The Vertical and Seasonal Distribution of Chlorophyll and Main Nutrients in a Mesotrophic Freshwater Reservoir

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***Abstract*-The mesotrophic Ikizcetepeler Reservoir was sampled monthly from February 2007 to June 2008 at three stations. Thermal stratification occurred in the reservoir from May to September. The results revealed high bands of chlorophyll in the epilimnion and metalimnion of the reservoir during summer and winter. Results suggest that high chlorophyll accumulation was a result of the increase in available light levels in spring and deep mixing, providing phytoplankton with the nutrients needed for grow in summer. Correlation analyses were used to determine the relationships between chlorophyll (µg/L), water temperature (^{o}C), total nitrogen (mg/L), total phosphorus (mg/L) and Secchi disk depth (m). Differences in chlorophyll, total phosphorus, total nitrogen and in Secchi disk transparency were not significant among sampling stations (p>0.01), but they were significant among seasons (p<0.01). Successful control of eutrophication requires an understanding of how nutrients, physical conditions and biological processes interact to affect algal growth and since the utility of chlorophyll in estimating algal biomass world-wide, this study was conducted to determine how variations in water temperature, total nitrogen, total phosphorus and water transparency affected the the vertical and seasonal distribution of chlorophyll in Ikizcetepeler Reservoir.**

Keywords- Ikizcetepeler Reservoir; phytoplankton biomass; total nitrogen; total phosphorus; water transparency

I. INTRODUCTION

One of the well-known effects of anthropogenic nutrient enrichment of lakes and reservoirs is the increase of phytoplankton biomass (Chlorophyll) [1] and [2]. Studies have shown that chlorophyll in lakes and reservoirs can be limited by nitrogen, phosphorus or by physical factors such as temperature or light [3], [4] and [5].

Nutrient concentrations can be used to determine which nutrient may be limiting to algal growth [6]. However, it is difficult to interpret the results when different taxa have different cellular N:P ratios and require different optimal environmental conditions [7]. Therefore, using N:P ratios might be a better way of interpreting nutrient limitation on algal growth [8].

Jappesen et al. [9] state that at low N: P ratios, phytoplankton community composition shiftes towards a dominance of N-fixing Cyanobacteria. Low N:P could create conditions that greatly benefit N-fixing cyanobacteria, which are able to outcompete other phytoplankton by importing considerable amounts of N from the atmosphere [10]. Thus, without a commensurate decrease in other nutrients, especially P, programmes that seek to improve water quality by reducing N loading may actually deteriorate water quality in freshwater ecosystems.

Wang et al. [11] argue that the TN:TP ratio is not inappropriate to be used as an index to discriminate lakes as N or P-limited because for a multi-species community, optimal N:P ratios vary greatly among phytoplankton species. Also, the effects of grazing by zooplankton could significantlty affect the dynamics of phytoplankton biomass over time and space.

Successful control of eutrophication requires an understanding of how nutrients, physical conditions and biological processes interact to affect algal growth. Because of the utility of chlorophyll in estimating algal biomass, it is important to know the spatial and temporal factors controlling its distribution. Correlations between environmental variables and algal biomass are useful for identifying the factors controlling algal growth on spatial and temporal scales [12], [13] and [14]. The purpose of this study was to gain an understanding of the environmental factors controlling the vertical, longitudinal and temporal distribution of algal biomass (chlorophyll) in the mesetrophic Ikizcetepeler Reservoir in northwest of Turkey.

II. STUDY SİTE

Ikizcetepeler Reservoir is located at 39º 29' N; 27º 56' E, 15 kilometers southwest of Balıkesir, Turkey (Fig. 1) and lies at 175 m above sea level. The reservoir is a mesotrophic man-made lake with an annual mean chlorophyll concentration of 5.5 µg L^{-1} and a Secchi disk depth of 1.75 m. It has a maximum depth of 25 m, a surface area of 10 km^2 and a length of 6.34 km. The reservoir is fed by Kile Stream and the maximum inflow (5000 m^3 sec^{-1}) occurred in spring and the minimum (25 m^3 sec^{-1}) occurred in fall (Fig. 2). It was built in 1992 and used for irrigation and drinking water [15].

III. MATERİAL AND METHODS

Three sampling stations were set in the reservoir. The first station was set near the main inlet (riverine zone), the second station was set between the first station and the dam (transitional zone) and the third station was set near the dam at the deepest part of the reservoir (lacustrine zone). Monthly sampling was initiated in February 2007 and ended in June 2008.

Total phosphorus (TP) concentrations were determined from non-filtered water as orthophosphate after persulphatic-acid hydrolysis at 135 ˚C for 2 hours. Total nitrogen (TN) concentrations were determined after digestion by the Kjeldahl method [16]. Routine measurements of chlorophyll and water temperature were taken at one meter intervals from

the surface to the bottom at each station using a 6600 model YSI water quality multi-probe. Chlorophyll was measured periodically according to the trichromatic method from the acetone-extracted samples to calibrate the probe. Chlorophyll values obtained from the acetone-extracted samples were not significantly different from those of measured by the YSI probe. Therefore, any corrections to the YSI probe data was not necessary. Secchi disk depth was measured on each sampling date.

