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Research Article

The Influence of Certain Physical and Chemical Variables on the Seasonal Dynamics of Phytoplankton Assemblages of a Source Inlet and the Outlet of the Shallow Hypertrophic Lake Manyas, Turkey

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Abstract: The relationships between water discharge, temperature, pH, conductivity, turbidity, nitrate, ammonium, phosphate and the seasonal dynamics of phytoplankton assemblages of one of the inlets, which is a source of waste for the lake, and the sole outlet of the shallow hypertrophic Lake Manyas, Turkey, were studied from January 2003 to August 2005. Conductivity, ammonium, nitrate, and phosphate concentrations were higher at the inlet than at the outlet. Diatoms and cyanobacteria were the dominant phytoplankton groups at both stations. *Achnantes microcephala* (Kütz.) Cleve was dominant throughout the year and *Microcystis aeruginosa* Kütz. was dominant in summer at both stations. *Planktothrix rubescens* Anagnostidis & Komarek and *Phacus pusillus* Lemmerm. were the subdominant species at Sığırcı Inlet in summer and autumn. Multiple regression analysis showed that conductivity and turbidity were the best predictors of phytoplankton biovolume at the inlet and of water discharge at the outlet. The purpose of this study was to determine the relationships between certain physical and chemical variables and the seasonal dynamics of phytoplankton assemblages of a waste source inlet and the sole outlet of the shallow hypertrophic Lake Manyas, Turkey.

Key Words: Conductivity, phytoplankton biovolume, regression analysis, turbidity, water discharge

Sığ ve Hipertrofik Manyas Gölünün Atık Kaynağı Olan Girişlerinden Birinde ve Suyun Çıkış Noktasında Bazı Fiziksel ve Kimyasal Değişkenlerin Fitoplankton Topluluklarının Mevsimsel Dinamiklerine Etkisi

Özet: Sığ ve hipertrofik Manyas Gölünün atık kaynağı olan girişlerinden birinde ve suyun çıkış noktasında fitoplankton topluluklarının mevsimsel dinamikleri ile su debisi, sıcaklık, pH, elektriksel iletkenlik, bulanıklık, nitrat, amonyum ve fosfat arasındaki ilişkiler Ocak 2003 ile Aralık 2005 tarihleri arasında çalışılmıştır. Elektriksel iletkenlik, nitrat, amonyum ve fosfat derişimleri girişte çıkıştan daha yüksek olarak bulundu. Diyatom ve Siyanobakteriler her iki istasyonda da dominant fitoplankton grupları olarak bulundu. *Achnantes microcephala* (Kütz.) Cleve yıl boyu ve *Microcystis aeruginosa* Kütz. yaz aylarında heri iki istasyonda dominant olarak bulundu. *Planktothrix rubescens* Anagnostidis & Komarek ve *Phacus pusillus* Lemmermann yaz ve sonbahar aylarında Sığırcı girişinde subdominant türler olarak tespit edildiler. Fitoplankton biyokütlenin tahmininde en iyi parametrenin girişte elektriksel iletkinlik, çıkışta ise su debisi olduğunu çoklu regresyon analizi gösterdi. Bu çalışmanın amacı, sığ ve hipertrofik Manyas Gölünün atık kaynağı olan girişlerinden birinde ve suyun çıkış noktasında fitoplankton topluluklarının mevsimsel dinamikleri ile bazı fiziksel ve kimyasal değişkenler arasındaki ilişkileri tespit etmekti.

Anahtar Sözcükler: Bulanıklık, elektriksel iletkenlik, fitoplankton biyohacmi, regresyon analizi, su debisi

Introduction

In spite of the increasing awareness of the importance of aquatic ecosystems, humans have adversely affected them by releasing excessive nutrients from point and nonpoint sources. As a consequence, phytoplankton blooms and associated disruption of the structure and functioning of these systems have been observed worldwide (Tatrai et al., 2003).

Spatial and temporal patterns of phytoplankton dynamics are predominantly produced by the relative availability of resources in the aquatic environment (Reynolds et al., 2002). To have a better view of the

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factors controlling seasonal patterns of phytoplankton, it is important to understand the relationships between the dynamics of environmental parameters and phytoplankton assemblages (Arhonditsis et al., 2004).

