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Seasonal Variations of Phytoplankton Community in Relation to Some Physical and Chemical Parameters in a Temperate Eutrophic Reservoir, Turkey

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Abstract

The Çaygören Reservoir is fed by the Simav Streamand the maximum inflow (1300 m^3 sec^{-1}) occurred in spring and the minimum (about 5.2 m^3 sec^{-1}) occurred in fall. It has an annual mean water capacity of 392 hm^3 and a total volume of 142.57 hm^3. A total of 192 taxa in 9 divisions were identified. *Cyclotella meneghiniana* Kützing, *Stephanodiscus neoastraea* Hakansson and Hickel of Bacillariophyta, *Gloeotila subconstricta* (G.S.West) Printz of Chlorophyta, *Mugeotia* sp. of Streptophyta, *Cryptomonas pyrenoidifera* Geitler, *Plagioselmis nannoplanctica* (H.Skuja) G.Novarino, I.A.N.Lucas and S.Morrall of Cryptophyta, *Aphanocapsa holsatica* (Lemmermann) G.Cronberg and J.Komárek, *Aphanothece clathrata* West and G.S.West and *Planktothrix* sp.of Cyanobacteria dominated phytoplankton at least for one season during the observation period. Species of Cryptophyta dominated phytoplankton during the winter, while Chlorophyta and Streptophyta species were dominant in the fall. Bacillariophyta species dominated phytoplankton in the spring and Cyanobacteria were dominant in the summer. The maximum phytoplankton biomass and abundance (106.5 mg L^{-1}; 273154 individual M^{-3}) were recorded in summer 2008 at the third station and the minimum biomass and abundance (0.23 mg L^{-1}; 799 individual M^{-3}) were recorded in winter 2007 at the second station. The canonical correspondence analysis (CCA) and correlation results showed that water temperature, transparency, phosphate, oxidation-reduction potential and water discharge had significant effects (Monte Carlo test, $p<0.05$) on the dynamics of dominant phytoplankton of the eutrophic Çaygören Reservoir.

Keywords: Phytoplankton, Temperate Eutrophic Reservoir, Water Discharge, Water Quality Parameters, CCA.

1. Introduction

Çaygören reservoir was built between 1965 and 1968 for the purpose of irrigation and hydropower generation. It is an important source of irrigation water for the towns of Sındırgı and Bigadiç in the province of Balıkesir, Turkey. It is used for flood control as its source stream (Simav Stream) sometimes reaches about 1500 m^3 sec^{-1} debt. The Çaygören Reservoir has a total length of 4.6 km, a surface area of 8.15 km^2 and a maximum depth of 53.5 m. The purpose of the present study is to determine the environmental variables responsible for the seasonal variations of the abundance, species composition and the biomass of the phytoplankton community of the temperate eutrophic Çaygören Reservoir.

Phytoplankton communities play an important role in aquatic ecosystems as they produce food and oxygen, which supports all other life forms (Fathiet al., 2001). Knowledge on their abundance and community composition provided further understanding of ecological interactions in aquatic ecosystems. The seasonal dynamics of phytoplankton have been investigated worldwide (Taveriniet al., 2009; Jeppesenet al., 2011; Elliott, 2012; Caroni et al., 2012; Feuchtmayret al., 2012).

In northern temperate lakes, phytoplankton succession is largely determined by the seasonal cycles of physical, chemical and biological factors, the relative importance of which varies with the different periods of the year (Tiinaet al., 2011). The spatial distribution of phytoplankton in lakes is highly heterogeneous. This heterogeneous distribution is mostly attributed to wind events,

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mixing and the contrasting gradients in the light and nutrient concentrations (Reynolds et al., 2002).

Considering the complexity of phytoplankton dynamics, studying the spatial and seasonal distribution of species and their relationships with the physicochemical parameters can give insights into understanding factors responsible for their dynamics. Arhonditsiset al 2004) stated that to determine which factors are effective on spatial and temporal distribution of phytoplankton, the system under study should have been sampled for at least two years.

The underwater light climate seems to be one of the selective environmental factors that strongly influence the species composition and biomass of phytoplankton in lakes. Water transparency has received much attention lately because of the self-limitation of photosynthesis imposed by phytoplankton. In turbid environments, algal species with gas vesicles can either move down to avoid the high light intensity at the water surface, or float up when underwater light conditions are poor (Pérez et al., 2007).

Nutrient limitation imposes compositional changes on the phytoplankton community. According to resource competition theory, nitrogen-fixing algae should dominate lakes when nitrogen is limiting. Assuming that phosphorus and nitrogen limit many algae in lakes, blue-green algae should dominate lakes when N:P ratios are low but other types should dominate when they are high (Chaffin et al., 2011).

For a better understanding of the processes affecting phytoplankton dynamics, it is important to study the linkage between changes in environmental variables and phytoplankton abundance, biomass and community composition (George et al., 2004). Multivariate statistical techniques have been proved to be useful for understanding interactions between the ecological factors and plankton communities in aquatic ecosystems (Kruk et al., 2002).

Although few studies have been published on the Çaygören Reservoir (Sevindik, 2010; Sevindiket al., 2011), the present study is the first attempt to describe the seasonal and spatial distribution of environmental variables and their relations with the phytoplankton composition in the temperate eutrophic Çaygören Reservoir using Canonical Correspondence Analysis (CCA) and Pearson’s correlation analysis.

2. Materials and Method

2.1. Study Area

The Çaygören Reservoir is located at 39° 17' 24" N; 28° 19' 16" E, 55 km southeast of Balıkesir, Turkey (Fig. 1). It lies at 273 m above the sea level and has a maximum depth of 28 m, a length of 4.6 km and a surface area of 9 km^2. The reservoir is fed by the Simav Stream. Its construction started in 1971 and it is used for irrigation and power generation (State Water Works, 2005).

