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Report

Diversity of phytoplankton in Kucukcekmece Lagoon channel, Turkey

Nese Yilmaz

Department of Freshwater Biology, Fisheries Faculty, Istanbul University, Ordu St. No: 200 Laleli, Istanbul, Turkey

E-mail: nyilmaz@istanbul.edu.tr; tel: +90 212 455 57 00; fax: +90 212 514 03 79

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Abstract: The composition and functional groups of phytoplankton in the channel from Kucukcekmece Lagoon to the Marmara Sea were investigated. Some water-quality parameters and nutrient variations were also recorded. Water samples were taken from the water surface between May-August 2008 at 5 sampling sites including the lake and the sea.

A total of 28 taxa were recorded, including Charophyta (1), Chlorophyta (4), Cryptophyta (1), Cyanophyta (3), Dinophyta (5), Euglenozoa (2) and Ochrophyta (12). According to the functional-group approach, the populations formed by 13 groups were most common in mesotrophic and eutrophic water.

The phytoplankton density (19-8842 individuals/cm^3) and chlorophyll-a content (4.45-40.36 mg/m^3) varied in broad ranges. The data from certain water-quality parameters and some nutrient experiments showed variations related to sampling points. As a result, the minimum and maximum water-quality parameters and nutrient concentrations were found to be in normal ranges. No high levels of nutrients were recorded. The presence of pollution indicated by freshwater and marine species with high chlorophyll-a concentrations showed that the study area was eutrophic.

Keywords: water quality, phytoplankton, Kucukcekmece Lagoon, Turkey

INTRODUCTION

Lagoon systems comprise approximately 13% of the earth's coastline. Coastal lagoons form a transition zone between terrestial and marine ecosystems, and are affected by physical, chemical and biological changes in both environments. They are unique and constitute very sensitive natural habitats for many life forms. They also have great socio-economic importance in terms of providing opportunities for agriculture, aquaculture, fishing, tourism and recreation [1]. Because of nutrient

richness, lagoons are one of the most productive coastal ecosystems, hosting a wide variety of species. Increasing pollution levels resulting from growing population and industrialisation pose a significiant threat to water quality and aquatic life in lagoons [2, 3].

Turkey is a coastal country surrounded by the sea on three sides and has a shoreline spanning about 7,816 km. There are 72 lagoon areas in Turkey [2]. Kucukcekmece Lagoon is in Marmara region and is considered to be a Class B wetland area. In the past the lake was a fishing area with a wide range of fish species as well as home to endemic plant species, migratory birds and waterfowls. The abolishment of its protected status, its opening to settlement in 1984, uncontrolled migration and consequent excessive construction have resulted in an increase in domestic pollution [4]. In addition, wastes from industrial establishments without treatment have caused further pollution [3].

Despite having great importance for Istanbul's metropolitan area, only a few limnological studies have been done in Kucukcekmece Lagoon. Some physico-chemical parameters were measured by Topcuoglu et al. [5]. The occurence of toxic cyanophytes was investigated by Albay et al. [6] and the water quality and heavy metal monitoring in water and sediment were done by Altun et al. [7]. Epipelic algae were studied by Polge et al. [8] and seasonal changes in zooplankton structures were examined by Ozcalkap and Temel [9]. A lagoon water quality index was applied to Kucukcekmece Lagoon by Taner et al. [1]. It was found that Kucukcekmece Lagoon is eutrophic and the level of eutrophication is gradually increasing. Topcuoglu et al. [5] found that the fish fauna has declined significantly. The increase of raw domestic sewage inputs from the growing lake-shore community has accelerated eutrophication. For public health Albay et al. [6] recommended monitoring cyanobacterial levels in the Kucukcekmece Lagoon, which is intensively used by Istanbul residents for recreational and fishery activities during the bloom seasons. Altun et al. [7] noted a remarkable increase in pollution and eutrophication since 1994 and high levels of heavy metal pollution in the sediment. Coskun et al. [10] pointed out an increase in pollution rate between 1992-2006 in urban areas of the Kucukcekmece Basin. Due to uncontrolled urban development especially on the southern part of the basin and motorway construction at the northern part of the basin, shoreline changes have occurred [10]. Ozcalkap and Temel [9] found high chlorophyll-*a* and nutrient concentrations in the water and the presence of indicator zooplankton species in the lake, indicating that it was being polluted by household wastes. However, information on water quality of this narrow channel where Lake Kucukcekmece opens into the Marmara sea is lacking.