Multivariate statistical analyses help to clarify relationships between environmental variables and organisms living in the system under study (Reghunath et al., 2002). Such analyses have been applied successfully to phytoplankton assemblages from various water bodies (Dokulil & Teubner, 2005)

Few studies have dealt with physical and chemical factors controlling the seasonal dynamics of phytoplankton assemblages in inlets and outlets of shallow, nutrient-rich lakes (Köhler, 1994). The objective of this study was to assess the influence of water discharge, temperature, pH, conductivity, turbidity, nitrate, ammonium, and phosphate on the seasonal dynamics of phytoplankton assemblages in a source inlet and the sole outlet of the shallow hypertrophic Lake Manyas, Turkey.

Materials and Methods

The study site is located at lat 40° 12' N, long 28° 00' E in the province of Balıkesir, Turkey (Figure 1). Lake Manyas is a shallow hypertrophic freshwater lake and it is a permanent wildlife reserve and a Ramsar site. The lake was awarded a class A wetland diploma by the European Council in 1976. The diploma has since been renewed (Turkish Ministry of Environment, 1997). Due to its ecological and limnological importance, various studies have been conducted on the lake in response to the interest in this national resource (Leroy et al., 2002; Albay & Akcaalan, 2003; Karafistan & Arık-Çolakoğlu, 2005).

Lake Manyas has a surface area of 159 km^2, an average depth of 1.5 m, a maximum depth of 3.5 m, and about 250 days of water retention time (Turkish Ministry of Environment, 1997). Sığırcı Stream, one of the tributaries of Lake Manyas, enters the lake at the north-eastern edge. The inlet of Sığırcı Stream was selected as a sampling station because this stream is laden with waste from numerous factories, farms, and households located alongside the stream. Sığırcı Inlet has an average depth of 1 m and it does not stratify throughout the year. Karadere Stream, located at the south-eastern edge, is the sole outlet of the lake. Karadere Outlet has an average depth of 2 m and it does not stratify throughout the year.

Sampling was carried out monthly at Sığırcı Inlet and Karadere Outlet from January 2003 to August 2005. December, January, and February were considered as winter; March, April, and May as spring; June, July, and August as summer; and September, October, and November as autumn. Samples were collected from 10 cm below the surface. Temperature, conductivity, and turbidity were measured using a 6600 model YSI multiprobe. NO_3, NH_4, and PO_4 concentrations were measured spectrophotometrically (APHA, 1995).

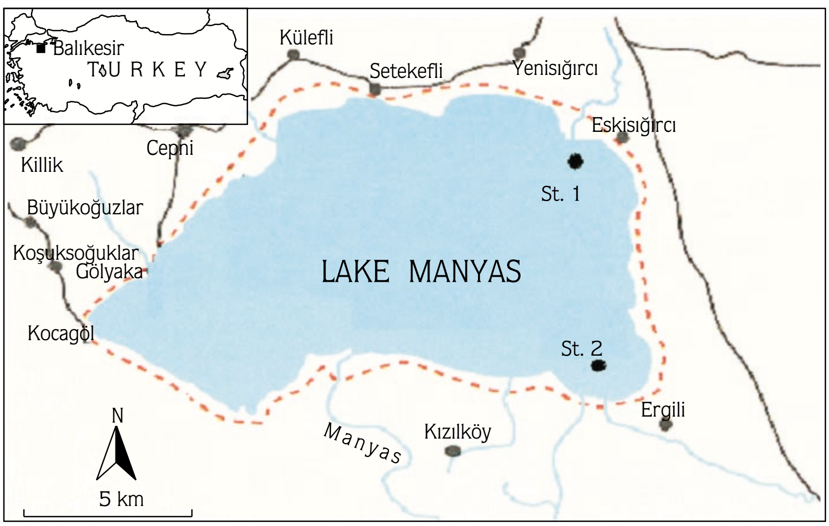


Figure 1. Map of Lake Manyas and its surroundings.

In the field, phytoplankton samples were placed in 250 ml dark bottles and fixed with Lugol's solution. In the laboratory, the fixed samples were first agitated, then poured into 50 ml graduated cylinders, and were allowed to settle for 24 h. At the end of the settling period, 45 ml of water was aspirated from each graduated cylinder, and the remaining 5 ml of water was poured into a small glass vial for microscopic analysis.

Enumeration and identification of the samples were performed using a Palmer-Maloney plankton counting-cell on a compound microscope, equipped with water immersion lenses and a phase contrast attachment. Phytoplankton species were identified according to the widely used taxonomic keys such as Geitler & Pascher (1925), Huber-Pestalozzi (1961), and Kelly (2000). The seasonal average biovolume of phytoplankton was calculated from cell numbers and cell size measurements (Sun & Liu, 2003). In each sampling period, to calculate the biovolume of each species, the dimensions of 3 specimens were measured. Therefore, a total of 12 specimens were used to calculate the seasonal average biovolume of each species. The reason for using 3 specimens instead of 1 was that the dimensions of each species usually change in response to the changes in the physical, chemical, and biological properties of the environment (Reynolds, 1984).

