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# The Relationships between Chlorophyll-a Dynamics, Certain Physical and Chemical Variables in the Temperate Eutrophic Çaygören Reservoir, Turkey

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## Abstract

The Çaygören Reservoir was sampled monthly from February 2007 to January 2009 at three stations to determine the relationships between the chlorophyll-a (Chl-a) dynamics and soluble reactive phosphorus (SRP), nitrate-nitrogen ($NO_3$-N), ammonium-nitrogen ($NH_4$-N), water discharge, water transparency, water temperature (T), specific conductance (SC) and pH. Thermal stratification occurred in the reservoir from May to September. The maximum chlorophyll-a concentrations were measured (using a YSI multi probe) in the fall and the minimu, SRP and $NO_3$-N were significant among seasons ($P<0.01$), but not among sampling stations ($p>0.01$). The differences in the Secchi disk transparency were significant both among sampling stations and seasons ($P<0.05$). The results of this study suggest that high chl-a concentrations resulted from the increase in available light in the spring and deep mixing in the fall which provided nutrients needed for phytoplankton growth.

**Keywords**: Chlorophyll-a, eutrophic reservoir, nutrients, water transparency

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## Introduction

The relationships between chlorophyll-a (Chl) and nutrients are one of the most extensively studied issues in limnology. These relationships form the basis for lake management strategies. Assessments of the variations in Chl-nutrient relationships have provided insight into the relative importance of chemical, physical and biological constraints on phytoplankton biomass in water bodies. Kuo et al. (2007) state that the relationships between Chl-a and nutrients in water bodies are robust in most geographical regions.

One of the well-known effects of anthropogenic nutrient enrichment of lakes and reservoirs is the increase of phytoplankton biomass (Jones and Knowlton, 2005). Studies have shown that chlorophyll in lakes and reservoirs can be limited by nitrogen, phosphorus or by physical factors such as temperature or light (Dzialowski et al., 2005). In lake studies, nitrogen and phosphorus are generally described as driver variables of chlorophyll-a and Secchi disk depth (Kagalou et al., 2008).

Chlorophyll-a is generally used surrogate for phytoplankton biomass in the lakeresearch. Although nutrients significantly influence the yield of chlorophyll in water bodies, studies suggest that other environmental factors such as the underwater light and water temperature need also to be considered (Soballe and Kimmel, 1987). Studies on temperate and subtropical lakes have demonstrated that mean summer Chl-a is a function of spring or summer mean phosphorus concentrations (Phillips et al., 2008).

The Çaygören Reservoirs is important for water supply, fisheries, agriculture and industry of the province of Balıkesir, Turkey. However, the catchments areas of this reservoir have been subject to agricultural, urban and industrial development which resulted in the deterioration of water the quality in the reservoir (Turkish Ministry of Environment and Forestry, 2007).

Only two research articles have been published on this reservoir (Sevindik, 2010; Sevindik et al., 2011). This study is the first attempt to determine the relationships between the seasonal dynamics of chlorophyll-a and soluble reactive phosphorus, nitrate-nitrogen, ammonium-nitrogen, water discharge, water transparency water temperature, specific conductance and pH in the eutrophic temperate Çaygören Reservoir in Northwest of Turkey.

## Materials and methods

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. It has a maximum depth of 28 m, a length of 4.6km and a surface area of 9 km$^2$. The Simav Stream feeds the reservoir. The reservoir was built in 1971 and it is used for irrigation and power generation (State Water Works, 2005).

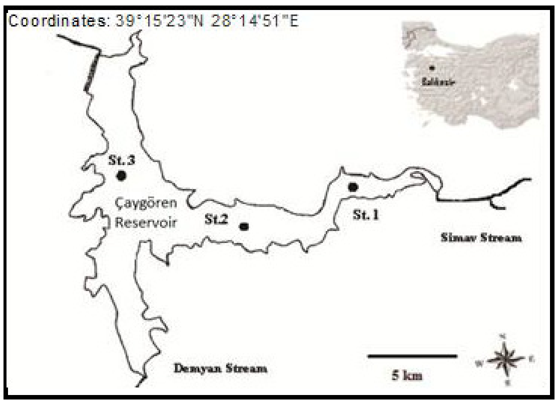

**Figure 1**: **Map of Çaygören Reservoir and the location of sampling stations**

Three sampling stations were set in the reservoir. The first station was set near the main inlet, the second station was set between the first station and the dam and the third station was set near the dam at the deepest part of the reservoir. Sampling was carried out monthly between February 2007 and January 2009. Samples were drawn vertically with 5m intervals using a Kemmerer water sampler.