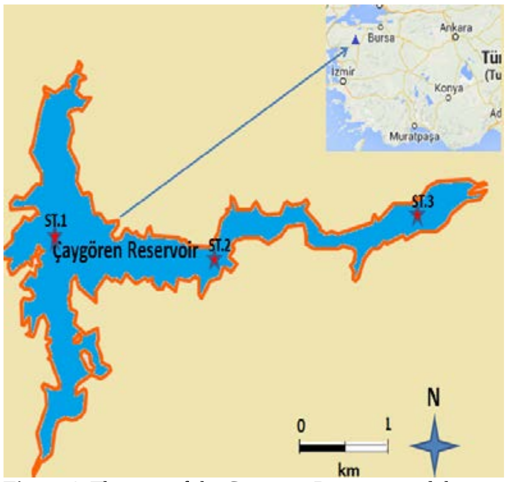

Figure 1. The map of the Çaygören Reservoir and the location of sampling stations (I think this should be placed under the figure above this paragraph or the figure should be moved to above this caption)

2.2. .Sampling Procedure and Chemical Analysis

Water sampling was carried out monthly from February 2007 to January 2009 for measurements of physical, chemical and biological parameters. Samples were collected vertically at 5 m intervals using a Kemmerer water sampler. Specific Conductivity (SC), pH, Oxidation-Reduction Potential (ORP) and water Temperature (T) were measured at 1 m intervals using a YSI multi probe. Water transparency was measured using a Secchi disk.

Concentrations of phosphate (PO_4), nitrate-nitrogen (NO_3-N) and ammonium-nitrogen (NH_4-N) were determined spectrophotometrically in samples collected from 1, 5 and 15 meters according to the standard methods (APHA, 1995). Water Discharge (WD) data were obtained from the State Water Works.

For the purpose of minimizing the errors, calibration of apparatus, running of blank and sample at known concentration, measurements in replicate were performed in the laboratory. The accuracy and precision of the used analytical methods were checked by means of standard samples, which were assayed with each series of samples (Table 1). A multipoint calibration of the YSI multi probe was done one day prior to the sampling. Zero and span checks were made regularly as the basic quality assurance procedure for analysis.

Table 1. Mean ± Standard deviation (SD) physical and chemical water characteristics for water quality parameters in the Çaygören Reservoir

Parameter	Depth	Control	St. 1	St. 2	St.3
Tmp	1 m	15.2±6.35	14±6.8	14±6.3	15±6.3
(^{o}C)	10 m	16.1±7.71	15±7.8	14±6.4	15±6.45
	15 m	13.9±7.65	14.6±7.1	13.9±6.39	13.9±6.38
Cond	1m	0.44±0.089	0.43±0.09	0.44±0.07	0.43±0.08
(mS cm^{-1})	10 m	0.46±0.081	0.44±0.08	0.24±0.04	0.24±0.07
	15 m	0.45±.0.0074	0.44±0.075	0.23±0.05	0.23±0.06
pH	1 m	9.9±0.59	9.8±0.6	9.78±0.61	9.73±0.63
	10 m	9.9±0.579	9.7±0.59	9.5±62	9.87±61
	15 m	9.8±0.61	9.75±0.58	10.9±5.91	10.8±5.71
ORP	1 m	102±43	102±42	101±48	101±43
(mV)	10 m	103±44.5	102±45	104±31	104±32
	15 m	100±43.12	101±43	103±34	103±33
PO_4	1 m	0.023±0.009	0.022±0.008	0.02±0.002	0.02±0.0012
(mg L^{-1})	10 m	0.024±0.009	0.024±0.01	0.034±0.02	0.031±0.013
	15 m	0.024±0.01	0.023±0.011	0.031±0.0079	0.03±0.0071
NO_3	1 m	0.19±0.051	0.2±0.05	0.21±0.05	0.23±0.045
(mg L^{-1})	10 m	0.21±0.043	0.2±0.04	0.18±0.04	0.19±0.038
	15 m	0.19±0.041	0.18±0.039	0.21±0.045	0.23±0.042
NH_4	1m	0.048±0.0023	0.05±0.002	0.025±0.0012	0.042±0.0011
(mg L^{-1})	10 m	0.071±0.0051	0.07±0.005	0.023±0.0011	0.041±0.0013
	15 m	0.072±0.0025	0.068±0.002	0.043±0.0021	0.043±0.0012
TSS	1 m	15.5±6.56	16±6.3	14±4.5	14±4.5
(mg L^{-1})	10 m	17±7.69	17±7.7	14.6±5.7	15.6±4.7
	15 m	16.8±7.25	16±7.2	15.9±6.5	15.9±4.5

2.3. Phytoplankton Sampling and Analysis

In the field, samples for phytoplankton were collected from 1, 5 and 15 meters and placed in 250 ml bottles and fixed with Lugol's solution. In the laboratory, the samples were first agitated, then poured into 50 ml graduated cylinders and were allowed to settle for 24 hours. At the end of the settling period, 45 ml of water was aspirated from each graduated cylinder and the remaining 5 ml was poured into a small glass vial for microscopic analysis. Enumeration and identification of phytoplankton were performed using a Palmer-Maloney counting cell and an Olympus BX 51 compound microscope equipped with water immersion lenses (40X and 60X magnifications) and a phase-contrast attachment.

Phytoplankton species were identified according to Huber–Pestalozzi (1941; 1950; 1969; 1972; 1982; and 1983), Bourrelly (1968), Krammer and Lange-Bertalot (1986; 1991; and 1999), Komarek and Anagnostidis (1986; 1989; 1999; and 2008), Anagnostidis and Komarek (1988), Round et al. (1990), Sims (1996) and John et al.(2003). Phytoplankton biomass was calculated from the biovolume data, assuming a specific gravity of one (Edmondson, 1971). Biovolume was calculated from cell numbers and cell size measurements (Sun and Liu, 2003).

2.4. Statistical Analysis

The CCA was used to determine the relationships between the dominant phytoplankton taxa and the environmental variables. The significance of environmental variables on the dominant taxa was determined with Monte Carlo tests. The CCA and Monte Carlo tests were performed using the CANOCO v.4.5 program (ter Braak and Smilauer, 2002). The relationships between the physicochemical variables and the dominant phytoplankton taxa were further analyzed using the Pearson's correlation coefficients.