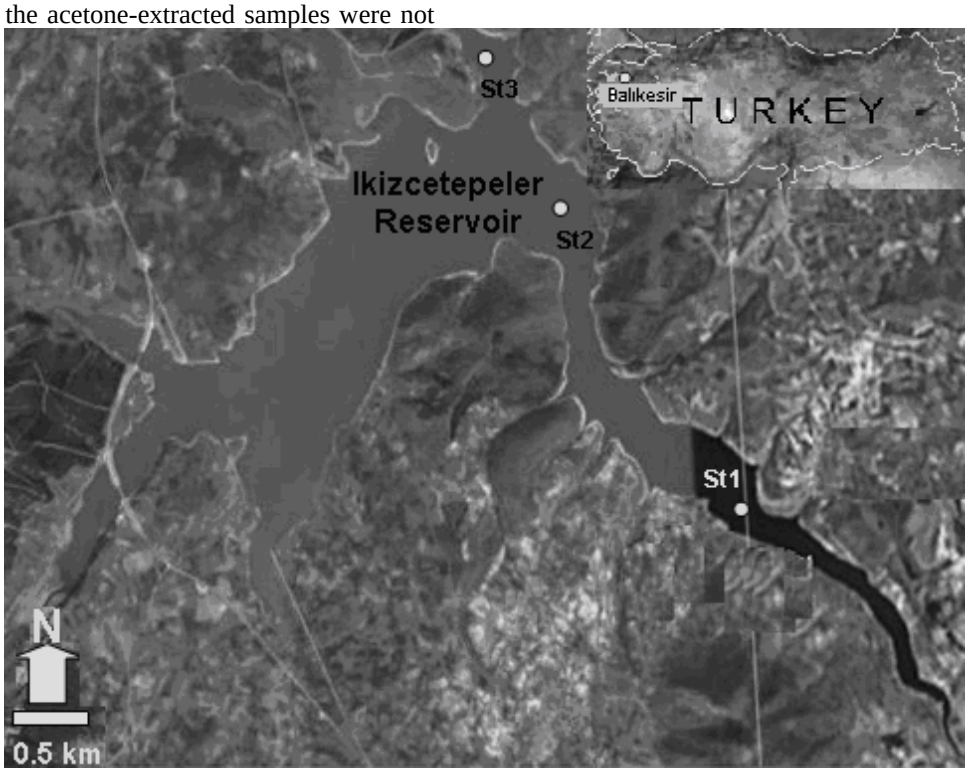

Figure 1. The map of Ikizcetepeler Reservoir and the location of sampling stations.

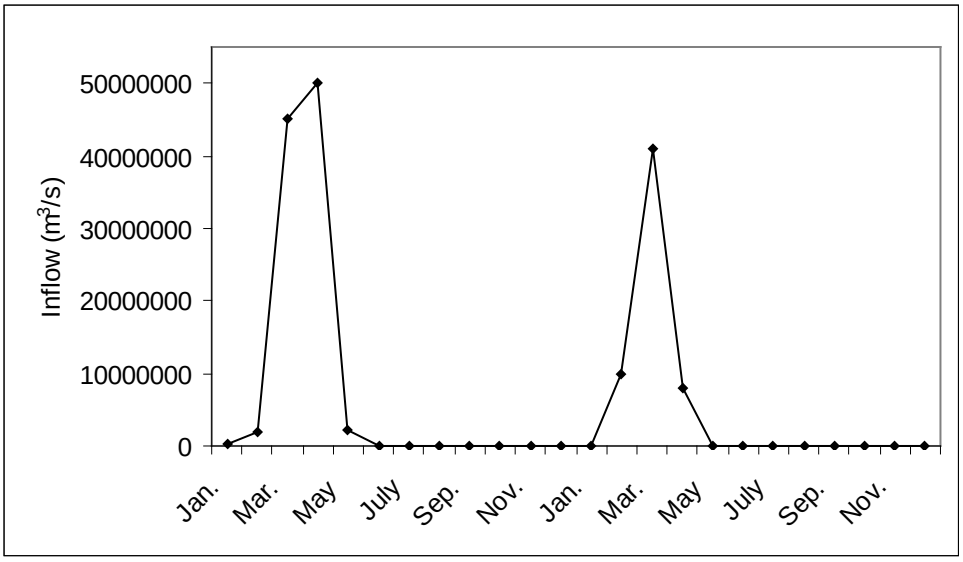

Figure 2. Monthly average of water flow from Kile Stream to Ikizcetepeler Reservoir from January 2007 to December 2008.

Data was log-transformed prior to statistical analysis to meet the requirements of normality for parametric tests. The Pearson's correlation test was applied to data for determining chlorophyll-nutrient relationships at each sampling station. An analysis of variance (ANOVA) test was applied to data for determining the statistical differences in chlorophyll and nutrient concentrations among sampling stations and seasons. Statistical analyses were performed using SAS program [17].