In aquatic ecosystems primary producers are phytoplankton species, which are used as indicator organisms for detection of water pollution because of their sensitivity towards rapid aquatic changes [11, 12]. Phytoplankton species are indicated by their functional groups in terms of their tolerance and sensivity level to different combinations of physicochemical and biological properties of aquatic systems [13, 14]. Dangerous pollution levels in Kucukcekmece Lagoon are anthropogenic [5, 7, 10]. Phytoplankton diversity, trophic structure, productivity and nutrient levels are important factors for determining and monitoring the pollution rate in the lagoon. This paper reports on the composition and functional groups of phytoplankton related to specific water quality parameters and nutrients along the channel joining Kucukcekmece Lagoon to the Marmara Sea.

STUDY AREA AND CLIMATE

Istanbul is situated on both the European (Thrace) and Asian (Anatolia) sides of the Bosphorus and is one of the most populous cities of Eurasia and Turkey's cultural and financial

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centre [15]. The area of Istanbul is around 5,750 km^2 and has a population of 14,160,000 (2014), 99% of which live in the city centre or suburban zones [16, 17].

Kucukcekmece Lagoon, with a surface area of 15.22 km^2, is located in the south-western part of Istanbul (41º00' N-28º43' E). It has a water capacity of 145 million cubic metres and a maximum depth of 20 metres. The streams that feed the lake are Nakkas, Ispartakule and Sazlidere [18, 19]. The freshwater inflow was notably reduced after 1998 upon the opening of Sazlidere Dam. The dam, with an annual capacity of 55 million cubic metres, is used for supplying potable water for Istanbul [20]. Kucukcekmece Lagoon is eutrophic and algal blooms occur usually during early spring and late fall. The study area covers the 1.5-km-long narrow channel which connects the lagoon with the Marmara Sea (Figure 1).

Figure 1. Map of study area (prepared by using Google Earth Programme and sampling stations (St. 1-5)

The climate in the study area is a subtropical type of the Mediterranean macro-climate. In the region the averages of annual temperature and annual precipitation from 1990 to 2000 were 14.4ºC and 666.8 mm respectively [8]. The rain regime and type are winter-autumn-spring-summer and central Mediterranean rain type respectively. The relative humidity is between 73-77%, which decreases to 65-68% in summer. The dominant wind type in the city is north-east originated [21].

SAMPLING AND ANALYSES

Samples were taken from the surface water at 5 stations (Figure 1) between May-August 2008, using Nansen bottles. The samples were subjected to Lugol's iodine for phytoplankton identification. Phytoplankton were counted with an inverted microscope according to Lund et al. [22]. Phytoplankton species were identified through references including several comprehensive reviews [23-32]. Phytoplankton functional groups have been employed to indicate environmental

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conditions and have proved to be more precise than phylogenetic grouping [33]. In the scheme proposed by Reynolds [34] and updated by Reynolds et al. [13], phytoplankton species are grouped into 33 functional groups, nominated by alphanumeric codes based on their survival strategies, tolerance and sensitivities. Such functional groups have been succesfully applied to both the freshwater phytoplankton and marine dinoflagellates that produce harmful algal blooms [35]. In this study phytoplankton assemblages were classified according to Reynolds et al. [13]. Chlorophyll-*a* concentrations were estimated according to Parsons and Strickland's methodology [36]. Salinity, conductivity and pH were measured on site using a WTW multi-meter. Concentrations of ortho-phosphate (PO_4-P), nitrate-nitrogen (NO_3-N) and nitrite nitrogen (NO_2-N) were determined in the laboratory by employing standard methods [37].

