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Evaluation of trophic state of lake Uluabat, Turkey

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Abstract: *Lake Uluabat, which is located in Marmara region, is one of the most productive lakes in Turkey. Due to concerns about potential pollution resulting from watershed sources and adjacent agricultural lands, a study of the trophic state of lake Uluabat was conducted during the period February 2003 to January 2004. Total nitrogen (TN), total phosphorus (TP), Secchi disc depth (SD) and chlorophyll a (Chl a) were analyzed monthly in order to assess the trophic state of the lake. According to calculated nutrient ratios, phosphorus was found to be the primary limiting nutrient in lake Uluabat. Carlson's trophic state index values, based on TP, SD and Chl a, indicated that lake Uluabat is an eutrophic system.*

Key words: *Chlorophyll-a, Lake Uluabat, Secchi disc depth, Total phosphorus, Total nitrogen, Trophic state index*
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Introduction

Eutrophication is becoming one of the main problems in water deterioration (Manojlovic *et al.,* 2007; Choi *et al.,* 2008). This process can be evaluated by determining the limiting nutrients and by calculating trophic state indices. The trophic state index (TSI) based on several biological, chemical and physical indicators, especially the Carlson-type TSI offers the most suitable and acceptable method for evaluating lake eutrophication (Xu *et al.,* 2001). Carlson (1977) introduced a set of lake trophic state indices (TSIs) based on measurement of water column phosphorus TSI (TSI_{TP}), chlorophyll a TSI ($TSI_{Chl\ a}$) and Secchi disc depth TSI (TSI_{SD}). Carlson's TSIs are based on the assumption that when phosphorus is the limiting nutrient in a lake, there will be a close relationship between TSI_{TP} and $TSI_{Chl\ a}$ (Matthews *et al.*, 2002).

Uluabat lake is an important national resource for Turkey and beyond and has been designated as a Ramsar site (International treaty for the conservation and sustainable utilization of wetlands). It is an important breeding, feeding and wintering site for significant members of bird populations. Some of these birds are globally threatened species, such as the dalmatian pelican (*Pelecanus crispus*) and pygmy cormorant (*Phalacrocorax pygmeus*) (Yarar and Magnin, 1997; Altinsacli and Griffiths, 2001; Cevik, 2004). The wetlands of lake Uluabat and its catchments face a number of problems and threats which could make these valuable resources change or degrade/disappear. Human activities, direct discharges to the lake (point pollution) and indirect discharges to the lake watershed (diffuse pollution) are great contributors to degradation and loss of Uluabat lake wetlands and deterioration of water quality. Thus, the aim of this study was to characterize the trophic state *via* three trophic state indices of lake Uluabat and to assess its nutrient limitation based on water quality data.

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Materials and Methods

Lake Uluabat, located in the Marmara region of Bursa, Turkey (40°10' N, 28°35' E), is a productive, shallow lake with a watershed area of 10555 km^2. The lake is largely fed by the Mustafakemalpasa river, and its main outflow is via Uluabat river (Gurluk and Rehber, 2006). In recent years, the lake has become shallower due to sedimentation from the catchments and environmental pollution has rapidly increased due to the marked increases in population and unplanned industrial development (Karacaoglu *et al.,* 2006). The mean surface area of lake in 1984, 1993 and 1998 was reported as 133.1, 120.5 and 116.8 km^2, respectively (Aksoy and Ozsoy, 2002; Salihoglu and Karaer, 2004). Domestic and industrial waste discharges affect water quality. A variety of pollutants such as sewage water, agricultural fertilizers and chemicals, animal waste, process wastes of foodstuff industries, tannery wastes, slaughterhouse wastes, and mining wastes from the watershed contribute to the eutrophication level (Salihoglu and Karaer, 2004).

Water analysis was done once a month at five stations from February 2003 to January 2004 – near the outflow of the lake (S1), south of the Island Halilbey (S2), southwest of Island Mutlu (S3), between Island Mutlu and the village of Eskikaraagac (S4) and near the village of Akcalar (S5) (Fig. 1). Because of the shallowness of lake Uluabat, water samples were taken from the surface. Temperature, pH, lake depth, and Secchi disc depth (SDD) were measured during the sample collection. Electrical conductivity ($EC_{(25^oC)}$) was measured with a Jenway conductivity meter. Samples for dissolved oxygen (DO), total phosphorus (TP), soluble reactive phosphorus (SRP), total nitrogen (TN), ammonium+nitrate nitrogen (DIN) and chlorophyll *a* (Chl *a*) concentrations were delivered immediately to the laboratory and determined according to standard methods (APHA, 1998). DO was measured by the Winkler method. TP and SRP concentrations were determined by the ascorbic acid

