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Seasonal succession and diversity of phytoplankton in a eutrophic lagoon (Liman lake)

Elif Neyran Soylu*[1] and Arif Gonulol[2]

[1]Department of Biology, Faculty of Arts and Science, Giresun University, 28100, Giresun, Turkey
[2]Department of Biology, Faculty of Arts and Science, Ondokuz Mayis University, 55139, Kurupelit, Samsun, Turkey

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Abstract: *The seasonal succession, composition and diversity of phytoplankton in a eutrophic lagoon (Liman lake) were studied between January 2002 and November 2003. Samples were collected from surface water and deeper (1m depth) at stations and species diversity (Shannon-Weaver, H) and evenness were calculated. Shannon Diversty was similar at Station 1 and Station 2. Minimum and maximum diversity values (0.101 and 0.765 bits.mm^{-3}) were recorded in June and July 2003 at Station 2. Cluster analysis and NMDS (Non metric multidimensial scaling) were applied to the phytoplankton community. The lagoon exhibits high conductivity (7211-10757 µScm^{-1}), mean temperature of 17.7°C, varying concentrations of dissolved oxygen (3.3-8.4 mgl^{-1}). Light, temperature, rainfall, turbidity and salinity were expected to be the main factors affecting the seasonal succession. The seasonal succession of phytoplankton were similar at surface water and 1m depth. A total of 130 taxa belonging to Bacillariophyta, Chlorophyta, Euglenophyta, Cyanophyta, Dinophyta, Xantophyta, Chrysophyta and Cryptophyta divisions were identified. Pseudanabaena limnetica, Kirchneriella obesa, Kirchneriella lunaris, Ankistrodesmus falcatus and Ankistrodesmus spiralis were highly represented.*

Key words: *Phytoplankton, Lagoon, Seasonal succession, Liman lake, Kizilirmak Delta, Salinity*
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Introduction

Lagoons are natural physiographic features consisting of shallow, open masses of saline or brackish water which are either isolated or semi-isolated from the adjacent sea by a barrier of sand or shingle, but receive salt from the sea as a result of natural causes (Healy, 1997). Their status mid-way between continental and marine conditions (Boutiere, 1974) makes them of major ecological interest. Because of their position at the end of drainage basins, which are enriched in nitrogen and phosphorous by human activities (Cloern, 2001; Shekhar *et al.,* 2008; Saravanakumar *et al.*, 2008; Senthilkumar *et al.,* 2008; Rajkumar *et al.,* 2009), lagoons have undergone natural processes of eutrophication.

Kizilirmak and Yesilirmak Deltas, located in the Blacksea Region, involve various kinds of lakes. Bafra Fish lakes (Balik lake, Uzungol) (Gonulol and Comak, 1992a,b and 1993a,b), Sarikum lake (Ozturk, 1994), Karabogaz lake (Baytut *et al*., 2006), Gici lake (Soylu and Gonulol, 2006), Simenit lake (Ersanli and Gonulol, 2006), Cernek lake (Tas and Gonulol, 2007), Tatli lake (Soylu *et al*., 2007), Sarikum lagoon (Sivaci *et al*., 2008) have been examined in the floristic way. Up to date there have been only sporadic studies of the lakes of Kizilirmak Delta and little is known about their limnological aspects and possible, appropriate, management strategies (Soylu *et al*., 2007). Liman lake, situated in the Kizilirmak Delta has been studied neither ecological nor floristic way. So it is much more important to study this lake to complete the algal flora of the delta.

Phytoplankton succession is a well-investigated phenomenon in aquatic ecology and several studies have described the patterns and underlying mechanisms of the seasonal dynamics (Rothhaupt, 2000). The knowledge of the composition and abundance of phytoplanktonic organisms constitutes an essential feature for the assessment of the trophic status in lakes and for the evaluation of the possible or optimal utilization of different water resources. The phytoplankton in aquatic ecosysytems is an important biological indicator of the water quality. While phytoplankton are major primary producers and the basis of the food chain in open water, some species on the other hand can be harmful to human and other organisms by releasing toxic subtances into the water.

The aim of the study was to analyse the seasonal variation in the diversity and composition of the phytoplankton and to contribute to the knowledge of the phytoplankton assemblages in the Kizilirmak Delta. In particular, we focus on environmental parameters such as salinity, turbidity, rainfall, light and temperature since these are major factors expected to influence phytoplankton succession and dominance.