IV. RESULTS

Ikizcetepeler Reservoir is a mesotrophic reservoir (annual mean chlorophyll: 5.5 μg/L and Secchi disk depth 175 cm)

[18]. Water temperature ranged from 4.4 °C to 26.7 °C. Maximum surface temperature was observed in June and minimum in February. Thermal stratification occurred from May to September (Fig. 3). The largest temperature difference (10 °C) between the surface and the bottom was observed in June 2007 at the third station.

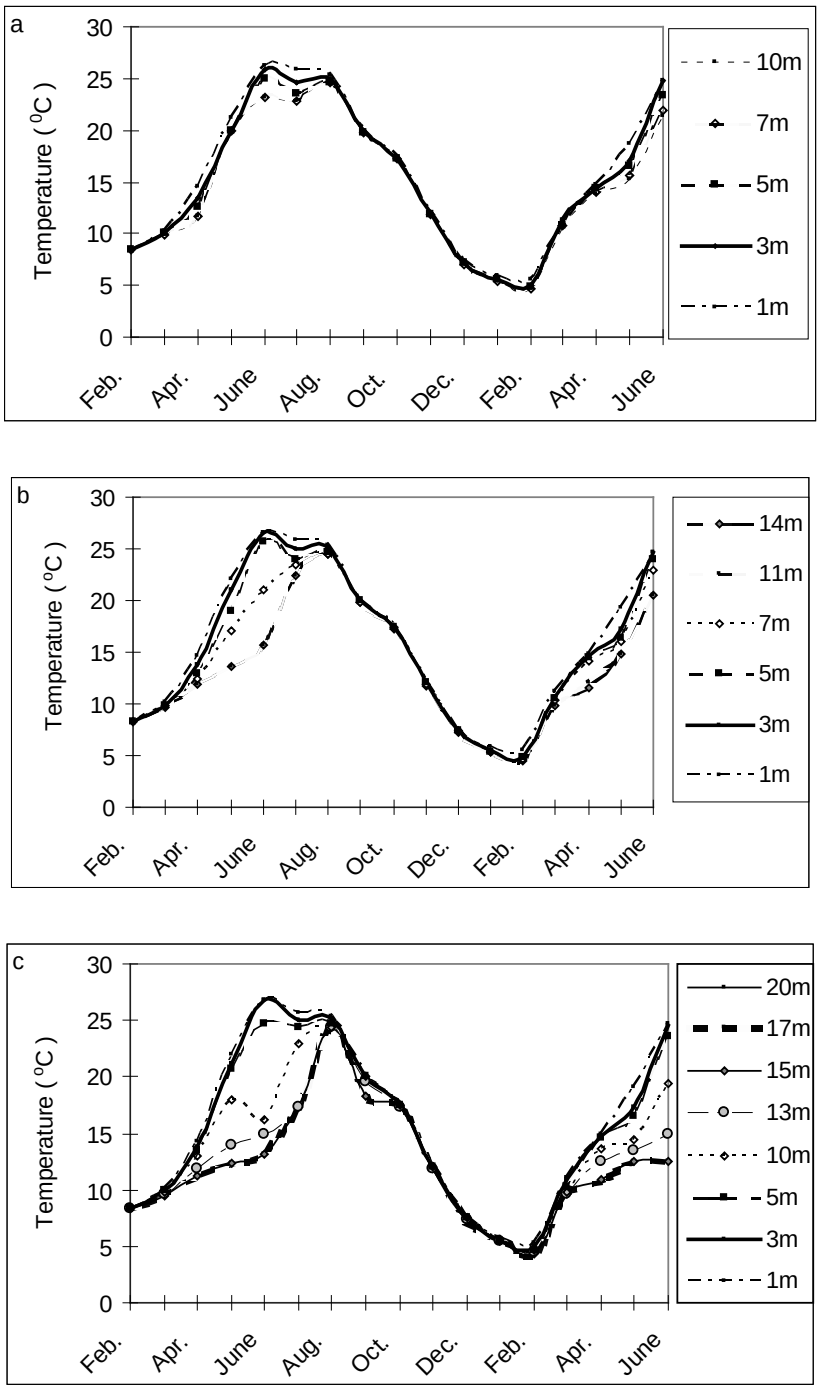

Figure 3. The vertical and seasonal distribution of water temperature (oC) in Ikizcetepeler Reservoir. a) at the first station, b) at the second station and c) at the third station.

Chlorophyll concentrations ranged from 0.8 µg/L to 14 µg/L at the first station, from 1.2 µg/L to 12 µg/L at the second station and from 0.6 µg/L to 15 µg/L at the third station (Fig. 4). There were epilimnetic and metalimnetic chlorophyll peaks during the thermal stratification. The chlorophyll peaks occurred at 1 and 5 meters at the first station, at 1, 3 and 5 meters at the second station and at 3, 5 and 13 meters at the third station. The magnitude of peaks were significantly different between seasons ($p<0.01$), but not between stations ($p>0.01$). Winter peaks were about 8 µg/L and summer peaks were about 13 µg/L at all stations (Fig. 4).