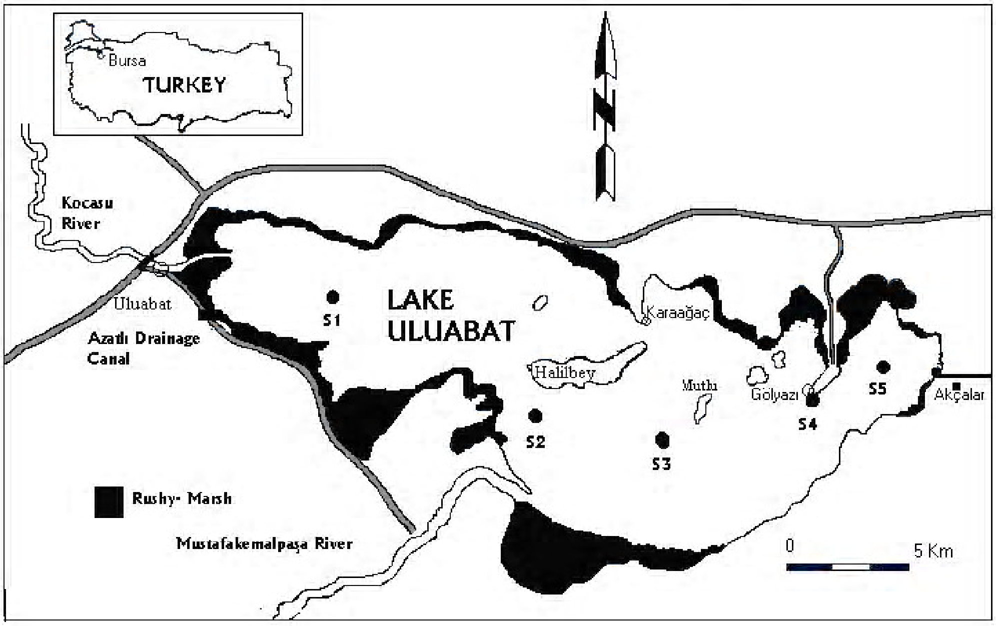

Fig. 1: The view of study area of lake Uluabat and sampling stations (adapted from Aksoy and Ozsoy, 2002)

method. Sulfuric acid-nitric acid digestion was carried out for TP. TN was measured by the Kjeldahl method. DIN concentration was determined by steam distillation. Chl *a* concentration was measured spectrophotometrically after acetone extraction (APHA, 1998).

The Carlson's trophic state indices (TSI_{TP}, $TSI_{Chl\,a}$ and TSI_{SD}) were calculated (Carlson, 1977) from the mean values of TP, Chl *a*, and SD using the following equations;

TSI_{TP} = 10 x [6 – ln (48/ TP)/ln 2]

$TSI_{Chl\,a}$ = 10 x [6 – (2.04 - 0.68 ln Chl *a*)/ln 2]

TSI_{SD} = 10 x [6 – lnSD/ln 2]

Annual average and standard deviation, minimum and maximum values were calculated using Minitab (version 15) statistical software (Minitab, 2006).

Results and Discussion

The ecological integrity of the lake Uluabat ecosystem is influenced by both its physical environment and water quality conditions. The ecological stability of lake Uluabat is threatened by the impact of both internal and external factors, especially the impact of the lake regulation and water extraction for agriculture, industries, and residents (Dalkiran *et al.,* 2006). Annual average and standard deviation, minimum and maximum values of some physical and chemical parameters of lake Uluabat is summarized in Table 1.

Phosphorus overloading is the most important cause of lake eutrophication (Jin *et al.,* 2005). P load calculated for lake Uluabat (8.48 gm^{-2}-year) on the basis of Vollenweider (1971) apparently indicated that the lake Uluabat is of an eutrophic state according to compiled data from State Water Affair. Trophic state graph prepared by the Organization for Economic Co-operation and Development (OECD) was taken place indicating the trophic level according to lake's P load (Saatci *et al.,* 1999). It was stated that lake Sapanca, another lake in Marmara region, was loaded over critical load respect to P with the value of 1.80 gPm^{-2}-year (Akkoyunlu and Ileri, 1998). Dalkiran *et al.* (2006) pronounced that high pollution entering lake Uluabat *via* Mustafakemalpas a stream, the Azatli drainage channel, and some companies near the lakeshore, have indicated the external pollution load and have changed the trophic status of the lake. The previous studies apparently showed that lake Uluabat is likely to become more eutrophic over time.