The statistical differences in the total phytoplankton abundance and biomass were determined using an ANOVA test. The ANOVA and the Pearson's correlation coefficients were calculated using SAS statistical software. Data were log transformed before the statistical analysis to obtain normal distribution (SAS Institute, 2003).

3. Results

3.1. Physico-Chemical Parameters

The maximum (1300 m^3 s^{-1}) and minimum (5.2 m^3 s^{-1}) inflows (WD) were recorded in April 2007 and September 2007, respectively (Fig. 2). Secchi disk depth ranged from 0.3 m to 1.5 m at St.1 and it ranged from 0.6 m to 1.9 m at St.2 and St.3 (Fig. 3). Water temperature ranged from 4.5^{o}C to 27.6 ^{o}C at all stations. Maximum surface water temperature values were measured in June and July and minimum values were measured in February (Fig. 4).

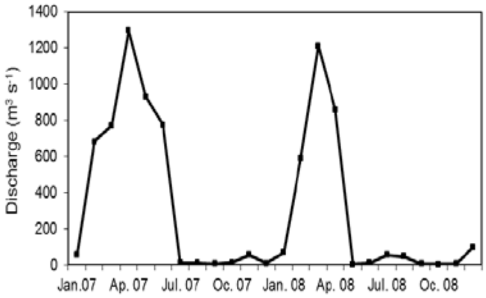

Figure 2. The seasonal variations in the water discharge (m3 s^{-1}) of the Çaygören Reservoir

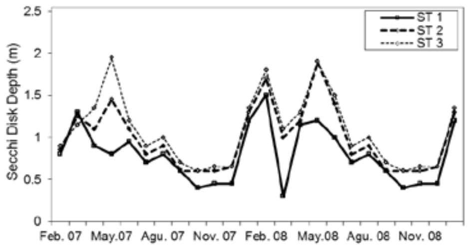

Figure 3 . The seasonal variations in the Secchi disk depth (m) of the Çaygören Reservoir

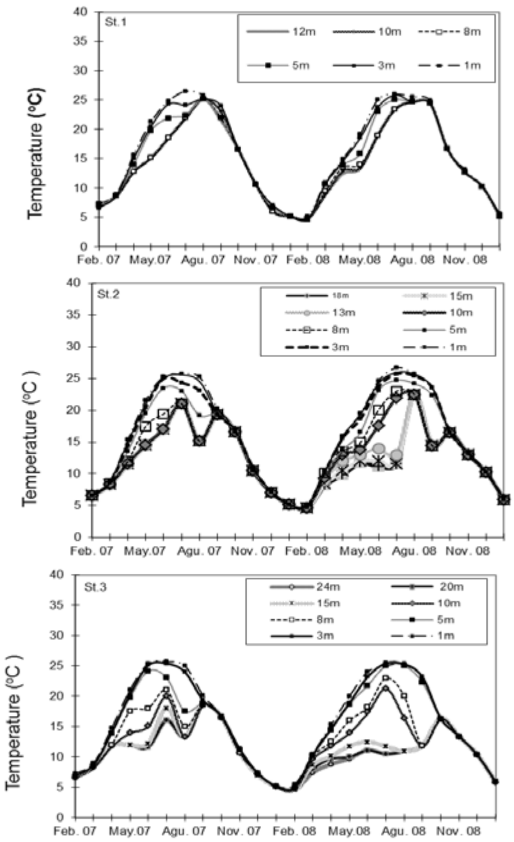

Figure 4. The seasonal variations in the water temperature (^{o}C) of the Çaygören Reservoir.

Specific conductivity ranged from 0.3 mS cm^{-1} to 0.6 mS cm^{-1} at all stations and it was lower in the winter than the other seasons (Fig. 5). pH ranged from 7.4 to 11.6 from February 2007 to September 2008 at all stations. From November 2008 to January 2009, pH fluctuated between 7.7 and 11 (Fig. 6).

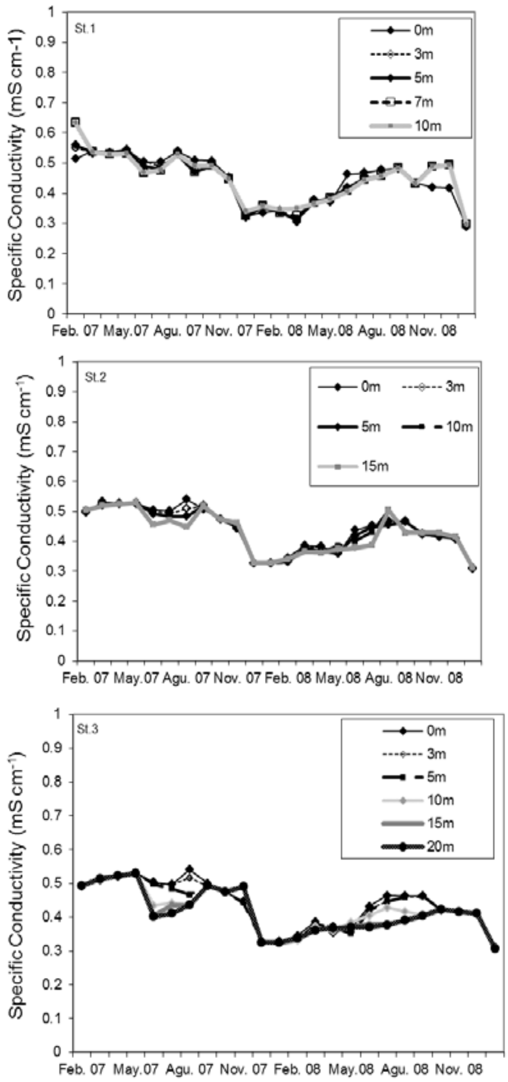

Figure 5. The seasonal variations in specific conductivity (mS cm^{-1}) of the Çaygören Reservoir

