, and heavy metal concentrations for the determination of the pollution level in the Küçükçekmece Lagoon channel, which is connected to the Sea of Marmara.

2. Material and methods

2.1. Study area

Lake Küçükçekmece is situated in the western (European) partition of Istanbul Province (41°00′ N–28°43′ E). The total surface area of the lake is about 15.22 km^2 with a maximum depth of 20 m. The lagoon is fed by three small rivers, namely Nakkaş, Ispartakule, and Sazlıdere [19,20]. The water capacity of the lake is about 145 million m^3 with variation due to some of the water coming from the Sea of Marmara through a 2 km-long narrow channel having 1.5 m-dept [10]. The region where the lagoon is located has a climate showing a monthly average temperature of 16.04°C and 42.68 kg m^{-2} average precipitation monthly in the period of 2020 [21].

2.2. Sampling

The samples were taken bimonthly from the surface from March to November using the Nansen bottles. The total sampling sites were 5 as shown in Fig. 1, 3 of which were located along the channel as well as one was in the lake and one was in the sea.

2.3. Phytoplankton identification and chlorophyll-a determination

The samples were collected using Nansen bottles and fixed with Lugol's iodine solution for phytoplankton identification. Phytoplankton was counted according to the procedure of Lund et al. [22] by utilization of an inverted microscope. Phytoplankters were identified using a Nikon-made microscope by reference to the literature, including several comprehensive reviews on the subject [23–31]. Cite AlgaeBase according to Guiry and Guiry [32] was used for the identification of all species recorded. 50 cc glass tubes were used for the samples collected and after the collection of the samples, 2–3 drops of Lugol's iodine were added to each sample. Phytoplanktonic organisms were kept for 24 h to settle down on each tube base. At the same time, the 5 cm^3 from each sample was taken into the chamber for counting. After 4 h waiting for the settle down of the organisms, the counting for each sample was performed using a Nikon TMS inverted microscope at a magnification of 400 according to Lund et al. [22]. For the identification of the organisms, the water samples collected from the study area were filtered using Whatman GF/A glass fiber filters and after filtration, the Petri dishes were used for the storage of the filters. By the examination of these filter papers, which were prepared by scraping of surfaces, a light microscope was employed for the identification of algae except the diatoms. The water samples containing diatoms were boiled for about 10–15 min in heat-resistant glass beakers after adding (1–2 drops) the mixture of HNO_3–H_2SO_4. Identification of each sample was carried out after the preparation of the fixed slide that was done by taking a few drops to a slide and evaporating water on the slide by using a heating plate [4]. Chlorophyll-a was determined using a spectrophotometric method and following the procedure of Parsons and Strickland [33], including extractions in 90% acetone carried out at +4°C in the dark for 24 h.

2.4. Measurements on physico-chemical parameters and determination of heavy metal concentrations

Salinity, electrical conductivity and pH were measured in the field using WTW Multi 340i/set made in by multiparameter. The water samples from the study area taken into sterile 50 mL falcon tubes were transferred to another sterile 50 mL falcon tubes by filtering through blue band filter paper in the laboratory. A dilution was performed for each filtered sample using 1% HNO_3 in a new 50 mL falcon tube. The dilution rate was 1/10 for all samples. After these steps, the concentrations of Al, B, Ca, Cd, Cr, Cu, Fe, K, Mg, Na, Ni, Pb, and Zn were determined using the multielement ICP Standard (Merck, Darmstadt/Germany) [9].

2.5. Statistical analyzes

Multivariate analysis of variance (MANOVA) with Tukey test was applied to the values found for the concentrations of heavy metals and mineral elements using IBM SPSS Statistics 25 software. Significant difference level is evaluated

