Research Article

Bioassessment of Ecological Status of Three Aegean Reservoirs Based on Phytoplankton Metrics

Üç Ege Barajının Fitoplankton Metriklerine Dayalı Ekolojik Durumunun Biyodeğerlendirilmesi

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Abstract

Assessing freshwater quality is getting more important since the implementation of the European Union Water Framework Directive. In the present study, the water quality of three reservoirs of the North Aegean basin of Turkey was assessed using Mediterranean Phytoplankton Trophic Index and Phytoplankton Trophic Index. Data were collected seasonally between summer 2014 and summer 2015 from three reservoirs. The reservoirs showed alkaline waters. The highest nutrients values of TP (203.5 µg L^{-1}) at Bayramiç Reservoir and TN (1012.0 µg L^{-1}) at Sevişler Reservoir were recorded. A total of 120 species were recorded and mostly represented by Bacillariophyta. The relationship between phytoplankton species and environmental variables was examined using multivariate analyses. The phytoplankton composition and distribution were governed by environmental variables. The most important structuring factors were total phosphorus, orthophosphate, total kjeldahl nitrogen, biological oxygen demand, total organic carbon, and temperature. The first two CCA axes explained 31% of cumulative percentage variance of species data with 97.7% between species-environment correlations, the situation which was also confirmed the Monte Carlo test ($p = 0.002$, $F = 1.157$). Med-PTI indicated good quality waters for Ayvacık and Bayramiç Reservoirs, while Sevişler Reservoir had a moderate water quality. Based on the PTI, the waters of the Bayramiç and Sevişler Reservoirs were classified as or moderate ecological status, while Ayvacık Reservoir indicated a good water quality. From these results, the Med-PTI and the PTI seem to be appropriate metrics for assessing the water quality of the reservoirs in the North Aegean River Basin.

Keywords: *water quality, phytoplankton, Med-PTI, PTI, reservoir*

Öz

Avrupa Birliği Su Çerçeve Direktifi'nin uygulanmasıyla birlikte su kalitesinin değerlendirilmesi büyük önem kazanmıştır. Bu çalışmada, Türkiye'nin Kuzey Ege Havzası'nda bulunan üç barajın su kalitesi Akdeniz Fitoplankton Trofik İndeksi ve Fitoplankton Trofik İndeksi kullanılarak değerlendirilmiştir. Veriler üç barajdan 2014 ve 2015 yaz dönemi arasında mevsimsel olarak toplanmıştır. Üç baraj alkali su özelliği göstermiştir. En yüksek nutrient değerleri olarak TP (203,5 µg L^{-1}) Bayramiç Baraj Gölü'nde ve TN (1012,0 µg L^{-1}) Sevişler Barajı'nde kaydedilmiştir. Toplamda 120 tür teşhis edilmiş ve türlerin çoğunluğu Bacillariophyta ile temsil edilmiştir. Fitoplankton türleri ve çevresel değişkenler arasındaki ilişki multivaryete analizler ile incelenmiştir. Fitoplankton kompozisyonu ve dağılımını çevresel değişkenler yönetmiştir. Toplam fosfor, ortofosfat, toplam Kjeldahl azotu, biyolojik oksijen ihtiyacı, toplam organik karbon ve sıcaklık en önemli faktörler olmuştur. İlk iki CCA ekseni tür verisinin %31 kümülatif yüzde varyansının %97,7 tür-çevre korelasyonu ile açıklamış ve durum Monte Carlo testi (p= 0,002 ve F = 1,157) ile doğrulanmıştır. Med-PTI, Ayvacık ve Bayramiç Barajları için iyi su kalitesini gösterirken Sevişler Barajı'nı orta su kalitesinde indike etmiştir. PTI'ye göre Bayramiç ve Sevişler Barajları orta ekolojik durumda sınıflandırılmışken Ayvacık Barajı iyi su kalitesinde indike edilmiştir. Sonuçlara göre, Med-PTI ve PTI'nin Kuzey Ege Havzası'nda bulunan barajların su kalitesinin değerlendirilmesinde uygun metrikler olduğu görülmüştür.

Anahtar sözcükler: *su kalitesi, fitoplankton, Med-PTI, PTI, baraj*

Introduction

Water is one of the essential factors for civilization, and also among the most important items in the new world order. Surface watercourses provide a number of ecosystem services to all living organisms and humans, such as water supply and purification, climate and flood regulation, fishery and recreation (Wallis et al. 2012). The water quality is of great importance also for human lives as it is commonly consumed and used by households (Cieszynska et al. 2012). During the last decades, anthropogenic activities have deteriorated water quality of reservoirs worldwide (Katsiapi et al. 2011; Çelekli and Öztürk, 2014). The increasing availability of nutrients such as nitrogen and phosphorous in freshwaters, especially associated with eutrophication, is affecting the performance of aquatic ecosystems (Leira et al. 2009; Delgado and Pardo, 2014).

Due to this, the European Union Water Framework Directive (WFD) required member states to assess and classify their surface water quality bodies (Directive, 2000). In this regard, biological quality elements such as phytoplankton, phytobenthos, macrophytes, benthic macroinvertebrates and fish are recommended by WFD as biological indicators for the assessment of surface waters (Directive, 2000; EC, 2009). The use of biological communities for monitoring the biotic integrity of aquatic ecosystems has a long history (Karr, 1981; Beck and Hatch, 2009) and their use will likely increase as human-induced pressures continue to increase and as pressures are exacerbated by climate warming (Brucet et al. 2013). Effective biological assessment should be based on reliable pressure–impact relationships (Karr and Chu, 1999; Dale and Beyeler, 2001; Davies and Jackson, 2006; Hering et al. 2006). Although the use of multiple taxonomic groups is thought to better distinguish the effects of multiple stressors (Dale and Beyeler, 2001; Hering et al. 2006) few studies have compared the response of different organism groups to different types of environmental stress (Johnson et al. 2006; Johnson and Hering, 2009).

Phytoplankton can be used as a good indicator of water quality changes, given its sensitivity and dynamic responses to changes in the surrounding environment (Reynolds, 1984, 2002; Padisák et al. 2006; Cheshmedjiev et al. 2010; Katsiapi et al. 2011; Çelekli and Öztürk, 2014). A number of phytoplankton indices such as phytoplankton trophic index (PTI) based on the composition, independently of the geographic region (Phillips et al. 2013) and the Mediterranean phytoplankton trophic index (Med-PTI) using the phytoplankton biovolume (Marchetto et al. 2009) have been developed for the purpose of Water Framework Directive (WFD). From that point, aims of the present study were to i) determine phytoplankton composition, ii) to evaluate relationship between phytoplankton assemblages and environmental factors and iii) assess water quality by use of the Mediterranean Phytoplankton Trophic Index (Med-PTI) (Marchetto et al. 2009) and Phytoplankton Trophic Index (PTI) (Philips et al. 2013) of three reservoirs in the North Aegean River Basin of Turkey.