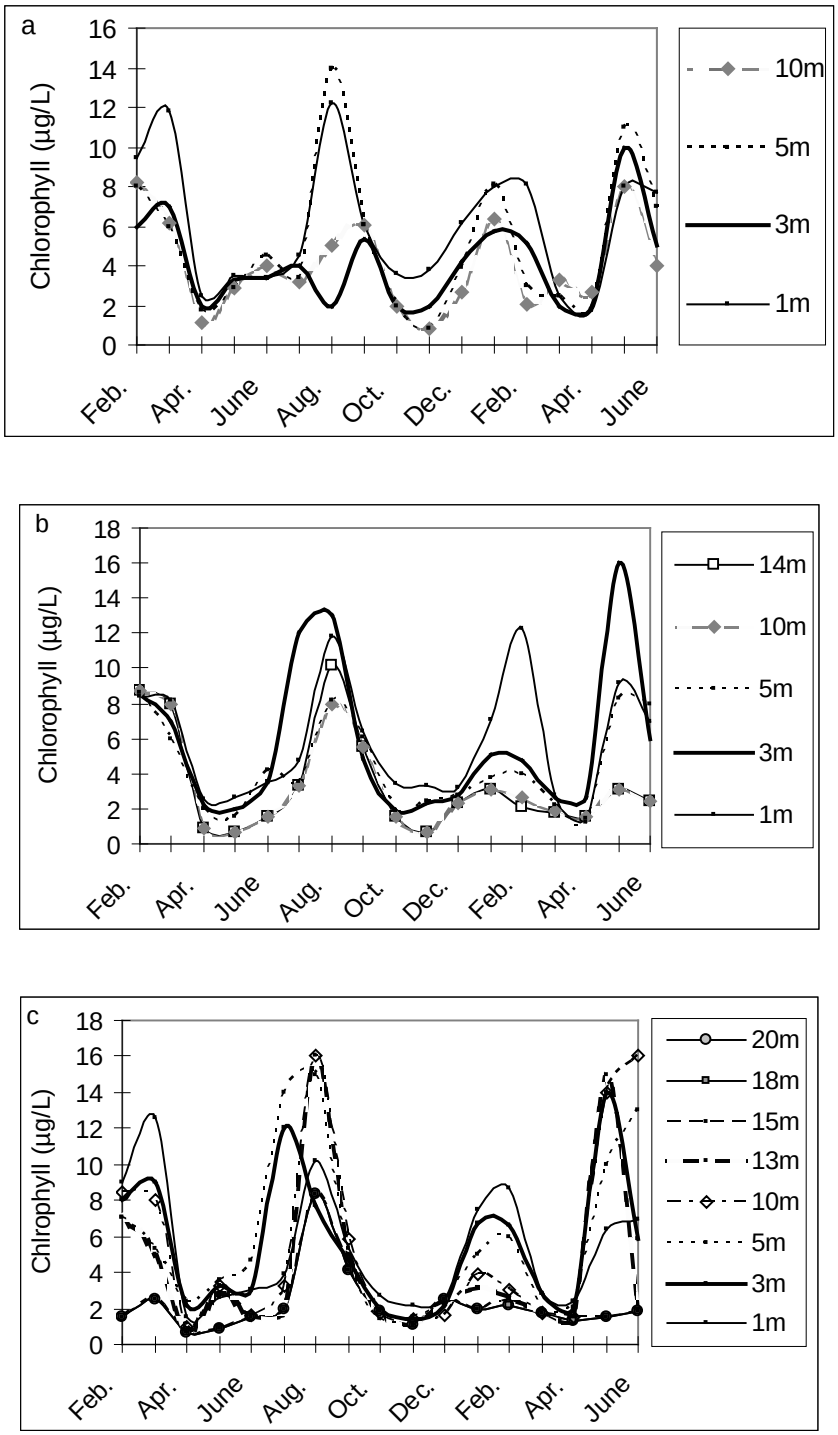

Figure 4. The vertical and seasonal distribution of chlorophyll (Chl; µg/L) in Ikizcetepeler Reservoir. a) at the first station, b) at the second station and c) at the third station.

At all stations, total phosphorus concentrations were higher in 2007 than in 2008. In 2007, the average concentration of TN was about 0.35 mg/L, except a peak of 0.45 mg/L in May at the first and third stations. In 2008, TP concentrations increased from 0.2 mg/L in December to 3 mg/L in April then decreased to about 0.1 mg/L and then increased to about 0.35 mg/L at all stations (Fig. 5).

