MAY 2018

Ph.D in Department of Biology

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**UNIVERSITY OF GAZIANTEP**

**GRADUATE SCHOOL OF**

**NATURAL & APPLIED SCIENCES**

# DETERMINATION OF ECOLOGICAL STATUS OF FRESHWATERS AND ECOLOGICAL PREFERENCES OF ALGAE IN THE WESTERN MEDITERRANEAN BASIN (TURKEY) USING MULTIVARIATE APPROACHES

**Ph.D. THESIS**

**IN**

**DEPARTMENT OF BIOLOGY**

**BY**

**ASSANE ANABI TOUDJANI**

**MAY 2018**

**Determination of Ecological Status of Freshwaters and Ecological Preferences of Algae in the Western Mediterranean Basin (Turkey) Using Multivariate Approaches**

**Ph.D. Thesis**

**in**

**Department of Biology**

**University of Gaziantep**

**Supervisor**

**Prof. Dr. Abuzer ÇELEKLİ**

**by**

**Assane Anabi TOUDJANI**

**May 2018**

REPUBLIC OF TURKEY
UNIVERSITY OF GAZİANTEP
GRADUATE SCHOOL OF NATURAL & APPLIED SCIENCES
DEPARTMENT OF BIOLOGY

Name of the thesis: Determination of Ecological Status of Freshwaters and Ecological Preferences of Algae in the Western Mediterranean Basin (Turkey) Using Multivariate Approaches

Name of the student: Assane Anabi TOUDJANI

Exam date: 03/05/2018

Approval of the Graduate School of Natural and Applied Sciences

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This is to certify that we have read this thesis and that in our consensus opinion it is fully adequate, in scope and quality, as a thesis for the degree of Doctor of Philosophy.

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Assane Anabi TOUDJANI

# ABSTRACT

**DETERMINATION OF ECOLOGICAL STATUS OF FRESHWATERS AND ECOLOGICAL PREFERENCES OF ALGAE IN THE WESTERN MEDITERRANEAN BASIN (TURKEY) USING MULTIVARIATE APPROACHES**

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**Ph.D. in Department of Biology**

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**May 2018**

**213 pages**

Several methods have been recently developed for water bioassessment. However, combining these methods to provide a realistic estimation of water quality is rare. The aim of this work was to assess freshwater quality using algae and multivariate approaches. Data were collected from 34 stations in the western Mediterranean basin of Turkey. A total of 206 phytoplankton and 102 diatom taxa were recorded in lentic and lotic systems respectively. Canonical correspondence analysis indicated that environmental variables influenced the distribution of algal taxa. In related to water quality, lakes and reservoirs showed moderate, good and high status according to Phytoplankton Trophic Index (PTI), Mediterranean Phytoplankton Trophic Index (Med-PTI) and the assemblage index (Q). Running waters showed poor to high ecological status based on Trophic Index Turkey (TIT). With regard to the trophic state, the lentic systems varied from oligotrophic to hypertrophic. It appears from this study that combining these metrics could be a useful approach for freshwater bioassessment. However, the use of these indices could lead to wrong interpretation of water quality because of ecoregional changes in algal composition, and there is a need to develop a national phytoplankton based metrics. Besides, TIT should be revised to include all diatom communities from various water types to extend its applicability to a number of aquatic systems.


**Keywords:** Lake; Running water, Biological indices, Bioassessment; Water quality.

# ÖZET

**BATI AKDENİZ HAVZASI (TÜRKİYE) ALGLERİN EKOLOJİK İSTEKLERININ VE SUCUL ORTAMLARIN EKOLOJİK DURUMLARININ ÇOK YÖNLÜ YAKLAŞIMLAR KULLANARAK BELİRLENMESİ.**

**TOUDJANI, Assane Anabi**

**Doktora Tezi, Biyoloji Bölümü**

**Tez Yöneticisi: Prof. Dr. Abuzer ÇELEKLİ**

**Mayıs 2018**

**213 sayfa**

Suların biyolojik olarak izlenmesi için son zamanlarda bazı yöntemler geliştirilmiştir. Ancak bu yöntemleri birlikte kullanarak su kalitesi hakkında değerlendirmede bulunmak hatalı sonuçlar verebilir. Bu tez algler ve çok değişkenli yaklaşımlar kullanılarak tatlı su kalitesini değerlendirmeyi amaçlamıştır. Örnekler, Türkiye'nin Batı Akdeniz Havzası'ndaki 34 tatlısu istasyonundan toplanmıştır. Lentik bölgelerden toplam 206 fitoplankton taksonu, lotik ekosistemlerden de toplam 102 diyatome taksonu tespit edilmiştir. CCA ile çevresel değişkenlerin alg türlerinin dağılımını etkilediği belirlenmiştir. Göller ve rezervuar sularınının ekolojik kalite durumu ise phytoplankton trophic index, Mediterranean phytoplankton trophic index ve fitoplankton Q indeksine göre orta ve iyi ekolojik durumda olmuştur. Akarsu ekosistemlerindeki suların ekolojik kalitesi ise trofik indeks Türkiye (TIT) indeksine göre kötü ekolojik durumdan yüksek ekolojik duruma doğru arttığı belirlenmiştir. Sucul ekosistemlerin trofik durumuna bakıldığında lentik sistemin oligotrofikten hipertrofikliğe doğru değişim göstermiştir. Bu çalışmada bu indekslerin birleştirilmesi tatlı suların biyolojik izlenmesi için yararlı olabileceği görülmüştür. Bununla birlikte bu indekslerin doğrudan kullanılması alg kompozisyonundaki değişimler nedeniyle su kalitesinin hatalı yorumlanmasına neden olabilir. Bu yüzden ulusal fitoplankton bazlı bir ölçüm geliştirmeye ihtiyaç vardır. Ayrıca TIT, tüm diyatome topluluklarını kapsayacak şekilde uygulanabilirliği gözden geçirilmelidir.



**Anahtar Kelimeler:** Göl; Akar su; Biyolojik indeksler; Biyodeğerlendirme; Su kalitesi.

To my parents, my wife Zouera and my daughter Yasmine

## ACKNOWLEDGEMENTS

This work was the result of successful various individual contributions in Turkey and elsewhere. I want here to take this opportunity to thank some of them who played a great role.

Prof. Dr. Abuzer ÇELEKLİ, the supervisor of this work is warmly acknowledged for this guidance, encouragement, support, inspiration and supervision.

I wish to express my deepest gratitude to Prof. Dr. Canan CAN (Gaziantep University) and Prof. Dr. Erdoğan ÇİÇEK (Nevşehir Hacı Bektaş Veli University) for their collaboration and their constant evaluation of this work.

I also would like to thank Prof. Dr. Ali Mahamane and Dr. Issiaka Youssoufa of the University of Diffa (Niger) for their encouragement.

My colleagues: Dr. Emine Gültekin, Dr. Hamdullah Arslanargun, Mrs. E. Yonca Gümüş, Mrs Seda Kayhan, and Mr. H. Ömer Lekesiz at Hydrobiology laboratory of the Biology Department (Gaziantep University) are warmly thanked for their efforts, knowledge, skills and sharing of data during the progress of the work.

Finally, I would like to express my acknowledgment to my friends in Turkey and elsewhere. Thank you for always being there and encouraging me throughout this work.

This study was supported by the General Direction of Water Management of the Ministry of Forestry and Water Affairs (Republic of Turkey) (project no: 20011K050400), DOKAY-ÇED Company, and the Scientific Research Projects Executive Council of University of Gaziantep.

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| | |
|---|---|
| TP | Total phosphorus |
| $P\text{-}PO_4$ | Orthophosphate |
| TN | Total nitrogen |
| $N\text{-}NO_2$ | Nitrite nitrogen |
| $N\text{-}NO_3$ | Nitrate nitrogen |
| $N\text{-}NH_4$ | Ammonium nitrogen |
| TKN | Total Kjeldahl nitrogen |
| SD | Secchi depth |
| TOC | Total organic carbon |
| DO | Dissolved oxygen |
| $BOD_5$ | Biological oxygen demand |
| PTI | Phytoplankton trophic index |
| Med-PTI | Mediterranean phytoplankton trophic index |
| EQR | Ecological quality ratio |
| TIT | Trophic index Turkey |
| TI | Trophic index |
| EPI-D | Eutrophication and/or Pollution Index - Diatom |
| TSI | Trophic State Index |

# CHAPTER I

# GENERAL INTRODUCTION

## 1.1 Importance of Water

Water is the most important and abundant compound of the world and makes up approximately 75% of its surface. However, only a very small quantity of the water is freshwater and appropriate for human use (Smol, 2008). Surface waters are important in drinking water supply, agriculture, irrigation; fish farming, recreation, climate and flood regulation and other activities to which the water should be monitored and assessed (Johnson et al., 1997; Holt, 2000; Van Leeuwen, 2000; Sargaonkar and Deshpande, 2003; Petraccia et al., 2006; Boyacioglu, 2007; UN, 2007; Goncharuk, 2008; Mustapha, 2008; Wallis et al., 2011; Cieszynska, et al., 2012; Patil et al., 2012; Ndungu, 2014). Water makes up about 70% of human bodies. More than half of the world's species of plants and animals live in water, and even our terrestrial-derived food is totally dependent on and often largely composed of water (Smol, 2008).

## 1.2 Water Pollution and Eutrophication

The quality of water is crucial before use, and is defined as its physical, chemical, biological parameters and organoleptic characteristics (Johnson et al., 1997; Sargaonkar and Deshpande, 2003; UN, 2007; Boyacioglu, 2007). The availability of clean water and the good ecological status of surface waters have been endangered by increasing loads of nutrients and chemicals (Malve, 2007). Polluted water may impact irrigated plants resulting in accumulation of salts in the root zone, by leading to loss of permeability of the soil because of excess sodium or calcium percolating, or by containing pathogens or pollutants which are directly toxic to crops or to those consuming them. Contaminants in irrigation water may accumulate in the soil and, after a period of years, render the soil unfit for agriculture. Even when the presence of pesticides or pathogenic organisms in irrigation water does not directly impact plant development, it may eventually impact the quality of the agricultural product for sale or farmers consumption (Enderlein et al., 1997). Freshwater quality deterioration usually comes from eutrophication, organic pollution, heavy metal contamination, excessive nutrient inputs, acidification or obnoxious fishing practices (Mustapha, 2008). Since the industrial revolution and the expanding of the human population, the production of a huge quantity of harmful products are increasing year by year and causes water deterioration. Anthropogenic activities, increased with industrial revolution have impacted water quality in a significant number of surface watercourses worldwide. Some pollutant products are used largely in agriculture (fertilizers, pesticides, fungicides etc.), in crafts (dye), factories, automotive etc. After use, these products are disharged directly in the water bodies or in the soil contaminating thus the underground and surface water through the intermediary of runoff water. Discharging of effluents and pollutants into watercourses may undesirable consequences on the ecosystems and their biodiversity (Gonzalo and Fernández, 2012). The availability of dyes in surface water ecosystems reduces light penetration, decreases photosynthetic activity and could cause aesthetic issues (Saratale et al., 2011). Also, many dyes or their metabolites in water bodies even at low concentration can cause a variety of diseases and disorders in living organisms such as allergy, skin irritation, and cancer (Çelekli et al., 2009; Salleh et al., 2011; Dotto et al., 2013). Anthropogenic activities have caused a number of negative impacts to the biodiversity, on the management of water resources, and the assessment of the biological integrity in the great proportion of inland aquatic ecosystems (Cao et al., 2007; Allan and Castillo, 2007; Delgado and Pardo, 2014). Environmental deterioration is any disturbance on the environment that is seen to be nuisible for biodiverty, in this way, anthropogenic activities have deteriored freshwater systems, generating consciousness and the increase in the development of bioassessing methods to evaluate the water quality of aquatic ecosystems (Kelly and Whitton, 1995; Hering et al., 2006, Delgado and Pardo, 2014). Discharging of wastewaters, nutrient-rich runoff, and land use irrigation had a great impact on watercourses over the last century (Billen et al., 2001; Wunsan et al., 2002; Ducharne et al., 2007, Delgado and Pardo, 2014). The increasing presence of nutrients such as nitrogen and phosphorous in fresh watercourses, generally related to eutrophication, is impacting the productivity and functioning of primary producers in aquatic ecosystems (Leira et al., 2009; Delgado and Pardo, 2014). Blooms of algae due to eutrophication (excessive enrichment with nutrients) increasing turbidity following the loss of living organisms due to oxygen decreasing or acidification are among effects of anthropogenic activities on freshwater aquatic ecosystems. The input of effluents from industries into receiving water may cause negative impacts on the ecosystems. As these waters become more eutrophic, the higher cost of water treatment has encouraged watershed management in North America, Taiwan, South Africa and elsewhere (Horne and Goldman, 1994). Due to this reason, developed countries have continually been assessing and categorising their watercourses, considering characteristic structure of their own rivers and have used this type of indices for revealing the current situation of their water quality level (Solak and Ács, 2011). The importance of managing freshwater ecosystems is becoming more evident every year (Horne and Goldman, 1994).

### 1.3 European Union Water Framework Directive

The increase of anthropogenic influences in watersheds during the last decades has lead limnologists to develop biomonitoring methods that can quickly evaluate the water quality of aquatic systems (Kelly and Whitton, 1998). In this sense, a great effort has been put forth worldwide to monitor fresh waters using not only physical and chemical variables, but also biological quality elements. Biomonitoring gives a direct measure of ecological integrity by using the species responses to the changes in environmental variables (Karr, 1991; Angermeier and Karr, 1994; Directive, 2000; EC, 2009). In accordance with this idea, the European Union water framework directive (WFD) required member states to protect and assess all their water resources, with the aim of achieving good ecological potential and good surface water quality status by 2015 (EC, 2009). The environmental objectives of the WFD were to i) prevent deterioration, ii) protect, and iii) enhance and restore water resources. Biological quality elements, including phytoplankton, phytobenthos, macrophytes, benthic macroinvertebrates, and fish are employed by the EU Water Framework Directive (WFD) 2000/60/EC as bioindicators for the monitoring of fresh waters (Directive, 2000; EC, 2009) (Figure 1.1.). According to the WFD, physicochemical parameters, as well as the hydromorphological data were used to support the biological quality elements.

In order to calibrate the use of the biomonitoring systems, the results of the biological metrics of each methods shall be transformed as an ecological quality ratios (EQR) for the purposes of categorisation of ecological status. These ratios shall represent the relationship between the values of the biological parameters obtained for a given surface waterourse and the values for these variables in the reference conditions applicable to that watersourse. The ratio shall be calculated as a numerical value between 1 (bad ecological status by) and 0 (high ecological status). Five ecological status classes have been determined and established (Figure 1.2).

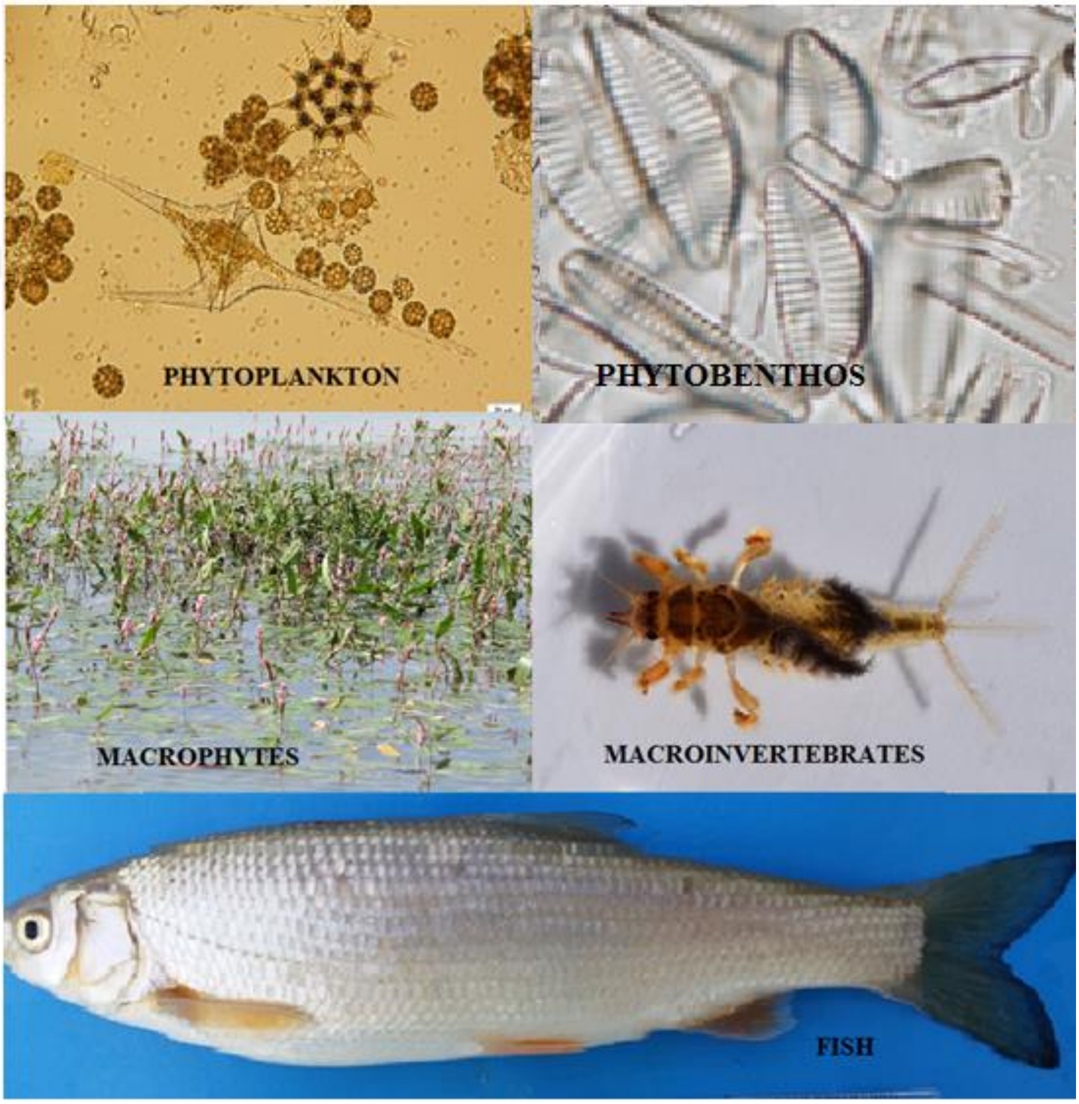



**Figure 1.1** Biological quality elements suggested by the WFD

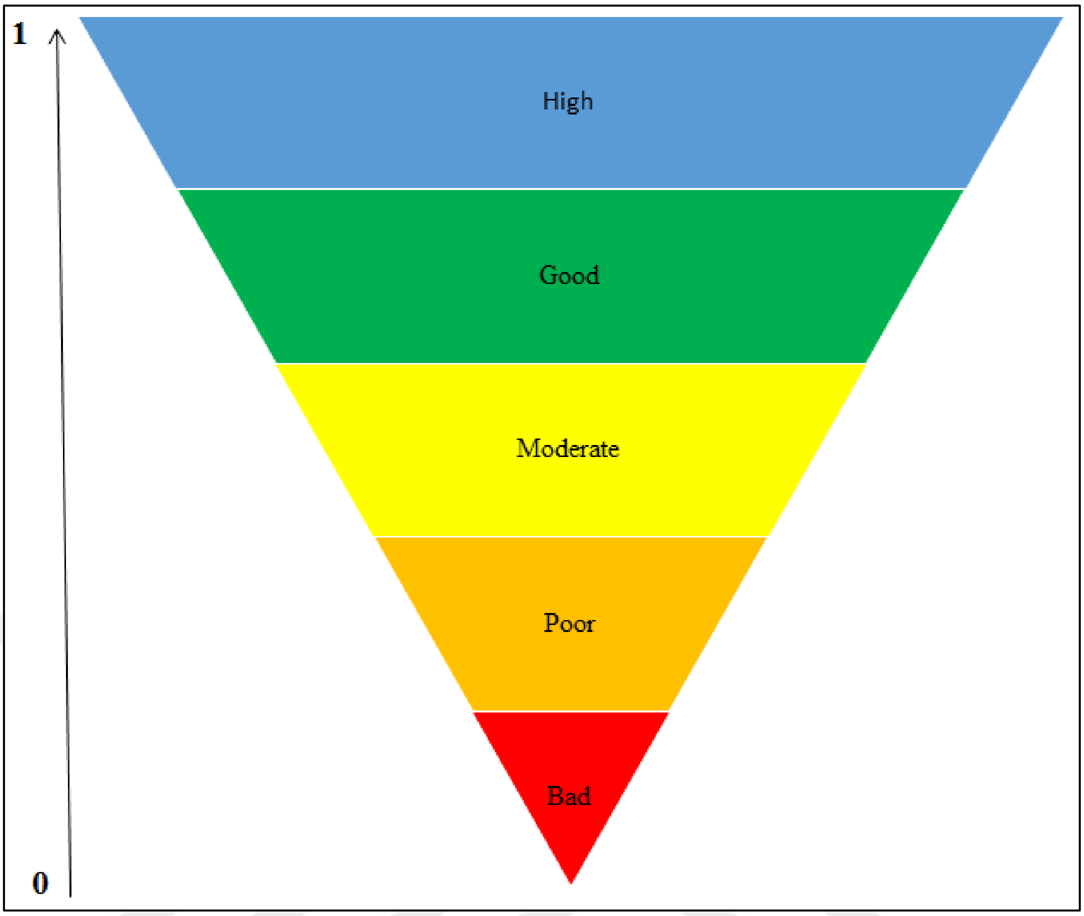



**Figure 1.2** Ecological quality ratio (0-1) and ecological status classes

Normative classifications of ecological status classifications for rivers, lakes, transitional waters and coastal waters were then established by the water framework directive. The normative definitions of ecological status classifications (High, good moderate, poor and bad status) are given in Table 1.1.

As a candidate country to the European Union, Turkey adapted the water frame directive for the assessment of its surface water bodies. For this reason, many studies based on the WFD have been carried out in the different regions of Turkey and start to become more and more important. According to Erdoğan (2016) the first project was conducted in Büyük Menderes River basin. Recently, two new projects conducted from 2014 to 2017 by the Ministry of forestry and water affairs for the establishment of an ecological assessment system for water quality and reference monitoring network in Turkey.

**Table 1.1** Normative definitions of ecological status classifications. General definition for rivers, lakes, transitional waters and coastal waters. From Annex V of the WFD (Directive, 2000)

| **Status** | **General condition** |
|---|---|
| High status | There are no, or only very minor, anthropogenic alterations to the values of the physicochemical and hydromorphological quality elements for the surface water body type from those normally associated with that type under undisturbed conditions. The values of the biological quality elements for the surface water body reflect those normally associated with that type under undisturbed conditions, and show no, or only very minor, evidence of distortion. These are the type specific conditions and communities. |
| Good status | The values of the biological quality elements for the surface water body type show low levels of distortion resulting from human activity, but deviate only slightly from those normally associated with the surface water body type under undisturbed conditions. |
| Moderate status | The values of the biological qualityelements for the surface water body type deviate moderately from those normally associated with the surface water body type under undisturbed conditions. The values show moderate signs of distortion resulting from human activity and are significantly more disturbed than under conditions of good status. |
| Poor and bad | Waters achieving a status below moderate shall be classified as poor or bad. |

### 1.4 Phytoplankton and Freshwater Quality

Phytoplankton or microalgae are free living photosynthetic microorganisms in aquatic systems and are primary producer of the limnetic zone. Phytoplankton communities dominate the surface water systems that cover 70% of the world's surface area (Reynolds, 2006). As prokaryotic or eukaryotic, unicellular, colonial or filamentous (Figure 1.3) free-living photosynthetic microorganisms in aquatic systems, phytoplankton play a key role in the organisation and functioning of aquatic ecosystems and are most relevant bioindicators for the monitoring of nutrient enrichment.

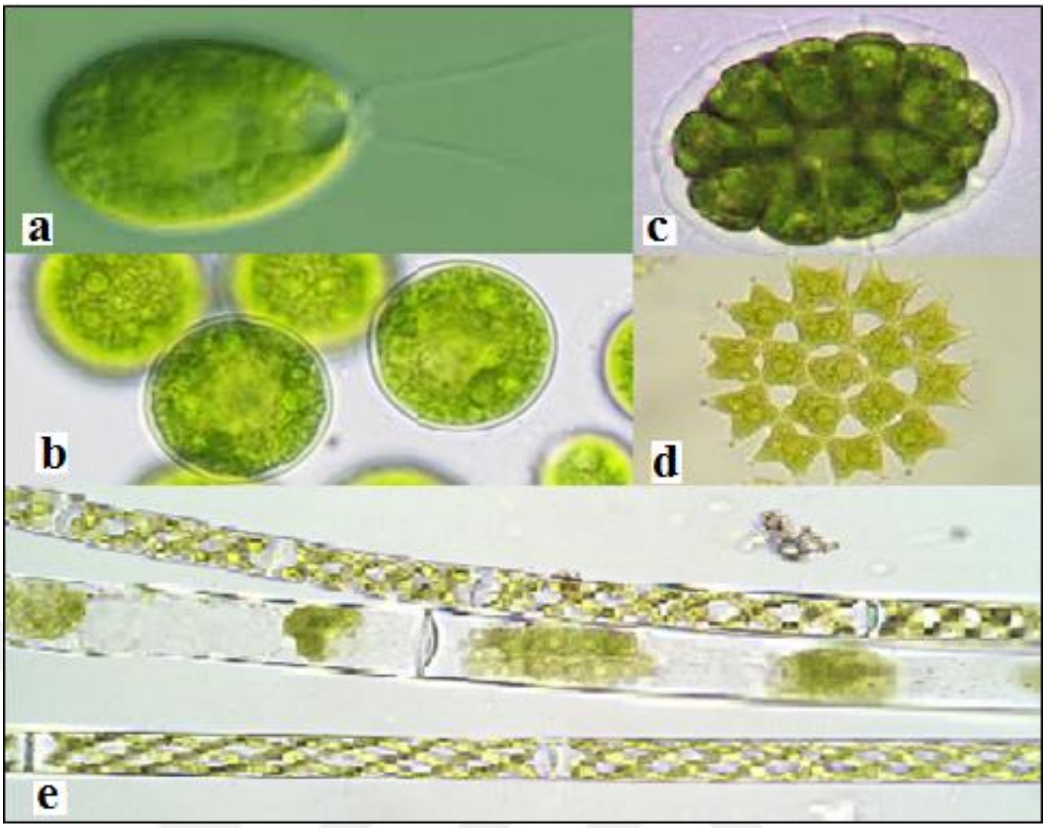



**Figure 1.3** Phytoplankton living forms a-b) unicellular, c-d) colonial, and e) filamentous, modified from Anonymous (2015) and SBSAC (2018)

The use of phytoplankton, one of the five biological quality elements as ecological indicator recommended by the WFD to evaluate surface waters is getting more and more important in lakes and reservoirs. Phytoplankton would be used as a good indicator for assessing water quality, due to its sensitivity and rapid responses to variations in its habitat (Padisák et al., 2006). The indicative value of phytoplankton biomass has long been recognized (Naumann, 1919; Nygaard, 1949; Poikane et al., 2011), and a number of metrics and methods have been developed for using phytoplankton in assessments of eutrophication (Carlson, 1977; OECD, 1982; Poikane et al., 2011) and its biovolume (Marchetto et al., 2009). Phytoplankton composition, abundance and its effect on transparency conditions are generally used in the assessment of the ecological status of surface water (Directive, 2000; EC, 2009; Mischke et al., 2012; Phillips et al., 2013). Firstly developed for lakes, phytoplankton functional system is being applied to other categories of reservoirs because of the similarity of the two systems (Reynolds, 1999, 2000). In this approach, an metric using phytoplankton functional groups has been recently proposed by Padisa´k et al. (2006). Several phytoplankton indices including the algae group index (AGI), Catálan Index, Barbe Index, Brettum index, phytoplankton trophic index (PTI), Mediterranean phytoplankton trophic index (Med-PTI) using the phytoplankton biovolume and Q assemblage index have been developed for the assessment of ecological status of lakes and reservoirs.

Currently, more than 4000 taxa of marine phytoplankton belonging to Cyanobacteria, Chlorophyta, Cryptophyta, Eustigmatophyta, Chrysophyta, Bacillariophyta, Dinophyta, Raphidophyta, Haptophyta, Euglenophyta, Prasinophyta, Glaucophyta, Anoxyphotobacteria phyla have been identified (Sournia et al. 1991; Tett and Barton, 1995; Reynolds, 2006). In comparison, this number is probably lower in fresh waters (Reynolds, 2006). Phytoplankton are a key bioindicator of the health and functioning of freshwaters in relation to high nutrient level, and for measuring the success of restoration measures following reductions in nutrient inputs (Carvalho et al., 2013). The composition of a phytoplankton assemblage is known to depend not only water quality, physical factors and lake basin size, but also on biological factors such as specific growth and loss rates among the algae, parasitism, predation, and competition (Lepistö et al., 2004, 2006). Phytoplankton community is responsible for the total primary production in surface waters (Reynolds, 1984; Vadeboncoeur et al., 2011; Cellamare et al., 2012), and because of their short life times, respond quickly to variations in their habitat (Schaumburg et al. 2004; Poikane et al., 2011; Cellamare et al., 2012). Phytoplankton communities have developed morphological and physiological adaptive strategies for surviving in different habitats (Margalef, 1978; Reynolds, 1998; 2006; Reynolds et al., 2002; Padisák et al., 2003; Becker et al., 2010; Fetahi et al., 2014), and reflect autecological aspects of preference and tolerance (Fetahi et al. 2014). Thirty nine (39) phytoplankton functional groups which may dominate or co-dominate potentially, and alternately, in a given environment have been identified (Reynolds et al., 2002; Padisak et al., 2009). The phytoplankton functional groups approach applied to aquatic systems has provided key information concerning the distribution of phytoplankton species in the limnetic zone in various regions of the word (Fabbro and Duivenvoorden, 2000; Kruk et al., 2002; Huszar et al., 2003; Leitão et al., 2003; Lopes et al., 2005; Romo and Villena, 2005; Sarmento et al., 2006; Becker et al., 2009, 2010).

Algae blooms happen when a species of algae reproduces rapidly and reaches high concentrations. Too much phosphorus and nitrogen (found in fertilizers, animal waste, and sewage) lead to perfect conditions for algae blooms. There are several socioeconomic issues associated with eutrophication due to increases in phytoplankton biomass, especially with high frequency and persistence of toxic cyanobacteria blooms (Carvalho et al., 2013). These include deterioration of drinking water quality, treatment for water supply, recreational activities, and conservation (Carvalho et al., 2013). Phytoplankton blooms principally blue green algae (Cyanobacterial) (Figure 1.4) present main challenges for the management of surface watercourses. Cyanobacterial blooms have adverse effects on freshwater quality and human health, with serious economic and ecological consequences (Hallegraeff, 1993; Mur et al., 1999; Carey et al., 2012). The increased occurence and persistence of blooms have been associated to human activities, especially nutrient enrichment watercourses regulation and climate change associated with rising levels of atmospheric $CO_2$ (Anderson et al., 2002; Mooij et al., 2005; Paul, 2008; Beardall et al., 2009; Paerl and Huisman, 2009; Carey et al., 2012; Carey et al., 2012). The surface scum produced by *Microcystis*, the most common cyanobacterium in freshwater blooms is well known to affect water quality conditions by reducing water valuable services (Paerl et al., 2001; Lehman et al., 2005, 2008, 2010; Acuna et al., 2012a, b; Lehman et al., 2013).

**Figure 1.4** Blue green algae blooms in freshwater systems (Paerl and Paul, 2012)

### 1.5 Phytobenthos in Running Water Monitoring

Benthic diatom have been indicated as good indicators of variations in nutrient levels in running waters (Hering et al., 2006; Johnson et al., 2006a, b, Johnson et al., 2014; Gottschalk, 2014). Phytobenthos communities (especially diatoms) have been widely used in running waters biomonitoring than lake and reservoirs bioassessment compared to phytoplankton and macrophytes (Vadeboncoeur and Steinman, 2002; Ács et al., 2005;Cellamare et al., 2012). Diatoms in running watercourses are a major group of phytobenthos and biodiversity of the ecosystems. They are becoming an useful tool for fresh water quality biomonitoring worldwide in recent decades (e.g., Rott et al., 1999, 2003; Prygiel et al., 1999; Lobo et al., 2004; Potapova et al., 2004; Wang et al., 2005; Herring et al., 2006; Taylor et al., 2007; Porter et al., 2008; Kelly et al., 2009; Rimet, 2012; Rimet et al., 2016). For many reasons, diatoms are largely applied in fresh waters bioassessment especially running water bodies. Several values of their metrics have been calculated for the prediction of water quality (Poikane et al., 2016). Diatom-based metrics usually indicate a highly significant and well response to nutrient gradients (Rott et al., 2003; Kelly et al., 2014, 2016) with higher correlation coefficients than those of other biological elements (Birk et al., 2012). Among biological quality elements, diatom assemblages often considered as important ecological indicators of water bodies due to their rapid and sensitive response to environmental changes (Kelly, 1998; Stoermer and Smol, 1999; Potapova et al., 2004; Rimet et al., 2007; Bona et al., 2007; Delgado and Pardo, 2014). For the assessment of water quality, benthic diatoms have been used since the 1900s (Kolkwitz and Marsson, 1908). In Europe, benthic diatom metrics such as IPS (Cemagref 1982), TI (Rott et al., 1999), EPI-D (Dell'Uomo, 2004), TDI (Kelly et al., 2008) and recently TIT (Çelekli et al., 2016, 2018) developed for running waters are successfully applied for water quality assessment worldwide.

Diatoms are an extremely diverse group of algae with about 100,000 species (Round, 1991; Mann and Droop, 1996). They are an important group of phytobenthos (often 90–95%) and are good bioindicators of water quality in running waters. The advantage in benthic diatoms is that they can be found in every surface water, at any time (Solak and Àcs, 2011). They have been widely used in biomonitoring because of their short life cycles and their quickly response to habitat changes (Hering et al., 2006; Bona et al., 2007; Delgado and Pardo, 2014).

In general, diatoms are unicellular algae, but they can form colonies life-forms. Diatom cells are usually referred to as a frustule. The wall is composed of two sections (valves) with different sizes. One valve with its girdle fits over the other girdle with its valve. The outer one is often referred to as the epitheca and the inner one as the hypotheca (Patrick and Reimer, 1966). The frustule is siliceous and brittle and ordinarily etched with lines, rows of dots or puncta (Prescott, 1961). The longitudinal line which appears in the middle of one or both valves is known as raphe and enables diatoms to move (Figure 1.5). There are two groups of Diatoms, the centrics and pennates. The common type of reproduction of diatoms is accomplished by vegetative reproduction in with mitosis. The pigments which are directly or indirectly associated with photosynthesis in diatoms are chlorophyll a and c; carotene α, β, ε; diadinoxanthin; diatoxanthin; fucoxanthin, neofucoxanthin A, and neofucoxanthin B (Patrick and Reimer, 1966). Fucoxanthin and carotene β are responsible of the characteristic brown color of diatoms. An example of living diatom and a cleaned frustule after treatment are given in Figure 1.6.

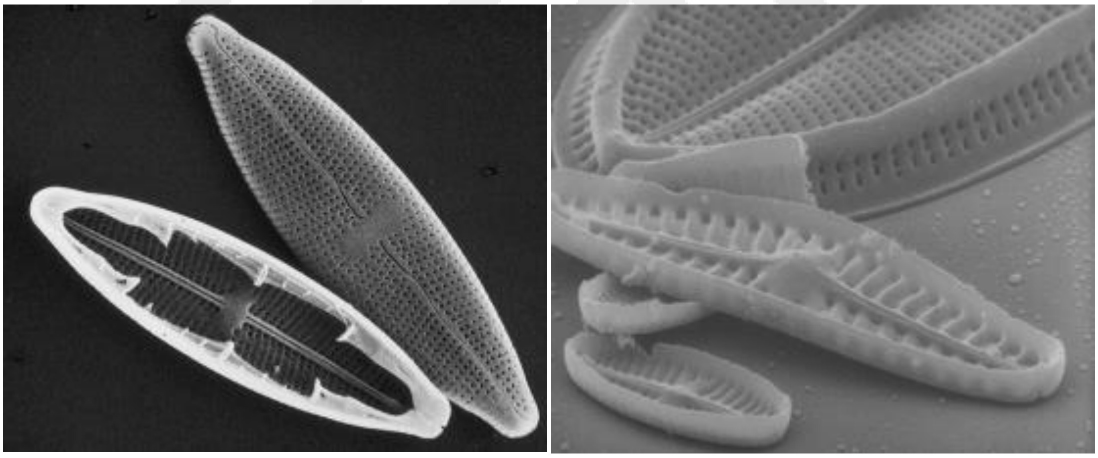


**Figure 1.5** Valves of Diatom under electronic microscope (Hürlimann and Niederhauser, 2007)

**Figure 1.6** *Cymbella tumida* (left): living material; (right): cleaned frustule after nitric acid treatment (Rimet, 2012)

Diatoms are present in various type of habitats, ranging from fresh and salt water. They live in intertidal zones and on damp soil, rocks, or plants where the spray from waves or falling water reaches them (Patrick and Reimer, 1966). They may present several life-forms during their development. They can be unicellular (Figure 1.7) and free moving at one stage, but attached to a peduncle and immobilized at another stage (Rimet, 2012). Diatoms can be found also in the types of colonies (e.g. chain, ribbon, zig zag Rosette, arbuscular, mucous).

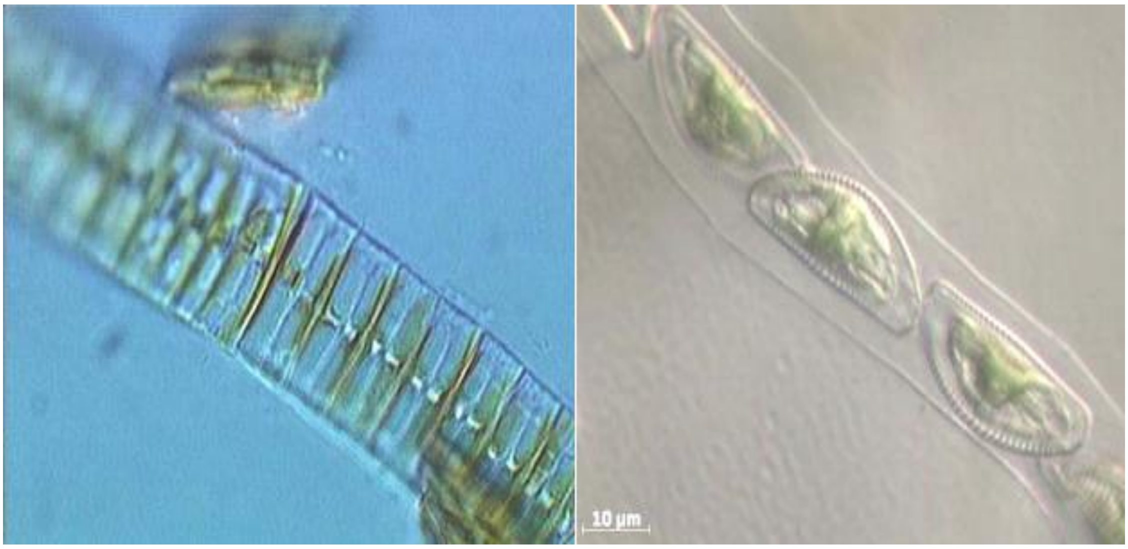



**Figure 1.7** Diatom life-forms (Rimet, 2012). (a) ribbon colony with *Fragilaria capucina* var. *vaucheriae*, (b) mucous tubules with *Encyonema minutum*

### 1.6 Objectives of the Present Study

The monitoring of water quality has a long history especially based on physicochemical data. However, biological assessment of freshwater ecosystems becomes more and more important since the implementation of European Union Water Framework Directive. The principal objective of this study was to evaluate the water quality of fresh waters bodies (lakes, reservoirs, streams and creeks) in the Western Mediterranean basin of Turkey based on phytoplankton and phytobenthos two of the mandatory five biological indicators indicated by the European Union Water Framework Directive using multivariate approaches. The objectives of the study were to:

1. Estimate the phyotoplankton assemblages and the structuring factors in Mediterranean lakes and reservoirs.
2. Determine the environmental divers of diatom communities' composition in running water bodies.
3. Evaluate the ecological status of lakes and reservoirs based on phytoplankton metrics
4. Evaluate running water quality based on new diatom metric developed in Turkey
5. Evaluate the trophic states of the lakes and reservoirs

The following hypotheses associated to aforementioned objectives were postulated and tested in the prensent study:

- First, there is no difference phytoplankton composition between lakes and reservoirs, and no difference in diatom composition between running waters.
- Second, environmental variables, especially pollution parameters (nutrients, organic matter) are the most important structuring factors of phytoplankton and diatom assemblages in lakes and reservoirs and running water bodies
- Third, there is no difference between the ecological status of the lakes and reservoirs on one hand and between running water bodies on the other hand
- Fourth, there is no difference between the trophic states of the lakes and reservoirs.

# CHAPTER II

# LITERATURE REVIEW

Surface freshwaters (lakes, reservoirs, and rivers) are among the most extensively degraded ecosystems on earth, and most of them have been degraded in multiple ways, (Stephen et al., 2011). Assessing the water quality in freshwater ecosystems should include biological as well as physicochemical parameters. Monitoring of water quality especially freshwater has à long history and based on biological quality elements as well as physicochemical parameters and nutrients (phosphate, nitrate…). In last decades, a significant effort has been done worldwide to monitor water quality using not only physicochemical parameters, but also bioindicators which are extremely sensible to environment changes. In this case, the direct study of the effects of pollution on biota is of great interest (Gonzalo and Fernández, 2012). Due to demographic change and socioeconomic activities, water quality in surface waters is degrading in many parts of the world (Schindler, 2006; Smol, 2008), disturbing thereby many aquatic ecosystem functions and services. In order to understand these disturbances and to provide solutions, the EU water framework directive (WFD) required all member states to protect and assess all fresh water bodies with the aim of achieving good water status at the latest 15 years from the date of entry into force of this Directive, (2000/60.EC). Biological quality elements, including phytoplankton, phytobenthos, macrophytes, benthic invertebrates and fish are recommended by the EU Water Framework Directive (WFD) 2000/60/EC to be used as bioindicators for the monitoring of surface waters (EC, 2009; Directive, 2000).

## 2.1 Physicochemical Parameters and Ecological Assessment

Assessment of water quality by using physical and chemical variables of ecosystems approach is the empiric way in water ecological status evaluation. Prior studies have been conducted on water quality using physicochemical parameters. (e.g. Renn, 1968; Pratti et al., 1971; Gaudet, 1979; Olajire and Imeokparia, 2001; Tepe et al., 2005; Janse et al., 2008; Mustapha, 2008; Manjare et al., 2010; Patil et al., 2012; Ndungu, 2014). The changes in physicochemical parameters of water provide valuable information on the quality of the water, the sources of the modifications and their effects on the functions, structures and biodiversity of the watercourses (Mustapha, 2008). The trophic state of the water bodies can be determined by using physicochemical parameters especially phosphate, temperature, nitrogen. However, there is a quite few number of criteria for the assessment of water quality using physicochemical parameters (e.g. Carlson 1977; OECD, 1982).

Rokade and Ganeshwade (2005) studied the effect of pollution on water quality of Salim Ali Lake at Aurangabad, Uttar Pradesh (India) and indicated high fluctuations in the physicochemical parameters demonstrating the intensity of pollution.

Mustapha, 2008, investigated the variations in physicochemical factors for determining the water quality of Oyun Reservoir, Offa, Kwara State, Nigeria. This study concluded that the reservoir had an excellent water quality and high ecological status.

Joshi et al. (2009) found that physicochemical parameters such as pH, electrical conductivity, total dissolved solids, total suspended solids, turbidity, and sodium values were higher than those of the prescribed limit in some water samples of River Ganga.

Cieszynska et al. (2012) applied physicochemical data to assess water quality in the Gdansk Municipality (South Baltic coast) and indicated that water quality of the watercourses in the region depends on their locations.

Sorlini et al. (2013) analyzed the physicochemical parameters in the Logone Valley (Chad-Cameroon) in order to identify the contamination problems. They detected high physicochemical levels both in aquifers and surface waters.

Using physicochemical properties of water to evaluate water quality provides a good impression of the state, function, structure, and sustainability of such watercourses (Mustapha, 2008). However, this method with instantaneous measurements mainly gives restricting knowledge of water conditions. The chemical data at each sampling period indicate the current state of the water quality and ignore the temporal and spatial variations of water quality in aquatic ecosystems (Rocha, 1992). On the other hand, the use of biological monitoring gives a direct information on the ecological integrity based on the response of organisms to the variations in environmental variables (Karr, 1991; John, 2000; EC, 2009).

In this study, the physicochemical parameters were used as supplementary elements as suggested by the FWD.

### 2.2 Bioassessment of Water Quality

Biological assessment is an important tool to evaluate biological integrity of watercourses, and consist of the monitoring and other direct investigations of aquatic living organisms such as phytoplankton, photobenthos, macrophytes, macroinvertebrates, fishes, etc. Cranstont et al. (1996) argued that, as a result, changes in the health of a catchment will be reflected in the aquatic living organisms. The biological communities that are under to pollutants react as integrators of the various present and past environmental stresses.

#### 2.2.1 Ecological Assessment Based on Phytoplankton

Early attempts were made in the 20 and 21 centuries to assess water quality focus on study of phytoplankton in monitoring lakes (e.g. Naselli Flores and Barone, 1998, Willén, 2001; Reynolds et al., 2002; Padisák et al., 2003; Lepistö et al., 2006; Naselli Flores and Barone, 2007; Salmaso and Padisák, 2007; Moreno-Ostos et al., 2008; Poikane et al., 2009; Tolotti et al., 2010; Pasztaleniec and Poniewozik, 2010; Poikane et al., 2011; Brucet et al., 2013; Carvalho et al., 2013; Crossetti et al., 2013; Demir et al., 2014; Poikane et al., 2016). A few studies were made in rivers and reservoirs assessment based on phytoplankton (e.g., Negro et al., 2000; Figueredo and Giani, 2001; Moreno-Ostos et al., 2008; Hoyer et al., 2009; Chellappa et al., 2009; Becker et al., 2010; Soylu and Gönülol, 2010; Katsiapi et al., 2011; Abonyi et al., 2012; Molina-Navarro et al., 2012, 2014; Çelekli and Öztürk, 2014). Phytoplankton are one of the five biological quality elements recommended as an ecological indicator by the European Union Water Framework Directive (Directive, 2000) to assess surface waters is getting more and more important in lakes and reservoirs. The normative definitions of ecological status classifications (high, good and moderate) for lakes based on phytoplankton are given in Table 2.1.

Reynolds et al. (2002) established a criteria of categorisation of phytoplankton species to be sensitive to habitat variations (essentially to eutrophication but also to shorter seasonal fluctuations in stratification and in the accessibility of adequate nutrient supplies) based on functional groups (Table 2.2). They sought to show some of the uses of the functional-group model.

**Table 2.1** Normative definitions of ecological status classifications. Definitions for high, good, moderate, poor and bad ecological status in lakes based on phytoplankton. From Annex V of the WFD (Directive, 2000)

| Status | Phytoplankton |
|---|---|
| High status | The taxonomic composition and abundance of phytoplankton correspond totally or nearly totally to undisturbed conditions. The average phytoplankton biomass is consistent with the type-specific physicochemical conditions and is not such as to significantly alter the type specific transparency conditions. Planktonic blooms occur at a frequency and intensity which is consistent with the type specific physicochemical conditions. |
| Good status | There are slight changes in the composition and abundance of planktonic taxa compared to the typespecific communities. Such changes do not indicate any accelerated growth of algae resulting in undesirable disturbance to the balance of organisms present in the water body or to the physico-chemical quality of the water or sediment. A slight increase in the frequency and intensity of the type specific planktonic blooms may occur. |
| Moderate status | The composition and abundance of planktonic taxa differ moderately from the type specific communities. Biomass is moderately disturbed and may be such as to produce a significant undesirable disturbance in the condition of other biological quality elements and the physico-chemical quality of the water or sediment. A moderate increase in the frequency and intensity of planktonic blooms may occur. Persistent blooms may occur during summer months. |
| Poor status | Waters showing evidence of major alterations to the values of the biological quality elements for the surface water body type and in which the relevant biological communities deviate substantially from those normally associated with the surface water body type under undisturbed conditions, shall be classified as poor. |
| Bad status | Waters showing evidence of severe alterations to the values of the biological quality elements for the surface water body type and in which large portions of the relevant biological communities normally associated with the surface water body type under undisturbed conditions are absent, shall be classified as bad. |

**Tablo 2.2** Functional groups of phytoplankton (Reynolds et al., 2002)

| Codon | Habitat |
|---|---|
| **A** | Clear, often well-mixed, base poor, lakes |
| **B** | Vertically mixed, mesotrophic small-medium lakes |
| **C** | Mixed, eutrophic small- medium lakes |
| **D** | Shallow, enriched turbid waters, including rivers |
| **N** | mesotrophic epilimnia |
| **P** | eutrophic epilimnia |
| **T** | deep, well-mixed epilimnia |
| **S1** | turbid mixed layers |
| **S2** | shallow, turbid mixed layers |
| **SN** | warm mixed layers |
| **Z** | clear, mixed layers |
| **X3** | shallow, clear, mixed layers |
| **X2** | shallow, clear mixed layers in meso-eutrophic lakes |
| **X1** | shallow mixed layers in enriched conditions |
| **Y** | usually, small, enriched lakes |
| **E** | usually small, oligotrophic, base poor lakes or heterotrophic ponds |
| **F** | Clear epilimnia |
| **G** | Short, nutrient- rich water columns |
| **J** | shallow, enriched lakes ponds and rivers |
| **K** | short, nutrient-rich columns |
| **H1** | dinitrogen-fixing Nostocaleans |
| **H2** | dinitrogen-fixing Nostocaleans of larger mesotrophic lakes |
| **U** | summer epilimnia |
| $\mathbf{L_O}$ | summer epilimnia in mesotrophic lakes |
| $\mathbf{L_M}$ | summer epilimnia in eutrophic lakes |
| **M** | dielly mixed layers of small eutrophic, low latitude lakes |
| **R** | metalimnia of mesotrophic stratified lakes |
| **V** | metalimnia of eutrophic stratified lakes |
| **W1** | small organic ponds |
| **W2** | shallow mesotrophic lakes |
| **Q** | small humic lakes |

In last decades, numerous phytoplankton metrics have been developed for the assessment of lakes and reservoirs:
Brettum (1989) in Norway, developed the Brettum index using the trophic preferences of species, modified by Dokulil and Teubner, 2006 in Austria.

Catalan et al. (2003) developed Catalán Index. The index is based on the percentage of biovolume of the different groups of phytoplankton.

Philippe et al. 2003 developed the ITP or Barbe Index in France. This index, using the proportion biovolume of given phytoplankton taxa, has been developed to infer the water quality of lakes from the composition of their phytoplankton assemblages.

Riedmüller et al. (2006) developed the Phytoplankton Trophic Lake Index (PTSI) based on type-specific indicator species, their trophic and weighting values in Germany.

Padisák et al. (2006) developed an assemblage index (Q) on basis of recent developments in phytoplankton ecology to evaluate the water quality of different lake types. The developed index ranged between 5 and 0 ($5 \geq Q \geq 0$), and can provide five (5) classes of qualification. They did not conclude for the superiority of the assemblage index as a monitoring tool of ecological status assessment within the WFD. However, they indicated that the proposed metric could has some remarkable characteristics that meet the idea of requirements of habitat based establishments. This index seems to be a useful tool for lakes assessment and has been tested in many counties.

Salmaso et al. (2006) used phytoplankton as an bioindicator of the water quality of the Deep Lakes South of the Alpsproposed and developed the Phytoplankton Trophic Index (PTI) in Italy. They concluded that the method applied to develop this index, and the subsequent result may be applied to study other lake types, providing a robust tool to evaluate the degree of specificity of the trophic indicator scores assigned to the single phytoplankton orders and species.

Marchetto et al. (2009) developed a phytoplankton based index called Mediterranean phytoplankton trophic index (Med-PTI) for estimating phytoplankton response to variations in nutrient levels in deep Mediterranean reservoirs. They indicated that the developed metric can be considered a useful tool for assessing the response of the phytoplankton to variations in nutrient concentration in deep reservoirs in agreement with the WFD guidelines.

Phillips et al. (2013) developed a composition metric, the plankton trophic index (PTI) to evaluate the status of lakes. They suggested that the taxonomic composition of the phytoplankton can be quantified using trophic optima derived from a pan-regional dataset and provided that country-specific reference values are used to account for climatic and biogeographical differences and can be used to compare and assess the status of lakes across Europe.

Hutorowicz and Pasztaleniec (2014) developed Phytoplankton Metrics for Polish Lakes (PMPL) in Poland. The PMPL includes abundance parameters of phytoplankton: the metrics: “chlorophyll a”, “total biomass” while the taxonomic composition is partly evaluated by the metric “biomass of cyanobacteria”

de Hoyos et al. (2014) New Mediterranean Assessment System for Reservoir’s Phytoplankton (NMASRP) in Cyprus and Portugal based on Chlorophyll-a (μg/L), Biovolume ($mm^3$/L), IGA (Index Des Grups Algals) and Cyanobacterial biovolume ($mm^3$/L) to assess reservoirs.

Phillips et al. (2014) developed Danish lake phytoplankton Index (DLPI) based on both abundance and composition metrics.

Aforementioned methods are useful tools for assessing water quality. However, combining these methods to provide a realistic estimation of water quality is rare. In this work, we proposed to evaluate the water quality by combining three of these methods and multivariable approaches to reduce the infuence of climate change and natural environmental variability on the credibility of phytoplankton applications.

Using phytoplankton for water quality assessment is a new topic in Turkey but start to become more and more important after 2000. During the last two decades, a number of studies using phytoplankton have been carried out in the different regions of Turkey.

Soylu and Gönülo (2010) studied the functional categorisation and composition of Phytoplankton in Liman Lake from a data collected between January 2002 and

December 2003 were they indicated an alternate between R-Strategists and C-Strategists groups in the succession of phytoplankton.

Demir et al. (2014) tested the Q assemblage index based on phytoplankton functional classification in Lake Mogan and provided a good water state estimation. They identified 76 phytoplankton species belonging to 12 functional groups. They argued that the Q index was useful to follow the principal seasonal variation of the physicochemical parameters and indicated a moderate ecological status for Lake Mogan.

Çelekli and Öztürk (2014) determined the water quality and ecological preferences of phytoplankton using a multivariate approach in Alleben Reservoir. They identified nine (9) functional groups (A, D, E, J, $L_O$, $L_M$, MP, P, and Y) as descriptors and a medium ecological status for the reservoir based on Q index and PTI, and argued that these indices should be suitable phytoplankton metrics to evaluate the water quality of the reservoir.

Çelekli et al. (2016) modified phytoplankton trophic index (PTI) for assessing many lentic ecosystems from 8 basins of Turkey (Lower Euphrates, Ceyhan, the West Mediterranean, the North Aegean, Sakarya, the West Black Sea, the East Black Sea, and Aras).

### 2.2.2 Ecological Assessment Based on Benthic Diatoms

Benthic diatoms are widely used as a representative for the entire phytobenthos community for many reasons in lakes and rivers environmental assessment. Diatoms in streams and rivers represent a major part of phytobenthos (often 90–95%) and aquatic biodiversity, and they have become a useful tool in water quality biomonitoring. Consisting of inert and easily preserved frustules, diatoms identification and analysis is less complicated than other phytobenthos algae. Besides, there is huge knowledge about diatom identification for a long time, resulting in a number of key boocks (e.g. Krammer and Lange-Bertalot, 1986-1991; Krammer 2000, 2002, 2003; Lange-Bertalot, 2001; Lange-Bertalot and Metzeltin, 1996) to facilitate the counting based on diatoms shape, constitution and characteristics. Similarity in water nutrient enrichment state deduction has been indicated using benthic diatoms as well as the entire phytobenthos communities

(Kelly et al., 2008). Phytobenthos are one of the five (5) bioindicators recommended as an ecological indicator by the European Union Water Framework Directive (Directive, 2000) to assess surface waters are widely used in evaluating running water quality. The normative definitions of ecological status classifications (high, good and moderate) for rivers based on phytobenthos are given in Table 2.3.

**Table 2.3** Normative definitions of ecological status classifications. Definitions for high, good, moderate, poor and bad ecological status in rivers based on phytobenthos. From Annex V of the WFD (Directive, 2000)

| Status | Phytobenthos |
|---|---|
| High status | The taxonomic composition corresponds totally or nearly totally to undisturbed conditions. There are no detectable changes in the average phytobenthic abundance. |
| Good status | There are slight changes in the composition and abundance phytobenthic taxa compared to the type-specific communities. Such changes do not indicate any accelerated growth of phytobenthos or higher forms of plant life resulting in undesirable disturbances to the balance of organisms present in the water body or to the physico-chemical quality of the water or sediment. The phytobenthic community is not adversely affected by bacterial tufts and coats present due to anthropogenic activity |
| Moderate status | The composition of phytobenthic taxa differs moderately from the type-specific community and is significantly more distorted than at good status. Moderate changes in the average phytobenthic abundance are evident. The phytobenthic community may be interfered with and, in some areas, displaced by bacterial tufts and coats present as a result of anthropogenic activities. |
| Poor status | Waters showing evidence of major alterations to the values of the biological quality elements for the surface water body type and in which the relevant biological communities deviate substantially from those normally associated with the surface water body type under undisturbed conditions, shall be classified as poor. |
| Bad status | Waters showing evidence of severe alterations to the values of the biological quality elements for the surface water body type and in which large portions of the relevant biological communities normally associated with the surface water body type under undisturbed conditions are absent, shall be classified as bad. |

Several diatom based indices have been carried out in freshwater ecological status and states evaluation based on phytobenthos (e.g. Van Dam et al., 1994; Kelly et al., 1995; Rott et al., 1997; Kelly et al., 1998; Rott and Pipp, 1999; Finlay et al., 2002; Rott et al., 2003; Potapova et al., 2004; Ács et al., 2005; Hering et al., 2006; Bona et al., 2007; Della Bella et al, 2007; Solak and Àcs, 2011; Cellamare et al., 2012; Beltrami et al., 2012; Schneider et al., 2013; Bennion et al., 2014, Delgado and Pardo, 2014, Wang et al., 2014). Due to this reason, several diatom indices were developed for the bioassessment of running water quality. Wang et al. (2014) listed the diatom indices widely used in river health assessment which are among the following metrics.

Percent Community Similarity of Diatoms (PSc) (Whittaker et al., 1958): This index is used to compare, monitor and examine sites, or average community of a category of monitor or reference sites with a test station. Percent community similarity scores varied from 0 (absence of similarity) to 100%.

Simple Autecological Index (SAI) (Lowe, 1974): This index is used to characterize different diatom species along an environmental (stressor) gradient and deduce environmental variations and impact on the phytobenthos community.

Descy Index (DI) (Descy, 1979): The first diatom index developed by Descy in 1979.

Pollution Tolerance Index for Diatoms (PTI) (Lange-Bertalot, 1979): This index is used to classify groups of diatoms based on their tolerance to increased pollutants, with species associated to a score from one (1) for most tolerant species to three (3) for relatively sensitive taxa.

Specific Pollution Sensitivity Index (SPI) (Coste, 1982): Bioassessment of water quality via calculating the proportion of specific pollution sensitive species.

Diatom Assemblage Index for Organic Pollution (DAIpo) (Watanabe et al., 1986): Calculates the relative abundance of eusaprobic and eurysaprobic species to assess the degree of polluted water.

Sládeèek Index (SLA) (Sládeèek, 2006): Bioassessment of water quality via calculating the proportion of saprobic diatom species.

Index of Leclercq and Maquet (ILM) (Leclercq and Maquet, 1987): This metric is used to indicate organic pollution and assess water quality. Derived from Sladecek's method, Leclercq and Maquet proposed other values for the "saprobic valencies" (s) and for the "indicator values" (v).

Generic Diatom Index (GDI) (Rumeau and Coste, 1988; Wu, 1999): This index is the ratio of abundance of *Achnanthes*, *Cocconeis* and *Cymbella*, to that of *Cyclotella*, *Melosira* and *Nitzschia* to measure diatom assemblage changes.

Percent Motile Diatoms (PMD) (Bahls, 1993): This is a siltation index, calculated as the relative percentage of *Navicula* + *Nitzschia* + *Surirella*. The three (3) genera are able to move towards the surface of water if they are covered by silt; their percentage in a given water body provides an idea about the level and frequency of siltation.

Trophic Diatom Index (TDI) (Kelly and Whitton, 1995, Kelly et al., 2008): This index was developed to evaluate the water quality of running waters (especially rivers) based on diatom composition.

Biological Diatom Index (BDI) ([Lenoir and Coste, 1996 ; Prygiel et al., 2002 ; Coste et al., 2009) : This index was developed using a list of 209 key species indicating various pollution sensitivities. The pollution sensitivity, or ''ecological profile'', is calculated using the species occurrence probability scores along a seven (7) quality classes scale.

Rott saprobic index (ROT) (Rott et al, 1997): This index is an improved saprobic index based on the Sládeèek Index; some saprobic values and indicator values have been changed.

Percent live diatoms (PDI) (Hill, 1997): This index is used to show the state of the diatom community. According to this metric, low score could be the consequence of high sedimentation with high algal biomass on substrates.

Percent Aberrant Diatom (PAD) (Mc Farland et al., 1997): PAD indicates the proportion of diatom assemblages in a sampling station that shown anomalies in striae patterns or frustule shapes. The index has been positively correlated with heavy metal presence in running water.

Shannon Diversity (for diatoms) (Barbour et al., 1999): this system consists of a function related to the number of taxa in a given water sample as well as the repartition evenness of individuals of those taxa.

Percent Sensitive Diatoms (PSD) (Barbour et al., 1999): This index is the total of the relative abundances of all intolerant taxa. The metric is especially applicable in smaller-order streams where algae may be naturally low.

Trophien index (TI) (Rott et al., 1999); This index has been developed to estimate the trophic status of running water in Austria. TI = (Sum of (Indicator Taxa Abundance * Indicator trophic value * Indicator weighting score)) / Sum of (Indicator Taxa Abundance * Indicator weighting score).

Diatom Model Affinity (DMA) (Passy and Bode, 2004): the index gives an evaluation of water quality by the determination of percent similarity to a model community that can be viewed as a reference standard. The high similarity to the model indicates assemblages that are minimally disturbed, while lower similarity suggests water quality problems.

Pampean Diatom Index (PDI&IDP) (Gómez and Licursi, 2001): IDP integrated both organic pollution and eutrophication, and has been applied for the biomonitoring of water quality in rivers and streams in the Pampean plain.

Eutrophication Pollution Index using diatoms (EPI-D) (Dell'Uomo, 1999, 2004): This diatom-based metric was calculated based on the sensitivity of diatom taxa to organic pollution, mineralization of water, and chloride.

Relative Abundance of Diatom Species (RAD) (Griffith et al, 2005): High taxa number is supposed to show high biotic integrity because many taxa are adapted to the situations present in their environments. Species number is predicted to be low with high pollution conditions because several species are sensitive.

Eastern Canadian Diatom Index (IDEC) (Lavoie et al, 2006; Grenier et al, 2010 ): This index is based on correspondence analysis (CA) to develop a chemistry-free index, where the position of the sites along the gradient of maximum variance is strictly determined by diatom assemblage structure and therefore is dependent on measured environmental variables.

Diatom Index for Australian Rivers (DIAR) (Chessman et al., 2007): This index is used as a broad-scale indicator of human influences on Australian rivers, especially the effects of agricultural and urban land use, and also for impact studies at local scales.

Trophic index Turkey (TIT) (Çelekli et al., 2016, 2018): Recently developed, the index was calculated based on species sensitivity to nutrient contents of the waters. The trophic weight and indicator values which served to calculate this index were calculated according to the repartition of diatom taxa in different TP classes.

As it can be clearly seen, except the newly developed trophic index Turkey (TIT), there is no diatom based metrics for freshwater quality assessment in Turkish. However, several previous studies (Gürbüz and Kıvrak, 2002; Akbulut et al., 2010; Tokatlı and Dayıoğlu, 2011; Solak, 2011; Solak and Àcs, 2011; Solak et al., 2012) were carried out in Turkey using foreign diatom metrics which could lead to lack of important knowledge concerning the quality of watercourses. However, it has been known that the direct application of foreign diatom based system could be a source a wrong interpretation of water quality because of the difference in diatom assemblage between various regions (Pan et al., 1996). In this thesis, we assessed running waters in the western Mediterranean basin of Turkey by combining trophic index Turkey (TIT), a national newly developed diatom-based metric, another Mediterranean called eutrophication and pollution index based on diatom (EPI-D) and the trophic index (TI).

# CHAPTER III

# MATERIAL AND METHODS

## 3.1 Description of the Study Area

The studied water bodies are located in the West of the Mediterranean region (in Turkish: Akdeniz Bölgesi) of Turkey. The Mediterranean basin of Turkey is limited by the Aegean basin to the west, the Central Anatolia basin to the north, the Eastern Anatolia basin to the northeast, the Southeastern Anatolia basin to the east, Syria to the southeast, and the Mediterranean Sea to the south (Figure 3.1). This region is approximately 110,000 $km^2$ and makes up 14% of the land of Turkey (Gündogan et al., 2009).

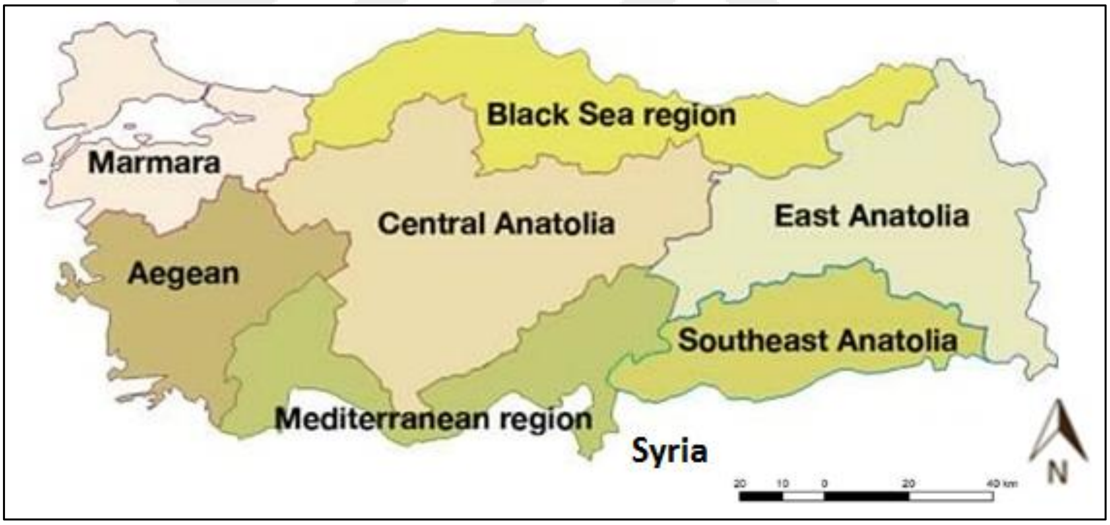



**Figure 3.1** Location of the study area (Mediterranean basin) on the map of Turkey, modified from Nations Online Projects (2018)

The climate of the basin is different from that the climate of the Mediterranean because the basin carries a parade between the Aegean, Central Anatolia and Mediterranean Regions. In the settlements with the Aegean and Mediterranean borders, the Mediterranean climate is dominant. The characteristics of the Mediterranean and continental climates are evident in the Denizli province basin settlements as they feature a gateway between the Aegean, Central Anatolia and the

Mediterranean Regions. The Mediterranean-Aegean transition climate can be seen in the Burdur province. In the continental climate, winters are cold and snowy and summers are hot and dry; In the Mediterranean climate, winters are warm and rainy, summers are hot and cold. In the basin, a large part of the annual total precipitation is in fall and the winter months. Snow in fall and frosts are rarely seen on the coast. The Mediterranean Basin of Turkey predominant vegetation cover is depending on the Mediterranean climate characteristics. Also, the Mediterranean region of Turkey is a mountain chains region (e.g. Toros mountains, Amonos mountains, ect.). The coastal plains of the region are formed in lower river watersheds. West Mediterranean basin consisted of many aquatic ecosystems (running waters, reservoirs and lakes) which play an important role in the socioeconomic activities, especially agriculture, irrigation and fish farming in the basin. The important water bodies of the Western Mediterranean Basin are shown in Table 3.1 and Figure 3.2 (Anonymous, 2016).