Method

Sampling and Analyses

Phytoplankton samples were collected seasonally between September 2014 and August 2015 from three reservoirs in the North Aegean River Basin of Turkey (Figure 1). Hydrobios plankton net (55 µm mesh size) was used to collect net-plankton. Water samples (250 ml) were directly taken from just beneath of the surface water from each reservoir for phytoplankton enumeration. Phytoplankton samples were fixed with lugol-glycerol's solution according to the standard method (Utermöhl, 1958; CEN, 2004, 2006). Water samples were stored in coolers with ice packs during the transfer to the laboratory for the analyses.

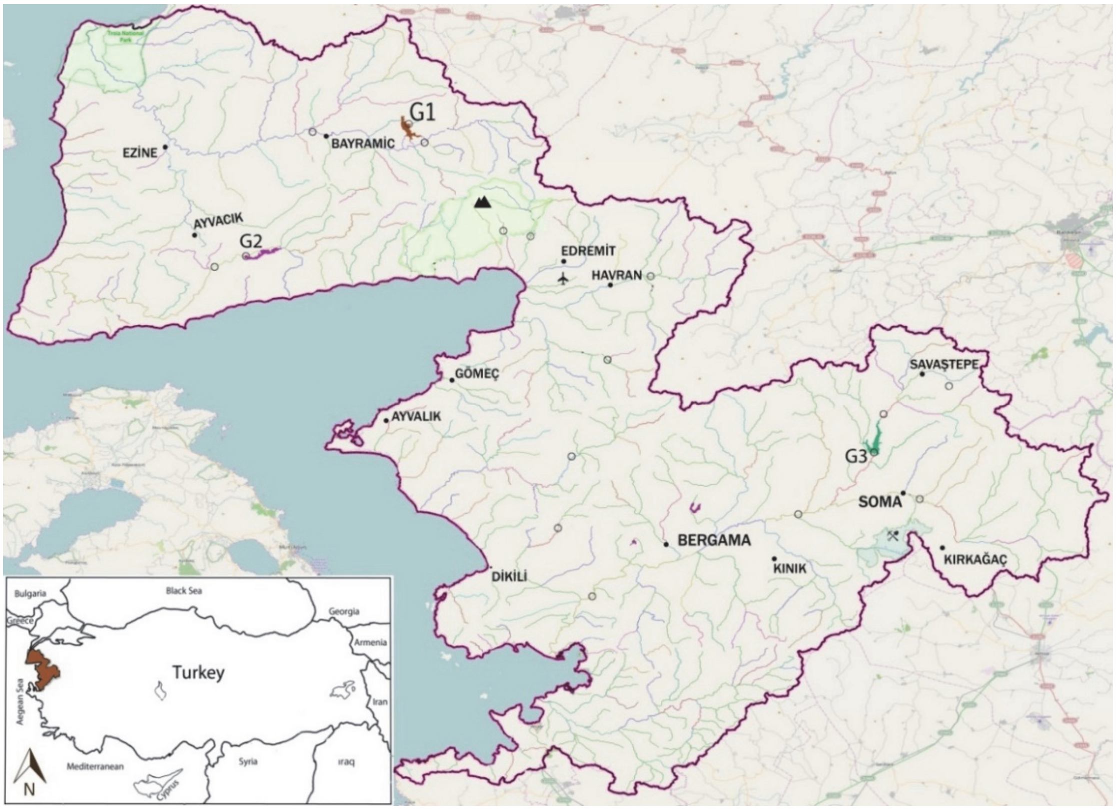

Figure 1. Location of three reservoirs (G1: Bayramiç Reservoir, G2: Ayvacık Reservoir, G3 Sevişler Reservoir).

Environmental variables such as pH, conductivity, salinity, dissolved oxygen and temperature measured *in situ* using an YSI professional plus oxygen–temperature meter. Water transparency was measured using a 20-cm Secchi disk (SD). Geographical data (altitude, latitude, and longitude) were recorded from a geographical positioning system. Geomorphological characteristics of the reservoirs are given in Table 1.

Analyses of chemical variables such as total nitrogen (TN), nitrate nitrogen (NO_3-N), nitrite nitrogen (NO_2-N), ammonium nitrogen (NH_4-N), total Kjeldahl nitrogen (TKN), total phosphorus (TP), orthophosphate (PO_4-P), biological oxygen demand (BOD_5) and dissolved oxygen (DO), and total organic carbon (TOC) were carried out in laboratory using standard methods (APHA, 2012).

Table 1

Geographical and Morphometry Characteristics of The Reservoirs

Reservoir		Typology	Longitude	Latitude	Cons.	Altit. (m)	Reser. Area (ha)	Max. depth (m)
Bayramiç	G1	R1D2A2J2	26.66980	39.81087	1996	159	608	41
Ayvacık	G2	R1D2A1J2	26.47838	39.60825	2007	307	64.3	43
Sevişler	G3	R1D2A1J1	27.55003	39.26500	1981	158	472	48

Note. R= altitude, D= depth, A= surface area, J= geology, Cons= construction, Altit= altitude Reser=reservoir

Phytoplankton taxa were identified using a light microscope (Olympus BX53) equipped with DP73 model digital camera and imaging software (Olympus CellSens Vers. 1.6) (CEN, 2003, 2004). Taxonomic identifications were performed following Ettl (1983), Komárek and Fott (1983), Krammer and Lange-Bertalot (1991a, b; 1999a, b), Komárek and Anagnostidis (1998), John et al. (2002), Wehr and Sheath (2003).

The enumeration of phytoplankton was done at magnifications of 400–600× (2 transects) under an inverted microscope (Olympus CKX41) (Utermöhl, 1958; Lund et al. 1958). Total biovolume for each taxon was calculated by multiplying the cell density by the unitary cell biovolume of the taxon, which was calculated using geometric shapes of cells proposed by Hillebrand et al. (1999) and Sun and Liu (2003).

Phytoplankton Trophic Index (PTI) (Philips et al. 2013) and the Mediterranean Phytoplankton Trophic Index (Med-PTI) (Marchetto et al. 2009), used to assess the status of the reservoirs according to the Water Framework Directive were calculated using the following Eq-1 and 2 respectively and then

$$PTI = \frac{\sum_{j=1}^{n} a_j * s_j}{\sum_{j=1}^{n} a_j} \qquad \text{(Eq-1)}$$

Where a_j is the proportion of j^{th} taxon in the sample and s_j is the optimum of j^{th} taxon in the sample.

$$MedPTI = \frac{\sum_{j=1}^{n} b_{j,k} * v_k * i_k}{\sum_{j=1}^{n} b_{j,k} * i_k} \quad \text{(Eq-2)}$$

Where, $b_{j,k}$ is the biovolume, v_k is trophic value, and i_k the indicator value of the *n* species in the sample.

Multivariate analysis.