Data were log-transformed prior to statistical analysis to meet the requirements of the parametric tests. A total of 62 samples (31 for each station) were used in the statistical analysis. The differences in the total number of phytoplankton species and the number of species in each group were tested using an ANOVA test. The relationships between water discharge, temperature, conductivity, pH, turbidity, NO_3 (nitrate), NH_4 (ammonium), PO_4 (phosphate), and the seasonal average biovolume of phytoplankton groups were analysed by multiple regression analysis using SAS software (SAS Institute, 1990).

Results

At Sığırcı Inlet, water discharge was about 380 $m^3 s^{-1}$ (standard deviation (SD): 50) in winter, about 420 $m^3 s^{-1}$ (SD: 30) in spring, about 5 $m^3 s^{-1}$ (SD: 2) in summer, and about 100 $m^3 s^{-1}$ in autumn (SD: 80) (Figure 2a). At Karadere Outlet, water discharge was about 1.11×10^4 $m^3 s^{-1}$ (SD: 565) in winter, 1.13×10^4 $m^3 s^{-1}$ (SD: 630) in spring, 1×10^3 $m^3 s^{-1}$ (SD: 150) in summer, and about 5×10^3 $m^3 s^{-1}$ in autumn (SD: 350) (Figure 2b). The main source of the water to Lake Manyas is Kocaçay Stream. Kocaçay Stream has an average discharge of 1.2×10^3 $m^3 s^{-1}$ in winter (SD: 1200), 1.2×10^4 $m^3 s^{-1}$ in spring (SD: 3143), 400 $m^3 s^{-1}$ in summer (SD: 250), and 5×10^3 $m^3 s^{-1}$ in autumn (SD: 4×10^3). Mürvetler Stream feeds the lake only in spring and dries up in the rest of the year.

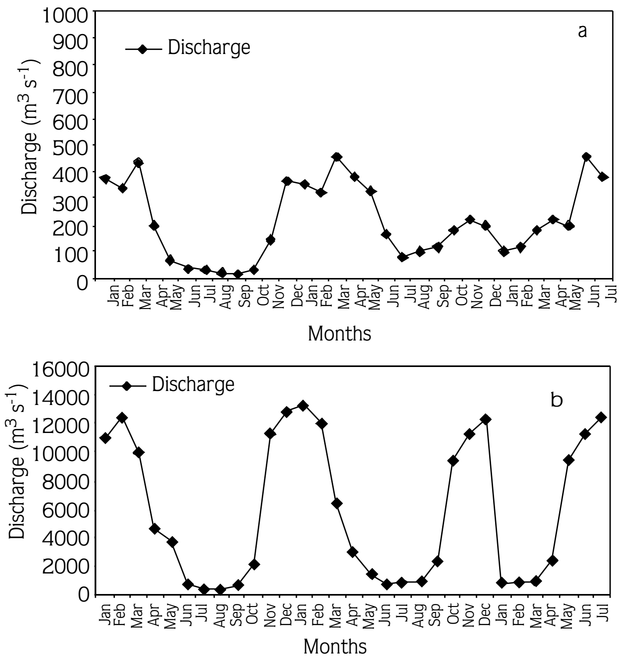


Figure 2. The monthly average values of water discharge ($m^3 s^{-1}$) from January 2003 to August 2005 (from General Directorate of State Hydraulic Works). a) In Sığırcı Stream, b) In Karadere Stream.

At Sığırcı Inlet, temperature was about 5 °C (SD: 3) in winter, about 15 °C in spring (SD: 5), about 27 °C (SD: 4) in summer, and about 18 °C in autumn (SD: 2.5) (Figure 3a). Conductivity values were about 0.4 mS cm^{-1} (SD: 0.11) in spring and about 0.9 mS cm^{-1} (SD: 0.23) for the rest of the year (Figure 3b). pH values were about 9 (SD: 2.1) in spring, 8 (SD: 1.34) in summer and autumn, and about 7 (SD: 1.11) in winter (Figure 3c). Nitrate concentration was about 6 mg l^{-1} (SD: 1.2) in summer and about 5 mg l^{-1} (SD: 0.67) in winter (Figure 3d). Ammonium concentrations were around 0.001 mg l^{-1}

(SD: 0.0009), except for a summer peak of 0.01 mg l^{-1} (SD: 0.0056) (Figure 3e). Phosphate concentrations were about 0.7 mg l^{-1} (SD: 0.13) in spring and about 0.2 mg l^{-1} (SD: 0.081) in winter (Figure 3f).