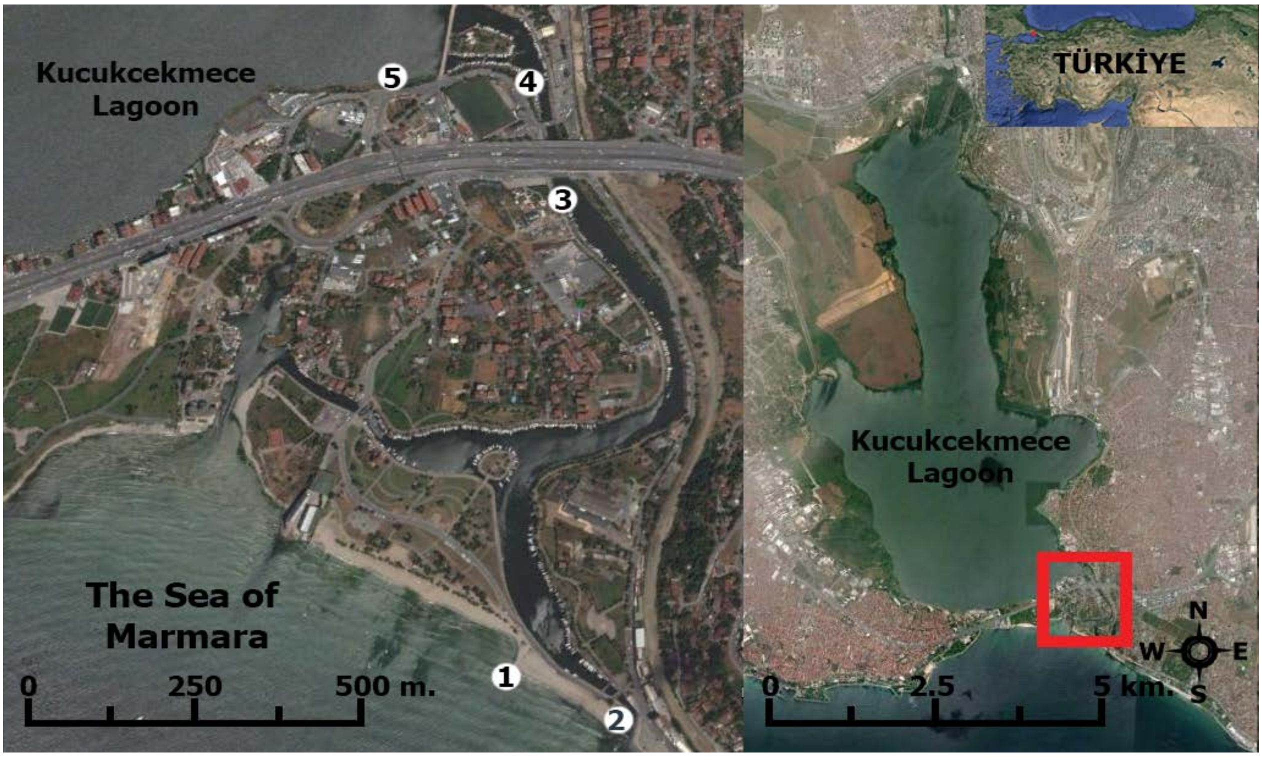

Fig. 1. The map showing the sampling sites at the study area (the image was produced using the Google-Earth Program).

at two levels as 0.01 and 0.05. Stations and seasons were chosen as factors for MANOVA tests [9].

3. Results and discussion

3.1. Results of the physico-chemical parameters of water and the concentrations of heavy metals

The results of physico-chemical parameters of water, and the concentrations of nutrients and heavy metals showed variations at the sampling sites. The pH range for the surface water was between 7.92 and 9.32 and the average value for pH was 8.21. The lowest pH value was recorded in November whereas the highest pH value was recorded in July (Table 2). It was observed that the pH of the research area was mainly in alkaline character. By previous studies performed by Taner et al. [34] and Yilmaz [8], the average pH ranges in surface waters of Küçükçekmece Lake were reported as between 7.23–8.19 and 6.27–8.31, respectively. Acceptable pH values for oligotrophic waters should be between 6–9 and the optimum pH for fish breeding should be between 7–8. Based on the pH values recorded, the pH of the area that the research conducted showed slightly alkaline character and was a slightly higher than normal limits.

The electrical conductivity values observed were showed variation between 2.55 and 40.00 mS cm^{-1}. The results were found to be higher than normal. Dissolved organic matter and salinity are the factors that electrical conductivity is formed accordingly. In our work, salinity was found to be varied between 7.20–25.4‰. As expected, the salinity rate was determined as showing a continuous decrease throughout the channel, from the sea to the lake (Table 2). Salinity has an indirect effect on climate in lagoons in which the change causes falling down in species richness [3]. In our research, related to the salinity rate, the concentrations of Na and Ca were determined as being higher than the standards formed by the United States Environmental Protection Agency (EPA) [35]. Once again, as expected, the salinity and conductivity rates were found to be showing continuous decreases throughout the channel, from the sea to the lake. Additionally, the Na concentration results from the ICP-OES measurements support the salinity and electrical conductivity results (Tables 1 and 2).

The results of the minimum and maximum concentrations of heavy metals and mineral nutrients determined using ICP-OES in the water samples from the sampling sites were shown in Table 1 and were as: 0.76–1.55 mg L^{-1} for Al, 4.28–13.88 mg L^{-1} for B, 1,201–1,693 mg L^{-1} for Ca, 45.20–120.40 μg L^{-1} for Cd, 432.40–1,398.40 μg L^{-1} for Cr, 232.00–1,043.00 μg L^{-1} for Cu, 663.40–2,315.60 μg L^{-1} for Fe, 626.20–1,435.20 mg L^{-1} for K, 738.00–1,113.00 mg L^{-1} for Mg, 1,882–6,084 mg L^{-1} for Na, 30.00–317.80 μg L^{-1} for Ni, 17.40–158.00 μg L^{-1} for Pb and 440.20–1,186.20 μg L^{-1} for Zn.

The lowest concentration levels were determined as: for Al, B, Cd, Cr, Cu, Mg, Ni, Pb in November at site 1; for Fe and K in March at site 1; for Ca in March at site 5; for Na in November at site 5, and for Zn in May at site 3 whereas the highest concentration levels were determined as: for Al, B, Cd, Cr, Cu, Fe, Ni, Pb, Zn concentrations in July at site 5, for Ca, K, Mg and Na in July at site 1. The continuous rises were recorded in the Al, B, Cd, Cr, Cu, Fe, Ni and Pb concentrations whereas the continuous downfalls were recorded in the Ca, K and Na concentrations from the sea to the lake. The Fe concentrations were found to be approximately 3 times higher at site 5 (in the lake) in comparison with site 1 (in the sea) throughout the research period. In Küçükçekmece Lagoon located where seawater, fresh water and brackish water occur together as a water combination, it is observed that the water quality was found to be getting poorer as the pollution levels increases in overtime [36]. In similar studies, it was shown that Küçükçekmece Lake is under threat due to urbanization, sewage, and pollution as a result of the discharges of domestic and industrial wastes [20,37,38]. In addition, the use of pesticides and pollutants originating from agricultural practices and traffic are among the factors that cause lowering water quality [39]. Also, the pollution carried by the streams flowing into the Küçükçekmece Lake increases the pollution level further.

A research was conducted by Altun et al. [40] in Küçükçekmece Lagoon that ran on for four terms: April–May, June–July, September–October and December–January and in the collected samples, the concentrations (in μg L^{-1}) were determined as: 4.0-4.0-8.0-0.5 for Cd, 29-34-32-8 for Cr, 15-76-8-51 for Pb, and 36-173-154-55 for Zn, respectively. In a previous study conducted in Ambarli Port, which is very close to the point where Küçükçekmece Lagoon connects to the Sea of Marmara, it was shown that the concentrations (in μg L^{-1}) of heavy metals were found to be as: <0.1 for Cd, <1 for Cr, 8.4 for Cu, 1.7 for Ni, 1.1 for Pb, and <5 for Zn. The results of these two studies showed that the pollution rate in Küçükçekmece Lagoon is higher compared to the Sea of Marmara [41].