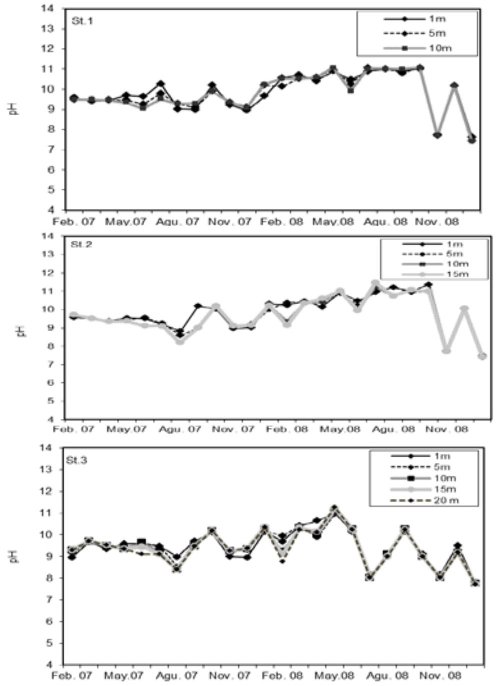

Figure 6 . The seasonal variations inthe pH of the Çaygören Reservoir

ORP ranged from 2 mV to 219.5 mV at all stations and it was lower in the summer than the other seasons (Fig. 7). PO_4 concentrations ranged from 0.005 mg L^{-1} to 0.06 mg L^{-1}, oscillating around 0.02 mg L^{-1} throughout the study period, except for a peak of 0.04 mg L^{-1} in October 2008 at the first station and another one of 0.06 mg L^{-1} in November 2007 at the second station (Fig. 8).

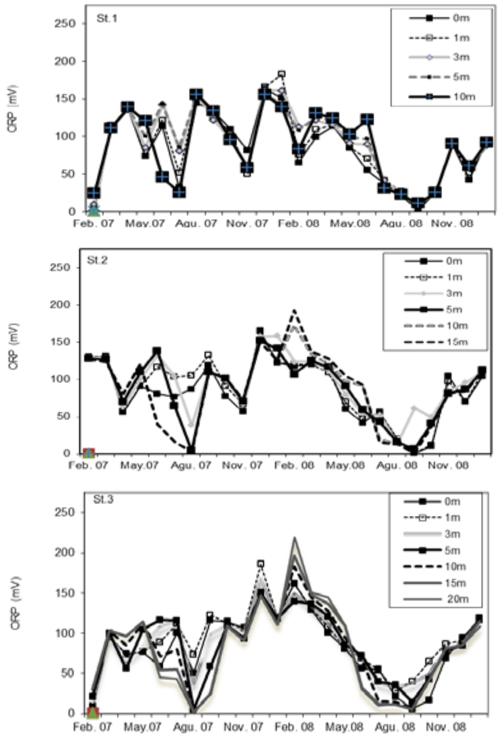

Figure 7. The seasonal variations in the oxidation-reduction potential (mV) of the Çaygören Reservoir

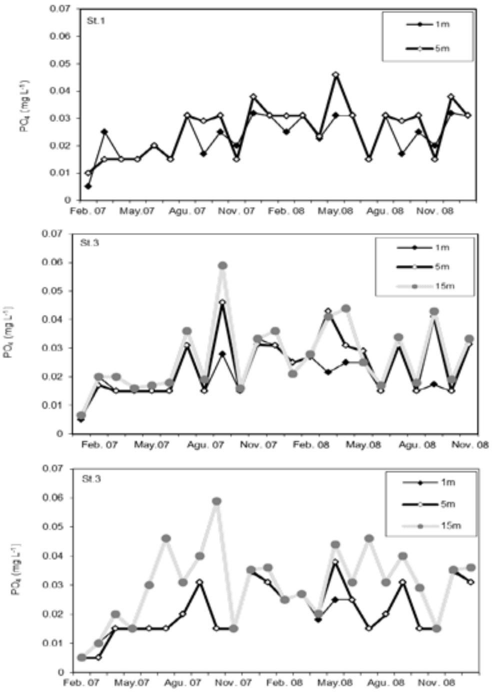

Figure 8 . The seasonal variations inthe phosphate (mg L^{-1}) of the Çaygören Reservoir

NO_3-N concentrations ranged from 0.055 mg L^{-1} to 0.3 mg L^{-1} at all stations. A decline of about 0.05 mg L^{-1} in NO_3-N occurred in the spring and fall at all stations during the study period (Fig.9). NH_4-N concentrations ranged from 0.005 mg L^{-1} to 0.017 mg L^{-1} at the first and second stations and they ranged from 0.001 mg L^{-1} to 0.02 mg L^{-1} at the third station (Fig. 10).

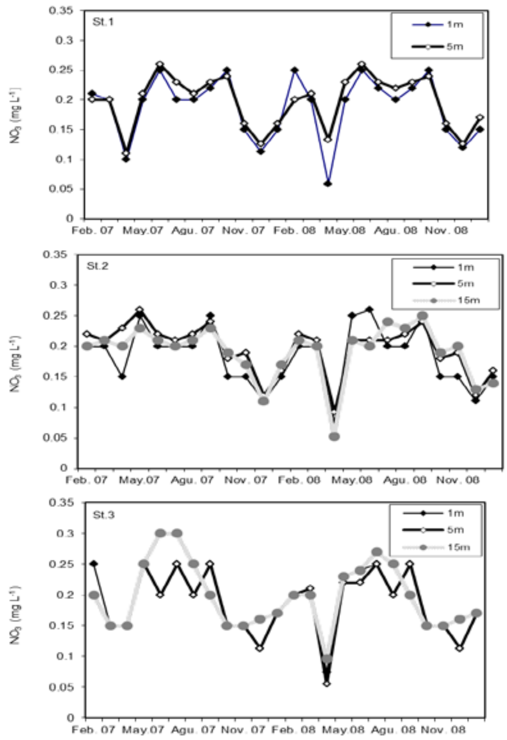

Figure 9. The seasonal variations in nitrate-nitrogen (mg L^{-1})