Materials and Methods

Kizilirmak Delta is situated along the Blacksea coast of Turkey (latitute: 41°30' to 41°45' N; longitude: 35°43' to 36°08' E). The larger part of the delta is composed of alluvial sediment supplied by the River Kizilirmak during the holocene. Liman lake is 10-20 km away from Bafra city in the Kizilirmak Delta (Fig. 1). All lakes in this area are shallow and their surface water levels are approximately

*** Corresponding author:** enkutluk@omu.edu.tr

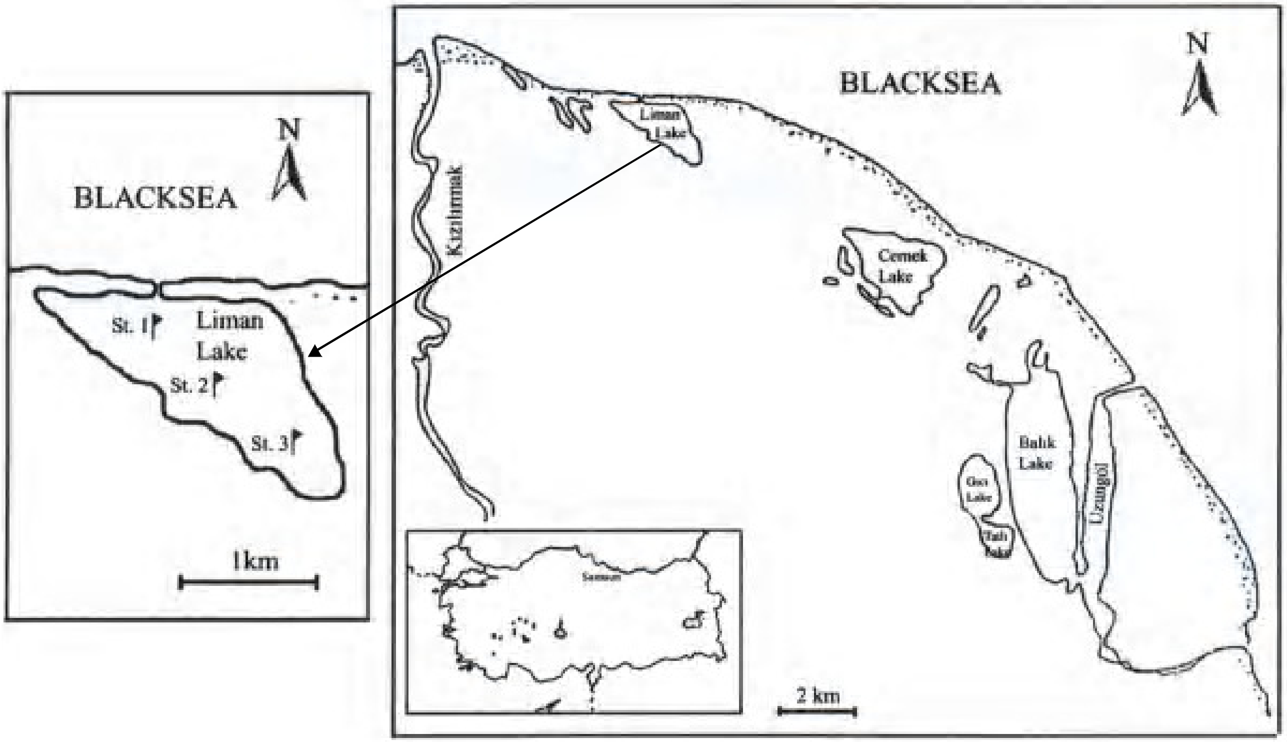

Fig. 1: Map of Liman lake and location of the sampling stations

at sea level. At the end of the dry season their water levels regularly fall below Blacksea level.

The lake's surface area is 270 ha. The length of the lake is approximately 3 km and the width is 1.4 km. The three sites sampled are shown on Fig. 1. Station 1 is situated near the North edge of the lake. The lake sediment is covered with sand and stones. Station 2 is situated in the center of the lake. The lake sediment is sandy. Station 3 is situated in the South east of the lake.

The climate regime in the area is the climate of Blacksea coastal region. The weather is hot in summers, mild and rainy in winters in sea shore. The amount of rain increase in November (85.2 mm) and December (80.3 mm) (Anonymous, 2003a).

Samples were collected monthly with 2 litre capacity Hydro-Bios water sampler to determine the density of the algae from January 2002 to November 2003 at three stations and two different depths: water surface and 1 meter depth. Phytoplankton determinations were carried out on subsamples preserved in acetic Lugol's solution; a constant volume of 10 ml was sedimented in the counting chambers. Algal cells were counted on a Prior inverted microscope at 400 x magnification, following Lund *et al*. (1958). At least 200 individuals were counted. In the evaluations the average of three countings from each stations was used. The remaining part of the water sample was filtered using Whatman GF/A fibre filter paper to identify the algae except Bacillariophyta. Bacillariophyta were identified in permanent slides under oil immersion at 1000 x magnification which had been prepared according to Round (1953). Taxonomic identifications were performed following John *et al*. (2003), Krammer and Lange-Bertalot (1991a,b and 1999a,b).

At the time of sampling, the water temperature, pH, dissolved O_2 and conductivity were measured *in situ* with C 534 multi-parameter analyser (Consort nv, Belgium). Surface water samples were collected for chemical anlyses and transfered to DSI laboratory. Other chemical analysis were performed according to standart methods (APHA, 1998) in DSI quality control laboratory in Samsun (Anonymous, 2003b).