Chlorophyll-a, specific conductance, pH and water temperature were measured at 5 m intervals using a YSI multi probe. Water transparency was measured using a Secchi disk. Concentrations of soluble reactive phosphorus (SRP), nitrate-nitrogen ($NO_3$-N) and ammonium-nitrogen ($NH_4$-N) were determined spectrophotometrically according to the standard methods by filtering a known volume of water through Whatman 934-AH filters from 1, 5 and 15m (APHA, 1995). Water discharge data was obtained from the State Water Works (State Water Works, 2005). An analysis of variance (ANOVA) test was applied to data for determining the statistical differences in chlorophyll-a among sampling stations and seasons. The relationships between the measured environmental variables and the chlorophyll-a concentrations were analyzed by calculating the Pearson correlation coefficients. The statistical analysis was performed using SAS program (SAS Institute, 2003). Data was log-transformed prior to statistical analysis to meet the requirements of normality. Chlorophyll-a was periodically measured spectrophotmetrically in unfiltered water according to the trichromatic method from the acetone-extracted samples to compare the values obtained by the YSI probe.

## Results

Chlorophyll-a ranged from 2.2 to 30.0µg $L^{-1}$ at the first station, it varied from 1.9 to 37.5µg $L^{-1}$ at the second station and it ranged from 1.4 to 35.0µg $L^{-1}$ at the third station. Chlorophyll-a peaks were observed at 1, 5, 8 and 10m at all stations (Fig. 2A). Soluble reactive phosphorus (SRP) ranged from 0.005 to 0.046mg $L^{-1}$ at the first station and it ranged from 0.005 to 0.059mg $L^{-1}$ at the second and third stations (Fig. 2B).

$NO_3$-N concentrations ranged from 0.08 to 0.26mg $L^{-1}$ at the first station, it ranged from 0.03 to 0.26mg $L^{-1}$ at the second station and it ranged from 0.07 to 0.30mg $L^{-1}$ at the third station (Fig. 3A). $NH_4$-N concentrations ranged from 0.0052 to 0.017mg $L^{-1}$ at the first and second stations and they varied from 0.001 to 0.020mg $L^{-1}$ at the third station (Fig. 3B).