A canonical correspondence analysis (CCA) was performed using the CANOCO software, version 4.5 to describe the structuring factors governing the composition of phytoplankton assemblages. Following ter Braak and Smilauer (1998), unimodal response models were employed for the ordination of analyses along gradients. Selected environmental variables were transformed log (x+1), except pH to reduce skewness (ter Braak and Smilauer, 1998). A weighted average (WA) regression of CALIBRATE program (Juggins & ter Braak, 1992) was used to estimate diatom species optima (*uk*) and tolerance (*tk*) levels for the environmental variables. For this purpose, weighted-average metrics assess only a single pressure (e.g. nutrients) or related pressures of environmental factors on organisms. For these analyses species representing over than 1% of the total biomass were selected.

Results

Physical and Chemical Parameters

The mean water quality parameters of the water bodies are presented in Table 2. The reservoirs had alkaline waters and no significant differences in pH and temperature values among reservoirs. The highest conductivity (434.5 µS cm^{-1}) and salinity (0.21 ppt) were measured at Sevişler Reservoir. With regard to nutrients, the highest values of TN (1012.0 µg L^{-1}) and $N\text{-}NO_3$ (217.0 µg L^{-1}) were recorded at Sevişler Reservoir, following at Bayramiç Reservoir. On the other hand, relatively higher TP (203.5 µg L^{-1}) value was found to be at Bayramiç Reservoir. Sevişler and Bayramiç Reservoirs had higher and similar TOC value than that of Ayvacık Reservoir. Ayvacık Reservoir had a higher Secchi depth value than those of Sevişler and Bayramiç Reservoirs.

Table 2

Mean ± SD (Standard Deviation) Values of Water Quality Parameters for All Seasons

Variables	Unit	G1	G2	G3
pH		8.8±0.1	8.7±0.1	8.8±0.2
Temperature	°C	22.2±6.7	19.9±7.2	21.4±6.7
Conductivity	µS cm^{-1}	275.8±71.8	343.8±96.9	434.5±107.5
DO	mg l^{-1}	9.3±1.8	8.6±1.9	8.8±0.9
TSS	mg l^{-1}	9.4±11.9	2.2±0.4	7.5±9.5
BOD	mg l^{-1}	22.8±26.5	13.3±8.8	10.5±7.6
COD	mg l^{-1}	72.0±74.9	51.8±35.4	46.5±28.4
TOC	mg l^{-1}	20.28±30.3	16.1±17.2	20.6±32.8
N-NH$_4$	µg l^{-1}	100.0±0.0	93.5±26.8	254.8±309.5
N-NO$_2$	µg l^{-1}	4.25±2.6	17.00±22.2	60.3±60.6
N-NO$_3$	µg l^{-1}	139.0±72.2	101.5±23.0	217.0±110.7
TKN	µg l^{-1}	642.0±574.8	578.3±362.7	546.0±271.4
TN	µg l^{-1}	764.5±593.1	681.8±462.4	1012.0±561.4
TP	µg l^{-1}	203.5±214.5	173.8±195.6	105.8±54.3
P-PO$_4$	µg l^{-1}	109.5±148.8	74.8±57.6	57.0±36.1
Salinity	ppt	0.15±0.02	0.18±0.03	0.21±0.04
SD	m	1.43±0.67	2.18±0.40	1.58±0.79

Box plots of TN, N-NO$_3$, TP, and P-PO$_4$ are given in Figure 2a, b, c, and d, respectively. A spatial variability was detected following the physicochemical variables of the reservoirs during the study period. The mean value of the chemical factors was mainly low at Ayvacık Reservoir comparing to the other reservoirs.

Phytoplankton and Environmental Relationship

During the present study, a total of 120 taxa were recorded and most of them belong to Bacillariophyta. Phytoplankton species such as *Cocconeis placentula*, *Cryptomonas ovata, Cyclotella bodanica, Cyclotella iris, Pediastrum simplex*, *Scenedesmus communis* and *Ulnaria ulna* were commonly found during the study period.

Among the total phytoplankton species, 64 phytoplankton taxa with abundance higher than 1% of the total biomass were selected for the multivariate analyses. To elucidate relationship between these phytoplankton species as response variables and six (6) environmental factors, CCA was performed. The phytoplankton composition and distribution were governed by environmental factors such as TOC, P-PO$_4$, temperature, TKN, BOD_5, and TP. The first two CCA axes explained 31% of cumulative percentage variance of species data with 97.7% between species-environment correlations during the study period (Table 3). The Monte Carlo test confirmed that the first two axes were highly significant (p= 0.002, F = 1.157).

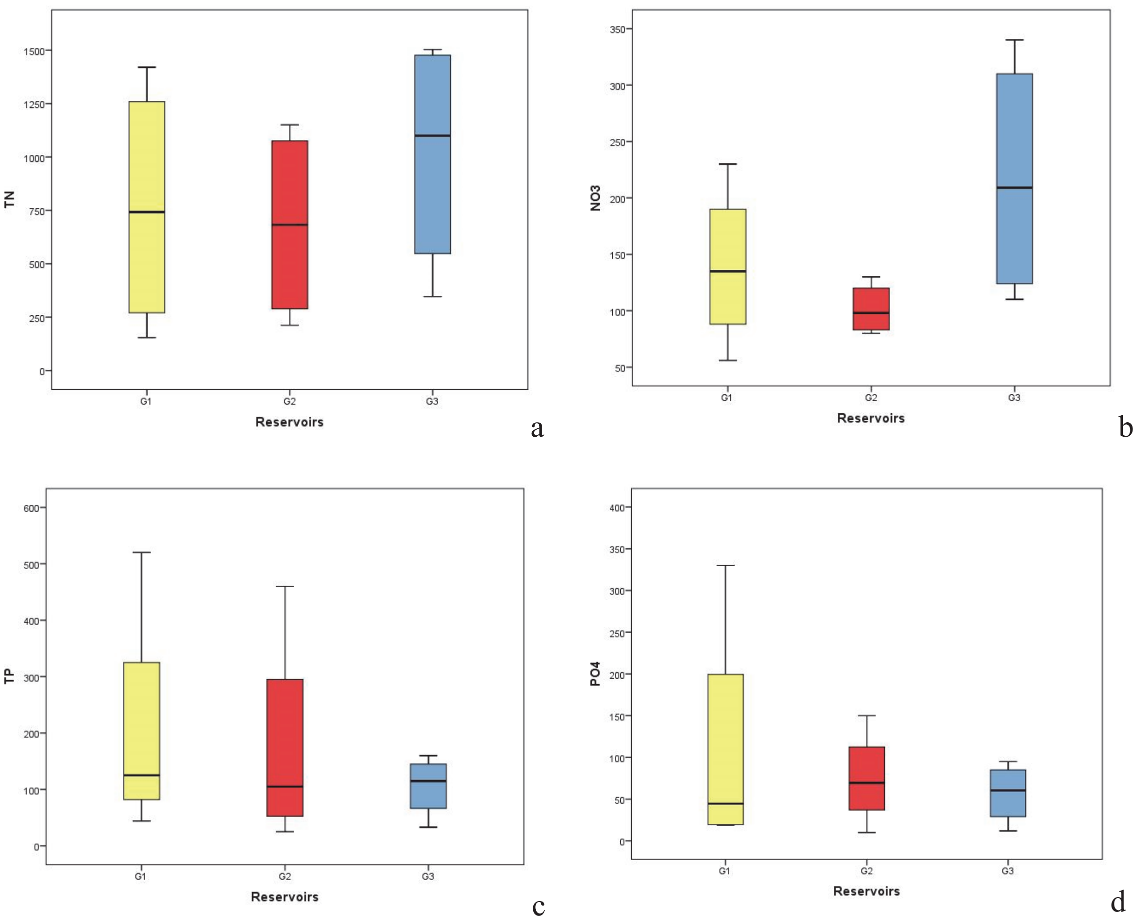

Figure 2. Box plot diagrams showing the variations of environmental variables among reservoirs: Codes of reservoirs are given in Table 1.