Changes in the phytoplankton community (*i.e.*, the species presence and their relative abundances) were examined with Nonmetric Multidimensional Scaling (NMDS) ordinations (Clarke, 1993) and Cluster analysis (average linkage method) using Bray-Curtis similarity matrices derived from square-root-transformed data. NMDS (Non metric multidimensial scaling) is a technic that makes clear the chronolgical ordination of different groups defined by Cluster analysis. Correlations between NMDS axis scores and square-root-transformed counts of each taxon were examined to determine which taxa contributed most to the distribution of samples in ordination space. The software used was the program PRIMER version 5.0 from Plymouth Marine Laboratory for Cluster, NMDS and Shannon-Wiener index (Shannon and Weaver, 1949).

Results and Discussion

A total of 130 planktonic algae was found: 45 Bacillariophyta, 31 Chlorophyta, 23 Euglenophyta, 23 Cyanophyta, 3 Dinophyta, 3 Xantophyta, 1 Chrysophyta and 1 Cryptophyta (Table 1).

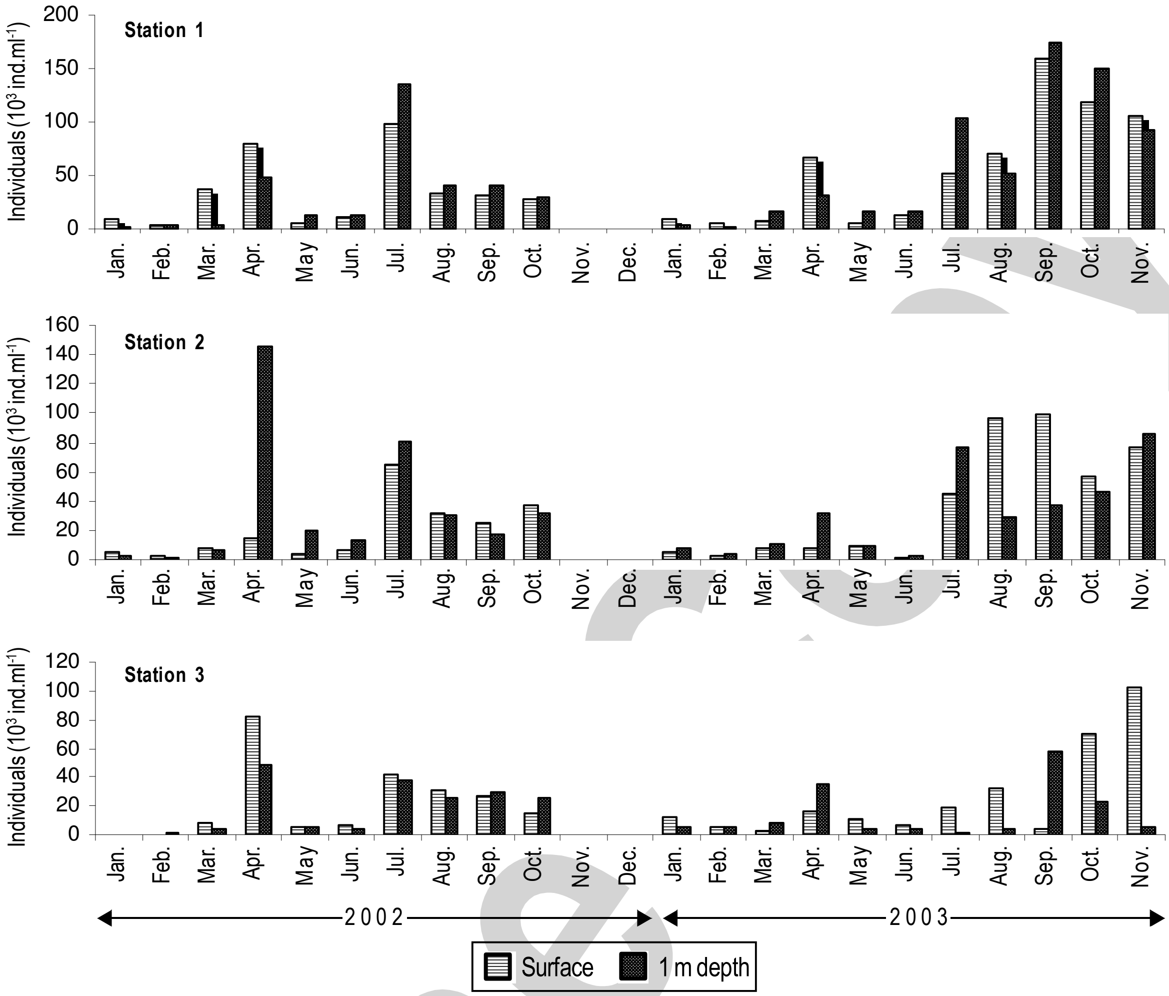

Fig. 2: Seasonal variation of phytoplankton density (ind.ml^{-1}) at surface and 1 m depth during sampling period

Although Bacillariophyta were dominant in respect to species number, Cyanophyta and Chlorophyta type phytoplankton was registered in terms of population density in Liman lake. *Pseudanabena limnetica*, *Merismopedia punctata*, *Ankistrodesmus falcatus* and *Kirchneriella lunaris* were found to be dominant and subdominant organisms in certain months alternately. Bacillariophyta reached its highest level contributing 53% of total organism numbers in May 2003 at Station 3. In this month, centric diatoms *Cyclotella ocellata* and *Melosira varians* were highly represented diatoms with respectively, 3975 and 1125 ind.m l^{-1}. (Fig. 2).