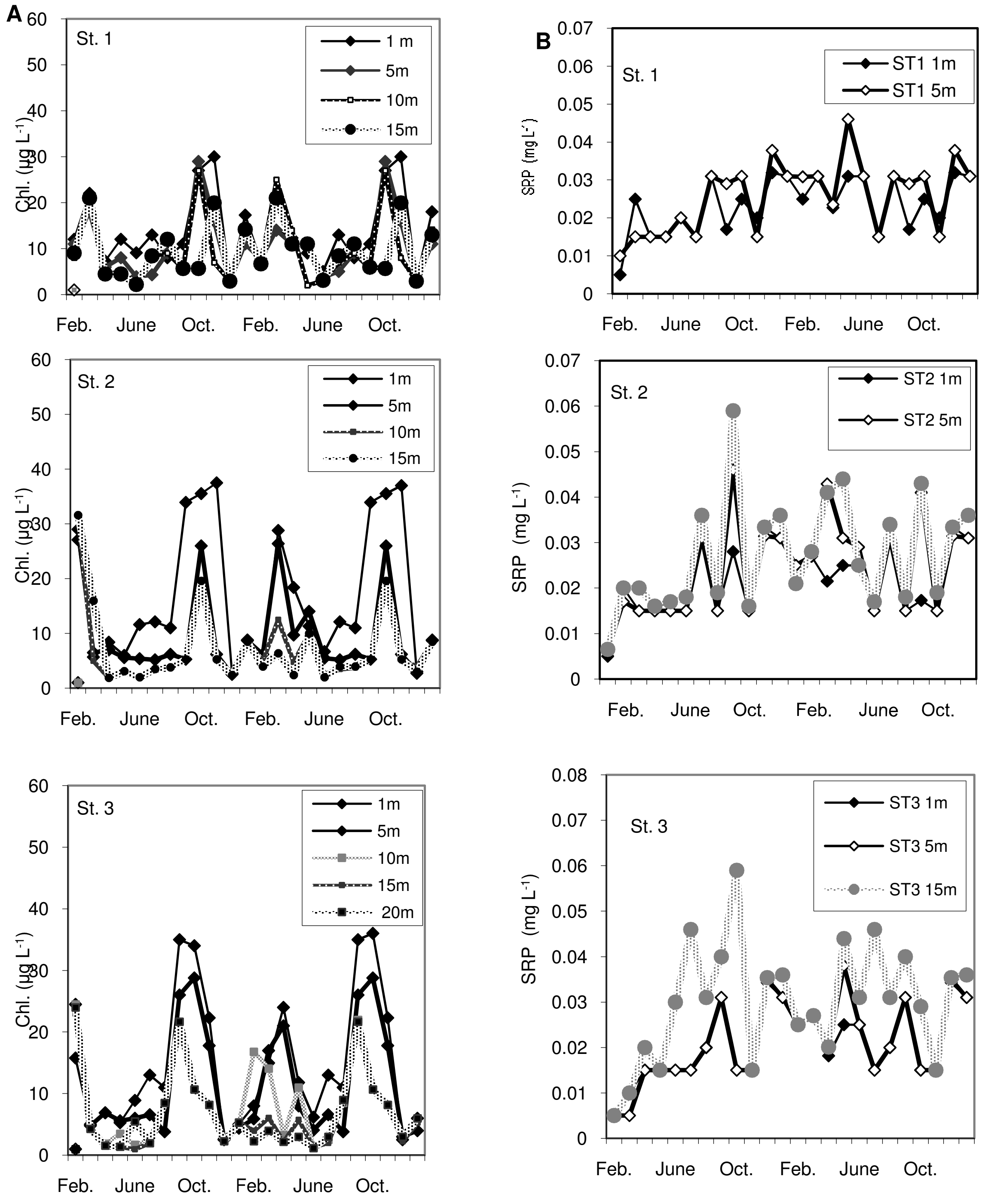

**Figure 2. A: The vertical and seasonal distribution of chlorophyll (Chl-a; µg $L^{-1}$) in the Çaygören Reservoir; B: The variations in Soluble reactive phosphorus (SRP; mg $L^{-1}$) of the Çaygören Reservoir**

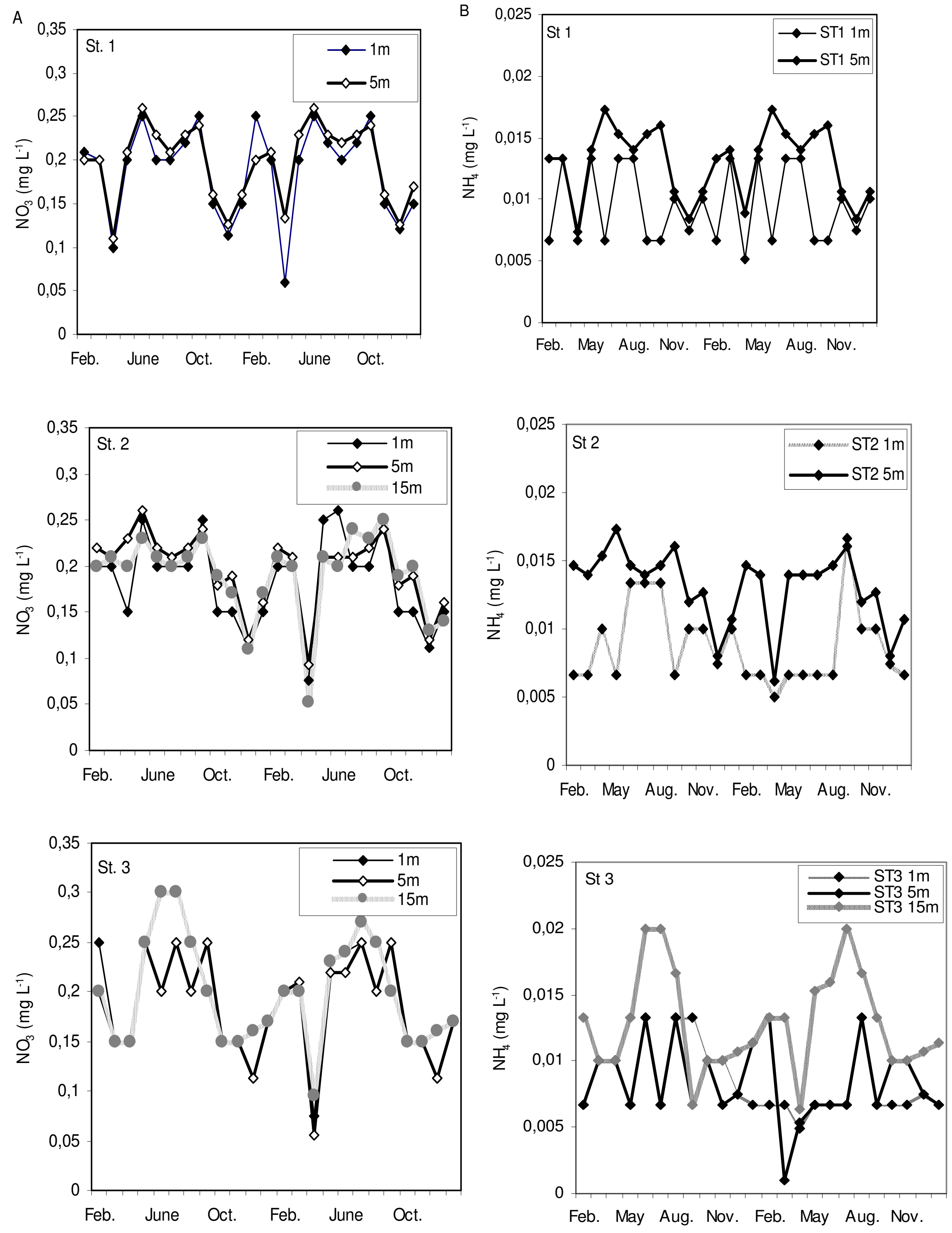

**Figure 3. A: The seasonal variations in nitrate (N-$NO_3$; mg $L^{-1}$) concentrations; B: The seasonal variations in ammonium ($NH_4$; mg $L^{-1}$) concentrations of the Çaygören Reservoir**

The maximum inflow (1300m$^3$ s$^{-1}$) to the reservoir was recorded in April 2007 and the minimum inflow (5.2 m$^3$ s$^{-1}$) was measured in September 2007 (Fig. 4A). Secchi disk depth ranged from 0.3 to 1.5 m at the first station and it varied from about 0.6 to 1.9 m at the second and third stations (Fig. 4B).