**Table 3.1** Main watercourses of the Western Mediterranean Basin

| **Running water** | **Reservoirs** | **Lakes** |
|---|---|---|
| Tersakan Creek | Elmalı Çayboğazı Dam | Lake Gölhisar Gölü |
| Sarıçay | Finike Alakır Dam | Lake Koca Gölü |
| Namnam Creek | Eşen 1 HES | Lake Avlan |
| Kargıcak Deresi | Akköprü Dam ve HES | Lake Köycegiz |
| Dalaman River | Belkaya Dam | Lake Yazır |
| Seki Creek | Çavdır Dam | |
| Çayiçi Creek | Kozağacı Dam | |
| Kocadere/Kızılöz Creek | Yapraklı Dam | |
| Kocadere Upper part | Geyik Dam | |
| Çavdır Creek | Akgedik Dam | |
| Boğluca Creek | Mumcular Dam | |
| Akçay Creek | Marmaris Dam | |
| Alakır Creek | Elmalı Çayboğazı | |
| Koca Creek/Kanlı Creek | Çavdır Dam | |
| Eşen Creek | Toptaş Dam | |
| | Yapraklı Dam | |
| | Osmankalfalar Dam | |
| | Geyik Dam | |

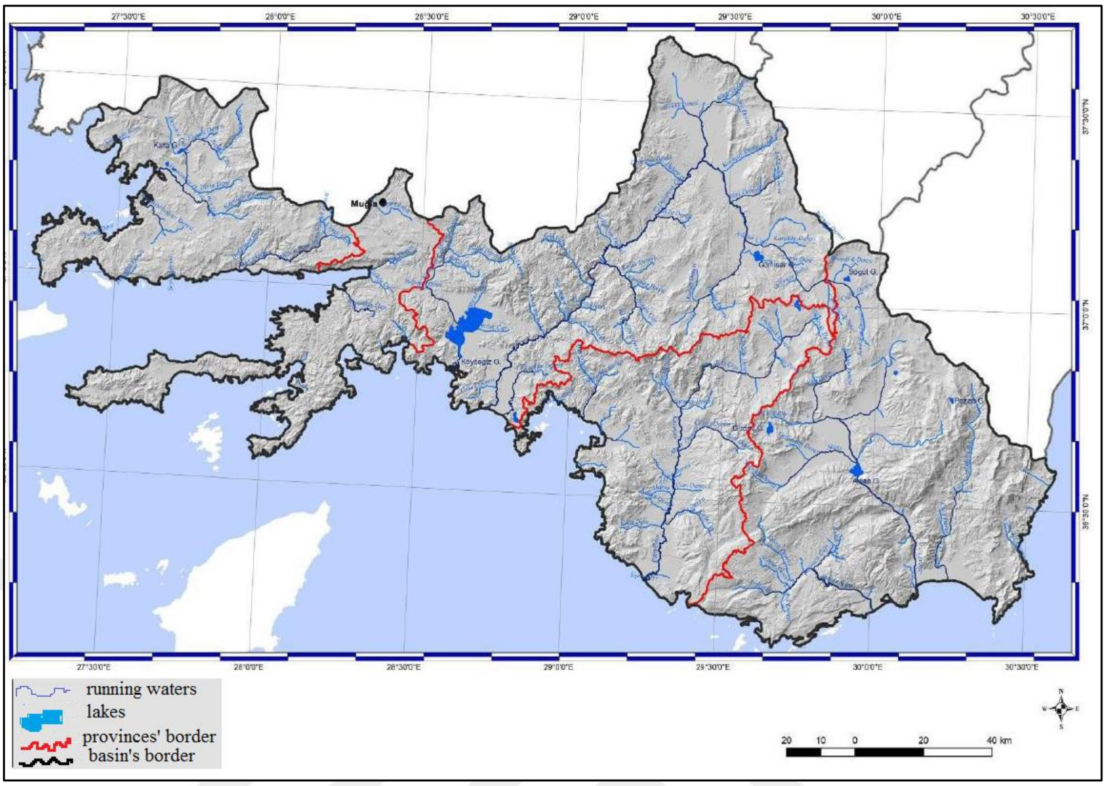



**Figure 3.2** Map of lakes and running waters bodies in the western Mediterranean basin of Turkey modified from Anonymous (2016)

### 3.2 Data sampling and analysis

Data were collected from thirty four (34) freshwater systems including twenty five (25) running waters (streams and creeks) and nine (9) lakes and reservoirs in the western Mediterranean basin of Turkey. The watercourses were seasonally sampled for water phycosicomical and biological (algal) analyses from summer 2014 to summer 2015 following standard methods (Kelly et al., 1998; EC, 2003; Gevrey et al., 2004). For phytoplankton identification, hydrobios plankton net was used to collect phytoplankton, while 250 ml water samples were directly taken from just beneath of the surface water to counting of phytoplankton taxa. On the other hand, epilithic diatoms were sampled in riffle areas from stones, by scraping the upper surface of the stones with a toothbrush. Physicochemical factors such as water pH, Temperature (T), Conductivity, Dissolved oxygen (DO), total dissolved solids (TDS), Total Suspended solids (TSS), Biological oxygen demand ($BOD_5$), Chemical oxygen demand (COD), Salinity, Alkalinity, were directly measured in *situ* from an YSI professional plus oxygen–temperature meter, while the water clarity of the lentic systems (lakes and reservoirs) was measured using a 20-cm Secchi disk.

Geographical data were read from a geographical positioning system (GPS). The chemistry of the watercourses (e.g., TN, N–NH4, N–NO3, N–NO2, TP, and P–$PO_4$ was the analyzed from the taken water sample by an accredited laboratory of DOKAY-ÇED (Ankara).

The phytoplankton and epilitic diatom species were identified under a light microscope (Olympus BX53) attached DP73 model digital camera with imaging software (Olympus CellSens Vers. 1.6) with the assistance of identification tools (Algaebase, Ettl, 1983; Komárek and Fott, 1983; Popovsky and Pfiester, 1990; Krammer and Lange-Bertalot, 1991a, b; Komárek and Anagnostidis, 1998; Krammer and Lange-Bertalot, 1999a, b; John et al., 2002; Wehr and Sheath, 2003; ect.), while phytoplankton taxa were counted using an inverted microscope (Olympus CKX41).

Multivariate and statistical analyses including canonical correspondence analysis (CCA), weighted averaging (WA) regression and Pearson's correlation test were carried out to understand the interactions between environmental parameters and algae species as well as among physicochemical variables.

### 3.3 Evaluation of water quality

The water quality of the sampled watercourses was evaluated using diatom and phytoplankton based metrics. We assessed first the ecological status of running waters (streams and creeks) following three diatom indices: Trophic index Turkey (Çelekli et al., 2016, 2018), and Eutrophication and Pollution Index Diatom-based (Dell'Uomo, 2004), and trophic index developed by Rott et al. (1999) while the lentic ecosystems (lakes and reservoirs) were assessed based on phytoplankton trophic index (Philips et al., 2013), Mediterranean phytoplankton trophic index (Marchetto et al., 2009), and the phytoplankton assemblage index (Padisák et al., 2006). In the second time, we assessed the trophic status of lakes and reservoirs were assessed following the trophic state index (Carlson, 1977) and the OECD system (OECD, 1982).

# CHAPTER IV

# ECOLOGICAL PREFERENCES OF BENTIC DIATOM (PHYTOBENTHOS)

## ABSTRACT

Running waters bioassessment is one of the challenges for the improvement of water quality in many counties and is getting more and more application since the implementation of the European Union water framework directive which required bioindicators including phytoplankton, phytobenthos, macrophytes, macroinvertebrates and fish to be used for water quality assessment. As an important part of phytobenthos, epilithic diatoms are widely used to in to estimate running water quality level. The main objective of this chapter was to characterize the composition and evaluate the ecological preferences of the diatom assemblages in twenty 25 running water stations in the Western Mediterranean basin of Turkey. The interactions between species and environmental variables was evaluated using canonical correspondence analysis (CCA). A total of 102 epilithic diatom taxa belonging to 22 genera were found. The most dominant genus was *Navicula* (29 species) followed by *Cymbella* (14 species). CCA indicated that the distribution of diatom composition was influenced by physicochemical factors. The first axes gave the species-environment correlations at 89.4% and cumulative percentage variance of species data at 9.4 %. *Clevamphora ovalis*, *Cocconeis placentula*, *Diatoma vulgaris* and *Ulnaria ulna* were found to be abundant in polytrophic conditions, in contrast to *Cymbella excisa*, *Fragilaria capucina*, *Gomphonema angustum* and *Gomphonema truncatum* were distributed in eutrophic and polytrophic conditions.

## 4.1 Introduction

Freshwater ecosystems play a key importance for humans, they provide us a number of benefits in addition to direct use such as drinking water supply, irrigation, fish farming, recreation. Wastewater treatment, flood control, water supply are some of the greatest functions of natural freshwater ecosystems. During the last century, natural continental aquatic systems water quality has been dramatically degraded due to demographic change, industrial revolution, and climate change resulting in severe water pollution and rarity in many regions of the world (Schindler 2006, Smol 2008). Anthropogenics activities have resulted a wide of alterations to aquatic biodiversity in the major part of surface water ecosystems (Allan and Castillo, 2007, Delgado and Pardo, 2014), and on the management of water resources requiring the development of suitable and accurate tools to control the biological integrity of aquatic ecosystems (Cao et al., 2007; Delgado and Pardo, 2014). Habitat deterioration is any variation or perturbation to the environment that became undesirable for living organisms, in this order anthropogenic influences have degraded water catchments, resulting consciousness and the increase in the scientific research in developing biomonitoring methods to evaluate the status of freshwaters (Kelly and Whitton, 1995; Hering et al., 2006; Delgado and Pardo, 2014). Discharge of wastewater, nutrient enriched runoff, and land erosion through agriculture and irrigation practices had a adverse effect on water resources during the last centuries (Billen et al., 2001; Wunsan et al., 2002; Ducharne et al., 2007; Delgado and Pardo, 2014; Toudjani et al. 2017). The occurrence of high amount of nutrients (nitrate, phosphate etc.) associated with anthropogenic activities or natural sources in aquatic ecosystems especially freshwaters could considerably affect the functioning of aquatic primary producers (phytobenthos, phytoplankton, and macrophytes).

The increasing availability of dyes in watercourses decreases light penetration which can reduces primary productivity and causes aesthetic issues (Saratale et al., 2011). Also, several dyes or their metabolites in water resources even at low content can be source of a number of diseases and disorders for living organisms such as allergy, skin irritation, and cancer (Çelekli et al., 2009).

In last decades, a great effort has been done in many regions of the world to monitor water quality using chemical and physical parameters, as well as biological indicators. In fact, one of the adverse consequences of pollutants is their impact on the biodiversity. Due to this reality, many countries considering the characteristic structure of their water bodies have developed monitoring programs and continually been assessing and categorizing their water resources and used biological indicators for revealing the current situation of their water quality level (Solak and Ács, 2011).

Aquatic organisms are suitable tools to evaluate and monitor anthropogenic pressures on surface watercourses (Solak et al., 2012; Çelekli and Öztürk, 2014; Demir et al., 2014). Aquatic organisms such as hytoplankton, phytobenthos, and macrophytes are largely employed as bioindicators in aquatic ecosystems. The occurrence, absence or proportion of species or composition in aforementioned groups indicates the characteristics of the habitat where they are living (Cellamare et al., 2012). Phytoplankton and phytobenthos, due to their short life periods, respond quickly to variations in the environment (Schaumburg et al., 2004; Cellamare et al., 2012). Phytobenthos species have relatively been used in few studies related to lake and reservoirs than phytoplankton and macrophytes were (e.g. Ács et al., 2005; Sgro et al., 2006; Cellamare et al., 2012; Novais et al., 2012; Bennion et al., 2014; Fidlerová and Hlúbiková 2016; Poikane et al., 2016).

Most researches using phytobenthos (hereafter related specifically to diatoms) were carried out in monitoring rivers and stream (e.g. Round, 1991; Vadeboncoeur and Steinman 2002; Rott et al., 2003; Potapova and Charles, 2003; Ács et al. 2004; Bellinger et al., 2006; Tokatlı and Dayioğlu; 2011; Della Bella et al., 2012; O'Driscoll et al., 2012; Leelahakriengkrai and Peerapornpisal, 2014; Delgado and Pardo, 2014). Diatoms in streams and rivers are major part of phytobenthos and aquatic biodiversity. They form a great proportion of the benthic organisms (often 90–95%) and they have become a suitable indicator for water quality biomonitoring. The advantage in attached diatoms is that they are found in every surface water at any period (Bona et al., 2007; Solak and Àcs, 2011; Delgado and Pardo, 2014). Besides, there is huge knowledge on the limnoecology of diatoms and their optimal environmental conditions and tolerance range to water chemistry (Van Dam et al., 1994; Potapova et al., 2004; Schneider et al., 2013; Delgado and Pardo, 2014). Diatoms are often applied for the control of nutrient enrichment due to their high sensitivity and specific capacity to respond spontaneously to a particular environmental change (Hering et al., 2006; Delgado and Pardo, 2014). Benthic diatoms assimilate dissolved nutrients and use the solar energy for primary productivity, making them key organisms at the base of the grazer's food web, constituting food resources for invertebrates, and fish (Finlay et al., 2002). Periphyton assemblage and distribution are impacted at local scales by environmental parameters such as water nutrients, light, temperature, flow, and type of substrate (Stevenson, 1996; Dodds and Biggs, 2002).

The aims of the chapter were to i) investigate the diatom assemblages and ii) understand the impact of physicochemical variables on the ecological preferences of diatom species in running water ecosystems located in the western Mediterranean basin of Turkey by use of multivariate analyses.

## 4.2 Materials and Methods

### 4.2.1 Study Area

The study was conducted in four (4) provinces (Muğla, Burdur, Denizli, and Antalya) of the western Mediterranean basin of Turkey. The western Mediterranean region consists of several running watercourses including Tersakan Deresi, Sarıçay stream, Namnam stream, Kargıcak creek, Dalaman stream, Seki stream, Çayiçi creek, Kocadere/Kızılöz creek, Çavdır stream, Boğluca stream, Akçay stream, Alakır stream, Koca stream, Eşen stream, Karabeyyurdu creek, Delin creek, Kanlı stream. According to Anonymous (2016), Dalaman Stream is the largest running watercourse in this region. The water collection area of the Dalaman Stream is around 3,500 $km^2$. Despite the fact that the area for water collection is not very large, the water is often too crowded because the upstream is surrounded by high mountains with abundant rainfall. The minimum amount of water carried by the Dalaman Stream at the moment is seen in August. The Esen Stream in the Muğla Province is the second largest running water of the Western Mediterranean Basin. A total of 25 stations (Figure 4.1) from aforementioned running watercourses were sampled at seasonal intervals during four seasons (summer and fall 2014, spring and summer 2015). Geographical characteristics and typology of the sampling station are sorted in Table 4.1. Photographs of some studied stations are presented in Figure 4.2.

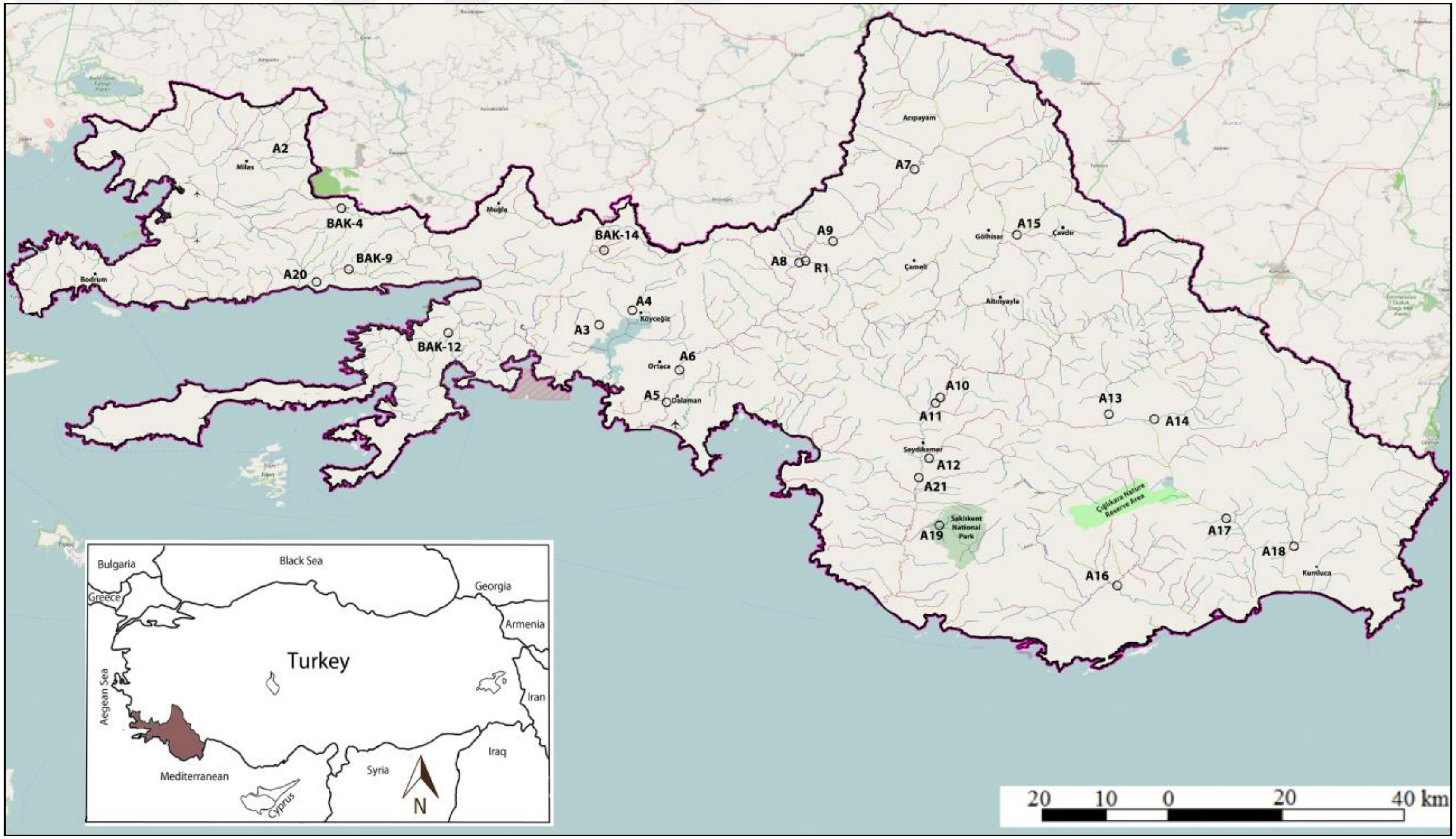



**Figure 4.1** Location of sampling stations. For stations' codes see Table 4.1

**Table 4.1** Geographical and hydro-morphologic data of the stations

| Provinces | Stations | Code | Typology | Latitude (N) | Longitude (E) | Altitude (m) |
|---|---|---|---|---|---|---|
| Muğla | Sarıçay creek | A2 | A1R1E2Y2D1J2 | 37° 22' 50.16" | 27° 53' 23.64" | 449 |
| Muğla | Namnam creek | A3 | A2R1E1Y2D1J2 | 36° 56' 28.14" | 28° 36' 33.659" | 12 |
| Muğla | Kargıcak creek | A4 | A1R2E2Y2D1J2 | 36° 45' 42.048" | 28° 45' 57.887" | 51 |
| Muğla | Dalaman stream | A5 | A2R1E1Y2D2J1 | 36° 50' 3.624" | 28° 47' 43.728" | 38 |
| Muğla | Dalaman stream | A6 | A2R1E1Y2D2J2 | 37° 18' 19.08" | 29° 20' 52.296" | 822 |
| Denizli | Dalaman stream | A7 | A2R2E2Y2D2J2 | 37° 5' 20.796" | 29° 5' 17.303" | 602 |
| Denizli | Dalaman stream | A8 | A2R2E1Y2D2J2 | 37° 8' 16.368" | 29° 9' 22.356" | 711 |
| Denizli | Dalaman stream | A9 | A2R2E1Y2D2J1 | 36° 46' 17.508" | 29° 24' 18.467" | 305 |
| Muğla | Seki stream | A10 | A2R2E2Y2D1J1 | 36° 45' 31.644" | 29° 23' 47.507" | 212 |
| Muğla | Seki stream | A11 | A2R2E1Y2D1J1 | 36° 37' 47.316" | 29° 22' 56.027" | 153 |
| Muğla | Çayiçi creek | A12 | A2R3E2Y2D1J1 | 37° 9' 3.024" | 29° 35' 16.548" | 959 |
| Antalya | Kızılöz creek | A13 | A2R3E1Y2D1J1 | 36° 19' 53.759" | 29° 49' 12.805" | 148 |
| Antalya | Kızılöz creek | A14 | A1R2E1Y2D1J1 | 36° 29' 23.928" | 30° 4' 24.78" | 370 |
| Burdur | Çavdır stream | A15 | A2R2E1Y2D1J2 | 36° 25' 37.436" | 30° 13' 52.356" | 101 |
| Antalya | Boğluca stream | A16 | A2R1E1Y2D1J1 | 36° 28' 26.256" | 29° 24' 12.419" | 129 |
| Antalya | Akçay stream | A17 | A2R3E2Y2D2J1 | 37° 2' 33.18" | 27° 56' 49.595" | 23 |
| Antalya | Alakır stream | A18 | A1R1E1Y2D1J1 | 36° 35' 8.484" | 29° 21' 25.74" | 85 |
| Antalya | Eşen stream | A19 | A2R2E2Y2D1J2 | 37° 22' 50.16" | 27° 53' 23.64" | 449 |
| Muğla | Kanlı stream | A20 | A1R1E1Y2D1J1 | 36° 56' 28.14" | 28° 36' 33.659" | 12 |
| Muğla | Eşen stream | A21 | A2R1E1Y2D2J2 | 36° 45' 42.048" | 28° 45' 57.887" | 51 |
| Muğla | Karabeyyurdu creek | BAK 12 | R1D2A1J2 | 36° 55' 23.484" | 28° 15' 25.775" | 194 |
| Muğla | Delin creek | BAK14 | A2R1E1Y2D1J2 | 37° 5' 20.58" | 28° 37' 41.808" | 393 |
| Muğla | Kaya creek | BAK4 | A2R1E1Y2D1J1 | 37° 12' 49.968" | 28° 0' 19.331" | 515 |

**Table 4.1** Continue

| Provinces | Stations | Code | Typology | Latitude (N) | Longitude (E) | Altitude (m) |
|---|---|---|---|---|---|---|
| Muğla | Kocabük creek | BAK9 | A1R1E1Y2D1J1 | 37° 4' 18.12" | 28° 1' 17.867" | 111 |
| Denizli | R1creek | R1 | R2D2A2J2 | 37° 5' 37.032" | 29° 5' 31.199" | 633 |

Typology codes (A, flow; R, altitude; J, geology; E, slope; Y, precipitation and D, drainage)

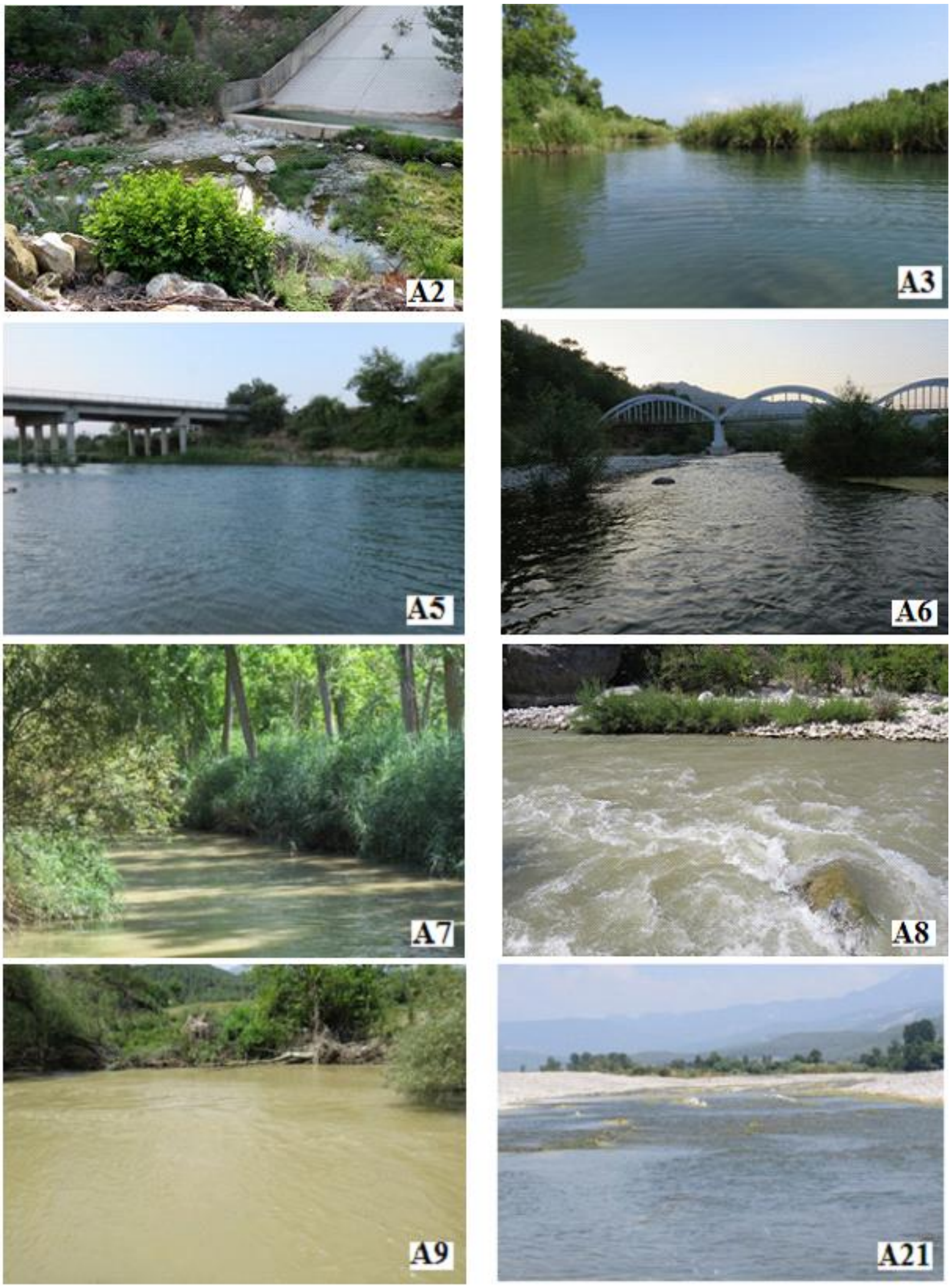



**Figure 4.2** Several sampled stations; Sarıçay creek (A2), Namnam creek (A3), Kargıcak creek (A4), Dalaman stream (A5, A6, A7, A8, and A9), Eşen stream (A21)

### 4.2.2 Field Sampling and Laboratory Techniques

#### 4.2.2.1 Field Sampling

Physico-chemical parameters such as water pH, Temperature (T), Conductivity, Dissolved oxygen (DO), Total Suspended solids (TSS), Biological oxygen demand ($BOD_5$), Chemical oxygen demand (COD), Salinity, Alkalinity, were directly taken *in situ* using an YSI professional plus oxygen–temperature meter from just beneath of the surface in the stations. Geographical characteristics such as elevation, latitude, and longitude were read from a geographical positioning system (GPS) during different seasons of the study time.

The phytobenthos (epilithic diatom) attached to sediment particles were sampled following to standard sampling methods for lotic (running waters) systems (Kelly et al., 1998; EC, 2003; Gevrey et al., 2004). In clear each epilithic samples were collected from stones, which are not moved under normal hydrological conditions, by scratching the upper surface of the stones by the use of toothbrush (Figure 4.3a). Immediately after collection, periphytic samples were fixed with Lugol's glycerol solution. Collected water samples were then conserved in coolers with ice packs (Figure 4.3b), during the transfer to the laboratory and conserved before analysis (Figure 4.3c).


**Figure 4.3** a) sampling; d) transfer in cooler with ice packs; and c) conservation in the laboratory of epilithic diatoms

#### 4.2.2.2 Laboratory Lechniques

##### 4.2.2.2.a Chemical variables measurement

Total organic carbon (TOC), ammonium nitrogen ($N\text{-}NH_4$), nitrite nitrogen ($N\text{-}NO_2$), nitrate nitrogen ($N\text{-}NO_3$), total Kjeldahl nitrogen (TKN), orthophosphate ($P\text{-}PO_4$), total phosphorus (TP), and total nitrogen (TN) were analysed using standard methods (APHA, 1989, 2012).

##### 4.2.2.2.b Diatoms cleaning prossess

Prior to permanent slides preparation, all the cell contents and organic matter were removed from samples. During this process, the hot acid (permanganate) method of cleaning was used according to the European committee for standardization (CEN, 2014). In clear, the sample was homogenized by shaking, 10 ml of the suspension was transferred into beakers and 2 ml of potassium permanganate ($KM_nO_4$) solution was added. 7 ml of diluted hydrochloric acid (HCl) was then added after 24 hours and heated on a hot plate at about 90 ± 5 °C. Distilled water was added at least three times, or until all traces of hydrochloric acid had been removed. The beaker was then removed from the heat and the content (cleaned diatom suspension) was transferred to a centrifuge tube topped up with distilled water then centrifuged at 6000 rpm for 3 minutes. Centrifugation was repeated three to five times (Figure 4.4).

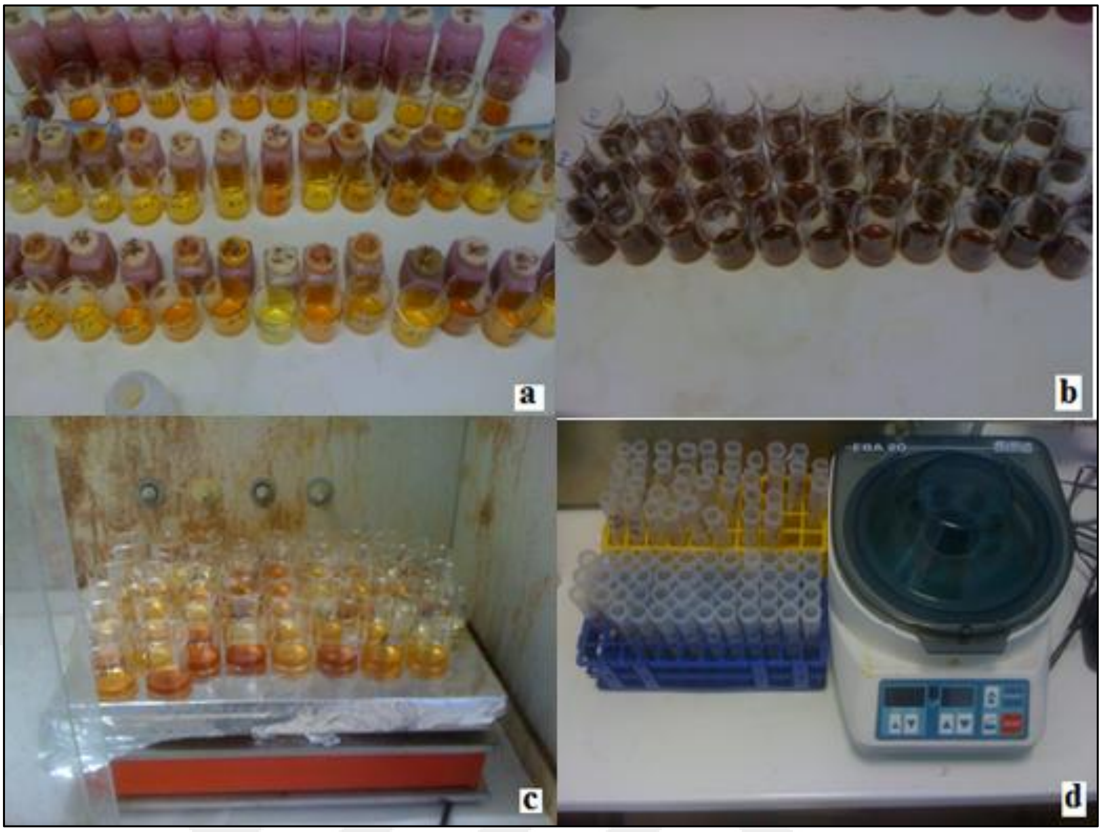



**Figure 4.4** a) Transfer of 10 ml to beaker, b) After addition of $KM_nO_4$ and HCl, c) heating and d) centrifugation process

#### 4.2.2.2.c Preparation of permanent slides

The cleaned diatom suspension was diluted to a suitable concentration and permanent slide mounts (Figure 4.5) were then prepared according to standard methods (CEN, 2003, 2014) for each sample for the enumeration of diatom species.

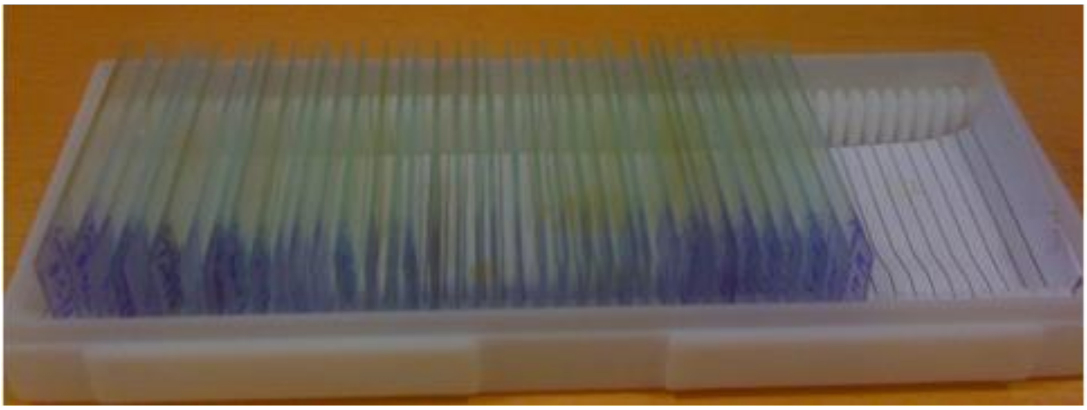


**Figure 4.5** Prepared permanent slides

#### 4.2.2.2.d Microscopic examination and identification

Diatoms identification and analyses were carried out in the hydrobiology's laboratory of the Biology department of Gaziantep University (Turkey) according to the standard methods (CEN, 2004, 2014). The prepared permanent slides were later examined at 1000x magnification using oil immersion microscopy to estimate taxonomic composition and relative abundance of with Olympus light microscope (Olympus BX53) attached the DP73 model digital camera with imaging software (Olympus CellSens Vers. 1.6) (Figure 4.6). The phytobenthos samples were identified and counted at species level according to primary identification diatom checklists and books (e.g., Krammer and Lange-Bertalot, 1991a, b, 1999a, b, Lange-Bertalot, 2001; Krammer, 2000, 2002). Relative percentages and biovolume of benthic algal were then calculated and used for statistical analyses and interpretation relevant to the assessment of water quality.

**Figure 4.6** Diatom examination and identification under Olympus light microscope (Olympus BX53)

### 4.2.3 Statistical Analyses

In order to estimate the relationship between the diatom species and physicochemical parameters a direct gradient analysis technique, canonical correspondence analysis (CCA) (ter Braak and Smilauer, 2002) was used. Prior to this, detrended correspondence analysis (DCA), which is a unimodal (Leps and Smilauer, 2003) was used at a gradient length more than 3.0. Environmental variables were measured in the study area at the 25 stations for analysis. Except pH, these variables were transformed using the function log (x+1), to decrease skewness (ter Braak and Smilauer, 1998). Statistical significance of environmental variables was estimated using the Pearson correlation test of SPSS statistical program. The transformed environmental variables and diatom abundances were analyzed using canonical correspondence analysis (CCA) with CANOCO for Windows 4.5 package (ter Braak and Šmilauer, 2002) to relate diatom assemblage structure to all predictor environmental variables and to explore the relationships among and between species and the environmental variables. A total of 8 environmental variables and species having a proportion higher than 1% were used for the CCA ordination. The significance of environmental factors to explain the variance of species data in CCA was examined following the forward selection of Monte Carlo permutation test. A weighted average (WA) regression was done to evaluate diatom taxa optima ($u_k$) and tolerance ($t_k$) values for each of the environmental variables.

The hypothesis of no difference in diatom composition (similarities in species composition) between the running watercourses was tested by means of vegetation tables (species-by-sites matrix) used by Schaumburg et al. (2004), while the Monte Carlo permutation test was used to test the hypothesis on relationship between the diatom taxa and the environmental factors. On the other hand, the hypothesis of no difference between the ecological status of running water bodies, the variance analysis (one-way ANOVA) was employed at 95% confidence interval using the program SPSS (IBM statistics version 23).

### 4.3 Results

#### 4.3.1 Physicochemical variables

Physico-chemical variables of the sites are summarized in (Table 4.2). The highest mean concentrations of TN (2208.8 µg $L^{-1}$) and $N$-$NO_3$ (1503.3 µg $L^{-1}$) were found in Çavdır Stream and Dalaman stream (A8) which were also located at higher altitudes 936 m and 821 m, respectively. With regard to phosphorous, the highest TP value (2263.3 µg $L^{-1}$) was recorded in Boğluca stream, while the highest $P$-$PO_4$ value (240.0 µg $L^{-1}$) was found in Sarı stream. The water bodies showed alkaline condition and their pH ranged between 8.1 and 8.7. With regard to geographical parameters, the lowest (14.2 °C) and highest (23.8 °C) mean of temperature were measured in Delin creek and Çayiçi Creek, respectively. Conductivity and salinity showed their highest values 823.2 µS $cm^{-1}$ and 0.4 ppt in Dalaman stream (A7) and Çavdır Stream. The Pearson's correlation test indicated positive and negative significant relationships among environmental variables (Table 4.3). Temperature is positively correlated with pH ($r= 0.432$, $p<0.01$), conductivity is positively correlated with total nitrogen ($r=0.574$, $p<0.01$) while dissolved oxygen was negatively correlated with total suspended solid ($r = -0.266$, $p<0.05$) and salinity ($r = -0.319$, $p<0.05$).

The seasonal distribution of $BOD_5$ and the nutrients especially TP, TN and $N$-$NO_3$ in the water bodies during the study period are given in Figure 4.7. According to the boxplots of Figure 4.7, there was no uniform distribution of the environmental variables in all running sampling stations.

**Table 4.2** Mean values of environmental variables combined from sampling stations. For stations' codes Table 4.1

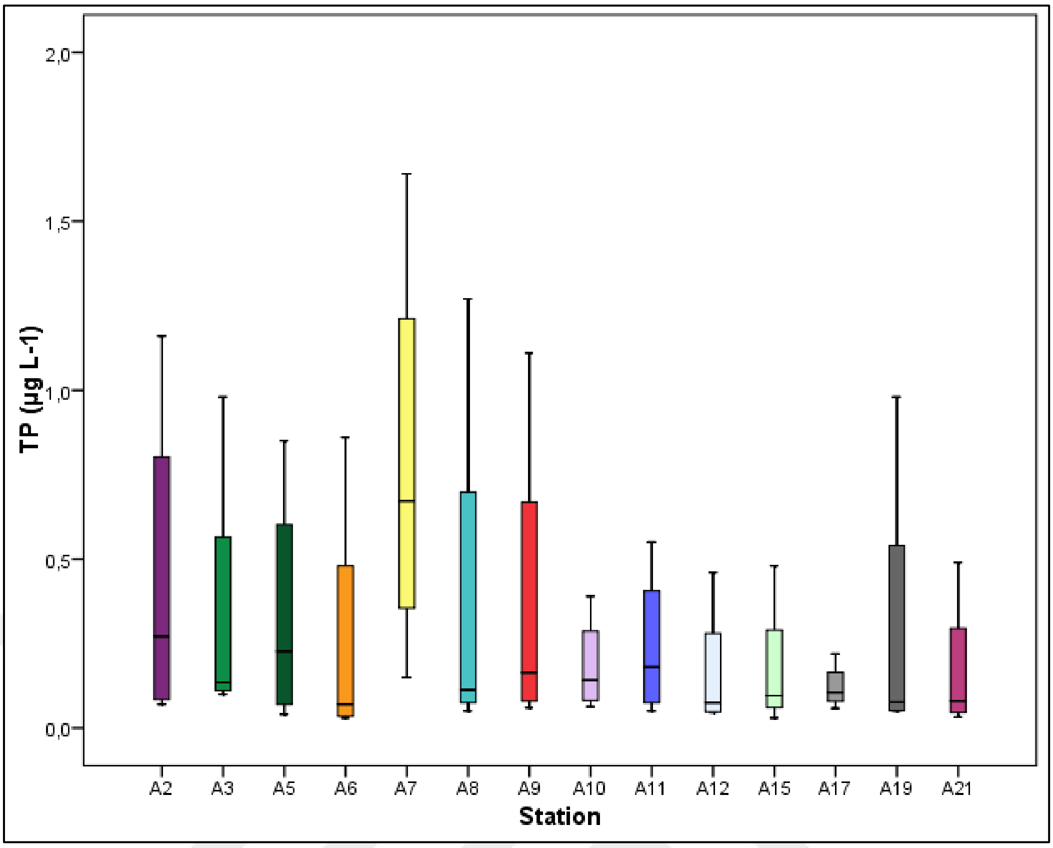
| | Alti m | Temp °C | Cond µS $cm^{-1}$ | pH | BOD mg $L^{-1}$ | TN µg $L^{-1}$ | N-$NH_4$ µg $L^{-1}$ | N-$NO_2$ µg $L^{-1}$ | N-$NO_3$ µg $L^{-1}$ | TP µg $L^{-1}$ | P-$PO_4$ µg $L^{-1}$ | Salinity ppt | $CaCO_3$ mg $L^{-1}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A2 | 433 | 18.1 | 179.4 | 8.3 | 14.5 | 1037.3 | 123.3 | 10.7 | 226.7 | 443.3 | 240.0 | 0.10 | 10.0 |
| A3 | 15 | 20.1 | 535.5 | 8.7 | 8.93 | 724.7 | 128.3 | 8.25 | 262.5 | 337.8 | 179.5 | 0.27 | 30.0 |
| A4 | 36 | 20.7 | 318 | 8.7 | 5.30 | 194.4 | 100.0 | 2.0 | 100.0 | 50.0 | 10.0 | 0.17 | 10.0 |
| A5 | 18 | 18.4 | 495.0 | 8.4 | 15.8 | 990.0 | 193.0 | 31.3 | 390.0 | 336.0 | 175.5 | 0.26 | 25.0 |
| A6 | 31 | 18.0 | 477.3 | 8.4 | 12.3 | 936.0 | 226.8 | 9.15 | 292.5 | 357.5 | 183.3 | 0.26 | 20.0 |
| A7 | 603 | 19.7 | 627.81 | 8.7 | 7.93 | 1786.3 | 117.5 | 34.5 | 1307.5 | 386.5 | 192.8 | 0.34 | 27.5 |
| A8 | 821 | 16.1 | 773.3 | 8.3 | 8.33 | 4029.7 | 1220.0 | 223.3 | 1503.3 | 783.3 | 341.7 | 0.43 | 25.0 |
| A9 | 710 | 19.4 | 776.5 | 8.6 | 5.65 | 1722.3 | 125.0 | 27.8 | 1030.0 | 374.3 | 214.0 | 0.42 | 35.0 |
| A10 | 264 | 14.5 | 331.7 | 8.1 | 5.07 | 574.2 | 126.7 | 6.60 | 306.7 | 184.3 | 137.3 | 0.18 | 20.0 |
| A11 | 200 | 16.0 | 330.0 | 8.5 | 11.7 | 940.5 | 438.0 | 81.5 | 680.0 | 240.5 | 163.8 | 0.16 | 17.5 |
| A13 | 1060 | 17.8 | 301 | 8.5 | 5.10 | 755.0 | 100.0 | 12.1 | 370.0 | 64.0 | 10.5 | 0.17 | 15.0 |
| A14 | 1043 | 14.6 | 670 | 7.4 | 5.20 | 1089.0 | 100.0 | 4.9 | 140.0 | 90.08 | 23.0 | 0.40 | 20.0 |
| A12 | 151 | 23.8 | 352.0 | 8.7 | 4.00 | 615.8 | 115.0 | 4.78 | 182.5 | 164.0 | 111.0 | 0.18 | 15.0 |
| A15 | 936 | 17.8 | 623.3 | 8.7 | 10.8 | 2208.8 | 195.0 | 33.0 | 1340.0 | 175.3 | 106.3 | 0.34 | 32.5 |
| A16 | 135 | 18.7 | 484.3 | 8.4 | 7.67 | 486.4 | 130.0 | 2.83 | 260.0 | 596.3 | 110.0 | 0.24 | 27.5 |
| A17 | 341 | 17.0 | 281.5 | 8.5 | 5.00 | 930.9 | 125.0 | 20.3 | 632.5 | 122.0 | 105.0 | 0.15 | 12.5 |
| A18 | 64 | 19.3 | 344.5 | 8.2 | 4.00 | 479.8 | 100.0 | 3.45 | 165.0 | 38.5 | 10.0 | 0.17 | 17.5 |
| A19 | 98 | 15.6 | 319.8 | 8.2 | 5.50 | 763.2 | 112.5 | 4.75 | 480.0 | 295.8 | 183.8 | 0.17 | 25.0 |
| A20 | 44 | 20.7 | 380.0 | 8.1 | 7.95 | 254.8 | 100.0 | 3.00 | 100.0 | 30.0 | 10.0 | 0.20 | 15.0 |
| A21 | 85 | 22.8 | 439.0 | 8.7 | 8.42 | 1265.0 | 123.3 | 23.8 | 917.5 | 170.5 | 117.5 | 0.22 | 25.0 |
| Bak4 | 516 | 16.8 | 234.0 | 8.4 | 9.50 | 149.5 | 100.0 | 4.00 | 100.0 | 50.0 | 10.0 | 0.13 | 15.0 |
| Bak9 | 86 | 16.4 | 312.0 | 8.3 | 10.2 | 208.9 | 100.0 | 3.00 | 100.0 | 40.0 | 10.0 | 0.18 | 10.0 |
| Bak12 | 144 | 14.2 | 563.0 | 8.4 | 4.00 | 285.0 | 100.0 | 2.00 | 100.0 | 40.0 | 10.0 | 0.35 | 30.0 |
| Bak14 | 375 | 18.2 | 271.9 | 8.6 | 6.5 | 609.9 | 323.0 | 21.0 | 150.0 | 54.5 | 21.5 | 0.15 | 17.5 |
| R1 | 615 | 20.5 | 504.0 | 8.8 | 4.41 | 231.7 | 100.0 | 3.05 | 130.0 | 65.0 | 10.0 | 0.27 | 27.5 |

**Table 4.3** Pearson's correlation test result among the environmental variables. Abbreviations of physico-chemical variables are given in the list of symbols/abbreviations

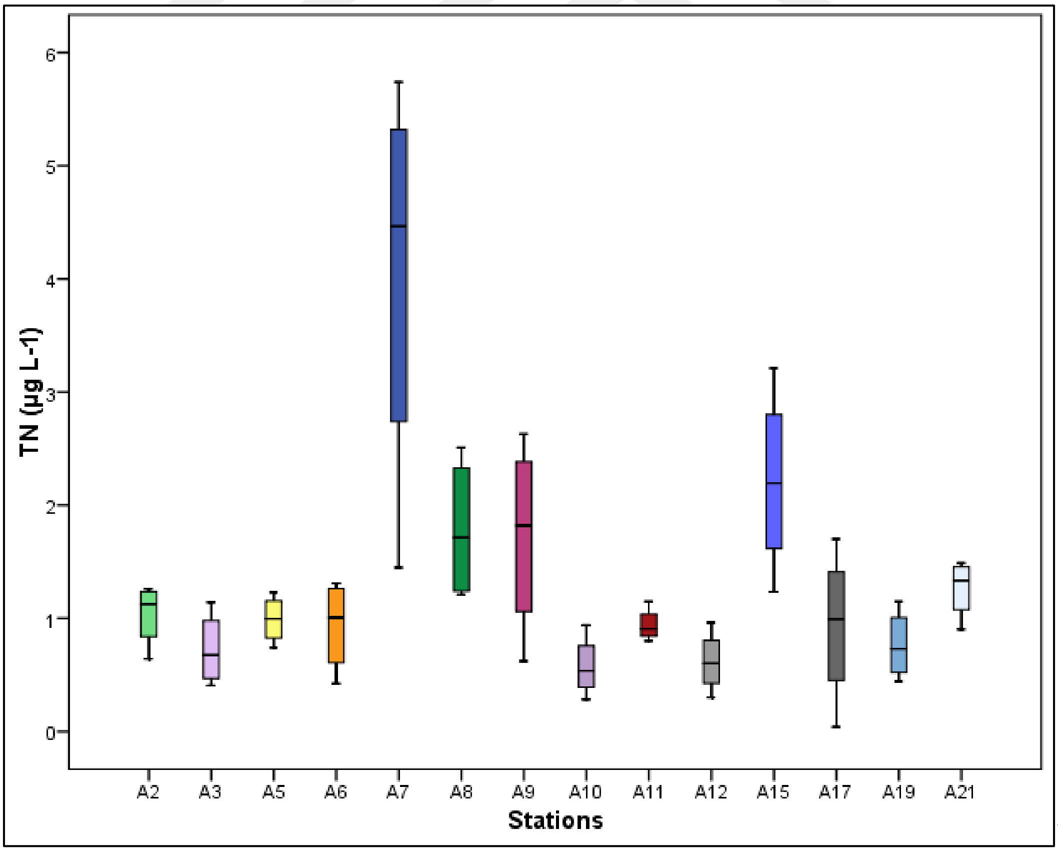
| | Altitude | pH | Temperature | Conductivity | $BOD_5$ | TN | $N\text{-}NO_2$ | $N\text{-}NO_3$ | TP | $P\text{-}PO_4$ |
|---|---|---|---|---|---|---|---|---|---|---|
| Altitude | | | | | | | | | | |
| pH | -0,081 | | | | | | | | | |
| Temperature | -0,104 | 0,432$^{**}$ | | | | | | | | |
| Conductivity | 0,244 | 0,133 | 0,488$^{**}$ | | | | | | | |
| DO | -0,149 | 0,321$^{**}$ | -0,303$^{*}$ | -0,360$^{**}$ | | | | | | |
| TSS | 0,220 | -0,079 | 0,057 | 0,286$^{*}$ | | | | | | |
| $BOD_5$ | -0,163 | 0,174 | 0,243 | 0,150 | | | | | | |
| COD | -0,145 | 0,158 | 0,244 | 0,111 | 0,961$^{**}$ | | | | | |
| TOC | -0,132 | 0,262$^{*}$ | 0,281$^{*}$ | 0,006 | 0,591$^{**}$ | | | | | |
| TN | 0,427$^{**}$ | 0,050 | 0,074 | 0,574$^{**}$ | 0,059 | | | | | |
| $N\text{-}NH_4$ | 0,055 | 0,011 | -0,030 | 0,214 | 0,011 | 0,463$^{**}$ | | | | |
| $N\text{-}NO_2$ | 0,284$^{*}$ | -0,011 | 0,098 | 0,493$^{**}$ | -0,038 | 0,687$^{**}$ | | | | |
| $N\text{-}NO_3$ | 0,397$^{**}$ | 0,185 | 0,008 | 0,468$^{**}$ | -0,057 | 0,814$^{**}$ | 0,455$^{**}$ | | | |
| TKN | 0,353$^{**}$ | -0,097 | 0,192 | 0,441$^{**}$ | 0,138 | 0,778$^{**}$ | 0,483$^{**}$ | 0,348$^{**}$ | | |
| TP | -0,139 | 0,163 | -0,139 | 0-,009 | 0,207 | 0,225 | 0,112 | 0,261$^{*}$ | | |
| $P\text{-}PO_4$ | -0,150 | 0,158 | -0,141 | -0,008 | 0,180 | 0,238 | 0,109 | 0,275$^{*}$ | 0,987$^{**}$ | |
| Salinity | 0,324$^{**}$ | 0,039 | 0,312$^{*}$ | 0,955$^{**}$ | 0,074 | 0,587$^{**}$ | 0,459$^{**}$ | 0,478$^{**}$ | 0,024 | 0,024 |
| Alkalinity | 0,086 | 0,177 | 0,256$^{*}$ | 0,573$^{**}$ | 0,101 | 0,212 | 0,085 | 0,320$^{**}$ | 0,045 | 0,032 |

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

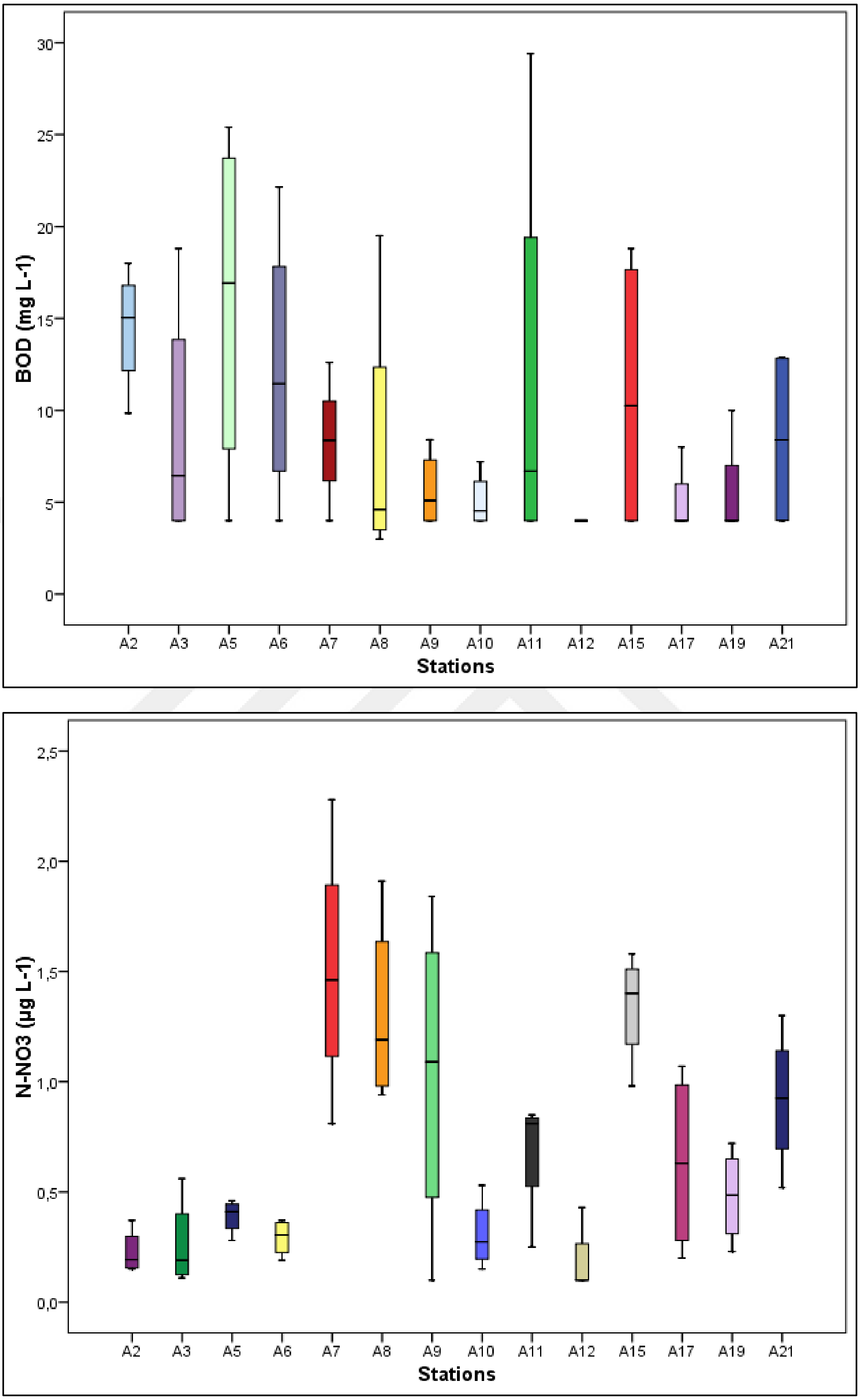


a)



b)

**Figure 4.7a** Box plot diagrams showing the distribution of a) TP and b) TN in the running water bodies




a)

b)

**Figure 4.7b** Box plot diagrams showing the distribution of a) BOD and N-$NO_3$ in the running water bodies

### 4.3.2 Diatom Species Richness and Assemblages

During the four seasons covering the study time, a maximum of 102 epilithic diatom taxa distributed in 22 genera including *Achnanthes*, *Amphora*, *Aulocoseria*, *Craticula*, *Cyclotella*, *Melosira*, *Hantzschia*, *Navicula* and others were identified (Appendix A). The most dominant genera were *Navicula* and *Cymbella* followed by *Nitzschia*, *Gomphonema*, *Fragilaria*, and *Cocconeis*. The most common and abundant species found during the study were *F. capucina*, *Cymbella excisa*, *Gomphonema parvulum*, *Ulnaria ulna* and *Cocconeis placentula* (Table 4.4). *Fragilaria capucina* species was recorded in all sites, while some of the rarely observed species were *Amphora inariensis*, *Cocconeis disculus*, *Diploneis modica*, *Cymatopleura amphicephala*, *Epithemia adnata*, *Navicula expecta* and *Surirella minuta*. The species number per site varied from a maximum of 28 at Dalaman stream (A8) and Eşen stream (A21) in the Muğla province to a minimum of 20 at Dalaman stream (A7), Ak stream (A17), Eşen stream (A19) in the Antalya province, Koca stream (A20), Karabeyyurdu Creek (BAK 12) and Kocabük Creek (BAK 9) (Figure 4.8). A slight change was observed in the seasonal diatom composition. A total of 49 diatom taxa were recorded in spring 2015, while 38 taxa were identified in fall 2014 (Figure 4.9). the list of species recorded in the different station in each season is presented in Appendices B, C, D, and E. Some of the diatom species recorded during the present study are sown in Figure 4.10.

**Table 4.4** The most common and abundant species found during the study

| Species | Maximum (%) | Mean (%) | Number of site |
|---|---|---|---|
| *Fragilaria capucina* Desmazières | 28.28 | 7.4 | 25 |
| *Cymbella excisa* Kützing | 38.33 | 15.68 | 21 |
| *Gomphonema parvulum* Kützing | 60.00 | 13.81 | 21 |
| *Ulnaria ulna* (Nitzsch) Compère | 26.48 | 7.25 | 21 |
| *Cocconeis placentula* Ehrenberg | 80.00 | 15.47 | 20 |
| *Diatoma vulgaris* Bory | 9.27 | 3.48 | 17 |
| *Cyclotella ocellata* Pantocsek | 12.76 | 3.96 | 15 |
| *Clevamphora ovalis* (Kützing) Mereschkowsky | 3.61 | 2.16 | 13 |
| *Gomphonema truncatum* Ehrenberg | 30.61 | 8.22 | 10 |
| *Navicula oppugnata* Hustedt | 7.07 | 2.61 | 10 |
| *Navicula laterostrata* Hustedt | 7.70 | 2.46 | 10 |
| *Fragilaria dilatata* (Brébisson) Lange-Bertalot | 8.96 | 3.37 | 9 |
| *Cymbella minuta* Hilse in Rabenhorst | 30.03 | 5.73 | 8 |
| *Aulacoseira granulata* (Ehrenberg) Simonsen | 15.76 | 4.83 | 8 |

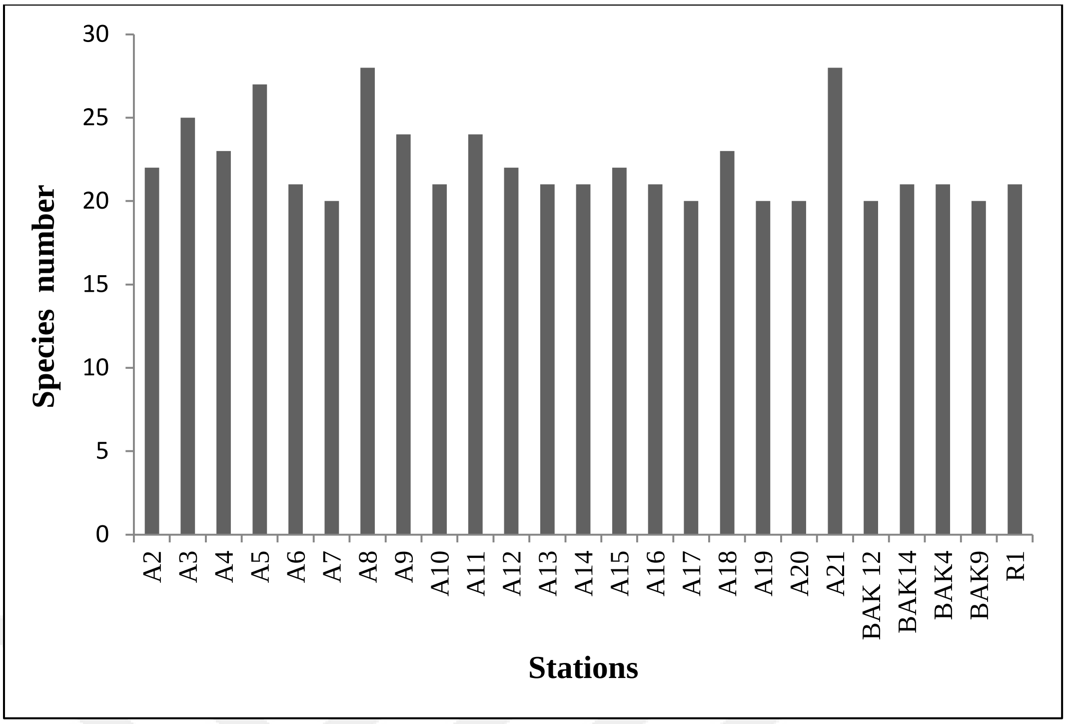



**Figure 4.8** Species number by site during the study. For station codes, see table 4.1

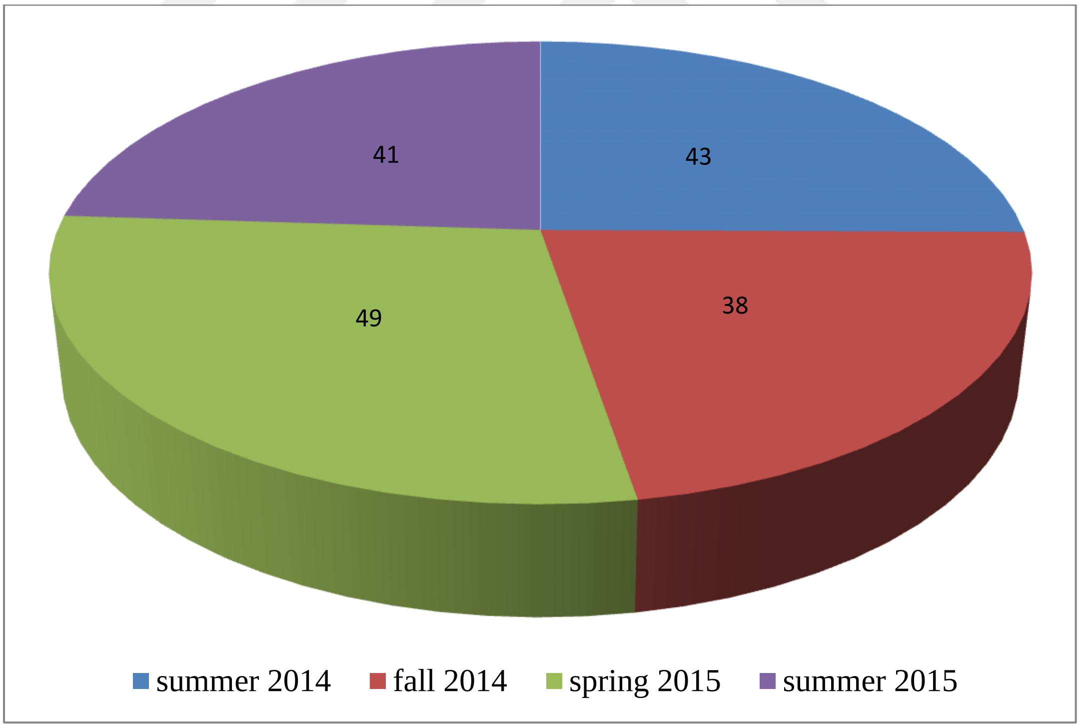



**Figure 4.9** Epilithic diatom species number per season in the running waters

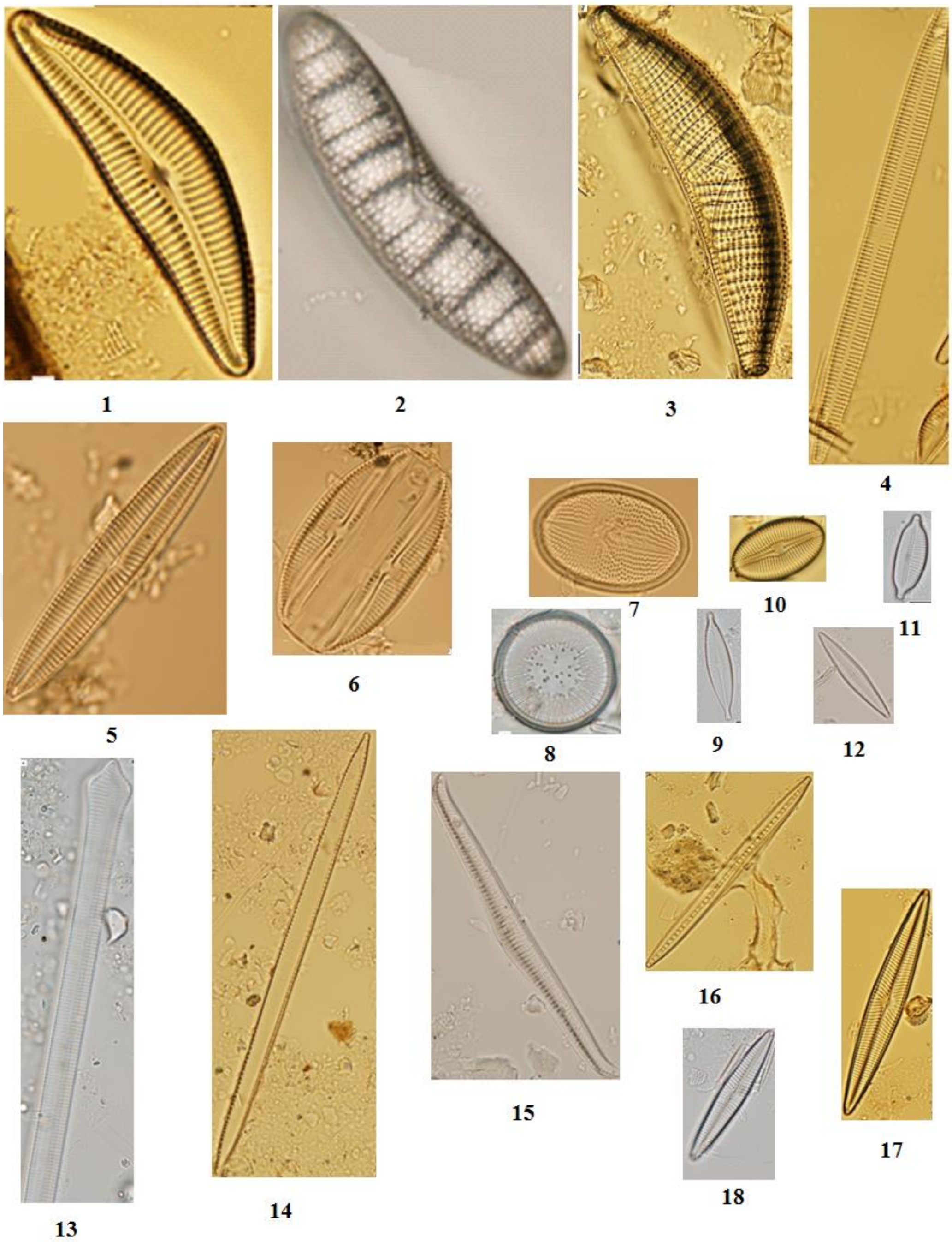


**Figure 4.10** 1) *Cymbella excisa*; 2) *Epithemia adnata*, 3) E. *turgida*; 4) *Ulnaria ulna*; 5) *Navicula tripunctata*, 6) *Clevamphora ovalis*, 7) *Cocconeis placentula*, 8) *Cyclotella meneghiniana*; 9) *Navicula cryptocephala*; 10) *Diploneis modica*; 11) *Cymbopleura amphicephala*; 12) *Gomphonema parvulum*; 13) *Ulnaria capitata*; 14) *Nitzschia sigmoidea*; 15) *Rhopalodia gibba*; 16) *Nitzschia dissipata*; 17) *Navicula cryptotenella*; 18) *N. radiosa*

### 4.3.3 Species environment relationships

The result of the Canonical Correspondence Analysis (CCA) using Monte Carlo permutation test for epilithic diatom species-environment variables relationship showed that the distribution of diatom composition was governed by physicochemical variables and the first axes gave the species-environment correlations at 89.4% and Cumulative percentage variance of species data at 9.4 % (Table 4.5). The most structuring factors were temperature, Altitude conductivity, $CaCO_3$, TP, N-$NO_3$, and P-$PO_4$.