A Water Quality Trading Policy by the Environmental Protection Agency (EPA) [35] has been implemented for preventing pollution in the US waterways by stopping the industrial, municipal, and agricultural discharges. A standard arranged in four different classes for the water quality was formed by the EPA along with the application of the acceptable limits for each element in each class. The related agricultural and environmental agencies in the different countries around the world have made various modifications according to their own needs in that standard (Table 3). In our work, the water quality is of as the Classes III–IV for Al; the Classes II–III–IV for Fe, Ni, Pb, and Zn; the Class IV for B, Ca, Cd, Cr, Cu and Na. The maximum concentrations of Al, Cd, Cr, Cu, Fe, Ni, Pb, and Zn were detected in July and meanwhile, the minimum phytoplankton density was recorded at the same period. In this period: only *Cyclotella atomus*, *Cyclotella ocellata*, *Fragilaria crotonensis*, *Ulnaria acus*, *Ulnaria ulna* and *Navicula cryptocephala* in Bacillariophyta; *Ankistrodesmus falcatus* and *Sphaerocystis planctonica* in Chlorophyta; *Microcystis aeruginosa* in Cyanobacteria; *Cryptomonas ovata* in Cryptophyta; *Ceratium fusus*, *Peridinium bipes*, *Peridinium conicum*, *Prorocentrum concavum*, *Prorocentrum micans* and *Prorocentrum minimum* in Miozoa; and *Euglena gracilis* and *Trachelomonas erosa* in Euglenozoa were identified in low numbers. As the dominant species: *Cyclotella atomus* at sites 1, 2, and 5; *Sphaerocystis planctonica* at site 3; and *Microcystis aeruginosa* at site 4 were identified, respectively.

The contamination level in freshwaters can be defined as using the data including the numbers of species, and

Table 1
Average values and standard errors of recorded concentrations of heavy metals and mineral nutrients at the sampling sites in Küçükçekmece Lagoon channel