Cyanophyta were found to be prominent in Bulgaria (Mur *et al*. 1993; Stoyneva, 2003) and Hungary (Padisak and Reynolds, 1998) which were in the same climatic zone with Turkey. Cyanophytes were also most numerous in Sanabria lake (Spain) (Hoyos and Comin, 1999) and Kitham lake (India) (Tiwari and Chauhan, 2006) in summer. During summer and winter the assemblages were characterised by a high development of *Pseudanabaena limnetica* in Donghu lake of China (Lei *et al.*, 2005). The permanent dominance of Oscillatoriales during summer and autumn has often been reported for eutrophic lakes in Central Europe (Berger and Sweers, 1988). Cyanophyta dominance, and sometimes bloom formation, are among the most visible symptoms of accelerated eutrophication of lakes and reservoirs (Moss *et al*., 1997). The dominance of Oscillatoriales in the lakes of Kizilirmak Delta region is a result of the anthropogenic induced eutrophication process.

The seasonal variation of total organism numbers were similar at surface and 1m depth in Liman lake. Peaks of phytoplankton were recorded in 2002 April, July and 2003 July, September. The contribution of *Pseudanabena limnetica* were highest in these months. Additionally, *Merismopedia punctata* was important contributing high to total organism numbers in September 2003. Total organism numbers reached its highest level with 173343 ind.ml^{-1} at Station 1 in September 2003 during the study period. *Pseudanabena limnetica* were found to be dominant, *Merismopedia punctata* were subdominant at all stations in this month (Fig. 3).

Water temperature varied between 9°C in January 2002 and 25°C in August 2002 and no significant differences were found