**Table 4.5** Summary of canonical correspondence analysis using Monte Carlo permutation test for epilithic diatom species-environment variables relationship

| Axes | λ1 | λ2 | λ3 | λ4 | T. inertia |
|---|---|---|---|---|---|
| Eigen values | 0.507 | 0.355 | 0.333 | 0.259 | 9.155 |
| Species-environment correlations | 0.906 | 0.894 | 0.865 | 0.823 | |
| Cumulative percentage variance | | | | | |
| of species data | 5.5 | 9.4 | 13.0 | 15.9 | |
| of species-environment relation | 24.6 | 41.8 | 58.0 | 70.5 | |
| Sum of all Eigen values | | | | | 9.155 |
| Sum of all canonical Eigen values | | | | | 2.060 |
| Test of significance of first canonical axis : Eigen value = 0.507 | | | | | |
| | | F-ratio = 3.222 | | p-value = 0.0240 | |

The ordination of CCA indicated that *Nitzschia umbonata*, *N. angustata*, *N. dissipata*, *Surirella angusta*, *Surirella brebissonii*, *Diatoma moniliformis*, and *Cyclotella meneghiniana* were assigned with high altitude and high content of N-$NO_3$ in Dalaman stream (A8 and A9) and Ak stream, while *Gomphonema minutum* and *C. placentula* preferred low concentration in Ak stream. *N. lanceolata*, *G. attenuatum*, *S. minuta* were correlated with high water conductivity and P-$PO_4$ in Seki stream, Boğluca stream and Eşen stream (A19), contrary to *D. vulgaris* and *Epithemia frickei* which preferred low P-$PO_4$ in Dalaman stream (A5), when *C. solea*, *Cymbella hantzschiana*, and *Cymbella excisa* were associated with low conductivity. *Cymbella minuta*, *N. capitatoradiata*, *Achnanthes impexa*, *Cyclotella iris*, *Navicula bryophila*, *Cymbella cistula* and *Navicula tuscula* were found at low temperature and low alkalinity ($CaCO_3$) in Eşen stream (A19) and Dalaman stream (A5) (Figure 4.11).

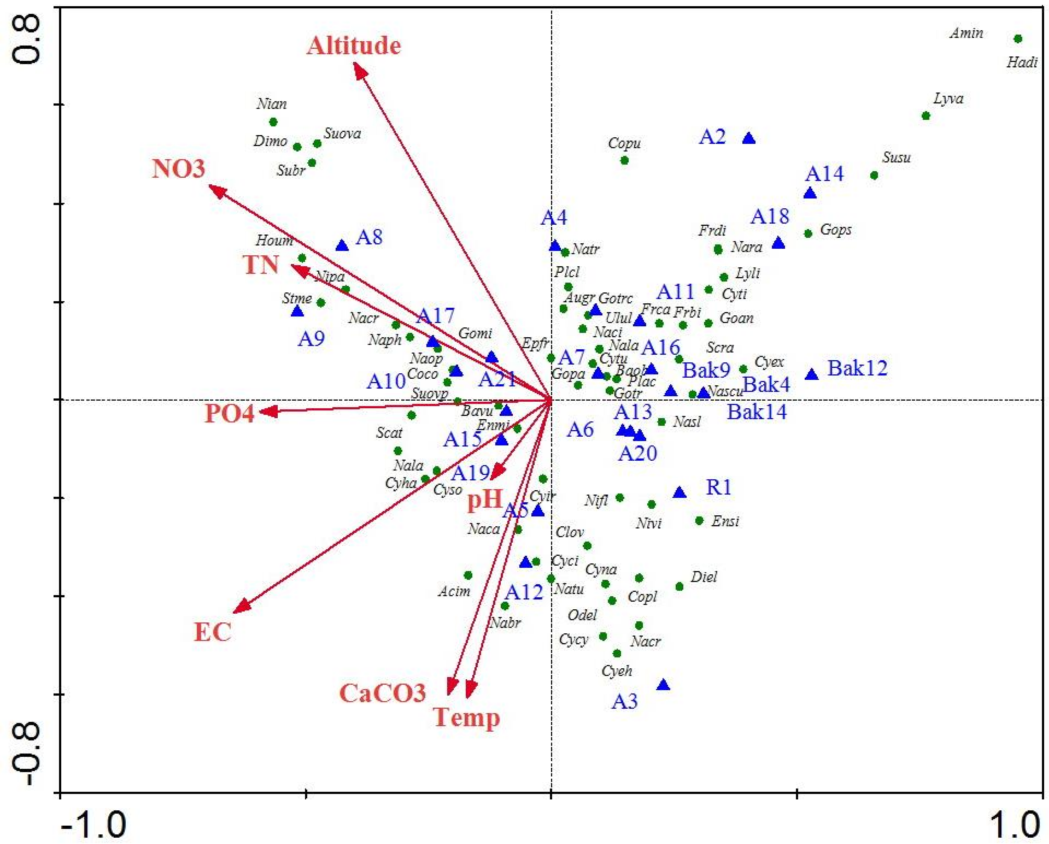



**Figure 4.11** Canonical correspondence analysis plot of species-environmental relationships in the sampling stations (up triangular). Species codes see Appendix A

In addition to the canonical correspondence analysis, diatom species-environment relationships were evaluated using weighted average (WA) regression. The results of WA regression are presented in Table 4.6. These results indicated that most of the diatom species recorded during the present were associated with alkaline water.

In related to nutrients, *S. brebissonii*, *N. umbonata* (Ehrenberg) Lange-Bertalot, *Nitzschia dissipata* (Kützing) Grunow, *Navicula oppugnata* Hustedt, *N. cryptocephala* Kützing, *D. moniliformis* were associated with high nutrient concentrations (TP and TN), while *C. disculus*, *C. excisa*, *Encyonema silesiacum* (Bleisch) D.G.Mann, *N. Radiosa*, and *N. slesvicensis* had relatively low TP and TN values. *N. lanceolata*, *G. Attenuatum*, and *S. minuta* were associated with the high P-$PO_4$ value according to the weighted average result (Table 4.6), when *D. vulgaris* and *E. frickei* were shown with low concentrations. On the other hand, *N. cryptocephala*, *N. phylepta*, *N. umbonata*, *C. meneghiniana* and *N. dissipata* preferred high N-$NO_3$ content.

With regard to water temperature, *A. impexa*, *Cymbopleura naviculiformis*, *N. capitatoradiata*, *N. bryophila*, *N. cryptotenella* preferred warm water in contrast to *C. disculus*, *Gomphonema pseudoaugur*, *S. angusta*, *S. brebissonii* and *Lysigonium lineatum* were related to low temperature.

In contrast to *Nitzschia flexa*, *N. cryptotenella*, *N. bryophila*, *Gomphonema angustum*, *Cymbella simonseni*, *C. cymbiformis*, *C. naviculiformis* which were at low altitude, species such as *G. pseudoaugur*, *N. umbonata*, *S. minuta* were located at high altitude. *Cyclotella meneghiniana*, *G. attenuatum*, *N. dissipata*, *N. umbonata* and *S. minuta* were associated with high conductivity, while *Surirella subsalsa*, *M varians*, *G. pseudoaugur*, *Gomphonema clavatum*, and *C. ocellata* preferred low conductivity.

The trophic preferences of diatom species established based on TP classes as: oligotrophic (<10 µg/l), mesotrophic (10-30 µg/1), eutrophic (30-100 µg/l), polytrophic (>100 µg/l) were determined based on the mean abundance of each species in each trophic class. The result indicated that species such as *Clevamphora ovalis*, *Cocconeis placentula*, *D. vulgaris* and *Ulnaria ulna* indicated a preferential occurrence polytrophic conditions, while species such as *Fragilaria capucina*, *Gomphonema angustum* and *G. truncatum* were distributed in eutrophic and polytrophic conditions.

**Table 4.6** Weighted average regression in sampling stations, $u_k$ and $t_k$ indicated optima and tolerance, respectively. For species code see Appendix A

| | | Temperature | | Altitude | | Conductivity | | TP | | P-PO$_4$ | | TN | | N-NO$_3$ | | CaCO$_3$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | °C | | m | | µS cm$^{-1}$ | | µg L$^{-1}$ | | µg L$^{-1}$ | | µg L$^{-1}$ | | µg L$^{-1}$ | | mg L$^{-1}$ | |
| Code | N2 | uk | ut | uk | ut | uk | ut | uk | ut | uk | ut | uk | ut | uk | ut | uk | ut |
| Acim | 1.12 | 26.06 | 0.71 | 152 | 56 | 435.1 | 112.0 | 253.9 | 678.8 | 123.0 | 289.9 | 598.9 | 615.2 | 149.4 | 622.3 | 15.84 | 10.61 |
| Amov | 4.41 | 22.78 | 3.05 | 106 | 257 | 715.4 | 244.0 | 224.7 | 129.5 | 94.7 | 58.8 | 1227.8 | 1073.6 | 334.9 | 410.7 | 24.20 | 6.12 |
| Augr | 8.74 | 16.50 | 3.99 | 502 | 424 | 410.8 | 269.5 | 374.8 | 380.7 | 172.7 | 192.5 | 1098.3 | 891.3 | 511.2 | 415.3 | 21.48 | 8.23 |
| Codi | 1.16 | 14.50 | 2.90 | 140 | 35 | 546.7 | 157.0 | 41.5 | 14.1 | 10.0 | 120.0 | 355.6 | 680.2 | 156.5 | 544.5 | 29.63 | 3.54 |
| Copl | 8.28 | 20.53 | 4.37 | 435 | 301 | 688.1 | 386.9 | 220.3 | 160.1 | 100.8 | 72.0 | 1537.7 | 1039.2 | 972.0 | 683.6 | 22.51 | 7.77 |
| Coplo | 1.53 | 23.43 | 5.16 | 164 | 605 | 513.3 | 127.9 | 114.9 | 48.0 | 22.7 | 22.0 | 566.0 | 272.4 | 148.4 | 73.3 | 27.33 | 9.63 |
| Cyir | 4.56 | 19.65 | 5.39 | 128 | 236 | 557.6 | 320.9 | 549.3 | 370.0 | 257.0 | 188.6 | 1113.0 | 1273.0 | 392.1 | 349.2 | 25.36 | 5.24 |
| Cyme | 1.26 | 23.84 | 1.05 | 669 | 372 | 1165.1 | 251.9 | 219.2 | 167.0 | 107.2 | 71.4 | 2642.5 | 1342.5 | 1714.7 | 875.3 | 20.72 | 5.47 |
| Cyoc | 9.70 | 16.49 | 3.71 | 278 | 334 | 294.0 | 118.0 | 251.8 | 363.0 | 102.8 | 167.7 | 701.2 | 330.2 | 274.4 | 165.8 | 17.03 | 5.52 |
| Cyso | 1.13 | 23.69 | 5.61 | 607 | 238 | 871.9 | 330.7 | 197.8 | 61.1 | 97.1 | 41.6 | 2112.8 | 671.3 | 1332.0 | 492.9 | 39.51 | 9.05 |
| Cyaf | 9.87 | 21.32 | 4.94 | 197 | 320 | 427.0 | 216.9 | 148.7 | 103.0 | 80.5 | 43.3 | 403.4 | 353.6 | 128.7 | 107.0 | 23.78 | 6.53 |
| Cyci | 2.52 | 23.72 | 1.53 | 348 | 473 | 708.3 | 176.0 | 185.8 | 83.1 | 70.0 | 55.8 | 868.9 | 838.0 | 379.6 | 507.9 | 28.32 | 5.41 |
| Cycy | 1.16 | 23.16 | 8.13 | 22 | 113 | 775.6 | 351.4 | 258.3 | 359.9 | 109.9 | 152.7 | 1105.6 | 332.3 | 124.6 | 141.4 | 24.63 | 3.54 |
| Cyex | 3.73 | 21.92 | 4.94 | 305 | 347 | 821.8 | 307.7 | 217.3 | 22.3 | 100.8 | 1.1 | 1440.5 | 982.8 | 780.4 | 847.7 | 24.42 | 6.73 |
| Cymi | 2.81 | 16.05 | 4.79 | 130 | 119 | 468.5 | 181.1 | 191.8 | 78.7 | 90.7 | 39.4 | 813.6 | 340.3 | 465.8 | 290.8 | 24.11 | 4.27 |
| Cyna | 2.23 | 27.12 | 6.03 | 83 | 52 | 388.7 | 51.8 | 32.7 | 11.0 | 16.4 | 14.3 | 387.6 | 272.4 | 156.0 | 192.3 | 19.33 | 4.16 |
| Cysi | 1.93 | 24.68 | 0.48 | 45 | 189 | 543.1 | 35.4 | 173.5 | 119.0 | 69.6 | 48.3 | 621.9 | 356.9 | 290.0 | 177.2 | 26.73 | 3.42 |
| Cytu | 1.84 | 21.93 | 3.70 | 475 | 70 | 328.3 | 287.9 | 194.0 | 104.2 | 82.4 | 51.9 | 1142.9 | 816.4 | 275.4 | 552.6 | 14.82 | 13.01 |
| Deel | 1.61 | 22.29 | 5.07 | 99 | 271 | 659.1 | 464.5 | 185.9 | 106.3 | 75.8 | 59.8 | 1132.9 | 251.7 | 166.7 | 199.1 | 22.11 | 10.13 |
| Dimo | 1.27 | 13.76 | 3.32 | 542 | 334 | 485.0 | 106.1 | 1176.4 | 551.5 | 558.0 | 247.5 | 2387.6 | 721.2 | 1836.8 | 431.3 | 16.20 | 7.07 |
| Dite | 3.24 | 24.75 | 5.16 | 142 | 316 | 470.9 | 111.7 | 123.2 | 116.1 | 29.8 | 31.1 | 800.5 | 972.9 | 318.3 | 446.0 | 25.36 | 7.04 |
| Divu | 6.30 | 17.32 | 5.09 | 256 | 245 | 529.9 | 265.6 | 231.4 | 190.9 | 107.8 | 87.5 | 984.5 | 936.8 | 519.8 | 526.4 | 21.66 | 3.86 |
| Frbi | 1.48 | 15.95 | 4.84 | 121 | 352 | 421.5 | 435.5 | 101.1 | 244.2 | 34.4 | 117.1 | 1032.4 | 1970.1 | 349.3 | 584.3 | 16.87 | 7.54 |
| Frca | 15.17 | 17.16 | 3.97 | 282 | 299 | 338.6 | 126.3 | 246.3 | 339.0 | 104.6 | 159.2 | 872.8 | 484.2 | 408.8 | 294.7 | 19.18 | 6.63 |
| Frdi | 3.37 | 16.36 | 4.12 | 228 | 317 | 310.6 | 148.0 | 203.3 | 410.0 | 82.6 | 194.8 | 760.4 | 452.9 | 270.9 | 191.6 | 15.84 | 4.45 |

**Table 4.6** Continue

| | | Temperature | | Altitude | | Conductivity | | TP | | $P\text{-}PO_4$ | | TN | | $N\text{-}NO_3$ | | $CaCO_3$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | °C | | m | | µS $cm^{-1}$ | | µg $L^{-1}$ | | µg $L^{-1}$ | | µg $L^{-1}$ | | µg $L^{-1}$ | | mg $L^{-1}$ | |
| Code | N2 | uk | ut | uk | ut | uk | ut | uk | ut | uk | ut | uk | ut | uk | ut | uk | ut |
| Frul | 18.99 | 18.12 | 4.65 | 311 | 329 | 504.9 | 314.5 | 277.8 | 340.1 | 116.8 | 156.0 | 1182.8 | 959.2 | 585.5 | 557.8 | 21.28 | 6.96 |
| Goan | 2.69 | 14.80 | 1.32 | 51 | 42 | 349.9 | 29.6 | 88.0 | 165.4 | 44.2 | 86.2 | 923.6 | 372.9 | 410.8 | 383.3 | 19.36 | 6.26 |
| Gocl | 3.54 | 14.65 | 2.23 | 117 | 91 | 297.4 | 59.5 | 658.8 | 199.9 | 266.2 | 72.2 | 868.9 | 69.5 | 537.8 | 324.3 | 20.11 | 7.54 |
| Gomi | 2.40 | 14.60 | 4.41 | 367 | 283 | 504.6 | 247.4 | 402.4 | 528.8 | 193.8 | 248.1 | 1110.1 | 1137.8 | 672.6 | 956.5 | 21.09 | 7.57 |
| Gopa | 13.07 | 18.40 | 4.26 | 253 | 267 | 459.1 | 237.0 | 279.5 | 346.7 | 124.5 | 162.7 | 876.8 | 880.6 | 390.5 | 433.7 | 19.87 | 6.41 |
| Gops | 1.46 | 14.13 | 9.05 | 1004 | 343 | 242.1 | 272.2 | 75.9 | 21.2 | 10.0 | 120.0 | 567.7 | 350.9 | 236.4 | 120.2 | 21.97 | 7.07 |
| Gotr | 4.95 | 18.84 | 3.39 | 195 | 266 | 415.7 | 225.3 | 439.1 | 510.1 | 202.7 | 235.0 | 760.6 | 519.6 | 346.5 | 308.2 | 20.88 | 5.51 |
| Gyat | 1.98 | 24.00 | 3.83 | 396 | 485 | 986.9 | 323.1 | 217.8 | 27.6 | 100.9 | 1.4 | 1846.8 | 1216.2 | 1129.6 | 1103.1 | 22.28 | 3.54 |
| Lyli | 2.83 | 14.52 | 1.38 | 564 | 614 | 475.2 | 227.4 | 141.1 | 278.5 | 45.1 | 114.1 | 872.2 | 291.2 | 238.5 | 203.2 | 19.01 | 5.67 |
| Lyva | 1.92 | 15.77 | 2.58 | 345 | 364 | 183.3 | 173.9 | 61.0 | 20.8 | 17.1 | 14.4 | 1209.0 | 200.5 | 364.4 | 33.1 | 11.96 | 4.27 |
| Nabr | 2.00 | 25.47 | 2.12 | 42 | 47 | 702.3 | 158.4 | 681.0 | 664.0 | 297.9 | 294.1 | 1277.2 | 198.0 | 536.2 | 615.2 | 27.45 | 3.54 |
| Naca | 4.04 | 26.79 | 7.57 | 308 | 277 | 461.0 | 216.5 | 100.3 | 90.8 | 46.7 | 49.0 | 757.0 | 836.7 | 391.9 | 553.3 | 21.12 | 12.08 |
| Naci | 2.15 | 18.21 | 2.03 | 149 | 256 | 320.4 | 24.8 | 592.4 | 672.9 | 269.8 | 315.8 | 644.6 | 897.7 | 323.2 | 405.4 | 16.40 | 7.12 |
| Nacl | 2.61 | 14.97 | 0.30 | 139 | 82 | 294.5 | 35.7 | 262.0 | 314.5 | 99.0 | 132.1 | 792.4 | 158.4 | 566.8 | 367.9 | 15.00 | 6.76 |
| Nacr | 3.79 | 22.06 | 4.20 | 574 | 190 | 804.4 | 446.6 | 353.9 | 397.8 | 170.0 | 187.9 | 2159.0 | 637.7 | 1377.7 | 748.7 | 22.06 | 11.48 |
| Nacri | 2.09 | 24.65 | 0.90 | 81 | 261 | 554.5 | 86.2 | 183.4 | 223.0 | 47.9 | 99.0 | 754.3 | 507.6 | 283.9 | 377.5 | 29.39 | 2.98 |
| Nala | 7.72 | 17.94 | 4.73 | 452 | 304 | 336.2 | 147.2 | 270.1 | 310.0 | 107.4 | 146.2 | 658.3 | 549.4 | 394.6 | 313.9 | 21.06 | 6.90 |
| Naop | 6.61 | 20.83 | 4.34 | 400 | 276 | 623.6 | 370.1 | 323.5 | 337.9 | 151.4 | 160.7 | 1573.9 | 784.4 | 946.9 | 762.5 | 20.05 | 7.44 |
| Naph | 2.82 | 20.36 | 4.06 | 384 | 355 | 656.6 | 471.0 | 372.3 | 179.3 | 180.2 | 94.7 | 1870.6 | 700.5 | 1426.4 | 362.3 | 25.02 | 8.53 |
| Nara | 2.12 | 22.37 | 4.42 | 153 | 168 | 342.3 | 40.5 | 68.1 | 63.9 | 25.2 | 22.5 | 369.1 | 205.2 | 128.9 | 77.9 | 20.00 | 6.76 |
| Nasl | 2.04 | 19.29 | 5.26 | 176 | 130 | 318.4 | 50.7 | 53.0 | 51.5 | 16.1 | 45.2 | 306.5 | 108.3 | 103.3 | 76.7 | 20.00 | 6.76 |
| Natr | 2.83 | 18.32 | 3.34 | 381 | 298 | 476.6 | 470.8 | 239.0 | 199.0 | 101.9 | 96.3 | 2179.7 | 1570.8 | 1019.5 | 276.7 | 17.86 | 11.45 |
| Nidi | 1.64 | 22.43 | 4.45 | 563 | 406 | 986.5 | 585.9 | 247.2 | 197.9 | 124.1 | 103.4 | 2282.8 | 1061.1 | 1644.1 | 675.2 | 20.43 | 5.04 |
| Nifl | 1.31 | 15.27 | 5.16 | 72 | 470 | 378.0 | 6.4 | 40.6 | 14.2 | 34.3 | 19.5 | 988.5 | 499.5 | 396.9 | 189.2 | 23.67 | 6.95 |
| Nire | 2.93 | 19.32 | 4.68 | 240 | 246 | 317.2 | 58.7 | 135.8 | 113.2 | 60.5 | 47.1 | 1216.0 | 95.6 | 399.3 | 344.6 | 11.00 | 6.76 |
| Nium | 1.69 | 21.80 | 6.56 | 704 | 122 | 1045.8 | 427.5 | 397.3 | 653.6 | 191.5 | 306.3 | 2568.1 | 313.2 | 1812.1 | 253.2 | 20.21 | 7.62 |
| Suan | 1.22 | 13.72 | 3.61 | 547 | 357 | 486.5 | 114.6 | 1146.5 | 855.6 | 539.8 | 417.2 | 2381.1 | 893.1 | 1803.9 | 735.4 | 16.02 | 7.07 |

**Table 4.6** Continue

| | | Temperature | | Altitude | | Conductivity | | TP | | $P\text{-}PO_4$ | | TN | | $N\text{-}NO_3$ | | $CaCO_3$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | °C | | m | | µS $cm^{-1}$ | | µg $L^{-1}$ | | µg $L^{-1}$ | | µg $L^{-1}$ | | µg $L^{-1}$ | | mg $L^{-1}$ | |
| Code | N2 | uk | ut | uk | ut | uk | ut | uk | ut | uk | ut | uk | ut | uk | ut | uk | ut |
| Subr | 1.46 | 14.12 | 3.32 | 507 | 334 | 473.7 | 106.1 | 1117.6 | 551.5 | 531.6 | 247.5 | 2310.7 | 721.2 | 1790.8 | 431.3 | 16.95 | 7.07 |
| Sumi | 1.67 | 21.40 | 2.55 | 943 | 13 | 907.3 | 259.5 | 169.8 | 77.1 | 76.4 | 60.1 | 2069.6 | 817.4 | 1254.7 | 268.7 | 36.39 | 3.54 |
| Susu | 2.15 | 17.54 | 1.66 | 295 | 283 | 212.2 | 163.4 | 65.3 | 8.1 | 11.0 | 4.9 | 1207.8 | 140.4 | 575.9 | 338.5 | 16.66 | 10.06 |
| | RMSE | 2.86 | | 258.45 | | 168.19 | | 190 | | 87.76 | | 670 | | 290 | | 5.72 | |
| | $R^2$ | 0.66 | | 0.36 | | 0.48 | | 0.62 | | 0.63 | | 0.30 | | 0.60 | | 0,45 | |

### 4.4 Discussion

#### 4.4.1 Physicochemical Parameters

The assessment of water quality by using physical and chemical variables of ecosystems has a long history. Physicochemical parameters as well as the hydro-morphological characteristics such as Temperature (T), Conductivity, Dissolved oxygen (DO), Total Suspended solids (TSS), Biological oxygen demand ($BOD_5$), Chemical oxygen demand (COD), Total organic carbon (TOC), Ammonium nitrogen ($N$-$NH_4$), Nitrate nitrogen ($N$-$NO_3$), Nitrite nitrogen ($N$-$NO_2$), Total N-nitrogen, orthophosphorus ($P$-$PO_4$), Salinity, Alkalinity, Transparency, Total phosphorus (TP), Total nitrogen (TN) and Chlorophyll-A concentration were used to support our biological elements. The changes in physical characteristics and chemical elements of water provide valuable information on the quality of the water, the source(s) of the variations and their impacts on the functions and biodiversity of the reservoir (Mustapha, 2008). Phosphorus is thought to be the most important nutrient responsible for eutrophication in these rivers (Litke, 1999; Potapova et al., 2004). Nutrient concentrations were relatively higher in Dalaman Stream (A8) than those of the other watercourses during the study period. In fact, Dalaman Stream (A8) was under pressures of human activities from Acıpayam District, several villages, and farming process. The water quality of this station could be degraded by the excessive addition of inorganic and organic matters generated municipal wastewater input, agricultural activities, livestock and nutrients enriched runoff. High population and the variety of industrial and agricultural activities could expose most watersheds near to big cyties to adverse and increasing environmental effects, principally to the pollutants generated by domestic and industrial sewages (Mancini and Arcà, 2000; Salomoni et al., 2006; Toudjani et al., 2017). In accordance with our results, Bellinger et al. (2006) reported that the combination of agricultural practices, known as major sources of inorganic and organic matters, livestock, organic pollutants coming from anthropogenics waste, washing of clothes, dishes and people with soaps and detergents has generated an important nutrient enrichment in the streams draining deforested watersheds in Tanzania. Phosphorus and nitrogen are the primary nutrients that in excessive amounts pollute our lakes, streams, and wetlands (MPCA, 2008). Phosphorus and nitrogen are key elements to life on Earth. Phosphorus is the second most abundant element in human bodies, found mostly in bones and teeth.

Phosphorus also is found in foods such as soft drinks and baking soda, fertilizers and cleaning products. Nitrogen makes up about 78 percent of the air is a major component of foods and fertilizers (OEPA, 2014).

### 4.4.2 Diatom richness and diversity

The diatoms taxa diversity and abundance are controlled by environmental parameters such as nutrients, temperature, light intensity, grazing pressure, substrate stability and discharge (Izagirre and Elosegi, 2005; Toman et al., 2014). A total of 102 taxa belonging to 22 genera were identified in the studied area (25 stations). The of species ranged between from 28 taxa to 20 taxa in the stations. The total species number in the present study is lower than those of a review study including the most common diatom taxa (129) from rivers, lakes, and reservoirs in Turkey (Solak et al., 2012b) and those of a limnologic study in Felent creek with 117 diatom taxa (Solak et al., 2012a). The commonly found species in the present study (e.g., *C. placentula*, *C. excisa*, *D. vulgaris*, *U. ulna*, *G. parvulum*, and *N. cryptocephala*) were listed in the previous studies in others running water bodies (Rott et al., 1999; Potapova and Charles, 2003; Dell'Uomo, 2004; Kelly et al., 2008; Della Bella et al., 2012; O'Driscoll et al., 2012; Solak et al., 2012a, b; Beltrami et al., 2012; Solak et al., 2012a; Çelekli and Öztürk, 2014; Delgado and Pardo, 2014; Kelly et al., 2014).

The species number per site found during this study was higher compared to some early literatures (e.g. Bellinger et al., 2006; O'Driscoll et al., 2012). This situation was confirmed by the highest nutrient concentrations especially orthophosphate (P-$PO_4$) and nitrate nitrogen (N-$NO_3$) found in our studied sites compared to those obtained in these previous studies. In contrary, our species number and species number per site were respectively lower than the result obtained by Tokatlı and Dayioğlu (2011) in Murat stream in which there was a gradual pollution and by Della Bella et al. (2012) in Italy. From that point, it can be seen that nutrients, especially nitrogen and phosphate play important role in algal species growing and richness in an aquatic system. Species richness is generally expected to be greater in not impacted ecosystems, but it has been reported that low stressors could be the source of increasing in diversity (Jüttner et al., 1996; Lowe and Pan, 1996; Jüttner et al., 2003) or may not show any changes despite high anthropogenic stressors (Jüttner et al., 1996; Bellinger et al., 2006). The increase of nutrient contents results in higher species number up to a median level, where high nutrient contents are shown as a limiting factor, which leads in decreased species number (Manyolov and Stevenson, 2006; Fidlerová and Hlúbiková, 2016). The differences in species diversity represent also the general higher heterogeneity of physicochemical, hydromorphological and geographical conditions in reservoirs having several purposes in comparison with much more homogeneous conditions in drinking water-supply reservoirs with lower levels of anthropogenic influences and the consequent pollution (Fidlerová and Hlúbiková, 2016). It has previously been reported that human activities could influence diatom assemblages and water quality state (e.g. Van Dam et al., 1994; Reynolds et al., 2002; Àcs et al., 2004; Bellinger et al., 2006; Hlúbiková et al., 2007; Padisák et al., 2009; Delgado and Pardo, 2014). Soininen (2007) reported that total phosphorus, nitrates, pH, conductivity, temperature, alkalinity, biological oxygen demand ($BOD_5$), calcium, chlorophyll a, altitude, and substrate type are major environmental factors for diatom distribution in streams. According to Beltrami et al. (2012), altitude and geology characteristics were the principle environmental variables influencing diatom assemblages in alpine streams. Biggs and Close (1989) indicated that stressors such as floods decrease the impact of grazing pressure because recolonization of macroinvertebrates take generally more time than the phytobenthic organisms growth while, Lange et al. (2011) demonstrated that light availability, nutrient contents, and grazing pressure characterize the stream diatom diversity. *Achnanthes*, *Amphora*, *Aulocoseria*, *Cocconeis*, *Craticula*, *Cyclotella*, *Cymbella*, *Cymatopleura*, *Melosira*, *Hantzschia*, *Gyrosigma*, *Gomphonema*, *Fragilaria*, *Eunotia*, *Epithemia*, *Diploneis*, *Diatoma*, *Denticula*, *Navicula*, *Surirella*, *Stauroneis*, and *Nitzschia* were recorded in our studied station. Most species of *Nitzschia*, *Gomphonema*, *Fragilaria*, *Navicula*, *Melosira* and *Surirella* genera belong to codon $T_B$ which inhabited highly lotic (streams and rivulets) environments (Reynolds et al. 2002; Padisák et al., 2009). In accordance with our finding, most the diatom genera found during our study were listed by Della Bella et al. (2012), in central Italy streams and in Murat stream (Turkey) by Tokatlı and Dayıoǵlu (2011) and in tropical streams (Tanzania) by Bellinger et al. (2006). *F. capucina*, *C. excisa*, *G. parvulum*, *U. ulna* and *C. placentula* were the most dominant species. These species were mostly found in sites with high to moderate ecological state and were early listed in others running water (Potapova and Charles, 2003; Tokatlı and Dayıoğlu, 2011; Della Bella et al., 2012; O'Driscoll et al., 2012). *Cymbella excisa* has been indicated as dominant taxa in I-II. water quality (less polluted) by Gómez and Licursi (2001). Furthermore, many species of the genus Cymbella are indicators of the oxygen-rich waters (Van Dam et al., 1994). According to Krammer and Lange-Bertalot (1991a), *U. ulna* has been adapted to several ecological states.

### 4.4.3 Structuring factors of diatom community composition

Relationships between diatoms and environmental parameters can be quantified to make diatoms suitable quantitative bioindicators of ecological states in ecosystems (Pan and Stevenson, 1996; Oliveira et al., 2001). Diatom species react quickly to environmental variations due to their short life-time, rapid dispersal and a large number of taxa with various tolerance range to physicochemical variables (Lotter et al., 1999). The species number and proportion of diatoms are determined by environmental variables such as nutrients, temperature, light intensity, grazing pressure, support stability and discharge (Izagirre and Elosegi, 2005). Phosphorus is thought to be the most important nutrient responsible for eutrophication in these rivers (Litke, 1999; Potapova et al., 2004).

In order to understand the interactions between the diatom species and environmental factors in the watercourses, direct gradient analysis technique, canonical correspondence analysis (CCA), was performed. The Monte Carlo permutation test result demonstrated that the distribution of diatom composition was influenced by physicochemical variables and the first axes on the CCA ordination gave the species-environment correlations at 89.4% and Cumulative percentage variance of species data at 9.4 %. Nutrients such as TP, TN, P-$PO_4$, N-$NO_2$, and N-$NO_3$ were the most explanatory factors. This confirmed our hypothesis (II) that environmental variables especially pollution parameters (nutrients, organic matter) are the most important structuring factors of phytoplankton composition and validated that diatoms and previously used to assess nutrient enrichment (e.g. Kelly et al., 1995; Rott et al., 1997; 1999; Coring, 1999; Dell'Uomo, 2004). Abonyi et al. (2012) indicated a relationship between benthic diatoms and nutrient which reflected human impacts along the River Loire (France). According to Strebel et al. (1989) and Almasri and Kaluarachchi (2004), the downstream increase of nutrient is a generally anthropogenic impact by agriculture and could be a useful indicator of eutrophication in large rivers (Turner et al., 2003). The result of CCA (Figure 4.10) supported by weighted average (WA) regression (Table 4.6) showed that *N. umbonata*, *C. meneghiniana*, *D. moniliformis*, *N. phylepta*, *N. cryptocephala* and *N. angustata* were associated with high concentrations of N-$NO_3$. *Cyclotella meneghiniana* was reported as pollution tolerant taxa by Venkatachalapathy and Karthikeyan (2013) and as taxa typical of polluted environments by Sladeček (1973), Kobayasi and Mayama (1989), Van Dam et al. (1994), Lobo et al. (1996, 2002) and Salomoni et al. (2006). Contrary species of the genus *Fragilaria*, especially *U. biceps*, *F. capucina*, and *F. incognita* were indicated with low nitrogen content especially TN, $NO_3$, and $NO_2$. Reynolds (2006) reported that *Fragilaria* did not have an unusually high demand for phosphorus or nitrogen. On the other hand, *N. lanceolata*, *S. minuta*, and *G. attenuatum* preferred high concentrations of TP and P-$PO_4$. According to Hlúbiková et al. (2007), a natural increase in nutrient concentration and organic compounds could lead to the appearance of pollution-tolerant species like *N. lanceolata*. *N. lanceolata* has been also indicated as tolerant to organic/eutrophic conditions (Van Dam et al., 1994; Delgado and Pardo, 2014). In accordance of our finding, *N. cryptocephala* has been previously noted to be nutrient tolerant taxa by Àcs et al. (2004) and tolerant to organic pollution and eutrophication by Salomoni et al. (2006). *N. angustata* and *N. umbonata* belong to codon D which habitat template is shallow nutrients enriched and low transparent watercourses including running waters (Reynolds et al., 2002; Padisák et al., 2009).

The trophic preferences of diatom species established based on TP classes. *Clevamphora ovalis*, *C. placentula*, *D. vulgaris* and *U. ulna* indicated a preferential occurrence polytrophic conditions, while species such as *F. capucina*, *G. angustum* and G. *truncatum* were distributed in eutrophic and polytrophic conditions. *U. ulna* has been reported to be highly pollution tolerant species (Round, 1991; Biggs and Kilroy, 2000; Potapova and Charles, 2003; Duong et al., 2006; Bere and Tundisi, 2011 ) and more tolerant to heavy organic pollution and eutrophication (Salomoni et al., 2006). *F. capucina* has been cited as an indicator of trophic state species (Wang et al., 2014) and low pollution tolerant species (Bere and Tundisi, 2011). In contrast to our findings, *C. excisa* was indicated as a low trophic indicator species (Wang et al., 2014), as a pollution sensitive diatom taxon (Delgado et al. 2012) and has been considered to be dominant in I-II. water quality (less polluted) (Gómez and Licursi, 2001).

# CHAPTER V

## BIOASSESSMENT OF RUNNING WATER BASED PHYTOBENTHOS (EPILITHIC DIATOMS)


## ABSTRACT

Water quality in aquatic ecosystems is an important issue because it maintains the ecological processes that support biodiversity. Diatoms in lotic ecosystems are an important group of phytobenthos and are good indicators of water quality especially in rivers and streams. This chapter aimed to evaluate 25 watercourses ecological status in the western Mediterranean basin of Turkey by the use of the trophic index Turkey (TIT) based on diatom combined to trophic index (TI) and eutrophication and pollution index diatom-based (EPI-D). Data were sampled during four seasons in the Western Mediterranean basin for biological and physicochemical analysis.

The Ecological status of the watercourses was evaluated following the ecological quality ratio based on TIT (EQR-TIT) and EIP-D. TIT values ranged between 1.53 and 2.8, while the highest and lowest EPI-D values were 1.01 and 1.88 respectively. With regard to ecological status, stations indicated poor, moderate, good or high according to the indices. A significant positive correlation between TIT, TI and EIP-D values and logTP proved that these diatom metric are a useful tool for the assessment of running water quality in a Western Meterranean basin approch.

## 5.1 Introduction

Water is a precious and essential natural resource for multiple uses (domestic, industrial and agricultural) (Sadat et al., 2011). Surface freshwaters are the most essential sources of water for human activities, but are unfortunately under several environmental disturbances and are being threatened as result of economical activities. Water quality in aquatic ecosystems is an important issue because it maintains the ecological processes that support biodiversity. Degradation of water quality in surface waters has increased worldwide because of the release of wastes resulting from urbanization, demographic change and industrial hazardous effluent into receiving waters (Schindler, 2006; Smol, 2008). Apart from that, climate change resulting from environmental disturbances causes a decrease in water quality and threatens the organization and functions of aquatic ecosystems. Water pollution, defined as physical, chemical, or biological degradation caused by human activity, disrupts living conditions and aquatic balances compromising thereby their multiple uses. However, the quality of surface water is influenced by both natural processes (soil erosion, precipitation, and evaporation) and human activity (agriculture, urban, and industrial wastewater) (Strobl & Robillard, 2008).

To deal with these problems and to provide solutions, the water framework directive (WFD) required member states of the Union to regularly assess running water quality by the use of so-called biological quality elements, among these are phytobenthos (especially benthic diatoms) (Directive, 2000; EC, 2009, Rott and Schneider, 2014). For each of these biological quality elements, the taxonomic composition and proportion of the species should be determined, and five categories of ecological status (high, good, moderate, poor and bad) should be established following normative definitions in the Directive (Directive, 2000; Schaumburg et al., 2004). The environmental aims of the WFD insist all surface watercourses to be ‘‘good ecological status’’ (defined as having a biota consistent with only slight alterations from that expected in the absence of human impacts) by 2015. Each Member State (MS) has had to define national systems for assessing ecological status for a range of biological quality elements, as defined in Annex V of the WFD (Kelly et al., 2009). In order to ensure comparability of such monitoring systems, the results of the systems operated by each member state shall be expressed as ecological quality ratios for the purposes of classification of ecological status. These ratios shall represent the relationship between the values of the biological parameters observed for a given watercourse and the scores for these parameters in the pristine conditions applicable to that watercourses.

Benthic diatoms in rivers and streams are a great part of phytobenthos and aquatic biodiversity. Due to this fact, they are widely used worldwide in freshwaters quality monitoring especially rivers and streams, and their based indices have been developed for the evaluation of water quality (e.g., Rott et al., 1999, 2003; Lobo et al., 2004; Potapova et al., 2004; Herring et al., 2006; Kelly et al., 2009; Rimet, 2012; Wang et al., 2014; Rimet et al., 2016). The advantage in benthic diatoms is that they can be found in every surface water at any time (Ács et al., 2004; Kiss et al., 2012). Diatom-based metrics usually indicate a highly significant and well response to nutrient gradients (Rott et al., 2003; Kelly et al., 2014) with higher correlation coefficients than those of other biological elements (Birk et al., 2012).

The aims of the chapter were to assess the ecological status in running watercourses located in the western Mediterranean basin of Turkey using trophic index Turkey (TIT), trophic index (TI) and Eutrophication and pollution index diatom-based (EPI-D).

## 5.2 Material and Methods

The water quality of watercourses was evaluated following three (3) diatom indices: Trophic index Turkey (TIT), Eutrophication and Pollution Index Diatom-based (EPI-D) and the trophic index (TI). TIT was calculated using the equation (Eq.1) proposed by Çelekli et al. (2016, 2018a). TIT values were then transformed as ecological quality ratios (EQRs) to evaluate the ecological status and the water quality of the studied watercourses according to the WFD (Eq.2). As suggested by the European Union waterframe work directive, EQR scores varied from zero (0) which indicates poor water ecological status to one (1) indicating high water ecological status. EPI-D was calculated according to the equation (Eq.3) proposed by Dell'Uomo (2004). TI score was determined based on the formula (Eq.4) developed by Rott et al. (1999) for Austrian rivers.

$$TIT = \frac{\sum_{i=1}^{n} b_i * e_i * c_i}{\sum_{i=1}^{n} e_i * c_i} \qquad \text{(Eq. 1)}$$

where $b_i$ is the trophic number of species i (1-5), $e_i$ the indicative weight number of species i (0-5) and $c_i$ abundance of species i (%). Increasing water quality corresponds to TIT values from 4 down to 0.

$$EQR = \frac{(4 - TIT_o)}{(4 - TIT_{ref})} \qquad \text{(Eq. 2)}$$

where, TITo and TITref are the observed and reference TIT, respectively. The ecological status boundary classes were deteremined according to the WFD, using the box-plot analysis for each typology.

$$EPI - D = \frac{\sum_{j=1}^{n} a_j * r_j * i_j}{\sum_{j=1}^{n} a_j * r_j} \qquad \text{(Eq. 3)}$$

where, EPI-D = Etrophication/pollution index of the stations; $a_j$ = abundance of the species j; $r_j$ = reliability of the species j, inversely proportional to its ecological "range"; values used: 5 for an optimum indicator, 3 for a good indicator, 1 for a sufficient indicator only; $i_j$= weighted integrated sensitivity index of the species j; the values attributed go from 0 (for environment of excellent quality) to 4 (degraded water body) (Table 5.1).

**Table 5.1** The ecological status levels based on EPI-D (Dell'Uomo, 2004)

| EPI-D values | Water quality |
|---|---|
| 0.0<1.0 | High |
| 1.0<1.7 | Good |
| 1.7<2.3 | Moderate |
| 2.3<3.0 | Poor |
| 3.0<4.0 | Bad |

$$TI = \frac{\sum_{i=1}^{n} TWi * Gi * Hi}{\sum_{i=1}^{n} Gi * Hi} \qquad \text{(Eq. 4)}$$

Where TI is the trophic index, Twi is trophic number of species i, Gi is the indicative weight number of species i (0 to 5), Hi is the abundace of species i (%). The ecological status levels according to this index, are presented in Tables 5.2.

**Table 5.2** The ecological status levels of the Trophic Index (TI) (Rott et al., 1999) modified by Çelekli et al. (2018b)

| **Water quality** | **TI values** |
|---|---|
| High | <1.4 |
| Good | 1.4-<2.0 |
| Moderate | 2.0-<2.7 |
| Poor | 2.7-3.3 |
| Bad | >3.3 |

## 5.3 Results

The studied sites' water quality was assessed based their ecological status using the trophic index Turkey (TIT) combined to the eutrophication and pollution index based on diatom (EPI-D). Values of TIT, EPI-D, TI and EQR based on TIT and its related ecological status are presented in Table 5.3. The highest (2.73) and lowest (1.53) TIT values were recorded respectively in Dalaman stream (A8) and Kaya creek, while EQR based on TIT changed from a minimum of 0.44 at Dalaman stream (A8) to a maximum of 0.99 Kaya and creeks. On the other hand, the highest (1.88) and lowest (1.01) EPI-D values were recorded respectively in Dalaman stream (A9) and Kaya creek, while the highest (2.89) and lowest (1.43) TI values were recorded respectively Sarıçay creek (A2) and Kızılöz creek (A13).

Ecological status of the sampled water bodies ranged from high to poor according to ecological quality ratios based on TIT. The good ecological status was the most recorded during the study followed by high ecological status while a poor water status was found only at the stations A8 of Dalaman stream (Table 5.3). According to EPI-D, the water quality all the stations indicated a good ecological status, except Dalaman stream (A9) which showed a moderate status during the study (Table 5.3). The water quality of the sampled stations based on the trophic index (TI) varied from poor to good status. Sarıçay creek (A2) was the only station indicating a poor ecological status and most of the stations showed a moderate water quality (Table 5.3).

In order to compare the suitability and applicability of the TIT, EPI-D and TI indices in the watercourses of the western Meditarranean basin, TIT and EPI-D were plotted against logTP (Figure 5.1). Based on $R^2$ scores, a higher part of variance of TIT was explained by logTP than it done with EPI-D and TI (Figure 5.1a,b and c). Total phosphorous (TP) also indicated a significant positive correlation with the trophic index (TIT). Besides, the $EQR_{TIT}$ scores showed a significant negative correlation with logTP ($R^2 = 0.67$, $p < 0.01$) (Figure 5.1d).

The test of no difference between the two indices was carried out using a variance analysis (one-way ANOVA). The result of this analysis indicated no significant difference between the lakes and reservoir. (one-way ANOVA; $P > 0.05$; $F = 0.76$) in related to their ecological status.

**Table 5.3** TIT, EQR, EPI-D and TI values and ecological status of the stations

| Stations | Code | TIT | EQR | Status | TI | Status | EPI-D | Status |
|---|---|---|---|---|---|---|---|---|
| Sarıçay creek | A2 | 2.18 | 0.64 | Moderate | 2.89 | Poor | 1.28 | Good |
| Namnam creek | A3 | 2.34 | 0.76 | Good | 2.34 | Moderate | 1.19 | Good |
| Kargıcak creek | A4 | 2.11 | 0.61 | Moderate | 1.87 | Good | 1.40 | Good |
| Dalaman stream | A5 | 2.33 | 0.63 | Moderate | 2.17 | Moderate | 1.29 | Good |
| Dalaman stream | A6 | 2.28 | 0.77 | Good | 2.16 | Moderate | 1.18 | Good |
| Dalaman stream | A7 | 2.48 | 0.71 | Moderate | 1.53 | Good | 1.39 | Good |
| Dalaman stream | A8 | 2.73 | 0.44 | Poor | 2.57 | Moderate | 1.37 | Good |
| Dalaman stream | A9 | 2.66 | 0.61 | Moderate | 2.64 | Moderate | 1.88 | Moderate |
| Seki stream | A10 | 2.50 | 0.84 | Good | 2.42 | Moderate | 1.22 | Good |
| Seki stream | A11 | 2.36 | 0.65 | Moderate | 2.31 | Moderate | 1.25 | Good |
| Çayiçi creek | A12 | 2.21 | 0.80 | Good | 1.96 | Good | 1.29 | Good |
| Kızılöz creek | A13 | 2.13 | 0.64 | Moderate | 1.43 | Good | 1.19 | Good |
| Kızılöz creek | A14 | 2.28 | 0.69 | Moderate | 1.81 | Good | 1.15 | Good |
| Çavdır stream | A15 | 2.62 | 0.61 | Moderate | 2.20 | Moderate | 1.35 | Good |
| Boğluca stream | A16 | 2.56 | 0.83 | Good | 2.62 | Moderate | 1.33 | Good |
| Akçay stream | A17 | 2.40 | 0.80 | Good | 2.44 | Moderate | 1.55 | Good |
| Alakır stream | A18 | 2.13 | 0.83 | Good | 1.64 | Good | 1.36 | Good |
| Eşen stream | A19 | 2.30 | 0.78 | Good | 1.68 | Good | 1.10 | Good |
| Kanlı stream | A20 | 1.85 | 0.93 | High | 1.80 | Good | 1.32 | Good |
| Eşen stream | A21 | 2.36 | 0.77 | Good | 2.13 | Moderate | 1.50 | Good |
| Karabeyyurdu creek | BAK 12 | 1.98 | 0.96 | High | 2.19 | Moderate | 1.07 | Good |
| Delin creek | BAK14 | 1.88 | 0.98 | High | 1.81 | Good | 1.03 | Good |
| Kaya creek | BAK4 | 1.53 | 0.99 | High | 1.51 | Good | 1.01 | Good |
| Kocabük creek | BAK9 | 1.89 | 0.99 | High | 2.14 | Moderate | 1.28 | Good |
| R1creek | R1 | 1.84 | 0.91 | High | 1.84 | Good | 1.18 | Good |

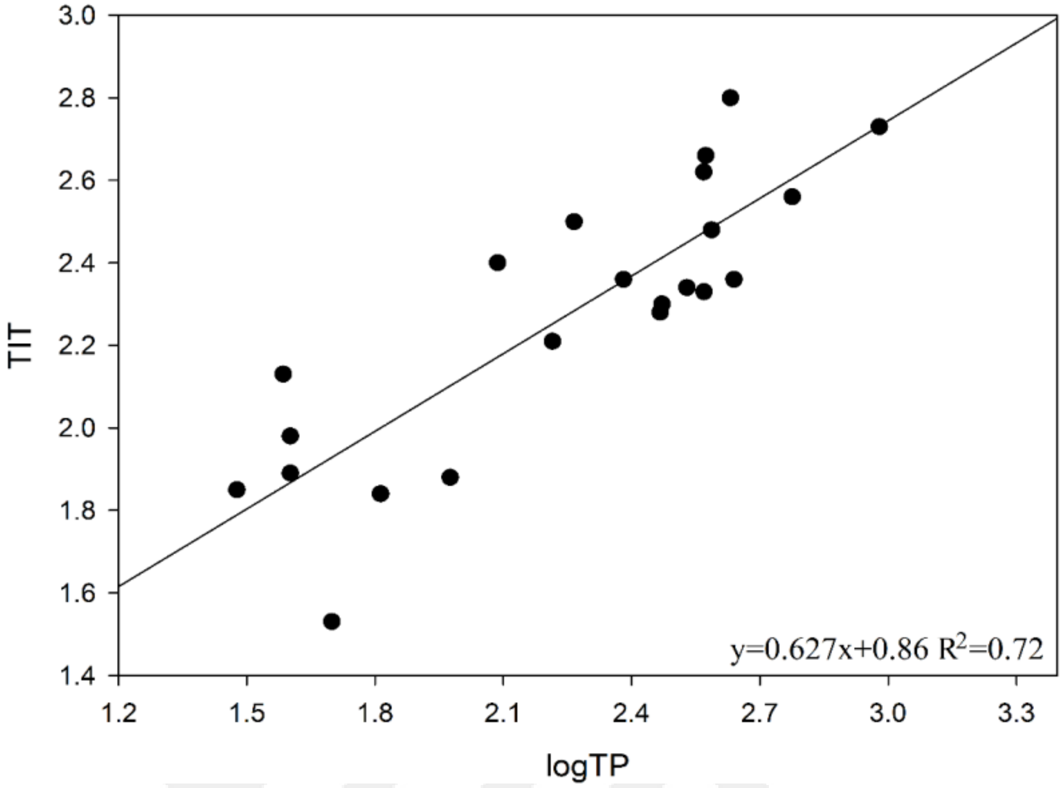



**Figure 5.1a** Plot of relationship between TP and trophic index Turkey (TIT)

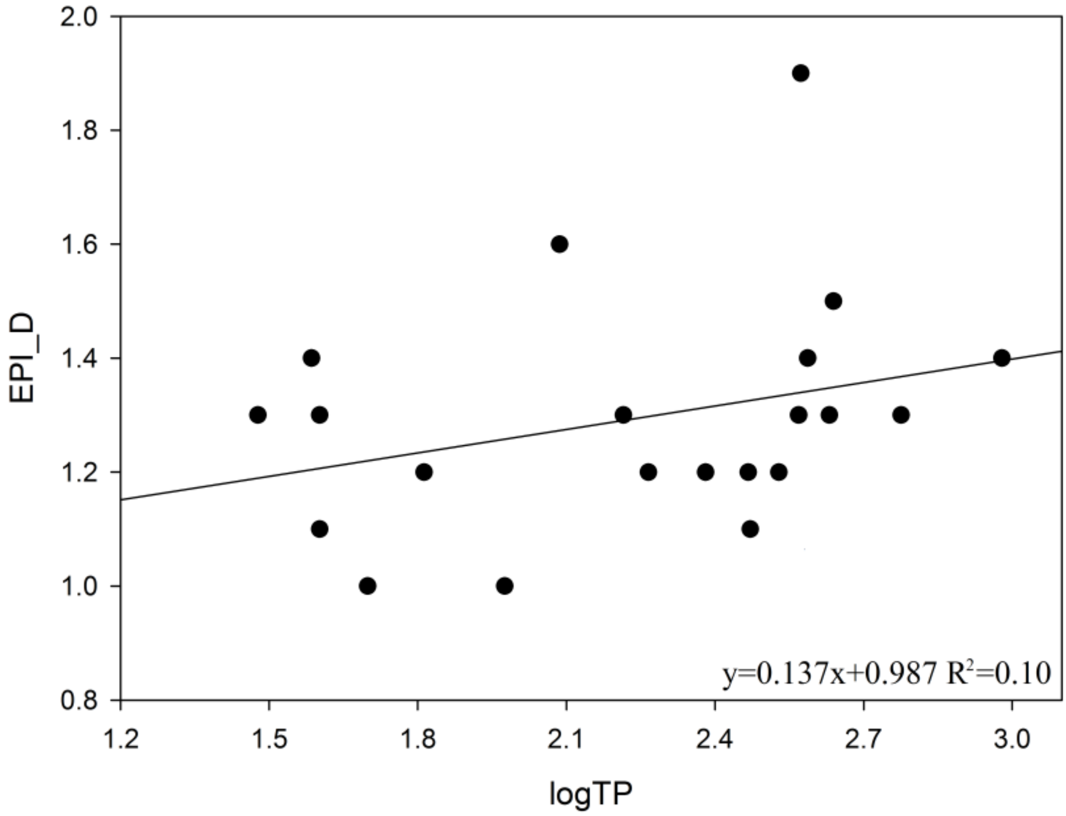



**Figure 5.1b** Plot of relationship between TP and eutrophic an pollution index (EPI-D)

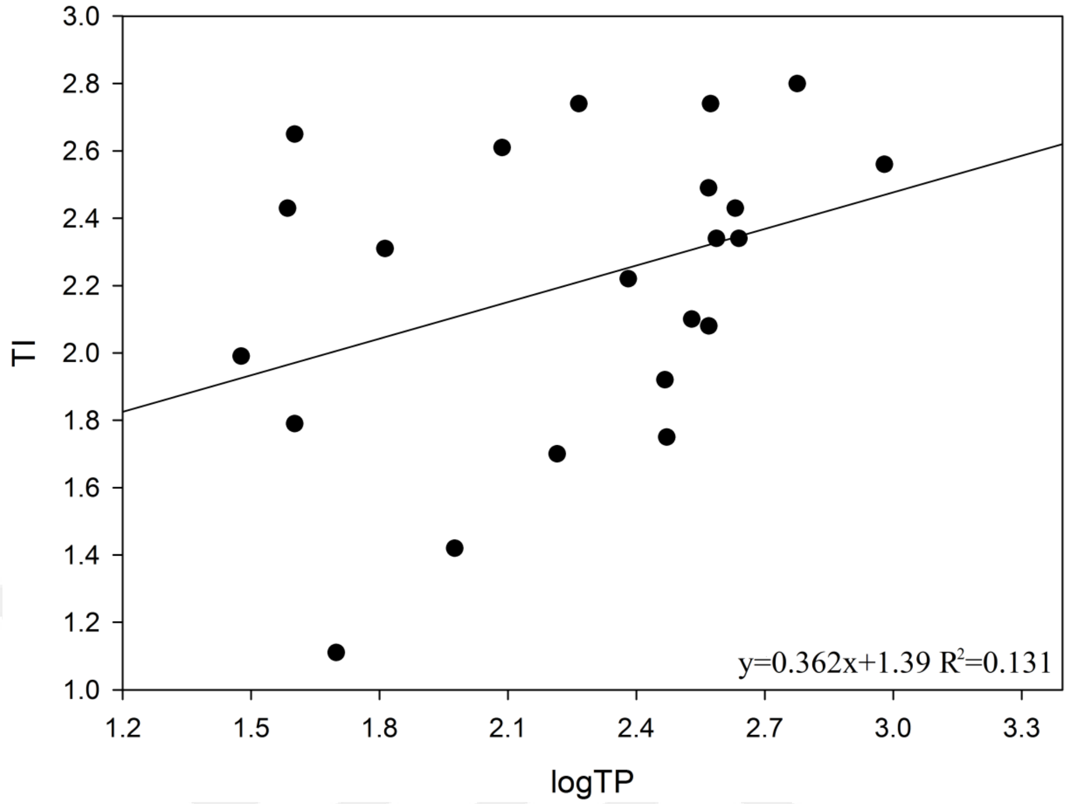



**Figure 5.1c** Plot of relationship between TP and trophic index (TI)

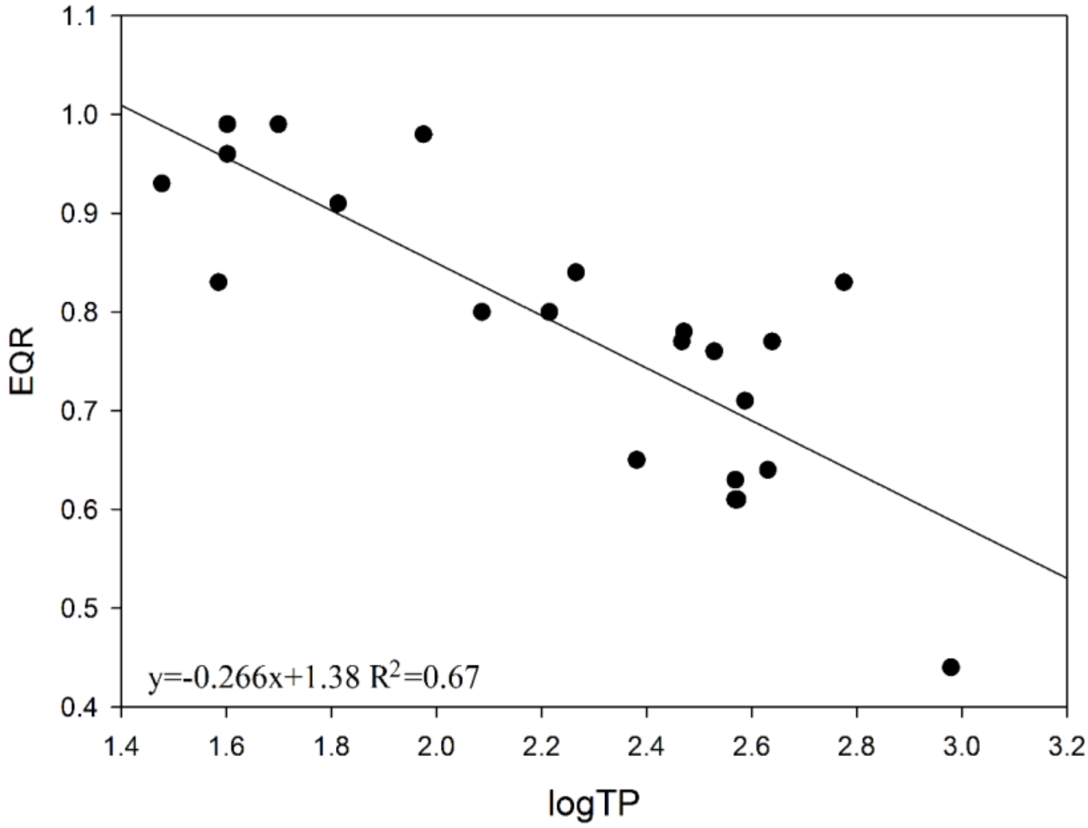



**Figure 5.1d** Plot of relationship between TP and and EQR-TIT

## 5.4 Discussion

As basin concept, we used during this study for the first time three diatom indices to evaluate running water including 25 stations in the western Mediterranean of Turkey. Using biological quality elements for Water quality assessment is a new topic in Turkey, but is getting more importance. As suggested by the UE WFD, many studies have been carried out recently in the different regions of Turkey.

Biological monitoring provides a direct measure of ecological integrity by using the species responses to the changes in environmental variables (Karr, 1991; Angermeier and Karr, 1994; EC, 2009). Among biological quality elements, diatom assemblages often considered as important ecological indicators of water bodies due to their rapid and sensitive response to environmental changes (Kelly, 1998; Potapova et al., 2004; Bona et al., 2007; Delgado and Pardo, 2014). For the assessment of water quality conditions, benthic diatoms have been used since the 1900s (Kolkwitz and Marsson, 1908). In Europe, benthic diatom metrics such as IPS (Cemagref, 1982), TI (Rott et al., 1999), EPI-D (Dell'Uomo, 2004) and TDI (Kelly et al., 2008) developed for running waters are successfully applied for water quality assessment worldwide. But, the environmental optima and tolerance ranges of diatom species may vary from one ecoregion to another, requiring local indices to be developed (Gomá et al., 2004; Lobo et al., 2004). Several authors (e.g. Kelly et al., 1998; Pipp, 2002; Rott et al., 2003; Dell'Uomo, 2004) indicated that diatom indices/metrics developed in certain parts of Europe are not effective when used in other areas of the same continent.

In related to the ecological status following TIT, a high ecological status was observed in Dalaman stream (R1), Karabey yurdu creek, Delin creek, Boğluca stream, Kocabük Creek, Koca stream and a good ecological status was observed in Alakır stream, Boğluca stream, Namnam Creek, Eşen stream, Dalaman stream (A6), Seki stream, Çayiçi Creek and Ak stream. Aforementioned stations had also low nutrient contents and non degraded hydromorphological characteristics representing pristine conditions watercourse type as recommended by the WFD (Directive, 2000). In according with our finding, high ecological status had been previously reported from different running water in many countries using various diatom-based indices (e.g. Beltrami et al., 2012; O'Driscoll et al., 2012). These watercourses as well as our sampled water bodies were located at similar altitudes (<400 m) and showed similar geological characteristics. The high water quality of aforementioned aquatic systems could be the consequence of the moderate 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. On the other hand, a poor status was observed at Dalaman stream (A8) which showed the highest nutrient (TN, TP; $N\text{-}NO_3$, $N\text{-}NO_2$, and $P\text{-}PO_4$) contents and characterized by the occurrence of pollution tolerant or eutrophication indicator species such as *N. umbonata*, *N. cryptocephala*, and *C. meneghiniana* during this study. As indicated before, Dalaman Stream (A8) was under pressures of human activities from Acıpayam District, several villages, and farming process. The water ecological status of this station could be impacted by huge addition of inorganic and organic matters generated by municipal waste input, agricultural practices, livestock and nutrient enriched runoff. Besides, agricultural practices, the input of wastewater, and organic pollutants generated by fish farming could be the causes the moderate states observed in Sarı stream, Dalaman stream (A5, A7, and A9), Seki stream (A11) and Çavdır Stream which are near to human settlements. Most of the highest nutrient (TN, TP; $N\text{-}NO_3$, $N\text{-}NO_2$, and $P\text{-}PO_4$) contents were found in these stations. *N. angustata*, *N.umbonata*, *N. cryptocephala*, *N. lanceolata*, and *N. dissipata* were commonly found in these stations. Besides, WA result (Table 5.7) supported by CCA (Figure 5.10) showed these species were relatively tolerant to high nutrient contents. Besides, relationships test (Figure 5.11) showed a significant positive correlation ($R^2$ =0.72, $p<0.01$) between TP and TIT. This situation has also been indicated early by other authors in different countries (e.g. Van Dam et al., 1994; Reynolds et al., 2002; Àcs et al., 2004; Salomoni et al., 2006; Hlúbiková et al., 2007; Padisák et al., 2009; Delgado and Pardo, 2014). Salomoni et al. (2006) reported that high population densities and the variety of anthropogenic activities expose many hydrographic basins close to large urban centers to heavy and rising environmental impacts, especially to the pollution by domestic and industrial waste residues.

This situation was confirmed by (Mancini and Arcà (2000) who reported that urbanization and agriculture practices in the study area affect the basins of watercourses.

According to EPI-D, all the watercourses indicated a good ecological status, except Dalaman stream (A9) which showed a moderate status during the study. This result is in accordance with that indicated by Della Bella et al. (2007) in wetlands of central Italy. It is also similar to those reported by Beltrami et al. (2012) found from rivers of Northern Italy. In fact, the authors indicated water quality changing mostly from high to good except three sites were considered of class III–IV or IV for EPI-D (moderate to bad quality). The water quality of the sampled stations based on the trophic index (TI) varied from poor to good status and most showed a moderate water quality. As it can be seen, TIT and EPI-D were more efficient than TI. This can be explained by the ecoregional characteristics. In fact, the two first indices were dedicated for Mediterranean rivers, while TI was developed for Alpine rivers 20 years ago.

Trophic status of the watercourses was also evaluated using TI. Two (2) mean trophic classes (Mesotrophic and eutrophic) and thee (3) semi-classes (oligo-mesotrophic, meso-eutrophic and eutro-polytrophic) were observed during the study. Similar water quality was previously reported by Beltrami et al. (2012) from rivers of Alto Adige/Südtirol (Northern Italy) using the same trophic index. Anthropogenic activities, geology, and climatic structures of catchment region had an impact on the water quality in the watersheds of the western Mediterranean basin. The studied water bodies were under human pressures such as agriculture, livestock, and urban waste. According to Anonymous (2016), 25% of the basin area is agricultural land, 57% of the agricultural areas are mixed agricultural lands and 34% is arable lands. The most common crops which grow in the basin are tomatoes, peppers, citrus fruits, apples, pears, quince, wheat, corn, and olives. Aforementioned factors could explain the highest nutrient concentrations observed in the stations. Besides, the water quality could be strongly deteriorated by the more addition of inorganic and organic matters from discharging wastes mining. Nutrients and pollutants deposition along the watersheds lead to the increase of nutrient the water bodies. It is stated that direct sewage inputs, runoff from fertilized soils and land degradation through seasonal (agriculture, irrigation) activities had a adverse effect on water resources over the last centuries (Wunsan et al., 2002; Ducharne et al., 2007; Delgado and Pardo, 2014).