	Season	Site 1	Site 2	Site 3	Site 4	Site 5
Al mg L^{-1}	March	0.89 ± 0.002^{b}	0.98 ± 0.004^{**b}	1.10 ± 0.011^{**b}	1.18 ± 0.003^{**b}	1.39 ± 0.003^{**b}
	May	1.09 ± 0.006^{a}	1.01 ± 0.001^{**a}	1.20 ± 0.003^{**a}	1.23 ± 0.006^{**a}	1.49 ± 0.008^{**a}
	July	1.22 ± 0.003^{a}	1.06 ± 0.006^{**a}	1.23 ± 0.004^{**a}	1.27 ± 0.010^{**a}	1.55 ± 0.005^{**a}
	November	0.76 ± 0.006^{b}	0.94 ± 0.008^{**b}	1.06 ± 0.010^{**b}	1.10 ± 0.002^{**b}	1.33 ± 0.007^{**b}
B mg L^{-1}	March	5.42 ± 0.018^{b}	7.57 ± 0.058^{**b}	8.95 ± 0.060^{**b}	10.17 ± 0.074^{*b}	11.95 ± 0.093^{**b}
	May	5.88 ± 0.039^{b}	8.12 ± 0.045^{**b}	9.97 ± 0.072^{**b}	10.65 ± 0.039^{*b}	13.24 ± 0.110^{**b}
	July	6.24 ± 0.034^{a}	8.74 ± 0.048^{**a}	10.78 ± 0.106^{**a}	11.57 ± 0.076^{*a}	13.88 ± 0.054^{**a}
	November	4.28 ± 0.038^{c}	6.84 ± 0.033^{**c}	8.22 ± 0.046^{**c}	9.25 ± 0.081^{*c}	11.04 ± 0.052^{**c}
Ca mg L^{-1}	March	1578 ± 24.614^{b}	1,386 ± 17.053^{*b}	1,336 ± 22.315^{*b}	1,255 ± 17.818^{**b}	1,201 ± 17.769^{**b}
	May	1619 ± 26.548^{a}	1,424 ± 22.218^{*a}	1,367 ± 25.833^{*a}	1,279 ± 21.231^{**a}	1,241 ± 16.376^{**a}
	July	1693 ± 30.139^{a}	1,453 ± 25.715^{*a}	1,399 ± 20.280^{*a}	1,288 ± 18.811^{**a}	1,299 ± 24.547^{**a}
	November	1313 ± 24.684^{b}	1,358 ± 16.437^{*b}	1,310 ± 20.439^{*b}	1,232 ± 24.398^{**b}	1,154 ± 14.661^{**b}
Cd μg L^{-1}	March	54.20 ± 0.650^{c}	63.00 ± 0.567^{**c}	73.40 ± 1.174^{**c}	80.20 ± 1.203^{*c}	97.00 ± 0.485^{**c}
	May	79.00 ± 1.106^{b}	89.20 ± 0.535^{**b}	100.40 ± 0.904^{**b}	100.80 ± 0.706^{*b}	113.20 ± 0.679^{**b}
	July	92.60 ± 1.482^{a}	99.60 ± 0.797^{**a}	107.00 ± 0.535^{**a}	106.20 ± 0.319^{*a}	120.40 ± 0.963^{**a}
	November	45.20 ± 0.497^{c}	60.20 ± 0.602^{**c}	67.60 ± 0.541^{**c}	75.00 ± 0.675^{*c}	88.80 ± 0.178^{**c}
Cr μg L^{-1}	March	466.40 ± 5.597	590.60 ± 7.678*	748.40 ± 8.981**	853.40 ± 15.361*	1,146.40 ± 12.610**
	May	502.00 ± 7.028	732.40 ± 10.254*	1,035.40 ± 17.602**	1,167.00 ± 17.505*	1,311.60 ± 13.116**
	July	518.80 ± 8.301	782.20 ± 13.297*	1,144.80 ± 14.882**	1,231.00 ± 23.389*	1,398.40 ± 20.976**
	November	432.40 ± 7.351	527.40 ± 6.329*	667.20 ± 8.006**	806.40 ± 9.677*	1,111.00 ± 14.443**
Cu μg L^{-1}	March	236.00 ± 2.856^{b}	518.60 ± 5.756^{*b}	588.40 ± 9.179^{*b}	713.60 ± 12.702^{**b}	916.20 ± 16.217^{*b}
	May	272.00 ± 3.917^{a}	556.60 ± 7.291^{*a}	644.80 ± 11.413^{*a}	778.80 ± 10.981^{**a}	998.20 ± 18.167^{*a}
	July	296.00 ± 4.558^{a}	586.60 ± 9.738^{*a}	685.40 ± 8.362^{*a}	800.20 ± 13.443^{**a}	1,043.20 ± 13.979^{*a}
	November	232.00 ± 3.851^{c}	468.20 ± 6.180^{*c}	512.20 ± 6.659^{*c}	666.60 ± 13.065^{**c}	883.40 ± 13.516^{*c}
Fe μg L^{-1}	March	663.40 ± 13.931^{b}	920.80 ± 23.020^{b}	1,013.20 ± 25.330^{*b}	1,317.80 ± 38.216^{b}	1,786.60 ± 48.238^{b}
	May	863.60 ± 21.590^{a}	1,111.20 ± 30.002^{a}	1,268.00 ± 32.968^{*a}	1,582.40 ± 28.483^{a}	2,104.00 ± 46.288^{a}
	July	897.40 ± 23.332^{a}	1,199.20 ± 28.781^{a}	1,315.40 ± 27.623^{*a}	1,682.20 ± 31.962^{a}	2,315.60 ± 55.574^{a}
	November	625.00 ± 13.750^{c}	883.80 ± 25.630^{c}	978.80 ± 28.385^{*c}	1,251.80 ± 28.791^{c}	1,622.80 ± 40.570^{c}
K mg L^{-1}	March	1,257.80 ± 20.125^{b}	900.40 ± 12.155^{*b}	820.80 ± 12.066^{**b}	756.40 ± 11.119^{**b}	626.20 ± 8.955^{**b}
	May	1,346.60 ± 24.239^{ab}	942.20 ± 13.850^{*ab}	839.00 ± 15.354^{**ab}	778.80 ± 13.551^{**ab}	649.00 ± 12.201^{**ab}
	July	1,435.20 ± 20.093^{a}	966.20 ± 13.913^{*a}	850.40 ± 11.480^{**a}	782.20 ± 10.638^{**a}	657.80 ± 11.380^{**a}
	November	1,126.60 ± 18.026^{c}	889.20 ± 12.093^{*c}	779.00 ± 15.113^{**c}	731.80 ± 13.392^{**c}	603.00 ± 11.035^{**c}
Mg mg L^{-1}	March	962.20 ± 21.168^{c}	938.80 ± 18.776^{*c}	901.00 ± 23.426^{c}	868.80 ± 21.720^{c}	858.80 ± 14.600^{*c}
	May	1,021.20 ± 25.530^{b}	958.60 ± 24.924^{*b}	937.40 ± 26.247^{b}	916.60 ± 24.748^{b}	895.40 ± 17.013^{*b}
	July	1,113.00 ± 23.373^{a}	991.00 ± 26.757^{*a}	940.40 ± 20.689^{a}	936.80 ± 21.546^{a}	918.20 ± 13.773^{*a}
	November	738.00 ± 19.188^{c}	916.20 ± 19.240^{*c}	875.00 ± 18.375^{c}	855.20 ± 24.801^{c}	822.80 ± 14.810^{*c}
Na mg L^{-1}	March	5,484 ± 140.390^{c}	4,444 ± 108.434^{c}	3,022 ± 74.341^{*c}	2,084 ± 56.685^{*c}	1,962 ± 41.202^{c}
	May	5,903 ± 167.061^{b}	4,770 ± 134.991^{b}	3,350 ± 96.145^{*b}	2,304 ± 65.664^{*b}	2,142 ± 57.191^{b}
	July	6,084 ± 119.254^{a}	4,804 ± 141.238^{a}	3,502 ± 78.445^{*a}	2,408 ± 50.809^{*a}	2,362 ± 61.884^{a}
	November	5166 ± 140.532^{c}	4,334 ± 91.447^{c}	2,906 ± 74.103^{*c}	1,990 ± 58.506^{*c}	1,882 ± 55.331^{c}
Ni μg L^{-1}	March	35.20 ± 0.493^{b}	60.80 ± 0.912^{*b}	120.60 ± 1.809^{**b}	180.60 ± 2.528^{**b}	281.20 ± 3.093^{**b}
	May	41.40 ± 0.662^{a}	77.00 ± 1.386^{*a}	158.60 ± 2.696^{**a}	249.20 ± 1.495^{**a}	302.20 ± 4.533^{**a}
	July	43.40 ± 0.738^{a}	82.20 ± 1.069^{*a}	170.80 ± 3.074^{**a}	259.80 ± 1.039^{**a}	317.80 ± 5.085^{**a}
	November	30.00 ± 0.390^{b}	57.80 ± 1.098^{*b}	110.40 ± 1.325^{**b}	175.40 ± 1.579^{**b}	269.80 ± 4.856^{**b}
Pb μg L^{-1}	March	20.40 ± 0.082^{b}	39.00 ± 0.468^{*b}	53.40 ± 0.374^{**b}	69.40 ± 0.486^{**b}	138.80 ± 0.139^{**b}
	May	23.40 ± 0.140^{a}	51.20 ± 0.563^{*a}	59.40 ± 0.356^{**a}	82.20 ± 0.329^{**a}	148.60 ± 0.594^{**a}
	July	38.60 ± 0.116^{a}	55.60 ± 0.778^{*a}	66.60 ± 0.599^{**a}	93.60 ± 0.842^{**a}	158.00 ± 0.948^{**a}
	November	17.40 ± 0.104^{b}	35.20 ± 0.352^{*b}	47.00 ± 0.141^{**b}	65.60 ± 0.394^{**b}	133.20 ± 0.400^{**b}
Zn μg L^{-1}	March	514.00 ± 6.168^{c}	522.40 ± 5.746**c	598.60 ± 4.190^{**c}	758.80 ± 9.864^{*c}	927.60 ± 11.131^{*c}
	May	598.00 ± 10.764^{b}	623.00 ± 7.476^{**b}	640.20 ± 3.841^{**b}	871.00 ± 12.194^{*b}	1,085.40 ± 16.281^{*b}
	July	642.00 ± 8.346^{a}	657.20 ± 9.858^{**a}	666.80 ± 6.001^{**a}	906.40 ± 15.409^{*a}	1,186.20 ± 16.607^{*a}
	November	490.00 ± 8.330^{c}	502.20 ± 6.026^{**c}	515.80 ± 5.158^{**c}	726.20 ± 11.619^{*c}	891.60 ± 8.916^{*c}