Relationship between species-environment is given on the ordination (Figure 3). Arrows of temperature, BOD_5 and TOC were associated with Bayramiç Reservoir while Ayvacık Reservoir had relatively lower TOC, temperature and BOD_5. Previously given common found species were mainly located the center of the ordination. The distribution of species such as *Ceratium furcoides*, *Merismopedia glacua*, *Coelastrum* *astroideum*, *Closterium dinae*, *Mougeotia gracilima* and *Tetraedron minimum* was governed by high temperature and TOC while phytoplankton species such as *Cocconeis placentula*, *Cyclotella meneghiniana,* *Cymatopleura elliptica*, *Gomphonema parvulum, Navicula capitatoriata, Pediastrum simplex* and *Ulnaria ulna* were related to TP and P-PO_4.

Table 3

Summary of Canonical Correspondence Analysis Using Monte Carlo Permutation Test for Phytoplankton-Environment Relationship

Axes	1	2	3	4	Total inertia
Eigenvalues	0.957	0.879	0.791	0.662	5.918
Species-environment correlations	0.997	0.977	0.966	0.934	
Cumulative percentage variance					
of species data	16.2	31.0	44.4	55.6	
of species-environment relation	26.2	50.3	71.9	90.0	
Sum of all eigenvalues					5.918
Sum of all canonical eigenvalues					3.653
Test of significance of first canonical axis: eigenvalue = 0.957					
	F-ratio = 1.157			p-value = 0.0020	

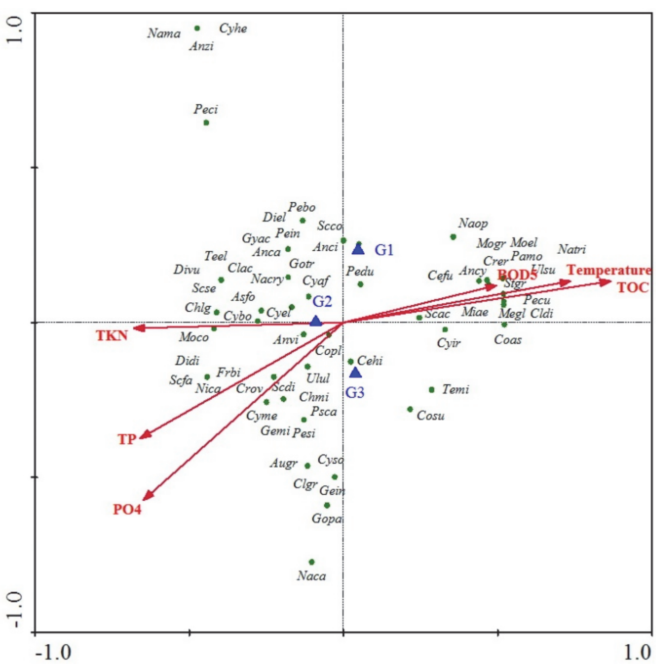

Figure 3. Canonical correspondence analysis plot of species-environmental relationships in the sampling reservoirs (up triangular). TOC, total organic carbon; BOD_5, biological oxygen demand; TP, total phosphorus, and TKN total Kjeldahl nitrogen. Codes of species are given in Table 5.

Results of WA regression are presented in Table 4. *Scenedesmus communis, Cocconeis placentula*, *Cyclotella meneghiniana*, *Ulnaria ulna*, *Gomphonella parvula*, *Pediastrum simplex*, *Scenedesmus acutus* were associated with high TP and $P\text{-}PO_4$ concentrations while *Straurastrum gracile*, *Peridiniopsis cunningtonii*, *Peridinium cinctum*, *Melosira lineata* and *Cryptomonas erosa* had relatively low TP tolerance values. *Tetrastrum elegans*, *Schoderia setigera*, *Geminella interrupta*, *Cymatopleura elliptica*, *Closterium gracile* and *Chlamydomanas globasa* were associated with high TN. With regard to temperature *Scedenasmus falcatus, Nitzschiana calida, Dinobryon divergens* were associated to the lowest optima value of temperature (12.5 °C), while *Ulothrix subconstricta*, *Straurastrum gracile*, *Pandorina morum*, *Navicula trivialis*, *Mougeotia elegantula* had the highest optima value of temperature (28.1°C).

Phytoplankton-based Indices and the Ecological Status of the Reservoirs

The ecological status of the reservoirs was assessed of based on phytoplankton metrics specially Med-PTI and PTI (Table 5). The highest Med-PTI and PTI values were recorded at Ayvacık Reservoir and Sevişler Reservoir respectively. With regard to ecological status, values of the Med-PTI index indicate good quality waters for Ayvacık and Bayramiç Reservoirs while Sevişler Reservoir had a Moderate water quality. Based on the PTI index, the waters of the Bayramiç and Sevişler Reservoirs were classified as or moderate ecological status while Ayvacık Reservoir indicated a good water quality.

Table 4

Weighted Average Regression in The Reservoirs. U_k and T_k Indicated Optima and Tolerance, Respectively