# CHAPTER VI

## LIMNOECOLOGY OF PHYTOPLANKTON IN THE LAKES AND RESERVOIRS

## ABSTRACT

Freshwater quality, especially lakes and reservoirs are seriously affected by anthropogenic activities and natural factors. Due to this reason, Lakes and reservoirs should be assessed at a local, regional and national level not using only physicochemical parameters, but also biological quality elements. Phytoplankton, as one of these biological quality elements are useful tool for the bioassessment surface waters. The aim of this work was to assess the water quality of three lakes and six reservoirs in the Western Mediterranean Basin (Turkey) using phytoplankton indices. Data were sampled seasonally from summer 2014 to summer 2015. The phytoplankton composition was characterized by 206 species belonging to 15 functional groups (**B**, **D**, **E**, **F**, **G**, **J**, $\mathbf{L_M}$, $\mathbf{L_O}$, **M**, **MP**, **P**, **T**, **W1**, **X1**, and **Y**). Environmental variables especially pH, nutrients, total organic carbon (TOC) and conductivity had a significant impact ($p<0.01$) on the distribution of phytoplankton composition. The canonical correspondence analysis used to investigate the relationships between phytoplankton species and physicochemical parameters indicated a 93.2% correspondence between species-environment correlations and 13.6% of cumulative percentage variance of species data.

## 6.1 Introduction

Freshwater quality, especially lakes and reservoirs are seriously affected by anthropogenic activities and natural factors. The types of organisms in these aquatic ecosystems are mainly determined by their waters' quality. Lotic aquatic systems are characterized by several groups of organisms that are classified by their location and by their adaptations in these environments. These organisms are categorized as plankton (free living organisms including phytoplankton and zooplankton), nekton (free-moving organisms) and benthos (attached organisms to hard substrates).

Phytoplankton are prokaryotic or eukaryotic free living photosynthetic microorganisms in aquatic systems and play a central role in the structure and functioning of aquatic ecosystems. They primary producer in food web, responsible for the total primary production in the limnetic zone and can grow rapidly and live in harsh conditions due to their unicellular or simple multicellular structure. Microalgae are present in all existing surface aquatic ecosystems, representing a big diversity of species living in a large range of environmental conditions. Phytoplankton response quickly to nutrient variations through changes in its abundance and composition (Reynolds, 1984; Rott, 1984; Naselli Flores and Barone, 1998; Reynolds et al., 2002; Schaumburg et al., 2004; Reynolds, 2006; Poikane et al,. 2011; Cellamare et al., 2012).

Phytoplankton could be used as a good bioindicator of water quality due to its sensitivity and ability to response in the surrounding environment changes (Reynolds, 1984; Padisák et al., 2003; EC, 2009; Padisák et al. 2006; Poikane et al., 2011; Katsiapi, et al., 2011). Spatial and temporal distribution of phytoplankton species could be explained by complex relationships between physical, chemical, and biological variables (Margalef, 1983; Pannard et al., 2008; Padisak et al., 2010). The impacts of chemical parameters on phytoplankton taxa have been largely demonstrated, while a few research concerning the role of physical factors on phytoplankton communities were carried out (Zohary et al., 2010; López et al., 2012). Throughout its annual development, the phytoplankton changes several quite different successional steps during which equilibrial compositions occur whether for shorter or longer periods (Padisák et al., 2003), thereby they have developed morphological and physiological adaptive strategies for surviving in different conditions (Margalef, 1978; Reynolds, 1998, 2002, 2006; Padisák et al., 2003; Becker et al., 2010). Data related to the composition, biomass, and biovolume of phytoplankton are being used for the biomonitoring of ecological status in watercourses (Marchetto et al., 2009; Çelekli and Öztürk, 2014). One of the most recent phytoplankton research interests is the establishment of the so-called phytoplankton functional groups (Abonyi et al., 2012).

Aims of this chapter were to i) estimate the phytoplankton composition, ii) determine phytoplankton functional groups in different ecosystems, and iii) evaluate the relationship between phytoplankton assemblages and environmental variables in three lakes and six reservoirs in the Western Mediterranean basin.

## 6.2 Material and Methods

### 6.2.1 Sampling Stations

The studied water bodies are located in the West Mediterranean Basin of Turkey which subdivided into five provinces including Aydın, Antalya, Burdur, Denizli and Muğla. According to the results of the Address-based census (ADNKS) of 2015 conducted by the Turkish Statistical Institute (TURKSTAT), the total population of in the Western Mediterranean Basin was 5.502.620. The surface area of the basin is 2103004,9 ha and consists of 65 sub-basins and 372 micro-basins (Anonymous, 2016). The study was conducted in all the provinces except the Aydın province. The locations of the water courses are given in Figure 6.1. Hydro-geographical features characteristics of the lakes and reservoirs are sorted in Table (6.1). Pictures of these water bodies are given in Figure 6.1.


**Figure 6.1** Location of sampling stations on the map. For stations codes, see Table 6.1

**Table 6.1** Hydro-geographical features of the lakes and reservoirs

| Province | Lakes/Reservoir | Latitude (N) | Longitude (E) | Area ($km^2$) | Depth (m) | Category | Typology |
|---|---|---|---|---|---|---|---|
| Denizli | Lake Gölhisar (G1) | 37° 7' 28.056" | 29° 36' 24.408" | 292.9 | 3 | Alkaline | R2D1A1J2 |
| Muğla | Çayboğazı reservoir (G3) | 36° 31' 38.748" | 29° 40' 47.675" | 135.4 | 52 | Calcareous | R2D1A1J2 |
| Muğla | Lake Avlan (G4) | 36° 34' 18.876" | 29° 57' 12.491" | 581.9 | 2 | Alkaline | R3D1A1J1 |
| Muğla | Geyik reservoir (G5) | 37° 23' 47.904" | 27° 52' 56.64" | 305.7 | 39 | Calcareous | R1D2A1J2 |
| Denizli | Çavdır reservoir (G7) | 37° 4' 25.032" | 29° 44' 2.22" | 180.8 | 44 | Calcareous | R1D2A1J2 |
| Antalya | Toptaş reservoir (G8) | 36° 25' 25.14" | 30° 21' 17.28" | 11.9 | 16 | Calcareous | R2D2A1J2 |
| Burdur | Yapraklı reservoir (G9) | 37° 1' 43.716" | 29° 27' 6.3" | 569.6 | 55 | Calcareous | R2D2A1J1 |
| Antalya | Osmankalfalar reservoir (G10) | 37° 6' 39.492" | 29° 53' 1.103" | 58.7 | 21 | Calcareous | R2D2A1J1 |
| Burdur | Lake Yazır (G11) | 37° 0' 9.852" | 29° 44' 3.599" | 227.8 | 1 | Alkaline | R3D2A1J1 |

Typology codes are R, altitude; D, depth; A, surface area; and J, geology

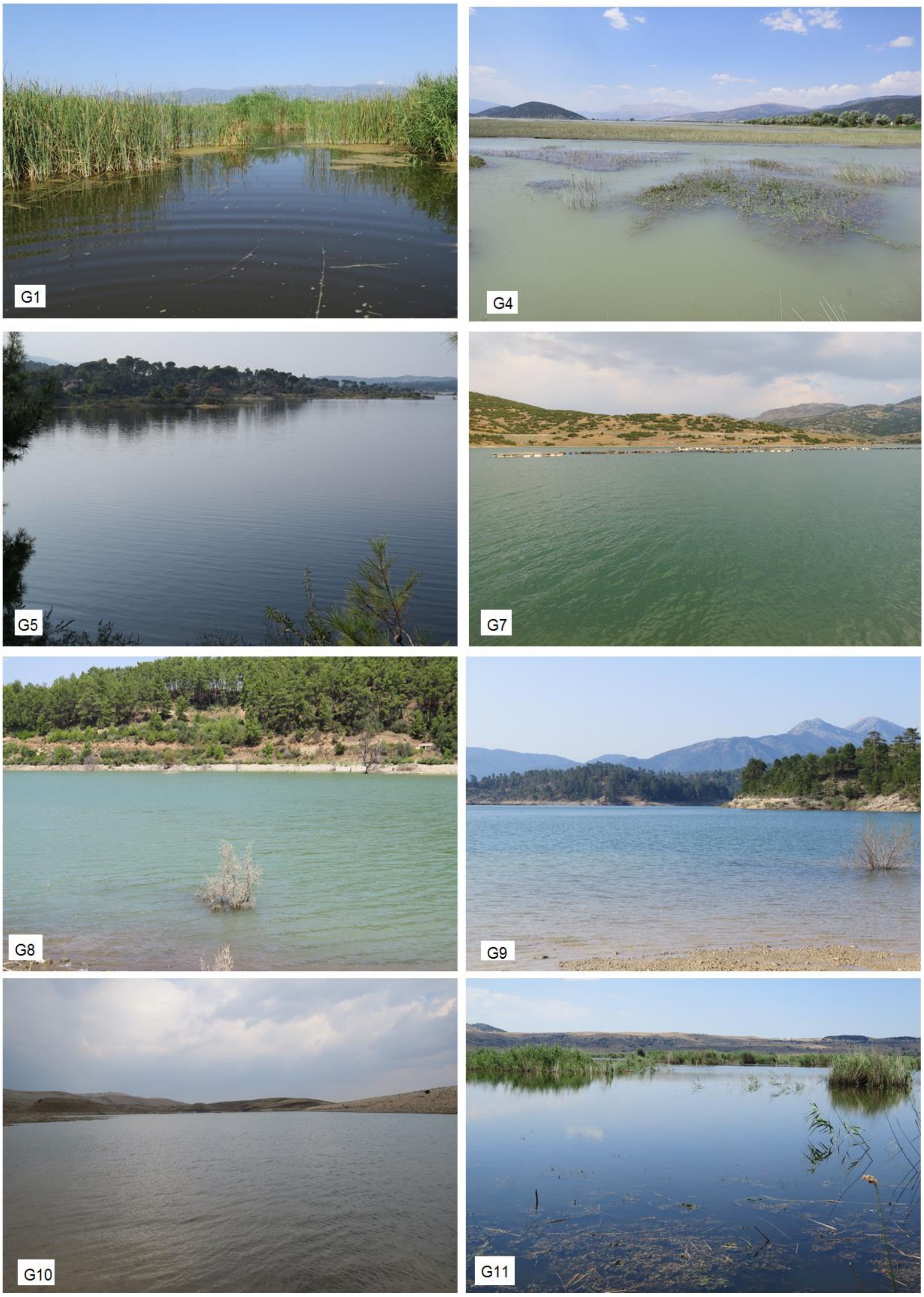



**Figure 6.2** Photographes of sampling stations. G1, Lake Gölhisar; G4, Lake Avlan; G5, Geyik reservoir; G7, Çavdır reservoir; G8, Toptaş reservoir; G9, Yapraklı reservoir; G10, Osmankalfalar reservoir; G11, Lake Yazır

### 6.2.2 Field Sampling

#### 6.2.2.1 Phytoplankton Sampling

Phytoplankton and water samples were collected from the lakes and reservoirs during four (4) seasons (summer 2014, fall 2014, spring 2015 and summer 2015. Hydrobios plankton net (55 µm mesh size) was used to collect net-plankton for phytoplankton identification(Figure 6.3a). Water samples (250 ml) were directly taken from just beneath of the surface water from each lake and reservoir for phytoplankton enumeration. Collected phytoplankton samples (Figure 6.3b) were fixed with lugol-glycerol's solution according to standard methods (CEN, 2006, 20012) and then conserved in thermoses with ice packs during the transport to the laboratory for the analyses (Figure 6.3c).

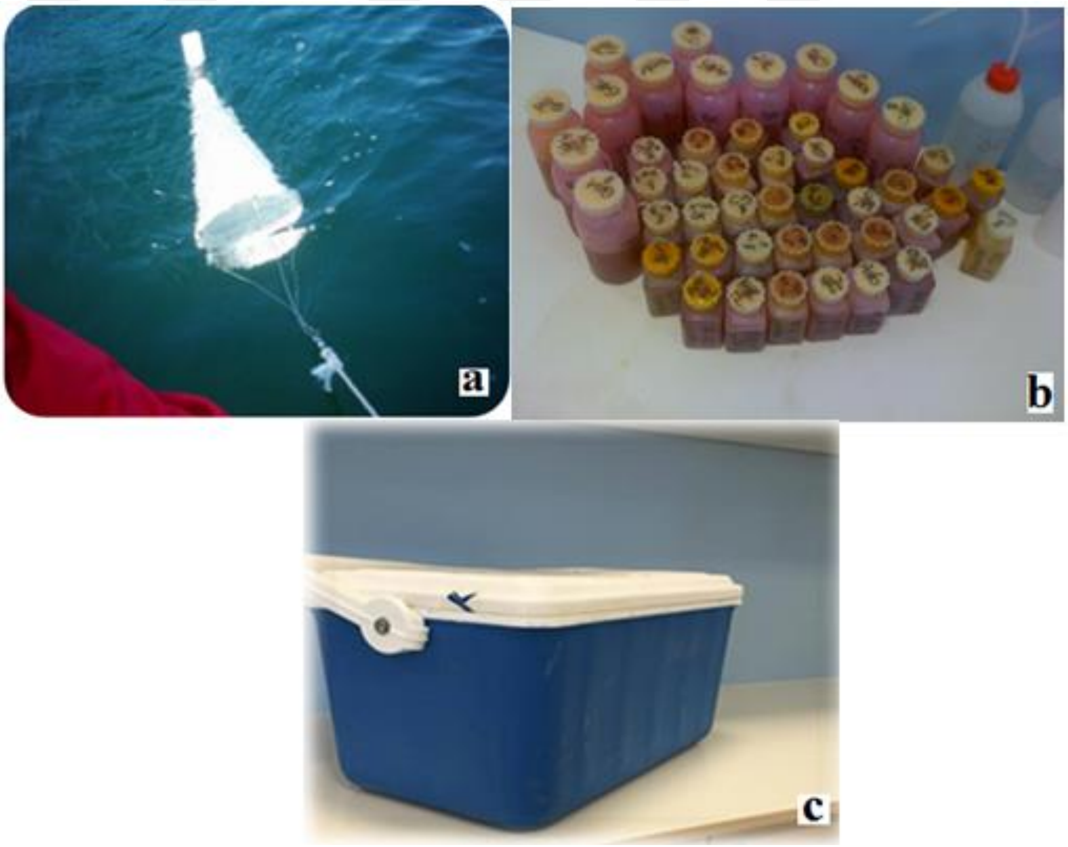



**Figure 6.3** Phytoplankton sampling a) Plankton net, b) Collected samples, and c) Cooler with ice packs

#### 6.2.6.2 Physicochemical Variables

Environmental variables such as temperature, pH, conductivity, salinity, total suspended solids and total dissolved solids (TDS) were recorded *in situ* using a YSI professional plus oxygen–temperature meter from just beneath of the surface in the stations (Figure 6.4a). Water clearness was seasonally estimated using a 20-cm Secchi disk during the different seasons (Figure 6.4b). Geographical characteristics such as altitude, latitude, and longitude were taken from a geographical positioning system (Garmin Vista HCx model GPS).


**Figure 6.4** Environmental variables sampling a) YSI professional plus, b) Secchi disk

### 6.2.3 Laboratory Examinations

#### 6.2.3.1 Chemical Variables

Analyses of chemical variables (e.g., TN, N–NH4, N–NO3, N–NO2, TP, and P–$PO_4$), dissolved oxygen (DO) and biological oxygen demand ($BOD_5$) were carried out by an accredited laboratory of DOKAY-ÇED (Ankara) using the standard methods (APHA, 2012).

#### 6.2.3.2 Identification and Enumeration of Phytoplankton

Phytoplankton identification, enumeration, and analyses were carried out in the hydrobiology laboratory of the biology department (Gaziantep University, Turkey) according to standard methods (Utermöhl, 1958; CEN, 2006, 2014). The identification of phytoplankton taxa was carried out using a light microscope (Olympus BX53) attached DP73 model digital camera with imaging software (Olympus CellSens Vers. 1.6) (Figure 6.5a). Phytoplankton enumeration was carried out using the following stapes. Fist, 100–150 ml sampling waters were allowed to settle for 24–48 hours in graduated cylinders (Figure 6.5b). After the waiting, about 85-135 ml sample is carefully siphoned (Figure 6.5c). Remain sample were put in counting chamber, placed on the inverted microscope and permitted to settle for the least 1 hour (Figure 6.5d). Phytoplankton were then counted following two perpendicular transects at magnifications of 400–600× using an inverted microscope (Olympus CKX41). At least 350-500 species at cell level were counted per sample. Unicellular species as well as colonial and filamentous species were counted as one individual species. Functional groups of phytoplankton assemblages were determined based on the system established by Reynolds et al. (2002) and Padisák et al. (2003, 2009). Identification books (Ettl, 1983; Komárek and Fott, 1983; Popovsky and Pfiester, 1990; Krammer and Lange-Bertalot, 1991a, b; Komárek and Anagnostidis, 1998; Krammer and Lange-Bertalot, 1999a, b; John et al., 2002; Wehr and Sheath, 2003) were used for the identification of phytoplankton. Total biovolume for each taxon was calculated by multiplying the species proportion by the unitary cell biovolume of the taxon calculated using geometric formula proposed by Rott (1981), Hillebrand et al. (1999) and Sun and Liu (2003).

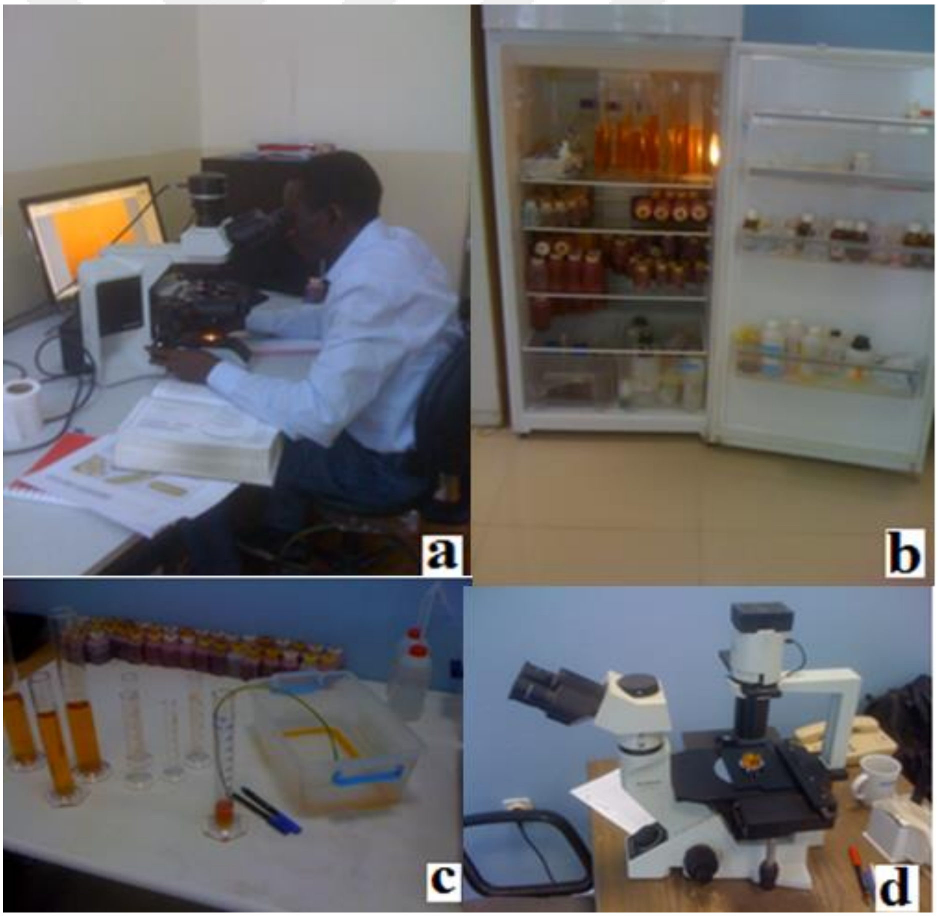



**Figure 6.5** Phytoplankton identification and enumeration: a) identification, b) setlling (24-48 hours), c) siphoning process, and d) counting chamber on inverted microscope

### 6.2.4 Multivariate analyses

A canonical correspondence analysis (CCA) using the CANOCO program was used was performed to evaluate the interactions between environmental factors and phytoplankton taxa in the lakes and reservoirs. Unimodal response models were applied for the ordination of analyses along gradients. Prior to this, all predictor factors except pH were transformed log (x+1) (ter Braak and Smilauer, 1998; Leps and Smilauer, 2003).

Weighted averaging (WA) regression of CALIBRATE program (Juggins and ter Braak, 1992) was used to estimate species optima ($u_k$) and tolerance ($t_k$) levels for environmental variables. Weighted averaging indices evaluate both an individual pressure (e.g., nutrients) and associated stressors of environmental factors on the biota. Moreover, calibration is a method widely applied in more complex analyses, such as ordination methods (Leps and Smilauer, 2003; Çelekli and Öztürk, 2014).

Only species having a percentage of over 1% were selected for the multivariate analyses. In order to understand the relationships between the environmental factors, a Pearson’s correlation test was carried out.

The hypothesis of no difference in phytoplankton assemblages (similarities in species composition) between lakes and reservoirs was tested by means of vegetation tables (species-by-sites matrix) used by Schaumburg et al. (2004), while the Monte Carlo permutation test was used to test the hypothesis on relationship between the phytoplankton taxa and the environmental variable matrices. On the other hand, the hypothesis of no difference between the ecological status of lakes and reservoir, the variance analysis (one-way ANOVA) was employed at 95% confidence interval using the program SPSS (IBM statistics version 23).

## 6.3 Results

### 6.3.1 Predictor variables

The studied watercourses showed different physicochemical characteristics spatially and temporally. The mean values of physicochemical variables in the lakes and reservoirs are given in Table 6.2. The lakes and reservoirs ecosystems showed alkaline water during the study period with pH values ranged from 8.41 at Lake Gölhisar to 9.02 at Lake Avlan. The highest mean temperature (24.9 °C) was measured in Toptaş reservoir located at 182 m a.s.l, while the lowest mean temperature value (17.5 °C) was measured in Osmankalfalar reservoir located at 1428 m a.s.l. With regard to nutrient contents and conductivity, higher values of TP (420.8 µg $L^{-1}$), P-$PO_4$ (176.0 mg $L^{-1}$), N-$NO_2$ (35.1 mg $L^{-1}$) and N-$NO_3$ (532.0 mg $L^{-1}$) were recorded in Osmankalfalar reservoir, when Lake Gölhisar was characterized by the highest values of conductivity (1308.3 µS $cm^{-1}$) and $BOD_5$ (26.8 mg $L^{-1}$). In related to water transparency, the highest Secchi depth (SD) value (3.43 m) was found at Yapraklı reservoir, while the lowest value (0.32 m) was recorded at Lake Yazır. The highest values of $CaCO_3$ (37.5 mg $L^{-1}$) and salinity (0.72 ppt) were found at Lake Gölhisar, in contrast to Geyik and Çayboğazı reservoirs which showed the lowest values 8.8 mg $L^{-1}$ and 0.11 ppt respectively. On the other hand, the highest dissolved oxygen (8.72 mg $L^{-1}$) and total suspended solids (48.6 mg $L^{-1}$) were recorded at Lake Avlan, while Lake Gölhisar and Yapraklı reservoir were associated with the lowest values 7.04 mg $L^{-1}$ and 3.32 mg $L^{-1}$ , respectively.

**Table 6.2** Mean of main physical chemical characteristics from sampling stations

| | Gölhisar | Çayboğazı | Avlan | Geyik | Çavdır | Toptaş | Yapraklı | Osmankalfalar | Yazır |
|---|---|---|---|---|---|---|---|---|---|
| Altitude (m) | 947 | 1197 | 1010 | 471 | 1122 | 182 | 1135 | 1428 | 1481 |
| pH | 8.41 | 8.72 | 9.02 | 8.54 | 8.83 | 8.52 | 8.71 | 8.43 | 8.21 |
| Temperature (°C) | 20.3 | 18.2 | 21.3 | 22.5 | 17.8 | 24.9 | 18.6 | 17.5 | 19.1 |
| Conductivity (µS $cm^{-1}$) | 1308.3 | 228.9 | 360.3 | 152.2 | 399.5 | 584.8 | 348.3 | 291.8 | 385.5 |
| DO (mg $L^{-1)}$) | 7.04 | 8.21 | 8.72 | 7.91 | 8.64 | 8.14 | 8.43 | 8.33 | 7.61 |
| TSS (mg $L^{-1}$) | 5.52 | 5.23 | 48.6 | 5.24 | 7.63 | 4.84 | 3.32 | 25.2 | 13.0 |
| $BOD_5$ (mg $L^{-1}$) | 26.8 | 10.1 | 11.5 | 15.8 | 15.7 | 6.04 | 8.92 | 4.82 | 12.8 |
| COD (mg $L^{-1}$) | 108.2 | 36.3 | 56.0 | 58.9 | 61.0 | 27.3 | 39.5 | 23.1 | 47.9 |
| TOC (mg $L^{-1}$) | 26.8 | 14.9 | 5.31 | 21.5 | 20.1 | 5.83 | 7.24 | 6.44 | 12.3 |
| TN (µg $L^{-1}$) | 1569.3 | 508.7 | 865.2 | 766.2 | 910.0 | 850.0 | 747.0 | 1073.8 | 950.7 |
| N-$NH_4$ (mg $L^{-1}$) | 219.3 | 120.3 | 161.3 | 138.0 | 279.0 | 133.5 | 142.8 | 155.8 | 100.0 |
| N-$NO_2$ (mg $L^{-1}$) | 15.6 | 16.6 | 29.6 | 14.0 | 10.3 | 9.43 | 8.72 | 35.1 | 2.34 |
| N-$NO_3$ (mg $L^{-1}$) | 587.5 | 195.3 | 252.5 | 214.5 | 410.0 | 380.3 | 253.5 | 532.0 | 215.0 |
| TKN (mg $L^{-1}$) | 1246.3 | 307.6 | 681.8 | 393.0 | 521.3 | 362.8 | 468.8 | 585.5 | 841.0 |
| TP (µg $L^{-1}$) | 309.5 | 182.0 | 365.5 | 248.0 | 274.3 | 171.8 | 196.0 | 420.8 | 150.0 |
| P-$PO_4$ (mg $L^{-1}$) | 108.3 | 63.0 | 148.8 | 60.0 | 106.3 | 60.0 | 61.8 | 176.0 | 21.0 |
| Salinity (ppt) | 0.72 | 0.11 | 0.23 | 0.12 | 0.21 | 0.34 | 0.24 | 0.22 | 0.23 |
| $CaCO_3$ (mg $L^{-1}$) | 37.5 | 12.5 | 15.0 | 8.8 | 17.5 | 21.3 | 22.5 | 15.0 | 20.0 |
| SD (m) | 0.62 | 1.81 | 0.43 | 1.44 | 2.04 | 0.72 | 3.43 | 0.91 | 0.32 |

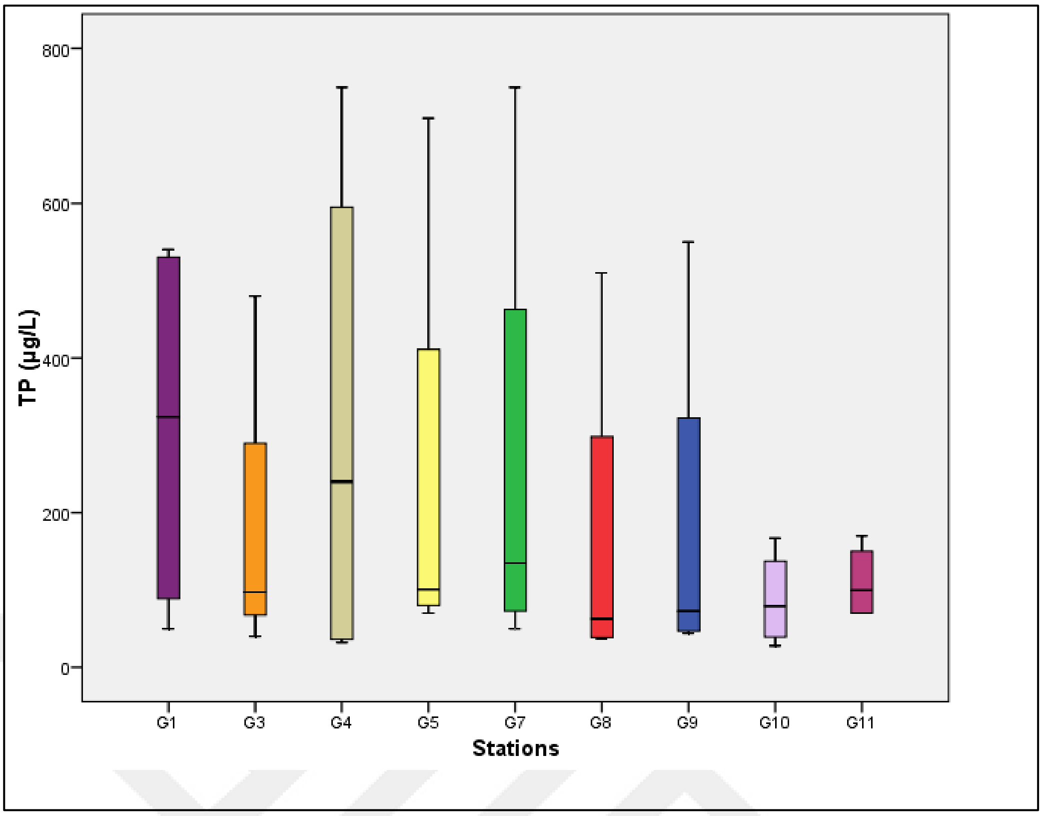
Pearson's correlation test was applied to examine the relationships between the environmental factors. As it can be seen in Table 6.3, Dissolved oxygen (DO), is negatively correlated with the water temperature ($r = -0.462$, $p<0.01$). Total phosphorus (TP) is positively correlated with $BOD_5$ ($r = 0.373$, $p<0.01$) and negatively correlated the temperature ($r=-0.307$, $p<0.05$). Total nitrogen (TN) is negatively correlated with water temperature ($r = -0.474$, $p<0.01$) and positively correlated with COD ($r = 0.375$, $p<0.01$) when water alkalinity ($CaCO_3$) is positively correlated with water conductivity ($r = 0.755$, $p<0.01$) and water salinity ($r=0.776$, $p<0.01$). The Secchi Disk depth is negatively correlated with total phosphorus concentration ($r = -0.301$, $p<0.05$). The Pearson's correlation test indicated that there was no correlation between pH and all the tested environmental variables. There was no also correlation between altitude and the other parameters, excepted temperature which indicated a significant negative correlation with altitude ($r = -0.421$, $p<0.01$).

The seasonal variation of physicochemical parameters was analyzed. Figure 6.6 indicated the seasonal distribution of some these parameters. This Figure showed that, there were no normal distribution of the physicochemical variables during the study period.

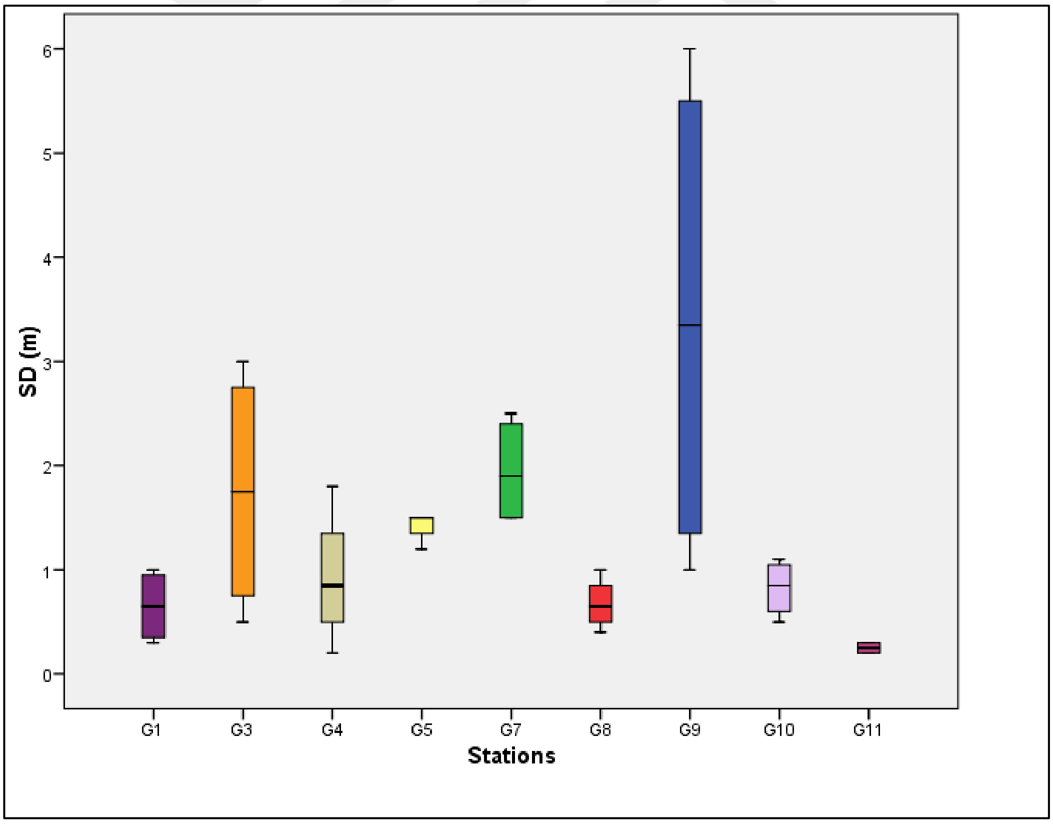
**Table 6.3** Pearson's correlation test result among the environmental variables

| | Altitude | pH | Temperature | Conductivity | $BOD_5$ | TN | $N\text{-}NH_4$ | $N\text{-}NO_2$ | $N\text{-}NO_3$ | TP | $P\text{-}PO_4$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| pH | 0.160 | | | | | | | | | | |
| Temperature | -0.421** | 0.175 | | | | | | | | | |
| Conductivity | -0.078 | 0.116 | 0.233 | | | | | | | | |
| DO | 0.156 | 0.091 | -0.462** | -0.163 | | | | | | | |
| $BOD_5$ | 0.047 | 0.231 | 0.020 | 0.499** | | | | | | | |
| TOC | 0.137 | -0.007 | 0.136 | 0.259 | 0.702** | | | | | | |
| TN | 0.013 | -0.105 | -0.474** | 0.252 | 0.259 | | | | | | |
| $N\text{-}NH_4$ | 0.258 | -0.107 | -0.103 | 0.079 | .103 | -0.024 | | | | | |
| $N\text{-}NO_2$ | 0.273 | 0.146 | -0.313* | -0.017 | 0.139 | 0.132 | 0.684** | | | | |
| $N\text{-}NO_3$ | -0.038 | -0.153 | -0.497** | 0.137 | 0.054 | 0.825** | -0.231 | -0.004 | | | |
| TKN | 0.028 | 0.032 | -0.237 | 0.296* | 0.239 | 0.867** | -0.254 | -0.140 | 0.686** | | |
| TP | 0.212 | 0.188 | -0.307* | 0.177 | 0.373** | 0.190 | 0.492** | 0.761** | 0.072 | | |
| $P\text{-}PO_4$ | 0.121 | 0.284 | -0.315* | 0.154 | 0.332* | 0.270 | -0.019 | 0.472** | 0.278 | 0.846** | |
| Salinity | -0.038 | 0.110 | 0.088 | 0.980** | 0.553** | 0.399** | 0.056 | 0.017 | 0.275 | 0.219 | 0.220 |
| SD | 0.061 | 0.036 | -0.046 | -0.185 | -0.091 | -0.163 | -0.181 | -0.303* | 0.008 | -0.301* | -0.242 |
| Alkalinity | 0.101 | 0.008 | -0.023 | 0.755** | 0.317* | 0.411** | 0.043 | 0-.010 | 0.271 | 0.080 | 0.082 |

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

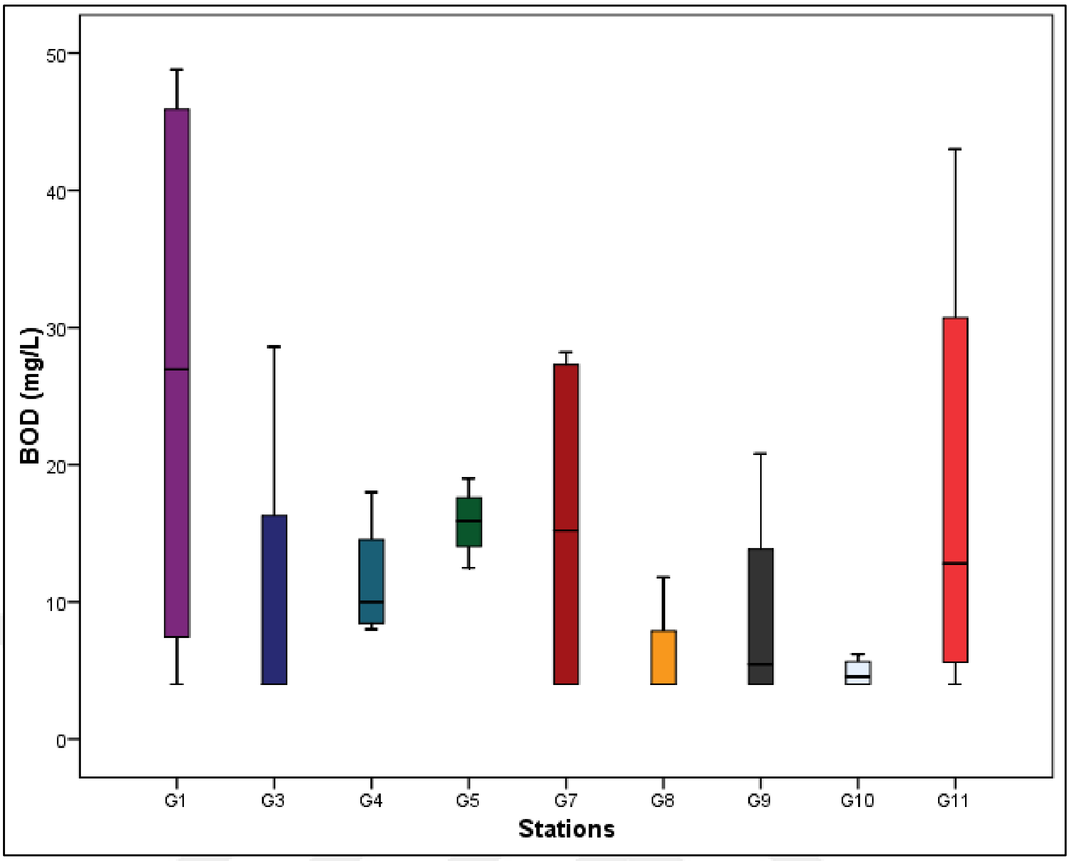



a)

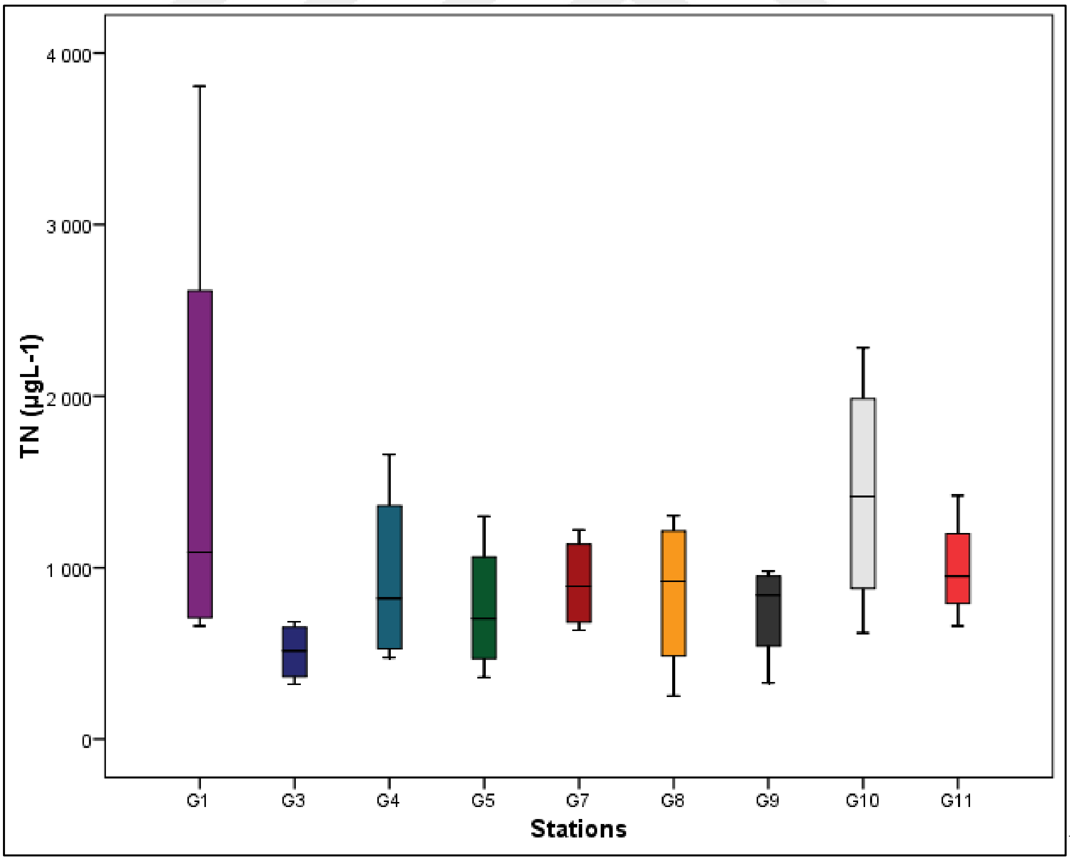



b)

**Figure 6.6a** Box plot diagrams showing the seasonal distribution of a) TP, and b) SD in the stations. The horizontal black line in the boxes indicates the median value of the variables




a)




b)

**Figure 6.6b** Box plot diagrams showing the seasonal distribution of a) BOD, and b) TN in the stations. The horizontal black line in the boxes indicates the median value of the variables

### 6.3.2 Phytoplankton Composition and Distribution

The phytoplankton composition of three lakes and six reservoirs was characterized by 206 species belonging to 8 phytoplankton phyla including Bacillariophyta, Cyanobacteria, Chlorophyta, Charophyta, Miozoa, Cryptophyta, Euglenozoa, and Ochrophyta were recorded during the study period (Appendix F). Fifteen functional groups: **B, D, E, F, G, J, $L_M$, $L_O$, M, MP, P, T, W1, X1,** and **Y** were recorded to be predominants and were subsequently examined in phytoplankton assemblages of studied water bodies (Table 6.4). Photographs of some non-diatom species and diatom species given in Figure 6.7.

**Table 6.4** Phytoplankton functional groups (FG) and their descriptor species and factor values in the lakes and reservoirs

| FG | Descriptor species | G1 | G3 | G4 | G5 | G7 | G8 | G9 | G10 | G11 |
|---|---|---|---|---|---|---|---|---|---|---|
| **B** | *Cyclotella ocellata* | - | - | - | 3 | 3 | 3 | 3 | 3 | - |
| | *Cyclotella iris* | - | 3 | 3 | 3 | - | 3 | 3 | - | 3 |
| **D** | *Fragilaria biceps* | - | - | - | - | - | - | - | 5 | - |
| **E** | *Dinobryon divergens* | 2 | - | - | - | - | - | - | | - |
| **F** | *Botryococcus braunii* | - | - | - | - | - | - | - | 5 | - |
| **G** | *Pandorina morum* | - | - | - | 1 | - | - | - | - | - |
| | *Coelastrum microporum* | - | - | - | - | - | - | - | 1 | - |
| **J** | *Tetraëdron minimum* | - | - | - | - | - | - | - | 1 | - |
| | *Pediastrum simplex* | - | - | - | - | - | 1 | - | - | - |
| | *Pediastrum duplex* | - | - | - | 1 | - | - | - | - | - |
| **$L_M$** | *Ceratium furcoides* | - | - | - | - | - | - | - | 0 | - |
| | *Ceratium hirundinella* | - | 0 | - | 0 | - | - | - | - | - |
| **$L_O$** | *Peridinium cinctum* | - | - | - | - | - | 5 | 5 | - | 3 |
| | *Peridiniopsis cunningtonii* | 3 | - | - | - | - | - | - | - | - |
| **M** | Microcystis aeruginosa | 0 | - | 0 | - | - | - | - | 0 | - |
| **MP** | *Ulnaria ulna* | - | 5 | - | - | - | - | - | - | - |
| | *Cymbella excisa* | 5 | 5 | 5 | - | - | - | - | 5 | 5 |
| **P** | *Fragilaria dilatata* | 5 | 5 | 5 | 5 | - | 5 | - | 5 | 5 |
| | *Staurastrum cingulum* | - | - | 5 | - | - | - | 5 | - | 5 |
| **T** | *Geminella interrupta* | - | - | - | - | 5 | - | - | - | - |
| **W1** | *Euglena acus* | 3 | - | 3 | - | - | - | - | 0 | - |
| **X1** | *Monoraphidium arcuatum* | - | - | - | - | - | - | 4 | - | - |
| | *Monoraphidium contortum* | - | 4 | - | - | - | - | - | - | - |
| **Y** | *Cryptomonas ovata* | 3 | - | 3 | 2 | - | 5 | - | - | 5 |

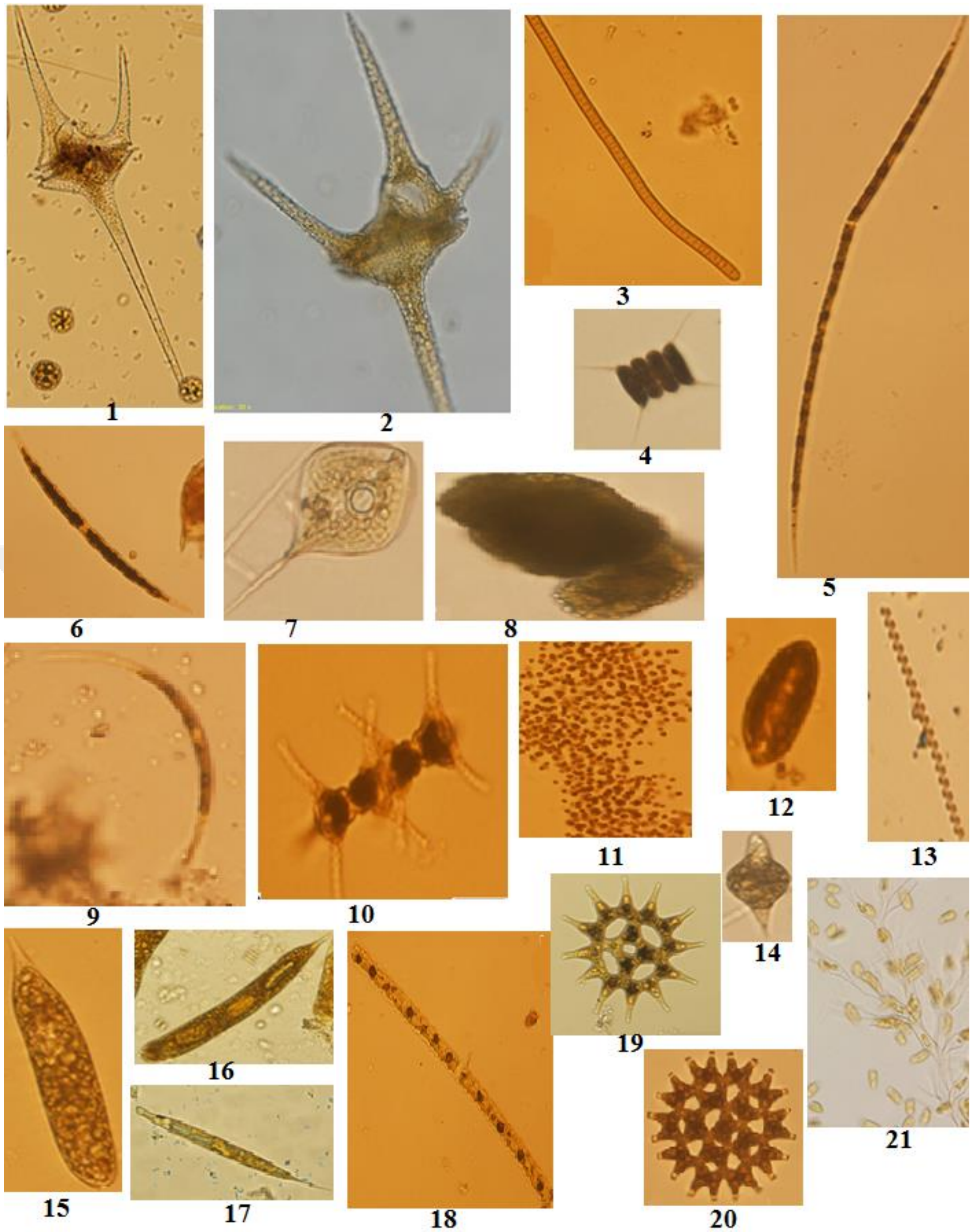



**Figure 6.7** 1) *Ceratium furcoides*; 2) *C. hirundinella*; 3) *Oscillatoria limosa*; 4) *Scenedesmus communis*; 5) *Closterium acirculare*; 6) *C. littorale*; 7) *Phacus caudatus*; 8) *Botryococcus braunii*; 9) *Monoraphidium arcuatum*; 10) *Staurastrum cingulum*; 11) *Microcystis aeroginosa*; 12) *Cryptomonas ovata*; 13) *Spirulina maior*; 14) *Euglena chlamydophora*; 15) *E. velata*; 16) *E. oxyuris*; 17) *E. acus*; 18) *Mougeotia quadrangulata*; 19) *Pediastrum simplex*; 20) *P. duplex*; 21) *Dinobryon divergens*

The Bacillariophyta phylum dominated the phytoplankton composition in terms of species number (107), when only one taxon (1) was observed in the Ochrophyta (Appendix B) during the study period. *Peridinium cinctum*, *C. ocellata*, *Cyclotella* *iris*, *Cymbella excisa*, *Ceratium hirundinella*, *Scenedesmus communis*, *Cryptomonas ovota*, *Microcystis aeruginosa*, *Navicula lanceolata*, and *Fragilaria capucina* were commonly found in the lakes and reservoirs. The species number per site changed also from a water body to another (Figure 6.8) and this number in the lakes was generally higher than those of reservoirs. The highest species number (77) was found at Lake Gölhisar, while the lowest (45) was recorded at Osmankalfalar reservoir. The lists of species recorded at each water body are given in Appendices G to O.

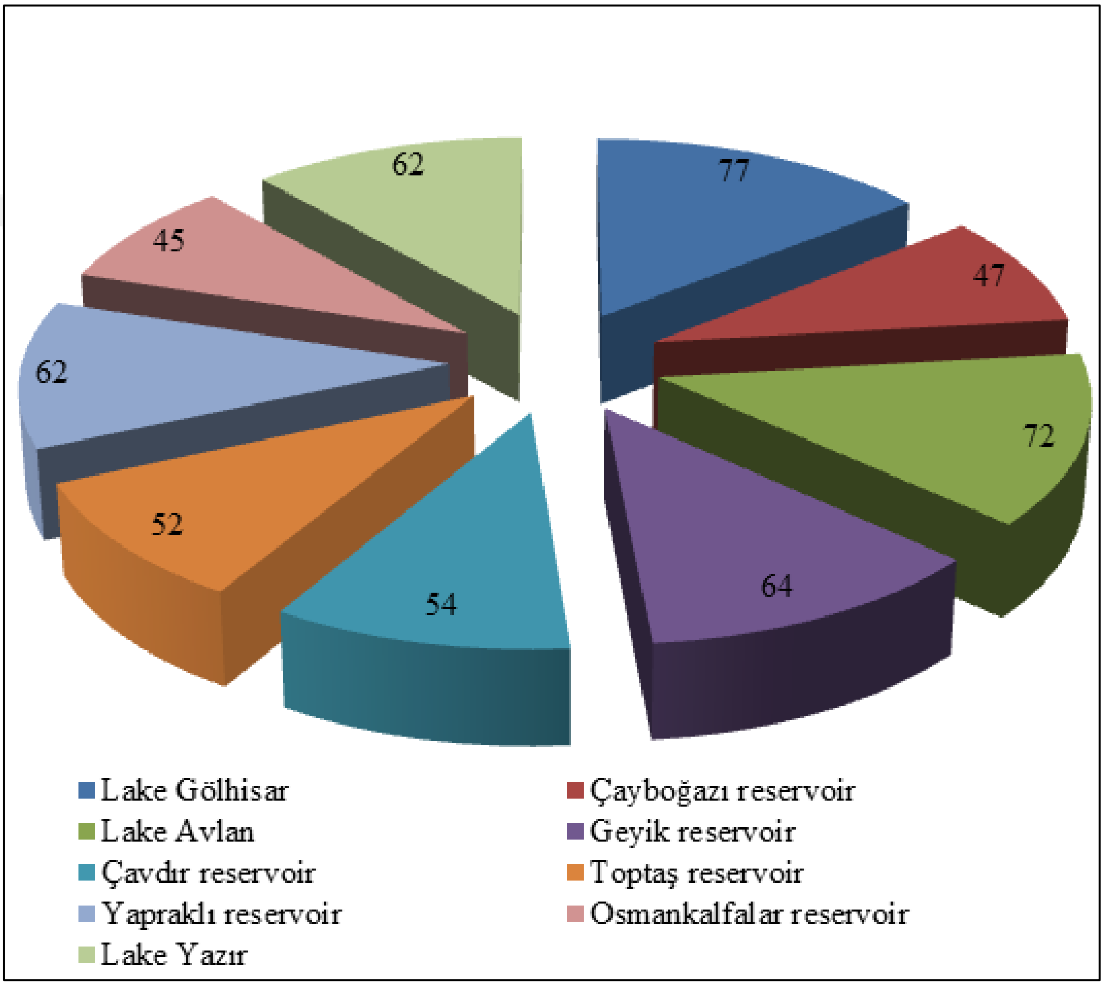



**Figure 6.8** Species number per site

### 6.3.3 Seasonality of Phytoplankton

The phytoplankton composition and biovolume changed specially during the study period according to the seasonal changes in water characteristics. Peaks of phytoplankton abundance did not appear at the same time at the different lakes and reservoirs, and phytoplankton succession showed distinct spatial heterogeneity during the four seasons (summer 2014, fall 2014, spring 2015 and summer 2015) in the different lentic ecosystems. The Figure 6.9a,b and c show the seasonal variations in the phytoplankton phyla' total biovolume ($\times10^4$ $\mu m^3.L^{-1}$) in the lakes and reservoirs. The mainly abundant phylum was Bacillariophyta followed by the Chlorophyta phylum. In Lake Gölhisar (G1), the highest total biovolume was observed respectively in Chlorophyta, Miozoa, and Bacillariophyta phyla in fall 2014 and summer 2015 while the lowest contribution was observed in Cyanobacteria, Charophyta and Cryptophyta species in spring 2015. The lowest total biovolume was found in Ochrophyta phylum in spring 2015 and the highest contribution in Bacillariophyta phylum in summer 2014, while Charophyta phylum was absent at the Çayboğazı reservoir during all the study period. Lake Avlan (G4) and Geyik reservoir (G5) had respectively their lowest total biovolume in Ochrophyta and Euglenozoa phyla in spring 2015, while Bacillariophyta species and Chlorophyta species had their peaks of abundance at Lake Avlan and Geyik reservoir during summer 2015 and 2014 respectively. At Çavdır reservoir Chlorophyta species total biovolume was high in summer 2014 when Ochrophyta contributed in a lower part to the phytoplankton total biovolume during spring 2015. On the other hand, at the same reservoir, Bacillariophyta species were the most abundant phytoplankton group in spring 2015. The lowest contributions were found in Cyanobacteria and Euglenozoa during summer and fall 2014, while Miozoa and Chlorophyta were abundant in summer 2014 and 2015 respectively at Toptaş reservoir. Bacillariophyta and Chlorophyta were abundant at Yapraklı reservoir during summer 2014 and 2015 respectively, while Charophyta and Bacillariophyta phyla dominated the phytoplankton community of Yapraklı reservoir during fall 2014 and summer 2015. The phytoplankton abundance was mainly dominated at Osmankalfalar reservoir by Bacillariophyta, while at Lake Yazır it was dominated by Miozoa. Charophyta phylum was not found at Toptaş reservoir, while Cryptophyta and Charophyta were absent at Osmankalfalar reservoir during the study period.

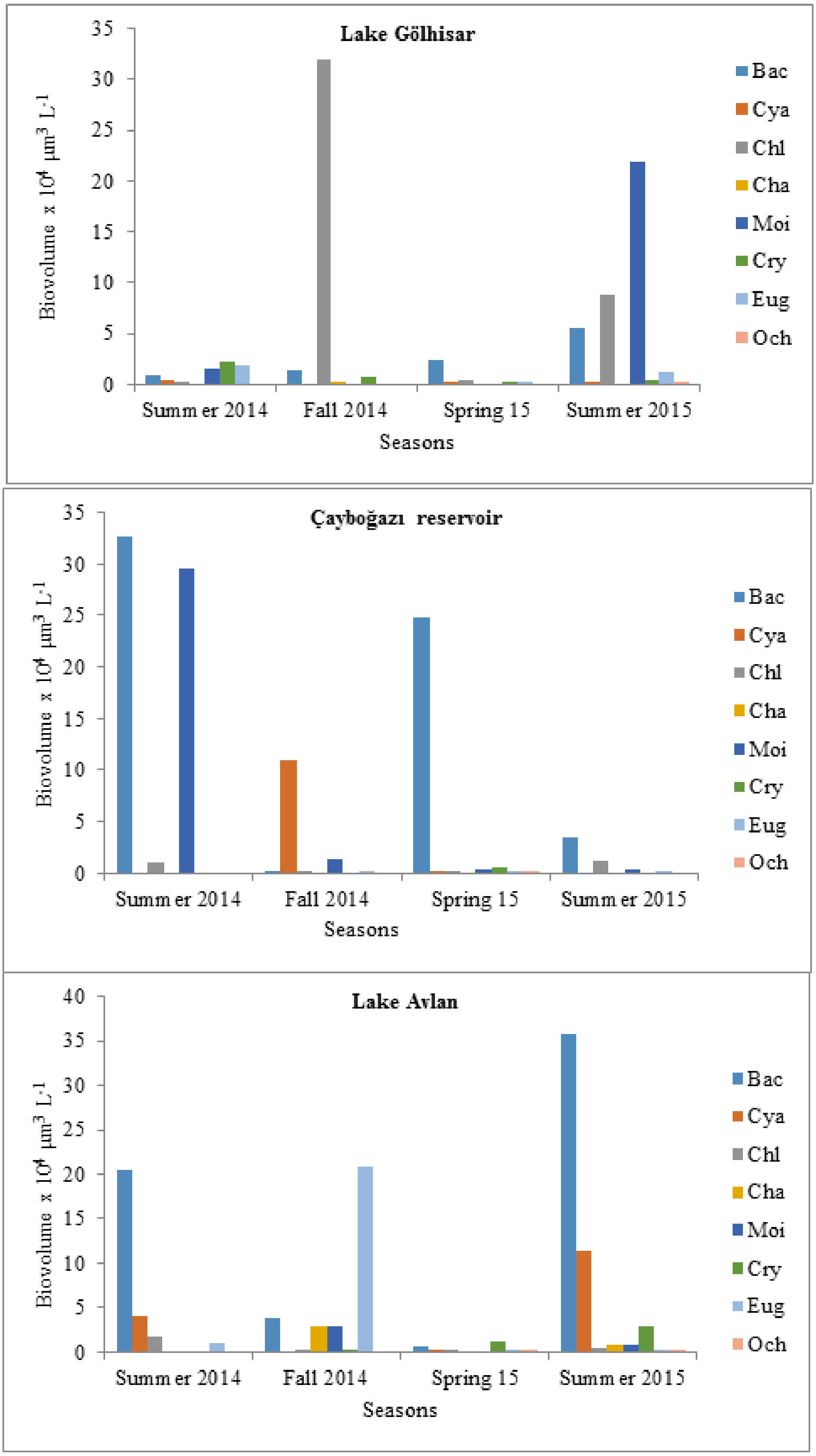



**Figure 6.9a** Seasonal variations in phytoplankton at Lakes Gölhisar, Avlan and Çayboğazı reservoir

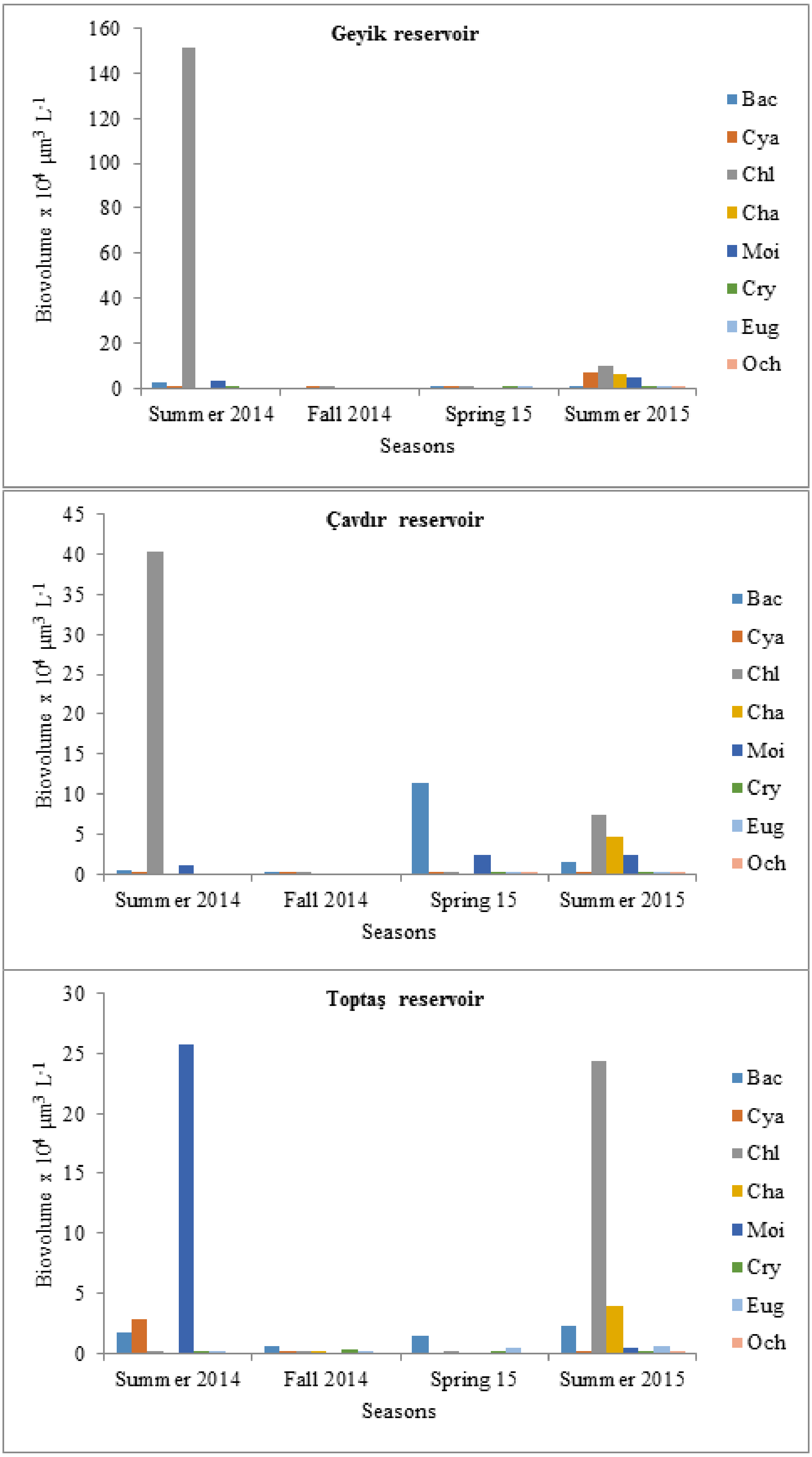



**Figure 6.9b** Seasonal variations in phytoplankton at Geyik, Çavdır and Toptaş reservoirs

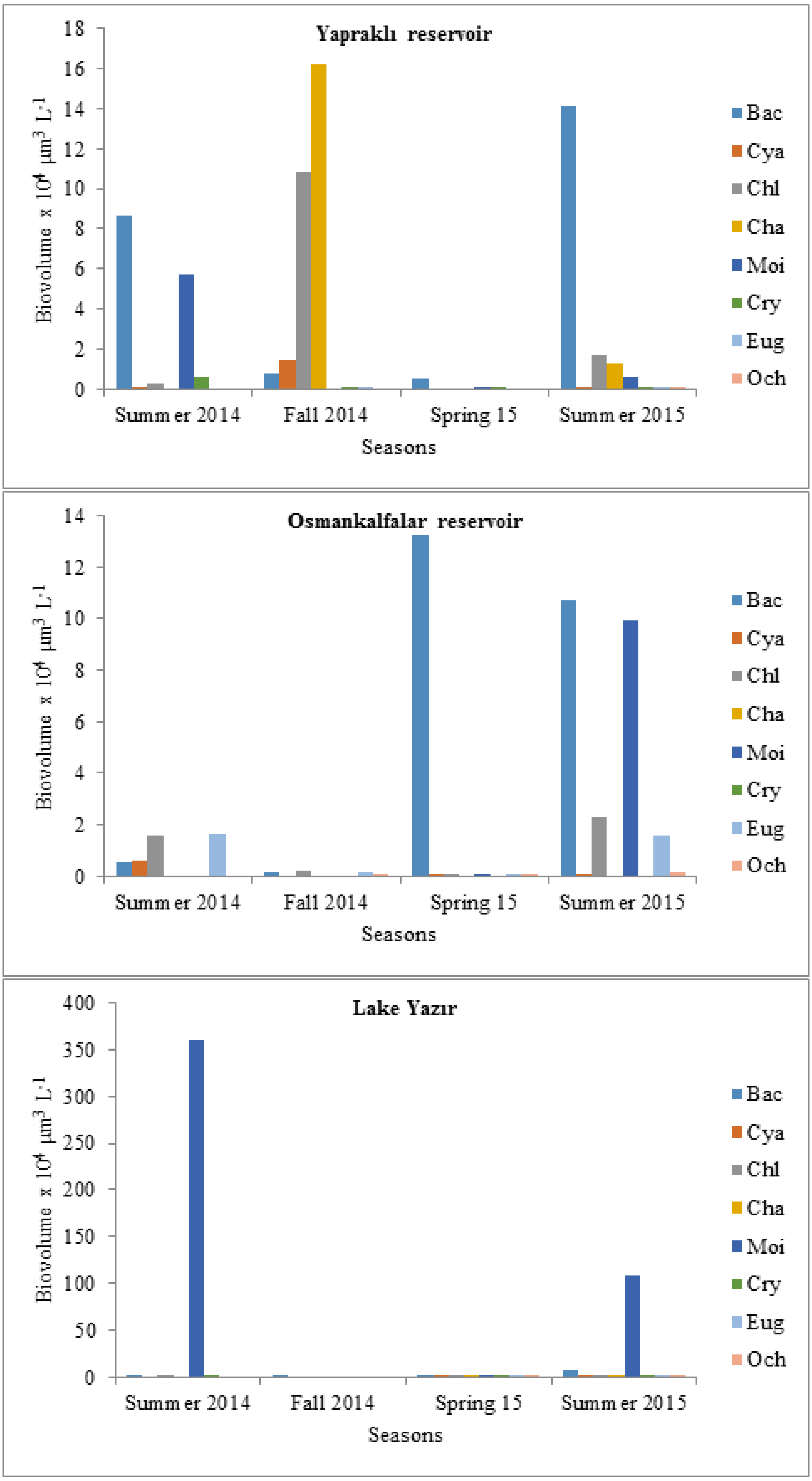



**Figure 6.9c** Seasonal variations in phytoplankton at Yapraklı, Osmankalfalar reservoirs and Lake Yazır

During the present study, it has appeared that the species number changed not only per site, but changed also per season. the species number changed from a minimum of 10 at Çavdır reservoir in summer 2014 to a maximum of 49 at Lake Avlan in summer 2015. This species number was generally higher in 2015 than those of 2014 (Table 6.5).