Note: Statistical analyzes were performed using the Tukey's test and MANOVA.
The mean difference is significant at $^{**}p < 0.01$ and $^{*}p < 0.05$ levels.

Table 2
Results of the pH, electrical conductivity and salinity measurements performed at the sampling sites

	pH				Salinity (‰)				Conductivity (mS cm^{-1})			
	Mar.	May	Jul.	Nov.	Mar.	May	Jul.	Nov.	Mar.	May	Jul.	Nov.
St.1	8.05	8.08	8.47	8.06	23.90	24.00	23.37	25.20	37.90	38.10	37.70	39.70
St.2	8.11	8.11	8.47	8.04	23.70	21.20	24.30	25.40	37.60	33.90	38.40	40.00
St.3	8.11	8.15	8.58	7.92	23.20	10.01	23.80	22.90	36.80	17.20	37.70	36.40
St.4	8.13	8.13	8.38	7.96	20.20	8.00	23.90	21.50	32.50	14.77	37.80	34.50
St.5	8.16	8.16	9.32	7.96	8.10	7.20	8.00	8.50	13.95	12.55	13.74	14.60

groups of existing relative organisms that observed. For this purpose, the species found in Cyanobacteria, diatoms, and green algae were used as available taxonomic groups for the evaluation of the biological conditions of the aquatic ecosystems [43,44]. Phytoplankton groups found in Küçükçekmece Lagoon include the members of diatoms, Cyanobacteria (especially *Microcystis aeruginosa* and *Anabaena flosaquae*), green algae (especially *Scenedesmus* sp.) and Miozoa (*Peridinium bipes*). The high heavy metal contamination rate could be one of the reasons for some nonresistant/tolerant phytoplankton species being found in low numbers. Known as to be sensitive to heavy metal contamination, the abundance of species in terms of in numbers show decreases whereas more tolerant species show increases in numbers [44,45].

The concentrations of the elements in the water samples collected from the sampling sites were given in Table 1. According to our data, the maximum and minimum values along with the sampling sites and the periods were as: 1.55 (in the site 5 in July)–0.76 (in the site 1 in November) for Al (mg L^{-1}); 13.88 (in the site 5 in July)–4.28 (in the site 1 in November) for B (mg L^{-1}); 1,693 (in the site 1 in July)–1,154 (in the site 5 in November) for Ca (mg L^{-1}); 120.40 (in the site 5 in July)–45.20 (in the site 1 in November) for Cd (µg L^{-1}); 1,398.40 (in the site 5 in July)–432.40 (in the 5 in November) for Cr (µg L^{-1}); 1,043.20 (in the site 5 in July)–232.00 (in the site 5 in November) for Cu (µg L^{-1}); 2,315.60 (in the site 5 in July)–625.00 (in the site 5 in November) for Fe (µg L^{-1}); 1,435.20 (in the site 1 in July)–603.00 (in the site 5 in November) for K (mg L^{-1}); 1,113.00 (in the site 1 in July)–822.80 (in the site 5 in November) for Mg (mg L^{-1}); 6,084 (in the site 1 in July)–1,882 (in the site 5 in November) for Na (mg L^{-1}); 317.80 (in the site 5 in July)–30.00 (in the site 1 in November) for Ni (µg L^{-1}), 158.00 (in the site 5 in July)–17.40 (in the site 1 in November) for Pb (µg L^{-1}); and 1,186.20 (in the site 5 in July)–490.00 (in the site 1 in November) for Zn (µg L^{-1}). Remarkably, the maximum concentrations of Al, B, Cd, Cr, Cu, Fe, Ni, Pb, and Zn were detected in site 5 in July whereas the minimum concentrations of Al, B, Cd, Cr, Cu, Fe, Ni, Pb, and Zn were determined in site 1 in November. On the other hand, the maximum and minimum concentrations of Ca, K, Mg and Na were detected at site 5 in November and at site 1 in July, respectively.

The evaluation done using the maximum values of the element concentrations and the trace element based freshwater classification system (Table 3) showed that the concentrations of all elements except Fe and Zn were appeared to be in the classification III section while the evaluation done using the minimum concentration values for B, Ca, Cd, Cr, Cu, K, Mg, and Na and the trace element based freshwater classification system (Table 3) showed that the concentrations for B, Ca, Cd, Cr, Cu, K, Mg, and Na were appeared to be in the classification IV section. At the same time, the concentrations of Fe, Ni, Pb, and Zn were classified in section II while the concentration of Al was found to be in the classification III section.

3.2. Phytoplankton composition and chlorophyll-a contents

A total of 46 taxa were identified, belonging to Bacillariophyta (20), Charophyta (4), Chlorophyta (6), Cryptophyta (1), Cyanobacteria (4), Euglenozoa (3) and Miozoa (8). Bacillariophyta was found to be the richest group in terms of diversity while Cyanobacteria was determined to be as the dominant group in terms of density. The distribution of phytoplankton groups and the taxa recorded were shown in Table 4.