Species	Codes	Temperature		BOD_5		TOC		TKN		TP		$P\text{-}PO_4$	
		u_k	t_k	u_k	t_k	u_k	t_k	u_k	t_k	u_k	t_k	u_k	t_k
Anabaena catenula	Anca	27.8	3.7	59.4	9.1	12.4	16.1	1360.0	291.6	120.0	94.3	68.9	49.6
Anabanea circinalis	Anci	27.4	0.8	42.7	31.9	23.0	20.3	992.4	703.6	84.9	67.2	46.0	43.9
Anabanea cylindrica	Ancy	27.7	0.7	20.7	5.6	60.1	14.6	240.0	116.9	34.9	9.5	13.3	6.2
Anabanea viriabilis	Anvi	26.4	1.3	33.6	24.2	7.8	4.2	1003.6	338.3	135.2	20.2	78.9	13.2
Anabaena zinserlingii	Anzi	17.6	3.7	2.8	9.1	1.0	16.1	849.0	291.6	130.0	94.3	20.0	49.6
Asterionella formosa	Asfo	21.4	9.2	20.0	10.5	8.4	5.6	813.9	210.7	114.2	35.4	71.8	8.1
Aulocaseria granulata	Augr	19.6	5.4	7.5	4.9	4.3	1.3	577.6	321.8	244.9	207.3	150.5	135.3
Bacillaria vulgaris	Bavu	14.0	3.7	2.8	9.1	2.8	16.1	464.0	291.6	100.0	94.3	46.0	49.6
Ceratium furcoides	Cefu	27.3	0.9	17.2	4.2	55.0	20.2	313.7	74.2	28.9	5.7	9.4	3.6
Ceratium hirindunella	Cehi	23.0	7.3	12.7	2.1	21.0	20.4	722.3	358.4	88.1	73.1	53.1	48.2
Chlamydomanas globasa	Chlg	13.5	1.1	5.3	5.0	6.7	7.7	659.4	391.7	92.9	14.1	52.3	12.7
Choroccocus minutus	Chmi	17.6	3.7	6.4	9.1	5.2	16.1	550.0	291.6	130.0	94.3	75.4	49.6
Closterium aciculare	Clac	14.9	2.5	3.6	2.5	3.4	1.7	484.9	60.8	107.3	21.2	53.2	20.8
Closterium dinae	Cldi	28.0	3.7	20.2	9.1	69.7	16.1	260.0	291.6	33.0	94.3	12.0	49.6
Closterium gracile	Clgr	25.9	3.7	12.9	9.1	4.5	16.1	910.0	291.6	160.0	94.3	95.0	49.6
Cocconeis placentula	Copl	20.2	6.6	13.3	12.7	12.2	24.3	369.9	289.8	309.6	224.9	144.1	120.5
Coelastrum astroideum	Coas	28.0	3.7	20.2	9.1	69.7	16.1	260.0	291.6	33.0	94.3	12.0	49.6
Cosmarium subcostatum	Cosu	26.8	1.5	16.1	5.2	32.8	46.1	627.3	459.6	104.8	89.8	58.9	58.7
Cryptomonas erosa	Crer	27.6	0.8	20.2	5.6	59.3	15.2	249.6	116.1	34.1	9.4	12.8	6.1
Cryptomonas ovata	Crov	17.9	6.7	8.0	5.1	6.0	4.9	688.2	365.8	187.8	162.7	87.4	42.5
Cyclotella bodanica	Cybo	19.6	6.8	20.5	23.0	8.0	4.7	818.9	363.7	112.7	21.7	66.5	11.9
Cyclotella iris	Cyir	27.1	1.1	18.2	6.0	44.3	30.0	422.5	347.6	66.8	64.3	34.1	42.0
Cyclotella meneghiniana	Cyme	14.2	1.6	5.7	3.9	7.0	6.3	507.6	471.5	339.8	241.7	170.2	131.7
Cymatopleura elliptica	Cyel	15.1	3.7	3.8	9.1	3.7	16.1	210.0	291.6	460.0	94.3	150.0	49.6

Table 4 continue		Temperature		BOD_5		TOC		TKN		TP		$P\text{-}PO_4$	
		u_k	t_k	u_k	t_k	u_k	t_k	u_k	t_k	u_k	t_k	u_k	t_k
Cymatopleura solea	Cyso	25.9	3.7	12.9	9.1	4.5	16.1	910.0	291.6	160.0	94.3	95.0	49.6
Cymbella excisa	Cyaf	19.0	5.8	8.3	4.9	15.3	18.5	647.6	280.4	93.4	52.2	44.4	35.1
Cymbella helvetica	Cyhe	17.6	3.7	2.8	9.1	1.0	16.1	849.0	291.6	130.0	94.3	20.0	49.6
Dinobryon divergens	Didi	12.5	3.7	9.9	9.1	13.8	16.1	1018.0	291.6	80.0	94.3	64.0	49.6
Diploneis elliptica	Diel	27.8	3.7	59.4	9.1	12.4	16.1	1360.0	291.6	120.0	94.3	68.9	49.6
Geminella interrupta	Gein	25.9	3.7	12.9	9.1	4.5	16.1	910.0	291.6	160.0	94.3	95.0	49.6
Geminella minor	Gemi	17.6	3.7	6.4	9.1	5.2	16.1	550.0	291.6	130.0	94.3	75.4	49.6
Gomphonema parvulum	Gopa	22.5	7.6	9.7	7.2	3.9	1.3	693.1	480.8	274.8	254.6	170.0	166.2
Gomphonema truncatum	Gotr	25.5	3.7	24.7	9.1	5.9	16.1	720.0	291.6	130.0	94.3	75.4	49.6
Merismopedia glacua	Megl	28.0	3.7	20.2	9.1	69.7	16.1	260.0	291.6	33.0	94.3	12.0	49.6
Microcystis aeruginosa	Miae	28.0	0.1	22.9	4.0	67.5	3.2	196.9	92.6	38.3	7.8	15.5	5.2
Monorophidium contortum	Moco	13.5	1.1	5.3	5.0	6.7	7.7	658.5	391.7	93.0	14.1	52.3	12.7
Mougeotia elegantula	Moel	28.1	3.7	25.8	9.1	65.1	16.1	129.0	291.6	44.0	94.3	19.3	49.6
Mougeotia gracilima	Mogr	26.7	3.7	14.3	9.1	41.0	16.1	365.0	291.6	25.0	94.3	6.9	49.6
Navicula capitatoriata	Naca	15.2	3.7	2.8	9.1	2.6	16.1	230.0	291.6	520.0	94.3	330.1	49.6
Navicula cryptotenella	Nacry	25.5	3.7	24.7	9.1	5.9	16.1	720.0	291.6	130.0	94.3	75.4	49.6
Navicula margalithii	Nama	17.6	3.7	2.8	9.1	1.0	16.1	849.0	291.6	130.0	94.3	20.0	49.6
Navicula oppugnata	Naop	26.7	3.7	14.3	9.1	41.0	16.1	365.0	291.6	25.0	94.3	6.9	49.6
Navicula trivialis	Natri	28.1	3.7	25.8	9.1	65.1	16.1	129.0	291.6	44.0	94.3	19.3	49.6
Nitzschiana calida	Nica	12.5	3.7	9.9	9.1	13.8	16.1	1018.0	291.6	80.0	94.3	64.0	49.6
Pandorina morum	Pamo	28.1	3.7	25.8	9.1	65.1	16.1	129.0	291.6	44.0	94.3	19.3	49.6
Pediastrum boryanum	Pebo	22.2	7.1	22.5	27.2	21.9	32.6	753.6	493.3	96.1	44.2	36.9	26.5
Pediastrum duplex	Pedu	24.0	6.2	20.3	11.2	26.4	35.6	393.0	344.0	175.7	198.8	72.8	60.7
Pediastrum integrum	Pein	27.8	3.7	59.4	9.1	12.4	16.1	1360.0	291.6	120.0	94.3	68.9	49.6
Pediastrum simplex	Pesi	21.4	5.4	12.1	9.6	4.6	1.4	618.9	286.4	227.4	184.7	139.0	120.6
Peridiniopsis cunningtonii	Pecu	28.0	0.1	22.9	4.0	67.5	3.2	196.8	92.6	38.3	7.8	15.5	5.2
Peridinium cinctum	Peci	16.3	2.5	2.8	9.1	1.6	1.3	713.9	272.2	119.5	21.2	29.1	18.4
Pleurosigma acuminatum	Plac	27.8	3.7	59.4	9.1	12.4	16.1	1360.0	291.6	120.0	94.3	68.9	49.6