**Table 6.5** Species number per season during the study period

| Sites | Summer 2014 | Fall 2014 | Spring 2015 | Summer 2015 |
|---|---|---|---|---|
| Lake Gölhisar | 16 | 18 | 33 | 46 |
| Çayboğazı reservoir | 13 | 14 | 25 | 33 |
| Lake Avlan | 11 | 21 | 23 | 49 |
| Geyik resevoir | 15 | 16 | 25 | 42 |
| Çavdır reservoir | 10 | 16 | 27 | 34 |
| Toptaş reservoir | 10 | 14 | 28 | 38 |
| Yapraklı reservoir | 12 | 19 | 18 | 43 |
| Osmankalfalar reservoir | 13 | 18 | 24 | 30 |
| Lake Yazır | 14 | 17 | 31 | 34 |

### 6.3.4 Species-Environmental variables Relationships

A canonical correspondence analysis was performed to evaluate the relationship between phytoplankton assemblages and environmental factors of the lakes and reservoirs. The results of CCA confirmed by the forward selection using the Monte Carlo test ($p=0.012$, $F = 1.977$) showed that 13.6% of cumulative percentage variance of species data and 93.2% between species-environment correlations were explained by the first two CCA axes. (Table 6.6). The partial CCA results (Table 6.7) indicated that explanatory factors such as pH, TP, $N\text{-}NO_3$, TOC, and conductivity had a key role ($p<0.02$) on the phytoplankton composition, dynamic and distribution among the water ecosystems during the study period.

**Table 6.6** Summary of CCA results using Monte Carlo permutation test for phytoplankton species-environment factors relationship

| Axes | λ1 | λ2 | λ3 | λ4 | Total inertia |
|---|---|---|---|---|---|
| Eigen values | 0.820 | 0.697 | 0.694 | 0.595 | 11.189 |
| Species-environment correlations | 0.964 | 0.932 | 0.965 | 0.909 | |
| Cumulative percentage variance | | | | | |
| of species data | 7.3 | 13.6 | 19.8 | 25.1 | |
| of species-environment relation | 18.4 | 34.1 | 49.7 | 63.0 | |
| Sum of all eigen values | | | | | 11.189 |
| Sum of all canonical eigen values | | | | | 4.452 |
| Test of significance of first canonical axis : eigen value = 0.820 | | | | | |
| | | | F-ratio = 1.977 | | p-value = 0.0120 |

**Table 6.7** Partial CCA result of Environmental variables

| Environmental variables | λ | F | P |
|---|---|---|---|
| Temperature | 0.578 | 2.166 | 0.002 |
| Conductivity | 0.545 | 2.034 | 0.002 |
| Altitude | 0.532 | 1.985 | 0.004 |
| $CaCO_3$ | 0.612 | 2.298 | 0.004 |
| TOC | 0.580 | 2.174 | 0.004 |
| TP | 0.575 | 2.153 | 0.002 |
| $PO_4$ | 0.554 | 2.071 | 0.004 |
| $NO_2$ | 0.518 | 1.929 | 0.004 |
| $BOD_5$ | 0.438 | 1.622 | 0.004 |

With regard to the CCA ordination (Figure 6.10), environmental factors such as pH, nutrients, TOC, conductivity, and water temperature governed phytoplankton distribution in the lakes and reservoirs. *C. ovata*, *N. lanceolata* and *Cryptomonas rostratiformis C. hirundinella*, *Zygnema pectinatum*, *Phacus caudatus*, *Microcystis flosaquae*, *Ulnaria ulna*, *Navicula cryptocephala*, *Gomphonema truncatum*, *Epithemia sorex*, and *Euglena proxima* were attributed to TP, P-$PO_4$, N-$NO_3$, in Geyik (G7) and Osmankalfalar (G10) reservoirs. *Fragilaria incognita*, *Navicula slesvicensis*, *Gomphonema parvulum*, *Clevamphora ovalis*, *C. ocellata*, *Cyclotella meneghiniana*, *Cocconeis placentula*, *Cymbella cymbiformis*, *Epithemia turgida*, *F. capucina*, *Diatoma tenuis*, *Gyrosigma attenuatum*, *Geminella interrupta*, *Scenedesmus obliquus*, *Euglena anabaena* and *E. chlamydophora* preferred high N-$NO_2$ and conductivity in Lake Gölhisar (G1). Species such as *Anabaena catenula*, *Cosmarium punctulatum*, *M. aeruginosa Cymbella gracilis*, *Diatoma vulgaris*, *Eunotia tenella*, *Fragilaria dilatata*, *Melosira lineata*, *Melosira varians*, *Chlamydomonas globosa*, *Pediastrum duplex*, *Chroococcus turgidus*, *Staurastrum crenulatum*, *Mougeotia boodlei* and *Trachelomonas scabra* were associated with warm waters while TOC governed especially the distribution of *Pediastrum boryanum*, *P. simplex*, *Navicula capitatoradiata*, and *Eunotia glacialis* in Toptaş reservoir (G8). The distribution of *C. iris*, *E. sorex*, *Chlamydomonas lapponica*, and *E. proxima* in Çayboğazı reservoir (G3) were associated with high alkaline water.

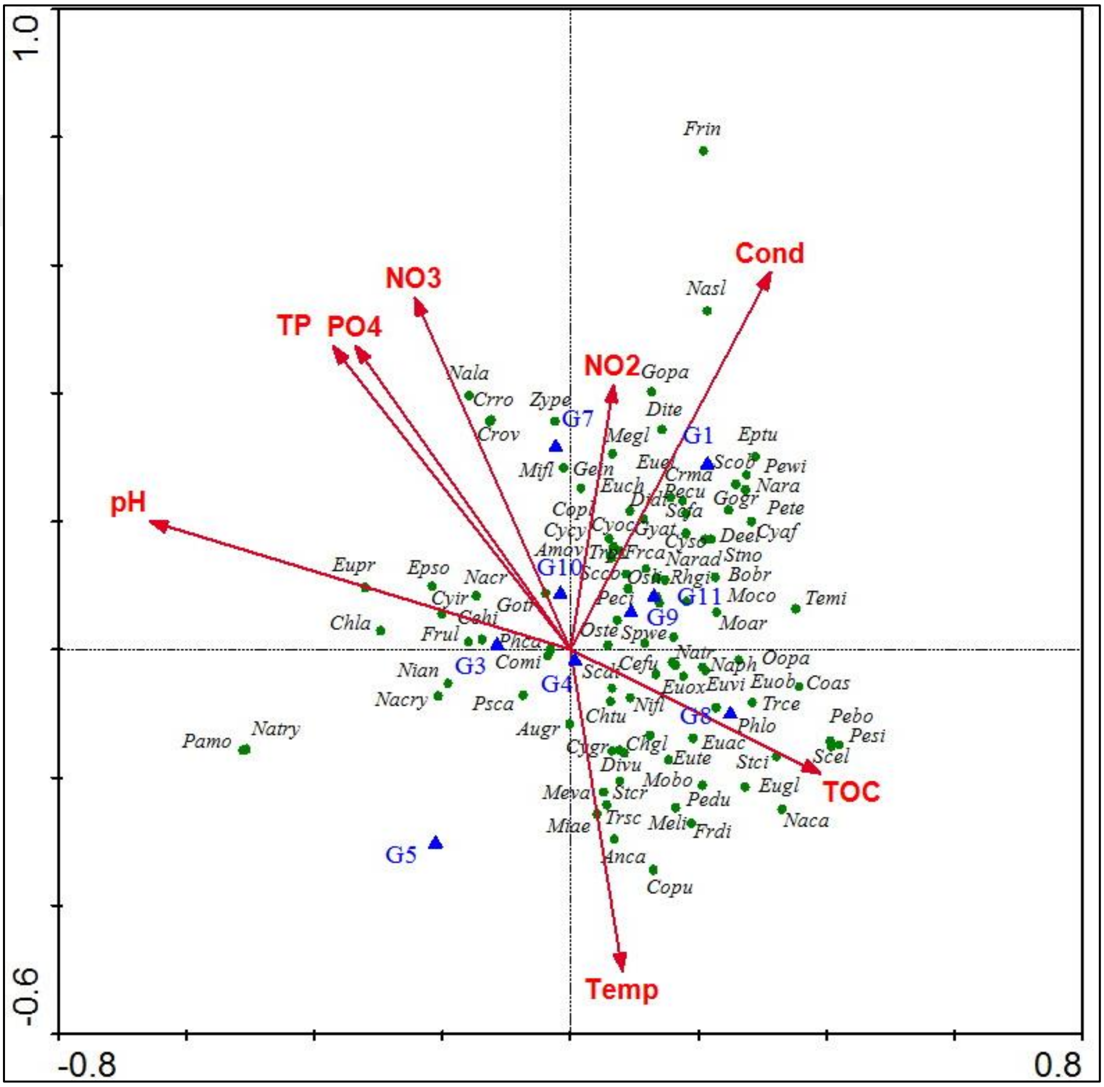



**Figure 6.10** Canonical correspondence analysis ordination of species-environmental relationships in the lakes and reservoirs (up triangular) Abbreviations of phsico-chemical variables are given in the list of symbols/abbreviations. For species codes see Appendix F

In addition to the canonical correspondence analysis, diatom species-environment relationships were evaluated using weighted average (WA) regression. The results of the weighted averaging regression evaluation of species optima ($u_k$) and tolerance ($t_k$)

scores to environmental parameters are given in Table 6.8. *F. capucina*, *S. communis*, *C. ocellata*, *C. turgidus*, *C. excisa*, *Euglena oxyuris*, and *G. parvulum* were common species in lakes and reservoirs with high $N_2$ (Hill's diversity) values.

According to these results, *C. ovata*, *N. lanceolate*, *Euglena viridis*, *Tetraedron minimum*, *Coelastrum microporum*, *Cymbella tumidula*, *E. sorex*, *F. incognita*, *G. parvulum* and *C. rostratiformis* preferred high nutrients (TP, P-$PO_4$, N-$NO_3$ and N-$NO_2$). On the other hand, *Stauroneis nobilis*, *Staurastrum cingulum*, *Scenedesmus ellipticus*, *P. boryanum*, *Navicula tripunctata*, *Navicula phylepta*, *Mougeotia parvula*, *N. capitatoradiata*, *G. attenuatum*, *Ulnaria biceps*, *C. gracilis*, *Cymbella tumida*, *Botryococcus braunii*, *Ulothrix subconstricta*, *M. boodlei*, *E. tenella*, *Euglena oblonga*, *D. vulgaris*, *C. punctulatum*, *A. catenula*, *P. cinctum*, *Pandorina morum*, *Nitzschia angustata*, *Navicula cryptotenella*, and *G. truncatum* were associeted to lower TP and N-$NO_3$. Phyotoplankton species such as *G. parvulum*, *F. incognita*, *D. tenuis, E. turgida* var.*granulata*, and *E. anabaena* were associated with high conductivity, in contrast to *U. subconstricta*, *T. scabra*, *S. crenulatum*, *Spirogyra weberi*, *P. morum*, *N. cryptotenella*, *M. aeruginosa*, *M. lineata*, *M/ varians*, *E. glacialis*, *C. punctulatum*, *A. catenula*, and *Aulacoseira granulata* which preferred lower conductivity.

In related to water temperature, *A. catenula*, *C. ovalis*, *C.globosa*, *C. punctulatum*, *Coelastrum astroideum*, *Euglena acus*, *E; oxyuris*, *E. glacialis*, *G. truncatum*, *M. varians*, *M. aeruginosa*, *N. capitatoradiata*, *Navicula cryptonella*, *P. morum*, *P. boryanum*, *P. Duplex*, *Phacus longicauda*, *S. cingulum*, *S. crenulatum*, *Trachelomonas cervicula*, and *T. scabra* were found to be abundant in warm water than others phytoplankton species. With regard to pH, most of the species preferred alkaline water. The results of the weighted averaging regression evaluation indicated also that species such as, *Z. pectinatum*, *S. crenulatum*, *M. flos-aquae*, *F. incognita*, *C. ovalis* preferred high values of TOC, while *Cymatopleura solea*, *C. tumidula*, *C. rostratiformis* , *U. biceps*, *G. attenuatum*, *Navicula cryptotenella*, *P. morum*, *S. nobilis*, *Trachelomonas pseudofelex* were associed with low TOC.

**Table 6.8** Weighted average regression in lakes and reservoirs, $u_k$ and $t_k$ indicated optima and tolerance, respectively. For species codes see Appendix F

| | Temperature °C | | pH | | Conductivity µS cm$^{-1}$ | | TP µg l$^{-1}$ | | P-PO$_4$ mg l$^{-1}$ | | N-NO$_3$ mg l$^{-1}$ | | N-NO$_2$ mg l$^{-1}$ | | TOC mg l$^{-1}$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Codes | $u_k$ | $t_k$ | $u_k$ | $t_k$ | $u_k$ | $t_k$ | $u_k$ | $t_k$ | $u_k$ | $t_k$ | $u_k$ | $t_k$ | $u_k$ | $t_k$ | $u_k$ | $t_k$ |
| Amov | 24.0 | 4.2 | 8.6 | 0.3 | 578.9 | 276.6 | 118.6 | 115.1 | 27.7 | 47.1 | 226.6 | 251.2 | 6.6 | 9.0 | 19.0 | 22.2 |
| Anca | 29.4 | 3.4 | 8.2 | 0.1 | 151.6 | 175.4 | 112.3 | 9.3 | 10.1 | 4.8 | 70.5 | 53.1 | 3.3 | 1.3 | 58.0 | 29.0 |
| Augr | 17.2 | 8.2 | 8.6 | 0.4 | 173.9 | 211.1 | 570.3 | 418.9 | 158.7 | 123.6 | 181.8 | 154.9 | 30.1 | 22.8 | 11.2 | 8.8 |
| Bobr | 23.0 | 2.2 | 8.8 | 0.4 | 294.7 | 161.3 | 41.8 | 51.8 | 11.4 | 4.9 | 276.9 | 114.2 | 38.9 | 25.6 | 12.7 | 20.5 |
| Cefu | 23.5 | 4.7 | 8.6 | 0.4 | 282.8 | 168.9 | 89.7 | 116.8 | 22.6 | 47.9 | 233.6 | 199.2 | 24.1 | 24.2 | 21.7 | 24.4 |
| Cehi | 20.5 | 5.8 | 8.8 | 0.2 | 293.6 | 107.5 | 197.8 | 230.4 | 66.1 | 105.7 | 253.2 | 192.3 | 17.3 | 32.0 | 12.5 | 12.0 |
| Chgl | 25.5 | 4.7 | 8.2 | 0.3 | 335.3 | 327.0 | 103.1 | 35.7 | 13.5 | 4.7 | 146.3 | 111.7 | 8.0 | 11.1 | 44.0 | 24.3 |
| Chla | 23.1 | 0.1 | 9.0 | 0.3 | 434.6 | 130.8 | 307.0 | 240.4 | 129.6 | 127.3 | 449.6 | 289.9 | 6.9 | 5.7 | 7.5 | 3.4 |
| Chtu | 22.1 | 5.7 | 8.5 | 0.4 | 299.2 | 135.1 | 167.6 | 260.0 | 51.9 | 102.8 | 171.5 | 186.8 | 14.7 | 23.6 | 23.2 | 23.0 |
| Copl | 20.8 | 3.2 | 8.5 | 0.3 | 369.6 | 167.6 | 94.2 | 63.1 | 17.8 | 16.9 | 223.8 | 152.1 | 15.0 | 12.6 | 39.0 | 26.9 |
| Coas | 24.7 | 4.1 | 8.3 | 0.2 | 458.8 | 304.4 | 89.4 | 43.6 | 15.1 | 3.3 | 201.2 | 96.3 | 11.6 | 12.1 | 34.4 | 26.4 |
| Comi | 22.2 | 6.6 | 8.7 | 0.3 | 335.0 | 77.1 | 513.1 | 222.0 | 195.7 | 129.6 | 401.9 | 148.5 | 29.5 | 16.7 | 5.0 | 2.2 |
| Copu | 27.3 | 3.2 | 8.3 | 0.3 | 216.2 | 131.9 | 87.2 | 57.6 | 12.2 | 3.2 | 90.1 | 33.8 | 4.1 | 1.6 | 36.6 | 32.1 |
| Crma | 19.0 | 7.1 | 8.2 | 0.2 | 576.3 | 360.6 | 122.9 | 41.3 | 18.4 | 3.2 | 264.7 | 207.3 | 3.6 | 2.5 | 9.8 | 10.0 |
| Crov | 18.5 | 6.4 | 9.3 | 0.7 | 504.7 | 796.8 | 752.0 | 459.7 | 289.4 | 188.9 | 234.6 | 294.6 | 73.9 | 61.3 | 11.7 | 20.5 |
| Caro | 14.8 | 2.7 | 9.0 | 0.7 | 310.5 | 43.4 | 500.8 | 562.9 | 193.1 | 221.7 | 511.2 | 456.6 | 56.1 | 57.5 | 3.4 | 2.9 |
| Cycy | 13.7 | 0.7 | 8.5 | 0.2 | 298.6 | 1.6 | 212.3 | 325.6 | 75.2 | 120.1 | 392.9 | 147.1 | 13.4 | 6.4 | 4.8 | 7.1 |
| Cyir | 19.7 | 5.5 | 9.0 | 0.3 | 395.1 | 119.4 | 441.6 | 333.8 | 195.3 | 167.7 | 392.2 | 209.9 | 11.1 | 11.2 | 10.6 | 7.5 |
| Cyoc | 15.0 | 3.7 | 8.5 | 0.2 | 297.0 | 66.3 | 61.0 | 83.1 | 17.1 | 30.6 | 536.0 | 293.4 | 13.7 | 12.0 | 4.2 | 11.9 |
| Cyso | 17.6 | 5.2 | 8.1 | 0.5 | 385.2 | 171.7 | 89.4 | 76.7 | 13.8 | 6.7 | 413.8 | 312.4 | 4.5 | 3.3 | 3.2 | 5.0 |
| Cyaf | 21.2 | 4.9 | 8.4 | 0.3 | 552.1 | 289.6 | 141.2 | 178.5 | 42.5 | 72.2 | 385.0 | 335.2 | 14.6 | 13.7 | 14.7 | 18.5 |
| Cygr | 23.2 | 1.9 | 8.7 | 0.3 | 325.9 | 39.0 | 41.8 | 6.3 | 10.5 | 2.2 | 71.4 | 40.4 | 4.0 | 6.0 | 10.2 | 6.7 |
| Cytu | 11.4 | 2.7 | 8.4 | 0.1 | 285.1 | 13.2 | 33.4 | 20.5 | 10.4 | 2.4 | 786.0 | 313.5 | 7.9 | 2.1 | 1.0 | 13.9 |
| Dite | 19.0 | 7.5 | 8.8 | 0.2 | 737.9 | 632.8 | 228.2 | 296.1 | 84.2 | 117.3 | 595.6 | 836.8 | 17.2 | 19.8 | 27.2 | 23.2 |

**Table 6.8** Continue

| | Temperature °C | | pH | | Conductivity µS $cm^{-1}$ | | TP µg $l^{-1}$ | | $P\text{-}PO_4$ mg $l^{-1}$ | | $N\text{-}NO_3$ mg $l^{-1}$ | | $N\text{-}NO_2$ mg $l^{-1}$ | | TOC mg $l^{-1}$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Codes | $u_k$ | $t_k$ | $u_k$ | $t_k$ | $u_k$ | $t_k$ | $u_k$ | $t_k$ | $u_k$ | $t_k$ | $u_k$ | $t_k$ | $u_k$ | $t_k$ | $u_k$ | $t_k$ |
| Divu | 23.0 | 1.8 | 8.7 | 0.3 | 327.3 | 69.6 | 43.8 | 49.1 | 13.3 | 18.0 | 97.3 | 103.3 | 9.5 | 13.4 | 14.0 | 8.5 |
| Didi | 14.0 | 4.1 | 8.3 | 0.3 | 333.3 | 119.7 | 194.5 | 326.2 | 46.6 | 155.6 | 295.7 | 468.4 | 7.4 | 17.1 | 3.3 | 4.4 |
| Epso | 23.5 | 1.3 | 9.0 | 0.7 | 562.9 | 235.0 | 362.5 | 223.8 | 156.8 | 123.8 | 520.0 | 261.8 | 8.4 | 4.6 | 8.4 | 8.7 |
| Eptu | 24.9 | 0.1 | 8.1 | 0.0 | 873.9 | 128.1 | 128.0 | 0.9 | 19.0 | 1.3 | 241.5 | 27.3 | 3.3 | 0.6 | 18.4 | 2.6 |
| Euel | 20.4 | 3.2 | 8.6 | 0.3 | 372.3 | 152.9 | 82.1 | 69.4 | 15.0 | 5.6 | 293.2 | 131.9 | 26.2 | 20.7 | 21.7 | 28.7 |
| Euac | 24.6 | 1.9 | 8.6 | 0.2 | 809.4 | 1062.7 | 212.7 | 303.2 | 79.6 | 113.1 | 186.6 | 137.5 | 8.0 | 12.0 | 15.9 | 17.4 |
| Euch | 21.3 | 6.8 | 8.9 | 0.7 | 462.2 | 274.1 | 395.2 | 483.7 | 145.2 | 195.2 | 194.4 | 117.3 | 46.5 | 50.9 | 8.5 | 6.1 |
| Euob | 28.8 | 4.5 | 8.5 | 0.3 | 635.8 | 231.9 | 62.0 | 54.7 | 13.3 | 5.2 | 96.3 | 125.8 | 4.7 | 1.3 | 10.1 | 6.9 |
| Euox | 18.0 | 5.8 | 8.4 | 0.3 | 321.3 | 104.1 | 54.2 | 105.7 | 18.6 | 40.2 | 356.3 | 194.8 | 14.8 | 17.0 | 4.5 | 7.5 |
| Eupr | 23.3 | 2.4 | 9.2 | 0.4 | 617.3 | 894.8 | 436.5 | 153.4 | 195.2 | 73.9 | 575.8 | 295.2 | 9.4 | 5.1 | 7.5 | 18.9 |
| Euvi | 14.6 | 6.4 | 8.5 | 0.8 | 243.7 | 84.7 | 602.7 | 477.4 | 261.4 | 214.8 | 494.3 | 422.8 | 46.4 | 25.2 | 13.0 | 3.2 |
| Eugl | 25.5 | 4.6 | 8.0 | 0.4 | 190.8 | 247.8 | 138.1 | 65.8 | 13.2 | 2.7 | 122.7 | 76.2 | 6.9 | 2.1 | 17.7 | 21.5 |
| Eute | 23.0 | 1.9 | 8.6 | 0.3 | 325.7 | 89.3 | 55.4 | 45.7 | 13.8 | 4.8 | 96.4 | 65.8 | 8.8 | 9.6 | 19.4 | 16.4 |
| Frbi | 13.9 | 1.2 | 8.4 | 0.1 | 283.8 | 2.1 | 42.8 | 7.1 | 11.1 | 2.8 | 528.2 | 68.8 | 13.7 | 0.7 | 1.0 | 13.9 |
| Frca | 17.0 | 5.8 | 8.5 | 0.3 | 391.4 | 337.0 | 140.2 | 175.1 | 39.7 | 69.9 | 365.3 | 415.2 | 14.1 | 18.2 | 15.3 | 22.1 |
| Frdi | 22.1 | 6.4 | 8.5 | 0.2 | 346.8 | 199.4 | 58.2 | 61.0 | 16.0 | 15.0 | 203.6 | 178.8 | 5.3 | 3.9 | 10.0 | 10.9 |
| Frin | 14.4 | 11.8 | 8.7 | 0.5 | 1160.1 | 849.7 | 453.9 | 278.4 | 168.7 | 131.7 | 1198.8 | 931.4 | 30.7 | 22.2 | 50.0 | 13.2 |
| Frul | 19.7 | 5.9 | 8.6 | 0.3 | 366.0 | 202.6 | 106.3 | 144.2 | 31.8 | 66.0 | 343.0 | 232.0 | 6.4 | 8.8 | 7.6 | 10.1 |
| Gein | 23.7 | 2.0 | 8.7 | 0.3 | 598.7 | 255.9 | 104.9 | 58.2 | 19.9 | 20.8 | 139.6 | 60.2 | 5.7 | 12.5 | 8.7 | 29.6 |
| Gogr | 24.5 | 1.4 | 8.2 | 0.4 | 726.6 | 368.5 | 112.9 | 51.0 | 18.0 | 4.3 | 208.6 | 104.0 | 4.1 | 4.9 | 19.1 | 9.2 |
| Gopa | 17.7 | 6.0 | 8.7 | 0.4 | 699.2 | 554.8 | 280.6 | 282.9 | 98.7 | 116.4 | 657.5 | 643.6 | 24.6 | 25.8 | 28.6 | 24.1 |
| Gotr | 22.9 | 3.0 | 8.5 | 0.3 | 499.5 | 193.9 | 103.6 | 25.8 | 19.7 | 2.5 | 262.8 | 142.2 | 2.7 | 4.4 | 6.7 | 10.9 |
| Gyat | 16.7 | 5.4 | 8.3 | 0.3 | 394.2 | 137.2 | 45.6 | 7.1 | 12.2 | 2.8 | 835.6 | 261.6 | 7.8 | 3.5 | 1.0 | 13.9 |
| Meli | 19.8 | 7.2 | 8.3 | 0.7 | 273.0 | 127.5 | 53.6 | 33.6 | 14.3 | 3.2 | 277.9 | 327.1 | 6.2 | 4.1 | 8.0 | 5.1 |
| Meva | 26.5 | 9.0 | 8.2 | 0.2 | 174.3 | 117.5 | 104.9 | 42.7 | 11.0 | 2.7 | 216.5 | 504.5 | 4.9 | 4.5 | 45.6 | 36.3 |

**Table 6.8** Continue

| Codes | Temperature °C | | pH | | Conductivity µS $cm^{-1}$ | | TP µg $l^{-1}$ | | $P\text{-}PO_4$ mg $l^{-1}$ | | $N\text{-}NO_3$ mg $l^{-1}$ | | $N\text{-}NO_2$ mg $l^{-1}$ | | TOC mg $l^{-1}$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $u_k$ | $t_k$ | $u_k$ | $t_k$ | $u_k$ | $t_k$ | $u_k$ | $t_k$ | $u_k$ | $t_k$ | $u_k$ | $t_k$ | $u_k$ | $t_k$ | $u_k$ | $t_k$ |
| Megl | 23.9 | 2.0 | 8.2 | 0.5 | 408.7 | 976.4 | 189.8 | 173.5 | 33.6 | 81.5 | 153.9 | 47.8 | 7.0 | 2.6 | 22.9 | 22.5 |
| Miae | 27.8 | 3.5 | 8.3 | 0.4 | 240.3 | 265.8 | 129.7 | 105.6 | 22.6 | 52.9 | 136.4 | 166.7 | 4.4 | 3.8 | 40.1 | 28.4 |
| Mifl | 20.3 | 1.1 | 8.3 | 0.3 | 356.9 | 3.7 | 67.0 | 31.8 | 15.1 | 3.3 | 228.8 | 29.5 | 27.7 | 13.6 | 60.7 | 18.1 |
| Moar | 23.3 | 1.8 | 8.5 | 0.3 | 470.4 | 268.4 | 57.9 | 48.0 | 14.3 | 4.2 | 126.1 | 86.1 | 8.3 | 7.7 | 14.6 | 5.3 |
| Moco | 24.4 | 1.2 | 8.3 | 0.4 | 667.8 | 497.9 | 103.6 | 56.6 | 17.5 | 3.5 | 182.2 | 133.6 | 3.0 | 0.7 | 22.7 | 10.1 |
| Mobo | 24.3 | 1.2 | 8.6 | 0.3 | 399.7 | 220.4 | 51.1 | 39.7 | 13.0 | 3.9 | 99.0 | 71.9 | 4.3 | 4.0 | 12.5 | 6.6 |
| Mopa | 22.6 | 1.8 | 8.6 | 0.3 | 351.1 | 24.7 | 41.5 | 14.9 | 12.6 | 3.2 | 102.5 | 75.0 | 11.2 | 11.5 | 19.2 | 20.9 |
| Naca | 29.1 | 4.4 | 8.6 | 0.2 | 468.7 | 199.7 | 42.0 | 32.3 | 11.8 | 3.2 | 56.8 | 57.9 | 5.0 | 1.0 | 10.8 | 17.1 |
| Nacr | 22.3 | 4.0 | 8.9 | 0.5 | 654.2 | 759.1 | 463.8 | 254.1 | 193.7 | 117.5 | 487.1 | 256.6 | 14.8 | 18.7 | 11.0 | 14.0 |
| Nacry | 24.2 | 3.9 | 8.8 | 0.3 | 319.0 | 116.7 | 97.3 | 25.4 | 19.5 | 3.7 | 181.6 | 74.7 | 2.2 | 1.2 | 9.5 | 7.5 |
| Nala | 17.1 | 5.5 | 9.4 | 1.0 | 338.0 | 222.1 | 842.0 | 572.3 | 324.6 | 240.2 | 188.6 | 88.3 | 89.3 | 66.9 | 7.2 | 9.2 |
| Naph | 23.7 | 1.2 | 8.8 | 0.1 | 365.2 | 183.9 | 43.4 | 35.0 | 13.4 | 4.9 | 215.9 | 123.0 | 26.3 | 27.6 | 7.4 | 2.6 |
| Nara | 24.5 | 1.4 | 8.2 | 0.4 | 759.6 | 427.7 | 117.8 | 52.2 | 18.4 | 4.0 | 209.2 | 107.6 | 3.8 | 4.7 | 19.3 | 7.7 |
| Narad | 21.0 | 5.9 | 8.5 | 0.2 | 698.4 | 1183.8 | 225.8 | 283.8 | 79.9 | 108.1 | 283.2 | 302.0 | 4.6 | 5.7 | 14.5 | 21.1 |
| Nasl | 18.7 | 9.1 | 8.7 | 0.3 | 863.4 | 584.5 | 288.7 | 267.5 | 104.1 | 110.0 | 756.1 | 765.4 | 23.3 | 16.8 | 41.1 | 23.7 |
| Natr | 21.3 | 2.6 | 8.5 | 0.3 | 392.0 | 149.7 | 42.0 | 10.3 | 12.2 | 2.6 | 190.8 | 193.8 | 10.1 | 9.0 | 7.5 | 6.9 |
| Natry | 27.7 | 5.8 | 9.2 | 0.4 | 232.4 | 19.9 | 100.6 | 23.9 | 20.0 | 2.4 | 144.3 | 179.2 | 2.1 | 2.8 | 2.4 | 18.1 |
| Nian | 23.2 | 0.0 | 8.8 | 0.0 | 320.1 | 34.1 | 99.8 | 17.8 | 20.0 | 2.5 | 198.3 | 40.5 | 2.0 | 0.2 | 10.7 | 15.3 |
| Nifl | 24.7 | 2.5 | 8.3 | 0.3 | 381.3 | 188.0 | 117.3 | 48.1 | 19.2 | 4.6 | 248.9 | 183.9 | 3.0 | 2.1 | 23.3 | 9.8 |
| Oopa | 24.9 | 4.0 | 8.3 | 0.4 | 639.1 | 378.3 | 84.2 | 67.9 | 17.2 | 2.8 | 180.7 | 91.9 | 3.8 | 0.8 | 14.1 | 6.6 |
| Osli | 23.8 | 2.3 | 8.5 | 0.4 | 322.0 | 314.0 | 140.0 | 17.8 | 20.9 | 3.3 | 165.8 | 133.3 | 2.9 | 2.2 | 28.5 | 10.8 |
| Oste | 24.7 | 4.5 | 8.3 | 0.5 | 441.6 | 219.9 | 146.9 | 210.8 | 27.0 | 64.3 | 291.7 | 111.8 | 3.9 | 12.6 | 20.1 | 10.0 |
| Pamo | 27.8 | 4.9 | 9.2 | 0.7 | 237.9 | 108.7 | 99.9 | 13.8 | 20.0 | 1.9 | 141.9 | 59.6 | 2.1 | 7.9 | 1.9 | 12.3 |
| Pebo | 30.9 | 2.3 | 8.5 | 0.2 | 587.9 | 54.1 | 41.8 | 7.2 | 12.1 | 2.8 | 186.6 | 223.9 | 6.5 | 2.3 | 5.5 | 2.4 |
| Pedu | 27.5 | 5.8 | 8.4 | 0.3 | 335.9 | 236.5 | 133.5 | 203.7 | 28.8 | 62.2 | 110.1 | 121.9 | 8.8 | 10.7 | 25.2 | 26.2 |

**Table 6.8** Continue

| | Temperature °C | | pH | | Conductivity µS $cm^{-1}$ | | TP µg $l^{-1}$ | | $P\text{-}PO_4$ mg $l^{-1}$ | | $N\text{-}NO_3$ mg $l^{-1}$ | | $N\text{-}NO_2$ mg $l^{-1}$ | | TOC mg $l^{-1}$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Codes | $u_k$ | $t_k$ | $u_k$ | $t_k$ | $u_k$ | $t_k$ | $u_k$ | $t_k$ | $u_k$ | $t_k$ | $u_k$ | $t_k$ | $u_k$ | $t_k$ | $u_k$ | $t_k$ |
| Pecu | 24.3 | 5.9 | 8.5 | 0.3 | 1406.3 | 1202.3 | 318.0 | 271.8 | 109.1 | 110.5 | 213.0 | 87.2 | 6.0 | 11.9 | 27.2 | 20.8 |
| Peci | 25.4 | 1.6 | 8.3 | 0.3 | 521.0 | 199.7 | 123.1 | 21.4 | 20.8 | 1.0 | 273.5 | 116.3 | 2.4 | 0.4 | 19.0 | 9.5 |
| Pewi | 24.8 | 2.4 | 8.2 | 0.4 | 821.8 | 393.6 | 124.2 | 46.0 | 18.5 | 4.6 | 226.0 | 105.7 | 3.6 | 3.8 | 19.8 | 17.9 |
| Phca | 22.0 | 1.0 | 8.7 | 0.2 | 327.9 | 32.8 | 473.0 | 332.8 | 179.9 | 130.7 | 395.2 | 100.9 | 30.9 | 9.1 | 8.0 | 27.8 |
| Phlo | 25.9 | 3.8 | 8.5 | 0.3 | 526.9 | 246.2 | 68.2 | 55.4 | 15.9 | 3.3 | 193.0 | 124.3 | 5.4 | 2.8 | 14.5 | 17.5 |
| Psca | 22.6 | 7.2 | 8.6 | 0.4 | 312.6 | 157.3 | 57.8 | 35.3 | 14.0 | 4.5 | 357.3 | 324.8 | 13.7 | 17.0 | 5.8 | 5.0 |
| Rhgi | 24.7 | 1.2 | 8.2 | 0.3 | 540.9 | 254.5 | 114.0 | 45.3 | 19.0 | 4.5 | 255.0 | 112.1 | 3.6 | 4.4 | 19.6 | 4.5 |
| Scco | 23.2 | 5.4 | 8.4 | 0.3 | 448.3 | 382.6 | 132.9 | 208.0 | 41.4 | 83.6 | 231.6 | 186.8 | 13.1 | 15.1 | 16.3 | 17.7 |
| Scdi | 23.1 | 5.8 | 8.5 | 0.4 | 384.7 | 144.2 | 99.6 | 161.6 | 30.5 | 63.2 | 253.3 | 228.2 | 8.6 | 9.3 | 7.7 | 5.4 |
| Scel | 31.0 | 3.3 | 8.5 | 0.3 | 582.7 | 75.0 | 47.9 | 104.6 | 14.7 | 46.5 | 144.0 | 231.2 | 6.5 | 7.4 | 5.7 | 2.1 |
| Scfa | 23.9 | 6.6 | 8.2 | 0.1 | 601.6 | 262.6 | 106.4 | 46.3 | 18.0 | 3.5 | 288.9 | 101.6 | 4.5 | 3.5 | 12.7 | 9.7 |
| Scob | 22.7 | 6.9 | 8.1 | 0.4 | 725.7 | 483.5 | 123.9 | 37.7 | 17.9 | 5.3 | 263.7 | 151.5 | 4.5 | 5.4 | 16.2 | 7.3 |
| Spwe | 24.5 | 5.9 | 8.1 | 0.3 | 227.6 | 462.9 | 168.2 | 138.3 | 24.6 | 67.8 | 205.5 | 471.5 | 8.3 | 11.0 | 26.1 | 27.6 |
| Stci | 28.6 | 4.8 | 8.5 | 0.2 | 515.6 | 133.4 | 40.9 | 16.3 | 12.3 | 2.8 | 144.0 | 163.8 | 6.9 | 4.4 | 7.5 | 4.1 |
| Stcr | 27.0 | 10.7 | 8.3 | 0.4 | 212.9 | 475.4 | 171.3 | 268.6 | 35.9 | 119.5 | 148.8 | 526.0 | 6.4 | 14.9 | 52.8 | 27.3 |
| Stan | 15.3 | 3.5 | 7.5 | 0.8 | 267.4 | 363.6 | 69.9 | 21.2 | 11.4 | 2.8 | 476.6 | 7.1 | 14.0 | 6.4 | 8.7 | 8.2 |
| Stno | 20.4 | 1.8 | 8.1 | 0.1 | 525.6 | 75.0 | 42.2 | 7.1 | 10.9 | 2.8 | 594.4 | 113.1 | 8.3 | 10.6 | 1.0 | 13.9 |
| Temi | 16.1 | 8.7 | 8.1 | 0.6 | 799.9 | 1125.3 | 784.9 | 436.4 | 324.2 | 217.0 | 601.6 | 460.5 | 31.1 | 27.8 | 17.1 | 15.2 |
| Trce | 26.6 | 3.4 | 8.4 | 0.3 | 597.6 | 273.0 | 67.5 | 52.5 | 15.5 | 3.5 | 174.3 | 122.4 | 4.5 | 1.5 | 11.2 | 6.4 |
| Trps | 14.2 | 3.2 | 8.3 | 0.1 | 305.4 | 105.5 | 99.9 | 61.0 | 16.3 | 5.1 | 275.9 | 210.9 | 5.3 | 5.8 | 1.5 | 0.9 |
| Trsc | 25.8 | 4.6 | 8.2 | 0.2 | 189.2 | 110.1 | 118.6 | 39.1 | 12.6 | 3.6 | 123.5 | 75.7 | 9.1 | 11.0 | 45.9 | 24.7 |
| Ulsu | 23.3 | 0.1 | 8.7 | 0.0 | 179.0 | 273.0 | 105.1 | 70.7 | 18.6 | 5.7 | 76.7 | 31.8 | 2.4 | 0.1 | 31.7 | 1.1 |
| Zype | 20.7 | 1.2 | 8.8 | 0.3 | 348.6 | 4.8 | 149.4 | 67.8 | 20.5 | 4.2 | 191.9 | 34.4 | 10.3 | 12.6 | 56.3 | 13.1 |
| | RMSE | 3.15 | | 0.32 | | 271.98 | | 140.76 | | 60.92 | | 217.05 | | 12.01 | | 9.80 |
| | $R^2$ | 0.70 | | 0.44 | | 0.47 | | 0.72 | | 0.72 | | 0.45 | | 0.60 | | 0.63 |

## 6.4 Discussion

### 6.4.1 Predictor variables

Water quality of a water body is characterized by the physical and chemical limnology (Sidnei et al., 1992; Mustapha, 2008). Water quality studies in various regions have demonstrated that climate and hydrology are dominant factors influencing lake functions and processes, such as nutrients, algal biomass and water clarity, nutrient relations and the mixing regime (Thornton and Rast, 1993; Lebo et al., 1994; Huzar et al., 2006; Lee et al., 2010). Variations in physical characteristics like temperature, transparency, and chemical elements of water provide valuable information on the water quality (Sidnei et al., 1992; Mustapha, 2008). Phytoplankton response directly to pressure through changes in its abundance and assemblage (Reynolds et al., 2002; Marchetto et al., 2009). The physical organization of the habitat and the presence of nutrients are, directly or indirectly, the principal factors which could influence the original phytoplankton community (Reynolds, 1980; Becker et al., 2010). Nutrient (i.e. mainly phosphorus (P) and nitrogen (N)) enrichment has resulted in strong deterioration of ecological dynamic and function of freshwater especially lakes worldwide (Smith, 2003; Spears et al., 2016).

In the present study nutrients in 2014 were mainly higher than those found in 2015 when the precipitation increased. In fact, it has been reported the effect of precipitation on the water quality of surface watercourses. In this order, Salmaso et al. (1998) attributed partially the maximum water input and power production of Lake S. Croce (Italy) to precipitation in autumn. Hooker and Hernandez (1991) and Costa and Silva (1995) supported that precipitation induce modifications in the physical and chemical characteristics of the water. TP variable was mainly high in the studied water bodies during the study period. The highest value of TP (420.8 µg $L^{-1}$) was found in Osmankalfalar reservoir (Table 3.3). This was probably the consequence of excessive fish farming and water seasonal level fluctuations (from 15 m to 3 m) due to irrigation. Sevindik et al. (2017) indicated that the seasonal difference in water inflow and the summer use of water for irrigation purposes caused the water level to decrease by 10m in İkizcetepeler reservoir (Turkey). According to Sgro et al. (2006), local factors may be more important determinants of water quality and increase variability among sites during low flow periods (typically warm seasons). In the same idea, Kennedy and Walker (1990) indicated that maximum environmental gradients are expected in reservoirs with high water retention time, high sedimentation rates and flow that are controlled by the water transport processes. With regard to lakes, Lake Avlan had higher TP value (365 µg $L^{-1}$) than other lakes. This lake was a very shallow and eutrophic ecosystem invaded by macrophytes. The highest conductivity, TN, TOC, N-$NO_3$, $BOD_5$ and salinity were obtained in Lake Gölhisar, a shallow lake with dense vegetation and turbid water. The lake is near to the District of Gölhisar and surrounded by several villages. This result could be the consequences of anthropogenic activities especially discharge of domestic waste and agriculture fertilizers which can affect the lake through generated organic nutrients. Mancini and Arcà (2000) reported that urbanization and agriculture practices in a study area could affect the basins of watercourses. High TN values were measured in Lake Gölhisar (1569.3 µg $L^{-1}$) and Osmankalfalar reservoir (1073.8 µg $L^{-1}$). These results could be partially due to human activities in the water bodies' catchments. In accordance with our result, Strebel et al. (1989) and Almasri and Kaluarachchi (2004) indicated that the downstream increase of nitrate is a common human impact by agriculture. Loehr (1974) and Dodds (2002) indicated that human activities that lead to cultural eutrophication include the use of agricultural fertilizers, livestock practices, and release of nutrient-rich sewage into the surface water. Besides, Lake Gölhisar has a long history and could be affected by natural eutrophication over years. Dodds (2002) stated that the filling of lakes with sediments is a natural process because lakes are depressions in the watershed that collect sediment over time. The water transparency was low and ranged between 0.32 m in Lake Yazır and 3.43 m in Yapraklı Reservoir. Lake Yazır was an eutrophic shallow (1 m depth) lake, invaded by macrophytes and surrounded by vegetation. However, this lake is located at the high altitude (1481 m) with the absence of human settlements and agricultural activities in its catchment. This could be due to its long history time and could be affected by natural eutrophication. Yapraklı was a deep (52 m) and newly constructed reservoir and had relatively low nutrients due to the absence of human settlements and agricultural practices in its catchment.

### 6.4.2 Phytoplankton composition and limnoecology

The phytoplankton showed temporally and spatially distribution in lakes and reservoirs in the West Mediterranean basin during the study period. Bacillariophyta was the most dominant phylum in 2014, while Dinophyceae of the Miozoa dominated the phytoplankton composition in 2015. This change could be due to decreased nutrient concentrations in 2015 with the increase of precipitations in this year. Besides, previous limnoecological studies (Van-den-Hoek et al., 1995; Oda and Bicudo, 2006) reported that dinoflagellates may persist in the ecosystem even when that element is no longer available due to their capability of surviving with low P consumption. During the present study, commonly found species (e.g. *P. cinctum*, *C. ocellata*, *C. iris*, *C. excisa*, *C. hirundinella*, *S. communis*, *C. ovota*, *M. aeruginosa*, *N. lanceolata*, and *F. capucina*) were also widespread on the Earth (Padisák et al., 2003; Xiao et al., 2011; Çelekli and Öztürk, 2014).

In term of functional groups, fifteen phytoplankton groups as descriptors were evaluated in the lentic ecosystems of the West Mediterranean basin of Turkey. Functional groups approach has recently been used in lakes ecological status assessment. An advantage of functional groups is that ecological features are linked with the trophic state or habitat preferences (Salmaso et al., 2015). Functional approaches such as functional groups (FG), Morpho-Functional Groups (MFG) and the Traditional Taxonomic Size Spectrum (TTSS) were included in studies aiming at assessing ecological status (Salmaso et al., 2015). With regard to the functional groups in the present study, the dinoflagellate was mainly characterized by *P. cinctum* of functional group $\mathbf{L_O}$ in Toptaş reservoir (171.7 µg $L^{-1}$ TP) and Lake Yazır (150.0 µg $L^{-1}$ TP) very shallow and eutrophic lake. Relatively, these high TP values for freshwater ecosystems were found to be lower compared to the others studied water bodies. WA result (Table 3.9) also indicated that this species preferred 123.1 µg $L^{-1}$ TP and warm waters during the study. Reynolds et al. (2002) and Padisák et al. (2009) stated that the habitat template of this groups is deep and shallow, oligo to eutrophic, medium to large lakes.

With regard to diatoms, *Cyclotella* species of functional group **B,** *C. ocellata* in Yapraklı reservoir in fall 2014 and *C. iris* in Yapraklı and Çayboğazı reservoirs in summer 2014 were predominant, when the nutrients values were relatively low. WA results (Table 6.8) indicated that *C. ocellata* preferred low TP (61.0 µg $L^{-1}$). This functional group has previously indicated as dominant in several Mediterranean fresh watercourses (Moreno-Ostos et al., 2008, Hoyer et al., 2009; Molina-Navarro et al., 2012; Çelekli and Öztürk, 2014). Besides, *Cyclotella* taxa were largely recorded in various trophic state aquatic ecosystems such as oligo-mesotrophic hard-water reservoirs (Dasí et al., 1998), Alleben Reservoir (Çelekli and Öztürk, 2014), Lake Vättern (Willén, 2001), Lake Skadar (Rakočević, 2012), Paraja limno-Reservoir in Spain (Molina-Navarro et al., 2014) and Mediterranean Marathonas Reservoir (Katsiapi et al., 2011). *Cyclotella* species are frequently associated with nutrient poor lakes (Bennion, 1994; Wunsam and Schmidt, 1995; Carvalho et al., 2013). The habitat of this group is mesotrophic small and medium sized lakes with species sensitive to the onset of stratification (Reynolds et al., 2002, Padisák et al., 2009), in agreement of the characteristic of Yapraklı and Çayboğazı reservoirs.

The cyanobacteria species *M. aeruginosa*, functional group **M (**eutrophic to hypertrophic, small- to medium-sized water bodies**)** was dominant in Osmankalfalar reservoir, Lake Avlan, and Lake Gölhisar in summer 2014. All these sites were classified as hypertrophic based on TP. WA result showed that *M. aeruginosa* preferred 129.7 µg $L^{-1}$ TP value. Besides, it is known that *M. aeruginosa* is bioindicator of eutrophication phenomena (Padisák et al., 1999; Kurmayer et al., 2003; Cook et al. 2004; Moustaka-Gouni et al., 2007; Katsiapi et al., 2011). *M. aeruginosa* commonly inhabits freshwater lakes during eutrophic periods (Davis et al., 2009; Lehman et al., 2013). This species was found respectively in Lake Mälaren, Sweden by Willén (2001), Lake Sumin (Poland) by Pasztaleniec and Poniewozik (2010) and Marathonas Reservoir in Greece (Katsiapi et al., 2011). The presence of these species in our studied stations could be associated with pressure (i.e. eutrophication) due to fish farming, the release of nutrient-rich sewage into water bodies and land use.

Relating to crytophytes, *C. ovata* of group **Y** (usually small and enriched lakes) was the most dominant species in Lake Gölhisar with $BOD_5$ (26.8 mg $L^{-1}$) and $NO_3$ (587.5 mg $L^{-1}$), highest values recorded in this study and in Lakes Yazır which showed mainly high $BOD_5$ (12.8 mg $L^{-1}$) value. The WA result assigned respectively 752 µg $L^{-1}$ and 825 µg $L^{-1}$ values of TP and TN to this species respectively. The presence of this species in these sites could indicate the water quality deterioration which could be the result of anthropogenic activities. Çelekli and Öztürk (2014) associated a high biovolume to *C. ovata* during the stratification period in Alleben Reservoir. Becker et al. (2010) argued that **Y** functional group has adapted to low light intensity in a Mediterranean reservoir. According to Sommer (1981), Huszar et al. (2000) and Padisák et al. (2009) *Cryptomonas spp*. of codon Y which are known for their rapid phosphorus uptake rates and relatively fast growth, are commonly found in low nutrient enriched aquatic ecosystems.

The Euglenoid species, *E. arcus* of the codon W1 predominated the phytoplankton composition of Osmankalfalar reservoir and Lake Gölhisar during summer 2014. These sites showed 1670 µg $L^{-1}$ and 540 µg $L^{-1}$ TP in summer 2014, respectively in this period (Table not shown), while WA result associated 212.7 µg $L^{-1}$ TP and 636.3 µg $L^{-1}$ TN values for this species. The habitat template of this group has been indicated by Reynolds et al. (2002) and Padisák et al. (2009) as ponds, even temporary, rich inorganic matter from husbandry or sewage. This situation could be similar to the conditions of Osmankalfalar reservoir and Lake Gölhisar due to their proximity to human settlements and agriculture activities in their catchments. In accordance with our finding, *E. arcus* was listed in Lake Mogan (Turkey) polluted by industrial and municipal wastes from the increased human population (Demir et al., 2014).

The interaction between predictor factors and the phytoplankton taxa in the lakes and reservoirs was elucidated by use of multivariate approaches. The results of the WA (Table 6.8) indicated that *C. ovata*, *N. lanceolata* and *C. rostratiformis* preferred high nutrient concentrations ($PO_4$, TP, $NO_2$, and $NO_3$), confirmed by CCA ordination (Figure 6.10). *C. rostratiformis* and *C. ovata* were assigned in the Y functional group (usually small and enriched lakes) (Reynolds et al., 2002; Padisák et al., 2009). *N. lanceolata* has been reported as tolerant to organic/eutrophic conditions (Van Dam et al., 1994; Delgado and Pardo, 2014). According to Hlúbiková et al. (2007), the natural increase in nutrient concentration and organic compounds could lead to the appearance of pollution-tolerant species like *N. lanceolata*. Results of WA (Table 6.8) showed that *A. catenula*, *C. punctulatum*, *S. crenulatum*, *M. varians*, and *M. aeruginosa* preferred warm waters, also clearly supported by CCA (Figure 6.10). *M. aeruginosa* was reported by Katsiapi et al. (2011) to the dominant species the cyanobacterial biovolume when water temperature was high. The dominance of bloom-forming cyanobacteria including *A. catenula* and *M. aeruginosa* has been related to high temperature (Caraco and Miller, 1998; Becker et al., 2009). With regard to WA, *C. lapponica, C. iris, E. sorex* and *E. proxima* were associated with alkaline waters, while *D. tenuis, F. incognita, E. turgida* and *N. slesvicensis* were associated with high conductivity. These species-environmental relationships were found in the ordination (Figure 6.10). *E. turgida* has been indicated with relatively high conductivity by Potapova and Charles (2003).

Multivariate analyses indicated that environmental factors strongly drive phytoplankton assemblages which were found to be dominant at their optimum conditions. This is in accordance with our hypothesis (II) that environmental variables especially pollution parameters (nutrients, organic matter) are the most important structuring factors of phytoplankton composition and confirmed that phytoplankton and adapted biotic indices would be suitable to use as indicators of anthropogenic pressure in lakes and reservoirs. A strong relationship between phytoplankton assemblages and environmental variables has been noted by several previous studies (e.g. Naselli-Flores, 2000; Crossetti and Bicudo, 2005; Romo and Villena, 2005; Porter et al., 2008; Becker et al., 2010; Abonyi et al., 2012; López et al., 2012; Yerli et al., 2012; Moreti et al., 2013; Devercelli and O'Farrell, 2013; Çelekli and Öztürk, 2014). According to Pasztaleniec and Poniewozik (2010), the quality and quantity of the phytoplankton depend in part on the nutrient load. In the present study, the dominant species changed spatial and temporal. Reynolds et al. (2002), Reynolds (2006), and Padisák et al. (2009) reported that the dominant phytoplankton taxa differed among water bodies and seasons due to the difference of species preference in tolerance ranges of water temperature, light, and nutrient limitations. Wherever the phytoplankton assemblage is primarily phosphorus limited, decreases in annual average total phosphorus (TP) contents should induce a decrease in phytoplankton composition, biomass, in contrast to an increase in water transparency and in the proportion and biodiversity of aquatic secondary producers (Jeppesen et al., 2000; Spears et al., 2016). The ecology of phytoplankton reservoir communities plays a pivotal role in their management and in the development of inland fisheries in the water scarce semi-arid regions of Rio Grandedo Norte State, Brazil (Chellappa et al., 2009). The similarity of our results with previously early studies could be explained by the Mediterranean region climate, geographical position and the similarity in physicochemical variables and the mixing regime supported by human activities in the watersheds.

### 6.4.3 Seasonality of phytoplankton

Seasonal influences are strong forces in phytoplankton assemblages' succession. Seasonal phytoplankton dynamics are controlled by physicochemical forces and biotic interactions (Reynolds, 2006; Anneville et al., 2002; Chen et al., 2009). The seasonal steps in algal size mainly depends on nutrient and temperature scales (Morabito et al., 2007; Reynolds, 2006; Chen et al., 2011). Phytoplankton react spontaneously to nutrient concentrations through modifications in its structure, biomass and composition (Reynolds et al., 2002; Marchetto et al., 2009). The peaks of phytoplankton biovolume were observed when the water temperature and the nutrients values especially TP and nitrate were optimum (Nõges et al., 2003). In shallow lakes, the impact of temperature is especially adverse when it synchronizes with low water quantity, and the degradation of water quality generally occurs in the warm season (Nõges et al., 2003; Rakočević, 2012). The physical structure of the environment and the presence of nutrients are, spontaneously or indirectly, the great major parameters that affect the prestine phytoplankton community (Reynolds, 1980; Reynolds, 2006; Becker et al., 2010).

The spatial and temporal occurrences of phytoplankton species were strictly associated with the changes of some important environmental factors in lakes and reservoirs in the Western Mediterranean basin of Turkey during the study seasons. The species number changed not only per site but changed also per season. the species number changed from a minimum of 10 at Çavdır reservoir in summer 2014 to a maximum of 49 at Lake Avlan in summer 2015. This species number was generally higher in 2015 than those of 2014. This situation was in accordance with previous study indicated that the peaks of phytoplankton biovolume were observed when the water temperature was optimum (Nõges et al., 2003). The Phytoplankton biovolume per phylum changed during the study period according to the seasonal changes in water characteristics. Peaks of phytoplankton abundance did not appear at the same time at the different lakes and reservoirs, and phytoplankton succession showed distinct spatial heterogeneity during the study in the lakes and reservoirs. The Figure 6.9a,b and c show the seasonal variations in the phytoplankton phyla' total biovolume (×104 µm3.L-1) in the lakes and reservoirs. The seasonal phytoplankton composition showed a marked change in abundance among studied water bodies. The mainly abundant phylum was Bacillariophyta followed by the Chlorophyta phylum. This situation is in agreement with previous studies in Valparáiso Reservoir (Spain) (Negro et al., 2000) in Lakes Abant and Gölköy (Çelekli, 2006) and in Alleben Reservoir (Çelekli and Öztürk, 2014). The phytoplankton composition observed had mainly similarities to those reported for others Mediterranean shallow lakes such as Lake Skadar in Montenegro (Rakočević, 2012), Alleben Reservoir (Çelekli and Öztürk, 2014) and Lake Mogan in Turkey (Demir et al., 2014) and Estonia, Czech Germany and Greece lakes (Erdoğan, 2016).

# CHAPTER VII

## BIOASSESSMENT OF THE LENTIC ECOSYSTEMS BASED ON PHYTOPLANKTON


### ABSTRACT

Lentic freshwaters (especially lakes and reservoirs) are complex aquatic ecosystems which evolution is governed by several natural and anthropogenic factors. The impact of these factors on the ecological state of lakes and reservoirs are often very variable from one environment to another. Aquatic organisms which are sensitive to the changes of their environment could be suitable tool to provide information about the quality state of the ecosystems in which they are found. Due to this reason, Lakes and reservoirs should be assessed at a local, regional and national level not using only physicochemical parameters, but also biological quality elements. Phytoplankton, as one of these biological quality elements are useful tool for the bioassessment surface waters. The aim of this work was to assess the water quality of three lakes and six reservoirs in the Western Mediterranean Basin (Turkey) using phytoplankton indices. Data were sampled seasonally from summer 2014 to summer 2015.

With regard to the water quality, the phytoplankton trophic index (PTI) values varied from 1.96 to 2.48; the Mediterranean phytoplankton trophic index (Med-PTI) ranged from 0.8 to 2.05, while the assemblage index (Q) values were between 3.22 and 2.10. Ecological quality ratio base on PTI ranged between 0.69 and 0.84, while it changed from 0.65 to 0.85 based on Med-PTI. Lakes and reservoirs showed similar ecological status ranged from moderate to high quality according to the three indices.

## 7.1 Introduction

Lentics fresh waters (especially lakes and reservoirs) are complex aquatic ecosystems which evolution is governed by several natural and anthropogenic factors. The impact of these factors on the ecological state of lakes and reservoirs are often very variable from one environment to another. The assessment of lakes and reservoirs water quality is based mainly on the major issues associated with these ecosystems. Eutrophication of lakes and reservoirs resulting in algae blooms has receiving more attention during the last centuries. Nutrient enrichment of aquatic systems due to soil erosion, runoff fertilization of croplands and livestock production, and discharges from sewage treatment plants is considered to be one of the major causes of environmental degradation in the last decades. Developing good indicators of anthropogenic impact on aquatic ecosystems related to different proposes become major challenge that could be resolved by the establishment of monitoring programs. Aquatic organisms which are sensitive to the changes of their environment could be suitable tool to provide information about the quality state of the ecosystems in which they are found. Due to this reason, Lakes and reservoirs should be assessed at a local, regional and national level not using only physicochemical parameters, but also biological quality elements. In this regard, the European Union water framework directive (WFD) recommended recently phytoplankton, phytobenthos, macrophytes, macroinvertebrates, and fish as bioindicators to be applied for surface water assessment (Directive, 2000; EC, 2009). However, the value of phytoplankton (algae) as biomonitors for fresh waters has already been recognized in the mid-19th century (Cohn, 1853; Dokulil, 2003). The first attempt to classify aquatic organisms as indicators of water quality was made by Cohn (1870), later modified by Mez (1898), while the relation of organisms to their water quality was more clearly defined by Kolwitz and Marson (1902, 1908,1909) by creating the term “Sapropbic organisms” (Dokulil 2003). According to WFD, watercourses with ecological stutus classified as moderate to bad should be restored by actions taken in and around the watercourse itself as well as its watershed. The effeciency of any restoring action should be surveyed by examining the amelioration in water quality. To reduce monitoring costs during restoring, the WFD requires that only the most sensitive bioindicators to environmental changes in watercourses should be monitor (EC, 2009, Marchetto et al., 2009; Phillips et al., 2013). If the major anthropogenic constraint is the load of nutrients, phytoplankton could be the natural choice for biomonitoring. Phytoplankton response quickly to nutrient variations through changes in its abundance and composition (Reynolds, 1984; Rott, 1984; Naselli Flores and Barone, 1998; Reynolds et al., 2002; Schaumburg et al., 2004; Reynolds, 2006; Poikane et al,. 2011; Cellamare et al., 2012).

Phytoplankton could be used as a good bioindicator of water quality due to its sensitivity and ability to response in the surrounding environment changes (Reynolds, 1984; Padisák et al., 2003; EC, 2009; Padisák et al. 2006; Poikane et al., 2011; Katsiapi, et al., 2011).

In last decades, a number of phytoplankton metrics and systems based its biovolume and abundance have been developed in order to evaluate ecological quality of aquatic ecosystems especially in lakes and reservoirs: e.g. Brettum index (Brettum, 1989) , Catalán Index (Catalan et al., 2003), ITP or Barbe Index (Philippe et al., 2003), Phytoplankton Trophic Lake Index (PTSI) (Riedmüller et al., 2006), assemblage index (Q) (Padisák et al., 2006), Phytoplankton Trophic Index (PTI) (Salmaso et al., 2006; Phillips et al., 2013 ), Mediterranean Phytoplankton Trophic Index (MedPTI) (Marchetto et al., 2009), Phytoplankton Metrics for Polish Lakes (PMPL) (Hutorowicz and Pasztaleniec, 2014), New Mediterranean Assessment System for Reservoir's Phytoplankton (NMASRP) (de Hoyos et al., 2014), Danish lake phytoplankton Index (DLPI) (Phillips et al., 2014).

One of the most recent phytoplankton research interests is the establishment of the so-called phytoplankton functional groups (Abonyi et al., 2012). Many limnological studies including the functional groups were carried out in many countries (e.g. Reynolds et al., 2002; Reynolds, 2006; Salmaso and Padisák, 2007; Moreno-Ostos et al., 2008; Padisák et al., 2003, 2006, 2009; Hoyer et al., 2009; Abonyi et al., 2012; Çelekli and Öztürk, 2014; Demir et al., 2014; Sevindik et al., 2017). The phytoplankton functional groups system, firstly proposed for lakes, is also a good tool for reservoirs, since the two ecosystems are widely similar because of their small spatial and temporal scales (Reynolds, 1999, 2002, 2006; Padisák et al., 2003, 2006, 2009; Becker et al., 2010).

Phytoplankton metrics have previously been used for biomotoring of Turkish freshwater lakes and reservoirs: e.g. Ömerli reservoir (Albay and Akçaalan, 2003), Lakes Abant and Gölköy (Çelekli, 2006), lake Manyas (Çelekli and Ongun, 2008), Alleben Reservoir (Çelekli and Öztürk, 2014), lakes Mogan, Abant, Karagöl and Poyrazlar (Atıcı and Tokatli, 2014), Lake Mogan (Demir et al., 2014), 47 shallow lakes (Erdoğan, 2016), and İkizcetepeler reservoir (Sevindik et al., 2017). With regard to basin approach, this work is the first test to monitor lakes and reservoirs in the Western Mediterranean Basin combining three phytoplankton metrics. This chapter aims to i) assess the ecological status of three lakes and six reservoirs in the Western Mediterranean basin by using phytoplankton trophic index (PTI), Mediterranean phytoplankton trophic index (Med-PTI) and the Q assemblage index.

## 7.2 Material and Methods

From summer 2014 to Summer 2015, we sampled three lakes and six reservoirs and collected phyotoplankton data which were served to calculate indices scores for the water quality assessment.

### 7.2.1 Phytoplankton trophic index (PTI)

The PTI value was determined for each of the lake and reservoir based on the weighted average of the optima from the taxa present in the lakes and reservoirs, with the proportion of total biovolume as weights according to the formula (Eq.5) proposed by Philips et al. (2013) and modified by Çelekli et al. (2016).

$$PTI = \frac{\sum_{j=1}^{n} a_j * s_j * i_j}{\sum_{j=1}^{n} a_j * i_j} \qquad \text{(Eq. 5)}$$

where $a_j$ is proportion of $_j$th taxon in the sample, $s_j$ is the optimum of jth taxon, and $i_j$ is the indicator value of jth taxon in the sample.

### 7.2.2 Mediterranean phytoplankton trophic index (MedPTI)

The Mediterranean phytoplankton trophic index originally proposed for the monitoring of deep reservoirs was used in this study to evaluate the water ecological status of both lakes and reservoirs. In this order, the trophic and indicator values of the species found in the water bodies were first determined. The value of the MedPTI index in the *i*-th reservoir or lake is then calculated using the equation (Eq.6) developed by Marchetto et al. (2009).

$$Med - PTI_i = \frac{\sum_{k=1}^{m} B_{j,k} * v_k * i_k}{\sum_{k=1}^{m} B_{j,k} * i_k} \qquad \text{(Eq. 6)}$$

where ($B_{j,k}$), is the biovolume, ($v_k$) is the trophic value and ($i_k$) is the indicator values of the *m* species found in that reservoir or lake.

### 7.2.3 Phytoplankton assemblage index (Q)

The phytoplankton assemblage index (Q) was calculated for the lakes and reservoir according to the formula (Eq.7) developed by Padisák et al. (2006).

$$Q = \sum_{j=1}^{n} p_i F \qquad \text{(Eq. 7)}$$

Where, $p_i$ is the relative proportion ( $p_i = n_i / N$ ; $n_i$ is biovolume of the $i^{th}$ functional group; $N$: total biovolume) of functional groups in total biovolume. F is a factor value determined for the $i^{th}$ functional class in the given lake or reservoir.

The factor number (F) for each functional group was established considering what would be the reference state of the corresponding reservoir or lake and probable algal community presence in it. In this case, higher factor F scores were attributed to which would be the original communities on the reservoir or lake and lower scores to communities supposed to be undesirable in reference conditions. Q index boundaries and the classification classes are given in Appendix P.

### 7.2.4 Ecological quality ratios (EQR)

As recommended by the European Union water framework directive (WFD), PTI and Med-PTI were calculated and then transformed as ecological quality ratios (EQR) for ecological status classification. The EQR was used as a numerical score ranged from zero (0) to one (1) according to the WFD, where high water quality is indicated by scores close to one (1) and bad water quality by scores close to zero (0). PTI, Med-PTI class boundaries and EQRs are presented in Appendix A. $EQR_{PTI}$ and $EQR_{MedPTI}$ were calculated using equations (Eq.8) and (Eq.9) respectively.

$$EQR_{PTI} = \left( \frac{PTI_{Obs} - PTI_{Max}}{PTI_{Ref} - PTI_{Max}} \right) \qquad \text{(Eq. 8)}$$

where $PTI_{Obs}$ is mean sample PTI for each lake and reservoirs, $PTI_{Max}$ is the maximum PTI score for type, $PTI_{Ref}$ is the reference PTI for type.

$$EQR_{MedPTI} = \left( \frac{4 - MedPTI_o}{4 - MedPTI_{ref}} \right) \qquad \text{(Eq. 9)}$$

Where, $MedPTI_o$ and $MedPTI_{ref}$ are the observed and reference MedPTI, respectively.

## 7.3 Results

The ecological characterization of the water bodies was estimated using PTI, Med-PTI, and the Q assemblage index.

### 7.3.1 Phytoplankton trophic index (PTI)

Values of phytoplankton trophic index (PTI) changed from 2.48 in Lake Gölhisar to 1.96 in Çavdır reservoir, while EQR_PTI ranged between 0.69 and 0.84. EQR-PTI indicated that all studied lakes and reservoirs had moderate water, except Çayboğazı and Yapraklı reservoirs which showed a good water ecological status (Table 7.1).

**Table 7.1** Corresponding Lakes and Reservoirs PTI, EQR values and ecological states

| Sites | | PTI | EQR_PTI | Ecological status |
|---|---|---|---|---|
| Lakes | Gölhisar | 2.48 | 0.75 | Moderate |
| | Avlan | 2.56 | 0.69 | Moderate |
| | Yazır | 2.54 | 0.73 | Moderate |
| Reservoirs | Çayboğazı | 2.43 | 0.71 | Moderate |
| | Geyik | 2.42 | 0.69 | Moderate |
| | Çavdır | 1.96 | 0.84 | Good |
| | Toptaş | 2.39 | 0.69 | Moderate |
| | Yapraklı | 2.36 | 0.78 | Good |
| | Osmankalfalar | 2.52 | 0.71 | Moderate |

Relationships between TP and PTI is shown in figure 7.1. The figure indicated that PTI had well regression with logTP and high determination of correlation value ($R^2$ = 0.958).