COMPOSITION, FUNCTIONAL GROUPS AND CHLOROPHYLL-*a* OF PHYTOPLANKTON

A total of 28 planktonic algae were identified, belonging to Charophyta (1), Chlorophyta (4), Cryptophyta (1), Cyanophyta (3), Dinophyta (5), Euglenozoa (2) and Ochrophyta (12). The distribution of phytoplankton groups is shown in Figure 2 and the list of recorded taxa according to sampling sites is given in Table 1. Ochrophyta was dominant in terms of species numbers. Dinophyta and Cyanophyta were highest in density. *Peridinium bipes* and *Prorocentrum micans* (Dinophyta) were dominant species while *Euglena gracilis* (Euglenozoa) and *Merismopedia glauca* (Cyanophyta) were subdominant species.

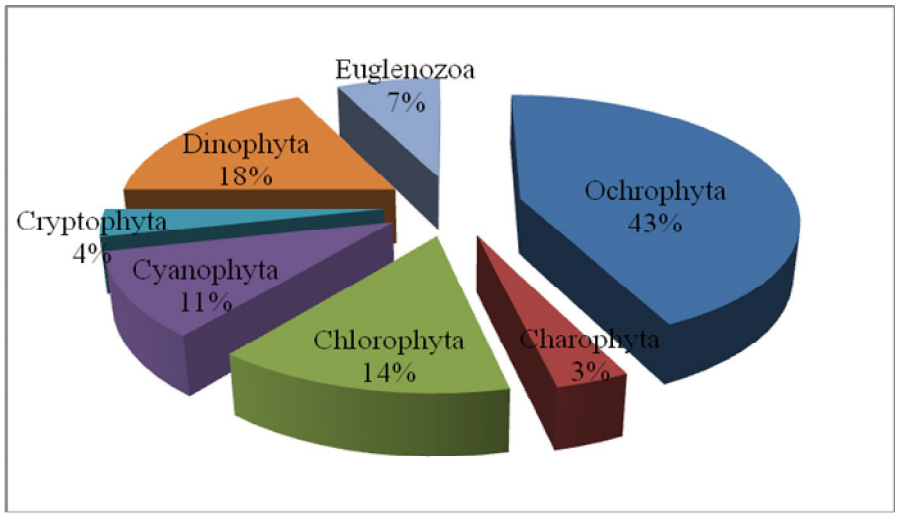

Figure 2. Diversity of phytoplankton groups in Kucukcekmece Lagoon channel

The density and chlorophyll-*a* content of the phytoplankton varied between 19-8842 individuals/cm^3 and 4.45-40.36 mg/m^3 respectively. The maximun phytoplankton density was recorded as 8842 individuals/cm^3 at station 3 in May 2008. *Peridinium bipes* and *Prorocentrum micans* were determined as dominant and subdominant species respectively. The minimum phytoplankton density was recorded as 19 individuals/cm^3 at station 4 in June 2008. *Prorocentrum micans* was recorded as the dominant species. The phytoplankton functional groups comprised more than 45 assemblages that were identified by alphanumerical codes in terms of their sensitivity and tolerance levels [13, 14]. In terms of functional group, the phytoplankton formed in 13 groups: B, C, D, N, X1, Y, F, J, Lo, M, MP, W1 and W2. These are typical for mesotrophic and eutrophic waters, tolerant to light and nutrient deficiencies and sensitive to nutrient depletion and increased

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pH (Table 2). The Lo assemblage (*Peridinium bipes*, *Peridinium conicum and Merismopedia glauca*), which constituted a great part of the phytoplankton, is mostly found in summer epilimnia in mesotrophic lakes. It is tolerant to segregated nutrients and sensitive to prolonged or deep mixing. *Prorocentrum micans*, *Prorocentrum minimum* and *Peridinium bipes* may cause red tides under appropriate conditions. These species of dinoflagellates are considered harmful phytoplankton [38].