Table 4 continue		Temperature		BOD_5		TOC		TKN		TP		$P\text{-}PO_4$	
		u_k	t_k	u_k	t_k	u_k	t_k	u_k	t_k	u_k	t_k	u_k	t_k
Pseudoanebena catenata	Psca	17.6	3.7	6.4	9.1	5.2	16.1	550.0	291.6	130.0	94.3	75.4	49.6
Scedenasmus falcatus	Scfa	12.5	3.7	9.9	9.1	13.8	16.1	1018.0	291.6	80.0	94.3	64.0	49.6
Scedenesmus dispar	Scdi	17.6	3.7	6.4	9.1	5.2	16.1	550.0	291.6	130.0	94.3	75.4	49.6
Scenedesmus acutus	Scac	22.8	9.1	13.6	11.6	43.1	46.6	239.8	35.4	205.1	301.9	67.6	97.6
Scenedesmus communis	Scco	22.0	6.3	14.0	10.9	22.3	27.5	438.8	275.4	142.0	158.2	53.3	53.2
Schoderia setigera	Scse	14.0	3.7	2.8	9.1	2.8	16.1	464.0	291.6	100.0	94.3	46.0	49.6
Straurastrum gracile	Stgr	28.1	0.1	23.6	4.0	66.9	3.2	180.7	92.6	39.7	7.8	16.4	5.2
Tetraedron minimum	Temi	27.1	1.5	17.1	5.2	42.2	46.1	533.9	459.6	86.5	89.8	47.0	58.7
Tetrastrum elegans	Teel	14.0	3.7	2.8	9.1	2.8	16.1	464.0	291.6	100.0	94.3	46.0	49.6
Ulnaria biceps	Ulbi	12.5	3.7	9.9	9.1	13.8	16.1	1018.0	291.6	80.0	94.3	64.0	49.6
Ulnaria ulna	Ulul	17.6	5.3	6.7	6.9	14.5	27.4	353.2	160.0	249.2	218.5	118.5	117.5
Ulothrix subconstricta	Ulsu	28.1	3.7	25.8	9.1	65.1	16.1	129.0	291.6	44.0	94.3	19.3	49.6
		RMSE	1.22		1.91		4.72		102.09		44.32		20.53
		R2	0.96		0.98		0.96		0.92		0.92		0.87

Table 5

Medpit, PTI and Ecological Status of The Reservoirs

Reservoir	MedPTI	Ecological status	PTI	Ecological status
Bayramiç Reservoir	2.73	Good	2.30	Moderate
Ayvacık Reservoir	3.30	Good	2.14	Good
Sevişler Reservoir	2.59	Moderate	2.32	Moderate

The Figure 4 indicated the relationships between logTP and the phytoplankton based indices. It is shown in this figure that the indices had a well-fitting with logTP. However, the highest coefficient of determination ($R^2 = 0.962$) showed that PTI was more competitive and had a remarkable correlation with logTP than Med-PTI (Figure 4a).

Discussion and Conclusion

Physical and Chemical Parameters

Spatial and temporal changes were observed in physicochemical variables of three reservoirs during the study period. The reservoirs showed alkaline water with pH ranged from 8.7 to 8.8. These pH values were higher than the mean pH value found at Alleben Reservoir (Çelekli and Öztürk, 2014) and similar to those found at İkizcetepeler Reservoir by Sevindik et al. (2017) in Turkey. The highest conductivity (434.5 µS cm^{-1}) and salinity (0.21 ppt) were measured at Sevişler Reservoir. These means conductivity were higher than those found at Pampulha Resevoir in Brazil (Figueredo and Giani, 2001) and similar to those of Sau Reservoir, a deep Mediterranean reservoir located in northeast Spain (Becker et al. 2010). With regard to nutrients, the TP values which ranged from 105.8 µg L^{-1} to 203.5 µg L^{-1} at studied reservoirs were higher than those the mean TP reported by Marchetto et al. (2009) for deep Reservoirs in Italy such as Cedrino, Cuga, Sos Canales, Pattada and Temo Reservoirs during the year 2006 and Valparáıso Reservoir (Negro et al., 2000) Spain. The values of TN ranged from 681.8 µg L^{-1} to 1012.0 µg L^{-1} were too higher than the mean TN reported by Chen et al. (2009) for Zeya reservoir in China. These high nutrients coming from especially anthropogenic activities such as agriculture, sewage discharge in surrounding areas and excessive net-cage fish farming in reservoir mainly impacted the reservoirs (Wetzel 2001).