At Karadere Outlet, temperature was about 5 °C (SD: 3) in winter, about 14 °C (SD: 5.5) in spring, about 26 °C (SD: 3) in summer, and about 22 °C (SD: 4) in autumn (Figure 4a). Conductivity values were about 0.3 mS cm^{-1}

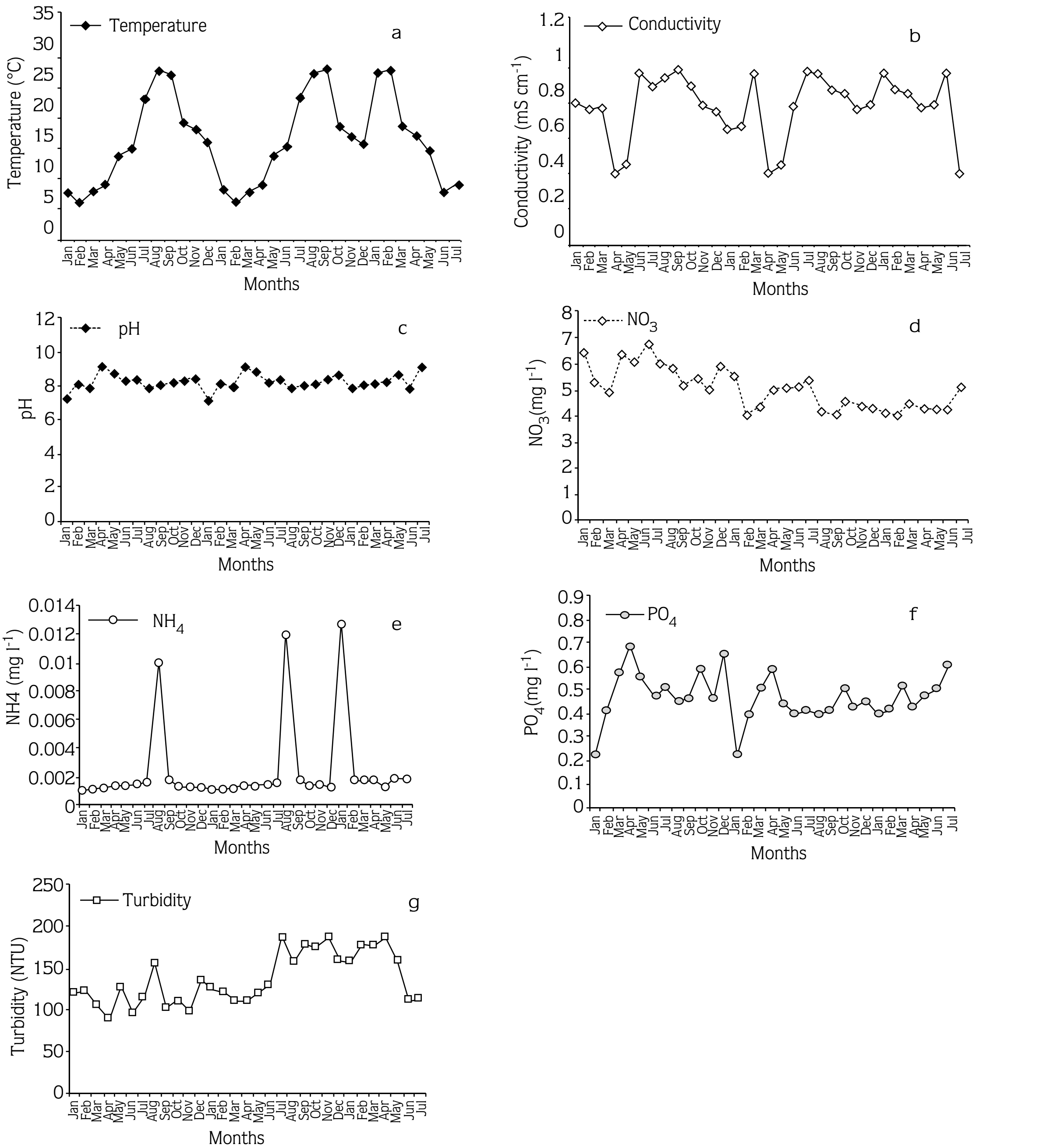


Figure 3. Monthly average values of temperature (°C) (a), conductivity (mS cm^{-1}) (b), pH (c), nitrate (NO_3) (mg l^{-1}) (d), ammonium (NH_4) (mg l^{-1}) (e), phosphate (PO_4) (mg l^{-1}) (f), and turbidity (NTU) (g) between January 2003 and August 2005 at Sığırcı Inlet.