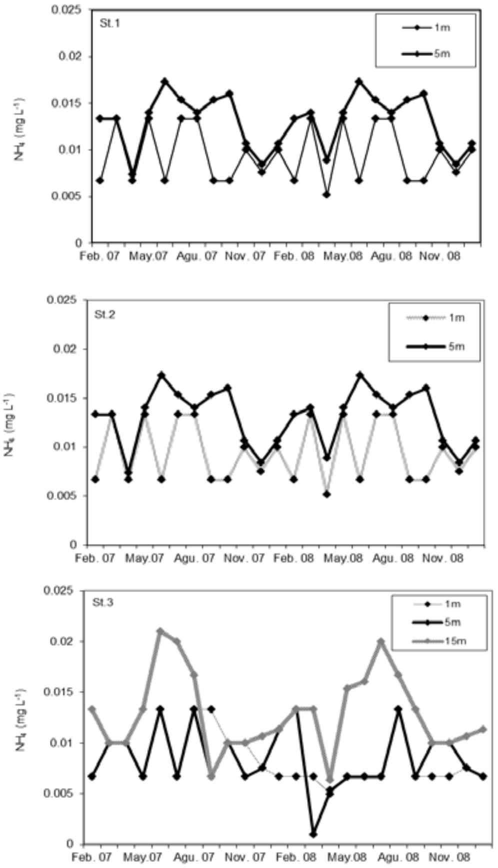

Figure 10. The seasonal variationsin the ammonium-nitrogen (mg L-1) of the Çaygören Reservoir

3.2. Phytoplankton Species and Biomass

A total of 192 taxa in nine major taxonomic categories were identified. During the winter, *Plagioselmis nannoplanctica* (H.Skuja) G.Novarino, I.A.N.Lucas and S.Morrall, Cryptophyta; 10% of the total biomass) dominated phytoplankton. In the spring, *Cyclotella meneghiniana* Kützing, (Bacillariophyta; 35% of the total biomass) and *Stephanodiscus neoastraea* Hakansson and Hickel (Bacillariophyta; 32% of the total biomass) were dominant. During the summer, *Planktothrix* sp. (Cyanobacteria; 33% of the total biomass), *Aphanocapsa holsatica* (Lemmermann) Cronberg (Cyanobacteria; 12.5% of the total biomass) and *Aphanothece clathrata* West and G.S.West (Cyanobacteria; 30% of the biomass) dominated phytoplankton. In the fall, *Gloeotila subconstricta* (G.S. West) Printz (Chlorophyta; 10% of the total biomass) and *Mougeotia* sp. (Streptophyta; 14% of the total biomass) were dominant in the Çaygören Reservoir (Fig. 11).

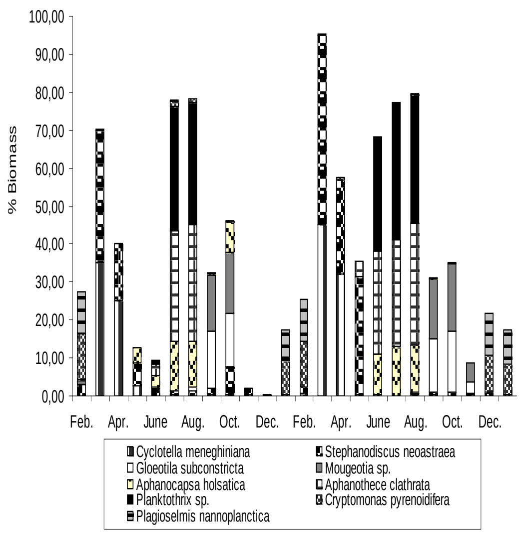

Figure 11. The percent biomass distribution of the dominant phytoplankton taxa in the Çaygören Reservoir

The maximum phytoplankton biomass was recorded in winter 2007 (78 mg L^{-1} at the first station, 99 mg L^{-1} at the second station and 106.5 mg L^{-1}at the third station) and the lowest biomass was recorded in December 2007 (0.31 mg L^{-1} at the first and the third stations and 0.23 mg L^{-1} at the second station; Fig. 12). The phytoplankton biomass was significantly different among the seasons (F=104, P<0.001), but not among the sampling stations (F=0.65, P>0.01).

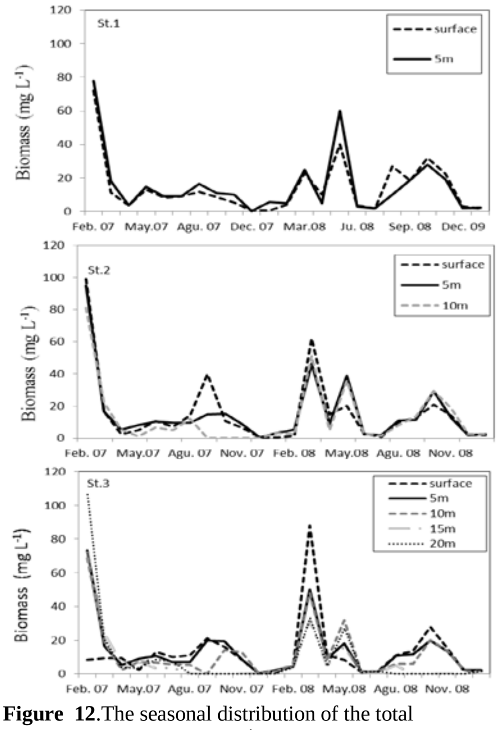

Figure 12.The seasonal distribution of the total phytoplankton biomass (g L^{-1}) in the Çaygören Reservoir

The maximum phytoplankton abundance was measured in summer 2008 because of optimum water temperature and sufficient light and the minimum abundance was recorded in winter 2007 because of low water temperature and insufficient light. The seasonal variations in phytoplankton abundance during 2007-2009 are presented in Fig. 13. The differences in the phytoplankton abundance were significant among the seasons ($F=64$, $P<0.001$), but not among the sampling stations ($F=0.39$, $P>0.05$).