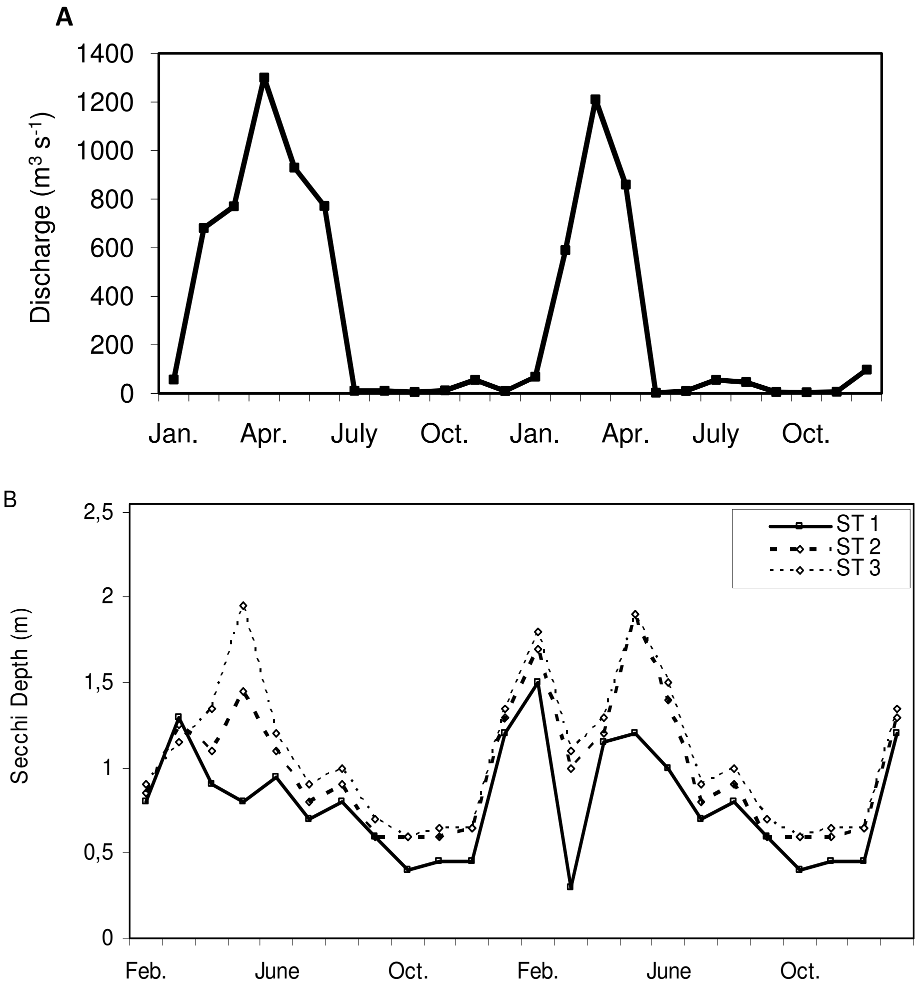

**Figure 4. A: Monthly average of water flow ($m^3 s^{-1}$) from Simav Stream to Çaygören Reservoir from January 2007 to December 2008; B: The variations in the Secchi disk depth (m) in the Çaygören Reservoir**

Water temperature ranged from 4.5 to 27.6°C at all stations. Maximum surface water temperature values were measured in June and July and minimum values were measured in February. Thermal stratification occurred in the reservoir from May to September (Fig. 5).