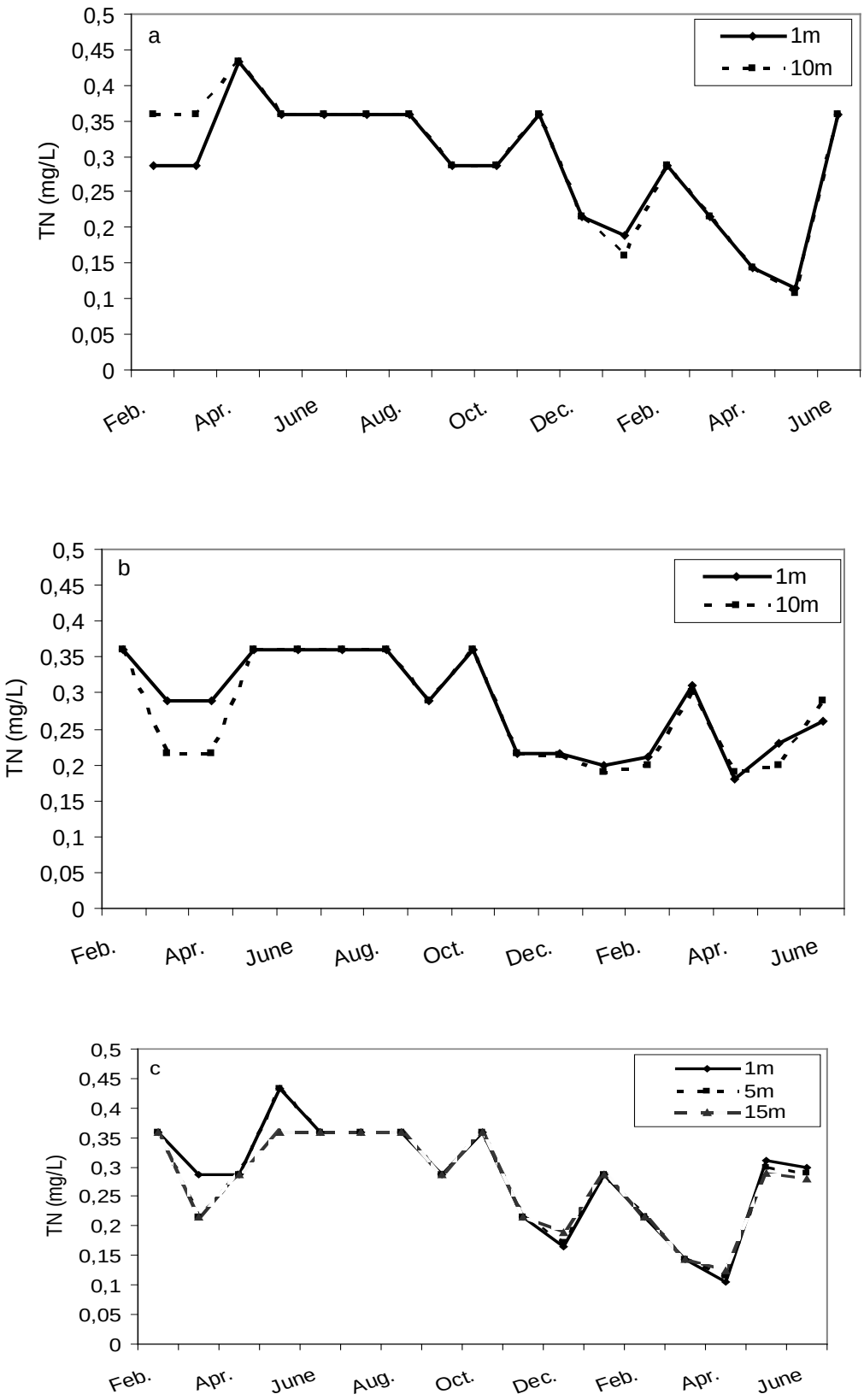

Figure 5. The vertical and seasonal distribution of total nitrogen (TN; mg/L) in Ikizcetepeler Reservoir. a) at the first station, b) at the second station and c) at the third station.

Total phosphorus concentrations were similar at the first and second stations, being higher (about 0.04 mg/L) in summer and lower (about 0.02 mg/L) in the other seasons. At the third station, total phosphorus concentrations fluctuated between 0.02 mg/L and 0.065 mg/L seasonally. Two distinct peaks of (0.09 mg/L) were observed in July 2007 and January 2008 (Fig. 6).