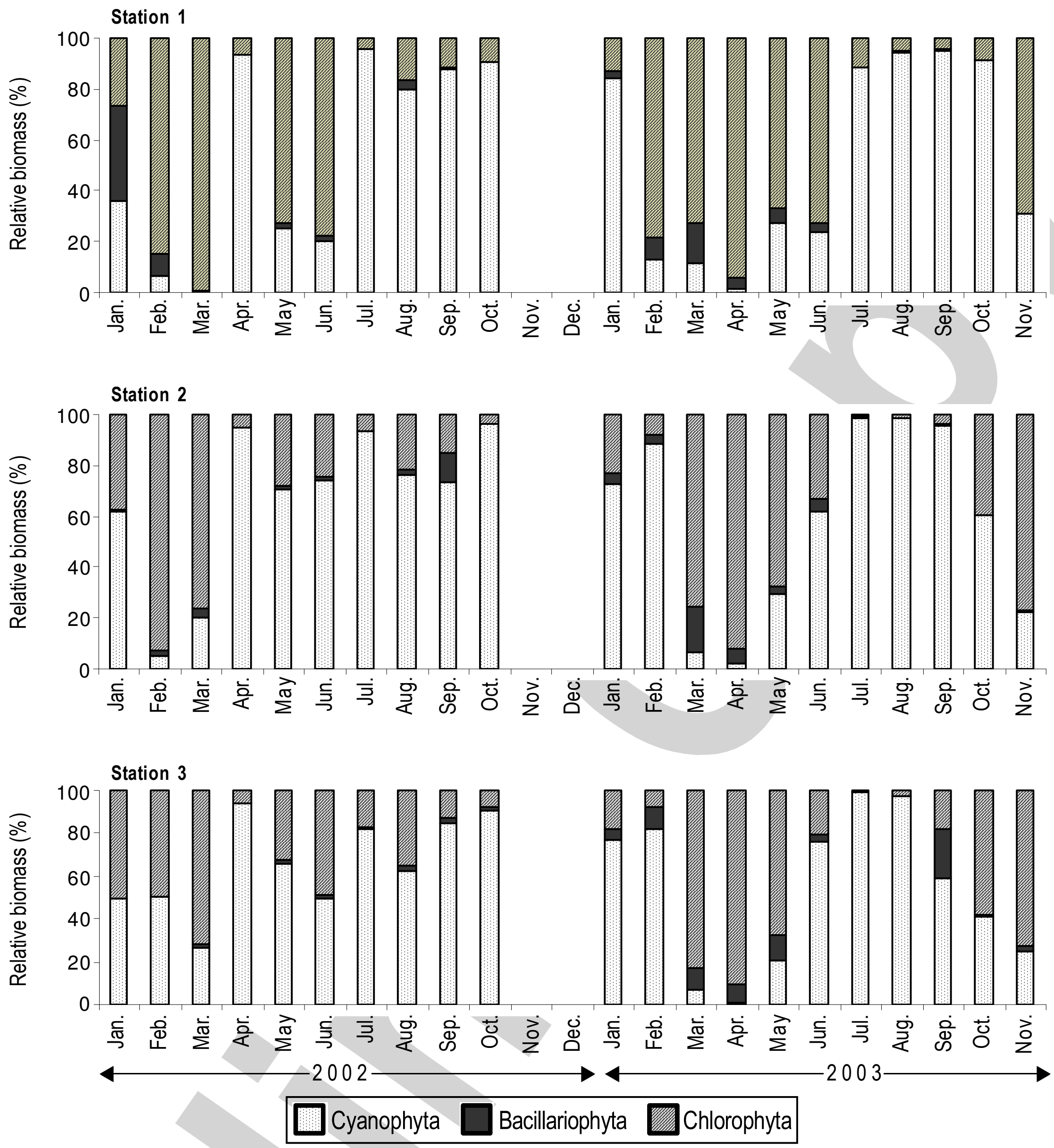

Fig. 3: Seasonal variation of the density of the main algal groups during the sampling period

between sites. Values of pH and dissolved oxygen varied between 7.8-9.9 and 3.35-8.45 mg l^{-1}, respectively. Total dissolved solids of Liman lake ranged between 5.3-7.3 g l^{-1}. Variation in environmental characteristics of Liman lake is shown in Table 2. The sampling sites were considered as a whole and the minimum, maximum and average values are listed.

Liman lake is relatively rich in phytoplankton species, compared to lake Erken, Sweden and lake Ferto (Neusiedlersee) (82-92 species), Austria and Hungary (53-63 species) (Padisak and Dokulil, 1994). Light, temperature and rainfall were the main factors forming this kind of phytoplankton type and species richness. The seasonal succession of phytoplankton is strongly influenced by temperature in Liman lake. It is indicated that Dinophyta members reached high cell numbers in the phytoplankton while the water temperature is above 15°C (Cetin and Sen, 1997). *Peridinium cinctum* and *Preperidinium* species favored high temperatures and increased their numbers between July and September while the water temperature was 18-26°C. The same situation was also seen in Keban and Derbent Dam lakes (Cetin and Sen, 1997; Tas and Gonulol, 2007). Total organism numbers showed a clear decrease in winter months, May and June due to high rainfall. Maximum total organism numbers were registered at Station 1 and Station 2 (159165 ind.m l^{-1} and 99172 ind.m l^{-1}, respectively) while monthly average rainfall reached its lowest level (3.2 mm) in 2003 September in Liman lake. Low algal growth observed in the winter period was mainly due to the low light and temperature in lake Como (Buzzi, 2002).

Table - 1: List of taxa from the Liman lake

CYANOPHYTA -
Chroococcales
Chroococcus dispersus (Keissler) Lemmermann
Chroococcus distans (G.M.Smith) Komarkova-Legnerove et Cronberg
Chroococcus limneticus Lemmermann
Chroococcus minor (Kutzing) Nageli
Chroococcus minutus (Kutzing) Nageli
Chroococcus pallidus Nageli
Chroococcus turgidus (Kutzing) Nageli
Chroococcus varius A.Braun in Rabenhorst
Cylindrospermum stagnale (Kutzing) Bornet et Flauhault
Desmococcus olivaceum (Persoon ex Acherson)
Microcystis aeruginosa (Kutzing) Kutzing
Microcystis incerta (Lemmermann) Lemmermann
Merismopedia elegans A.Braun
Merismopedia glauca (Ehrenberg) Nageli
Merismopedia punctata Meyen

Hormogonales
Oscillatoria curviceps C.Agardh ex Gomont
Oscillatoria guttulata Van Goor
Pseudanabaena limnetica Lemmermann
Spirulina laxa G.M.Smith