Table 1. List of recorded taxa at the five sampling sites (M: May 2008, J: July 2008, A: August 2008)

	St. 1			**St. 2**			**St. 3**			**St. 4**			**St. 5**		
	M	J	A	M	J	A	M	J	A	M	J	A	M	J	A
DIVISION:CHAROPHYTA															
Order: Desmidiales															
Cosmarium formosulum Hoff.	+	-	-	-	-	-	-	-	-	+	-	-	-	-	-
DIVISION:CHLOROPHYTA															
Order: Chlorococcales															
Monoraphidium falcatus Corda) Ralfs	-	+	+	-	-	-	+	-	-	+	-	-	+	-	-
Oocystis borgei J. Snow	-	-	-	+	-	-	-	-	-	-	-	-	-	+	-
Pediastrum dublex Meyen	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-
Scenedesmus sp.	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-
DIVISION: CRYPTOPHYTA															
Order: Cryptomonadales															
Cryptomonas ovata Ehr.	+	-	+	-	-	+	-	-	-	+	-	-	-	-	-
DIVISION: CYANOPHYTA															
Order: Chroococcales															
Merismopedia glauca (Ehr.) Naeg.	-	-	+	-	-	+	-	-	+	+	-	-	-	-	-
Microcystis aeruginosa (Kütz.) Kütz	+	-	-	-	-	-	-	-	-	+	-	-	-	-	-
Order: Oscillatoriales															
Oscillatoria tenuis C.Agarth Gomont	-	-	-	-	-	-	+	+	+	-	-	+	-	-	+
DIVISION: DINOPHYTA															
Order: Peridiniales															
Peridinium bipes F.Stein	+	-	-	+	-	+	+	-	-	+	-	-	+	-	-
Peridinium conicum (Gran) Ostenfeld & Schmidt	+	-	-	+	-	+	+	-	-	+	-	-	+	-	-
Prorocentrum concavum Fukuyo	-	-	+	+	-	+	-	-	+	-	+	+	-	-	+
Prorocentrum micans Ehr.	-	-	+	+	-	+	-	-	+	-	+	+	-	-	+
Prorocentrum minimum (Pavillard) J.Schiller	-	-	+	+	-	+	-	-	+	-	+	+	-	-	+
DIVISION: EUGLENOZOA															
Order: Euglenales															
Euglena gracilis G. A. Klebs	+	-	+	-	-	+	+	-	+	+	+	-	+	-	-
Trachelomonas hispida (Perty) F. Stein	+	-	-	+	-	+	+	-	-	-	-	-	-	-	-
DIVISION:OCHROPHYTA															
Order: Centrales															
Aulocoseira italica (Ehr.) Simonsen	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-
Cyclotella atomus Hust.	+	-	+	+	-	+	+	-	-	+	-	-	-	-	-
Cyclotella ocellata Pant.	+	-	+	+	-	+	+	-	-	+	-	-	-	-	-
Order: Pennales															
Achnanthes lanceolata (Brébisson ex Kützing) Grunow	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-
Asterionella formosa Hassal	+	-	-	+	-	-	-	-	-	-	-	-	-	-	-
Cocconeis placentula Ehr.	-	-	+	+	-	-	-	-	-	-	-	-	-	+	-
Cymbella affinis Kütz.	-	-	-	-	+	-	+	-	-	-	-	-	+	+	-
Diatoma vulgaris Bory de Saint-Vincent	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Navicula cuspidata(Kütz.) Kütz.	+	-	+	-	-	-	-	+	-	-	+	-	-	-	-
Pinnularia viridis (Nitzsch) Ehr.	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-
Ulnaria acus (Kutz.) M.Aboal	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-
Ulnaria ulna (Nitzsch) P.Compere	-	-	+	-	+	+	-	+	+	-	-	-	+	-	-