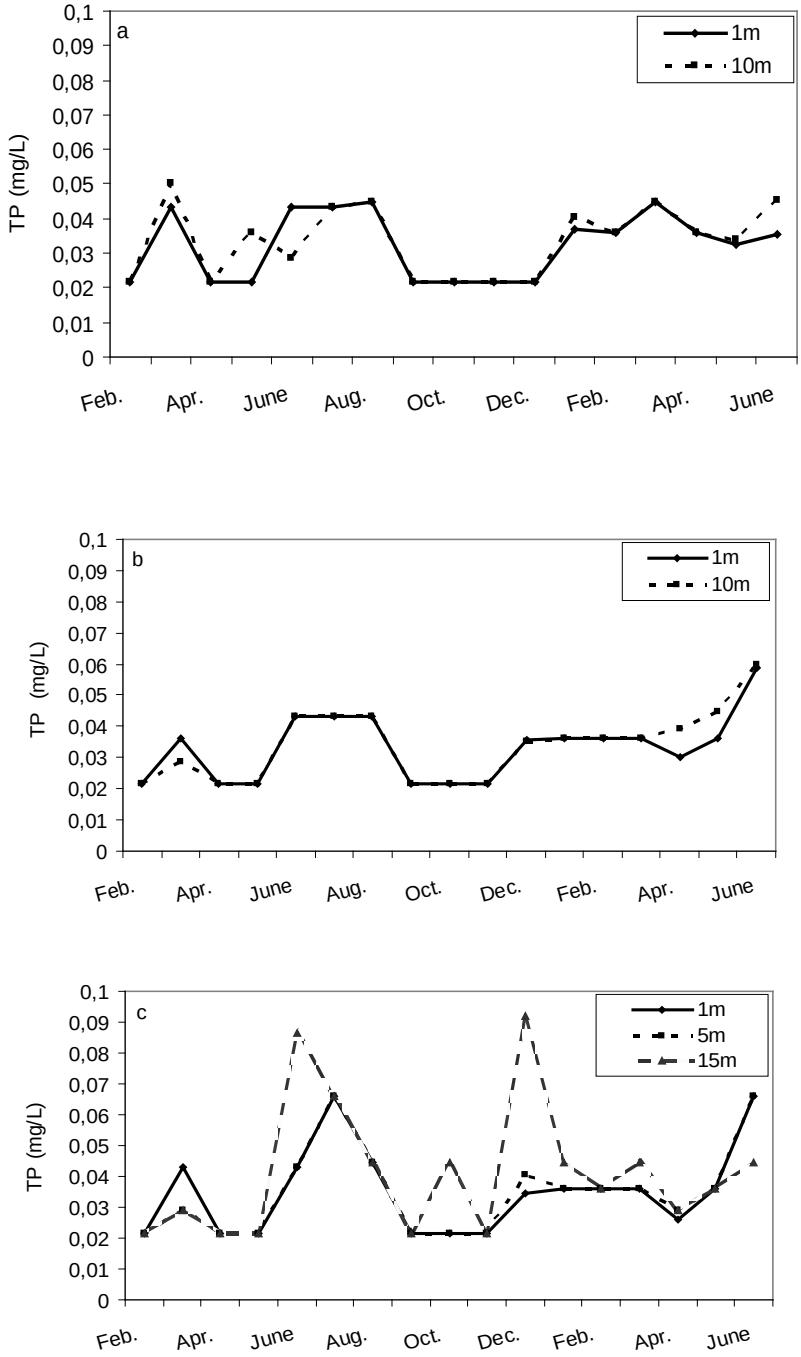

Figure 6. The vertical and seasonal distribution of total phosphorus (TP; mg/L) in Ikizcetepeler Reservoir. a) at the first station, b) at the second station and c) at the third station.

The TN: TP ratios ranged from 7 in summer to 8 in winter with an annual mean of 6 at the first station. They ranged from 7 in summer to 9 in winter with an annual mean of 7 at the second station. The TN: TP ratios ranged from 5 in summer to 7 in winter with an annual mean of 5 at the third station.

The highest Secchi disk depth (400 cm) was measured at the third station in May 2007 and the lowest (41 cm) in

October 2007 at the first station. The Secchi disk transparency was higher at the third station than the others (Fig. 7).

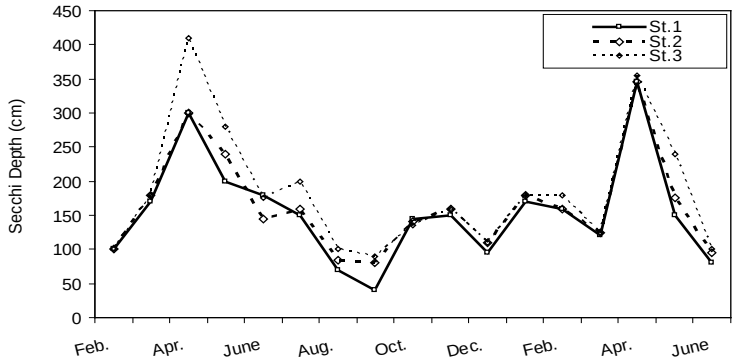

Figure 7. The seasonal distribution of Secchi disk depth (cm) in Ikizcetepeler Reservoir. a) at the first station, b) at the second station and c) at the third station.

Seasonal differences in concentrations of chlorophyll (F=25, p<0.01) and in Secchi disk transparency (F=27, p<0.01) were significant, but the differences in total phosphorus (F=23, p>0.01) and in total nitrogen (F=22, p>0.01) concentrations were not significant. Differences in concentrations of chlorophyll (F=37, p>0.01), total phosphorus (F=33, p>0.01), total nitrogen (F=23, p>0.01) and for Secchi disk depth (F=37, p>0.01) were not significant among sampling stations. Pearson's correlation coefficients between chlorophyll, water temperature and Secchi disk depth were significant (p<0.01; Table), whereas the correlations between chlorophyll, total phosphorus and total nitrogen were not significant (p>0.01; Table).

TABLE :

Pearson correlations coefficents between chlorophyll (Chl) and water temperature (Tmp.), total nitrogen (TN), total phosphorus (TP) and Secchi disk depth (Secchi) at the first, second and third stataions.