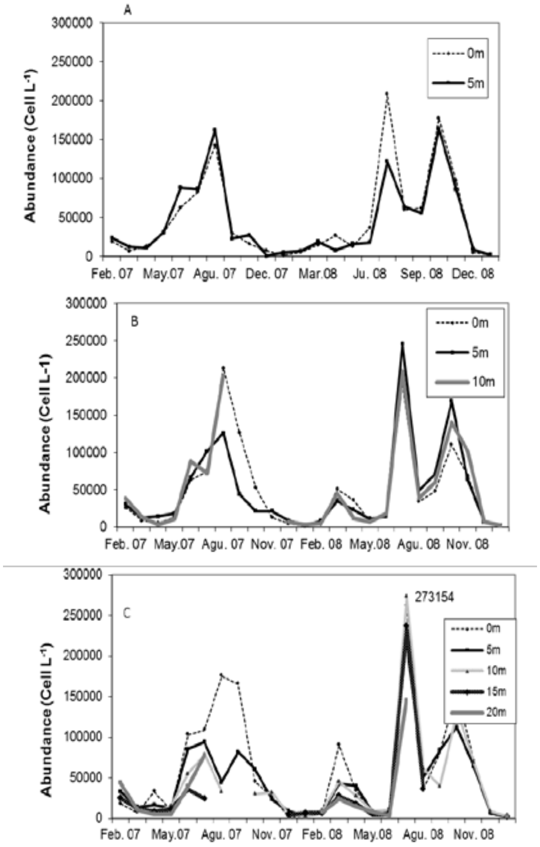

Figure 13. The seasonal dynamics of the total phytoplankton abundance (cell L-1) in the Çaygören Reservoir

3.3. Statistical Analysis of Phytoplankton Species, Biomass and Physico-Chemical Parameters

In the Çaygören Reservoir, from CCA analysis, the first and second axes of CCA explained 77.2% of the total variance in the dominant phytoplankton taxa-environment relationships (eigenvalues, 0.8 and 0.55). The third and fourth axes explained 22.3% of the total variance (eigenvalues, 0.378 and 0.016). Table 2 shows the results of the Monte Carlo tests for the significance of the physicochemical parameters in order of the variance they explain. According to these results, water temperature, water discharge, Secchi disk transparency, oxidation-reduction potential and phosphate had significant effects on the dynamics of the phytoplankton ($p<0.05$).

Table 2. The variance explained by each variable in the Çaygören Reservoir

Variable	Variable number	Variance explained	P	F
T (ºC)	1	0.72	0.002*	7.91
WD ($m^3 s^{-1}$)	9	0.53	0.002*	7.57
Secc. (m)	2	0.29	0.032*	3.02
Scond. (mS cm^{-1})	3	0.07	0.271	1.110
NO_3-N (mg L^{-1})	6	0.02	0.382	0.154
ORP (mV)	4	0.26	0.038*	2.86
pH	5	0.05	0.584	0.261
NH_4-N (mg L^{-1})	7	0.03	0.714	0.571
PO_4 (mg L^{-1})	8	0.25	0.039*	2.85

*significant at 0.05 level.

The first axis of CCA was positively related to T, SC, NH_4-N and PO_4 and it was negatively related with Secchi disk transparency, NO_3-N, ORP, WD and pH. The second axis was positively related to Secchi disk transparency, NO_3-N, ORP, pH and NH_4-N and it was negatively related with T, SC, PO_4 and WD (Fig. 14).

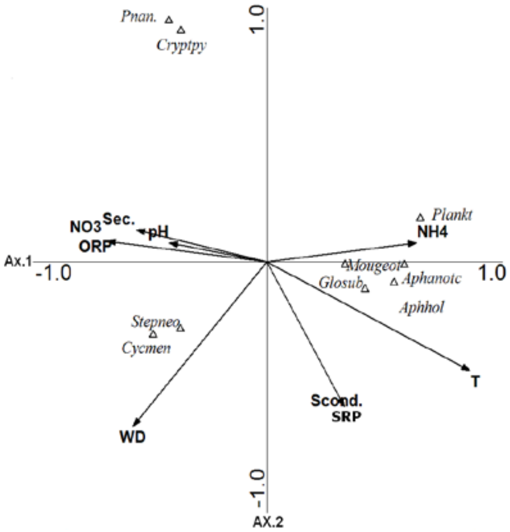

Figure 14. The diagram ofCanonical Correspondence Analysis (CCA)showing the relationships between the environmental variables and the dominant phytoplankton taxain the Çaygören Reservoir.Abbreviation for species: Cycmen, *Cyclotella meneghiniana*; Stepneo, *Stephanodiscus neoastraea*; Glosub, *Gloeotila subconstricta*; Aphhol, *Aphanocapsa holsatica*; Plankt, *Planktothrix* sp.; Cryptpy, *Cryptomonas pyrenoidifera*; Aphanotc,*Aphanothece clathrata*; Mougeot, *Mougeotia* sp.; Pnan, *Plagioselmis nannoplanctica*.

Fig. 14 shows the relationships between environmental variables and the dominant phytoplankton taxa. The distribution of cyanobacteria, *Planktothrix*sp., *A. holsatica* and *A. clathrata*, along the positive side of the first axis of CCA diagram, reflected their occurrence at high temperature. *G. subconstricta* (Chlorophyta) and *Mougeotia*sp. (Streptophyta) were located on the positive side of the first axis and they were negatively related with water transparency and NO_3-N. The cryptophytes, *C. pyrenoidifera* and *P. nannoplanctica* were located on the positive side of the second axis and they were negatively related with T. The diatoms, *C. meneghiniana* and *S. neoastraea* were located on the negative side of the second axis and they were positively related to WD.