(SD: 0.10) in winter and spring and about 0.4 mS cm^{-1} (SD: 0.12) in summer and autumn (Figure 4b). pH values oscillated about 8.5 (SD: 1.3) throughout the study period (Figure 4c). Nitrate concentrations were about 5 mg l^{-1} (SD: 1.43) in winter, 4.5 mg l^{-1} (SD: 1.4) in spring, and about 3.5 mg l^{-1} (SD: 1.1) in summer and autumn (Figure 4d). Ammonium concentrations were about 0.001 mg l^{-1} (SD: 0.00082) throughout the year, except for a summer peak of 0.005 mg l^{-1} (SD: 0.0009) (Figure 4e). Phosphate concentrations were about 0.2 mg l^{-1} (SD: 0.096) in summer and 0.1 mg l^{-1} (SD: 0.054) for the rest of the year (Figure 4f).

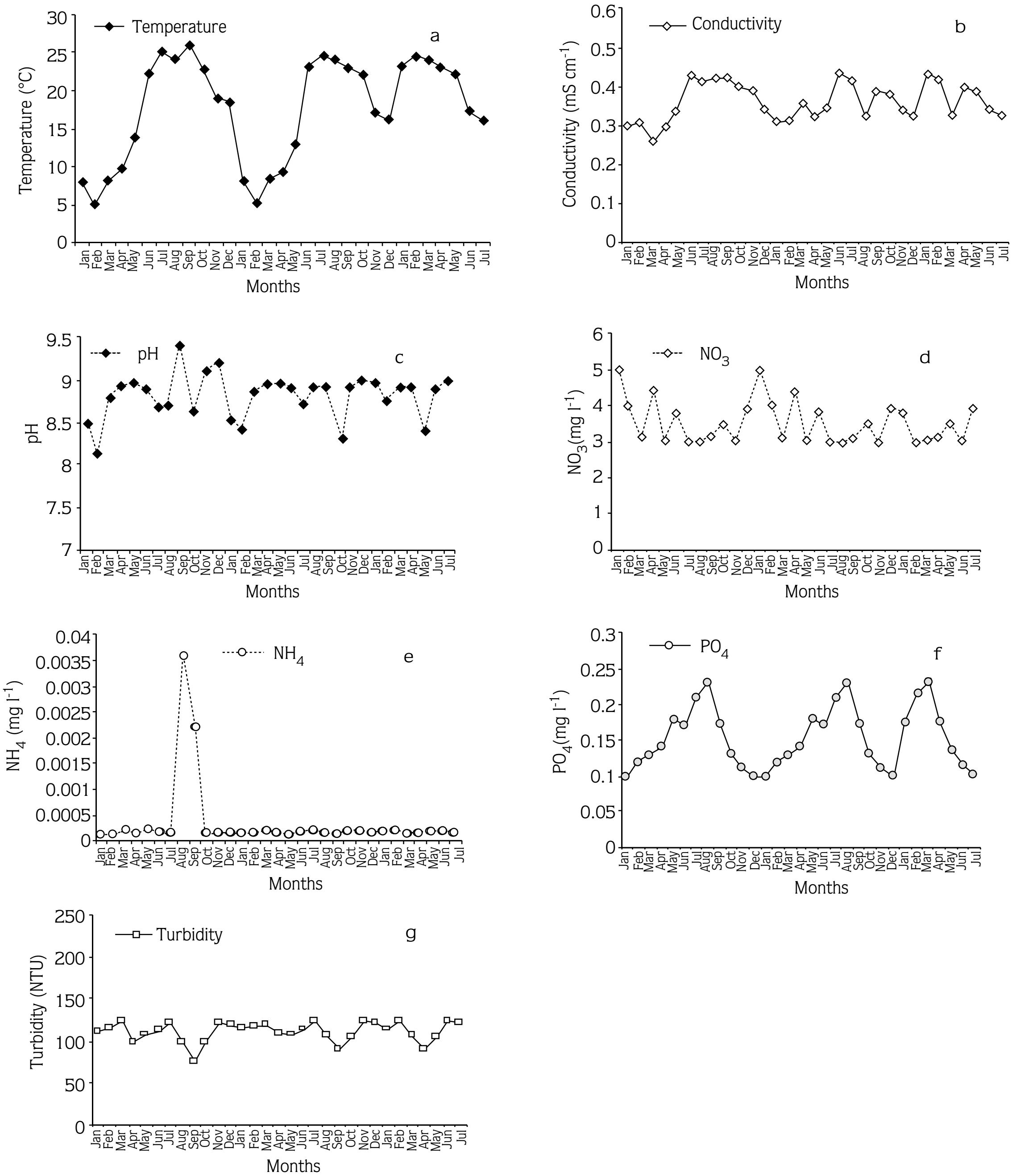


Figure 4. Monthly average values of temperature (°C) (a), conductivity (mS cm^{-1}) (b), pH (c), nitrate (NO_3) (mg l^{-1}) (d), ammonium (NH_4) (mg l^{-1}) (e), phosphate (PO_4) (mg l^{-1}) (f), and turbidity (NTU) (g) between January 2003 and August 2005 at Karadere Outlet.

At the inlet, the total phytoplankton biovolume was 4.7×10^7 µm^3 l^{-1} in winter, 7.7×10^7 µm^3 l^{-1} in spring, 4.2×10^7 µm^3 l^{-1} in summer, and 1.1×10^7 µm^3 l^{-1} in autumn. At the outlet, the total phytoplankton biovolume was 5.6×10^7 µm^3 l^{-1} in winter, 7.6×10^7 µm^3 l^{-1} in spring, 8.2×10^7 µm^3 l^{-1} in summer, and 3.4×10^7 µm^3 l^{-1} in autumn (Figure 5).