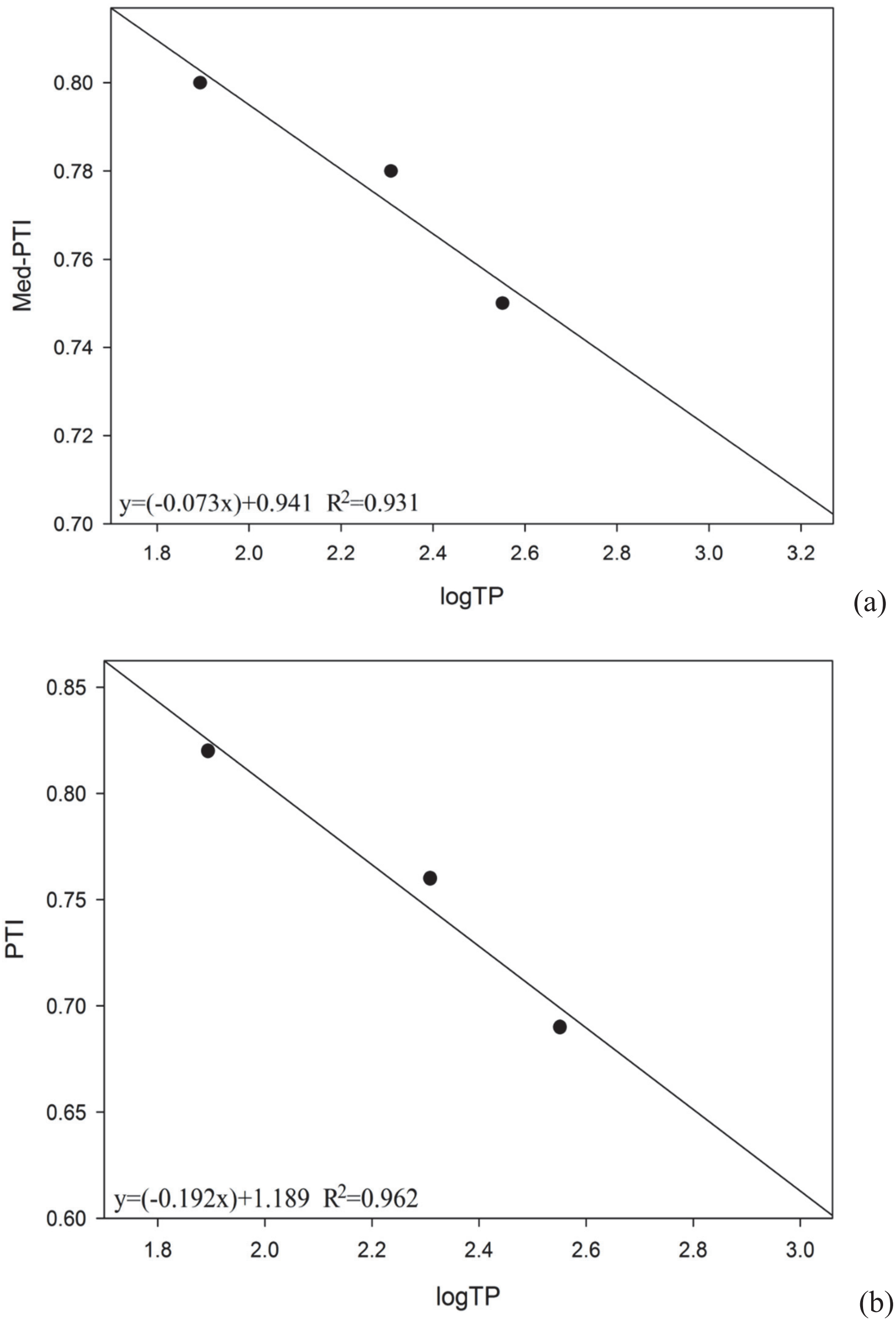

Figure 4. Relationship between logTP a) MedPTI and b) PTI in the reservoirs.

Phytoplankton Composition and Their Environmental Relationships

During the present study, Bacillariophyta was the most dominant group in the phytoplankton composition. Dominancy of this group in phytoplankton community is also agreement with previous studies in Valparáiso Reservoir (Negro et al. 2000), El Gergal Reservoir (Hoyer et al. 2009) Spain, Marathonas Reservoir (Greece) (Katsiapi et al. 2011), Paraja limno-Reservoir in Spain (Molina-Navarro et al. 2014) and in Alleben Reservoir by Çelekli and Öztürk (2014) and İkizcetepeler Reservoir by Sevindik et al. (2017) in Turkey.

Multivariate analyses (CCA and WA) indicated that *S. communis, C. placentula*, *Cyclotella meneghiniana*, *U. ulna* and *P. simplex* were associated with high nutrients (TP) concentrations. *C. meneghiniana* was considered as a pollution tolerant species (Venkatachalapathy and Karthikeyan, 2013; Wang et al. 2014) and as species typical of polluted environments (Van Dam et al. 1994; Salomoni et al. 2006). *P. simplex* occurs in the freshwater plankton of various eutrophic reservoirs from neutral to alkaline water bodies (Komàrek and Jonkovskà, 2001; Pasztaleniec and Poniewozik, 2004). According to Krammer and Lange-Bertalot (1991a), *U. ulna* has been adapted to different ecological conditions. *S. communis* was indicated to have a wide distribution in freshwaters, mainly in those with moderate temperature and in the slightly eutrophicated ones (Hegewald, 1977; Bica et al. 2012).

Ecological Status and Water Quality

Ecological status of lentic ecosystems can be assessed using phytoplankton biovolume and composition as metrics (EC, 2009; Poikane et al. 2011; Phillips et al. 2013). In the present study, the water quality of the reservoirs was evaluated by the use of phytoplankton metrics such as the Mediterranean phytoplankton index (Med-PTI) (Marchetto et al. 2009) and the phytoplankton trophic index (PTI) (Philips et al. 2013). Two ecological statuses (good and moderate) were recorded for the reservoirs during the study period.

The good ecological status recorded at Ayvacık Reservoir based on Med-PTI (3.30) and PTI (2.14). This status could be a consequence of the low land use for agriculture which generates inorganic and organic nutrients and the low free to roam through the water bodies of organic pollutants generated from human activities. Besides, Ayvacık Reservoir is a newly constructed reservoir and was not be affected by natural eutrophication. This ecosystem is especially affected by water fluctuation for irrigation purposes. Similar ecological status, using PTI and Med-PTI was previously found in Mediterranean reservoirs such as Sau Reservoir (Spain) (Becker et al. 2010) and Pareja limno-reservoir (Spain) (Molina-Navarro et al. 2014). On the other hand, the input of wastewater and the organic pollutants generated by agricultural activities, and fish farming could be the causes of the moderate states observed Sevişler Reservoir based on Med-PTI (2.59) and PTI (2.32) indices. Furthermore, this reservoir is an old reservoir in the North Aegean River Basin, it was constructed in 1987, and its water level fluctuated and decreased to 5 m in the summer due to irrigation. Its water quality could also be affected by the natural accumulation of sediments coming from the catchment area. The moderate ecological status was found to be similar with status of deep Mediterranean reservoirs (Italy) (Marchetto et al. 2009), some lakes in Europe (Philips et al. 2013) and the Alleben Reservoir in Turkey (Çelekli and Öztürk, 2014) which indicated similar physicochemical characteristics. Furthermore, the significant positive relationship between PTI and TP observed during the present study was previously found in European freshwater bodies (Philips et al. 2013). This indicated that PTI as a metric can be used to assess water quality of lentic ecosystems.

With regard to EQR, Bayramiç Reservoir had two ecological status (moderate or good) with a good water quality (2.73) based on Med-PTI and a moderate water quality (2.30) based on PTI. Both indices showed same ecological status for Ayvacık Reservoir with a good status and Sevişler Reservoir with moderate status. This change in water quality could due to the water retention time which could a key factor in seasonal changes for physicochemical variables (Çelekli and Öztürk, 2014). Previously, Straškraba (1999) demonstrated the influence of water retention on the vertical stability of reservoirs. According to Soares (2008), despite the similarities between reservoirs, which are in the same geographical region with similar climate, and are comparable in size, the distinct watershed features and water retention time could be responsible for marked differences between these reservoirs.

Multivariate approaches indicated that phytoplankton composition and distribution were mainly governed by environmental factors by TP, DO, TKN, BOD_5, TOC and temperature. The first two CCA axes explained 31% of cumulative percentage variance of species data with 97.7% between species-environment correlations during the study period. With regard to the ecological status, values of the Med-PTI indicated good quality waters for Ayvacık and Bayramiç Reservoirs, while Sevişler Reservoir had a moderate water quality. Based on the PTI, Bayramiç and Sevişler Reservoirs were classified as or moderate ecological status, while Ayvacık Reservoir indicated a good water quality. From these results, the Med-PTI and the PTI seem to be appropriate metrics for assessing the ecological status of the reservoir.