BACILLARIOPHYTA -
Centrales
Cyclotella ocellata Pantocsek

Pennales
Amphora coffeaeformis (C.Agardh) Kutzing
Amphora ovalis Kutzing
Caloneis silicula (Ehrenberg) Cleve
Cocconeis pediculus Ehrenberg
Cocconeis placentula Ehrenberg
Cymbella affinis Kutzing
Cymbella cistula (Ehrenberg) Kirchner
Cymbella minuta Hilse ex Rabenhorst
Cymbella prostrata (Berkeley) Cleve
Cymbella ventricosa C.Agardh
Diatoma vulgaris Bory
Encyonema perpusillum (A.Cleve) D.G.Mann
Entomoneis alata (Ehrenberg) Ehrenberg
Entomoneis paludosa (W.Smith) Reimer
Epithemia smithii Carruthers
Epithemia sorex Kutzing
Fragilaria ulna (Nitzsch) Lange-Bertalot
Gomphonema olivaceum (Hornemann) Brëbisson var. *olivaceum*
Gyrosigma attenuatum (Kutzing) Rabenhorst
Meridion circulare (Greville) C.Agardh
Navicula cincta (Ehrenberg) Ralfs
Navicula cryptocephala Kutzing
Navicula digitoradiata Gregory et Ralfs in Pritchard
Navicula elginensis Gregory et Ralfs in Pritchard var. *elginensis*
Navicula platystoma Ehrenberg
Navicula pupula Kutzing
Navicula radiosa Kützing
Navicula rhyncocephala Kützing
Navicula veneta Kutzing
Nitzschia acicularis (Kutzing) W.Smith
Nitzschia closterium (Ehrenberg) W.Smith
Nitzschia constricta (Kutzing) Ralfs
Nitzschia palea (Kutzing) W.Smith
Pinnularia appendiculata (C. Agardh) Cleve
Rhoicosphaneia abbreviata (C.Agardh) Lange-Bertalot
Surirella brebissonii Krammer Lange-Bertalot
Surirella ovalis Brëbisson

CHLOROPHYTA -
Chlorococcales
Ankistrodesmus falcatus (Corda) Ralfs
Ankistrodesmus spiralis (W.B.Turner) Lemmermann
Botryococcus braunii Kutzing
Eudorina elegans Ehrenberg
Kirchneriella elegans Playfair
Kirchneriella lunaris (Kirchner) K.Mobius
Kirchneriella irregularis (G.M. Smith) Korshikov
Kirchneriella obesa (West) Schmidle
Monoraphidium griffithii (Berkeley) Komarkova-Legnerova
Monoraphidium minutum (Nageli) Komárková-Legnerová
Monoraphidium mirabile (West et G. West) Pankow
Oocystis pusilla Hansgirg
Pediastrum dublex Meyen
Raphidocelis contorta (Schmidle) Marvan
Scenedesmus abundans (Kirchner) Chodat
Scenedesmus arcuatus (Lemmermann) Lemmermann
Scenedesmus communis E.H. Hegewald
Scenedesmus magnus Meyen
Scenedesmus obtusus Meyen
Tetraedron minimum (A. Braun) Hansgirg
Tetrastrum triangulare (Chodat) Komárek

Desmidiales
Closterium kuetzingii Brebisson
Closterium praelongum Brebisson
Cosmarium venustum (Brebisson) W. Archer
Staurastrum gracile Ralfs
Selenastrum gracile Reinsch

Oedogoniales
Oedogoniom cleveanum Wittrock

CHRYSOPHYTA -
Chrysomonadales
Dinobyron sertularia Ehrenberg

CRYPTOPHYTA -
Cryptomonadales
Cryptomonas ovata Ehrenberg

DINOPHYTA -
Peridiniales
Peridinium cinctum (O.F. Muller) Ehrenberg
Preperidinium meunieri (Pavillard) Elbrachter
Protoperidinium brevipes (Paulsen) Balech

EUGLENOPHYTA -
Euglenales
Euglena clavata Skuja
Euglena elastica Prescott
Euglena elongata Schewiakoff
Euglena gracilis G.A. Klebs
Euglena minuta Prescott
Euglena oxyuris Schmarda
Euglena polymorpha P.A. Dangeard

Euglena proxima P. A. Dangeard
Phacus acuminatus A. Stokes
Phacus chloroplastes Prescott
Phacus stokesii Lemmermann
Trachelomonas hispida (Perty) F. Stein
Trachelomonas hispida var. *punctata* Lemmermann
Trachelomonas lacustris Drezepolski
Trachelomonas pulcherrima Playfair
Trachelomonas rotunda Svirenko
Trachelomonas scabra Playfair
Trachelomonas scabra var. *ovata* Playfair
Trachelomonas similis A. Stokes
Trachelomonas volvocina Ehrenberg

XANTOPHYTA -
Goniochloris fallax Fott
Goniochloris mutica (A. Braun) Fott
Goniochloris smithii (Baurrelly) Fott

Table - 2: Variation in environmental characteristics of Liman lake

	Minimum	Maximum	Average
Temperature (°C)	9	25	17.7
Rainfall (mm)	6.2	710.2	86.8
Total dissolved solids (mg l^{-1})	5300	7360	5800
Dissolved O_2 (mg l^{-1})	3.3	8.4	6.7
pH	7.8	9.0	8.6
Conductivity (µScm^{-1})	7211	10757	7757
Alkalinity (mg l^{-1} $CaCO_3$)	190	275	233
Total hardness (mg $l^{-1}$$CaCO_3$)	1020	1390	1100
Ca^{2+} (mg l^{-1})	55	119	109
Mg^{2+} (mg l^{-1})	187.2	267.5	215
PO_4^{3} (mg l^{-1})	0	0.04	0.014
NH_3-N (mg l^{-1})	0	0.50	0.16
NO_2^--N (mg l^{-1})	0	0.106	0.22
NO_3^--N (mg l^{-1})	0	0.91	0.22

As the water of Liman lake is shallow and windexposed, intense mixing and turbid state conditions causes low light penetration into the water column. Many diatoms in the phytoplankton were of bentic origin (epipelic, epiphytic, epilithic) resuspended by waves especially January 2003 may be due to high rainfall and turbidity. Thus the species (*e.g. Pseudanabaena limnetica*) that have low light requirements and are well adaptad to a high mixing frequency were found to be as dominant or subdominant organisms. Intense mixing and high irradiance in summer promoted the development Pseudanabaenaceae, as reported in South-temperate lagoon, the Albufera of Valencia (Romo and Miracle, 1993) and the Bolmon Lagoon (Chomerat *et al*., 2007).