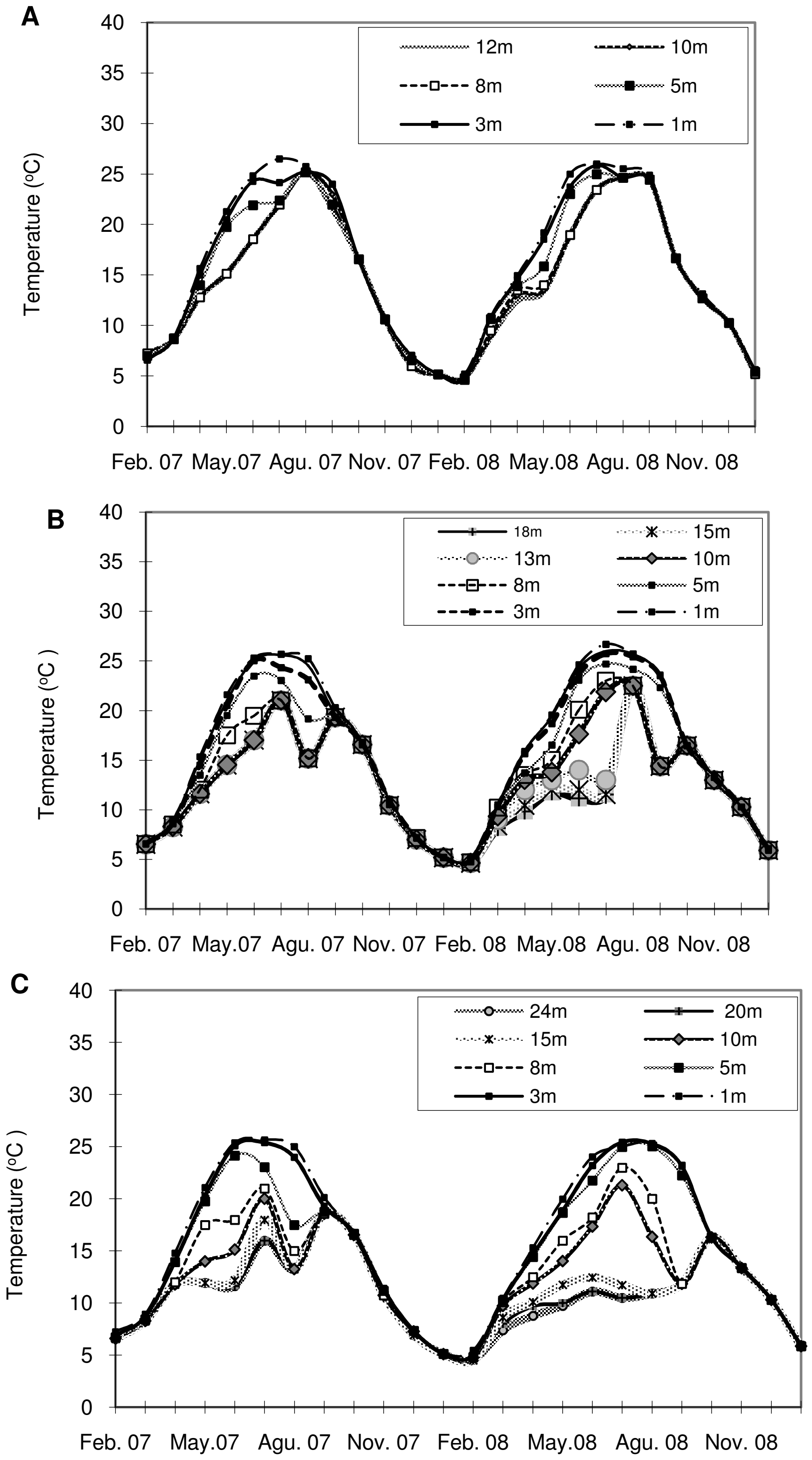

**Figure 5: The seasonal variations in water temperature (T;ºC) of the Çaygören Reservoir**

Specific conductance ranged from 0.3 to 0.54mS cm$^{-1}$ at the first station, it ranged from 0.31 to 0.53mS cm$^{-1}$ at the second station and it ranged from 0.30 to 0.53mS cm$^{-1}$ at the third station. Specific conductance was lower in the winter than the other seasons (Fig. 6A). 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 11.0 (Fig. 6B).