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According to previous studies carried out in the freshwaters in the Marmara region, Ochrophyta members were found to be the commonest group [8, 39-43]. Ochrophyta was represented by 12 species. *Cyclotella atomus* and *Cyclotella ocellata* (Centrales) were recorded at stations 1-4. These centric diatoms are typical components of oligotrophic lakes. *Cyclotella* species indicate mesotrophic lakes with species sensitive to the onset of stratification [44, 45]. *Aulocoseira italica* was only found at station 3. *Aulocoseira* spp. are found in mesotrophic and eutrophic waters [13]. Codon B was represented by *Cyclotella atomus*, *Cyclotella ocellata* and *Aulocoseira italica*— all centric diatoms. This group is tolerant to light deficiency and sensitive to a rise in pH. Codon C was represented by *Asterionella formosa* (Pennales), a species of small and medium eutrophic lakes [13], recorded at stations 1-2. *Ulnaria ulna* was found at all sampling points except station 4. It is a characteristic inhabitant of eutrophic lakes and prefers inorganically turbid, shallow lakes [13, 44, 46]. *Ulnaria acus* was only found at station 4. Codon D was represented by *U. acus* and *U. ulna* (pennate diatoms). They usually occur in shallow, enriched turbid waters and are sensitive to nutrient depletion [13, 14]. *Pinnularia viridis*, *Cocconeis placentula*, *Cymbella affinis* and *Navicula cuspidata* were recorded at station 2, stations 1, 2 and 5, stations 2, 3 and 5, and stations 1, 3 and 4 respectively. It has been determined that the numbers of diatom taxa are higher in water samples taken in May 2008 and July 2008. In general, increases in light and temperature lead to phytoplankton accumulation, especially to high diatom abundance in the spring [47].

Table 2. Functional groups of recorded phytoplankton species [13]

Codon	Habitat	Typical Representatives	Tolerance	Sensitivities
B	Vertically mixed, mesothrophic, small to medium lakes	*Aulocoseira italica* *Cyclotella atomus* *Cyclotella ocellata*	Light deficiency	pH rise, Si depletion stratification
C	Eutrophic, small- and medium-sized lakes	*Asterionella formosa*	Light, C deficiency	Onset of stratification
D	Shallow, enriched turbid waters including rivers	*Ulnaria acus* *Ulnaria ulna*	Flushing	Nutrient depletion
N	Mesotrophic epilimnia	*Cosmarium formosulum*	Nutrient deficiency	Stratification, pH rise
X1	Shallow, mixed layers in enriched conditions	*Monoraphidium falcatus*	Stratification	Nutrient depletion
Y	Usually small, enriched lakes	*Cryptomonas ovata*	Low light	Phagothrophs
F	Clear epilimnia	*Oocystis borgei*	Low nutrients high turbidity	CO_2 deficiency
J	Shallow, enriched lakes, ponds and rivers	*Pediastrum dublex* *Scenedesmus* sp.	-	Settling into low light
Lo	Summer epilimnia in mesotrophic lakes	*Peridinium bipes* *Peridinium conicum* *Merismopedia glauca*	Segregated nutrients	Prolonged or deep mixing
M	Dielly mixed layers of small, eutrophic, low latitude lakes	*Microcystis aeruginosa*	High insolation	Mixing, poor light stratification
MP	Frequently-stirred-up, inorganically turbid shallow lakes	*Achnanthes lanceolata* *Cymbella affinis* *Navicula cuspidata* *Oscillatoria tenuis*	-	-
W1	Small organic ponds	*Euglena gracilis*	High BOD	Grazing
W2	Shallow mesotrophic lakes	*Trachelomonas hispida*	-	-

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Chlorophyta are usually found in abundance in mesotrophic and eutrophic lakes [40]. Chlorococcales have been recorded in aquatic environments which are transitioning from oligotrophic to eutrophic [45]. In this study Chlorococcales are represented by 4 species. The X1 assemblage includes *Monoraphidium falcatus*, which was recorded at all stations except station 2. Members of codon X1, found in shallow water in enriched conditions, are tolerant to stratification and sensitive to nutrient depletion. Members of the F group are tolerant to deep mixing and are present in clear water, with high diversity in mesotrophic lakes. The F assemblage, which can develop in clear epilimnia, is tolerant to low nutrients and high turbidity. It includes *Oocystis borgei*, which was only recorded at stations 2 and 5, and only a small increase was observed in July 2008 at station 5 (58 individuals/cm^3). The J assemblage consisted of *Pediastrum dublex* and *Scenedesmus* sp. (Chlorococcales), which are characteristic of shallow, enriched lakes, ponds and rivers. *Pediastrum dublex* and *Scenedesmus* sp. were only found at stations 1 and 4 respectively. *Scenedesmus* spp. are prominent in shallow, highly enriched systems [13] and are frequently dominant in freshwater lakes and rivers [48]. In the present study, *Scenedesmus* sp. was only recorded in low number (12 individuals/cm^3) in May 2008.