	TN	TP	Tmp.	Secchi
Pooled Data	0.33	0.29	0.32	0.31
Station 1	0.01	0.45	0.001	0.22
Station 2	0.21	0.13	0.09	0.48
Station 3	0.34	0.48	0.54*	0.49*

*statistically significant at p= 0.01

V. DISCUSSION

In the Ikizcetepeler Reservoir, chlorophyll concentrations differed significantly from season to season and from station to station. The variable nature of chlorophyll in lakes and reservoirs is a common phenomenon due to the dynamics of environmental parameters affecting phytoplankton growth [2]. High chlorophyll bands observed in the upper depths of the reservoir were probably as a result of springtime increase in available light levels. It is also likely, that summer peaks were driven by deep mixing and an influx of water from below the thermocline providing phytoplankton with the nutrients needed for growth [5]**.** Light intensity is an important factor contributing to seasonal differences in chlorophyll concentrations. Given that nutrient concentrations are usually non-limiting in the reservoir, differences in the timing of phytoplankton bloom might be primarily related to variations in irradiance [19].

During thermal stratification, light penetration reaches below the thermocline due to low turbulence and this in turn causes higher primary production in upper depths with the sufficient light for photosynthesis. Light limitation caused by deep mixing is projected to limit the development of algal biomass during winter months [20]. Secchi disk depth was about 2 m and chlorophyll peaks were observed from 1 to 7 meters where light was probably limiting to phytoplankton in deeper depths. Significant correlations between chlorophyll and Secchi disk transparency suggest that light was critical to chlorophyll production in the Ikizcetepeler 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. More mixed riverine and transitional zones with higher suspended solids (from the inflow) have lower transparency, while lacustrine zone with lower suspended solids (due to higher settling rates) has higher water transparency. Scheffer [21] states that in the absence turbulence, a large proportion of the suspended material settles down, leading to higher water transparency.

Mixing due to water inflow not only serves to homogenize the reservoir, it also helps maintaining the particulates in suspension, maintaining a state of light limitation. Perkins and Underwood [22] state that suspended solids are diluted, settled and used by the lake biota farther down from the entrance point. Rapid flow to reservoirs can indirectly influence algal photosynthesis by augmenting particle content and weakening underwater light.

Although no significant correlations were observed between chlorophyll and total nitrogen, low TN: TP ratios (<10) during warm seasons suggest that primary productivity might has been colimited by nitrogen and light in the reservoir, especially during the summer [23] and [6]. Canfield [12] states that lakes with TN: TP ratios below 10 are generally considered N limited and co-limited by nitrogen and phosphorus at ratios between 10 and 17. According to Smith et al. [24], lakes with N:P ratios <10 have strong nitrogen-limiting conditions. However, even if externally available nutrient limitation occurred for short periods, algae could still grow using internal nutrients absorbed during periods of

abundant nutrient supply [25]. Thus, chlorophyll dynamics were more likely to be affected by light than nutrients in Ikizcetepeler Reservoir.

The summer chlorophyll peaks (about 15μg/L) were higher than winter peaks (about 10μg/L) at all stations. The differences observed between individual seasonal peaks were probably due to temperature effects on the phytoplankton population growth. It is well known that algae have an optimal temperature for growth. Below the optimal temperature, algal growth rates increase with temperature and above the optimal temperature, growth rates decrease due to inactivation or denaturation of proteins [26].

VI. CONCLUSIONS

The results of this work showed that in the mesotrophic Ikizcetepeler Reservoir, chlorophyll dynamics were more affected by light than nutrients. Light plays a fundamental role in controlling the amount of particulates: whenever more light is available, the growth of photoautotrophs is stimulated, resulting in the formation of additional particulates, which in turn reduce water transparency, completing a feedback loop that fine-tunes transparency according to the light input [27]. Although light seemed to the primary factor controlling chlorophyll concentration in the reservoir, low TP: TN ratios (<10) suggests that the importance of nutrients, especially nitrogen cannot be totally discarded.

Peaks in chlorophyll just prior to the onset and at the termination of thermal stratification suggest that it is possible that the springtime increase in available light levels is the primary driver behind the observed phytoplankton bloom. It could also be taht the summer peaks were driven by deep mixing and an influx of water from below the thermocline providing phytoplankton with the nutrients needed for growth. Finally, it would be worthwhile to include the effect of grazing pressure by zooplankton which could have a major influence on phytoplankton biomass dynamics in future studies.

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REFERENCES

[1] Cubbage, D. Lawrence, G. Tomasky, I. Valiela, Relationship of reproductive Output in Acartia tonsa, chlorophyll concentration, and land-derived nitrogen loads in estuaries of Waquoit Bay, Massachusetts. Biol. Bull., 1999, 197, 294-295.

[2] S.R. Carpenter, D. Ludwig, W. A. Brock, Management of eutrophication in lakes subject to potentially irreversible change. Ecol. Appl., 2000, 9, 751–771.