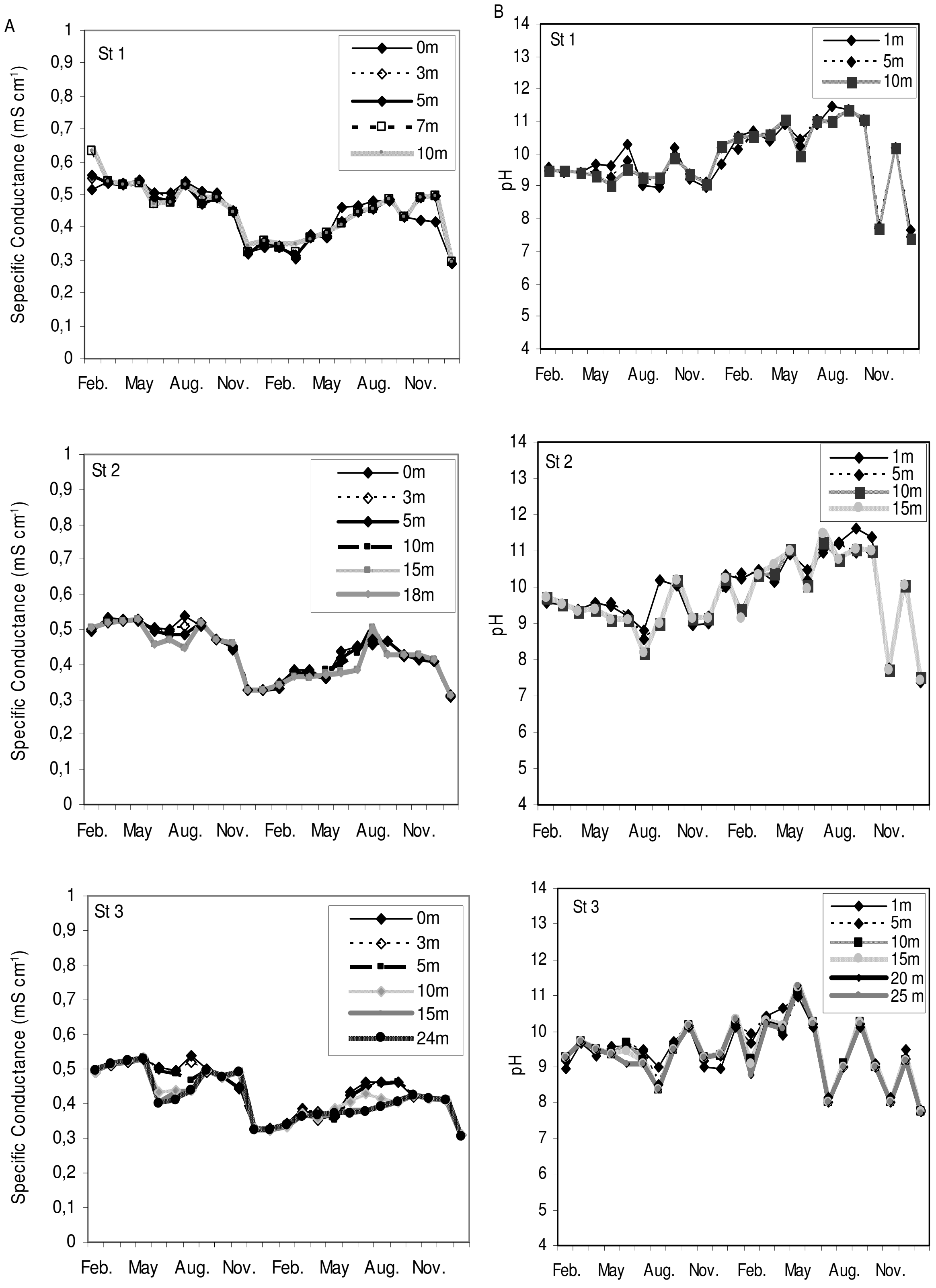

**Figure 6. A: The seasonal variations in specific conductance (mS cm$^{-1}$); B: The seasonal variations of the pH of the Çaygören Reservoir**

The Pearson correlation coefficients between the physicochemical parameters and the chlorophyll-a concentrations are shown in Table 1. Chlorophyll-a was significantly correlated to SRP (r=0.77), Secchi disk depth (r=0.74), pH (r=0.61), water discharge (r=-0.55) and nitrate-nitrogen (r=0.51). There were significant seasonal differences in the concentrations of chlorophyll-a (F=23, P<0.01), however the differences among sampling stations were not significant (F=2.45, P>0.05).

**Table 1: The Pearson correlation coefficients between the physicochemical parameters in the Çaygören Reservoir (2007- 2009)**

| | **Chl** | **T** | **Secchi** | **SC** | **pH** | **NO$_3$-N** | **NH$_4$-N** | **SRP** | **WD** |
|---|---|---|---|---|---|---|---|---|---|
| **Chl** | 1 | 0.34 | **0.74** | 0.43 | **0.61*** | **0.51*** | 0.41 | **0.77*** | **-0.55*** |
| **T** | 0.34 | 1.0 | -0.5 | 0.6* | -0.4 | -0.6* | 0.6* | -0.6* | 0.21 |
| **Secchi** | **0.74*** | -0.5 | 1.0 | 0.01 | 0.1 | 0.01 | 0.01 | 0.2 | -0.25 |
| **SC** | 0.43 | 0.6* | 0.01 | 1.0 | -0.5* | 0.1 | 0.2 | -0.99* | -0.40 |
| **PH** | **0.61*** | 0.4 | 0.1 | -0.5* | 1.0 | -0.5* | -0.1 | 0.5* | -0.1 |
| **NO$_3$-N** | **0.51*** | 0.6* | 0.0 | 0.1 | -0.5* | 1.0 | 0.2 | -0.8* | 0.14 |
| **NH$_4$-N** | 0.44 | 0.6* | 0.0 | 0.2 | -0.1 | 0.2 | 1.0 | -0.4 | -0.1 |
| **SRP** | **0.77*** | -0.6* | 0.2 | -0.8* | 0.5* | -0.8* | -0.4 | 1.0 | -0.1 |
| **WD** | **-0.55*** | 0.21 | -0.25 | 0.40 | 0.1 | 0.4 | -0.1 | 0.43 | 1.0 |

*significant at 0.05 level, **Abbreviations: T, water temperature; Secchi, Secchi disk depth; SC, specific conductance; Chl, chlorophyll; WD, water discharge; SRP, soluble reactive phosphorus**

## Discussion

Based on chlorophyll-a content (annual mean: 16µg $l^{-1}$) and Secchi disk depth (about 1 m) Çaygören Reservoir can be classified as eutrophic (OECD, 1982). Chlorophyll-a concentrations differed significantly from season to season, but not from station to station. The variable nature of chlorophyll-a in lakes and reservoirs is a common phenomenon due to the dynamics of environmental variables affecting phytoplankton growth (Carpenter et al., 2000).

Although there were slight variations in chlorophyll-a concentrations among sampling stations, the variations were not statistically significant (P>0.01). Soballe and Bachmann (1984) stated that spatial heterogeneity was often less prominent in small lakes and thus sampling from close locations might have in some cases not led to significant differences in results. The Çaygören Reservoir is a small system and this might have been the cause for non significant spatial heterogeneity among sampling stations.