There were significant correlations between the following the physicochemical variables and the dominant taxa:

Secchi disk transparency and *G. subconstricta*, Secchi disk transparency and *Mougeotia*sp.; pH and *G. subconstricta*, pH and *A. clathrata*; NH_4-N and *Planktothrix* sp.;WD and *C. meneghiniana* and WD and *S. neoastraea* (Table 3).

Table 3. The Pearson's correlation coefficients between the physicochemical parameters and the dominant phytoplankton taxa in the Çaygören Reservoir between 2007 and 2009

	T	Secc	SC	ORP	PH	NO_3	NH_4	PO_4	WD
T	1	-0.5	0.6*	-0.6*	0.4	-0.6*	0.6*	-0.6*	0.1
Secc	-0.5	1	0.01	0.2	0.1	0.01	0.01	0.2	0.4
SC	0.6*	0	1	-0.8*	-0.5*	0.1	0.2	0.8*	0.4
ORP	-0.6*	0.2	-0.8*	1	0.5*	-0.8*	-0.4	-0.91*	0
pH	0.4	0.1	-0.5*	0.5	1	-0.5*	-0.1	0.5*	-0.1
NO_3	-0.6*	0	0.1	-0.8	-0.5*	1	0.2	-0.8*	0.4
NH_4	0.6*	0	0.2	-0.4	-0.1	0.2	1	-0.4	-0.1
PO_4	-0.6*	0.2	0.8*	-0.91*	0.5*	-0.8*	-0.4	1	0
WD	0.13	0.4	0.4	0.01	-0.1	0.4	-0.1	0.1	1
Cycmen	-0.2	0.2	0.1	0.2	0.2	0.1	-0.3	0.2	0.7*
Stepneo	-0.1	0.3	0.1	0.2	0.2	0.1	-0.3	0.2	0.7*
Glosub	-0.1	-0.6*	0.2	0.1	0.6*	0.2	-0.2	0.9*	-0.3
Mougeot	0.3	-0.5*	0.2	0.1	0.4	0.2	0	0.9*	-0.4
Aphhol	0.5*	-0.1	-0.2	-0.3	-0.4	-0.2	0.2	-0.3	0
Aphanotc	0.5*	0.1	0	-0.3	-0.6*	0	0.1	-0.3	0.2
Plankt	0.5*	0.2	-0.4	-0.4	-0.6*	-0.4	0.5*	-0.4	-0.3
Cryptpy	-0.7*	0.4	-0.5*	0.3	0.4	-0.45	-0.2	-0.42	-0.3
Pnan	-0.7*	0.4	-0.6*	0.3	0.41	-0.36	-0.2	-0.41	-0.4

*significant at 0.05 level.

Abbreviation: Cycmen, *Cyclotella meneghiniana*; Stepneo, *Stephanodiscus neoastraea*; Glosub, *Gloeotila subconstricta*; Aphhol, *Aphanocapsa holsatica*; Plankt, *Planktothrix* sp.; Pnan, *Plagioselmis nannoplanctica*; Cryptpy, *Cryptomonas pyrenoidifera*; Aphanotc, *Aphanothece clathrata*;Mougeot,*Mougeotia* sp.

There were significant correlations between most of the water quality parameters (Table 3). Significant positive correlations were observed between T and SC, T and NH_4; pH and ORP, pH and PO_4; ORP and PO_4, while negative correlations were obtained between T and $P0_4$, T and NO_3-N, T and ORP; SC and PO_4, SC and pH, SC and ORP; ORP and pH, ORP and NO_3-N; NO_3-N and PO_4.

4. Discussion

4.1. Statistical Analysis and Interpretation of Physico-Chemical Parameters

The results of the present study showed that water temperaturewas negatively correlated with NO_3-N and it was positively correlated to NH_4-N. The significant positive correlation between ammonium concentrations and water temperature could probably be attributed to the intensified ammonification ofNO_3-N with the increased water temperature (Liikanen and Martikainen, 2003). Ammonium is often used preferentially by phytoplankton over nitrate when both substrates are available in the water column (Stolte and Riegman, 1996). The negative correlation between the nitrate concentrations and water temperature may also indicate the effective consumption of the winter stock of nitrate by phytoplankton during the summer blooms in the Çaygören Reservoir (Temponeras*et al.*, 2000).

ORP and PO_4 were negatively correlated. ORP is the most important factor influencing the exchange process of phosphorus between the water and sediments (Li *et al.*, 2010). It is well known that a decrease of ORP results in the deoxidization of metal-oxides, which might lead to a release of PO_4, whereas a rise of ORP helps to cause more PO_4 to be absorbed (House and Deniso, 2000). It could be concluded that high PO_4 concentrations in the summer were attributed to the transfer of PO_4 from the bottom layers due to low ORP values in the Çaygören Reservoir.

Raised temperatures stimulate the overall mineralization and thereby liberate organic- bound phosphorus into the sediment pore water. In addition to this direct effect, increased microbial activity lowers the redox potential in the surface sediment, which may induce release of Fe-bound phosphorus (Wilhelm and Adrian, 2008).

There is a positive correlation between specific conductivity and PO_4. Specific conductivity is often considered as parameter showing the degree of nutrient loading (Parinet*et al.*, 2004). Intensive agriculture has been practiced in the drainage basin of the Çaygören Reservoir. Agricultural nonpoint sources are a major contributing factor to surface water eutrophication worldwide.

Secchi disk transparency and water temperature were negatively correlated. In standing water bodies, turbidity increases with nutrient levels, which stimulate phytoplankton growth, especially during warm seasons (Scheffer and van Nes, 2007). Low Secchi disk depths in the summer timing are probably due to high abundance of phytoplankton. The eutrophic Çaygören Reservoir is dominated by Cyanobacteria in summer. Cyanobacteria strongly absorb light causing reduced water transparency (LaBounty, 2008).