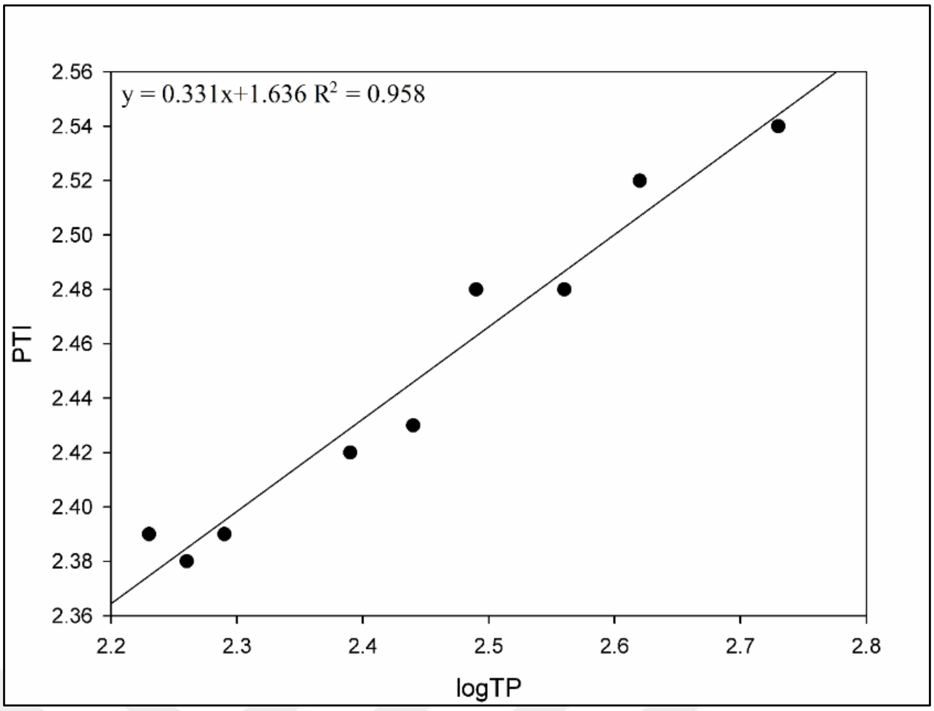



**Figure 7.1** Plot of PIT versus TP

### 7.3.2 Mediterranean phytoplankton trophic index (Med-PTI)

The Mediterranean phytoplankton trophic index (Med-PTI) values ranged from 2.05 in Toptaş reservoir to 0.8 in Lake Yazır. According to these values, the EQR changed from 0.65 to 0.85. EQR-MedPTI showed that high, good, and medium states were found for Lake Gölhisar, Lake Avlan, and Lake Yazır, respectively. With regard to reservoirs, Çayboğazı, Çavdır, Toptaş, and Yapraklı reservoirs had medium status and others had good state (Table 7.2).

**Table 7.2** Corresponding Lakes and Reservoirs Med-PTI, EQR values and ecological states

| | Sites | Med-PTI | EQR_MedPTI | Status |
|---|---|---|---|---|
| Lakes | Gölhisar | 1.54 | 0.84 | High |
| | Avlan | 1.69 | 0.76 | Good |
| | Yazır | 0.8 | 0.65 | Moderate |
| Reservoirs | Çayboğazı | 1.45 | 0.85 | Good |
| | Geyik | 1.48 | 0.69 | Moderate |
| | Çavdır | 1.81 | 0.79 | Good |
| | Toptaş | 2.05 | 0.81 | Good |
| | Yapraklı | 1.74 | 0.81 | Good |
| | Osmankalfalar | 1.34 | 0.65 | Moderate |

Relationship between total phosphorus (TP) and Med-PTI given in Figure 7.2. The figure indicated that Med-PTI showed well regression with logTP ($R^2$ =0.902).

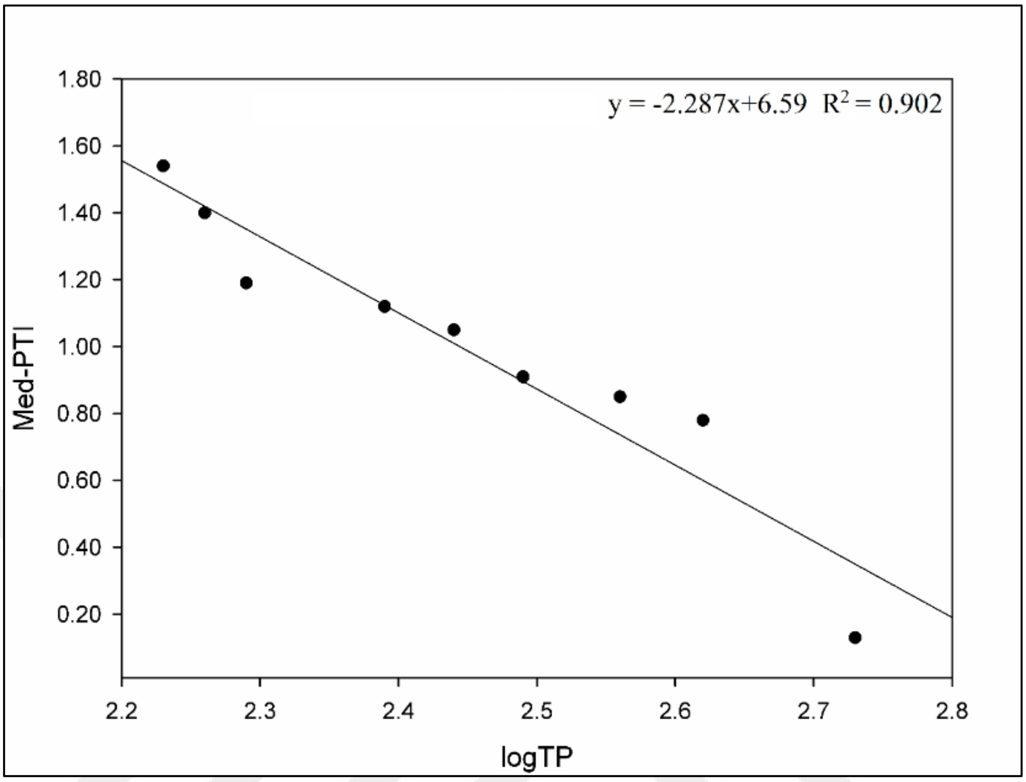



**Figure 7.2** Plot of Med-PTI versus TP

### 7.3.3 Phytoplankton Assemblage Index (Q)

The highest Q index (3.22) was found in Lake Yazır, whereas it's lowest with 2.10 was determined in Yapraklı reservoir. Results of Q assemblage index indicated that all water bodies had medium status, except good state for Lake Yazır (Table 7.3). Relationships between total phosphorus (TP) and Q index is given in Figure 7.3. which indicated that all indices showed well regression with logTP ($R^2$ = 0.5). With Regard to the ecological status observed following the three indices, the variance analysis (one-way ANOVA) indicated a significant difference between the lakes and reservoir. (one-way ANOVA; $P<0.05$; F = 255.5).

**Table 7.3** Corresponding Lakes and Reservoirs Q values associated with EQR values and ecological states

| | Sites | Q index | State |
|---|---|---|---|
| Lakes | Gölhisar | 2.62 | Medium |
| | Avlan | 2.59 | Medium |
| | Yazır | 3.22 | Good |
| Reservoirs | Çayboğazı | 2.37 | Medium |
| | Geyik | 2.20 | Medium |
| | Çavdır | 2.64 | Medium |
| | Toptaş | 2.36 | Medium |
| | Yapraklı | 2.10 | Medium |
| | Osmankalfalar | 2.40 | Medium |

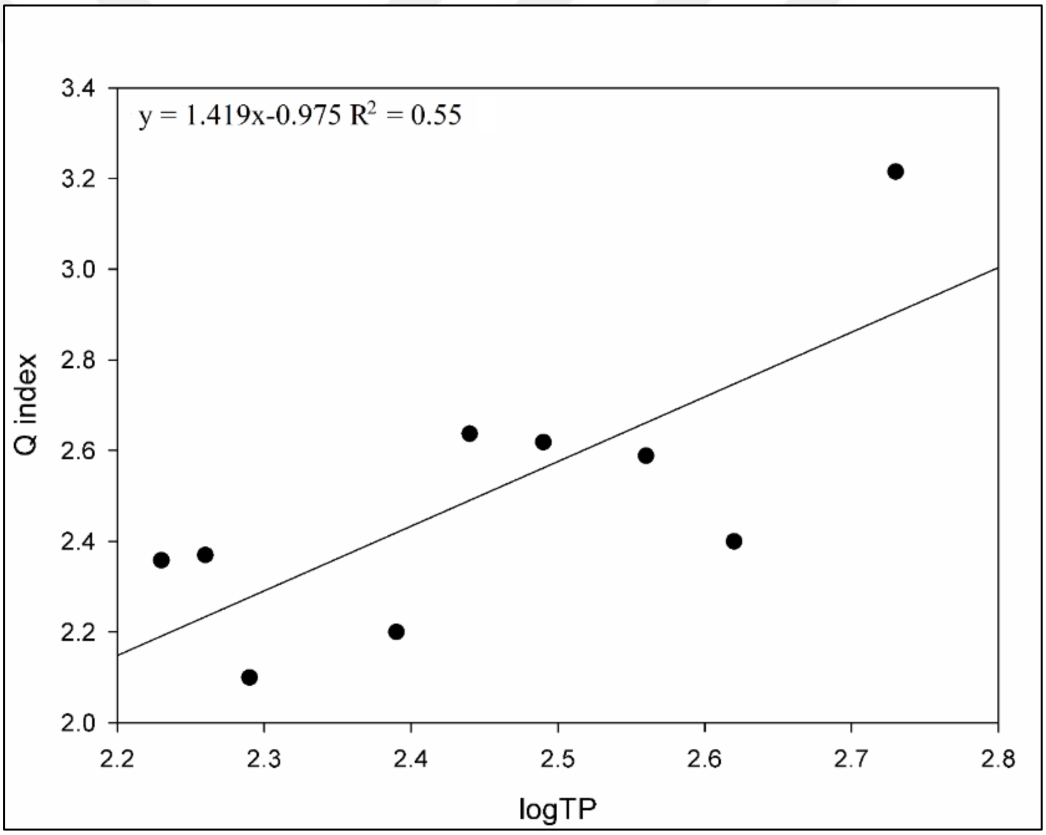



**Figure 7.3** Plot of Q index versus TP

### 7.4 Disccusion

Water quality, especially the ecological status of lakes and reservoirs ecosystems could be evaluated using phytoplankton based metrics (Directive, 2000; EC, 2009; Poikane et al., 2011; Phillips et al., 2013). PTI values in this present study changed from 1.96 in Çavdır reservoir to 2.48 in Lake Gölhisar. These values were higher than those found in Alleben Reservoir (Turkey) (Çelekli and Öztürk, 2014) and lower than the values found in Lakes Lugano and Maggiore which are deep lakes in Italy (Salmaso et al., 2006). Med-PTI ranged from 0.8 in Lake Yazır to 2.05 in Toptaş reservoir. These results were different from those found in deep Mediterranean reservoirs (Italy) (Marchetto et al., 2009). The Q index values which ranged from 2.10 in Yapraklı reservoir to 3.2 in Lake Yazır were higher than those found in a deep subtropical Faxinal Reservoir (Brazil) (Becker et al., 2009). But lower than those found in Spain in a deep Mediterranean reservoir, Sau Reservoir (Spain) (Becker et al., 2010).

With regard to ecological status based on EQR-PTI, moderate water quality was observed in all the lakes and some reservoirs during the present study. In accordance with our results, Çelekli and Öztürk (2014) previously reported a moderate ecological status for Alleben Reservoir in Turkey. The values of EQR-PTI indicated that Yapraklı and Çavdır reservoirs had good ecological status, while Çayboğazı, Toptaş, and Çavdır reservoirs were classified in this state by EQR-MedPTI. On the other hand, all reservoirs and lakes had medium ecological status based on Q assemblage index except Lake Yazır which showed good ecological state. The good ecological state obtained during the present study using EQR (based on PTI and Med-PTI) and Q assemblage index was indicated in Mediterranean reservoirs such as Sau Reservoir (Spain) (Becker et al., 2010) and Pareja limno-reservoir (Spain) (Molina-Navarro et al., 2014). The high ecological state in Lake Gölhisar associated to EQR-MedPTI is probably due to moderate human activities on and around this lake especially agriculture practices, fish farming, and organic pollutants input from wastewater which are great sources of organic and inorganic nutrients in freshwater. From this result, the method of Med-PTI firstly developed for evaluating the response of the phytoplankton to changes in nutrient concentration in deep reservoirs by Marchetto et al. (2009) could be reliable for assessing the ecological status of shallow reservoirs and lakes. Among these indices, PTI had more competitive with a higher coefficient ($R^2$ =0.958) than others, which was clearly indicated in Figure 3.13, 3.14 and 3.15. Besides, this significant positive relationship between PTI and TP was previously found in European freshwater bodies (Philips et al., 2013). The results of this study revealed that the application of phytoplankton charactiristics could be a useful biomonitoring tool for assessing water quality in a basin approach.

## CHAPTER VIII

## TROPHIC STATES OF THE LAKES AND RESERVOIRS

## ABSTRACT

Water quality is the definition of the state or condition of watercourses relative to the requirements of the aquatic living organisms and human needs. The trophic state of the lakes and reservoirs is generally measured using physicochemical and biological parameters including water transparency, total phosphorus, total nitrogen, and chlorophyll-a. The aim of this chapter was to examine the trophic state of 3 lakes and 6 reservoirs in the western Mediterranean basin of Turkey following the Carlson's Trophic State Index and the OECD trophic classification systems. Environmental data were collected during 4 seasons.

Total phosphorus concentrations and the Secchi depth values among stations and seasons. In summer 2014, the highest TP (540 µg/L) and SD (2.5 m) were recorded at Lake Gölhisar and Çayboğazı reservoir respectively. Çavdır reservoir showed the highest TP (750 µg/L) and SD (1.5 m) in fall 2014, while the lowest TP value, 28 µg/L in summer 2014 was measured at Osmankalfalar reservoir. In spring 2015, the peaks of TP (170 µg/L) and SD (5 m) were recorded at Lake Yazır and Yapraklı reservoir respectively, while the lowest TP concentration (32 µg/L) in summer was recorded at Lake Avlan. With regard to water quality, 3 trophic categories were found based on Carlson's index, while 4 were found according to OECD criteria. Yaprakli reservoir was mesotrophic according to SD based on Carlson system, while other reservoirs and lakes showed eutrophic status according to TP and SD. OECD criteria classified lakes and reservoirs as hypertrophic based on TP. According to SD, all lakes had hypertrophic status, while Geyik, Toptaş, and Osmankalfalar reservoirs were eutrophic; Çayboğazı and Çavdır reservoirs were recorded as meso-eutrophic, while an oligotrophic status was found at Yapraklı reservoir.

## 8.1 Introduction

Water quality is characterized based on of the state or condition of water bodies which responses to the requirements of the aquatic organisms and human needs. It is measured as physical, chemical, biological and organoleptic (taste-related) properties of water (Johnson et al., 1997; UN, 2007; Ndungu, 2014). The water state can be affected naturally or through human activities by nutrient enrichment caused which stimulate primary producers. This phenomenon is known as eutrophication. The trophic state of lakes is indicative of their biological productivity, that is, the number of living organisms supported within environmental variables, primarily in the form of algae (Randolph and Wilh, 1984; Denys, 2004; Çelekli, 2006).

The expression eutrophication was wrongly used by limnologists and needs to be clearly defined. Hutchinson (1973) gave a clear history of the evolution and usage of the expression since Weber (1907) first used the expression to characterize the aspect of wetlands. The previously use of the expression was widely descriptive, based on the appearance of lakes, hypolimnetic oxygen reduction, and key taxa of attached macroinvertebrates. Unnecessary to indicate that several freshwater resources seemed to be not easy to classify using these methods. By the mid-1970s, the term eutrophication had appeared to have taken on new definitions in several cases. Thereby it became probable to estimate the primary productivity of water bodies spontaneously, and the principal impact of anthopogenic activities in water bodies' watershed and the concept of water turnover became known. The expression began then to be used in a large dynamic way, involving variations in both within reservoirs functions and landwater relationships (Schindler, 2006). During the later stages of eutrophication, the watercourse is stifled by excessive plant life because of higher concentrations of nutrients such as nitrogen and phosphorus. Anthropogenic activities such as urban construction, sewage discharges, agricultural practices, and industrial development could accelerate the phenomenon (MPCA, 2008).

To evaluate the eutrophication in aquatic systems, limnologists used to determine the relationships between water quality, nutrients, and phytoplankton communities and productivity for establishing a trophic characterization of water bodies. There are numerous systems to use water quality data which depend on mean objectives, the type of samples, and the size of the sampling area. Many studies related to eutrophication in aquatic ecosystems have been done, as indicated previous methods established for categorization, modeling and interpretations of collected data (Simeonov et al., 2002; Boyacioglu and Boyacioglu, 2007, Alobaidy et al., 2010). One of the most important ways to transmit information on water quality changes is by the development of applicable metrics (Dwivedi and Pathak, 2007, Alobaidy et al., 2010). Metrics are developed using the scores of different physicochemical and biological variables in a water body. The use of metrics in monitoring systems to evaluate ecosystem state has the ability to transmit the general public and decision-makers about the evolution of the ecosystem (Nasirian, 2007; Simoes et al., 2008; Alobaidy et al., 2010). This approach could also help to establish a standart system for assessing successes and failures of management techniques for amelioring water quality (Rickwood and. Carr, 2009; Alobaidy et al., 2010). Water quality indices (WQI) have been applied to control water quality using physicochemical parameters since the 1970s. The first water quality index has been developed by Horton (1965), and since a huge interest has been given to the establishment of ‘water quality index’ systems with the idea of developing a tool to make easy the interpretation of water quality data (Liou et al., 2004; Boyacioglu 2007), and many water quality indices that have been developed to evaluate water quality in United States, Canada and Europe.

The trophic characterization based on the level of the productivity of the aquatic ecosystems is termed trophic states of the system. The trophic state of a lake is the biological productivity, what could be defined as the quantity of plants and animals in a lake which determined the water quality of aquatic ecosystems and served as water quality indicator (Ndungu, 2014). Freshwater ecosystems can be classified by their step of eutrophication. The trophic state of lakes and reservoirs is generally measured using physicochemical and biological parameters including water transparency (Secchi disk), total phosphorus, total nitrogen and chlorophyll-a. Four great trophic state classes including oligotrophic (few foods), eutrophic (many foods), mesotrophic which falls between these two firs categories, and the hypertrophic state were considered based on the trophic metrics. Transparency as a definition of water clarity can be used to combine an analytical orientation for a watercourse, the localization of transparency differences in a watercourse, and to compare various water resources. Water transparency shows the scale of aquatic organisms activity and could be taken quickly by the use of a Secchi disk (Preisendorfer 1986; Zaneveld and Pegau, 2004). The Secchi depth of a given sampling stations, which shows the clarity of the water depends on to the level of dissolved solids in water, which in the end gives the quantity of biomass. High water transparency is measured when the occurrency of microalgae and quantity of suspended elements in water is lower. Transparency may also be impacted by the input of nutrients into the water body, especially phosphorus coming from sources such as plantations, wastewaters etc. (Çako et al., 2013) and also by suspended solids generated generally by activities such as urbanization near to aquatic ecosystems, agriculture and livestock rejections, and industrial sewage. Phosphorus is an essential nutrient for plant life and plays a key role for algae growth, it can be found naturally in the environment, but can be a source of pollution of water at a high rate. Anthopogenics activities, however, have resulted in excessive loading of phosphorus into several freshwater ecosystems. This could be a source of water pollution by promoting algae bloom, especially in lakes (MPCA, 2007). While there are a number of ways to measure phosphorus, total phosphorus (TP) provides a good overview of how much phosphorus is in the water as it includes both the dissolved fraction that is available for plant uptake, as well as any particulate phosphorus bound to suspended particles (BPMP, 2017).

Several studies have been carried out throughout Turkey for evaluating water quality of Lakes based on trophic systems: in Lake Manyas and Ömerli Reservoir (Albay and Akçaalan, 2003 a, b), Lake Burdur (Girgin et al., 2004), Manyas Lake (Karafistan and Arık-Çolakoğlu, 2005), in Yeniçağa Lake (Saygı-Başbuğ and Demirkalb, 2004), Lakes Abant and Gölköy (Çelekli, 2006). Recently, Erdoğan (2016) studied the water quality of 47 shallow lakes including Hamam, Poyrazlar, Abant, Büyük, Derin, Nazlı, İnce, Serin, Pedina, Eymir, Mogan, Taşkısığı, Küçük Akgöl, Büyük Akgöl, Çubuk, Gölcük Bolu, Yeniçağa, Gölhisar, Mert, Erikli, Saka, Gebekirse, Barutçu, Karagöl İzmir, Gölcük Ödemiş, Emre, Gökgöl, Karagöl Denizli, Azap, Gölcük Sakarya, Yayla, Saklı, Baldımaz, Gıcı, Tatlı, Sarıkum, Kocagöl, Gerede, Keçi, Karagöl Bolu, Uyuz, Balıklı, Kaya, Eğri, Sarp, Kaz, and Seyfe Göleti using the Carlson’s trophic state index (TSI). However, until the present study, there were few or no studies concerning our studied water bodies including lakes Gölhisar, Avlan and Yazır, Çayboğazı, Geyik, Çavdır, Toptaş, Yapraklı and Osmankalfalar reservoirs.

The measurement of physicochemical and biological parameters such as nutrient contents, water transparency and the amount of chlorophyll a could provides great information for interpreting their relationship with the trophic state in freshwater ecosystems. In this chapter, the trophic states of lakes Gölhisar, Avlan and Yazır, Çayboğazı, Geyik, Çavdır, Toptaş, Yapraklı and Osmankalfalar reservoirs in the Western Mediterranean basin of Turkey were determined and compared based on their water transparency and the concentrations of total phosphorus.

## 8.2 Material and Methods

### 8.2.1 Stady Area and Data Collection

During this study the trophic state of 3 lakes (Gölhisar, Yazır and Avlan), and 6 reservoirs (Çayboğazı, Geyik, Çavdır, Toptaş, Yapraklı, and Osmankalfalar) in the western Mediterranean basin of Turkey (Figure 8.1) were examined based on Trophic State Index (TSI) Carlson (1977) and Carlson and Simpson (1996) and the OECD trophic classification system (OECD, 1982). Environmental data such as conductivity, pH, total dissolved solids (TDS), salinity, and temperature were measured in situ using an YSI professional plus oxygen–temperature meter from just beneath of the surface in the stations, while water transparency was seasonally taken using a 20-cm Secchi disk during four seasons (from summer 2014 to summer 2015). Altitude, latitude, and longitude of the sampling stations were read from a geographical positioning system (Garmin Vista HCx model GPS). Chemical variables (e.g., TN, $N–NH_4$, $N–NO_3$, $N–NO_2$, TP, and $P–PO_4$) and biological oxygen demand ($BOD_5$) were analyzed using a standard method (APHA, 2012).


**Figure 8.1** Location of the studied lakes and reservoirs in the West Mediterranean basin from Anonymous (2016)

### 8.2.2 Trophic States of the Sites

#### 8.2.2.1 Trophic State Index (TSI) carlson (1977)

The trophic state index (TSI) Carlson (1977) based on calculating an index to determine the trophic state of a given water body on a scale of total phosphorus, Secchi depth, and chlorophyll is one of the commonly used classification methods for aquatic ecosystems especially lakes and reservoir. The TSI can be calculated by the following equations (Eq.10, Eq.11 and Eq.12) proposed by Carlson (1977).

$$TSI_{(TP)} = 10(6 - \ln[48/TP]/\ln[2]) \quad \text{(Eq. 10)}$$

$$TSI_{(SD)} = 10(6 - \ln[SD]/\ln[2]) \quad \text{(Eq. 11)}$$

$$TSI_{(Cho)} = 10(6 - (2.04 - 0.68\ln[Cho]/\ln[2])) \quad \text{(Eq. 12)}$$

Where $TSI_{(TP)}$ the trophic state referenced to total phosphorus (TP), $TSI_{(SD)}$ is the trophic state referenced to Secchi depth (SD), and $TSI_{(Cho)}$ is the trophic state referenced the concentration of chlorophyll a.

In the present chapter, physicochemical data such as total phosphorus and water transparency were used to calculate the TSI index and to evaluate the water quality according to Carlson (1977). The trophic state classifications were determined based on trophic state index (TSI) as described in Table 8.1.

**Table 8.1** Trophic classification for lakes based on TSI (Carlson, 1977)

| **Class** | **TSI** |
|---|---|
| Oligotrophic | 0–40 |
| Mesotrophic | 40–50 |
| Eutrophic | 50-70 |
| Hypertrophic | >70 |

#### 8.2.2.2 OECD (OECD, 1982) Classification System

The OECD system (OECD, 1982) classification method based on total phosphorus and Secchi depth was also used to classified trophic states of the aquatic systems. The trophic state classes of the waters bodies based on the OECD (1982) system were determined as described in Table 8.2.

**Table 8.2** Trophic classification system for lakes (OECD, 1982)

| Class | Total phosphorus (TP) (µg/L) | Secchi depht (SD) (m) |
|---|---|---|
| Ultraoligotrophic | <4 | >12 |
| Oligotrophic | 4-10 | 12-6 |
| Mesotrophic | 10-35 | 6-3 |
| Eutrophic | 35-100 | 3-1.5 |
| Hypertrophic | >100 | <1.5 |

### 8.2.3 Statistical Analyses

To test the hypothesis of no difference trophic states between lakes and reservoir based on Carlson (1977) and OECD (OECD, 1982) trophic classification systems, the variance analysis (one-way ANOVA) was employed at 95% confidence interval using the program SPSS (IBM statistics version 23).

## 8.3 Results

### 8.3.1 Seasonal variation of total phosphorus and Secchi depth

The seasonal variation of total phosphorus (TP) and Secchi depth (SD) is given in Table 8.3. The total phosphorus contents and the Secchi depth values changed not only from one sampling station to another but also varied for the same station during the study period. In summer 2014, the highest TP (540 µg/L) and SD (2.5 m) were recorded at Lake Gölhisar and Çayboğazı reservoir respectively. Çavdır reservoir showed the highest TP (750 µg/L) and SD (1.5 m) in fall 2014, while the lowest TP values, 28 and 50 µg/L respectively in summer 2014 and fall 2014 were measured at Osmankalfalar reservoir. In spring 2015, the peaks of TP (170 µg/L) and SD (5 m) were recorded at Lake Yazır and Yapraklı reservoir respectively, while the lowest TP concentration (32 µg/L) in summer was recorded at Lake Avlan. On the other hand, the lowest SD was found at Lake Yazır during all the four seasons.

**Table 8.3** Variation of total phosphorus (TP) and Secchi depth (SD) during the study

| | **Summer2014** | | **Fall 2014** | | **Spring 2015** | | **Summer 2015** | |
|---|---|---|---|---|---|---|---|---|
| | **TP** | **SD** | **TP** | **SD** | **TP** | **SD** | **TP** | **SD** |
| Lake Gölhisar | 540 | 0.9 | 520 | 0.4 | 50 | 1.0 | 128 | 0.3 |
| Çayboğazı reservoir | 95 | 2.5 | 480 | 0.5 | 100 | 1.0 | 40 | 3.0 |
| Lake Avlan | 440 | 0.8 | 750 | 0.2 | 40 | 0.9 | 32 | 1.8 |
| Geyik reservoir | 90 | 1.2 | 710 | 1.5 | 70 | 1.5 | 112 | 1.5 |
| Çavdır reservoir | 95 | 2.3 | 750 | 1.5 | 50 | 2.5 | 175 | 1.5 |
| Toptaş reservoir | 86 | 0.7 | 510 | 0.4 | 40 | 1.0 | 37 | 0.6 |
| Yapraklı reservoir | 95 | 6.0 | 550 | 1.0 | 50 | 5.0 | 44 | 1.7 |
| Osmankalfalar reservoir | 28 | 1.1 | 50 | 0.5 | 108 | 0.7 | 167 | 1.0 |
| Lake Yazır | 70 | 0.3 | 70 | 0.2 | 170 | 0.2 | 130 | 0.3 |

Units: TP (µg/L); SD (m)

### 8.3.2 Trophic State Based on TSI Carlson (1977)

#### 8.3.2.1 Trophic state variation in relation to total phosphorus

Trophic State Index (TSI) Carlson (1977) was used to determine trophic states of lakes and reservoirs in the West Mediterranean basin of Turkey. The result of TSI classification (Table 8.4) indicated that the trophic states of the lakes and reservoirs changed from one station to another and through the seasons. Peaks of TP corresponding to hypertrophic state (>70) were recorded at all stations in fall 2014 except for Osmankalfalar reservoir and Lake Yazır which indicated an eutrophic state (50-70). On another hand, all water bodies showed an eutrophic state in spring 2015 except Osmankalfalar reservoir which was hypertrophic. All the resevoirs (Çayboğazı, Çavdır, Toptaş, Yapraklı and Osmankalfalar) were eutrophic in summer 2014 and 2015, while Lake Gölhisar was hypertrophic. Lake Yazır was eutrophic in summer 2014 and indicated an hypertrophic state in summer 2015 in contast to Lake Avlan which was hypertrophic in summer 2014 and became eutrophic in summer 2015. The one-way ANOVA test between the mean TSI values indicated that there was no significant variation between the stations ($F= 0.34$, $p> 0.05$).

**Table 8.4** Trophic state of the stations in relation to total phosphorus (Carlson, 1977)

| | Summer 2014 | Fall 2014 | Spring 2015 | Summer 2015 |
|---|---|---|---|---|
| Lake Gölhisar | Hyp | Hyp | Eut | Hyp |
| Çayboğazı reservoir | Eut | Hyp | Eut | Eut |
| Lake Avlan | Hyp | Hyp | Eut | Eut |
| Geyik reservoir | Eut | Hyp | Eut | Eut |
| Çavdır reservoir | Eut | Hyp | Eut | Eut |
| Toptaş reservoir | Eut | Hyp | Eut | Eut |
| Yapraklı reservoir | Eut | Hyp | Eut | Eut |
| Osmankalfalar reservoir | Eut | Eut | Hyp | Eut |
| Lake Yazır | Eut | Eut | Eut | Hyp |

Hyp = hypertrophic, Eut = eutrophic, Mes = mesotrophic

#### 8.3.2.2 Trophic state variation in relation to Secchi depth

The trophic state of the water bodies and their corresponding SD during the study period are given in Table 8.5. A hypereutrophic state (TSI >70, and a Secchi depth <0.5) was observed for G11 all the study period except in spring 2015. An eutrophic state (TSI ranged between 50 and 70, and a Secchi depth between 0.5 and 1 m) was observed in summer 2014 and spring 2015 for Lake Gölhisar, Lake Avlan, Geyik reservoir, Toptaş reservoir and Osmankalfalar reservoir, while a mesotrophic state (TSI ranged between 40 and 50, and a Secchi depth between 2 and 2.5 m) was observed for Çavdır reservoir and Çayboğazı reservoir. An oligotrophic state for Yapraklı reservoir (TSI <40, and a Secchi depth >5 m) was observed in summer 2014 and spring 2015. During fall 2014, Çavdır reservoir, Geyik reservoir, Osmankalfalar reservoir, Yapraklı reservoir and Çayboğazı reservoir indicated a eutrophic state, when a hypereutrophic state was observed in Lake Gölhisar, Lake Avlan and Toptaş reservoir. A mesotrophic state was observed for Çayboğazı reservoir, while the other water bodies showed a eutrophic state in summer 2015 except for Lakes Gölhisar and Yazır which showed a hypereutrophic state. A one-way ANOVA test between the means indicated that there was significant variation between the stations ($F= 6.35$, $P < 0.001$).

**Table 8.5** Trophic state of the stations in relation to Secchi depth (Carlson, 1977)

| | **Summer 2014** | **Fall 2014** | **Spring 2015** | **Summer 2015** |
|---|---|---|---|---|
| Lake Gölhisar | Eut | Hyp | Hyp | Hyp |
| Çayboğazı reservoir | Mes | Eut | Eut | Mes |
| Lake Avlan | Eut | Hyp | Hyp | Eut |
| Geyik reservoir | Eut | Eut | Hyp | Eut |
| Çavdır reservoir | Mes | Eut | Hyp | Eut |
| Toptaş reservoir | Eut | Hyp | Hyp | Eut |
| Yapraklı reservoir | Oli | Eut | Oli | Eut |
| Osmankalfalar reservoir | Eut | Eut | Hyp | Eut |
| Lake Yazır | Hyp | Hyp | Eut | Hyp |

Hyp = hypertrophic, Eut = eutrophic, Mes = mesotrophic

### 8.3.3 Trophic State Based on OECD (1982)

#### 8.3.3.1 Trophic State Variation in Relation to Total phosphorus

The variation of trophic state in relation to TP during the study period is given in Table 8.6. The classification based on OECD system according to the TP values in µg/L classified all lakes and reservoirs in tow classes (hypertrophic and eutrophic) except Osmankalfalar reservoir and Lake Avlan which indicated a mesotrophic state in summer 2014 and summer 2015 respectively. The commonly found state was the eutrophic class.

**Table 8.6** Trophic state of the stations in relation to total phosphorus (OECD, 1982)

| | **Summer 2014** | **Fall 2014** | **Spring 2015** | **Summer 2015** |
|---|---|---|---|---|
| Lake Gölhisar | Hyp | Hyp | Eut | Hyp |
| Çayboğazı reservoir | Eut | Hyp | Hyp | Eut |
| Lake Avlan | Hyp | Hyp | Eut | Mes |
| Geyik reservoir | Eut | Hyp | Eut | Hyp |
| Çavdır reservoir | Eut | Hyp | Eut | Hyp |
| Toptaş reservoir | Eut | Hyp | Eut | Eut |
| Yapraklı reservoir | Eut | Hyp | Eut | Eut |
| Osmankalfalar reservoir | Mes | Eut | Hyp | Hyp |
| Lake Yazır | Eut | Eut | Hyp | Hyp |

Hyp = hypertrophic, Eut = eutrophic, Mes = mesotrophic

#### 8.3.3.2 Trophic state variation in relation to Secchi depth

With regard to SD values, four classes were found in the studied stations. Oligotrophic state was observed only at Yapraklı reservoir in summer 2014. This reservoir indicated hypertrophic, mesotrophic and eutrophic states in fall 2014, spring and summer 2015 respectively (Table 8.7). On the other hand, hypertrophic was the dominant class during the four seasons of the study compared to eutrophic and mesotrophic states.

**Table 8.7** Trophic state of the station in relation to Secchi depth (OECD, 1982)

| | Summer 2014 | Fall 2014 | Spring 2015 | Summer 2015 |
|---|---|---|---|---|
| Lake Gölhisar | Hyp | Hyp | Hyp | Hyp |
| Çayboğazı reservoir | Eut | Hyp | Hyp | Mes |
| Lake Avlan | Hyp | Hyp | Hyp | Eut |
| Geyik reservoir | Hyp | Eut | Eut | Eut |
| Çavdır reservoir | Eut | Eut | Eut | Eut |
| Toptaş reservoir | Hyp | Hyp | Hyp | Hyp |
| Yapraklı reservoir | Oli | Hyp | Mes | Eut |
| Osmankalfalar reservoir | Hyp | Hyp | Hyp | Hyp |
| Lake Yazır | Hyp | Hyp | Hyp | Hyp |

Hyp = hypertrophic, Eut = eutrophic, Mes = mesotrophic, Oli = oligotrophic

### 8.3.4 Comparison of the TSI(TP) and TSI(SD)

The two indices indicated similar trophic state (eutrophic) in spring 2015 for Çayboğazı reservoir, Osmankalfalar reservoir, Toptaş reservoir, Geyik reservoir, and Lake Avlan. The significant was observed in summer 2014 at Yapraklı reservoir which indicated a hypertrophic state following $TSI_{(TP)}$ and on the other hand became oligotrophic based on $TSI_{(SD)}$ (Figure 8.2).

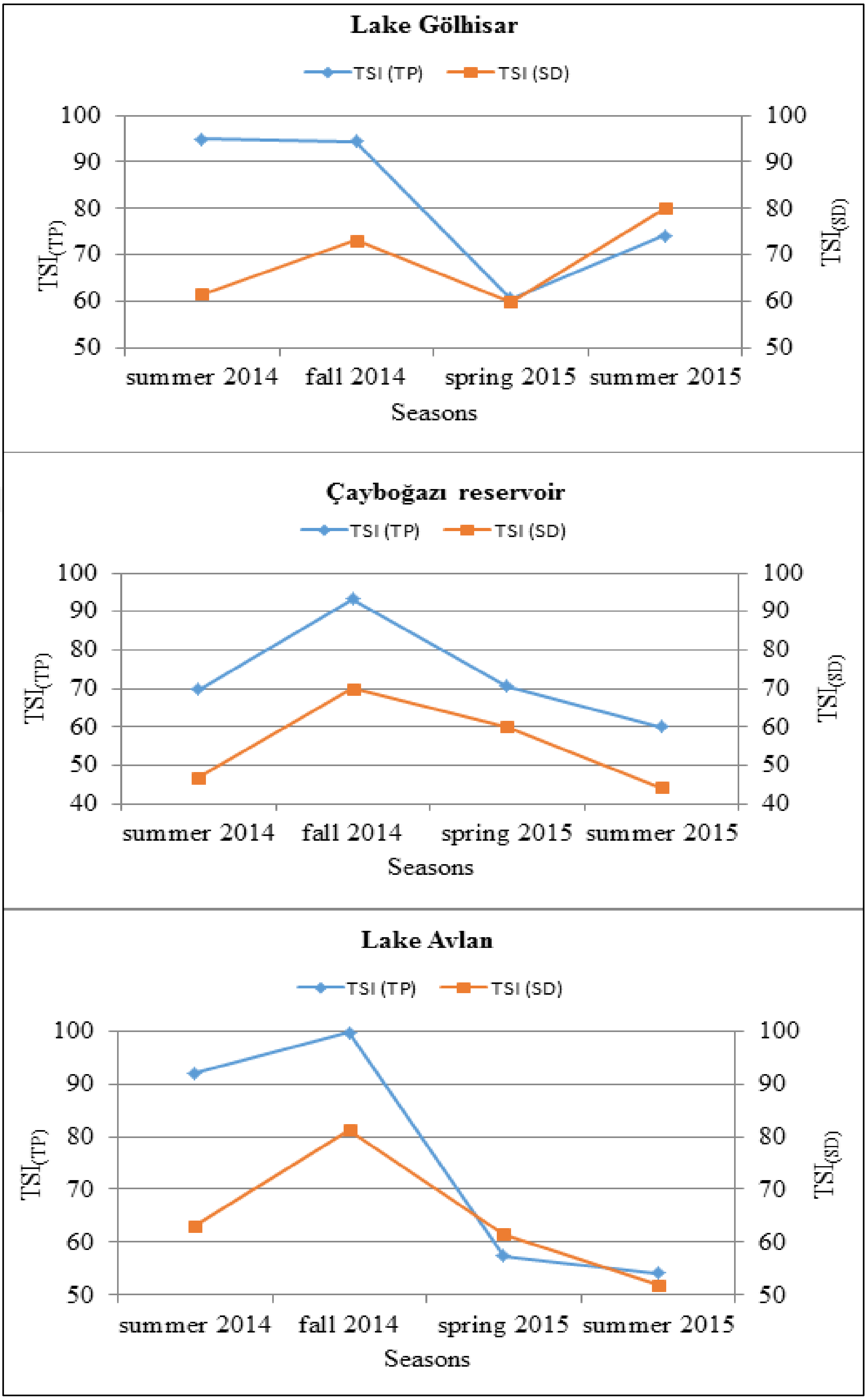



**Figure 8.2a** variation of $TSI_{(TP)}$ and $TSI_{(SD)}$ in Lake Gölhisar, Çayboğazı reservoir and Lake Avlan

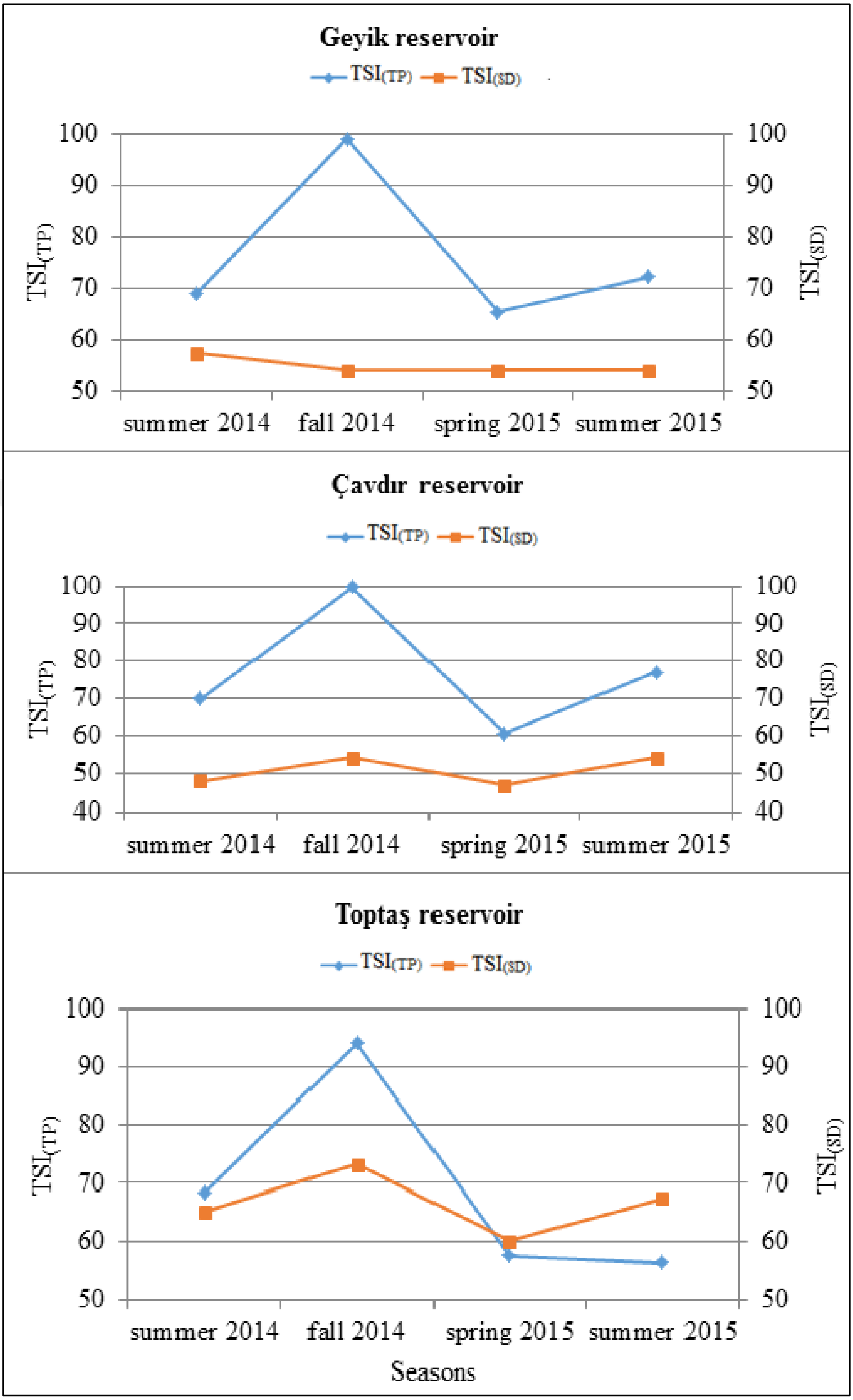



**Figure 8.2b** variation of $TSI_{(TP)}$ and $TSI_{(SD)}$ in Geyik reservoir, Çavdır reservoir and Toptaş reservoir

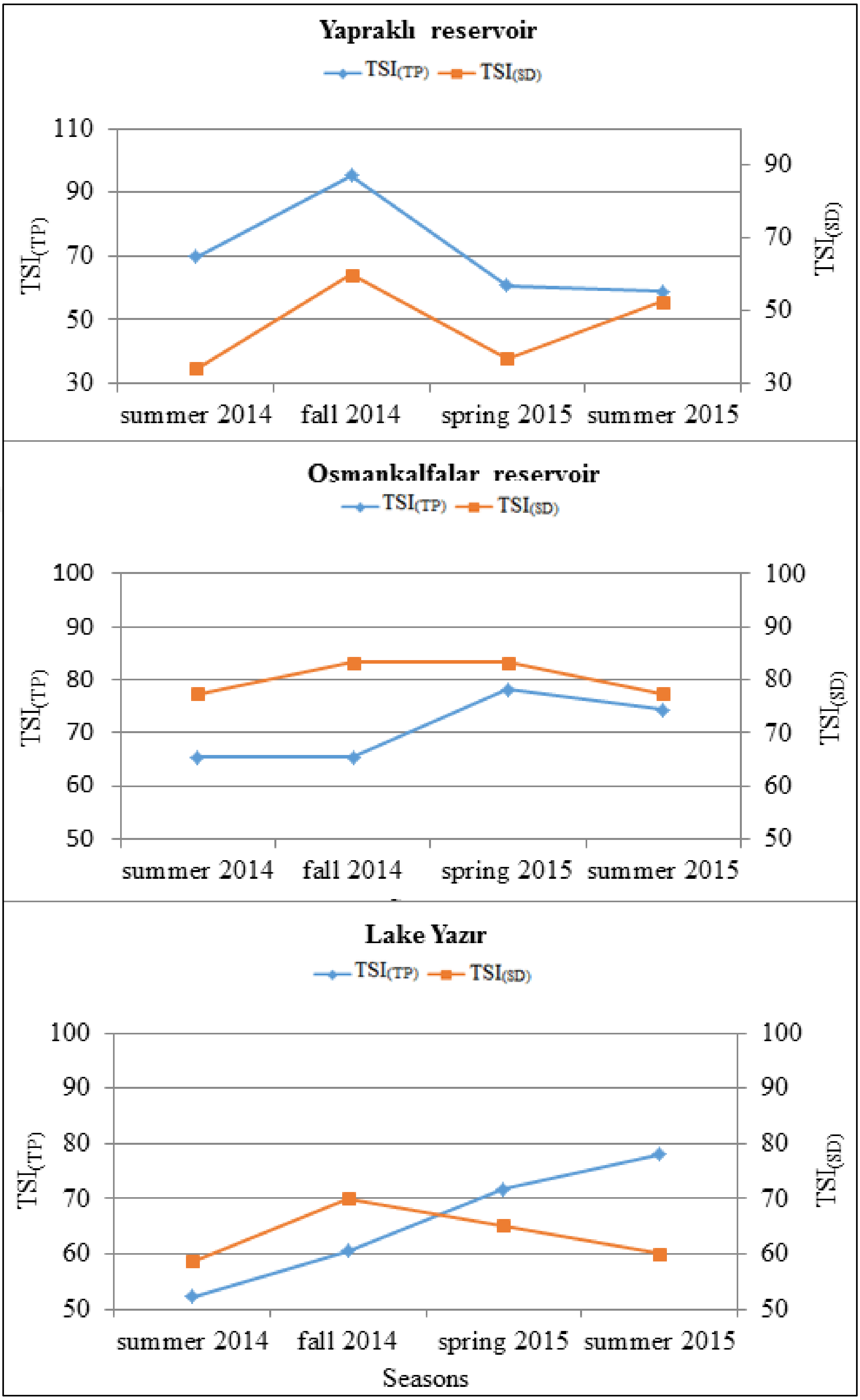



**Figure 8.2c** variation of $TSI_{(TP)}$ and $TSI_{(SD)}$ in Yapraklı reservoir, Osmankalfalar reservoir and Lake Yazır

## 8.4 Disccussion

### 8.4.1 Environmental variables

Physicochemical parameter study is very important to get exact idea about the quality of water (Patil et al., 2012). The quality of surface water depends on various nutrients and their concentration, which are mostly derived from the water bodies catchment area.

Total phosphorus (TP) variable was mainly high in the water bodies during the study time. The highest value of TP (420.8 µg $l^{-1}$) was found in Osmankalfalar reservoir (Table 1). This is probably the consequence of excessive fish farming and water seasonal level fluctuations (from 15 m to 3 m) due to irrigation. Sevindik et al., 2017 indicated that the seasonal variation of precipitations and the high use of water in summer for irrigation purposes decrease water level for about 10 m in İkizcetepeler reservoir (Turkey). According to Sgro et al. (2006), local parameters may be more important determinants of water quality and increase variability among sites during low flow periods. In the same idea, Kennedy and Walker (1990) indicated that maximum environmental gradients are associated in reservoirs with high water retention time, high sedimentation rates and flow that are controlled by advective processes. With regard to lakes, Lake Avlan had higher TP value (365 µg $l^{-1}$) than other lakes. This lake was a very shallow and eutrophic ecosystem invaded by macrophytes. Lake Gölhisar, a shallow lake with dense vegetation and turbid water. The lake is near to the District of Gölhisar and surrounded by several villages. This result could be the consequences of anthropogenic activities especially discharge of domestic waste and agriculture fertilizers which can affect the lake through generated organic nutrients. Mancini and Arcà (2000) reported that urbanization and agriculture practices in a study area could affect the basins of watercourses. High TN values were measured in Lake Gölhisar (1569.3 µg $l^{-1}$) and Osmankalfalar reservoir (1073.8 µg $l^{-1}$). These results could be partially due to human activities in the water bodies' catchments. In accordance with our result, Strebel et al. (1989) and Almasri and Kaluarachchi (2004) indicated that the downstream increase of nitrate is a common human impact by agriculture. Loehr (1974) and Dodds (2002) indicated that human activities that lead to cultural eutrophication include the use of agricultural fertilizers, livestock practices, and release of nutrient-rich sewage into the surface water.

### 8.4.2 Trophic State

In the present study the trophic states of 3 lakes and 6 reservoirs were examined in the west Mediterranean basin of Turkey based on Carlson (1977) TSI system which was developed on the hypothesis that there is a close relationship between total phosphorus, chlorophyll-a and Secchi depth in phosphorus limited lakes (Matthews et al., 2002) and the OECD classification system (OECD, 1982). Lakes and reservoirs showed different trophic states according to TP and SD variables and the classification system at the different water bodies but indicated similar trophic states based on each of the two systems. This situation confirmed our hypothesis of no difference between the trophic states of the lakes and reservoirs. Three trophic categories were (Mesotrophic, eutrophic and hypertrophic) recorded based on TSI (Carlson, 1977), while four trophic states (Oligotrophic, Mesotrophic, eutrophic and hypertrophic) were found according to the OECD criteria (OECD, 1982). Brenner et al., 1999 and Dodds (2002) reported that lakes may not clearly fall into an individual class in any of the classification methods. For example, TP could be high enough for a lake to be categorized as eutrophic, but water clarity by suspended sediments could keep the chlorophyll amount in the mesotrophic range. Also, TP and phytoplankton composition could be low in a lake with extensive macrophytes biomass and production.

Yaprakli reservoir was mesotrophic according to SD based on Carlson (1977) system, while other reservoirs and lakes showed eutrophic status according to TP and SD. OECD criteria classified lakes and reservoirs as hypertrophic based on TP. According to SD, all lakes had hypertrophic status, while Geyik, Toptaş, and Osmankalfalar reservoirs were eutrophic; Çayboğazı and Çavdır reservoirs were recorded as meso-eutrophic, while an oligotrophic status was observed for Yapraklı reservoir. Similar trophic status related to TP and SD were previously found in early studies (Carlson, 1977; Vollenweider and Kerekes, 1982; Marchetto et al., 2009). These trophic states have also been indicated by Moreno-Ostos et al. (2008) in El Gergal Reservoir (Spain), Becker et al. (2010) in Sau Reservoir (Spain), at Lakes

Sumin and Másluchowskie in Eastern Poland (Pasztaleniec and Poniewozik, 2010), at Pareja limno-Reservoir (Spain) (Molina-Navarro et al., 2012, 2014) at Alleben Reservoir (Turkey) (Çelekli and Öztürk, 2014), at Lake Lacanau and Lakes Parentis and Hourtin (France) (Cellamare et al., 2012). According to the Carlson’s Trophic State Indices and OECD trophic classifications using Secchi depth, and total phosphorous mesotrophic and meso-eutrophic states were indicated at Lake Abant and Gölköy respectively (Çelekli, 2006). In accordance with our finding, Erdoğan (2016) reported a high variability from hypertrophic to oligotrophic for 48 lakes and 12 reservoirs including Gölhisar which showed a hypertrophic state during the present study. The Mediterranean characteristics the geographical properties, climate, land use, and anthropogenic activities which could change environmental factors could be the consequence of the similarity of the trophic states of the reservoirs and lakes.

The mesotrophic, eutrophic and hypertrophic states observed at the lakes and reservoirs could be due to anthropogenic activities. In fact, livestock and agriculture activities have an important place in the Western Mediterranean Basin. The most common crops which grow in the basin are tomatoes, peppers, citrus fruits, apples, pears, quince, wheat, corn, and olives. Fish production and packaging, olive oil production and mining are the main commercial activities. These activities are a great source of organic and inorganic pollutants in a river catchment. Salomoni et al. (2006) reported that high population densities and the large number of industrial and agricultural activities expose most watersheds near to large urban centers to adverse environmental impacts, particularly to pollutions by domestic and industrial wastewaters. This situation was confirmed by Mancini and Arcà (2000) who reported that urbanization and agriculture practices in the study area affect the basins of watercourses.

# CHAPTER VIV

# CONCLUSION

## 9.1 Phytoplankton composition and water quality in the lakes and reservoirs

This study revealed that phytoplankton brings complementary information, reflected and integrated unambiguously the ecological status of the lakes and reservoirs. A total of 206 species belonging to 9 classes and 15 functional groups with a dominance of **B** group were identified during the study period. *P. cinctum, C. ocellata, C. hirundinella, P. morum, C. ovota, M. aeruginosa, M. flosaquae* and *Peridinium willei* had important contributions to total phytoplankton biovolume. Phytoplankton functional groups system was used as an indicator of trophic status for lakes and reservoirs in Turkey for the first time as basin wide. The study confirmed the suitable applicability of this system groups for evaluationg the trophic state and provided valuable and complementary knowledge on phytoplankton structures, development, and tolerances to classify and define phytoplankton dynamics in the water bodies. The spatial and temporal occurrences of phytoplankton species were strictly associated with the changes of some important environmental factors in lakes and reservoirs in the West Mediterranean basin. This interactions between predictor factors and the phytoplankton communities in the lakes and reservoirs was elucidated by use of multivariate approaches. Results of the present study indicated that the dominance of phytoplankton assemblages differed among water bodies and seasons due to the difference of species preference in the tolerance range of water temperature and nutrient limitations. Trophic state indices and ecological quality ratio based on PTI and Med-PTI and Q assemblage index were used to evaluate trophic states and ecological quality of lakes and reservoirs in this basin. As basin approach, the present study regarding limnoecology of phytoplankton assemblages in lakes and reservoirs is the first study in Turkey. Further limnoecological studies with multivariate approaches and indices should be conducted to resolve some of the biological deteriorations of different water bodies that this study has pointed out. The use of statistical analysis to examine the impact of various complex predictor factors on the phytoplankton species composition and distribution is pontentially a suitable tool to understand the role of the effective parameters. From that point, the present work is be a contribution to the use of phytoplankton characteristics as a ecological indicators in this region. However, the use of these indices could lead to erroneous interpretation of water quality because ecoregional changes in algal composition, and there is a need to develop a national phytoplankton based metrics as the newly developed diatom-based metric called trophic index Turkey.

### 9.2 Epithic diatom composition and water quality in the running waters

A total of 102 species of epilithic diatoms from 22 running water (stream and creek) were identified during the present study. *Navicula*, *Cymbella*, *Nitzschia*, *Gomphonema*, *Fragilaria*, and *Cocconeis* were the most dominant genus recorded while *F. capucina*, *C.excisa*, *G. parvulum*, *U. ulna* and *C. placentula* were the common and abundant species observed in the stations. The ecological states obtained for the different sites based on the trophic index relate exactly the state of deterioration of these water bodies due to human activities such as agriculture and fisheries in the basin. The Trophic index in Turkey (TIT) should be appropriate for our studied water bodies and this conclusion is similar to that found in the previous reports of Yusano et al., (1994) and Pongpan and Yuwadee (2014), who suggested that the usefulness of the index should be developed from the organisms in that area. However, this index should be revised to include all phytobenthos communities from lakes, reservoirs and running water to extend its applicability to a number of aquatic systems in Turkey and wherever.

### 9.3 Trophic state and water quality in the lakes and reservoirs

The trophic state of 3 lakes and 6 reservoirs in the western Mediterranean basin of Turkey based on Carlson’s Trophic State Index the OECD trophic classification system. Total phosphorus concentrations and the Secchi depth values among stations and seasons. In summer 2014, the highest TP (540 µg/L) and SD (2.5 m) were recorded at Lake Gölhisar and Çayboğazı reservoir respectively. Çavdır reservoir showed the highest TP (750 µg/L) and SD (1.5 m) in fall 2014, while the lowest TP values, 28 and 50 µg/L respectively in summer 2014 and fall 2014 were measured at Osmankalfalar reservoir. In spring 2015, the peaks of TP (170 µg/L) and SD (5 m) were recorded at Lake Yazır and Yapraklı reservoir respectively, while the lowest TP concentration (32 µg/L) in summer was recorded at Lake Avlan.

With regard to water quality, 3 trophic categories were recorded based on trophic state index, while 4 trophic states were found according to the OECD criteria. Yaprakli reservoir was mesotrophic according to SD based on Carlson system, while other reservoirs and lakes showed eutrophic status according to TP and SD. OECD criteria classified lakes and reservoirs as hypertrophic based on TP. According to SD, all lakes had hypertrophic status, while Geyik, Toptaş, and Osmankalfalar reservoirs were eutrophic; Çayboğazı and Çavdır reservoirs were recorded as meso-eutrophic, and oligotrophic status was observed for Yapraklı reservoir. From that point, it appeared that they applied systems seem to be suitable to assess the trophic state of the studied water bodies.

## REFERENCES


Abonyi, A., Leitão, M., Lançon, A. M., Padisák J. (2012). Phytoplankton functional groups as indicators of human impacts along the River Loire (France), *Hydrobiologia*, **698**, 233–249.

ACA. Agència Catalana de l'Aigua. 2003. Desenvolupament d'un índex integral de qualitat ecològica i regionalització ambiental dels sistemes loacustres de Catalunya. Generalitat de Catalunya, Department de Medi Ambient i Habitatge. Spain : Agència Catalana de l'Aigua.

Acuna, S. C., Deng, D. F., Lehman, P. W., Teh, S. J. (2012a). Dietary effects of Microcystis on Sacramento splittail, Pogonichthys macrolepidotus, *Aquatic Toxicology,* **110**, 1–8.

Acuna, S., Baxa, D., Teh, S. (2012b). Sublethal dietary effects of microcystin producing Microcystis on threadfin shad, Dorosoma petenense, *Toxicon*, **60**, 1191–1202.

Akbulut, N., Akbulut, A., Günsel, S. and Solak, C.N. (2010). Use of epilithic diatoms to evaluate water quality of Kızılırmak River. Turkey: Hacettepe University (Fund N°: 0701601006), Final Report, in Turkish.

Albay, M., Akcaalan, R. (2003a). Factors influencing the phytoplankton steady state assemblages in a drinking-water reservoir (Ömerli Reservoir, Istanbul), *Hydrobiologia*, **502**, 85-95.

Albay, M., Akcaalan, R. (2003b). Comparative study of periphyton colonization on common reed (Phragmites australis) and artifical substrate in a shallow lake, Manyas, Turkey, *Hydrobiologia*, **506**, 531-540.

Allan, JD, Castillo, MM. (2007). Stream Ecology: Structure and Function of Running Waters. 2nd ed. Berlin: Springer, 436 p.

Almasri, M. N., Kaluarachchi, J. J. (2004). Assessment and management of long-term nitrate pollution of ground water in agriculture-dominated watersheds, *Journal of Hydrology*, **295**, 225–245.

Alobaidy, A H M. J, Abid, H. S., Maulood, B. K. (2010). Application of Water Quality Index for Assessment of Dokan Lake Ecosystem, Kurdistan Region, Iraq, *Journal of Water Resource and Protection*, **2**, 792-798.

Anderson, D., Glibert, P., Burkholder, J. (2002). Harmful algal blooms and eutrophication: nutrient sources, composition, and consequences, *Estuar. Coasts*, **25**, 704-726.

Angermeier, P. L., Karr, J. R. (1994). Biological Integrity versus Biological Diversity as Policy Directives -Protecting biotic resources, *BioScience*, **44**, 690-697.

Anneville, O., Ginot, V., Druart, J. C. Angeli, N. (2002). Long-term study (1974–1998) of seasonal changes in the phytoplankton in Lake Geneva: a multi-table approach, *Journal of Plankton Research*, **24**, 993–1008.

Anonymous (2015). Biologie végétale: III. Les algues. Available at: www.ecofog.gf. Accessed 05.12.2017.

Anonymous (2016). Ülkemize özgü su kalitesi ekolojik değerlendirme sisteminin kurulması projesi (Project N° 188.02.01). Ankara: Orman ve Su İşleri Bakanlığı, Su Yönetimi Genel Müdürlüğü.

APHA, American Public Health Association. (2012). American Water Works Association, Water Environment Federation, Standard Methods for the Examination of Water and Wastewater. 22nd Edition, 1496. p. Washington, D.C.

Atıcı, T., Tokatli, C. (2014). Algal Diversity and Water Quality Assessment with Cluster Analysis of Four Freshwater Lakes (Mogan, Abant, Karagöl and Poyrazlar) of Turkey, *Wulfenia journal*, **21**, 155-196.

Ács, É., Szabó, K., Tóth, B., Kiss, K. T. (2004). Investigation of benthic algal communities, especially diatoms of some Hungarian streams in connection with reference conditions of the Water Framework Directives, *Acta Botanica Hungarica*, **46**, 255–277.

Ács, É., Reskóné, N. M., Szabó, K., Taba, G., Kiss, K. T. (2005). Application of epiphytic diatoms in water quality monitoring of Lake Velence recommendations and assignments, *Acta Botanica Hungarica*, **47**, 211–223.

Bahls, LL. (1993). Periphyton bioassessment methods for Montana streams. Montana water quality bureau, department of health and environmental science. Montana: Helena.

Barbour, MT, Gerritsen, J, Snyder, B D, Stribling, JB. (1999). Rapid bioassessment protocols for use in streams and wadeable rivers. Washington: Usepa.

Beardall, J., Stojkovic, S., Larsen, S. (2009). Living in a high $CO_2$ world: impacts of global climate change on marine phytoplankton, *Plant Ecology and Diversity*, **2**, 191-205.

Becker, V., Caputo, L., Ordóñez, J., Marcé, R., Armengol, J., Crossetti, L. O., Huszar, V. L. M. (2010). Driving factors of the phytoplankton functional groups in a deep Mediterranean reservoir, *Water Research*, **44**, 3345–3354.

Becker, V., Huszar, V. L. M., Crossetti, L. O. (2009). Responses of phytoplankton functional groups to the mixing regime in a deep subtropical reservoir, *Hydrobiologia*, **628**, 137-151.

Bellinger, B. J., Christine, C., Catherine, M. O. (2006). Benthic diatoms as indicators of eutrophication in tropical streams, *Hydrobiologia*, **573**, 75–87.

Beltrami, M. E., Ciutti, F., Cappelletti, C., Losch, B., Alber, R., Ector, L. (2012). Diatoms from Alto Adige/Sudtirol (Northern Italy): characterization of assemblages and their application for biological quality assessment in the context of the Water Framework Directive, *Hydrobiologia*, **695**, 153–170.

Bennion, H. (1994). A diatom-phosphorus transfer-function for shallow, eutrophic ponds in Southeast England, *Hydrobiologia* **276**, 391–410.

Bennion, H., Kelly, M. G., Juggins, S., Yallop, M. L., Burgess, A., Jamieson, B. J., Krokowski, J. (2014). Assessment of ecological status in UK lakes using benthic diatoms, *Freshwater Science*, **33**, 639–654.

Biggs, B. J. F., Close, M. E. (1989). Periphyton biomass dynamics in gravel bed rivers – the relative effects of fl ows and nutrients, *Freshwater Biology*, **22**, 209–231.

Billen, G., Garnier, J., Ficht, A., Cun, C. (2001). Modelling response of water quality in the Seine river estuary to human activity in its watershed over the last 50 years, *Estuaries*, **24**, 977–993.

Birk, S., Bonne, W., Borja, A., Brucet, S., Courrat, A., Poikane, S., Solimini, A., de Bund, W. v., Zampoukas, N., Hering, D. (2012). Three hundred ways to assess Europe's surface waters: An almost complete overview of biological methods to implement the Water Framework Directive, *Ecological Indicators*, **18**, 31–41.

Bona, F., Falasco, E., Fassina, S., Griselli, B., Badino, G. (2007). Characterization of diatom assemblages in mid-altitude streams of NW Italy, *Hydrobiologia*, **583**, 265–274.

BPMP. Bow River Phophorus Management Plan. (2017). Water quality and phosphorus. PMP Information Series, 2. p. Available at: http://aep.albeta.ca. Accessed 25.01.2018.

Boyacioglu, H. (2007). Development of a water quality index based on a European classification scheme. *Water SA*, **33**, 101-106.

Boyacioglu, H., Boyacioglu, H. (2007). Surface Water Quality Assessment by Environmetric Methods, *Environmental Monitoring and Assessment*, **131**, 371-376.

Brenner, M., Whitmore, T. J., Lasi, M. A., Cable, J. E., Cable P. H. (1999). A multiproxy trophic state reconstruction for shallow Orange Lake, Florida, USA: Possible influence of macrophytes on limnetic nutrient concentrations, *Journal of Paleolimnology*, **21**, 215-233.

Brettum, P. (1989). Alger som indikatorer pa vannkvalitet i norske innsjøer. Niva Report, Planteplankton.

Brucet, S., Poikane, S., Lyche-Solheim, A., Birk, S. (2013). Biological assessment of European lakes: ecological rationale and human impacts, *Freshwater Biology*, **58**, 1106–1115.

Cao, Y., Hawkins, C. P., Olson, J. (2007). Modeling natural environmental gradients improves the accuracy and precision of diatom-based indicators, *Journal of the North American Benthological Society*, **26**, 566–585.

Caraco, N. F. Miller, R. (1998). Effects of CO2 on competition between cyanobacterium and eukaryotic phytoplankton, *Canadian Journal of Fisheries and Aquatic Sciences*, **55**, 54–62.

Carey, C. C., Ibelings, B. W., Hoffmann, E. P., Hamilton, D. P., Brookes, J. D. (2012). Eco-physiological adaptations that favour freshwater cyanobacteria in a changing climate, *water research*, **46**, 1394-1407.

Carlson, R. E. (1977). A trophic state index for lakes. *Limnology and Oceanography*, **22**, 361–369.

Carvalho, L., Poikane, S., Lyche Solheim, A., Phillips, G., Borics, G., Catalan, J., De Hoyos, D., Drakare, S., Dudley, B.J., Järvinen, M., Laplace-Treyture, C., Maileht, K., McDonald, C., Mischke, U., Moe, J., Morabito, G., Nõges, P., Nõges, T., Ott, I., Pasztaleniec, A., Skjelbred, B., Thackeray, S. J. (2013). Strength and uncertainty of phytoplankton metrics for assessing eutrophication impacts in lakes, *Hydrobiologia*, **704**, 127–140.

Catalan, J, Ventura, M, Munné, A, Godé, L. (2003). Desenvolupament d'un index integral de qualitat ecològica I regionalització ambiental dels sistemes lacustres de Catalunya. Generalitat de Catalunya, Spain : Agencia Catalana del Aigua.

Cellamare, M., Morin, S., Coste, M., Haury, J. (2012). Ecological assessment of French Atlantic lakes based on phytoplankton. phytobenthos and macrophytes, *Environmental Monitoring and Assessment*, **184**, 4685–4708.

Chellappa, N. T., Chellappa, T., Camara, F. R..A., Rocha, O., Chellappa, S. (2009). Impact of stress and disturbance factors on the phytoplankton communities in Northeastern Brazil reservoir, *Limnologica*, **39**, 273–282.

Chen, M., Li, J., Dai, X., Sun, Y., Chen, F. (2011). Effect of phosphorus and temperature on chlorophyll a contents and cell sizes of Scenedesmus obliquus and Microcystis aeruginosa, *Limnology*, **12**, 187–192.