High chlorophyll-a bands were observed in the upper depths of the reservoir during the spring and the fall. The chlorophyll-a bands were probably a result of an increase in available light in spring and nutrient levels during the fall. Light intensity is an important factor contributing to seasonal differences in chlorophyll-a concentrations. The differences in the timing of chlorophyll-a maxima might have been primarily related to variations in irradiance (Iriarte et al., 2004). It is likely, that fall peaks were driven by deep mixing and an influx of water from below the thermocline providing phytoplankton with the nutrients needed for growth (Dzialowski et al., 2005).

The maximum Secchi disk depth was 2 m and chlorophyll-a peaks were observed from 1 to 10m where light was probably limiting to phytoplankton (Fang and Liu, 2006). Furthermore, Secchi disk depth and chlorophyll-a were highly and significantly correlated (r=0.74, P<0.01), suggesting that light was critical to chlorophyll-a dynamics in the Çaygören Reservoir.

Water transparency increased from headwaters to the dam in the reservoir. This was probably a result of low turbulence and higher rate of particle settling at the third station. Low Secchi disk depths at the first and second stations were probably due to high silt loads from the inflowing rivers and the growth of phytoplankton (Wondie et al., 2007). In the absence turbulence, a large proportion of the suspended material settles down, leading to higher water transparency. Scheffer and van Nes (2007) state that suspended solids are diluted, settled and probably used by the lake biota farther down from the entrance point.

Nitrate was negatively correlated with pH suggesting that nitrate concentrations decrease with the increasing rate of photosynthesis. pH ranged from 7.4 to 11.6 throughout the study at all stations. pH was higher in summer than the other seasons. The high pH values were probably attributed to the increase in photosynthesis in summer. In eutrophic lakes, algae take up nitrate and $CO_2$ from water causing the increase of pH during daylight (Jones-Lee and Lee, 2005).

Water temperature was positively correlated to $NH_4$-N. Significant positive correlation between $NH_4$-N and water temperature could probably be attributed to the intensified ammonification and nitrate reduction with increased temperature (Liikanen and Martikainen, 2003). The negative correlation between nitrate and water temperature may indicate the effective utilization of the winter stock of nitrate during the summer blooms (Temponeras et al., 2000).

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 were significant correlations between chlorophyll-a and SRP and $NO_3$-N . Phillips et al. (2008) state that the chl-a yield in lakes is a function of both phosphorus and nitrogen concentrations. Studies have shown that the amount of chlorophyll-a produced by a given concentration of phosphorus is sensitive to variations in the nitrogen concentrations (Prairie et al., 1989).

There was a high positive correlation between specific conductance and SRP. Specific conductance 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 world wide (Tilman et al., 2001). Runoff from the agricultural lands has high nutrient content, resulting in the increases in SRP concentrations.

The most distinctive patterns in nutrient dynamics were observed in ammonium ($NH_4$) concentrations. $NH_4$ peaked in summer at deeper layers of the reservoir each year. This pattern of recurrence coincided with the highest water temperature. High temperature must have triggered the accumulation of ammonium produced by bacterial activity. Beutel (2001) pointed out that in eutrophic lakes, deep layers get anoxic and reduced compounds such as sulfide or ammonium accumulate in deep layers.

Water discharge was negatively correlated with chl-a (r=-0.55). The phytoplankton biomass decreases with the increase of cell washout rate. There are many lakes that naturally maintain low algal biomass as a result of high dilution rates, which causes cell washout (Jones and Welch, 1990). The dilution of lake water can principally affect the formation of algal blooms by decreasing water retention time, washing out algal cells and reducing the nutrient concentrations.

In summary, the peaks of chl-a prior to the onset of thermal stratification suggest that the increase in the available light is the primary driver behind the observed chlorophyll-a peaks in the spring time. The fall peaks of chl-a probably resulted from deep mixing. The results also show that water discharge is among the most important factors affecting the dynamics of chl-a in reservoirs.

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## References

**APHA., 1995.** Standard methods for the examination of water and wastewater. American Public Health Association, Washington, DC, 1325 p.

**Beutel, M. W., 2001.**, Oxygen consumption and ammonia accumulation in the hypolimnion of Walker Lake, Nevada. *Hydrobiologia,* **466**:107–117.

**Carpenter, S. R., Ludwig, D. and Brock, W. A., 2000.** Management of eutrophication in lakes subject to potentially irreversible change. *Ecological Applications*, **9:**751-771.

**Dzialowski, A. R., Wang, S. H., Lim, N. C., Spotts, W. W. and Huggins, D. G., 2005.** Nutrient limitation of phytoplankton growth in central plains reservoirs, USA. *Journal of Plankton Research*, **27**:587-595.

**Fang, T. and Liu, J. T., 2006.** Vertical distribution of species of nitrogen and phosphorus in the sediments of Lake Donghu. *Journal of Environmental Sciences*, **27**:1078-82.