At Siğirci Inlet, *Achnanthes microcephala* (Kütz.) Cleve comprised 46% of the total phytoplankton biovolume in winter and 40% in spring; *Microcystis aeruginosa* Kützing 45% in summer and 30% in autumn; *Planktothrix rubescens* Anagnostidis & Komarek 40% in autumn; and *Phacus pusillus* Lemmermann 40% in summer (Figure 6a). At Karedere Outlet, *Achnantes microcephala* comprised 50% of the total phytoplankton biovolume in winter and spring; *Leptolyngbya tenuis* (Gomont) Anagnostidis & Komarek 50% in winter; *Microcystis aeuriginosa* 30% in summer, and *Gomphosphaeria aponina* Kütz. 25% in summer (Figure 6b).

At Sığırcı Inlet, turbidity and conductivity came out as predictive variables for Bacillariophyta biovolume when running the forward selection procedure of the regression analysis; water temperature and nitrate as predicting variables for Chlorophyta biovolume; nitrate, conductivity, and phosphate as predictive variables for cyanobacteria biovolume; and conductivity and turbidity as predictive variables for Euglenophyta biovolume (Table).

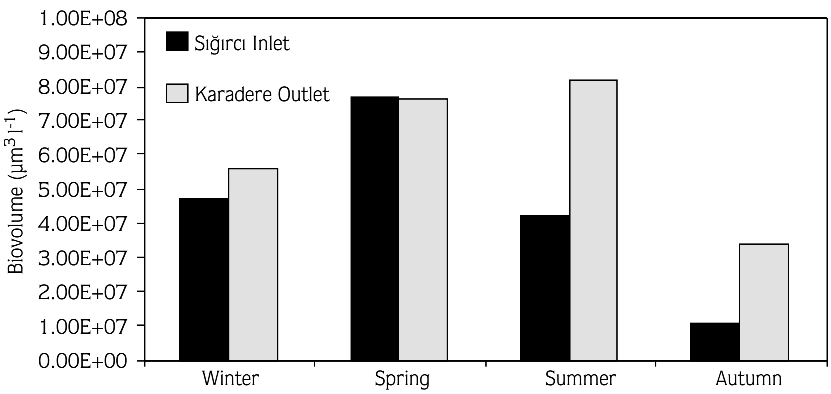
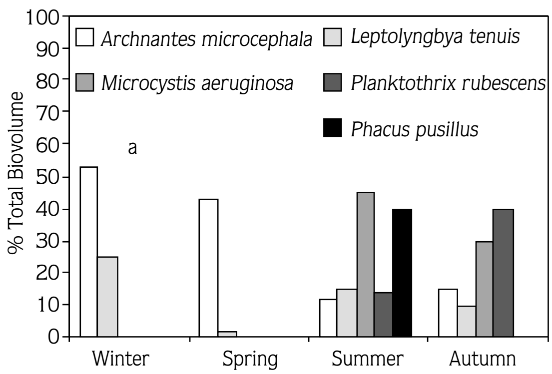


Figure 5. The seasonal average of the total phytoplankton biovolume (µm^3 l^{-1}) at Sığırcı Inlet and Karadere Outlet.