The members of the Bacillariophyta division have been reported as the richest species group having variation in many studies carried out in the freshwaters of Turkey. Also, dinoflagellates and diatoms were noted as the dominant group in many lagoon systems [4,46–48]. Bacillariophyta was represented by 20 species. *Cyclotella atomus* and *Cyclotella ocellata* from Stephanodiscales order was recorded in all samples collected from all sampling sites. These centric diatoms are typical components of oligotrophic lakes. It is shown in many investigations that *Cyclotella* sp. are indicative of mesotrophic lakes with sensitivity to the onset of stratification [49,50]. *Aulacoseira italica* was only detected in the samples collected from sites 4 and 5. It is known that these genus members are found in mesotrophic and eutrophic waters [43]. The diatoms, *Coscinodiscus excentricus* (a marine centric diatom one) and *Ulnaria ulna* (a pennate one) were identified in the samples collected from all sampling sites. *Ulnaria ulna* is known to be a characteristic inhabitant of eutrophic lakes and referred as to being found in inorganically turbid shallow lakes [43,49]. *Ulnaria acus* was found in all samples taken from all sites except site 5. It usually occurs in shallow, enriched turbid waters and is sensitive to nutrient depletion [43,51]. And, the following species recorded were: *Pinnularia viridis* at sites 3 and 4; *Cocconeis placentula* at station 3. *Cymbella affinis* and *Cymbella tumida* at sites 2, 4, and 5; *Navicula cryptocephala* at sites 2, 3, and 4.

Table 3
Recorded taxa in accordance with the sampling sites in Küçükçekmece Lagoon

RECORDED TAXA	Site 1	Site 2	Site 3	Site 4	Site 5
DIVISIO: BACILLARIOPHYTA (43%)					
Amphora ovalis (Kütz.) Kützing	+	–	+	–	–
Asterionella formosa Hassall	+	+	+	+	–
Aulacoseira italica (Ehr.) Simonsen	–	–	–	+	+
Cocconeis placentula Ehrenberg	–	–	+	–	–
Coscinodiscus excentricus Ehrenberg	+	+	+	+	+
Cyclotella atomus Hustedt	+	+	+	+	+
Cyclotella ocellata Pantocsek	+	+	+	+	+
Cymbella affinis Kützing	–	+	–	+	+
Cymbella tumida (Bréb.) Van Heurck	–	+	–	+	+
Fragilaria crotonensis Kitton	+	–	–	–	–
Gomphonema clavatum Ehrenberg	–	–	–	–	+
Gomphonema truncatum Ehrenberg	–	–	–	–	+
Melosira varians C. Agardh	+	–	+	–	–
Navicula cryptocephala Kützing	–	+	+	+	–
Navicula cuspidata (Kütz.) Kützing	–	–	+	–	–
Nitzschia acicularis (Kütz.) W. Smith	–	–	+	–	–
Pinnularia viridis (Nitzsch) Ehrenberg	–	–	+	+	–
Pleurosigma salinarum (Grun.) Grunow	–	–	+	–	–
Ulnaria acus (Kütz.) Aboal	+	+	+	+	–
Ulnaria ulna (Nitzsch) Compère	+	+	+	+	+
DIVISIO: CHAROPHYTA (9%)					
Closterium gracile Brébisson ex Ralfs	+	–	+	–	–
Cosmarium depressum (Näge.) P.Lundell	–	–	+	+	–
Mougeotia sp.	–	–	+	–	–
Staurastrum crenulatum (Näge.) Delponte	–	–	–	–	+
DIVISIO: CHLOROPHYTA (13%)					
Ankistrodesmus falcatus (Corda) Ralfs	+	+	+	–	+
Kirchneriella sp.	–	+	+	+	+
Oocystis borgei J.W. Snow	–	–	–	–	+
Scenedesmus communis E.Hegewald	–	–	–	+	–
Scenedesmus sp.	–	–	–	–	+
Sphaerocystis planctonica (Korshikov) Bourrelly	–	+	+	+	–
DIVISIO: CRYPTOPHYTA (2%)					
Cryptomonas ovata Ehrenberg	+	+	+	+	+
DIVISIO: CYANOBACTERIA (CYANOPHYTA) (9%)					
Anabaena flosaquae Brébisson ex Bornet & Flauhault	+	–	+	+	+
Merismopedia glauca (Ehr.) Kützing	–	–	+	–	–
Microcystis aeruginosa (Kütz.) Kützing	+	+	+	+	+
Oscillatoria tenuis C.Agardh ex Gomont	+	–	+	+	–
DIVISIO: EUGLENOZOA (EUGLENOPHYTA) (7%)					
Euglena gracilis G.A. Klebs	–	+	–	+	+
Phacus sp.	–	–	–	–	+
Trachelomonas hispida (Perty) F.Stein	+	+	+	–	+
DIVISIO: MIOZOA (DINOPHYTA) (17%)					
Ceratium furca (Ehr.) Claparède & Lachmann	–	–	+	–	–
Ceratium fusus (Ehr.) Dujardin	+	–	+	–	–
Ceratium tripos (O.F. Müller) Nitzsch	–	+	–	–	–
Peridinium bipes F.Stein	+	+	+	+	+
Peridinium conicum (Gran) Ostenfeld & Schmidt	+	+	+	–	+
Prorocentrum concavum Y.Fukuyo	+	+	+	+	–
Prorocentrum micans Ehrenberg	+	+	+	+	–
Prorocentrum minimum (Pavillard) J.Schiller	+	+	+	+	–

Table 4
Trace element based freshwater classification

	Al mg L^{-1}	B mg L^{-1}	Ca mg L^{-1}	Cd μg L^{-1}	Cr μg L^{-1}	Cu μg L^{-1}	Fe μg L^{-1}	K mg L^{-1}	Mg mg L^{-1}	Na mg L^{-1}	Ni μg L^{-1}	Pb μg L^{-1}	Zn μg L^{-1}
I	≤0.3	≤1	75	≤2	≤20	≤20	≤300	20	50	125	≤20	≤10	≤200
II	≤0.3	≤1	200	5	50	50	1,000	50	150	125	50	20	500
III	1	≤1	800	7	200	200	5,000	–	–	250	200	50	2,000
IV	>1	>1	–	>7	>200	>200	>5,000	–	–	>250	>200	>50	>2,000

Sources: United States Environmental Protection Agency (EPA) [35];
Surface Water Quality Regulations of Turkey [42].