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Extended Turkish Abstract
(Genişletilmiş Türkçe Özet)

Su Kalitesinin Biyolojik Değerlendirmesi: Üç Ege Barajının Fitoplankton Metriklerine Dayalı Ekolojik Durumu

Su kalitesinin insan yaşamındaki önemi büyüktür. Gün geçtikçe antropojenik etkilerin artmasıyla birlikte Avrupa'da ve dünyada bulunan birçok baraj gölündeki su kalitesi kötüye gitmektedir. Azot ve fosforun su kütlelerindeki artışıyla birlikte ötrofikasyon meydana gelmekte ve su kalitesinin yanında birçok sucul ekosistem bu durumdan etkilenmektedir. Bu yüzden Avrupa Birliği Su Çerçeve Direktifi (SÇD) ile su kütlelerinin durumunun fitoplankton, fitobentoz, makrofit, makroomurgasız ve balık gibi birçok biyolojik kalite bileşeni ile değerlendirilmesi zorunlu hale getirilmiştir.

Su Çerçeve Direktifi'nin uygulanmaya başlamasıyla birlikte su kalitesinin değerlendirilmesi büyük önem kazanmıştır. Fitoplankton SÇD'ye göre özellikle durgun sularda su kalitesi değişimlerinin gözlenmesinde kullanılan önemli bir indikatördür. SÇD'nin uygulanması maksadıyla Avrupa'da su kalitesinin değerlendirilmesi için fitoplankton indeksleri geliştirilmektedir. Akdeniz Fitoplankton Trofik İndeksi (Med-PTI) ve Fitoplankton Trofik İndeksi (PTI) geliştirilen indeksler arasında en yaygın kullanılan indekslerdir. Bu çalışmada, Türkiye'nin Kuzey Ege Nehir Havzası'nda bulunan üç baraj gölünde (Bayramiç, Sevişler ve Ayvacık) öncelikli olarak fitoplankton kompozisyonu belirlenmiş, fitoplankton kompozisyonu ve çevresel faktörler arasında ilişki kurulmuş ve nihai olarak su kalitesi Akdeniz Fitoplankton Trofik İndeksi (Med-PTI) ve Fitoplankton Trofik İndeksi (PTI) kullanılarak değerlendirilmiştir.

Fitoplankton örnekleri üç baraj gölünden 2014 ve 2015 yaz dönemi arasında mevsimsel olarak toplanmıştır. pH, iletkenlik, tuzluluk, çözünmüş oksijen ve sıcaklık parametreleri arazide ölçülmüştür. Toplam azot, nitrat azotu, nitrit azotu, amonyum azotu, toplam Kjeldahl azotu, toplam fosfor, ortofosfat, biyolojik oksijen ihtiyacı ve toplam organik karbon standard metotlar kullanılarak laboratuarda ölçülmüştür. Fitoplankton taksonları kameralı ışık mikroskobu ile ilgili teşhis kitapları kullanılarak teşhis edilmiştir. Fitoplankton sayımları invert mikroskop yardımı ile Utermöhl metoduna göre gerçekleştirilmiş ve geometrik şekillerden faydalanılarak fitoplankton biyohacimleri hesaplanmıştır. Kanonik Uyum Analizi (CCA) CANOCO 4.5 programı, Weighted Average regresyon analizi ise CALIBRATE yazılımı ile gerçekleştirilmiştir.

Üç barajın da suları alkali özellik göstermiştir. En yüksek nutrient değerleri olarak Bayramiç Barajı'nda TP 203,5 µg L^{-1} olarak ölçülmüşken Sevişler Barajı'nda TN 1012,0 µg L^{-1} olarak ölçülmüştür. Toplamda 120 fitoplankton türü teşhis edilmiş ve teşhis edilen türlerin çoğunluğu diyatomeler ile temsil edilmiştir. Fitoplankton türleri ve çevresel değişkenler arasındaki ilişki multivaryete analizler ile incelenmiştir. Fitoplankton kompozisyonu ve dağılımı çevresel değişkenler ile uyumlu çıkmıştır. TP, P-PO4, TKN, BOİ5, TOC ve sıcaklık en önemli faktörler olmuştur. İlk iki CCA ekseni tür verisinin kümülatif yüzde varyansının %31'ini %97,7 tür-çevre korelasyonu ile açıklamış ve durum Monte Carlo testi (p= 0,002, F = 1,157) ile doğrulanmıştır. *Ceratium furcoides*, *Merismopedia glacua*, *Coelastrum astroideum*, *Closterium dinae*, *Mougeotia gracilima*, ve *Tetraedron minimum* türleri yüksek sıcaklık ve toplam organik karbon ile ilişkilendirilirken, *Cocconeis placentula*, *Cyclotella meneghiniana, Cymatopleura elliptica*, *Gomphonema parvulum, Navicula capitatoriata, Pediastrum simplex,* ve *Ulnaria ulna* türleri toplam fosfor ve ortofosfat ile ilişkilendirilmiştir.

Ağırlıklı ortalama rekrasyon analizi sonuçlarına göre; *Scenedesmus communis, Cocconeis placentula*, *Cyclotella meneghiniana*, *Ulnaria ulna*, *Gomphonella parvula*, *Pediastrum simplex*, *Scenedesmus acutus* türleri yüksek toplam fosfor ve ortofosfat toleransına sahipken, *Straurastrum gracile*, *Peridiniopsis cunningtonii*, *Peridinium cinctum*, *Melosira lineata* and *Cryptomonas erosa* ise düşük toplam fosfor tolerans değerlerine sahip çıkmıştır. *Tetrastrum elegans*, *Schoderia setigera*, *Geminella interrupta*, *Cymatopleura elliptica*, *Closterium gracile* ve *Chlamydomanas globasa* yüksek toplam azot ile ilişkilendirilmiştir. *Scedenasmus falcatus, Nitzschiana calida, Dinobryon divergens* türleri sıcaklık açısından en düşük optima değerine (12.5 °C) sahipken *Ulothrix subconstricta*, *Straurastrum gracile*, *Pandorina morum*, *Navicula trivialis*, *Mougeotia elegantula* sıcaklık açısından en yüksek optima değerine (28.1°C) sahip çıkmıştır.

Med-PTI ve PTI İndeksleri sonuçlarına gore, Med-PTI Ayvacık ve Bayramiç Baraj Gölleri için iyi su kalitesini gösterirken Sevişler Baraj Gölü'nü orta su kalitesinde indike etmiştir. PTI İndeksi'ne gore Bayramiç ve Sevişler Barajı orta ekolojik durumda sınıflandırılmışken Ayvacık Barajı iyi su kalitesinde indike edilmiştir. Sonuçlara gore, Med-PTI ve PTI'nin Kuzey Ege Havzası'nda bulunan baraj göllerinin su kalitesinin değerlendirilmesinde uygun metrikler olduğu görülmüştür.