Chen, X, Wang, X., Wu, D., He, S., Kong, H., Kawabata, Z. (2009). Seasonal variation of mixing depth and its influence on phytoplankton dynamics in the Zeya reservoir, China, *Limnology*, **10**, 159–165.

Chessman, B. C., Bate, N., Gell, P. A., Newall, P. (2007). A diatom species index for bioassessment of Australian rivers, *Marine and Freshwater Research*, **58**, 542-557.

Cieszynska, M., Wesolowski, M., Bartoszewicz, M., Michalska, M., Nowacki, J. (2012). Application of physicochemical data for water-quality assessment of watercourses in the Gdansk Municipality (South Baltic coast), *Environmental Monitoring and Assessment*, **184**, 2017–2029.

CEN. Comité européen de normalisaation. (2003) Water quality - Guidance standard for the routine sampling and pretreatment of benthic diatoms from rivers. European Standard EN, 13946, Brussels: European Committee for Standardization, 14 p.

CEN. Comité européen de normalisaation. (2006). Water quality - Guidance standard on the enumeration of phytoplankton using inverted microscopy (Utermöhl technique). European Standard EN, 15204. Brussels: European Committee for Standardization, 16 p.

CEN. Comité européen de normalisation. (2012). Water quality - Sampling - Part 3: Preservation and handling of samples. - European Standard EN, 5667-3. Brussels: European Committee for Standardization, 12 p.

CEN. Comité européen de normalisaation. (2014). Water quality- guidance for the routine sampling and preparation of benthic diatoms from rivers and lakes. European Standard EN 13946. Brussels: European Committee for Standardization, 16 p.

Cohn, F. (1853). Über lebende organismen im trinkwasser, *Z. klein Medezin*, **4**, 229-237.

Cohn, F. (1870). Über den Brunnenfaden (Crenothix polyspora) mit Bemerkungen über die mikroshopische Analyse des Brunnenwassers. *Chon's Beiträge zur biologie de pflanzen*, **3**, 1-108.

Cook, C. M., Vardaka, E., Lanaras, T. (2004). Toxic cyanobacteria in Greek Freshwaters, 1987–2000: Occurrence, toxicity, and impacts in the Mediterranean region, *Acta Hydrochimica et Hydrobiologica*, **32**, 107–124.

Coring, E. (1999). Situation and developments of algal (diatom)- based techniques for monitoring rivers in Germany. In Prygiel, J., B. A. Whitton and J. Bukowska (eds), Use of Algae for Monitoring Rivers III. Douai: Agence de l'Eau Artois-Picardie, 122–127 p.

Costa, HH, Silva, PR. (1995). Limnological research and training in Sri Lanka: state of the art and future needs. In Gopal, B. and R. G.Wetzel (eds), Limnology in Developing Countries. Índia: SIL, 39 p.

Coste, M. (1982). Study of Biological Methods Appr'eciation Quantitative Qualit'e of Water. Lyon, France : Cemagref, Rapport Q E. Lyon, Agence de l'Eau Rhone-Méditerranée Corse.

Coste, M., Boutry, S., Rosebery, J. T., Delmas, F. (2009). Improvements of the biological diatom index (BDI): Description and efficiency of the new version (BDI-2006), *Ecological Indicators*, **9**, 621-650.

Cranston, PS, Fairweather, P, Clarke, G. (1996). Biological indicators of water quality. In J. Walker and D.J. Reuter (eds) Indicators of Catchment Health: a technical perspective. Melboune: CSIRO, 143-154 p.

Crossetti, L. O., Bicudo, C. E. M. (2005). Structural and functional phytoplankton responses to nutrient impoverishment in mesocosms placed in a shallow eutrophic reservoir (Garcas Pond), Sao Paulo, Brazil, *Hydrobiologia*, **541**, 71–85.

Crossetti, L. O., Becker, V., Cardoso, L. d. S., Rodrigues, L. R., da Costad, L. S., da Motta-Marques, D. (2013). Is phytoplankton functional classification a suitable tool to investigate spatial heterogeneity in a subtropical shallow lake?, *Limnologica*, **43**, 157–163.

Çako, V., Baci, S., Shena, M. (2003). Water Turbidity as One of the Trophic State Indices in Butrinti Lake, *Journal of Water Resource and Protection*, **5**, 1144-1148.

Çelekli, A. (2006). Comparative analysis of seasonal water quality changes and algae potential between lake abant and lake gölköy. Turkey: Abant İzzet Baysal University, Department of Biology Graduate School of Arts and Sciences, PhD Thesis, 395 p.

Çelekli, K., Ongun, T. (2008). Spatial and temporal dynamics of the steady-state phytoplankton assemblages in a temperate shallow hypertrophic lake (Lake Manyas, Turkey), L*imnology*, **9**, 115–123.

Çelekli, A., Öztürk, B. (2014). Determination of ecological status and ecological preferences of phytoplankton using multivariate approach in a Mediterranean reservoir, *Hydrobiologia*, **740**, 115–135.

Çelekli, A., Yavuzatmaca, M., Beyazcicek, E., Bozkurt, H. (2009). Effect of initial reactive red 120 concentrations on the biomass production and dye uptake by Spirulina platensis, *Fresenius Environmental Bulletin*, **18**, 994-998.

Çelekli, A., Toudjani, A. A., Kayhan, S., Lekesiz, H. Ö., Gümüş, E. Y. (2016). Bati Akdenġz Havza Ġzleme Raporu, In Ülkemize özgü su kalitesi ekolojik değerlendirme sisteminin kurulması projesi, (Project N°: 188.02.01). Ankara: Orman ve Su İşleri Bakanlığ, Su Yönetimi Genel Müdürlüğü, 1089 p.

Çelekli, A., Toudjani, A. A., Gümüş, E. Y., Kayhan, S., Lekesiz, H. Ö., Çetin, T. (2018a). Determination of trophic weight and indicator values of diatoms in Turkish running waters for water quality assessment. *Turkish Journal of Botany*, doi:10.3906/bot-1704-40.

Çelekli, A., Toudjani, A. A., Gümüş, E. Y., Kayhan, S., Lekesiz, H. Ö., Çetin, T. (2018b). Establishment of Reference Monitoring Network in Turkey. Turkey: General Direction of Water Management of the Ministry of Forestry and Water Affairs.

Dasí, M. J., Miracle, M. R., Camacho, A., Soria, J. M., Vicente, E. (1998). Summer phytoplankton assemblages across trophic gradients in hard-water reservoirs, *Hydrobiologia*, **369**, 27–43.

Davis, T. W., Berry, D. L., Boyer, G. L., Gobler, C. J. (2009). The effects of temperature and nutrients on the growth dynamics of toxic and non-toxic strains of Microcystis during cyanobacterial blooms, *Harmful Algae*, **8**, 715–725.

de Hoyos, C, Catalan, J, Dörflinger, G, Ferreira, J, Kemitzoglou, D, Laplace-Treyture, C, López, JP, Marchetto, A, Mihail, O, Morabito, G, Polykarpou, P, Romão, F, Tsiaouss, V. (2014). Water Framework Directive Intercalibration Technical Report: Mediterranean Lake Phytoplankton ecological assessment methods. Luxembourg: Ed. Poikane, S., 65 p.

Delgado, C., Pardo, I. (2014). Comparison of benthic diatoms from Mediterranean and AtlanticSpanish streams: Community changes in relation to environmentalfactors, *Aquatic Botany*, **120**, 304–314.

Della Bella, V., Pace, G., Barile, M., Zedde, A., Puccinelli, C., Ciadamidaro, S., Danieli, P. P., Andreani, P., Aulicino, F. A., Belfiore, C., Mancini, L. (2012). Benthic diatom assemblages and their response to human stress in small-sized volcanic-siliceous streams of central Italy (Mediterranean eco-region), *Hydrobiologia*, **695**, 207–222.

Dell'uomo, A. (1999). Use of algae for monitoring rivers in Italy: currrent situation and perspectives. In: Prygiel J.,Whitton B.A. and Bukowska J. (eds), Use of algae for monitoring rivers III. Douai: Agence de l'Eau Artois-Picardie, 17-25 p.

Dell'uomo, A. (2004). L'indice diatomico di eutrofizzazione/polluzione (EPI-D) nel monitoraggio delle azque correnti, line guida. Universita di Camerino: Dipartimento di Botanica ed Ecologia.

Demir, A. N., Fakioğlu, Ö., Dural, B. (2014). Phytoplankton functional groups provide a quality assessment method by the Q assemblage index in Lake Mogan (Turkey), *Turkish Journal of Botany*, **38**, 169-179.

Descy, J. P. (1979). A new approach to water quality estimation using diatoms, *Nova Hedwigia*, **64**, 305-323.

Descy, J. P., Coste M. (1991). A test of methods for assessing water quality based on diatoms, *Verhandlungen des Internationalen Verein*, **24**, 2112-2116.

Devercelli, M., O'Farrell, I. (2013). Factors affecting the structure and maintenance of phytoplankton functional groups in a nutrient rich lowland river, *Limnologica*, **43**, 67–78.

Directive. (2000). Directive 2000/60/EC of the European parliament and of the council of 23 October 2000 establishing a framework for community action in the field of water policy. *Official Journal of the European Committee*, **327**, 1–72.

Dodds, W. K., Biggs, B. J. F. (2002). Water velocity attenuation by stream periphytonand macrophytes in relation to growth form and architecture, *Journal of the North American Benthological Society*, **21**, 2–15.

Dodds, WK. (2002). Freshwater Ecology. Concepts and Environmental Applications (J. H. Thorp and A. P. Covich, Eds.). San Diego Academic Press, 338-339 p.

Dolulil, MT. (2003). Alagae as ecological bio-indicators (chapter 9). In: Markert, B. A., Breure . A. M., Zechmeister, H. G. (Eds), Bioindicators and biomonitors. Amsterdam: Elesevier, 285-327 p.

Dokulil, M, Teubner, K. (2006). Bewertung der Phytoplanktonstruktur stehender Gewässer gemäß der EU-Wasser rahmenrichtlinie: Der modifizierte Brettum Index. In: DGL-Tagungsbericht 2005 Karlsruhe: 356-360 p.

Dotto, G. L., M. Vieira, L. G., Esquerdo, V. M., Pinto, L. A. A. (2013). Equilibrium and thermodynamics of azo dyes biosorption onto Spirulina platensis, *Brazilian Journal of Chemical Engineering*, **30**, 13 – 21.

Ducharne, A., Baubion, C., Beaudoin, N., Benoit, M., Billen, G., Brisson, N., Garnier, J., Kieken, H., Lebonvallet, S., Ledoux, E., Mary, B., Mignolet, C., Poux, X., Sauboua, E., Schott, C., Théry, S., Viennot, P. (2007). Long term prospective of the Seine River system: confronting climatic and direct anthropogenic changes. *Science of the Total Environment*, **375**, 292–311.

Dwivedi, S. L., Pathak, V. (2007). A Preliminary Assignment of Water Quality Index to Mandakini River, Chitrakoot, *Indian Journal of Environmental Protection*, **27**, 1036-1038.

Enderlein, US, Enderlein, RE, Williams, WP. (1997). Water quality requirements. In: Helmer R, Hespanhol I (eds) Water pollution control-a guide to the use of water quality management. London: Published on behalf of WHO-UNEP-Water Supply and Sanitation Collaborative Council. E and FN Spon.

Erdoğan, Ş. (2017). Impacts of eutrophication and climate change on phytoplankton community structure, size diversity, and phytoplankton based ecological status. Turkey: Middle East Technical University, Department of biology, PhD Thesis, 176 p.

Ettl, H. (1983). Chlorophyta I Phytomonadina. In Su¨ßwasserflora von Mitteleuropa. Band 6. Stuttgart: Gustav Fischer Verlag.

EC. European Communities. (2009). Water Framework Directive intercalibration technical report. Part 2. In: Poikane S. editor. Lakes. Ispra (Italy): European Commission: Joint Research Centre.

Fabbro, L. D., Duivenvoorden, L. J. (2000) A two-part model linking multidimensional environmental gradients and seasonal succession of phytoplankton assemblages, *Hydrobiologia*, **438**, 13-24.

Fetahi, T., Schagerl, M., Mengistou, S. (2014). Key drivers for phytoplankton composition and biomass in an Ethiopian highland lake, *Limnologica*, **46**, 77–83.

Fidlerová, D., Hlúbiková, D. (2016). Relationships between benthic diatom assemblages' structure and selected environmental parameters in Slovak water reservoirs (Slovakia, Europe), *Knowledge and Management of Aquatic Ecosystems*, **417**, 1-22.

Figueredo, C. C., Giani, A. (2001). Seasonal variation in the diversity and species richness of phytoplankton in a tropical eutrophic reservoir, *Hydrobiologia*, **445**, 165–174.

Finlay, J. C., Khandwala, S., Power, M. E. (2002). Spatial scales of carbon flow in a river food web, *Ecology*, **83**, 1845–1859.

Gaudet, J. J., (1979). Seasonal changes in nutrients in a tropical swamp : North Swamp, Lake Naisha, Kenya. *Journal of Ecology*, **63**, 953-981.

Gevrey, M., Rimet, F., Parck, Y. S., Giraudel, J. L., Ector, L., Lek, S. (2004). Water quality assessment using diatom assemblages and advanced modelling techniques, *Freshwater Biology*, **49**, 208–220.

Girgin, S., Kazancı, N., Dügel, M. (2004). ON limnology of Deep and Saline Lake Burdur in Turkey, *Acta Hydrochimica et Hydrobiologica*, **32**, 189-200.

Gomá, J., Ortiz, R., Cambra, J., Ector, L. (2004). Water quality evaluation in Catalonian Mediterranean rivers using epilithic diatoms as bioindicators, *Vie et Milieu-Life and Environment*, **54**, 81–90.

Goncharuk, V. V. (2008). A new concept of supplying the population with a quality drinking water, *Journal of Water Chemistry and Technology*, **30**, 129–136.

Gonzalo, M, Fernández, MdR. (2012). Diatoms as Indicators of Water Quality and Ecological Status: Sampling, Analysis and Some Ecological Remarks. In Ecological Water Quality - Water Treatment and Reuse. Publisher: InTech,. 184-204 p.

Gottschalk, S. (2014). Benthic diatoms in lakes: environmental drivers and ecological assessment. Uppsala: Swedish University of Agricultural Sciences, Faculty of Natural Resources and Agricultural Sciences, Department of Aquatic Sciences and Assessment, PhD Thesis, 52 p.

Gómez, N., Licursi, M. (2001). The Pampean Diatome Index (PDI) for assessment of rivers and streams in Argentina. *Aquatic Ecology*, **35**, 173-181.

Grenier, M., Lavoie, I., Rousseau, A. N., Campeau, S. (2010). Defining ecological thresholds to determine class boundaries in a bioassessment tool: The case of the Eastern Canadian Diatom Index (IDEC), *Ecological Indicators*, **10**, 980-989.

Griffith, M. B., Hill, B. H., McCormick, F. H., Kaufmann, P. R., Herlihy, A. T., Selle, A. R. (2005). Comparative application of indices of biotic integritybased on periphyton, macroinvertebrates, and fishto southern Rocky Mountain streams, *Ecological Indicators*, **8**, 117-136.

Gupta, J., Akhmouch, A., Cosgrove, W., Hurwitz, Z., Maestu, J., Unver, O. (2013). Policymakers' reflections on water governance issues, *Ecology and Society*, **18**, 35.

Gündogan, K., Bayram, F., Capak, M., Tanriverdi, F., Karaman, A., Ozturk, A., Altunbas, H., Gökce, C., Kalkan, A., Yazıcı, C. (2009). Prevalence of Metabolic Syndrome in the Mediterranean Region of Turkey: Evaluation of Hypertension, Diabetes Mellitus, Obesity, and Dyslipidemia, *Metabolic Syndrome and Related Disorders*, **7**, 427-434.

Gürbüz, H., Kıvrak, E. (2002). Use of epilithic diatoms to evaluate water quality in the Karasu River of Turkey, *Jounal of Environmental Biology*, **23**, 239-246.

Hallegraeff, G. M. (1993). A review of harmful algal blooms and their apparent increase, *Phycologia*, **32**, 79-99.

Hering, D., Johnson, R. K., Kramm, S., Schmutz, S., Szoszkiewicz, K., Verdonschot, P. F. M. (2006). Assessment of European streams with diatoms. macrophytes.macroinvertebrates and fish: a comparative metric-based analysis of organismresponse to stress, *Freshwater Biology*, **51**, 1757–1785.

Hill, B. H. (1997). The use of periphyton assemblage data in an index of biotic integrity, *Bulletin of the North American Benthological Society*, **14**, 158.

Hillebrand, H., Dürselen, C. D., Kirschtel, D., Polingher, D., Zohary, T. (1999). Biovolume calculation for pelagic and benthic microalgae, *Journal of Phycology*, **35**, 403–424.

Hlúbiková, D., Hindáková, A., Matúš, H., Miettinen, J. (2007). Application of diatom water quality indices in influenced and non-influenced sites of Slovak rivers (Central Europe), *Archiv für Hydrobiologie , Supplement*, **161**, 444-460.

Holt, M. S. (2000). Sources of chemical contaminants and routes into the freshwater environment. *Food Chemistry and Toxicology*, **38**, S21–S27.

Hooker, E., Hernandez, S. (1991). Phytoplankton biomass in Lake Xolotlan (Managua): its seasonal and horizontal distribution. *Hydrobiological Bulletin*, **25**, 125–131.

Horne, AJ, Goldman, CR. (1994). Limnology, 2nd ed. Published. New York : McGraw-Hill, 576 p.

Horton, R. K. (1965). An index number system for rating water quality. *Journal of Water Pollution Control Federation*, **37**, 300-305.

Hoyer, A. B., Moreno-Ostos, E., Vidal, J., Blanco, J. M., Palomino-Torres, L. R., Basanta, A., Escot, C., Rueda, F. J. (2009). The influence of external perturbations on the functional composition of phytoplankton in a Mediterranean reservoir, *Hydrobiologia*, **636**, 49–64.

Huszar, V., Kruk, C., Caraco, N. (2003). Steady state of phytoplankton assemblage of phytoplankton in four temperate lakes (NE USA), *Hydrobiologia*, **502**, 97–109.

Hutchinson, G. E. (1973). Eutrophication, *American Scientist*, **61**, 269–279.

Hutorowicz, A., Pasztaleniec, A. (2014) . Phytoplankton metric of ecological status assessment for polish lakes and its performance along nutrient gradients, *Polish Journal of Ecology*, **62**, 525–542.

Huszar, V. L. M., Silva, L. H. S., Marinho, M., Domingos, P., Sant'Anna, C. (2000). Cyanoprokaryote assemblages in eight productive tropical Brazilian waters, *Hydrobiologia*, **424**, 67–77.

Huzar, V. L. M., Caraco, N. F., Roland, F., Cole, J. (2006) Nutrient chlorophyll relationships in tropical–subtropical lakes: do temperate models fit?, *Biogeochemistry*, **79**, 239–250.

Hürlimann, J, Niederhauser, P. (2007). Méthodes d'analyse et d'appréciation des cours d'eau. Diatomées Niveau R (région). État de l'environnement n° 0740. Berne : Office fédéral de l'environnement, 132 p.

Izagirre, O., Elosegi, A. (2005). Environmental control of seasonal and inter-annual variations of periphytic biomass in a North Iberian stream, *Annales de Limnologie – International Journal of Limnology*, **41**, 35–46.

Janse, J. H., Domis, L., Scheffer, M., Lijklema, L., Klinge, M., Mooij, W. M. (2008). Critical phosphorus of different types of shallow lakes and the consequences for management estimated with the ecosystem model PCLake, *Limonlogica*, **38**, 203-219.

Jeppesen, E., Jensen, J. P., Søndergaard, M., Lauridsen, T. L., Landkildehus, F. (2000). Trophic structure, species richness and biodiversity in Danish lakes: changes along a phosphorus gradient, *Freshwater Biology*, **45**, 201-218.

John, DM, Whitton, BA, Brook, JA. (2002). The Freshwater Algal Flora of the British Isles. 1st ed. Cambridge: Cambridge University Press.

Johnson, L. B., Richards, C., Host, G. E., Arthur, J. W. (1997). Landscape influences on water chemistry in Midwestern stream ecosystems, *Freshwater Biology*, **37**, 193–208.

Johnson, R. K., Hering, D., Furse, M. T., Clarke, R. T. (2006a). Detection of ecological change using multiple organism groups: metrics and uncertainty, *Hydrobiologia*, **566**, 115-137.

Johnson, R., Hering, D., Furse, M., Verdonschot, P. M. (2006b). Indicators of ecological change: comparison of the early response of four organism groups to stress gradients, *Hydrobiologia*, **566**, 139-152.

Johnson, R. K., Angeler, D. G., Moe, S. J., Hering, D. (2014). Cross-taxon responses to elevate nutrients in European streams and lakes. *Aquatic Sciences*, **76**, 51-60.

Joshi, D. M., Kumar, A., Agrawal, N. (2009). Assessment of the irrigation water quality of River Ganga In Haridwar District, *Rasayan Journal of Chemistry*, **2**, 285-292.

Juggins, S, . ter Braak, CFJ. (1992). CALIBRATE-Program for species-environment calibration by (weighted averaging) partial least squares regression. London: University College, Environmental Change Res Cent.

Jüttner, I., Sharma, S., Dahal, B. M., Ormerod, S. J., Chimonides, P. J., Cox, E. J. (2003). Diatoms as indicators of stream quality in the Kathmandu Valley and Middle Hills of Nepal and India, *Freshwater Biology*, **48**, 2065–2084.

Jüttner, I., Rothfritz, H., Ormerod, S. J. (1996). Diatoms as indicators of river quality in the Nepalese Middle Hills with consideration of the effects of habitat-specific sampling, *Freshwater Biology*, **36**, 475–486.

Karafıstan, A., Arık-Çolakoğlu, F. (2005). Physical, chemical and microbiological water qualıty of the Manyas Lake, Turkey, *Mitigation and Adaptation Strategies for Global Change*, **10**, 127–143.

Karr, J. R. (1991). Biological Integrity: A Long-Neglected Aspect of Water Resource Management, *Ecological Applications*, **1**, 66-84.

Katsiapi, M., Moustaka-Gouni, M., Michaloudi, E., Kormas, K. A. (2011). Phytoplankton and water quality in a Mediterranean drinking-water reservoir (Marathonas Reservoir, Greece), *Environmental Monitoring and Assessment*, **181**, 563–575.

Kelly, M. G., Whitton, B. A. (1995). The trophic diatom index: a new index for moni-toring eutrophication in rivers, *Jounal of Applied Phycology*, **7**, 433–444.

Kelly, M. G., Cazaubon, A., Coring, E., Dell'Uomo, A., Ector, L., Goldsmith, B., Guasch, H., Laugaste, R., Hürlimann, J., Jarlman, A., Kawecka, B., Kwandrans, J., Lindstrøm, E. A., Leitao, M., Marvan, P., Padisák, J., Pipp, E., Prygiel, J., Rott, E., Sabater, S., VanDam, H., Vizinet, J. (1998). Recommendations for the routine sampling of diatoms for water quality assessments in Europe, *Jounal of Applied Phycology*, **10**, 215-224.

Kelly, M., Bennett, C., Coste, M., Delgado, C., Delmas, F., Denys, L., Ector, L., Fauville, C., Ferréol, M., Golub, M., Jarlman, A., Kahlert, M., Lucey, J., Ní Chatháin, B., Pardo, I., Pfister, P., Picinska-Faltynowicz, J., Rosebery, J., Schranz, C., Schaumburg, J., Van Dam, H.,Vilbaste, S. (2009). A comparison of national approaches to setting ecological status boundaries in phytobenthos assessment for the European Water Framework Directive: results of an intercalibration exercise, *Hydrobiologia*, **621**, 169–182.

Kennedy, RH., Walker WW. (1990). Reservoir nutrient dynamics. In: Thorton, K.W., Kimmel, B.L., Payne, F.E. (Eds.), Reservoir Limnology: Ecological Perspectives. New York: John Wiley and Sons, 109–132 p

Kiss, K. T., Klee, R., Ector, L., Ács, É. (2012). Centric diatoms of large rivers and tributaries in Hungary: morphology and biogeographic distribution. *Acta Botanica Croatica*, **71**, 311–363.

Kobayasi, H., Mayama, S. (1989). Evaluation of riverwater quality by diatoms, *Korean Jounal of Phycology*, **4**, 121–133.

Kolkwitz, R., Marsson, M. (1908). Ökologie der pflanzlichen Saprobien, *Berichte der Deutschen Botanischen Gesellschaft*, **26**, 505-519.

Kolkwitz, R., Marsson, M. (1902). Grundsätze für die biologische Beurteilung des Wassers nach seiner Flora und Fauna, *Mitteilungen der Prüfungsanstalt für Wasserversorgung und Abwasserreinigung*, **1**, 33-72.

Kolkwitz, R., Marsson, M. (1909). Ökologie der tierishen Saprobien. *Internationale Revue der gesamten Hydrobiologie*, **2**, 126-152.

Komárek, J, Anagnostidis, K. (1998). Cyanoprokaryota Chroococcales. In Susswasserflora von Mitteleuropa. Jena: Gustav Fisher.

Komárek, J, Fott, B. (1983). Chlorophyceae (Grünalgen) Ordnung: Chlorococcales. In Huber–Pestallozi – Das Phytoplankton des Süßwassers Systematik und Biologie 7 Teil. Stuttgart: 1 Hälfte E Schweizerbart'sche Verlagsbuchhandlung.

Krammer, K, Lange-Bertalot, H. (1991a). Bacillariophyceae. 3 Teil: Centrales. Fragilariaceae. Eunotiaceae. In Ettl. H.. J. Gerloff. H. Heynig and D. Mollenhauer (Hrsgb.). Süß-wasser- flora von Mitteleuropa. Band 2. Stuttgart: Fischer Verlag.

Krammer, K, Lange-Bertalot, H. (1991b). Bacillariophyceae. 4 Teil: Achnanthaceae. Kritische Erganzungen zu Navicula (Lineolatae) und Gomphonema. In Ettl. H.. G.

Gartner. J. Gerloff. H. Heynig and D. Mollenhauer (eds). Süßwasserflora von Mitteleuropa. Band 2. Stuttgart: Fischer Verlag.

Krammer, K, Lange-Bertalot, H. (1999a). Bacillariophyceae. 1 Teil: Naviculaceae. In Ettl H., J.Gerloff, H. Heynig and D. Mollenhauer (eds). Süßwasserflora von Mitteleuropa. Band 2. Heidelberg, Berlin: Akademischer Verlag.

Krammer, K, Lange-Bertalot, H. (1999b). Bacillariophyceae. 2 Teil: Bacillariaceae. Epithemiaceae. Surirellaceae. In Ettl H., J. Gerloff, H. Heynig and D. Mollenhauer (eds). Süß-wasser- flora von Mitteleuropa. Band 2. Heidelberg, Berlin: Akademischer Verlag.

Kruk, C., Mazzeo, N., Lacerot, G., Reynolds, C. S. (2002). Classification schemes for phytoplankton: A local validation of a functional approach to the analysis of species temporal replacement, *Journal of Plankton Research*, **24**, 901–912.

Kurmayer, R., Christiansen, G., Chorus, L. (2003). The abundance of microcystin-producing genotypes correlates positively with colony size in Microcystis sp. and determines its microcystin net production in Lake Wannsee, *Applied Environmental Microbiology*, **69**, 787–795.

Lange, K., Liess, A., Piggott, J. J., Townsend, C. R., Matthaei, C. D. (2011). Light, nutrients and grazing interact to determine stream diatom community composition and functional group structure, *Freshwater Biology*, **56**, 264–78.

Lange-Bertalot H. (1979). Pollution tolerance of diatoms as a criterion for water quality estimation, *Nova Hedwigia*, **64**, 285-304.

Lavoie, I., Campeau, S., Grenier, M., Dillon, P. J. (2006) A diatom-based index for the biological assessment of eastern Canadian rivers: an application of correspondence analysis (CA), *Canadian Jounal of Fisheries and Aquatic Sciences*, **8**, 1793-1811.

Lehman, P. W., Boyer, G., Hall, C., Waller, S., Gehrts, K., (2005). Distribution and toxicity of a new colonial Microcystis aeruginosa bloom in the San Francisco Bay Estuary, California, *Hydrobiologia*, **541**, 87–90.

Lehman, P. W., Boyer, G., Satchwell, M., Waller, S., (2008). The influence of environmental conditions on the seasonal variation of Microcystis abundance and microcystins concentration in San Francisco Estuary, *Hydrobiologia*, **600**, 187–204.

Lehman, P. W., The, S. J., Boyer, G. L., Nobriga, M., Bass, E., Hogle, C. (2010). Initial impacts of Microcystis on the aquatic food web in the San Francisco Estuary, *Hydrobiologia*, **637**, 229–248.

Lehman, P. W., Marr, K., Boyer, G. L., Acuna, S., The, S. J. (2013). Long-term trends and causal factors associated with microcystis abundance and toxicity in san francisco estuary and implications for climate change impacts, *Hydrobiologia*, **718**, 141-158.

Lebo. M. E., Reuter, J. E., Goldman, C. R., Rhodes, C. L. (1994). Interannual variability of nitrogen limitation in a desert lake: influence of regional climate. *Canadian Journal of Fisheries and Aquatic Sciences*, **51**, 862–872

Leclercq, L, Maquet, B. (1987). Two new chemical and diatomic quality indices running water. Application to Samson and sesaffluents. Comparison with other chemical indices biocenotic and diatomic. Belgium: Inst Roy Sc Natur, Documents de Travail, 113 p.

Lee, J. H., Kim, J., Kim, D., Hwang, S., An, K. (2010). Nutrients and chlorophyll-a dynamics in a temperate reservoir influenced by Asian monsoon along with in situ nutrient enrichment bioassays, *Limnology*, **11**, 49–62

Leelahakriengkrai, P., Peerapornpisal, Y. (2014). Evaluation of the Trophic Benthic Diatom Index in some Main Rivers of Thailand, *Advances in Environmental Biology*, **8**, 248-254.

Leira, M., Chen, G., Dalton, C., Irvine, K., Taylor, D. (2009). Patterns in freshwater diatom taxonomic distinctness along an eutrophication gradient, *Freshwater Biology*, **54**, 1–4.

Leitão, M., Morata, S., Rodriguez, S., Vergon, J. P. (2003). The effect of perturbations on phytoplankton assemblages in a deep reservoir (Vouglans, France), *Hydrobiologia*, **502**, 73–83.

Lenoir, A, Coste, M. (1996). Development of a practical diatom index of overall water quality applicable to the French national water Board network. In Whitton BA, Rott E, (eds). Use of Algae for Monitoring Rivers II. Innsbruck: Studia Student G.m.b.H, 29-43 p.

Lepistö, L., Holopainen, A., Vuoristo, H., Rekolainen, S. (2006). Phyotoplakton assamblages as a criterion in the ecological classification of lakes in Finlad, *Boreal Environment Research*, **11**, 35-44.

Leps, J, Smilauer, P. (2003). Multivariate analysis of ecological data using CANOCO. Cambridge: University Press.

Liou, S. M., Lien, S., Wang, S. H. (2004) Generalized water quality index for Taiwan. *Environmental Monitoring and Assessment*, **96**, 35-52.

Lobo, E. A., Callegaro, V. L. M., Oliveira, M. A., Salomoni, S. E., Schuler, S., Asai, K. (1996). Pollution Tolerant Diatoms from lotic Systems in the Jacuí Basin, Rio Grande do Sul, Brasil, *Iheringia. Série Botânica*, **47**, 45–72.

Lobo, EA, Callegaro, VLM., Bender, P. (2002). Utilizaçaô de algas diatomáceas epilíticas como indicadoras da qualidade da água em rios e arroios da Regiaõ Hidrográfica do Guaíba, RS, Brasil. Santa Cruz do Sul: Edunisc, 127 p.

Lobo, E. A., Bes, D., Tudesque, L., Ector, L. (2004). Water quality assessment of the Pardinho river, RS, Brazil, using epilithic diatom assemblages and faecal coliforms as biological indicators, *Vie et Milieu – Life and Environment*, **54**, 115–125.

Loehr, R. C. (1974). Characteristics and comparative magnitude of non-point sources, *Journal of Water Pollution Control Federation*, **46**, 1849-1872.

Lopes, M. R. M., Bicudo, C. E. M., Ferragut, M. C. (2005). Short term spatial and temporal variation of phytoplankton in a shallow tropical oligotrophic reservoir, southeast Brazil, *Hydrobiologia*, **542**, 235–247.

López, N. L., Rondón, C. A. R, Zapata, Á., Jiménez, J., Villamil, W., Arenas, G., Rincón, C., Sánchez, T. (2012). Factors controlling phytoplankton in tropical high-mountain drinking-water reservoirs. *Limnetica*, **31**, 305-322.

Lowe, RL, Pan, Y. (1996). Benthic algal communities as biological monitors. In Stevenson, R. J., M. L. Bothwell and R. L. Lowe (eds), Algal Ecology: Freshwater Benthic Ecosystems. San Diego: Academic Press, 705–739 p.

Lowe. RL., (1974). Environmental requirements and pollution tolerance of freshwater diatoms. Cincinnati, Ohio, USA: US Environmental Protection Agency . 670/4-74-005.

Malve, O. (2007). Water quality prediction for river basin Management. Finland: Helsinki University of Technology, Department of Civil and Environmental Engineering, Water Resources Laboratory, PhD Thesis, 126 p.

Mancini, L., Arcá, G. (2000). Carta della Qualità Biologica dei Corsi d'Acqua della Regione Lazio. Italy : Regione Lazio. Assessorato Ambiente. Dipartimento Ambiente e Protezione Civile, 156 p.

Manjare, S. A., Vhanalakar, S. A., Muley, D. V. (2010), Analysis of water Quality using Physico-Chemical parameters Tamdalge Tank in Kolhapur District, Maharashtra, *International Journal of Advanced Biotechnology and Research*, **1**, 115-119.

Mann, D. G., Droop, S. J. M. (1996). Biodiversity, biogeography and conservation of diatoms, *Hydrobiologia*, **336**, 19-32.

Manyolov, KM, Stevenson, RJ. (2006). Density dependent algal growth along N and P nutrient gradients in artificial streams. In: Ognjanova-Rumenova N. and Manoylov K. (eds.), Advances in phycological studies. Moscow, Russia: Pensoft Publishers, 333–352 p.

Margalef, R. (1978). Life forms of phytoplankton as survival alternatives in an unstable environment, *Oceanologica acta*, **1**, 493-509.

Margalef, R. (1983). Limnología. Barcelona, Spain: Omega, 1010 p.

Marchetto, A., Padedda, B. M., Mariani, M. A., Lugliè, A., Sechi, N. (2009). A numerical index for evaluating phytoplankton response to changes in nutrient levels in deep Mediterranean reservoirs, *Journal of Limnology*, **68**, 106–121.

McFarland, B. H., Hill, B. H., Willingham, W. T. (1997). Abnormal Fragilaria sp. (Bacillariophyceae) in streams impacted by mine drainage, *Journal of Freshwater Ecology*, **12**, 141-149.

Mez, E. (1898). Mikroskopische Wasseranalyse. Berlin: Spinger Verlag.

MPCA. Minnesota Pollution Control Agency. (2007). Phosphorus: Sources, Forms, Impact on Water Quality. Water Quality/Impaired Waters 3.12, 2. p. Available at: www.pca.state.mn.us/hot/legislature/reports/phosphorus-report.html. Accessed 17.01.2018.

MPCA. Minnesota Pollution Control Agency. (2008). Nutrients: Phosphorus, Nitrogen Sources, Impact on Water Quality. Water Quality/Impaired Waters 3.22, 2. p. Available at: www.pca.state.mn.us/hot/legislature/reports/phosphorus-report.html. Accessed 17.01.2018.

Mischke, H, Thackeray, S, Dunbar, M, McDonald, C, Carvalho, L, de Hoyos, C, Jarvinen, M, Laplace-Treyture, C, Morabito, G, Skjelbred, B, Solheim, AL, Brierley, B, Dudley, B. (2012). Deliverable D3.1-4: Guidance document on sampling, analysis and counting standards for phytoplankton in lakes. Germany: Wiser, 51 p.

Molina-Navarro, E., Martínez-Perez, S., Sastre-Merlín, A., del Pozo, D. M. (2012). The limnological characteristics and zooplankton community of a newly created site: The Pareja Limno-reservoir, *Limnetica*, **31**, 95–106.

Molina-Navarro, E., Martínez-Perez, S., Sastre-Merlín, A., Verdugo-Althöfer, M., Padisák, J. (2014). Phytoplankton and suitability of derived metrics for assessing the ecological status in a limno-reservoir, a Water Framework Directive nondefined type of Mediterranean water body, *Lake and Reservoir Management*, **30**, 46–62.

Mooij, W. M., Hülsmann, S., De Senerpont Domis, L. N., Nolet, B. A., Bolier, P. L. E., Boers, P. C. M., Dionisio Pires, L. M., Gons, H. J., Ibelings, B. W., Noordhuis, R., Poterielje, R., Wolfstein, K., Lammens, E. H. R. R. (2005). The impact of climate change on lakes in the Netherlands: a review, *Aquatic Ecology*, **39**, 381-400.

Morabito, G., Oggioni, A., Caravati, E., Panzani, P. (2007). Seasonal morphological plasticity of phytoplankton in Lago Maggiore (N. Italy), *Hydrobiolgia*, **578**, 47–57.

Moreno-Ostos, E., Cruz-Pizarro, L., Basanta, A., George, D. G. (2008). The spatial distribution of different phytoplankton functional groups in a Mediterranean reservoir, *Aquatic Ecology*, **42**, 115–128.

Moreti, L. O. R., Martos, L., Bovo-Scomparin, V. M., Rodrigues, L. C. (2013). Spatial and temporal fluctuation of phytoplankton functional groups in a tropical reservoir, *Maringá*, **35**, 359-366.

Moustaka-Gouni, M., Vardaka, E., Tryfon, E. (2007). Phytoplankton species succession in a shallow Mediterranean lake (L. Kastoria, Greece): Steady-state dominance of Limnothrix redekei, Microcystis aeruginosa and Cylindrospermopsis raciborskii, *Hydrobiologia*, **575**, 129–140.

Mur, LR., Skulberg, OM., Utkilen, H. (1999). Cyanobacteria in the environment. In: Chorus, I., Bartram, J. (Eds.), Toxic Cyanobacteria in Water: A Guide to Their Public Health, Consequences, Monitoring and Management. Suffolk: St. Edmundsbury Press, 15-40 p.

Mustapha, M. K. (2008). Assessment of the Water Quality of Oyun Reservoir. Offa. Nigeria. Using Selected Physico-Chemical Parameters, *Turkish Journal of Fisheries and Aquatic Science*, **8**, 309-319.

Naselli-Flores, L., Barone, R. (1998). Phytoplankton dynamics in two reservoirs with different trophic state (Lake Rosamarina and Lake Arancio, Sicily, Italy), *Hydrobiologia*, **369**, 163–178.

Naselli-Flores, L., Barone, R. (2007). Pluriannual morphological variability of phytoplankton in a highly productive Mediterranean reservoir (Lake Arancio, Southwestern Sicily), *Hydrobiologia*, **578**, 87–95.

Naselli-Flores, L., Padisák, J., Dokulil, M. T., Chorus, I. (2003). Equilibrium/steady-state concept in phytoplankton ecology, *Hydrobiologia*, **502**, 395–403

Nasirian, M. (2007). A New Water Quality Index for Environmental Contamination Contributed by Mineral Processing: A Case Study of Amang (Tin Tailing) Processing Activity, *Journal of Applied Sciences*, **7**, 2977-2987.

Nations Online Project (2018). Regions map of Turkey. Available at: http://www.nationsonline.org/oneworld/first.shtml. Accessed 25.01.2018.

Naumann, E. (1919). Nagra synpunkter angaende limnoplanktons okologi med sarskild hansyn till fytoplankton. *Svensk Botanisk Tidskrift*, **13**, 129-163

Ndungu, JN. (2014). Assessing Water Quality in Lake Naivasha. Netherland, University of Twente, Department of water Engineering and Management, Faculty of

Engineering Technology and Faculty of Geoinforrmation and Earth Observation, PhD Thesis, 151 p.

Negro, A. I., de Hoyos, C., Vega, J. C. (2000). Phytoplankton structure and dynamics in Lake Sanabria and Valparáıso reservoir (NW Spain), *Hydrobiologia*, **424**, 25–37.

Novais, M. H., Blanco, S., Delgado, C., Morais, M., Hoffmann, L., Ector, L. (2012). Ecological assessment of Portuguese reservoirs based on littoral epilithic diatoms, *Hydrobiologia*, **695**, 265–279.

Nŏges, T., Noges P., Laugaste, R. (2003). Water level as the mediator between climate change and phytoplankton composition in a large shallow temperate lak,. *Hydrobiologia*, **506**,: 257-263.

Nygaard, G. (1949). Hydrobiological studies of some Danish lakes and ponds, *Kongelige Danske Videnskabernes Selskab*, *Biologiske Skrifter*, **7**, 1-293.

Oda, A. C. R., Bicudo, C. E. M. (2006). Ecology of Peridinium gatunense and Peridinium umbonatum (Dinophyceae) in a shallow, tropical, oligotrophic reservoir (IAG Pond), São Paulo, southeast Brazil, *Acta Limnologica Brasiliensis*, **18**, 165-180.

O'Driscoll, C., de Eyto, E., Rodgers, M., O'Connor, M., Asam, Z. Z., Xiao, L. (2012). Diatom assemblages and their associated environmental factors in upland peat forest rivers, *Ecological Indicators*, **18**, 443-451.

OECD. Organisation for Economic Cooperation and Development. (1982). Eutrophication of Waters, Monitoring, Assessment and Control. Paris: OECD Cooperative Programme on Monitoring of Inland Waters (Eutrophication Control).

OEPA. Ohio Environmental Protection Agency. (2014). The Impact of Phosphorus and nitrogen on Water Quality, 2. p. Available at: www.epa.ohio.gov/dsw. Accessed 05.01.2018.

Olajire, A. A., Imeokparia, F. E. (2001).Water Quality Assessment of Osun River: Studies On Inorganic Nutrients, *Environmental Monitoring and Assessment*, **69**, 17–28.

Oliver, R. L., Ganf, G. G. (2000). Freshwater blooms. In: Whitton, B.A., Potts, M. (Eds.), The Ecology of Cyanobacteria. Dordrecht: Kluwer Academic Publishers, 149-194 p.

Padisák, J, Köhler, J, Hoeg, S. (1999). The effect of changing flushing rates on development of late summer Aphanizomenon and Microcystis populations in a shallow lake, Müggelsee, Berlin, Germany. In J. G. Tundisi, and M. Straškraba (Eds.), Theoretical reservoir ecology and its applications. Netherlands: Backhuys, 411–424 p.

Padisák, J., Borics, G., Fehér, G., Grigorszky, I., Oldal, I., Schmidt, A., Zámbóné-Doma, Z. (2003). Dominant species, functional assemblages and frequency of equilibrium phases in late summer phytoplankton assemblages in Hungarian small shallow lakes, *Hydrobiologia*, **502**, 157–168.

Padisák, J., Borics, G., Grigorszky, I., Soróczki-Pintér, E. (2006). Use of phytoplankton assemblages for monitoring ecological status of lakes within the Water Framework Directive: the assemblage index, *Hydrobiologia*, **553**, 1–14.

Padisák, J., Crossetti, L., Naselli-Flores, L. (2009). Use and misuse in the application of the phytoplankton functional classification: a critical review with updates, *Hydrobiologia*, **621**, 1-19.

Padisak, J., Hajnal, E., Naselli-Flores, L., Dokulil , M. T., Noges, P., Zohary, T. (2010). Convergence and divergence in organization of phytoplankton communities under various regimes of physical and biological control, *Hydrobiologia*, **639**, 205–220.

Paerl, H. W., Fulton, R. S., Moisander, P. H., Dyble, J. (2001). Harmful freshwater algal blooms, with an emphasis on cyanobacteria, *The Scientific World*, **1**, 76-113.

Paerl, H. W., Huisman, J. (2009). Climate change: a Catalyst for global expansion of harmful cyanobacterial blooms, *Environmental Microbiology Reports*, **1**, 27-37

Paerl, H. W., Paul, V. J. (2012). Climate change: links to global expansion of harmfulcyanobacteria, *Water research*, **46**, 1349-1363.

Pan, Y., Stevenson, R. J., Hill, B. H., Herlihy, A. T., Collins, C. B. (1996). Using diatoms as indicators of ecological conditions in lotic systems: a regional assessment, *Journal of the North American Benthological Society*, **15**, 481-494.

Passy, S. I., Bode, R. W. (2004). Diatom model anity (DMA), a new index for water quality assessment, *Hydrobiologia*, **524**, 241-251.

Pasztaleniec, A., Poniewozik, M. (2010). Phytoplankton based assessment of the ecological status of four shallow lakes (Eastern Poland) according to Water Framework Directive–a comparison of approaches, *Limnologica*, **40**, 251–259

Patil, P. N., Sawant, D. V., Deshmukh, R. N. (2012). Physico-chemical parameters for testing of water – A review, *Internatıonal Journal of Envıronmental Scıences*, **3**, 1194-1207.

Patrick, R, Reimer, CW. (1966). The diatoms of the United States. Vol 1. Philadelphia: Monographs- Academy of Natural Sciences, 688 p.

Paul, VJ. (2008). Global warming and cyanobacterial harmful algal blooms. In: Hudnell, H.K. (Ed.), Cyanobacterial Harmful Algal Blooms: State of the Science and Research Needs. New York: Springer, 239-257 p.

Petraccia, L., Liberati, G., Masciullo, S. G., Grassi, M., Fraioli, A. (2006). Water, mineral waters and health, *Clinical Nutrition*, **25**, 377–385.

Philippe, M, Vey, V, Barbe, J. (2003): Actualisation de la méthode de diagnose rapide des plans d'eau. Analyse critique des indexes de qualité des lacs et propositions d'indexes de fonctionnement de l'ecosystème lacustre. Lyon: Cemagref.

Phillips, G., Lyche-Solheim, A., Skjelbred, B., Mischke, U., Drakare, S., Free, G., Järvinen, M., de Hoyos, C., Morabito, G., Poikane, S. (2013). A phytoplankton trophic index to assess the status of lakes for the Water Framework Directive, *Hydrobiologia*, **704**, 75–95.

Phillips, G, Free, G, Karottki, I, Laplace-Treyture, C, Maileht, K, Mischke, U, Ott, I, Pasztaleniec, A, Portielje, R, Søndergaard, M, Trodd, W, Van Wichelen; J. (2014). Water Framework Directive Intercalibration Technical Report: Central Baltic Lake Phytoplankton ecological assessment methods. Luxembourg: Ed. Poikane, S., 184 p.

Poikane, S., van den Berg, M., Hellsten, S., de Hoyos, C., Ortiz-Casas, J., Pall, K., Portielje, R., Phillips, G., Solheim, A. L., Tierney, D. (2011). Lake ecological assessment systems and intercalibration for the European Water Framework Directive: aims, achievements and further challenges, P*rocedia Environmental Sciences*, **9**, 153–168.

Poikane, S., Kelly, M., Cantonati, M., (2016). Benthic algal assessment of ecological status in European lakes and rivers: Challenges and opportunities, *Science of the Total Environ*ment, **568**, 603-613.

Popovsky, J, Pfiester, LA. (1990). Dinophyceae (Dinoflagellida).In Süßwasserflora von Mitteleuropa. Band 6. Jena: Gustav Fischer Verlag.

Porter, S. D. Mueller, D. K., Spahr, N. E., Munn, M. D., Dubrovsky, N. M. (2008). Efficacy of algal metrics for assessing nutrient and organic enrichment in flowing waters, *Freshwater Biology*, **53**, 1036–1054.

Potapova, M., Charles, D. F. (2003). Distrivution of benthic diatoms in US rivers in relation to conductivity and ionic composition, *Freswater Biology*, **48**, 1311-1328.

Potapova, M., Charles, D. F., Ponade, K. C., Winter, D. M. (2004). Quantifying speciesindicator values for trophic diatom indices: comparison of approaches, *Hydrobiologia*, **517**, 25–41.

Pratti, L., Paranello, R., Pesarin, P. (1971). Assessment of surface water quality by single index of pollution, *Water Research*, **5**, 741-751.

Preisendorfer, R. W. (1986) Secchi disk science: Visual optics of natural waters, *Limnology and Oceanography*, **31**, 909-926.

Prescott, GW. (1961). Algae of Western Great Lake Area. Dubuque, Iowa: Brown Comp. Publications, 977 p.

Prygiel, J, Whitton, BA., Bukowska, J. (1999). Use of algae for monitoring rivers III. Douai: Agence de l'Eau Artois-Picardie, 271 p.

Prygiel, J., Carpentier, P., Almeida, S., Coste, M., Druart, J. C., Ector, L., Guillard, D., Honore, M. A., Iserentant, R., Ledeganck, P., Lalanne-Cassou, C., Lesniak, C., Mercier I., Moncaut, P., Nazart, M., Nouchet, N., Peres, F., Peeters, V., Rimet, F., Rumeau, A., Sabater, S., Straub, F., Torrisi, M., Tudesque, L., Van de Vijver, B., Vidal, H., Vizinet J., Zydek, N. (2002). Determination of the biological diatom index (IBD NF T 90-354): Results of an intercomparison exercise, *Journal of Applied Phycology*, **14**, 27-39.

Rakočević, J. (2012). Spatial and temporal distribution of phytoplankton in Lake Skadar, *Archives of Biological Sciences*, **64**, 585-595.

Renn, CE. (1968). A study of water quality. Chestertown, Maryland: Lamotte chemical products company, , 46 p.

Reynolds, CS. (1984). The ecology of freshwater phytoplankton. Cambridge: Cambridge University Press, 384 p.

Reynolds, C. S. (1998). What factors influence the species composition of phytoplankton in lakes of different trophic status?, *Hydrobiologia*, **369**, 11-26.

Reynolds, CS. (1999). With or against the grain: responses of phytoplankton to pelagic variability. In: Whitfield M., Matthews J. And Reynolds C.S. (eds), Aquatic Life cycle strategies. Survival in a variable environment. UK: Marine Biological Association of the UK, 15-43 p.

Reynolds, CS. (2006). The Ecology of Phytoplankton. Cambridge: Cambridge University Pres, 535 p.

Reynolds, C. S., Huszar, V., Kruk, C., Naselli–Flores, L., Melo, S. (2002). Towards a functional classification of the freshwater phytoplankton, review, *Journal of Plankton Research*, **24**, 417-428.

Rickwood, C. J., Carr, G. M. (2009). Development and Sensitivity Analysis of a Global Drinking Water Quality Index, *Environmental Monitoring and Assessment*, **156**, 73-90.

Riedmüller, U, Hoehn, E, Nixdorf, B, Mischke, U. (2006). Bewertung der natürlichen Seen Deutschlands anhand des Phytoplanktons. Berlin (Germany): Deutsche Gesellschaft für Limnologie (DGL).

Rimet, F. (2012). Diatoms: an ecoregional indicator of nutrients, organic matter and micropollutants pollution. Université de Grenoble, Laboratoire Inra Umr-Carrtel, France : PhD Thesis, 203 p.

Rimet, F. (2012). Recent views on river pollution and diatoms, *Hydrobiologia*, **683**, 1–24.

Rimet, F., Bouchez, A., Tapolczai, K. (2016). Spatial heterogeneity of littoral benthic diatoms in a large lake: monitoring implications, *Hydrobiologia*, **771**, 179–193

Rocha, R. D. R. (1992). Inflation and stabilization in Yugoslavia, *Contemporary Economic Policy*, **10**, 21-38.

Rokade, P. B., Ganeshwade, R. M. (2005), Impact of pollution on water quality of Salim Ali Lake at Aurangabad, Uttar Pradesh, *Journal of Zoology*, **25**, 219-220

Romo, S., Villena, M. J. (2005). Phytoplankton strategies and diversity under different nutrient levels and planktivorous fish densities in a shallow Mediterranean lake, *Journal of Plankton Research*, **27**, 1273–1286.

Rott, E. (1991). Methodological aspects and perspectives in the use of periphyton for monitoring and protecting rivers. In: Whitton, B. A., Rott, E. and Friedrich, G. (eds.) Use of Algae for Monitoring Rivers. Univ. Innsbruk: Institüt für Botanik, 9-16 p.

Rott, H. E. (1984). Phytoplankton as biological parameter for the trophic characterization of lakes, *Verhandlungen des Internationalen Verein Limnologie*, **22**, 1078-1085.

Rott, E., Schneider, S. C. (2014). A comparison of ecological optima of soft-bodied benthic algea in Norwegian and Austrian rivers and consequences for river monitoring in Europe, *Science of the Total Environment*, **475**, 180-186.

Rott, E., Pipp, E., Peister, P. (2003). Diatom methods developed for river quality assessment in Austria and a cross-chech against numerical trophic indication methods used in Europe, *Algological Studies*, **110**, 91-115.

Rott, E, Hofmann, G, Pall, K, Pfister, P, Pipp, E. (1997). Indikationslisten für Aufwuchsalgen. Teil 1. Saprobielle Indikation. Wien: Bundesministerium für Land- und Forstwirtschaft, 1-73 p.

Rott, E, Pfister, P, Van Dam, H, Pipp, E, Pall, K, Binder, N, Ortler, K. (1999). Indikationslisten für Aufwuchsalgen. Teil 2: Trophieindikation sowie geochemische Pra¨ferenz, taxonomische und toxikologische Anmerkungen. Wien: Bundesministerium für Land- und Forstwirtschaft.

Round, F. E. (1991). Diatoms in river water-monitoring studies, *Journal of Applied Phycology*, **3**, 129–145.

Rumeau, A., Coste, M. (1988). Introduction to the systematics of freshwater diatoms. For the practical use of a generic diatomic index, *Bulletin Français de la Pêche et de la Pisciculture*, **309**, 1-69.

Sadat, A., Essan, B. Z. N., Sorho, S., Bernard, P. (2011). Intérêt de l'analyse multidimensionnelle pour l'évaluation de la qualité physico-chimique de l'eau d'un système lacustre tropical : cas des lacs de Yamoussoukro (Côte d'Ivoire), *Journal of Applied Biosciences*, **38**, 2573 – 2585.

Salleh, M. A., Mahmoud, M., , Abdul Karim, D. K., Idris, W. A. W. (2011). Cationic and anionic dye adsorption by agricultural solid wastes: A comprehensive review. *Desalination*, **280**, 1-13.

Salmaso, N., Burigo, R., Decet, F., Moccia, A., Azzalini, G., De Toffol, V., Fontanive, M., Oppo, C., Portunato, L., Sacco Taz, L., Zoppè E., Cordella, P. (1998). Indagini limnologiche su un lago ampliato del sistema idroelettrico del Piave (Lago di Santa Croce, Belluno), *Acqua and Aria*, **8**, 95–103.

Salmaso, N., Morabito, G., Buzzi, F., Garibaldi, L., Simona, M., Mosello, R. (2006). Phytoplankton as an Indicator of the Water Quality of the Deep Lakes South of the Alps, *Hydrobiologia*, **536**, 167–187.

Salmaso, N., Naselli-Flores, L., Padisak, J. (2015). Functional classifications and their application in phytoplankton ecology, *Freshwater Biology*, **60**, 603–619.

Salmaso N., Padisák, J. (2007). Morpho-Functional Groups and phytoplankton development in two deep lakes (Lake Garda, Italy and Lake Stechlin, Germany), *Hydrobiologia*, **578**, 97-112.

Salomoni, S. E., Rocha, O., Callegaro, V. L., Lobo, E. A. (2006). Epilithic diatoms as indicators of water quality in the Gravataí river, Rio Grande do Sul, Brazil, *Hydrobiologia*, **559**, 233–246.

Saratale, R. G., Saratale, G. D., Chang, J. S., Govindwar, S. P. (2011). Bacterial decolorization and degradation of azo dyes: A review, *Journal of the Taiwan Institute of Chemical* Engineers, **42**, 138-157.

Sargaonkar, A., Deshpande, V. (2003) Development of an overall index of pollution for surface water based on a general classification scheme in Indian context, *Environmental Monitoring and Assessment*, **89**, 43-67.

Sarmento, H., Isumbisho, M., Descy, J. P. (2006). Phytoplankton ecology of Lake Kivu (east Africa), *Journal of Plankton Research*, **28**, 815–829.

Saygı-Başbuğ, Y., Demirkalp, F. Y. (2004). Trophic status of shallow Yeniçağa Lake (Bolu, Turkey) in relationship to physical and chemical environment, *Fresenius Environmental Bulletin*, **13**, 385-393.

SBSAC. Soft-bodied Strem algae of California (2018). Filaments unbranched. Available at: http://dbmuseblade.colorado.edu. Accesseded 09.04.2018.

Schaumburg, J., Schranz, C., Foerster, J., Gutowski, A., Hofmann, G., Meilinger, P., Shneider, S., Schmedtje, U. (2004). Ecological classification of macrophytes and phytobenthos for rivers in Germany according to the Water Framework Directive, *Limnologica*, **34**, 283-301.

Schaumburg, J, Schmedtje, U, Schranz, C, Köpf, B, Schneider, S, Stelzer, D. (2004). Instruction protocol for the ecological assessment of lakes for implementation of the EU Water Framework Directive: Macrophytes and phytobenthos. München: Bayerisches Landesamt für Wasserwirtschaft.

Schiefele, S, Schreiner, C. (1991). Use of diatoms for monitoring nutrient enrichment, acidification and impact of salt in rivers in Germany and Austria. In: Whitton BA, Rott E, Friedrich G, (eds). Use of algae for monitoring rivers. Düsseldorf, Germany. Innsbruck: Institut für Botanik, Universität Innsbruck, Studia Student, 103-110 p.

Schindler, D. W. (2006). Recent advances in the understanding and management of eutrophication, *Limnology and Oceanography*, **51**, 356-363.

Schneider, S. C., Kahlert, M., Kelly, M. G. (2013). Interactions between pH and nutrientson benthic algae in streams and consequences for ecological status assessmentand species richness patterns, *Science of the Total Environment*, **444**, 73–84.

Sevindik, T. O., Çelik, K., Naselli-Flores, L. (2017). Spatial heterogeneity and seasonal succession of phytoplankton functional groups along the vertical gradient in a mesotrophic reservoir, *Annales de limnologie-International Journal of Limnology*, **53**, 129-141.

Sidnei, M. T., Fakio, A. L. T., Maria, C. R., Francises, A. E., Adaunto, F. (1992). Seasonal variation of some limnological factors of Lagoa does Guarana, a Varzea lake of the Rio Paranana State of Mato Groso do Sul, Brazilian, *Hydrobiology*, ***25***, 269-276.

Simeonov, V., Einax, J. W., Stanimirova, I., Kraft, J. (2002). Environmetric Modeling and Interpretation of River Water Monitoring Data, *Analytical and Bioanalytical Chemistry*, **374**, 898-905.

Simoes, F. S., Moreira, A. B., Bisinoti, M. C., Gimenez, S. M. N., Yabe, M. J. S. (2008). Water Quality Index as a Simple Indicator of Aquaculture Effects on Aquatic Bodies, *Ecological Indicators*, **8**, 476- 484.

Sgro, G.,V., Ketterer, M. E., Johansen, J. R. (2006). Ecology and assessment of the benthic diatom communities of four Lake Erie estuaries using Lange-Bertalot tolerance values, *Hydrobiologia*, **561**, 239–249.

Sladeček, V. (1973). System of water quality from the biological point of view, *Archiv für Hydrobiologie Beiheft*, **7**, 1–218.

Sládeèek, V. (2006). Diatoms as indicators of organic pollution, *Acta hydrochimica et hydrobiologica*, **14**, 555–566.

Smith, V. (2003). Eutrophication of freshwater and coastal marine ecosystems: a global problem. *Environmental Science and Pollution Research*, **10**, 126-139.

Smol, JP. (2008). Pollution of lakes and rivers: a paleoenvironmental perspective / John P. Smol. – 2nd ed. Oxford: Blackwell Publishing, 383 p.

Soininen, J. (2007). Environmental and spatial control of freshwater diatoms – a review, *Diatom Research*, **22**, 473–490.

Solak, C. N. (2011). The application of diatom indices in the Upper Porsuk River, Kütahya-Turkey, *Turkish Journal of Fisheries and Aquatic Sciences*, **11**, 31-36.

Solak, C. N., Àcs, E. (2011). Water Quality Monitoring in European and Turkish Rivers Using Diatoms, *Turkish Journal of Fisheries and Aquatic Sciences*, **11**, 329-337.

Solak, C. N., Barinova, S., Ács, É., Dayioglu, H. (2012a). Diversity and ecology of diatoms from Felent Creek (Sakarya river basin), Turkey, *Turkish Journal of Botany*, **36**, 191-203.

Solak, C. N., Ector, L., Wojtal, A. Z., Ács, É., Morales, E. A. (2012b). A review of investigations on diatoms (Bacillariophyta) in Turkish inland waters, *Nova Hedwigia Beihefte*, **141**, 431-462.

Sommer, U. (1981). The role of r- and K selection in the succession of phytoplankton in lake Constance, *Acta Oecologica*, **2**, 327– 342.

Sorlini, S., Palazzini, D., Sieliechi, J. M., Ngassoum, M. B. (2013). Assessment of Physical-Chemical Drinking Water Quality in the Logone Valley (Chad-Cameroon), *Sustainability*, **5**, 3060-3076.

Sournia, A., Chrétiennot-Dinet, M. J., Ricard, M. (1991). Marine plankton: how many species in the world oceans?, *Journal of Plankton Research*, **13**, 1093–9.

Soylu, E. N., Gönülol, A. (2010). Functional Classification and Composition of Phytoplankton in Liman Lake, *Turkish Journal of Fisheries and Aquatic Sciences*, **10**, 53-60.

Spears, B. M., Mackay, E. B., Yasseri, S., Gunn, I. D. M., Waters, K. E., Andrews, C., Cole, S., De Ville, M., Kelly, A., Meis, S., Moore, A. L., Nürnberg, G. K., Van Oosterhout, F., Pitt, J. A., Madgwick, G., Woods, H. J., Lürling, M. (2016). A meta-analysis of water quality and aquatic macrophyte responses in 18 lakes treated with lanthanum modified bentonite (Phoslock®), *Water Research*, **97**, 111-121.

Stephen R. Carpenter, Emily H. Stanley, and M. Jake Vander Zanden (2011). State of the world's freshwater ecosystems: physical, chemical, and biological changes. *Annual Review of Environment and Resources*, **36**, 75–99.

Steinberg, C., Schiefele, C. (1987). Biological indication of trophy and pollution of running waters, *Zeitschrift für Wasser- und Abwasser-Forschung*, **21**, 227-234.

Stevenson, RJ. (1996). The stimulation and drag of current. In: Stevenson R.J., Bothwell M.L., Lowe R.L. (eds.). Algal Ecology. San Diego: Academic Press, 321–340 p.

Stoermer, EF., Smol, JP. (1999). The Diatoms: Applications for the Environmental and Earth Sciences. xii + 469 pp. Cambridge, New York, Melbourne: Cambridge University Press.

Strebel, O., Duynisveld, W. H. M., Böttcher, J. (1989). Nitrate pollution of groundwater in Western Europe, *Agriculture, Ecosystems and Environment*, **26**, 189–214.

Strobl, R. O., Robillard, P. D. (2008). Network design for water quality monitoring of surface freshwaters: A review, *Journal of Environmental Management*, **87**, 639-648.

Sun, J., Liu, D. (2003). Geometric models for calculating cell biovolume and surface area for phytoplankton, *Journal of Plankton Research*, **25**, 1331–1346.

Taylor, J., Prygiel, J., Vosloo, A., de La Rey, P., Van Rensburg, L. (2007). Can diatom-based pollution indices be used for biomonitoring in South Africa? A case study of the Crocodile West and Marico water management area, *Hydrobiologia*, **592**, 455–464.

Tepe, Y, Mutlu, E. (2005). Physico-chemical characteristics of Hatay Harbiye Spring water, Turkey, *Journal of Institute of Science and Technology*, **6**, 77-88.

ter Braak, CJF. (1995). Ordination. In Jongman. R.H.G.. C.J.F. ter Braak and O. F. R. Van Tongeren (eds). Data Analysis in Community and Landscape Ecology. Cambridge: Cambridge University Press.

ter Braak, CJF., Šmilauer, P. (2002). CANOCO Reference Manual and CanoDraw for Windows User's Guide: Software for Canonical Community Ordination (version 4.5). Ithaca: Microcomputer Power Press.

ter Braak, CJF., Šmilauer, P. (1998). CANOCO Reference Manual and User's Guide to CANOCO for Windows (Version 4). Wageningen: Center for Biometry.

Tett, P., Barton, E. D. (1995). Why are there about 5000 species of phytoplankton in the sea?, *Journal of Plankton Research*, **17**, 1693–704.

Thornton, JA., Rast, W. (1993). A test of hypotheses to the comparative limnology and assessment of eutrophication in semi-arid manmade lakes. In: Straskraba M, Tundisi JG, Duncan A (eds) Comparative reservoir limnology and water quality management. Boston: Kluwer Academic Publishers, 1–24 p.

Tokatlı, C., Dayioğlu, H. (2011). Use of epilithic diatoms to evaluate water quality of Murat Stream (Sakarya River Basin, Kütahya): Different Saprobity Levels and pH Status, *Journal of Applied Biological Sciencies*, **5**, 55-60.

Tolotti, M., Boscaini, A., Salmaso, N. (2010). Comparative analysis of phytoplankton patterns in two modified lakes with contrasting hydrological features, *Aquatic Sciencies*, **72**, 213–226.

Toman, M. J., Grošelj, A. M., Zelnik, I. (2014). The infl uence of selected factors on the distribution of epilithic diatoms in a torrential river the Kamniška Bistrica (Slovenia), *Acta Botanica Croatica*, **73**, 447–463.

Toudjani, A. A., Çelekli, A., Gümüş, E. Y., Kayhan, S., Lekesiz, H. Ö., Çetin, T. (2017). A new diatom index to assess ecological quality of running waters: a case study of water bodies in western Anatolia, *Annalles de Limnologie. - International Journal of Limnology*, **53**, 333–343.

Trolle, D., Hamilton, D. P., Pilditch, C. A., Duggan, I. C., Jeppesen, E. (2011). Predicting the effects of climate change on trophic status of three morphologically varying lakes: implications for lake restoration and management, *Environmental Modelling and Software*, **26**, 354-370.

Turner, R. E., Rabalais, N. N., Justic, D., Dortch, Q. (2003). Global patterns of dissolved N, P and Si in large rivers, *Biogeochemistry*, **64**, 297–317.

UN. United Nations. (2007). "Glossary of Environment statistics, stadies in methods". New York.

Utermöhl, H. (1958). Zur Vervollkommnung der quantitativen phytoplankton–methodik, *Mitteilungen Internationale Vereinigung Theoretische und Angewandte Limnologie*, **9**, 1-38.

Vadeboncoeur, Y., Steinman, A. D. (2002). Periphyton function in lake ecosystems, *Scientific World Journal*, **2**, 1449–1468.

Vadeboncoeur, Y., Mcintyre, P. B., Vander Zanden, M. J. (2011). Borders of biodiversity: Life at the edge of the world's large lakes, *BioScience*, **61**, 526–537.

Van Dam, H., Mertens, A., Sinkeldam, J. (1994). A coded checklist and ecological indi-cator values of freshwater diatoms from The Netherlands, *Netherlands Journal of Aquatic Ecology*, **28**, 117–184.

Van-den-Hoek, C, Mann, DG, Jahns, HM. (1995). Algae: an introduction to phycology. Cambridge: Cambridge University Press, 627 p.

Van Leeuwen, F. X. R. (2000). Safe drinking water: The toxicologist's approach, *Food Chemistry and Toxicology*, **38**, S51–S58.

Venkatachalapathy, R., Karthikeyan, P. (2013). Benthic Diatoms in River Influenced By Urban Pollution, Bhavani Region, Cauvery River, South India. *International Journal of Innovative Technology and Exploring Engineering* **2**, 206-210.

Wallis, C, Seon-Massin, N, Martini, F, Schouppe, M. (2011). Implementation of the water framework directive: When ecosystem services come into play. Brussels: Onema Meetings Recap.