[3] J.J. Elser, E.R. Marzolf, C.R. Goldman, Phosphorus and nitrogen limitation of phytoplankton growth in the freshwaters of North America: a review and critique of experimental enrichments. Can. J. Fish. Aquat. Sci., 1990, 47, 1468-1477.

[4] J.R. Jones, M.F. Knowlton, K.G. An, Developing a Paradigm to Study and Model the Eutrophication Process in Korean Reservoirs. Kor. J. Limnol., 1997, 30, 463-471.

[5] A.R. Dzialowski, S.H. Wang, N.C. Lim, W.W. Spotts, D.G. Huggins, Nutrient limitation of phytoplankton growth in central plains reservoirs, USA. J. Plankton Res., 2005, 27, 587-595.

[6] J.R. Jones, M.F. Knowlton, Chlorophyll Response to Nutrients and Non-algal Seston in Missouri Reservoirs and Oxbow Lakes. Lake Reserv. Manage., 2005, 21, 361-371.

[7] R.E. Hecky, P. Kilham, Nutrient limitation of phytoplankton in freshwater and marine environments: A review of recent evidence on the effects of enrichment. Limnol. Oceanogr., 1988, 33, 796-822.

[8] Lagus, J. Suomela, G. Weithoff, K. Heikkilä, H. Helminen, J. Sipura, Species-specific differences in phytoplankton responses to N and P enrichments and the N:P ratio in the Archipelago Sea, northern Baltic Sea. J. Plankton Res., 2004, 26, 779-798.

[9] E. Jeppesen, J.P Jensen, M. Søndergaard, T.L. Lauridsen, Response of fish and plankton to nutrient loading reduction in eight shallow Danish lakes with special emphasis on seasonal dynamics. Freshwater Biol., 2005, 50, 1616-1627.

[10] V.H. Smith, S.J. Bennett, Nitrogen : phosphorus supply ratios and phytoplankton community structure in lakes. Arch. Hydrobiol., 1999, 146, 37-53.

[11] H.J. Wang, X.M. Liang, P.H. Jiang, J. Wang, S.K. Wu, H.Z. Wang, TN:TP ratio and planktivorous fish do not affect nutrient-chlorophyll relationships in shallow lakes. Freshwater Biol., 2008, 53, 935-944

[12] D.E. Canfield, Prediction of Chlorophyll A concentrations in Florida Lakes: The importance of Phosphorus and Nitrogen. Water Resour. Bull., 1983, 19, 255-262.

[13] K. An, S.S. Park, Indirect influence of the summer monsoon on chlorophyll-total phosphorus models in reservoirs: a case study. Ecol. Model., 2002, 152, 191-203.

[14] C.R. Kratzer, P.L. Brezonik, A Carlson-type trophic state index for nitrogen in Florida lakes. Water Resour. Bull., 1981, 17, 713-715.

[15] State Water Works, Manyas Project [in Turkish]. Ankara, Turkey. State Water Works, 2005.

[16] APHA, Standard methods for the examination of water and wastewater. Washington, DC. American Public Health Association, 1995.

[17] SAS Institute, SAS/STAT Users Guide (Version 9.1). Cary, NC, USA. SAS Institute Inc., 2003.

[18] OECD, Eutrophication of waters. Monitoring, assessment and control. Paris, France. OECD, 1982.

[19] Iriarte, D.A. Purdie, Factors controlling the timing of major spring bloom events in an UK south coast estuary. Estuar. Coast. Shelf Sci., 2004, 61, 679–690.

[20] J.T. Lehman, Mixing Patterns and Plankton Biomass of the St. Lawrence Great Lakes under Climate Change Scenarios. J. Great Lakes Res., 2002, 28, 583-596.

[21] M. Scheffer, Ecology of shallow lakes, Chapman and Hall, London, 1998.

[22] R.G. Perkins, G.J. C. Underwood, Gradients of chlorophyll a and water chemistry along a eutrophic reservoir with determination of the limiting nutrient by in situ nutrient addition. Water Res., 2000, 34, 713-724.

[23] K.E. Havens, R.T. James, L. East, V.H. Smith, N: P ratios, light limitation, and cyanobacterial dominance in a subtropical lake impacted by non-point source nutrient pollution. Environ. Pollut., 2003, 122, 379-390.

[24] V.H. Smith, V.J. Bierman, B.L. Jones, K.E. Havens, Historical trends in the Lake Okeechobee ecosystem IV. Nitrogen: phosphorus ratios, cyanobacterial dominance, and nitrogen fixation potential. Arch. Hydrobiol., 1995, 107, 71–88.

[25] Y. Liu, L.Z. Yang, Establishment and application of prediction model for total phosphorus in channel reservoirs. J. Southwest Jiaotong Univ., 2004, 39(5), 653–655.

[26] D.A. Ratkowsky, R.K. Lowry, T.A. McMeekin, A.N. Stokes, R.E. Chandler, Model for bacterial culture growth rate throughout the entire biokinetic temperature range. J. Bacteriol., 1983, 154, 1222–1226.

[27] J. Huisman, Population dynamics of light-limited phytoplankton: Microcosm experiments. Ecology, 1999, 80, 202–210.