Asterionella formosa that lives in mixed, small and medium eutrophic lakes [43] was recorded in the samples collected from all sites except site 5. It was observed that the numbers of diatom taxa were higher in water samples taken in the period of spring-summer. In general, light duration and temperature rises are the cause for the biomass increase of phytoplankton. This is especially observed in diatom abundance at a high level in spring.

Charophyta are represented by *Cosmarium depressum*, *Closterium gracile*, and *Staurastrum crenulatum* in Desmidiales and *Mougeotia* sp. in Zygnematales. *Cosmarium depressum* which is indicative of mesotrophic waters was recorded in low numbers in the samples collected from sites 3 and 4 [43]. *Closterium gracile* at sites 1 and 3 and *Staurastrum crenulatum* at site 5 were being detected in May in low numbers. *Closterium aciculare* was recorded as the dominant species in autumn samples at the station where the greenhouses are located at Kamil Abduş Lagoon [4]. The members of Desmidiales order are very sensitive to chemicals showing fluctuations in the water. Generally, desmids flourish very well in acidic waters and are used as indicators of aquatic systems. In our work, desmids were rarely spotted during the study period. *Mougeotia* sp. was recorded only at site 3.

The members of Chlorophyta are usually found abundantly in mesotrophic and eutrophic lakes [50]. Chlorophyta division is represented by six species. *Ankistrodesmus falcatus* at all sites except site 4, *Oocystis borgei* and *Scenedesmus* sp. at site 5, *Scenedesmus communis* at site 4 were found in our study. *Scenedesmus* sp. are prominently found in shallow, highly enriched water systems [43] and are frequently dominant in freshwaters [52]. In our study, *Scenedesmus* spp. recorded was found to be in a gradual increase in numbers (1,128 individual cm^{-3}) during the period of one month, only in March.

Cyanobacteria is represented by 4 taxa and its members usually prefer eutrophic environments [53]. *Merismopedia glauca*, a characteristic species of summer epilimnia in mesotrophic lakes [53] was recorded only at site 3. *Oscillatoria tenuis* was found to be at sites 1, 3, and 4 while *Microcystis aeruginosa* was recorded at all sites. Species belonging to *Oscillatoria* and *Microcystis* genera are known to be the cause of excessive blooms. *Microcystis aeruginosa*, usually living in eutrophic waters is a well-known Cyanobacterium that is responsible for the emanation of toxic water blooms all over the world. Shallow, warm, and eutrophic reservoirs are having the most favorable conditions to provide development for *Microcystis aeruginosa* [43,51,54]. *Microcystis* is a dangerous species posing threat to public health as well as to all aquatic organisms and migratory birds due to a toxin it secretes to the lake ecosystem.

Cryptophyta represented by *Cryptomonas ovata* was found to be in all sampling locations. *Cryptomonas ovata* usually lives in small lakes having an enriched environment with low-level light and is found in low numbers [43,51].

Euglenozoa (formerly named as Euglenophyta) are represented by *Euglena gracilis*, *Phacus* sp. and *Trachelomonas hispida*. *Euglena gracilis* was recorded in the samples collected from sites 2, 4, and 5. It is mostly found in waters having high levels of organic pollution [53]. *Trachelomonas hispida* typically lives in shallow mesotrophic lakes and this species was found to be in the samples collected from all sites except site 4 [43,51]. *Phacus* sp. was identified in the samples taken from site 5.

Miozoa (formerly known as Dinophyta) is represented by eight species. In our study, *Ceratium fusus* at sites 1 and 3, *Ceratium furca* at site 3, *Ceratium tripos* at site 2 were found. *Peridinium bipes* was identified in the samples taken from the all-sampling sites. *Peridinium conicum* (except site 4), *Prorocentrum concavum* (except site 5), *Prorocentrum micans* (except site 5) and *Prorocentrum minimum* (except site 5) were identified in all samples collected from the all-sampling sites. According to Reynolds et al. [43], the habitat template is described as summer epilimnia in mesotrophic lakes for *Prorocentrum micans*, *Prorocentrum minimum* and *Peridinium bipes*, which were identified as dominant and subdominant species in this study, could be cause of the excessive blooms called red-tide in suitable conditions. These algae are known to be as harmful species for aquatic systems [55]. In Lesina Lagoon, besides *Prorocentrum* genus, various potentially harmful, biotoxin-producing species including *Alexandrium minutum*, *Amphidinium carterae* and *Gonyaulax spinifera* were recorded [48].

Lagoons are known as productive ecosystems having a rich diversity of organisms. Although their importance for nature is known, lagoons draw limited attention for research purposes regarding with identification of phytoplankton composition, and the determination of nutrient and heavy metal concentrations in Turkey as well as around the world [4,8,56]. In studies performed on the determination of phytoplankton composition in lagoon systems, mainly diatoms, dinoflagellates, Cyanobacteria and green algae are reported to be found [4,46–48]. In many lagoons including Küçükçekmece Lagoon, it is observed that especially Bacillariophyta members are found to be as the richest group in terms of diversity. By many studies, it is revealed that eutrophic conditions in the ecosystems play role in preventing the occurrence of the rich diversity of algal flora [4,46,48].