One of the strongly selective environmental factors that restricts the species number is certainly the high salinity of the lake. Williams (1964) defined the lakes as saline lakes containing in excess of 3 g l^{-1} of total dissolved solids. Total dissolved solids of Liman lake ranged between 5.3-7.3 g l^{-1}. In the study area there was a wide

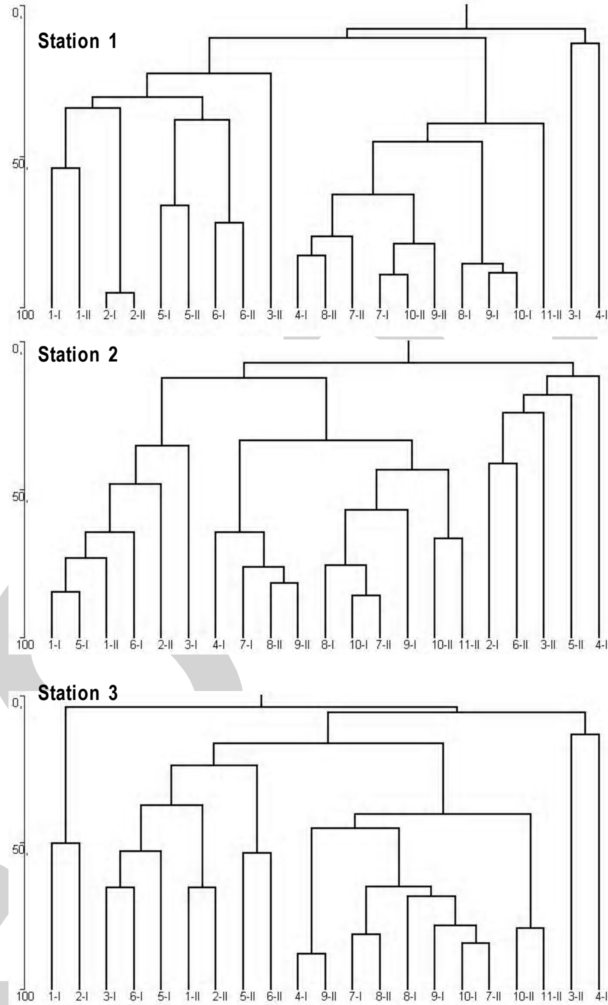

Fig. 4: Dendrograms for hierarchical clustering of months (indicated with a number) using complete linking of Bray-Curtis similarities calculated phytoplankton abundance data during 2002-2003 (I: 2002, II: 2003)

spectrum of ecologically different algae groups, freshwater, brackish and even marine affinities. Some marine species (*Preperidinium meuneri* and *Protoperidinium brevipes*) that were not seen before in any Turkish lakes were found in Liman lake. Additionally, halophilic species, *Amphora coffeaeformis, Navicula cincta, Navicula cryptocephala, Nitzschia closterium* and *Botryococcus braunii* were identified.

The diagram obtained by cluster analysis indicates that at the lowest hierarchical level two clusters are clearly separated at Station 1 (Fig. 4). The first group is a large group including all season samples. The second group includes 2002 and 2003 spring samples and is characterized by the dominance of *Ankistrodesmus spiralis* together with *Kirchneriella lunaris*. In Station 2 a cluster diagram constitued by two assemblages at lowest hierarchical level. The first one is formed by all season samples and the second one includes winter, summer and spring samples. Two clusters are separated at the lowest hierarchical level at Station 3. The first group includes 2002 winter samples and characterized by the