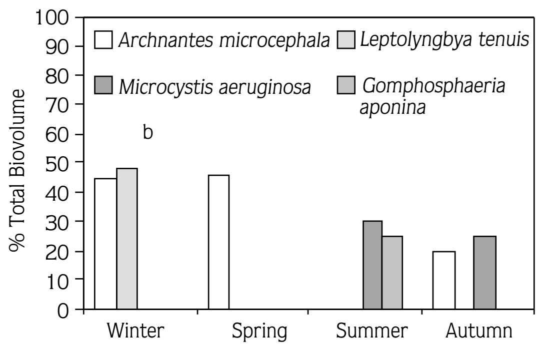


Figure 6. The percentage (%) contribution of the dominant phytoplankton species to the total biovolume. a) at Sığırcı Inlet, b) at Karadere Outlet.

Table. Regression models for predicting the biovolume of the phytoplankton groups at Sığırcı Inlet and Karadere Outlet of Lake Manyas between January 2003 and August 2005.

Group / Station	Bacillariophyta	Chlorophyta	Cyanobacteria	Euglenophyta
Sığırcı	log[V] = 0.44 + 0.2 log[Turb.] + 0.25 log[Cond.]* ($n = 31$, $R^2 = 0.45$)	log[V] = -36.3 + 2.5 log[Temp.] + 33.3 log[NO_3] * ($n = 31$, $R^2 = 0.58$)	log[V] = -30.8 + 21.8 log[NO_3] – 7.8 log[Cond.] + 9.7 log[PO_4]* ($n = 31$, $R^2 = 0.44$)	log[V] = -0.97 - 0.51 log[Cond.] + 0.93 log[Turb.]** ($n = 31$, $R^2 = 0.97$)
Karadere	log[V] = -10 -3 log[Discharge] – 13.9 log[PO_4]# ($n = 31$, $R^2 = 0.24$)	log[V] = 11.5 – 1.4 log[Discharge] +11.9 log[pH]# log[Turb.]# ($n = 31$, $R^2 = 0.15$)	log[V] = 12 – 1.4 log[Discharge] + 0.4 log[NH_4] –10.3 log[Turb.]# ($n = 31$, $R^2 = 0.27$)	log[V] = -3.8 – 1.5 log[Discharge] –2.5 log[Temp.]+ 0.3 log[NH_4]* ($n = 31$, $R^2 = 0.45$)

#P > 0.05 *P < 0.05 **P < 0.01

At Karadere Outlet, water discharge and phosphate came out as predictive variables for Bacillariophyta biovolume when running the forward selection procedure of multiple regression analysis; water discharge, pH, and turbidity as predictive variables for Chlorophyta biovolume; water discharge, ammonium, and turbidity as predictive variables for the biovolume of cyanobacteria; and water discharge, temperature, and ammonium as predictive variables for the biovolume of Euglenophyta (Table).

Out of the total of 156 phytoplankton species, 145 were recorded from Sığırcı Inlet and 105 from Karadere Outlet during the study. ANOVA results showed that the total number of the phytoplankton species were significantly different between the inlet and the outlet ($F = 55$, $P < 0.05$). The number of species in each group was also significantly different between the inlet and the outlet ($F = 35$, $P < 0.05$).

Discussion

Conductivity, nitrate, ammonium, and phosphate concentrations were higher at the inlet than they were at the outlet. The higher values were attributable to the direct entrance of untreated waste from factories, farms, and households carried by Sığırcı Stream. The lower levels of nutrients at the outlet probably resulted from dilution, sedimentation, and uptake by the lake biota (Perkins & Underwood, 2000). Nutrients are diluted, settled, and probably used by the lake biota by the time they arrive at the outlet, as this station is farther down from the waste entrance point.

The total number of phytoplankton species was higher at Sığırcı Inlet than at Karadere Outlet. The higher number of species at Sığırcı Inlet was probably due to the longer water residence time at this station. Longer water residence time enhances the development of additional phytoplankton, especially cyanobacteria. Cyanobacteria are known to have longer generation time than other phytoplankters and, therefore, are more susceptible to drifting (Reynolds, 1984). Sığırcı Stream has low water discharge, which results in longer water residence time at the inlet. The lower species number of cyanobacteria at Karadere Outlet was attributable to higher discharge rates compared with Sığırcı Inlet.