As eutrophication is dependent on the limiting nutrient concept, the most obvious step toward protection and restoration of a lake is to limit or treat the input of the excessive nutrient load (Xu *et al.,* 2003). Thus, the ratio of nitrogen to phosphorus in inputs is thought to be a logical starting point in examining the factors controlling nutrient limitation. If there were no biogeochemical processes affecting the relative availability of nitrogen and phosphorus within an ecosystem, then the N:P ratio would be a perfect predictor for determining the limiting nutrient (Howarth, 1988; Anonymous, 2000). Akkoyunlu and Ileri (1998) stated that phosphorus tends to be the limiting factor when N:P ratio is greater than 7:1. If not, nitrogen tends to be the limiting factor. In this study, phosphorus was found to be the primary limiting nutrient in lake Uluabat according to the calculated N:P ratios (mean 239.8±13.08) (Table 2). In addition, as seen in Table 2, N:P ratios during March and April (N:P<7:1) suggest that cyanobacteria is dominant, whereas Bacilloriphyta is dominant in other months (N:P>7:1). The relative abundance of cyanobacteria compared to other algal groups is closely related to the TN/TP ratio. According to Tonno and Noges (2003) planktic-N_2fix can occur if the ratio of TN/TP is equal or lower than the mass ratio of 7:1. In lake Uluabat, 76% of calculated N:P ratios was found to be higher than 29:1. Cyanobacteria have been found to dominate lake primary production at TN:TP≤29:1 and are much less abundant at higher ratios (Havens *et al.,* 2003; Hakanson *et al.,* 2007; Tonno and Noges, 2003).

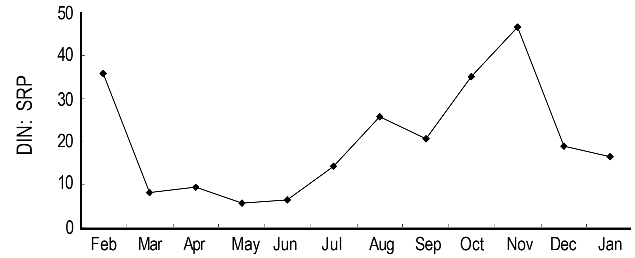

Fig. 2: Monthly variation of DIN:SRP (Values indicates the average of five stations)

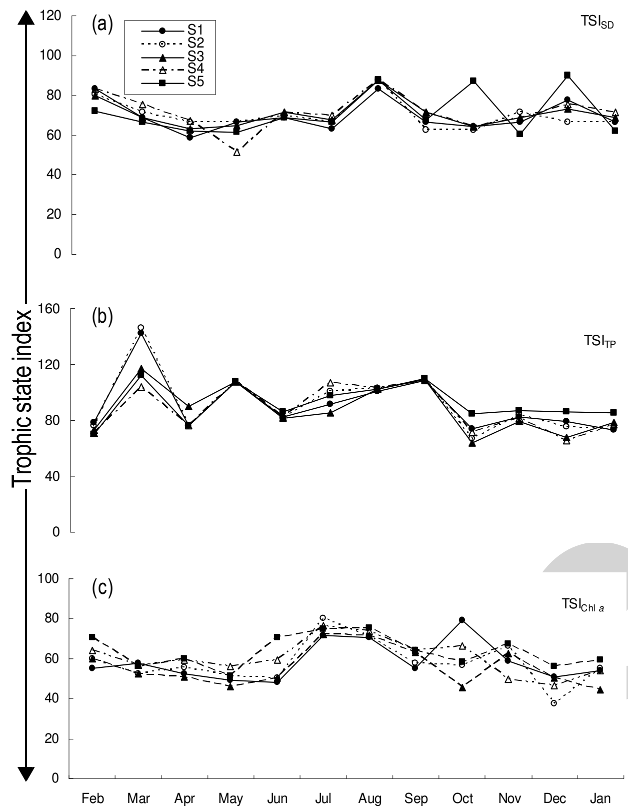

Fig. 3: Monthly variations in trophic state index calculated from the (a) Secchi disc depth (b) total phosphorus (c) chlorophyll *a*

Table - 1: Some physical and chemical parameters of lake Uluabat (minimum, maximum and mean values)