**Iriarte, A. and Purdie, D. A., 2004.** Factors controlling the timing of major spring bloom events in an UK south coast estuary. *Estuarine, Coastal and Shelf Science*, 6:679-690.

**Jones, C. J. and Welch, E. B., 1990.** Internal Phosphorus Loading Related to Mixing and Dilution in a Dendritic, Shallow Prairie Lake. *Research journal of the Water Pollution Control Federation*, **62**:847-852.

**Jones, J. R. and Knowlton, M. F., 2005.** Chlorophyll-a Response to Nutrients and Non-algal Seston in Missouri Reservoirs and Oxbow *Lakes. Lake and Reservior Management*, **21:** 361-371.

**Jones-Lee, A. and Lee, F. G., 2005.** Eutrophication (Excessive Fertilization), Water Encyclopedia: Surface and Agricultural Water. Wiley, Hoboken, N.J., USA, 114 p.

**Kagalou, I., Papastergiadoub, E. and Leonardosa, I., 2008.** Long term changes in the eutrophication process in a shallow Mediterranean lake ecosystem of W. Greece: Response after the reduction of external load. *Journal of Environmental Management*, **87**:497-506.

**Kuo, J. T., Hsieh, M. H., Lung, W. S. and She, N., 2007.** Using artificial neural network for reservoir eutrophication prediction. *Ecological Modeling*, **200**:171-177.

**Liikanen, A. and Martikainen, P. J., 2003.** Effect of ammonium and oxygen on methane and nitrous oxide fluxes across sediment–water interface in a eutrophic lake. *Chemosphere*. **52**: 1287–1293.

**OECD., 1982.** Eutrophication of waters. Monitoring, assessment and control. OECD, Paris, France, 154 p.

**Parinet B., Lhote, A. and Legube, B., 2004.** Principal component analysis: an appropriate tool for water quality evaluation and management-application to a tropical lake system. *Ecological Modeling*, **178**:295-311.

**Phillips, P., Pietiläinen, O. P., Carvalho, L., Solimini, A., Lyche Solheim, A. and Cardoso, A.C., 2008.** Chlorophyll-a-nutrient relationships of different lake types using a large European dataset. *Aquatic Ecology*, **42**:213-226.

**Prairie, Y. T., Duarte, C. M. and Kalff, J., 1989.** Unifying nutrient–chlorophyll-a relationships in SAS Institute. 2003.

**SAS/STAT Users Guide (Version 9.1).** SAS Institute Inc., Cary, North Carolina, USA. 220p.

**Sevindik T. O., 2010.** Phytoplankton Composition of Caygoren Reservoir, Balikesir-Turkey. *Turkish Journal of Fisheries and Aquatic Sciences*, **10**295-304.

**Sevindik , T. O., Çelik, K. and Gönülol, A., 2011.** Twenty New Records for Turkish Freshwater Algal Flora from Çaygören and Ikizcetepeler Reservoirs (Balıkesir, Turkey). *Turkish Journal of Fisheries and Aquatic Sciences*, 11:399-406.

**Scheffer, M. and van Nes, E. H., 2007.** Shallow lakes theory revisited. Various alternative regimes driven by climate, nutrients, depth and lake size. *Hydrobiologia*, **584**:455-466.

**Soballe, D. M. and Bachmann, R. W., 1984.** Influence of reservoir transit on riverine algal transport and abundance. *Canadian Journal of Fisheries and Aquatic Sciences*, **41**:1803–1813.

**Søballe, D. M. and Kimmel, B. L., 1987.** A Large-Scale Comparison of Factors Influencing Phytoplankton Abundance in Rivers, Lakes, and Impoundments. *Ecology*, **68**:1943-1954.

**State Water Works., 2005.** Manyas Project [in Turkish]. 25th Regional Branch. State Water Works, Balıkesir, Turkey (in Turkish), 123p.

**Temponeras, M., Kristiansen, J. and Moustaka-Gouni, M., 2000.** Seasonal variation in phytoplankton composition and physical and chemical features of the shallow Lake Doïrani, Macedonia, Greece. *Hydrobiologia*, **424**:109-122.

**Tilman, D., Fargione, J., Wolff, B., D'Antonio, C., Dobson, A., Howarth, R., Schindler, D., Schlesinger, W. H., Simberloff, D. and Swackhamer, D., 2001.** Forecasting agriculturally driven global environmental change. *Science*, **292**:281-284.

**Turkish Ministry of Environment and Forestry, 2007.** The Environmental Report for the City of Balıkesir. Technical Report No. 2007/10. Turkish Ministry of Environment and Forestry, Ankara, Turkey.

**Wilhelm, S. and Adrian, R., 2008.** Impact of summer warming on the thermal characteristics of a polymictic lake and consequences for oxygen, nutrients and phytoplankton. *Freshwater Biology*, **53**:226–237.

**Wondie, A., Mengistu, S., Vijverberg, J. and Dejen, E., 2007.** Seasonal variation in primary production of a large high altitude tropical lake (Lake Tana, Ethiopia): effects of nutrient availability and water transparency. *Aquatic Ecology*, **41**:195-207.