Nitrate was negatively correlated with pH. It has long been known that the dense populations of phytoplankton deplete the carbon dioxide present in natural waters, resulting in the rise of pH. Jones-Lee and Lee (2005) state that algae take up nitrate and CO_2 from water, causing the increase of pH during daylight in eutrophic lakes. The higher pH values found in the Çaygören Reservoir must accordingly have been a result of the depletion of free CO_2 in the water due to high rate of photosynthesis.

pH is the master variable in the chemistry of aquatic systems and it affects the kinetics of nutrient uptake and controls the chemical species of most of the nutrient ions that algae require. Carbon fixation as a consequence of photosynthetic activity can displace the carbon dioxide-bicarbonate-carbonate equilibrium that is the most common pH-buffering mechanism in freshwater systems. Photosynthesis thus tends to increase pH in lakes (Haande *et al*., 2011).

4.2. Statistical Analysis and Interpretation of Phytoplankton and Physico-Chemical Parameter Relationships

In the CCA diagram, the cyanobacteria, *Planktothrix*sp., *A. clathrata* and *A. holsatica* occurred near NH_4-N and water temperature vectors. *Planktothrix* sp. was the most abundant cyanobacterium that dominated phytoplankton in the summer in the Çaygören Reservoir. The timing of *Planktothrix* bloom in the Çaygören Reservoir appears to be related to high temperature of the eutrophic condition of the reservoir. Temperature is one of the most important factors affecting the biology of phytoplankton species by controlling the rate of enzymatic reactions within the cells. In addition, temperature also regulates the multiplication rate and standing stock of natural phytoplankton populations (Niu*et al.*, 2011).

Padisak *et al.* (2009) state that small colonial non-N-fixing cyanobacteria prefer well-mixed environments at high water temperatures. The high nutrient levels in the Çaygören Reservoir probably accounted for the development of this cyanobacterium during the summer time.

Water temperature had significant correlations with *A. clathrata* and *A. holsatica*. Komarek and Anagnostidis (1999) point out that *A. clathrata* and *A. holsatica* prefer eutrophic waters. *A. clathrata* and *A. holsatica* are widely collected in eutrophic Turkish lakes during the summer (Sevindik*et al.*, 2010).

C. meneghiniana (Bacillariophyta) and*S. neoastraea* (Bacillariophyta) dominated phytoplankton in the spring. Diatoms are usually common during cooler or windier conditions in freshwater lakes (Munawar and Munawar, 1986). These species were occasionally abundant at the shallower first station. Although *Cyclotella* and *Stephanodiscus* species are widely collected in freshwater phytoplankton, some of them are also benthic (Hutchinson, 1967). They might have been drifted from the bottom due to wind-driven water turbulence at this shallow station.

In the CCA diagram, *S. neoastraea* and *C. meneghiniana* occurred near the water discharge vector. Their relations with the water discharge suggest that these species might have been drifted from the bottom of the feeding river. The highest water discharge occurred in the spring when these species were dominant in the reservoir. The flow rate in rivers is probably the most effective factor controlling the population density of diatoms in the inlets of lakes. Baykal *et al.* (2011) found out that *Stephanodiscus* species were abundant in Melen River, Turkey. They state that *Stephanodiscus* species are well adapted to turbulent and turbid river systems with high nutrient concentrations.

Bere and Tundisi (2011) observed high abundance of benthic *C. meneghiniana* in the eutrophic Monjolinho River, Brazil. They state that certain benthic diatoms are associated with eutrophication and may be used as indicator species of eutrophication in running waters. Although the phytoplankton of the feeding river was not explored during the study, the high nutrient concentration of the Simav Stream might have favored high abundance diatoms in the system (Gunduz*et al.*, 2010).

G. subconstricta (Chlorophyta) and*Mougeotia*sp. (Streptophyta) were dominant during the fall. In the CCA diagram, these species occurred near the water temperature and NH_4-N vectors. They had significant negative correlations with Secchi disk transparency and significant positive correlations with PO_4. The dominance of these filamentous green algae in October seems to be related to the fall overturn in the Çaygören Reservoir. In the fall, nutrients are increased and the transparency is decreased due to the overturn in the reservoir.

C. pyrenoidifera (Cryptophyta) and *P. nannoplanctica* (Cryptophyta) dominated phytoplankton during the winter time. These species had significant negative correlations with water temperature. Low water temperatures and low light availability may have acted as selecting factors for this group during the winter since Cryptophytes are adapted to a low light intensity (Barone and Naselli-Flores, 2003).Various factors may regulate Cryptophyta seasonality in lakes, but it seems that the key factor in the success of Cryptophyta species is their low light requirement. Low Secchi disk transparency, during the winter in the Çaygören Reservoir, might have favored the success of this group during the winter.

The maximum phytoplankton abundance was measured in the summer because of sufficient light and high water temperature and the minimum abundance was measured in the winter because of insufficient light and low water temperature. In temperate lakes, low winter irradiance and water temperature preclude the development of high phytoplankton density in the winter time (Peeters *et al.*, 2007). The high phytoplankton densities in the summer were probably attributed to the dominance of cyanobacteria (over 80%). The high abundance of cyanobacteria during warm seasons in the Çaygören Reservoir can be attributed to the increased water temperature.

Although the maximum phytoplankton density was measured in the summer, the maximum biomass was measured in the spring. This was probably due to the dominance of cyanobacteria in the summer. Cyanobacteria have a smaller cell size than most of the other phytoplankton groups (Ciotti*et al.*, 2002). Therefore, high abundance of cyanobacteria might have not resulted in a high phytoplankton biomass in the Çaygören Reservoir.

5. Conclusions

The present study revealed that the important factors affecting the density, biomass and dominance of the phytoplankton in a temperate eutrophic reservoir were water temperature, underwater light (transparency), water discharge and the relative concentrations of nutrients. High density of cyanobacteria does always not warrant high biomass in the eutrophic freshwater systems. The flow rate of feeding rivers can significantly affect the population density of diatoms in the inlets of reservoirs. Finally, low water temperatures and low light availability may favor Cryprophyta dominance in the eutrophic temperate lakes.

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