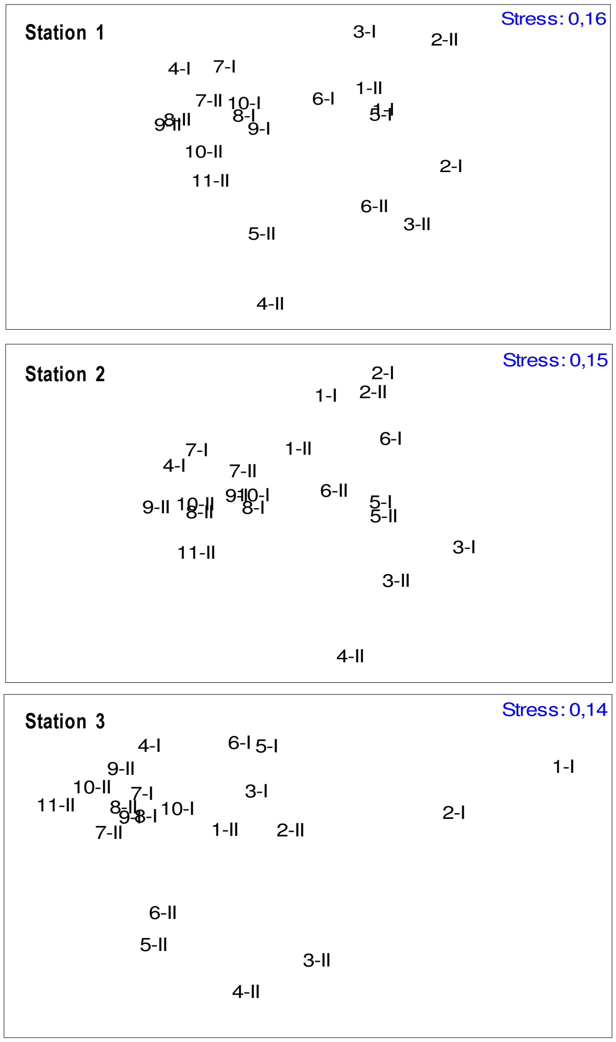

Fig. 5: Two-dimensional MDS analysis of phytoplankton abundance in Liman lake during 2002-2003 (I: 2002; II: 2003)

presence of *Merismopedia punctata*. The second group is formed by all season samples.

MDS ordination 2-dimensial was performed using similarities between samples. In the ordination graph, 2003 March, April and 2002 January, February months are progressive more distant at three stations (Fig. 5).

Relative species abundance (evenness) around 0 indicated a high single-species dominance *(i.e. Pseudanabena limnetica)* that formed 95% of the total organism number with 92415 ind.ml^{-1} in July 2002. The bloom pattern of this species resulted in decrease of *H'*, indicating low evenness. Evenness ranging from near to 1 in May 2003 indicated equal abundance of all species at Station 1. Shannon Diversity was similar and rather low at both stations although 130 taxa were identified in the lagoon. The reasons for the low diversity can be the low light and salinity. Salinity and diversity correlates negatively as commonly observed for different kinds of biota in the case of lake Ferto (Padisak *et al.*, 2006; Kalff, 2002).

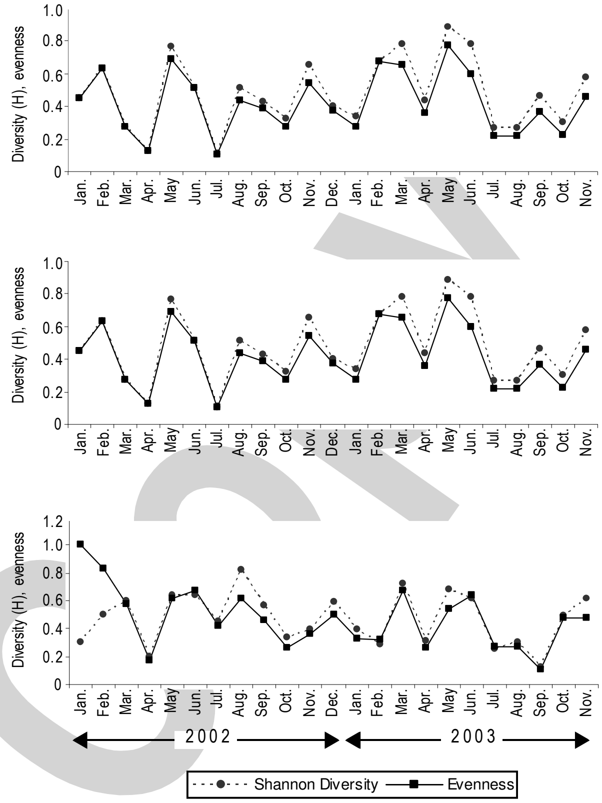

Fig. 6: Shannon diversity and evenness at the sampling stations

Minimum and maximum diversity values (0.101 and 0.765 bits.mm^{-3}) were recorded in July and June 2003 at Station 2. *Pseudanabaena limnetica* comprised 94% of total organism numbers and showed high dominance values, low richness and diversity in September 2003 at Station 3. Evenness reached its highest level (1) in January 2002 in the same station (Fig. 6). High species diversity values usually indicate diverse and well-balanced communities, while low values indicate stress or impact (Bode *et al.*, 2002). Lowest diversity index value (0.101 bits.mm^{-3}) was registered in 2003 July at Station 2. The potential for such a low species diversity and biomass also indicates substantial pollution. The most important stresses on Liman lake are organic enrichments, nutrients, pesticides, herbicides, physical changes by canalisation and sediment load, as the same in Tatli lake (Soylu and Gonulol, 2006) and Gici lake (Soylu *et al.*, 2007).

Acknowledgments

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