Cosmarium formosulum (Charophyta) is a member of the functional N group, tolerant to nutrient deficiency and sensitive to rises in pH and indicates mesotrophic waters. This species was recorded in low numbers at station 1 (35 individuals/cm^3) and station 4 (23 individuals/cm^3) in May 2008. Desmidiales members are very sensitive to chemical variations of water. Generally, they prefer acidic water and are used as indicators in aquatic systems [46].

Cyanophyta is represented by 3 taxa which usually prefer eutrophic environments [49]. *Merismopedia glauca*, a charachteristic of summer epilimnia in mesotrophic lakes, was recorded at stations 1-4. It is in the Lo assemblage and is tolerant to segregated nutrients and sensitive to prolonged or deep mixing [49]. Codon MP includes *Oscillatoria tenuis*, a typical filamentous cyanophyte of inorganically turbid shallow lakes, and was found at stations 3-5. The M assemblage is represented by *Microcystis aeruginosa*. It was recorded at stations 1 and 4. It is tolerant to high insolation and sensitive to mixing and poor light stratification. Species of *Oscillatoria* and *Microcystis* are known to be the cause of excessive blooms. *M. aeruginosa*, which usually inhabits eutrophic waters, is a cyanobacterium notorious for forming toxic water blooms all over the world. Shallow, warm and eutrophic reservoirs provide the most favourable conditions for its development [13, 14, 50]. *Microcystis* is a danger to public health, as well as all aquatic organisms and migratory birds, by secreting a toxin called microcystin into the water. Albay et al. [6] recorded microcystin at high levels in Kucukcekmece Lagoon.

Chlorophyll-*a* increased along the canal from the sea to the lagoon. Sokamoto [47] expressed that the chlorophyll-*a* content of eutrophic lakes is between 5-140 mg/m^3. Based on the chlorophyll-*a* values, it can be said that the study area is eutrophic.

PHYSICO-CHEMICAL PROPERTIES

The data for some water quality parameters and nutrients showed some differences which depend on the sampling points. The minimum and maximum water quality parameters and nutrient concentrations of water samples are shown in Table 3.

During this study, the average pH was 7.59. It is known that pH varies between 6-9 in clear waters [46]. Salinity and conductivity were lower than those of the sea and the lagoon. Phosphate concentration increased along the channel and the highest concentration was recorded in the lagoon. Maximum nitrite and nitrate concentrations were detected at stations 3-5. The minimum and

maximum water-quality parameters and nutrient concentrations were found to be in normal ranges. No high levels of nutrients were recorded.

Table 3. Minimum and maximum measured values of some physico-chemical parameters, nutrients and chlorophyll-*a* in Kucukcekmece Lagoon channel

	Minimum	**Maximum**
pH	6.27	8.31
Salinity (%)	11.8	24.9
Conductivity (mS/cm)	19.7	39.2
Nitrite (µg/L)	0.27	5.63
Nitrate (µg/L)	0.109	15.034
Ortho-phosphate (µg/L)	0.061	0.083
Chlorophyll-*a* (mg/m^3)	4.45	40.36

CONCLUSIONS

The functional group approach constitutes a useful means of understanding phytoplankton communities. Determining the trophic structure and pollution levels of aquatic environments in aquatic systems is a means of determining the health of aquatic systems. The presence of pollution indicated by freshwater and marine species with high chlorophyll-*a* concentrations shows that the study area was eutrophic. Continued studies and monitoring of phytoplankton are needed in the Kucukcekmece Basin.

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