Parameter	Minimum	Maximum	Mean±SD
Temperature (°C)	6.6	28	16.4±7.47
pH	7.74	9.10	8.69±0.16
Depth (cm)	145	440	268.36±16.6
SDD (cm)	15	115	54.42±21.5
$EC_{(25^oC)}$ (μScm^{-1})	430	770	555.7±68.2
DO (mgl^{-1})	5.40	13.2	7.61±1.99
Chl *a* (mgm^{-3})	1.99	156.9	30.4±33.9
TN (mgl^{-1})	0.56	264.5	84.9±7.88
TP (mgl^{-1})	0.06	19.1	1.11±2.48
DIN (mgl^{-1})	4.12	32.6	23.1±3.74
SRP (mgl^{-1})	0.05	1.34	1.12±0.07

This suggests the probable lack of cyanobacteria dominance in lake Uluabat. This was also widely supported by the monthly variation of DIN:SRP ratios observed in this study (Fig. 2). DIN:SRP ratios, <10:1 by mass, are considered to indicate strongly nitrogen limitation conditions that favor the growth and proliferation of N_2-fixing cyanobacteria (Karacaoglu *et al.,* 2006). In lake Uluabat, 66% of calculated DIN:SRP ratios was found to be higher than 10:1, suggesting that cyanobacteria were not the dominant taxonomic group. Similarly, Karacaoglu *et al.* (2006) also indicated that Bacilloriphyta were dominant in all year except for few months.

TSI values calculated on the basis of Secchi disc depth, total phosphorus and chlorophyll *a* showed a characteristic seasonal variation (Fig. 3). The mean values of, $TSI_{TP,}$ $TSI_{Chl\ a}$ and TSI_{SD} were, 90.18, 59.28 and 70.3, respectively. TSI values given strongly suggested that the Uluabat is classified as in an eutrophic state based on the $TSI_{Chl\ a}$, TSI_{SD} and hypereutrophic state based on the TSI_{TP}. The mean TSI value of 73.25 also supports indicated that Lake Uluabat is in an eutrophic state. Lower values of TSI (50-60) refer lower boundary of classical eutrophy, TSI 60-70 shows dominance of blue-green algae and possible occurrence of algal scum and higher values of TSI (70-80) indicates very eutrophic conditions

Table - 2: Calculated TN/TP ratios at each of the sampling station in lake Uluabat, Turkey

Sampling date	Station 1	Station 2	Station 3	Station 4	Station 5
2003					
February	21.28	15.37	15.16	25.67	32.39
March	0.05	0.11	0.37	1.26	0.51
April	7.43	7.14	2.46	5.12	3.86
May	97.78	87.91	79.64	113.11	75.70
June	525.33	439.80	345.16	654.66	526.60
July	288.09	162.50	508.92	63.82	161.54
August	290.36	213.44	231.97	218.08	300.56
September	126.91	90.64	91.54	70.15	114.80
October	599.19	726.31	915.63	409.43	238.75
November	312.21	199.61	298.37	231.27	234.53
December	544.44	653.57	1012.50	1265.71	283.33
2004					
January	54.42	56.32	43.76	53.45	35.95

along with heavy algal blooms throughout the summer period (Carlson, 1977). Similarly, Kitaka *et al.* (2002) concluded that lake Naivasha was found eutrophic with $TSI_{Chl\,a}$, TSI_{SD} and TSI_{TP} values of 56.1, 57.7 and 59.2, respectively. Morkoc *et al.* (1998) suggested that the lake Sapanca was in an oligotrophic state according to TSI values less than 45. Matthews *et al.* (2002) also concluded that lake Whatcom was found oligotrophic according to mean TSI values which were found to be less than 45. Also, Maltanski reservoir was assessed as eutrophic state according to $TSI_{Chl\,a}$, TSI_{SD} and hypereutrophic state based on the TSI_{TP} (Goldyn *et al.,* 2003).

Furthermore, when the results obtained from this research were compared with the OECD's standard table (Vollenweider and Kerekes 1982), it was shown that lake Uluabat is in an eutrophic state based on the Chl *a* and SD, and hypereutrophic state based on the TP and TN.

The overall evaluation of this study clearly indicated that clear signals of eutrophication were observed in lake Uluabat during the study period. Due to its importance as being a Ramsar site, management solutions must be urgently developed in order to avoid the destruction of the lake. The results of the present study also suggested that phosphorus was the limiting nutrient in lake water. Therefore, comprehensive efforts must be undertaken to control excessive phosphorus inputs as well as to evaluate phosphorus release from sediment.

Acknowledgments

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