The total phytoplankton density recorded during the study period is given in Fig. 2. The minimum phytoplankton density was recorded as 76 individual cm^{-3} at site 1 in March whereas the maximum phytoplankton density was recorded as 3,283 individual cm^{-3} at site 5 in November. *Peridinium bipes* (25 individual cm^{-3}) in March at site 1 and *Microcystis aeruginosa* (2,392 individual cm^{-3}) in November at site 5 were identified as dominant species. *Anabaena flosaquae* (797 individual cm^{-3}) was found to be a subdominant species following *Microcystis aeruginosa* in November. Chlorophyll-a contents were found to be showing variation between 0.99–55.32 mg m^{-3}. The minimum content was determined in March at site 5 whereas the maximum content was determined in May at site 5 (Fig. 3). It was observed that there was a gradual increase in the chlorophyll-a concentrations from the Sea of Marmara towards to the lake and the highest concentration was recorded at site 5, of which is located at the Küçükçekmece Lake. According to Sakamoto [57], the 5–140 mg m^{-3} for chlorophyll-a is indicative of eutrophic conditions. The values (0.99–55.32 mg m^{-3}) obtained in our study point out that the area where research was conducted shows eutrophic character. Chlorophyll-a is one of the main pigments in all plant species and 1%–2% of dry matter of phytoplanktonic algae is formed by chlorophyll-a. It is used as a mean for algal biomass estimation. For this reason, chlorophyll-a is an important indicator to show the trophic level.

4. Conclusion

Brackish as well as freshwater were present in the study area along with marine species of phytoplankton. The phytoplankton community structure consisted of the members of Bacillariophyta, Chlorophyta, Cyanobacteria, and Miozoa divisions. Bacillariophyta was determined as the richest group in terms of species diversity. The distribution of phytoplankton groups detected was similar to the study carried out earlier by Yilmaz et al. [44] but the subdominant group Cyanobacteria observed in the former study was found to be as the dominant group in our study in terms of density. *Cyclotella atomus*, *Cyclotella ocellata*, *Asterionella formosa*, *Ulnaria acus* and *Ulnaria ulna* in Bacillariophyta, *Microcystis aeruginosa* and *Oscillatoria tenuis* in Cyanobacteria, *Prorocentrum micans*, *Prorocentrum minimum* and *Peridinium bipes* in Miozoa, *Euglena gracilis* and *Trachelomonas hispida* in Euglenozoa identified in our study were the phytoplankters causing excessive blooms in marine and freshwaters. Harmful algal blooms are quite common in marine, brackish and freshwater

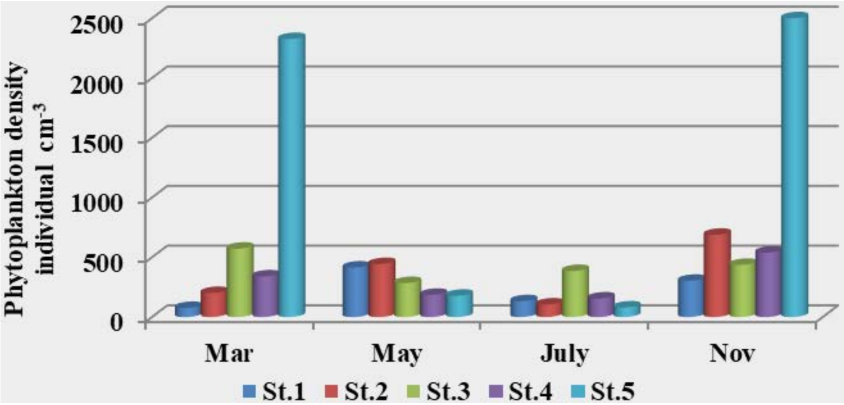

Fig. 2. Phytoplankton density (individual cm^{-3}) with variations in accordance with the sampling sites.

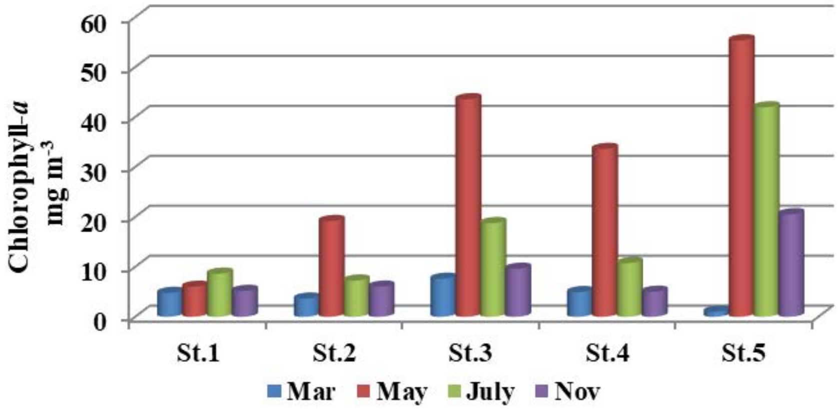

Fig. 3. Chlorophyll-a (mg m^{-3}) with variations in accordance with the sampling sites.

ecosystems, especially blooms of dinoflagellates and Cyanobacteria adversely affecting fisheries and the natural environment [55].

When compared to the previous study performed by Yilmaz et al. [44], increases in pH and chlorophyll-a concentration were found to be. Indicator species of mesotrophic and eutrophic waters being present, limited species diversity, and elevated levels of density and chlorophyll-a concentration indicate that the study area is having eutrophic characteristics. In addition, pH values measured were found to be close to eutrophy. Showing parallelism to the findings of the earlier limnological studies, as our finding, it can be said that Küçükçekmece Lagoon is under anthropogenic pressure due to the high-volume domestic and industrial pollution load. In our study, the concentration levels of Al, Cd, Cr, Cu, Fe, Ni, Pb, and Zn were determined as high. High-volume heavy metal pollution loads could be due to industrial discharges from surrounding facilities.

Studies on the evaluation of phytoplankton community structure and heavy metal pollution play important roles in having information about the trophic state, productivity, and pollution level in aquatic environments. Related to this, all toxins originated from algae are not only toxic to fish but also to other aquatic organisms as well as humans. Due to the negative effects of excessive blooms, the research on determining, controlling and prevention of algal blooms is being one of the hot topics today. Therefore, detailed studies are needed to be carried out in Küçükçekmece Lagoon Basin to controlling- improving the water quality as well as taking necessary cautions for eutrophication.

Declaration of conflicting interests

The authors declare that they have no conflict of interests.

Informed consent

This manuscript did not involve human or animal participants; therefore informed consent was not collected.

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