The regression analysis showed that conductivity and turbidity were the best predictors of phytoplankton biovolume at the inlet and water discharge at the outlet. This is probably due to the fact that water discharge controls the water residence time, which controls the growth of phytoplankton in the inlet type systems (Köhler, 1994). Water discharge to Sığırcı Inlet is almost negligible during summer and early autumn when the water level drops to about 0.5 m. This, in turn, causes high conductivity during warm seasons when cyanobacteria and Euglenophyta are abundant. Dinka et al. (2004) found out that when water level increased in a shallow lake (Neusiedler See), on the Hungarian-Austrian border, it prevented an increase in conductivity. At Sığırcı Inlet, the maximum depth varied from 1.56 to 0.43 m throughout the study period. During high water level usually Bacillariophyta was dominant, while during low water level Cyanobacteria and Euglenophyta were dominant.

Water discharge was one of the predictive variables of the biovolume of all phytoplankton groups at Karadere Outlet. At Sığırcı Inlet, on the other hand, the discharge was not a significant variable for predicting the biovolume for any phytoplankton group. This was probably due to the fact that water discharge at the inlet was usually too low to drive the dynamics of phytoplankton, especially during the warm seasons when plankton are more active (Muylaert et al., 2000).

Temperature and turbidity were significant variables for predicting the biovolume of chlorophyta. This suggests that optimum light and temperature were driving the dynamics of chlorophytes in the inlet and outlet of Lake Manyas. Temponeras et al. (2000) found similar results from a shallow Macedonian-Greek lake.

Cyanobacteria were usually abundant in summer. High temperature and turbidity and perhaps low water discharge played a critical role in the selection of this group during warm seasons (Reynolds, 1984). High turbidity is a result of continues wind-induced turbulence since the lake is shallow and the bottom is covered by mud (Büyükışık & Parlak, 1989).

Anabaena spiroides Klebahn, *Aphanocapsa elachista* W.West & G.S.West, *Gomphosphaeria aponina* Kütz., *Merismopedia tenuissima* Lemmermann, and *Microcystis aeruginosa* were frequently collected from both stations in summer. These species are known to thrive well in shallow, nutrient-rich aquatic environments with relatively longer water residence time (Olding et al., 2000). High temperature, nutrients, and turbidity probably played a critical role in the selection of these species. Turbidity was always higher than 100 NTU at both stations, meaning that the light must have been limited to the majority of phytoplankton.

Planktothrix rubescens and *Phacus pusillus* were collected only during the summer when ammonium concentration and water temperature were high. *Planktothrix rubescens* is known as a common member of the phytoplankton assemblages of wind-exposed eutrophic shallow lakes with reduced light availability (Reynolds et al., 2002). *Phacus pusillus* was the most dominant euglenoid that grew excessively during the summer at Sığırcı Inlet. Shipin et al. (1999) found that *Phacus pusillus* was a versatile heterotroph and grew well under low light and hypertrophic conditions. Sığırcı Inlet, with high nutrient concentrations, conductivity, and turbidity, seemed to be a favourable place for this euglenoid.

Cyclotella stylorum Brightwell, *Achnanthes microcephala*, *Fragilaria pinnata* Ehrenb., *Nitzschia palea* Grunow, and *Scenedesmus communis* Hegewald were abundant throughout the year at both stations. The abundance of these species could be attributable to the general characteristics of the sampling stations such as high nutrient levels, high turbidity, and shallowness (Reynolds et al., 2002). *Fragilaria pinnata* is known as an indicator of eutrophic waters (Akbay et al., 1999). Although *Cyclotella staylorium* is known to grow best in oligotrophic lakes, this species is commonly collected from the eutrophic lakes across Turkey (Akbay et al., 1999).

In summary, the regression analyses showed that high water discharge is the driving factor of phytoplankton dynamics, but it loses its importance when it drops to the level that it cannot wash away phytoplankton in the inlet and outlet of shallow lakes. The lower discharge allows a greater retention time for planktonic algae, which, in turn, enhances the growth of phytoplankton populations in nutrient rich environments. Finally, turbidity, water temperature, and conductivity also seem to be the critical variables for predicting the seasonal patterns of phytoplankton biovolume in inlets and outlets of shallow hypertrophic lakes.

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