Wang, Y. K., Stevenson, R. J., Metzmeier, L. (2005). Development and evaluation of a diatom-based index of Biotic Integrity for the Interior Plateau Ecoregion, USA, *Journal of the North American Benthological Society*, **24**, 990–1008.

Wang, X., Zheng, B., Liu, L., Li, L. (2014). Use of diatoms in river health assessment, *Annual Research and Review in Biology*, **4**, 4054-4074.

Watanabe, T., Asai, K., Houki, A. (1986). Numerical estimation to organic pollution of flowing water by using the epilithic diatom assemblage-diatom assemblage index (DAIpo), *Science of the Total Environment*, **55**, 209-218.

Weber, C. A. (1907). Aufbau und Vegetation der Moore Norddeutschlands, *Botanische Jahrbücher für Systematik*, **90**, 19–34.

Wehr, JD, Sheath, RG. (2003). Freshwater Algae of North America: Ecology and Classification. San Jose: Academic Press.

Whittaker, R. H., Fairbanks, C. W. (1958). A study of plankton copepod communities in the Columbia basin, Southeastern Washington, *Ecology*, **39**, 46-65.

Willén, E. (2001). Phytoplankton and Water Quality Characterization: Experiences from the Swedish Large Lakes Mälaren, Hjälmaren, Vättern and Vänern, *Ambio*, **30**, 529-537.

Willén, E. (2003). Dominance patterns of planktonic algae in Swedish forest lakes, *Hydrobiologia*, **502**, 315–324.

Willén, E. (2007). Växtplankton i sjöar, Report of Bedömningsgrunder Institutionen för Miljöanalys. Sweden: Uppsala.

Wu, J. T. (1999). A generic index of diatom assemblages as bioindicator of pollution in the Keelung River of Taiwan, *Hydrobiologia*, **397**:79-87.

Wunsam, S., Schmidt, R. (1995). A diatom-phosphorus transfer functions for Alpine and pre-alpine lakes, *Memorie dell'Istituto Italiano di Idrobiologia*, **53**, 85–99.

Wunsan, S., Cattaneo, A., Bourassa, N. (2002). Comparing diatom species. genera andsize in biomonitoring: a case study form streams in the Laurentians (Québec.Canada), *Freshwater Biology*, **47**, 325–340.

Xiao, L., Wang, T., Hu, R., Han, B., Wang, S., Qian, X., Padisάk J. (2011). Succession of phytoplankton functional groups regulated by monsoonal hydrology in a large canyon-shaped reservoir, *Water Research*, **45**, 5099-5109.

Yasuno, M., Fukushima, S., Sugaya, Y. (1994). Monitoring of Benthic Flora and Fauna in Channels Draining a Sewage Plant. In: Jeffrey, D.W. and Madden, B. (eds.). Bioindicators and Environmental Management: Academic Press.

Yerli, S. V., Kıvrak, E., Gürbüz, H., Manav, E., Mangıt, F., Türkecan, O. (2012). Phytoplankton community, nutrients and chlorophyll a in Lake Mogan (Turkey); with comparison between current and old data, *Turkish Journal of Fisheries and Aquatic Sciences*, **12**, 95–104.

Youngman, RE. (1978). Measurement of chlorophyll. Great Britain: Water Research Center, Medmenham Laboratory, 23 p.

Zaneveld, J. R., Pegau, W. S. (2004). Robust underwater visibility parameter, *Optics Express*, **11**, 2997-3009.

Zelinka, M., Marvan, P. (1961). Zur Präzisierung der biologischen Klassifikation der Reinheit fliessender Gewässer, *Archiv fur Hydrobiologie*, **57**, 389-407.

Zohary, T., Padisák J., Naselli-Flores, L. (2010). Phytoplankton in the physical environment: beyond nutrients, at the end, there is some light, *Hydrobiologia*, **639**, 261–269.

## APPENDICES

**Appendix A** List of diatom species and varieties found in the studied sites

| Species | Code |
|---|---|
| *Achnanthes impexa Lange-Bertalot* | Acim |
| *Amphora subcapitata* (Kisselew) Hustedt | Amsu |
| *Aulocoseria granulata* (Ehrenberg) Simonsen | Augr |
| *Bacillaria obtusa* (W.Smith) Elmore | Baob |
| *Diatoma vulgaris* Bory | Divu |
| *Clevamphora ovalis* (Kützing) Mereschkowsky | Clov |
| *Cocconeis disculus* (Schumann) Cleve in Cleve & Jentzsch | Codi |
| *Cocconeis placentula* Ehrenberg | Copl |
| *Cocconeis placentula var. Placentula* Ehrenberg | Coplp |
| *Cocconeis placentula var.lineata* (Ehrenberg) Van Heurck | Coplv |
| *Cocconeis scutellum* Ehrenberg | Cosc |
| *Craticula accomoda* (Hustedt) D.G. Mann | Crac |
| *Craticula halophila* (Grunow) Cleve | Crha |
| *Cyclotella iris* Brun & Héribaud-Joseph | Cyir |
| *Cyclotella meneghiniana* Kützing | Cyme |
| *Cyclotella ocellata* Pantocsek | Cyoc |
| *Cymatopleura solea* (Brébisson) W. Smith | Cyso |
| *Cymbella cistula* (Hemprich) Kirchner | Cyci |
| *Cymbella cymbiformis* Agardh | Cycy |
| *Cymbella ehrenbergii* Kützing | Cyeh |
| *Cymbella excisa* Kützing | Cyex |
| *Cymbella hantzschiana* Krammer | Cyha |
| *Cymbella helvetica* Kützing | Cyhe |
| *Cymbella mesiana* Cholnoky | Cymes |
| *Cymbella simonseni* Krammer | Cyst |
| *Cymbella tumida* (Brébisson) van Heurck | Cytu |
| *Cymbopleura amphicephala* Näegeli in Kützing | Cyam |
| *Cymbopleura naviculiformis* (Auerswald ex Heiberg) Krammer | Cyna |
| *Denticula elegans* Kützing | Deel |
| *Diatoma hyemalis* (Roth) Heiberg | Dihy |
| *Diatoma moniliformis* (Kützing) D.M.Williams | Dimo |
| *Diatoma tenuis* C.Agardh | Dite |
| *Dickieia expecta* S.L.VanLandingham | Naex |
| *Diploneis modica* Hustedt | Dimo |
| *Encyonema minutum* (Hilse) D.G.Mann | Enmi |

**Appendix A** Continue

| Species | Code |
|---|---|
| *Encyonema silesiacum* (Bleisch) D.G.Mann | Ensi |
| *Epithemia adnata* (Kützing) Brébisson | Epad |
| *Epithemia cistula* (Ehrenberg) Ralfs | Epar |
| *Epithemia frickei* Krammer | Epfr |
| *Eunotia tenella* (Grunow) Hustedt | Eute |
| *Fragilaria capucina* Desmazières | Frca |
| *Fragilaria crotonensis* Kitton | Frcr |
| *Fragilaria dilatata* (Brébisson) Lange-Bertalot | Frdi |
| *Gomphonema acuminatum* Ehrenberg | Goac |
| *Gomphonema angustum* C. Agardh | Goan |
| *Gomphonema clavatum* Ehrenberg | Gocl |
| *Gomphonema gracile* Ehrenberg | Gogr |
| *Gomphonema minutum* (C. Agardh) C. Agardh | Gomi |
| *Gomphonema parvulum* Ku¨tzing | Gopa |
| *Gomphonema pseudoaugur* Lange-Bertalot | Gops |
| *Gomphonema truncatum* Ehrenberg | Gotr |
| *Gyrosigma acuminatum* (Kützing) Rabenhorst | Gyac |
| *Gyrosigma attenuatum* (Kützing) Rabenhorst | Gyat |
| *Hantzschia distinctepunctata* var. *circuligera* Compère | Hadi |
| *Hantzschia weyprechtii Grunow* | Hawe |
| *Lysigonium lineatum* (Dillwyn) Trevisan | Lyli |
| *Lysigonium varians* (C.Agardh) De Toni | Lyva |
| *Navicula bryophila* J.B.Petersen | Nabr |
| *Navicula capitatoradiata* H.Germain | Naca |
| *Navicula cincta* (Ehrenberg) Ralfs in Pritchard | Naci |
| *Navicula clementis* Grunow | Nacl |
| *Navicula constans* Hustedt | Naco |
| *Navicula cryptocephala* Kützing | Nacr |
| *Navicula cryptonella* Lange-Bertalot | Nacry |
| *Navicula digitoradiata* (Gregory) Ralfs | Nadi |
| *Navicula gregaria* Donkin | Nagr |
| *Navicula jaagii* Meister | Naja |
| *Navicula lanceolata* (C.Agardh) Kützing | Nala |
| *Navicula laterostrata* Hustedt | Nalat |
| *Navicula leptostriata* Jørgensen | Nale |
| *Navicula margalithii* Lange-Bertalot | Nama |
| *Navicula oppugnata* Hustedt | Naop |
| *Navicula peregrina* (Ehrenberg) Kützing | Nape |
| *Navicula phylepta* Kützing | Naph |
| *Navicula radians* Héribaud-Joseph | Narad |
| *Navicula radiosa* Kützing | Nara |
| *Navicula recens* (Lange-Bertalot) Lange-Bertalot | Nare |

**Appendix A** Continue

| Species | Code |
|---|---|
| *Navicula schoenfeldii* Hustedt | Nasc |
| *Navicula slesvicensis* Grunow in van Heurck | Nasl |
| *Navicula tripunctata* (O.F.Müller) Bory | Natr |
| *Navicula trivialis* Lange-Bertalot | Natri |
| *Navicula tuscula* Ehrenberg | Natus |
| *Navicula veneta* Kützing | Nave |
| *Navicula vitabunda* Hustedt | Navi |
| *Nitzschia angustata* (W.Smith) Grunow | Nian |
| *Nitzschia brevissima* Grunow in Van Heurck | Nibr |
| *Nitzschia dissipata* (Kützing) Grunow | Nidi |
| *Nitzschia elongata* Hassal | Niel |
| *Nitzschia flexa* Schumann | Nifl |
| *Nitzschia recta* Hantzsch ex Rabenhorst | Nire |
| *Nitzschia sigmoidea* (Nitzsch) W.Smith | Nisi |
| *Nitzschia umbonata* (Ehrenberg) Lange-Bertalot | Nium |
| *Stauroneis phoenicenteron* (Nitzsch) Ehrenberg | Stph |
| *Surirella amphioxys* W.Smith | Suam |
| *Surirella angusta* Kützing | Suan |
| *Surirella brebissonii* Krammer & Lange-Bertalot | Subr |
| *Surirella minuta* Brébisson | Sumi |
| *Surirella ovalis* Brébisson | Suov |
| *Surirella subsalsa* W.Smith | Susu |
| *Ulnaria biceps* (Kützing) Compère | Ulbi |
| *Ulnaria ulna (*Nitzsch) Compère | Ulul |

**Appendix B** List of diatom species reccorded in the running water stations in summer 2014

| Species | A2 | A3 | A5 | A6 | A7 | A8 | A9 | A10 | A11 | A12 | A15 | A17 | A19 | A21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Achnanthes impexa* Lange-Bertalot | - | - | - | - | - | - | - | - | - | + | - | - | - | + |
| *Aulacoseira granulata* Simonsen | + | - | - | - | + | - | - | - | - | + | + | + | + | - |
| *Clevamphora ovalis* (Kützing) Mereschkowsky | - | + | + | + | + | + | - | - | - | - | - | - | - | - |
| *Cocconeis placentula* Ehrenberg | + | + | + | - | + | + | + | + | + | + | + | + | + | + |
| *Cyclotella iris* Brun & H-Joseph | - | - | + | + | + | - | - | - | + | + | - | - | - | - |
| *Cyclotella meneghiniana* Kützing | - | - | - | + | + | - | + | - | - | - | - | - | - | - |
| *Cymatopleura solea* Smith | - | - | - | - | - | + | - | - | - | - | - | - | - | - |
| *Cymbella affinis* Kützing | - | + | - | - | - | - | - | - | - | - | + | - | + | + |
| *Cymbella amphicephala* Näegeli | - | + | - | - | - | - | - | - | - | - | - | - | - | - |
| *Cymbella cistula* Kirchner | - | - | + | - | - | - | - | - | - | - | + | - | - | - |
| *Cymbella cymbiformis* Agardh | - | + | - | - | - | - | - | - | + | - | - | - | - | - |
| *Cymbella ehrenbergii* Kützing | - | + | - | - | - | - | - | - | - | - | - | - | - | - |
| *Cymbella excisa* Kützing | - | - | + | + | - | + | + | + | + | - | - | - | - | - |
| *Cymbella hantzschiana* Krammer | - | - | - | - | - | + | - | - | - | - | - | - | - | - |
| *Cymbella minuta* Hilse | - | - | + | + | - | + | - | + | - | - | - | + | + | - |
| *Cymbella tumida* Heurck | + | - | - | - | - | + | - | - | - | - | - | - | - | - |
| *Denticula elegans* Kützing | - | + | - | - | - | - | - | - | - | - | - | - | - | - |
| *Diatoma vulgaris* Bory | - | - | + | + | + | - | + | + | + | - | - | + | + | - |
| *Fragilaria biceps* Ehrenberg | - | - | - | + | + | - | - | - | + | - | - | - | - | - |
| *Fragilaria capucina* Desmazières | - | - | - | - | - | - | - | - | - | - | + | - | - | - |
| *Ulnaria ulna* (Nitzsch) Compère | - | + | + | + | + | + | + | + | + | - | - | - | - | + |
| *Gomphonema minutum* Agardh | - | - | - | + | - | + | + | + | + | - | + | - | - | - |
| *Gomphonema parvulum* Kützing | - | + | + | + | + | - | - | + | - | - | + | + | - | + |
| *Gomphonema truncatum* Ehrenberg | - | + | + | + | - | - | - | - | - | - | + | - | - | - |
| *Gyrosigma acuminatum* Rabenhorst | + | - | - | - | - | - | - | - | - | - | - | - | - | - |
| *Gyrosigma attenuatum* Rabenhorst | - | - | + | - | - | - | + | - | - | - | - | - | - | - |

**Appendix B** Continue

| Species | A2 | A3 | A5 | A6 | A7 | A8 | A9 | A10 | A11 | A12 | A15 | A17 | A19 | A21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Navicula bryophila* J.B.Petersen | - | + | - | - | - | - | - | - | - | - | - | - | - | + |
| *Navicula cryptocephala* Kützing | + | - | - | - | - | + | + | - | + | - | - | - | - | - |
| *Navicula cryptonella* Lange-Bertalot | - | - | - | + | - | - | - | - | - | - | - | - | - | + |
| *Navicula laterostrata* Hustedt | - | - | - | - | - | - | + | - | - | + | - | - | - | - |
| *Navicula margalithii* Lange-Bertalot | - | - | - | - | - | - | - | - | + | - | - | - | - | - |
| *Navicula oppugnata* Hustedt | + | - | + | - | - | + | + | - | + | - | + | + | + | + |
| *Navicula phyllepta* Kützing | - | - | - | - | - | - | + | - | - | - | - | - | - | - |
| *Navicula radiosa* Kützing | - | - | - | - | - | - | - | - | + | - | - | - | - | - |
| *Navicula trivialis* Lange-Bertalot | - | - | - | - | + | + | - | - | - | - | - | - | - | - |
| *Navicula tuscula* Ehrenberg | - | - | + | - | - | - | - | - | - | - | - | - | - | - |
| *Nitzschia dissipata* Rabenhorst | - | - | - | - | - | - | + | - | - | - | - | - | - | - |
| *Nitzschia elongata* Hassal | + | - | - | - | - | - | - | - | - | - | - | - | - | - |
| *Nitzschia obtusa* W.Smith | + | - | - | - | - | - | - | - | - | - | - | - | - | - |
| *Nitzschia recta* H. ex Rabenhorst | + | - | - | - | - | - | - | - | - | - | - | - | - | - |
| *Nitzschia sigmoidea* (Nitzsch) Smith | - | - | - | - | - | - | + | - | - | - | - | - | - | - |
| *Nitzschia umbonata* L-Bertalot | - | - | - | - | - | - | + | - | - | - | + | - | - | - |
| *Surirella minuta* Brébisson | - | - | - | - | - | - | - | - | - | - | + | - | - | - |

+ and – indicate presence and absence of species. For station codes, see Table 5.1

**Appendix C** List of diatom species reccorded in the running water stations in fall 2014

| Species | A2 | A3 | A5 | A6 | A7 | A8 | A9 | A1- | A11 | A12 | A15 | A16 | A17 | A19 | A21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Aulacoseira granulata* Simonsen | + | - | - | - | - | - | - | - | - | - | - | + | - | + | - |
| *Clevamphora ovalis* (Kützing) Mereschkowsky | - | - | - | - | - | - | - | - | + | - | - | - | - | - | - |
| *Cocconeis placentula* Ehrenberg | + | + | - | + | - | - | - | +- | + | + | - | - | + | - | - |
| *Cocconeis placentula* var. *lineata* Heurck | + | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| *Cyclotella iris* Brun & H-Joseph | - | - | - | - | - | - | - | - | - | - | - | + | - | + | - |
| *Cyclotella ocellata* Pantocsek | + | + | - | + | - | - | - | + | - | + | - | - | + | - | - |
| *Cymbella affinis* Kützing | + | + | - | + | - | + | - | - | + | + | - | + | + | - | + |
| *Cymbella cymbiformis* Agardh | - | - | - | - | - | - | - | - | - | - | - | + | - | - | - |
| *Cymbella helvetica* Kützing | - | - | - | - | - | + | - | - | - | - | - | - | - | - | - |
| *Cymbella minuta* Hilse | - | - | - | - | - | - | - | - | + | - | - | - | - | - | - |
| *Cymbella simonsenii* Krammer | - | + | - | - | - | - | - | - | - | - | - | - | - | - | - |
| *Diatoma moniliformis* Williams | - | - | - | - | - | + | - | - | - | - | - | - | - | - | + |
| *Diatoma vulgaris* Bory | - | + | - | - | - | - | - | + | + | - | - | - | - | - | + |
| *Diploneis modica* Hustedt | - | - | - | - | - | - | - | - | - | - | - | + | - | - | - |
| *Fragilaria capucina* Desmazières | + | - | - | + | - | - | - | + | + | + | - | - | + | - | - |
| *Fragilaria crotonensis* Kitton | - | - | - | - | - | - | - | - | + | - | - | - | - | - | - |
| *Ulnaria ulna* (Nitzsch) Compère | - | + | - | + | - | + | - | - | - | + | - | + | - | - | + |
| *Gomphonema angustum* Agardh | - | - | - | - | - | - | - | - | - | - | - | - | - | - | + |
| *Gomphonema clavatum* Ehrenberg | - | + | - | + | - | - | - | - | + | + | - | - | - | - | - |
| *Gomphonema minutum* Agardh | - | - | - | - | - | + | - | - | - | - | - | + | - | - | + |
| *Gomphonema parvulum* Kützing | - | + | - | + | - | + | - | - | + | + | - | - | - | - | + |
| *Melosira lineata* Agardh | - | + | - | - | - | - | - | - | - | - | - | - | - | - | - |
| *Navicula clementis* Grunow | - | - | - | - | - | - | - | - | + | - | - | - | - | - | - |
| *Navicula constans* Hustedt | - | - | - | + | - | - | - | - | - | + | - | - | - | - | - |
| *Navicula cryptocephala* Kützing | - | - | - | - | - | + | - | - | - | - | - | - | - | - | + |
| *Navicula lanceolata* Kützing | + | - | - | - | - | - | - | + | - | - | - | - | - | - | - |

**Appendix C** Continue

| Species | A2 | A3 | A5 | A6 | A7 | A8 | A9 | A1- | A11 | A12 | A15 | A16 | A17 | A19 | A21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Navicula leptostriata* Jørgensen | - | - | - | - | - | - | - | + | - | - | - | - | - | - | - |
| *Navicula oppugnata* Hustedt | - | - | - | - | - | + | - | - | - | - | - | - | - | - | + |
| *Navicula peregrina* Kützing | - | - | - | - | - | - | - | - | - | - | - | - | + | - | - |
| *Navicula phyllepta* Kützing | - | - | - | - | - | - | - | - | + | - | - | - | - | - | + |
| *Navicula recens* Lange-Bertalot | - | + | - | - | - | - | - | - | - | - | - | - | - | - | - |
| *Navicula trivialis* Lange-Bertalot | - | - | - | - | - | - | - | - | - | - | - | - | + | - | - |
| *Navicula vitabunda* Hustedt | - | - | - | - | - | - | - | + | - | - | - | - | - | - | - |
| *Nitzschia angustata* Grunow | - | - | - | - | - | + | - | - | - | - | - | - | - | - | - |
| *Nitzschia dissipata* Rabenhorst | - | - | - | - | - | - | - | - | - | - | - | - | - | - | + |
| *Nitzschia umbonata* Lange-Bertalot | - | - | - | - | - | + | - | - | - | - | - | - | - | - | - |
| *Surirella angusta* Kützing | - | - | - | - | - | + | - | - | - | - | - | - | - | - | - |
| *Surirella brebissonii* Krammer & L-Bertalot | - | - | - | - | - | + | - | - | - | - | - | - | - | - | + |

+ and – indicate presence and absence of species. For station codes, see Table 5.1

**Appendix D** List of diatom species reccorded in the running water stations in spring 2015

| Species | A2 | A4 | A5 | A6 | A8 | A11 | A14 | A15 | A16 | A17 | A18 | A19 | A20 | A21 | Bak4 | Bak9 | Bak12 | R1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Amphora inariensis* | + | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| *Amphora subcapitata* | - | - | + | + | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| *Aulacoseira granulata* | - | - | - | - | - | - | + | - | - | + | - | - | - | - | - | - | - | - |
| *Clevamphora ovalis* | + | - | - | + | - | - | - | - | - | - | - | - | + | + | - | + | - | - |
| *Cocconeis disculus* | - | - | - | - | - | - | - | - | - | - | - | - | - | + | - | - | - | - |
| *Cocconeis placentula* | - | + | + | - | - | - | - | + | - | + | - | - | + | - | - | + | + | - |
| *Cocconeis scutellum* | - | - | - | - | - | - | - | - | - | - | - | - | - | + | - | - | - | - |
| *Cyclotella ocellata* | + | + | - | - | - | + | + | - | + | - | + | - | - | - | + | - | + | + |
| *Cyclotella radiosa* | - | - | - | - | - | - | - | - | - | - | - | - | - | + | - | - | - | - |
| *Cymatopleura solea* | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| *Cymbella affinis* | + | - | + | + | + | + | + | + | + | - | + | + | + | + | + | + | + | + |
| *Cymbella tumida* | - | - | - | - | - | - | - | - | - | - | - | - | - | - | + | - | - | - |
| *Denticula elegans* | + | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | + | - |
| *Diatoma tenuis* | - | - | - | - | - | - | - | + | - | - | - | - | - | - | - | - | - | - |
| *Diatoma vulgaris* | - | - | + | + | + | + | - | - | + | - | - | - | + | + | + | - | + | - |
| *Epithemia frickei* | - | - | - | - | - | - | - | - | + | - | - | - | - | - | - | - | - | - |
| *Fragilaria biceps* | - | - | - | - | - | - | - | - | - | - | + | - | - | + | - | - | - | - |
| *Fragilaria capucina* | + | - | + | + | + | + | - | + | + | + | + | + | + | + | + | + | + | + |
| *Fragilaria dilatata* | + | - | - | - | - | - | + | + | + | - | + | - | - | - | + | - | - | - |
| *Fragilaria fasciculata* | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| *Ulnaria ulna* | + | - | + | + | + | + | + | + | + | + | + | + | + | + | - | + | + | + |
| *Gomphonema angustum* | - | - | + | + | - | - | - | - | - | - | + | - | - | - | - | - | - | - |
| *Gomphonema parvulum* | + | - | - | - | + | - | - | + | + | + | + | - | + | + | + | + | + | + |
| *Gomphonema pseudoaugur* | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| *Gomphonema truncatum* | - | - | + | - | + | - | - | - | + | - | - | - | + | + | + | + | - | - |
| *Hantzschia weyprechtii* | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |

**Appendix D** Continue

| Species | A2 | A4 | A5 | A6 | A8 | A11 | A14 | A15 | A16 | A17 | A18 | A19 | A20 | A21 | Bak4 | Bak9 | Bak12 | R1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Melosira lineata* | - | - | - | - | - | + | + | - | - | - | + | - | - | - | - | - | - | - |
| *Melosira varians* | + | - | - | + | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| *Navicula capitatoradiata* | - | - | - | - | - | - | - | - | - | + | - | - | - | - | - | - | - | - |
| *Navicula cincta* | - | - | - | - | - | - | - | + | + | - | - | - | - | - | - | + | - | - |
| *Navicula clementis* | - | - | - | - | - | + | - | - | - | - | + | - | - | - | - | - | - | - |
| *Navicula digitoradiata* | - | - | - | - | - | - | + | - | - | - | - | - | - | - | - | - | - | - |
| *Navicula expecta* | - | - | - | - | - | + | - | - | - | - | - | - | - | - | - | - | - | - |
| *Navicula lanceolata* | - | - | + | - | - | + | - | + | - | - | - | - | + | - | - | - | - | - |
| *Navicula pusilla* | - | - | - | - | - | - | + | - | - | - | - | - | - | - | - | - | - | - |
| *Navicula radiosa* | - | - | - | + | + | - | - | - | - | - | - | + | - | - | - | - | - | - |
| *Navicula schoenfeldii* | - | - | - | - | - | - | + | - | - | - | - | - | - | - | - | - | - | - |
| *Navicula tripunctata* | - | - | - | - | - | - | - | - | - | - | - | - | - | + | - | - | - | - |
| *Navicula trivialis* | - | - | - | - | - | - | - | - | - | - | - | - | - | + | - | - | - | - |
| *Navicula veneta* | - | - | - | - | - | - | - | + | - | - | - | - | - | + | - | - | - | - |
| *Nitzschia brevissima* | - | - | - | - | - | - | + | - | + | - | - | - | - | - | - | - | - | - |
| *Nitzschia dissipata* | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | + | - | - |
| *Nitzschia flexa* | - | - | + | - | - | - | - | - | - | - | - | - | + | - | - | - | - | - |
| *Nitzschia recta* | - | - | + | + | - | - | - | - | - | - | - | - | - | + | - | - | - | - |
| *Surirella angusta* | - | - | - | - | - | - | - | - | - | - | - | - | - | + | - | - | - | - |
| *Surirella ovalis* | - | - | - | - | + | - | - | - | - | - | - | - | - | - | - | - | - | - |
| *Surirella subsalsa* | + | - | + | - | - | - | - | - | - | - | - | - | - | + | - | - | - | - |

+ and – indicate presence and absence of species. For station codes, see Table 5.1

**Appendix E** List of diatom species reccorded in the running water stations in summer 2015

| Species | A3 | A5 | A6 | A8 | A9 | A10 | A11 | A12 | A13 | A15 | A16 | A17 | A18 | A19 | A21 | R1 | Bak 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Aulacoseira granulata* | - | - | - | - | + | - | - | - | - | + | + | - | - | + | - | - | - |
| *Clevamphora ovalis* | + | + | - | - | + | - | - | - | - | - | - | + | + | - | - | - | - |
| *Cocconeis placentula* | + | + | + | + | + | + | + | + | - | + | + | + | + | + | + | - | + |
| *Cyclotella ocellata* | - | + | - | - | - | + | + | + | - | - | - | + | + | - | + | - | + |
| *Cymatopleura solea* | - | - | - | - | + | - | - | - | - | - | - | - | - | - | - | - | - |
| *Cymbella affinis* | + | + | + | + | + | + | + | + | - | + | - | + | - | + | + | + | + |
| *Cymbella cistula* | - | - | - | - | - | - | - | - | - | + | - | - | - | - | - | + | - |
| *Cymbella mesiana* | - | + | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| *Cymbella minuta* | - | - | - | - | - | + | - | - | - | - | + | - | - | + | - | - | - |
| *Cymbella naviculiformis* | - | - | - | - | - | - | - | + | - | - | - | - | + | - | + | - | - |
| *Cymbella silesiaca* | + | + | - | + | - | - | - | - | - | - | - | - | - | - | - | - | - |
| *Denticula elegans* | - | - | - | - | + | - | + | - | - | - | - | - | - | - | - | - | - |
| *Diatoma hyemalis* | + | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| *Diatoma tenuis* | + | + | - | - | - | - | + | + | - | - | - | + | - | - | + | - | - |
| *Diatoma vulgaris* | - | + | + | + | - | + | - | + | - | - | + | + | - | + | + | + | - |
| *Epithemia adnata* | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | + | - |
| *Epithemia cistula* | - | + | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| *Eunotia tenella* | - | - | + | - | + | - | - | + | - | - | - | - | - | - | + | + | - |
| *Fragilaria capucina* | + | + | + | + | + | - | + | + | - | + | - | + | + | - | + | + | + |
| *Fragilaria dilatata* | + | - | - | - | - | - | - | + | - | - | - | - | - | - | + | - | + |
| *Ulnaria ulna* | + | + | - | + | + | + | - | + | - | - | - | + | + | - | + | - | + |
| *Gomphonema gracile* | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | + | - |
| *Gomphonema minutum* | - | - | - | - | - | + | - | - | - | + | - | - | - | - | - | - | - |
| *Gomphonema parvulum* | - | - | + | + | + | + | + | - | - | + | + | + | + | - | - | + | + |
| *Gomphonema pseudoaugur* | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | + | - |
| *Gomphonema truncatum* | - | - | - | - | - | - | - | - | - | + | - | - | - | - | - | - | - |

**Appendix E** Continue

| Species | A3 | A5 | A6 | A8 | A9 | A10 | A11 | A12 | A13 | A15 | A16 | A17 | A18 | A19 | A21 | R1 | Bak 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Melosira lineata* | - | - | - | - | + | - | - | - | - | - | - | - | - | - | - | - | - |
| *Navicula capitatoradiata* | - | - | - | - | + | - | + | + | - | - | - | + | + | - | - | + | - |
| *Navicula cryptonella* | + | + | - | + | + | - | - | - | - | - | - | - | - | - | - | + | - |
| *Navicula halophila* | - | - | - | - | - | - | - | - | - | - | - | - | - | - | + | - | - |
| *Navicula jaagii* | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | + | - |
| *Navicula lanceolata* | - | - | - | + | - | + | - | - | - | - | - | + | - | - | - | + | - |
| *Navicula oppugnata* | - | - | - | - | - | - | - | - | - | + | + | - | - | + | - | - | - |
| *Navicula phyllepta* | - | - | - | - | + | - | - | - | - | - | - | - | - | - | - | - | - |
| *Navicula radians* | - | - | - | - | - | + | - | - | - | - | - | - | + | - | - | - | + |
| *Navicula slesvicensis* | - | - | - | - | - | + | + | - | - | - | - | - | + | - | - | - | - |
| *Nitzschia umbonata* | - | - | - | - | - | - | - | - | - | + | - | - | - | - | - | - | - |
| *Stauroneis phoenicenteron* | + | + | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| *Surirella amphioxys* | - | - | - | + | - | - | - | - | - | - | - | - | - | - | - | - | - |
| *Surirella minuta* | - | - | - | - | - | - | - | - | - | + | - | - | - | - | - | - | - |

+ and – indicate presence and absence of species. For station codes, see Table 5.1

**Appendix F** List of all phytoplankton taxa recorded during the study period

| Bacillariophyta (Bac) | |
|---|---|
| Species | Code |
| *Amphipleura lindheimeri* Grunow | Amli |
| *Clevamphora ovalis* (Kützing) Mereschkowsky | Amov |
| *Amphora subcapitata* (Kisselew) Hustedt | Amsu |
| *Aulacoseira granulata* (Ehrenberg) Simonsen | Augr |
| *Cocconeis placentula* Ehrenberg | Copl |
| *Cocconeis placentula var. lineata* (Ehrenberg) v | Copll |
| *Cocconeis placentula var. Placentula* Ehrenberg | Coplv |
| *Cyclotella cyclopuncta* Håkansson & J.R.Carter | Cycy |
| *Cyclotella dallasiana* W.Smith | Cyda |
| *Cyclotella fottii* Hustedt in Huber-Pestalozzi | Cyfr |
| *Cyclotella iris* Brun & Héribaud-Joseph | Cyir |
| *Cyclotella krammeri* Håkansson | Cykr |
| *Cyclotella meneghiniana* Kützing | Cyme |
| *Cyclotella ocellata* Pantocsek | Cyoc |
| *Cyclotella plitvicensis* Hustedt | Cypl |
| *Cyclotella radiosa* (Grunow) Lemmermann | Cyra |
| *Cymatopleura solea* (Brébisson) W.Smith | Cyso |
| *Cymbella affinis* Kützing | Cyaf |
| *Cymbella amphicephala* Näegeli in Kützing | Cyam |
| *Cymbella aspera* (Ehrenberg) Cleve | Cyas |
| *Cymbella caespitosa* (Kützing) Brun | Cyca |
| *Cymbella cistula* (Ehrenberg) O.Kirchner | Cyci |
| *Cymbella cymbiformis* C.Agardh | Cycym |
| *Cymbella gracilis* (Hustedt) Krammer | Cygr |
| *Cymbella hantzschiana* Krammer | Cyha |
| *Cymbella laevis* Nägeli in Rabenhorst | Cyla |
| *Cymbella minuta* Hilse in Rabenhorst | Cymi |
| *Cymbella naviculiformis* (Auerswald ex Heiberg) Cleve | Cyna |
| *Cymbella tumida* (Brébisson) van Heurck | Cytu |
| *Denticula elegans* Kützing | Deel |
| *Denticula valida* (Pedicino) Grunow in van Heurck | Deva |
| *Diatoma tenuis* C.Agardh | Dite |
| *Diatoma vulgaris* Bory | Divu |
| *Epithemia frickei* Krammer | Epfr |
| *Epithemia sorex* Kützing | Epso |
| *Epithemia turgida* (Ehrenberg) Brun | Eptu |
| *Eunotia glacialis* Meister | Eugl |
| *Eunotia tenella* (Grunow) Hustedt | Eute |
| *Ulnaria biceps* (Kützing) Compère | Frbi |
| *Fragilaria capucina* Desmazières | Frca |
| *Fragilaria dilatata* (Brébisson) Lange-Bertalot | Frdi |

**Appendix F** continue

| Bacillariophyta (Bac) | |
|---|---|
| Species | Code |
| *Fragilaria fasciculata* (C.Agardh) Lange-Bertalot | Frfa |
| *Fragilaria incognita* Reichardt | Frin |
| *Fragilaria leptostauron* (Ehrenberg) Hustedt | Frle |
| *Fragilaria parasitica* (W.Smith) Grunow | Frpa |
| *Fragilaria acus* Lange-Bertalot | Frac |
| *Ulnaria biceps* (Kützing) Compère | Frbi |
| *Gomphonema acuminatum* Ehrenberg | Goac |
| *Gomphonema angustatum* (Kützing) Rabenhorst | Goan |
| *Gomphonema angustum* C.Agardh | Goang |
| *Gomphonema augur* Ehrenberg | Goau |
| *Gomphonema gracile* Ehrenberg | Gogr |
| *Gomphonema mammilla* Ehrenberg | Goma |
| *Gomphonema minutum* (C.Agardh) C.Agardh | Gomi |
| *Gomphonema parvulum* Kützing | Gopa |
| *Gomphonema pseudoaugur* Lange-Bertalot | Gops |
| *Gomphonema subtile* Ehrenberg | Gosu |
| *Gomphonema truncatum* Ehrenberg | Gotr |
| *Gyrosigma acuminatum* (Kützing) Rabenhorst | Gyac |
| *Gyrosigma attenuatum* (Kützing) Rabenhorst | Gyat |
| *Hantzschia distinctepunctata var. circuligera* Compère | Hadi |
| *Melosira lineata* (Dillwyn) C.Agardh | Meli |
| *Melosira varians* C.Agardh | Meva |
| *Navicula angusta* Grunow | Naan |
| *Navicula bryophila* J.B.Petersen | Nabr |
| *Navicula capitatoradiata* H.Germain | Naca |
| *Navicula cari* Ehrenberg | Nacar |
| *Navicula cincta* (Ehrenberg) Ralfs in Pritchard | Naci |
| *Navicula cryptocephala* Kützing | Nacr |
| *Navicula cryptonella* Lange-Bertalot | Nacry |
| *Navicula expecta* S.L.VanLandingham | Naex |
| *Navicula gregaria* Donkin | Nagr |
| *Navicula halophila* (Grunow) Cleve | Naha |
| *Navicula lanceolata* (C.Agardh) Kützing | Nala |
| *Navicula phyllepta* Kützing | Naph |
| *Navicula porifera* Hustedt | Napo |
| *Navicula pseudomutica* Hustedt | Naps |
| *Navicula pupula* Kützing | Napu |
| *Navicula radians* Héribaud-Joseph | Nara |
| *Navicula radiosa* Kützing | Narad |
| *Navicula slesvicensis* Grunow | Nasl |
| *Navicula soehrensis* Krasske | Naso |

**Appendix F** continue

| Bacillariophyta (Bac) | |
|---|---|
| Species | Code |
| *Navicula tripunctata* (O.F.Müller) Bory | Natr |
| *Navicula trivialis* Lange-Bertalot | Natri |
| *Navicula veneta* Kützing | Nave |
| *Nitzschia angustata* (W.Smith) Grunow | Nian |
| *Nitzschia calida* Grunow | Nica |
| *Nitzschia flexa* Schumann | Nifl |
| *Nitzschia palea* (Kützing) W.Smith | Nipa |
| *Nitzschia recta* Hantzsch ex Rabenhorst | Nire |
| *Nitzschia sigma* (Kützing) W.Smith | Nisi |
| *Nitzschia solita* Hustedt | Niso |
| *Rhopalodia gibba* (Ehrenberg) Otto Müller | Rhgi |
| *Rhopalodia gibba var. minuta* Krammer | Rhgiv |
| *Stauroneis anceps* Ehrenberg | Stan |
| *Stauroneis anceps var.siberica* Grunow | Stanv |
| *Stauroneis nobilis* Schumann | Stno |
| *Surirella minuta* Brébisson | Sumi |
| *Surirella ovalis* Brébisson | Suov |
| *Ulnaria ulna* (Nitzsch) Compère | Ulul |
| **Chlorophyta (Chl)** | |
| *Botryococcus braunii* Kützing | Bobr |
| *Botryosphaerella sudetica* (Lemmermann) P.C.Silva | Bosu |
| *Chlamydomonas crassa* H.R.Christen | Chcr |
| *Chlamydomonas debaryana* Goroschankin | Chde |
| *Chlamydomonas globosa* J.W.Snow | Chgl |
| *Chlamydomonas lapponica* Skuja | Chla |
| *Coelastrum astroideum* De Notaris | Coas |
| *Coelastrum microporum* Nägeli | Comi |
| *Eudorina elegans* Ehrenberg | Euel |
| *Geminella interrupta* Turpin | Gein |
| *Geminella ordinate* (West & G.S.West) Heering | Geor |
| *Monoraphidium arcuatum* (Korshikov) Hindák | Moar |
| *Monoraphidium contortum* (Thuret) Komárková | Moco |
| *Mougeotia boodlei* (West & G.S West) Collins | Mobo |
| *Mougeotia nummuloides* (Hassall) De Toni | Monu |
| *Mougeotia parvula* Hassall | Mopa |
| *Mougeotia pulchella* (Wittrock) De Toni | Mopu |
| *Mougeotia quadrangulata* Hassall | Moqu |
| *Mougeotia scalaris* Hassall | Mosc |
| *Oocystis borgei* J.W.Snow | Oobo |
| *Oocystis parva* West & G.S.West | Oopa |
| *Pandorina morum* (O.F.Müller) Bory | Pamo |

**Appendix F** continue

| **Chlorophyta (Chl)** | |
|---|---|
| Species | Code |
| *Pediastrum boryanum* (Turpin) Meneghini | Pebo |
| *Pediastrum duplex* Meyen | Pedu |
| *Pediastrum simplex* Meyen | Pesi |
| *Pediastrum tetras* (Ehrenberg) Ralfs | Pete |
| *Scenedesmus abundans* (O.Kirchner) Chodat | Scab |
| *Scenedesmus communis* E.Hegewald | Scco |
| *Scenedesmus dimorphus* (Turpin) Kützing | Scdi |
| *Scenedesmus ellipticus* Corda | Scel |
| *Scenedesmus falcatus* Chodat | Scfa |
| *Scenedesmus longispina* R.Chodat | Sclo |
| *Scenedesmus obliquus* (Turpin) Kützing | Scob |
| *Spirogyra dubia* Kützing | Spdu |
| *Spirogyra elongate* (Vaucher) Kützing | Spel |
| *Spirogyra grevilleana* (Hassall) Kützing | Spgr |
| *Spirogyra inflate* (Vaucher) Dumortier | Spin |
| *Spirogyra weberi* Kützing | Spwe |
| *Tetraëdron minimum* (A.Braun) Hansgirg | Temi |
| *Treubaria setigera* (W.Archer) G.M.Smith | Trse |
| *Ulothrix subconstricta* G.S.West | Ulsu |
| **Cyanobacteria (Cya)** | |
| *Anabaena catenula* Kützing ex Bornet & Flahault | Anca |
| *Anabaena planctonica* Brunnthaler | Anpl |
| *Anabaena verrucosa* J.B.Petersen | Anve |
| *Aphanizomenon issatschenkoi* (Usacev) Proshkina-Lavrenko | Apis |
| *Calothrix parietina* Thuret ex Bornet & Flahault | Capa |
| *Chroococcopsis chroococcoides* (F.E.Fritsch) K & Anagnostidis | Chch |
| *Chroococcus disperses* (Keissler) Lemmermann | Chdi |
| *Chroococcus turgidus* (Kützing) Nägeli | Chtu |
| *Chroodactylon ornatum* (C.Agardh) Basson | Chor |
| *Merismopedia glauca* (Ehrenberg) Kützing | Megl |
| *Microcystis aeruginosa* (Kützing) Kützing | Miae |
| *Microcystis flosaquae* (Wittrock) Kirchner | Mifl |
| *Nostoc linckia* Bornet ex Bornet & Flahault | Noli |
| *Oscillatoria agardhii* Gomont | Osag |
| *Oscillatoria brevis* Kützing ex Gomont | Osbr |
| *Oscillatoria cortiana* Meneghini ex Gomont | Osco |
| *Oscillatoria limosa* C.Agardh ex Gomont | Osli |
| *Oscillatoria tenuis* C.Agardh ex Gomont | Oste |
| *Pseudanabaena catenata* Lauterborn | Psca |
| *Snowella lacustris* (Chodat) Komárek & Hindák | Snla |

**Appendix F** continue

| | |
|---|---|
| **Miozoa (Mio)** | |
| *Ceratium furcoides* (Levander) Langhans | Cefu |
| *Ceratium hirundinella* (O.F.Müller) Dujardin | Cehi |
| *Peridiniopsis cunningtonii* Lemmermann | Pecu |
| *Peridinium cinctum* (O.F.Müller) Ehrenberg | Peci |
| *Peridinium lomnickii* Woloszynska | Pelo |
| *Peridinium willei* Huitfeldt-Kaas | Pewi |
| **Charophyta (Cha)** | |
| *Cosmarium punctulatum* Brébisson | Copu |
| *Cosmarium subcrenatum* Hantzsch in Rabenhorst | Cosu |
| *Closterium acerosum* Ehrenberg ex Ralfs | Clac |
| *Closterium aciculare* T.West | Claci |
| *Closterium dianae* Ehrenberg ex Ralfs | Cldi |
| *Closterium littorale* | Clli |
| *Closterium moniliferum* Ehrenberg ex Ralfs | Clmo |
| *Closterium parvulum* Nägeli | Clpa |
| *Staurastrum chaetoceras* (Schröder) G.M.Smith | Stch |
| *Staurastrum cingulum* (West & G.S.West) G.M.Smith | Stci |
| *Staurastrum crenulatum* (Nägeli) Delponte | Stcr |
| *Zygnema pectinatum* (Vaucher) C.Agardh | Zype |
| **Euglenozoa (Eug)** | |
| *Euglena acus* (O.F.Müller) Ehrenberg | Euac |
| *Euglena anabaena* Mainx | Euan |
| *Euglena chlamydophora* Mainx | Euch |
| *Euglena geniculate* Dujardin | Euge |
| *Euglena oblonga* F.Schmitz | Euob |
| *Euglena oxyuris* Schmarda | Euox |
| *Euglena proxima* P.A.Dangeard | Eupr |
| *Euglena viridis* (O.F.Müller) Ehrenberg | Euvi |
| *Phacus caudatus* Hübner | Phca |
| *Phacus longicauda* (Ehrenberg) Dujardin | Phlo |
| *Phacus parvulus* G.A.Klebs | Phpa |
| *Trachelomonas cervicula* Stokes | Trce |
| *Trachelomonas granulosa* Playfair | Trgr |
| *Trachelomonas hispida* (Perty) F.Stein | Trhi |
| *Trachelomonas pseudofelix* Deflandre | Trps |
| *Trachelomonas scabra* Playfair | Trsc |
| *Trachelomonas zorensis* Deflandre | Trzo |
| **Cryptophyta (Cry)** | |
| *Campylomonas reflexa* (M.Marsson) D.R.A.Hill | Care |
| *Cryptomonas erosa* Ehrenberg | Cyer |
| *Cryptomonas marssonii* Skuja | Cyma |

**Appendix F** continue

| | |
|---|---|
| *Cryptomonas ovata* Ehrenberg | Cyov |
| *Cryptomonas rostratiformis* Skuja | Cyro |
| **Ochrophyta (Och)** | |
| Species | Code |
| *Dinobryon divergens* O.E.Imhof | Didi |

**Appendix G** List of species found at Lake Gölhisar

| Species | Su14 | Fa14 | Sp15 | Su15 |
|---|---|---|---|---|
| *Clevamphora ovalis* (Kützing) Mereschkowsky | - | + | + | + |
| *Anabaena catenula* Kützing ex Bornet & Flahault | - | - | - | + |
| *Aulacoseira granulata* (Ehrenberg) Simonsen | - | - | - | + |
| *Botryococcus braunii* Kützing | - | - | + | + |
| *Ceratium furcoides* (Levander) Langhans | - | - | - | + |
| *Chlamydomonas globosa* J.W.Snow | - | - | + | + |
| *Chroococcus dispersus* (Keissler) Lemmermann | - | - | + | - |
| *Chroococcus turgidus* (Kützing) Nägeli | - | - | - | + |
| *Cocconeis placentula* Ehrenberg | - | + | + | + |
| *Coelastrum astroideum* De Notaris | - | - | - | + |
| *Cryptomonas marssonii* Skuja | - | - | - | + |
| *Cryptomonas ovata* Ehrenberg | + | + | + | + |
| *Cyclotella ocellata* Pantocsek | - | + | + | + |
| *Cymbella excisa* Kützing | - | + | + | + |
| *Denticula elegans* Kützing | - | - | - | + |
| *Diatoma tenuis* C.Agardh | - | + | + | - |
| *Dinobryon divergens* O.E.Imhof | - | - | + | - |
| *Epithemia sorex* Kützing | - | - | - | + |
| *Epithemia turgida* var. *granulata* (Ehrenberg) Brun | - | - | - | + |
| *Eudorina elegans* Ehrenberg | - | - | + | - |
| *Euglena acus* (O.F.Müller) Ehrenberg | + | - | + | + |
| *Euglena chlamydophora* Mainx | - | - | - | + |
| *Euglena oblonga* F.Schmitz | - | - | - | + |
| *Euglena proxima* P.A.Dangeard | + | - | - | - |
| *Fragilaria capucina* Desmazières | - | + | + | - |
| *Fragilaria dilatata* (Brébisson) Lange-Bertalot | + | - | + | - |
| *Fragilaria famelica* (Kützing) Lange-Bertalot | - | + | - | - |
| *Fragilaria incognita* Reichardt | - | + | - | - |
| *Fragilaria ulna* var. *acus* (Kützing) Lange-Bertalot | - | + | + | + |
| *Gomphonema gracile* Ehrenberg | - | - | - | + |
| *Gomphonema parvulum* Kützing | - | + | + | - |
| *Gomphonema truncatum* Ehrenberg | - | - | + | + |
| *Merismopedia glauca* (Ehrenberg) Kützing | + | - | - | - |
| *Microcystis aeruginosa* (Kützing) Kützing | + | - | + | - |
| *Monoraphidium arcuatum* (Korshikov) Hindák | - | - | - | + |
| *Monoraphidium contortum* (Thuret) K-Legnerová | - | - | - | + |
| *Mougeotia boodlei* (West & G.S West) Collins | - | - | - | + |
| *Mougeotia pulchella* (Wittrock) De Toni | - | + | - | - |
| *Mougeotia quadrangulata* Hassall | - | - | - | + |
| *Mougeotia scalaris* Hassall | - | - | - | + |
| *Navicula cincta* (Ehrenberg) Ralfs | - | - | + | - |
| *Navicula cryptocephala* Kützing | + | - | - | - |

**Appendix G** Continue

| Species | Su14 | Fa14 | Sp15 | Su15 |
|---|---|---|---|---|
| *Navicula lanceolata* (C.Agardh) Kützing | - | - | + | + |
| *Navicula oblonga* (Kützing) Kützing | - | - | + | - |
| *Navicula radians* Héribaud-Joseph | - | - | - | + |
| *Navicula radiosa* Kützing | + | - | + | - |
| *Navicula slesvicensis* Grunow in van Heurck | - | + | - | - |
| *Navicula tripunctata* (O.F.Müller) Bory | - | - | + | - |
| *Nitzschia brevissima* Grunow in van Heurck | - | - | + | - |
| *Nitzschia palea* (Kützing) W.Smith | - | - | + | - |
| *Oocystis parva* West & G.S.West | - | - | - | + |
| *Oscillatoria limosa* C.Agardh ex Gomont | - | - | - | + |
| *Oscillatoria tenuis* C.Agardh ex Gomont | - | - | - | + |
| *Pandorina morum (O.F.Müller) Bory* | - | - | + | + |
| *Pediastrum tetras* (Ehrenberg) Ralfs | - | - | - | + |
| *Peridiniopsis cunningtonii* Lemmermann | + | - | - | + |
| *Peridinium willei* Huitfeldt-Kaas | - | - | - | + |
| *Phacus longicauda* (Ehrenberg) Dujardin | - | - | + | + |
| *Pseudanabaena catenata* Lauterborn | - | - | - | + |
| *Rhopalodia gibba* (Ehrenberg) Otto Müller | - | - | - | + |
| *Rhopalodia gibba* var. *minuta* Krammer | - | - | - | + |
| *Scenedesmus communis* E.Hegewald | + | - | + | + |
| *Scenedesmus falcatus* Chodat | - | - | - | + |
| *Scenedesmus longispina* R.Chodat | - | - | - | + |
| *Scenedesmus obliquus* (Turpin) Kützing | - | - | - | + |
| *Spirogyra grevilleana* (Hassall) Kützing | - | + | - | - |
| *Spirogyra inflata* (Vaucher) Dumortier | - | + | - | - |
| *Spirogyra weberi* Kützing | - | + | - | + |
| *Staurastrum crenulatum* (Nägeli) Delponte | - | + | - | - |
| *Stauroneis anceps* Ehrenberg | - | - | + | - |
| *Stauroneis anceps* var. *siberica* Grunow | - | - | + | - |
| *Stauroneis nobilis* Schumann | - | - | + | - |
| *Surirella ovalis* Brébisson | - | - | + | - |
| *Tetraëdron minimum* (A.Braun) Hansgirg | + | - | - | - |
| *Trachelomonas cervicula* Stokes | - | - | - | + |
| *Trachelomonas pseudofelix* Deflandre | - | - | + | - |

Su14= summer 2014; Fa14=fall 2014; Sp15= spring 2015; Su15= summer 2015; + and - represent occurrence and absence respectively

**Appendix H** List of species found at Çayboğazı reservoir

| Species | Su14 | Fa14 | Sp15 | Su15 |
|---|---|---|---|---|
| *Clevamphora ovalis* (Kützing) Mereschkowsky | - | - | + | |
| *Botryococcus braunii* Kützing | - | - | + | - |
| *Campylomonas reflexa* (M.Marsson) D.R.A.Hill | - | - | + | - |
| *Ceratium furcoides* (Levander) Langhans | - | + | - | - |
| *Ceratium hirundinella* (O.F.Müller) Dujardin | + | + | - | - |
| *Chlamydomonas globosa* J.W.Snow | - | - | - | + |
| *Chlamydomonas lapponica* Skuja | + | - | - | - |
| *Chroococcus turgidus* (Kützing) Nägeli | - | - | + | - |
| *Cocconeis placentula* Ehrenberg | - | - | + | + |
| *Cryptomonas marssonii* Skuja | - | - | + | - |
| *Cryptomonas ovata* Ehrenberg | - | - | + | - |
| *Cyclotella dallasiana* W.Smith | - | - | + | - |
| *Cyclotella iris* Brun & Héribaud-Joseph | + | + | - | + |
| *Cyclotella ocellata* Pantocsek | - | - | + | + |
| *Cyclotella plitvicensis* Hustedt | - | - | + | - |
| *Cymbella affinis* Kützing | - | - | + | + |
| *Cymbella caespitosa* (Kützing) Brun | - | - | - | + |
| *Cymbella hantzschiana* Krammer | - | - | - | + |
| *Diatoma vulgaris* Bory | - | - | + | + |
| *Euglena chlamydophora* Mainx | - | - | + | - |
| *Euglena oxyuris* Schmarda | - | - | - | + |
| *Euglena viridis* (O.F.Müller) Ehrenberg | - | + | - | - |
| *Eunotia tenella* (Grunow) Hustedt | - | - | - | + |
| *Fragilaria capucina* Desmazières | - | - | + | + |
| *Fragilaria dilatata* (Brébisson) Lange-Bertalot | - | - | + | + |
| *Fragilaria ulna* var. *acus* (Kützing) L-Bertalot | + | + | + | + |
| *Gomphonema augur* Ehrenberg | - | - | + | - |
| *Gomphonema gracile* Ehrenberg | - | - | - | + |
| *Gomphonema parvulum* Kützing | - | - | + | + |
| *Gomphonema subtile* Ehrenberg | - | - | - | + |
| *Melosira lineata* (Dillwyn) C.Agardh | - | - | + | - |
| *Monoraphidium contortum* (Thuret) K-Legnerová | - | - | - | + |
| *Navicula cryptocephala* Kützing | - | - | - | + |
| *Navicula cryptonella* Lange-Bertalot | + | - | - | + |
| *Navicula radians* Héribaud-Joseph | - | - | - | + |
| *Nitzschia angustata* (W.Smith) Grunow | + | - | - | + |
| *Nitzschia flexa* Schumann | - | - | - | + |
| *Peridiniopsis cunningtonii* Lemmermann | - | - | + | - |
| *Peridinium willei* Huitfeldt-Kaas | - | - | - | + |
| *Scenedesmus communis* E.Hegewald | - | - | + | - |
| *Scenedesmus ellipticus* Corda | - | + | - | - |
| *Scenedesmus falcatus* Chodat | - | - | + | - |

**Appendix H** Continue

| Species | Su14 | Fa14 | Sp15 | Su15 |
|---|---|---|---|---|
| *Surirella minuta* Brébisson in Kützing | - | - | + | - |
| *Trachelomonas pseudofelix* Deflandre | - | - | + | - |
| *Trachelomonas scabra* Playfair | - | - | - | + |
| *Ulothrix subconstricta* G.S.West | - | - | - | + |

Su14=summer 2014; Fa14=fall 2014; Sp15= spring 2015; Su15= summer 2015; + and - represent occurrence and absence respectively

**Appendix I** List of species found at Lake Avlan

| Sepecies | Su14 | Fa14 | Sp15 | Su15 |
|---|---|---|---|---|
| *Clevamphora ovalis* (Kützing) Mereschkowsky | - | - | + | + |
| *Anabaena planctonica* Brunnthaler | - | - | - | + |
| *Botryococcus braunii* Kützing | - | - | + | + |
| *Ceratium furcoides* (Levander) Langhans | - | - | + | + |
| *Chlamydomonas globosa* J.W.Snow | - | - | + | - |
| *Chlamydomonas lapponica* Skuja | + | - | - | - |
| *Chroococcus turgidus* (Kützing) Nägeli | - | + | - | + |
| *Chroodactylon ornatum* (C.Agardh) Basson | - | - | - | + |
| *Closterium aciculare* T.West | - | + | - | - |
| *Cocconeis placentula* Ehrenberg | - | - | + | + |
| *Cocconeis placentula* var. *placentula* Ehrenberg | - | - | - | + |
| *Coelastrum astroideum* De Notaris | - | - | - | + |
| *Cosmarium punctulatum* Brébisson | - | - | - | + |
| *Cryptomonas ovata* Ehrenberg | + | + | + | + |
| *Cryptomonas rostratiformis* Skuja | - | + | - | - |
| *Cyclotella iris* Brun & Héribaud-Joseph | + | - | - | + |
| *Cyclotella ocellata* Pantocsek | - | - | - | + |
| *Cymbella excisa* Kützing | - | + | + | + |
| *Cymbella cymbiformis* C.Agardh | - | + | - | - |
| *Cymbella gracilis* (Rabenhorst) Cleve | - | - | + | - |
| *Cymbella laevis* Nägeli in Rabenhorst | - | - | + | - |
| *Denticula elegans* Kützing | - | - | + | - |
| *Diatoma vulgaris* Bory | - | - | + | + |
| *Epithemia sorex* Kützing | + | - | - | + |
| *Euglena acus* (O.F.Müller) Ehrenberg | - | - | - | + |
| *Euglena anabaena* Mainx | - | - | + | - |
| *Euglena chlamydophora* Mainx | - | + | + | + |
| *Euglena oblonga* F.Schmitz | - | - | - | + |
| *Euglena oxyuris* Schmarda | - | - | - | + |
| *Euglena proxima* P.A.Dangeard | + | - | - | - |
| *Euglena viridis* (O.F.Müller) Ehrenberg | - | - | - | + |
| *Fragilaria capucina* Desmazières | - | + | + | + |
| *Fragilaria dilatata* (Brébisson) Lange-Bertalot | - | - | - | + |
| *Fragilaria parasitica* (W.Smith) Grunow | - | - | - | + |
| *Fragilaria ulna* var. *acus* (Kützing) L-Bertalot | + | + | - | + |
| *Geminella ordinata* (West & G.S.West) Heering | - | - | - | + |
| *Gomphonema angustum* C.Agardh | - | + | - | - |
| *Gomphonema minutum* (C.Agardh) C.Agardh | - | - | + | - |
| *Gomphonema parvulum* Kützing | - | + | + | + |
| *Gomphonema pseudoaugur* Lange-Bertalot | - | + | - | - |
| *Melosira lineata* (Dillwyn) C.Agardh | - | - | - | + |
| *Microcystis aeruginosa* (Kützing) Kützing | + | - | + | + |

**Appendix I** Continue

| Species | Su14 | Fa14 | Sp15 | Su15 |
|---|---|---|---|---|
| *Monoraphidium arcuatum* (Korshikov) Hindák | - | - | - | + |
| *Mougeotia boodlei* (West & G.S West) Collins | - | - | - | + |
| *Navicula capitatoradiata* H.Germain | - | - | - | + |
| *Navicula cryptocephala* Kützing | + | + | - | - |
| *Navicula lanceolata* (C.Agardh) Kützing | - | + | - | - |
| *Navicula ordinaria* Hustedt | - | + | - | - |
| *Navicula phyllepta* Kützing | - | - | - | + |
| *Navicula radiosa* Kützing | - | - | + | - |
| *Navicula slesvicensis* Grunow | - | - | - | + |
| *Navicula tripunctata* (O.F.Müller) Bory | - | - | + | - |
| *Nitzschia flexa* Schumann | - | - | - | + |
| *Nitzschia recta* Hantzsch ex Rabenhorst | - | + | - | - |
| *Nitzschia sigma* (Kützing) W.Smith | - | + | - | - |
| *Nostoc linckia* Bornet ex Bornet & Flahault | - | - | - | + |
| *Oocystis parva* West & G.S.West | - | - | - | + |
| *Pandorina morum* (O.F.Müller) Bory | - | - | - | + |
| *Pediastrum duplex* Meyen | - | + | - | - |
| *Pediastrum simplex* Meyen | - | + | - | - |
| *Pediastrum tetras* (Ehrenberg) Ralfs | - | - | - | + |
| *Peridiniopsis cunningtonii* Lemmermann | - | - | - | + |
| *Phacus longicauda* (Ehrenberg) Dujardin | - | - | + | + |
| *Phacus parvulus* G.A.Klebs | - | - | - | + |
| *Pseudanabaena catenata* Lauterborn | - | - | - | + |
| *Scenedesmus communis* E.Hegewald | - | + | + | - |
| *Scenedesmus ellipticus* Corda | - | - | - | + |
| *Snowella lacustris* (Chodat) Komárek & Hindák | - | - | - | + |
| *Staurastrum cingulum* (West & G.S.West) Smith | - | - | - | + |
| *Trachelomonas cervicula* Stokes | - | - | - | + |
| *Trachelomonas pseudofelix* Deflandre | - | - | + | - |
| *Zygnema pectinatum* (Vaucher) C.Agardh | - | - | - | + |

Su14= summer 2014; Fa14=fall 2014; Sp15= spring 2015; Su15= summer 2015; + and - represent occurrence and absence respectively

**Appendix J** List of species found at Geyik reservoir.

| Species | Su14 | Fa14 | Sp15 | Su15 |
|---|---|---|---|---|
| *Clevamphora ovalis* (Kützing) Mereschkowsky | - | - | - | + |
| *Anabaena catenula* Kützing ex Bornet & Flahault | - | - | - | + |
| *Anabaena verrucosa* J.B.Petersen | - | - | + | - |
| *Aphanizomenon issatschenkoi* (U.) P-Lavrenko | - | - | - | + |
| *Aulacoseira granulata* (Ehrenberg) Simonsen | + | + | - | + |
| *Botryococcus braunii* Kützing | - | - | - | + |
| *Calothrix parietina* Thuret ex Bornet & Flahault | - | - | - | + |
| *Ceratium furcoides* (Levander) Langhans | - | - | - | + |
| *Ceratium hirundinella* (O.F.Müller) Dujardin | + | - | - | - |
| *Chlamydomonas globosa* J.W.Snow | - | - | + | + |
| *Chroococcus turgidus* (Kützing) Nägeli | - | - | + | + |
| *Closterium acerosum* Ehrenberg ex Ralfs | - | - | - | + |
| *Cocconeis placentula* Ehrenberg | - | - | + | + |
| *Cocconeis placentula* var. *placentula* Ehrenberg | - | - | + | - |
| *Coelastrum astroideum* De Notaris | - | - | + | + |
| *Cosmarium punctulatum* Brébisson | - | - | - | + |
| *Cryptomonas erosa* Ehrenberg | + | - | - | - |
| *Cryptomonas ovata* Ehrenberg | - | - | + | + |
| *Cyclotella meneghiniana* Kützing | - | + | - | - |
| *Cyclotella ocellata* Pantocsek | - | - | + | + |
| *Cylindrospermum muscicola* K ex B & Flahault | - | - | + | - |
| *Cymbella affinis* Kützing | - | - | - | + |
| *Diatoma vulgaris* Bory | - | - | - | + |
| *Euglena chlamydophora* Mainx | - | - | + | - |
| *Euglena oxyuris* Schmarda | - | - | - | + |
| *Eunotia glacialis* Meister | - | - | - | + |
| *Fragilaria capucina* Desmazières | - | - | + | + |
| *Fragilaria dilatata* (Brébisson) Lange-Bertalot | - | - | + | - |
| *Fragilaria incognita* Reichardt | - | - | - | + |
| *Fragilaria ulna* var. *acus* (Kützing) L-Bertalot | + | - | - | + |
| *Gomphonema parvulum* Kützing | - | - | - | + |
| *Melosira lineata* (Dillwyn) C.Agardh | - | - | + | - |
| *Melosira varians* C.Agardh | - | - | - | + |
| *Microcystis aeruginosa* (Kützing) Kützing | - | + | - | + |
| *Monoraphidium arcuatum* (Korshikov) Hindák | - | - | - | + |
| *Mougeotia boodlei* (West & G.S West) Collins | - | - | - | + |
| *Mougeotia nummuloides* (Hassall) De Toni | - | - | + | - |
| *Navicula capitatoradiata* H.Germain | - | - | - | + |
| *Navicula cryptonella* Lange-Bertalot | + | - | - | - |
| *Navicula lanceolata* (C.Agardh) Kützing | - | - | + | - |
| *Navicula oppugnata* Hustedt | + | - | - | - |
| *Navicula slesvicensis* Grunow in van Heurck | - | - | - | + |

**Appendix J** Continue

| Species | Su14 | Fa14 | Sp15 | Su15 |
|---|---|---|---|---|
| *Navicula trivialis* Lange-Bertalot | + | - | - | - |
| *Navicula veneta* Kützing | - | - | + | - |
| *Nitzschia flexa* Schumann | - | - | - | + |
| *Oscillatoria limosa* C.Agardh ex Gomont | - | - | + | + |
| *Oscillatoria tenuis* C.Agardh ex Gomont | + | + | + | - |
| *Pandorina morum* (O.F.Müller) Bory | + | - | - | - |
| *Pediastrum duplex* Meyen | - | + | - | + |
| *Pediastrum simplex* Meyen | - | + | - | - |
| *Pediastrum tetras* (Ehrenberg) Ralfs | - | - | + | - |
| *Peridiniopsis cunningtonii* Lemmermann | - | - | - | + |
| *Peridinium lomnickii* Woloszynska | + | - | - | - |
| *Peridinium willei* Huitfeldt-Kaas | - | - | - | + |
| *Pseudanabaena catenata* Lauterborn | + | - | + | - |
| *Scenedesmus communis* E.Hegewald | + | - | + | + |
| *Scenedesmus dimorphus* (Turpin) Kützing | - | - | + | - |
| *Scenedesmus obliquus* (Turpin) Kützing | - | - | + | - |
| *Snowella lacustris* (Chodat) K & Hindák | - | - | - | + |
| *Spirogyra dubia* Kützing | + | - | - | - |
| *Spirogyra weberi* Kützing | - | - | - | + |
| *Staurastrum crenulatum* (Nägeli) Delponte | - | - | - | + |
| *Tetraëdron minimum* (A.Braun) Hansgirg | - | + | - | - |
| *Trachelomonas scabra* Playfair | - | - | - | + |

Su14= summer 2014; Fa14=fall 2014; Sp15= spring 2015; Su15= summer 2015; + and - represent occurrence and absence respectively

**Appendix K** List of species found at Çavdır reservoir

| Species | Su14 | Fa14 | Sp15 | Su15 |
|---|---|---|---|---|
| *Amphipleura lindheimeri* Grunow | - | - | + | - |
| *Clevamphora ovalis* (Kützing) Mereschkowsky | - | - | + | + |
| *Aulacoseira granulata* (Ehrenberg) Simonsen | - | - | + | - |
| *Botryococcus braunii* Kützing | - | - | + | + |
| *Ceratium furcoides* (Levander) Langhans | - | - | + | + |
| *Ceratium hirundinella* (O.F.Müller) Dujardin | + | - | + | + |
| *Chlamydomonas globosa* J.W.Snow | - | - | - | + |
| *Chroococcus turgidus* (Kützing) Nägeli | - | - | + | + |
| *Cocconeis placentula* Ehrenberg 1838 | + | - | - | - |
| *Cocconeis placentula* var. *placentula* Ehrenberg | - | - | - | + |
| *Cryptomonas marssonii* Skuja | - | - | + | - |
| *Cryptomonas ovata* Ehrenberg | - | - | + | + |
| *Cryptomonas rostratiformis* Skuja | - | - | + | - |
| *Cyclotella iris* Brun & Héribaud-Joseph | + | + | - | - |
| *Cyclotella ocellata* Pantocsek | - | - | + | + |
| *Cymbella affinis* Kützing | - | - | - | + |
| *Denticula elegans* Kützing | - | - | - | + |
| *Diatoma vulgaris* Bory | - | - | + | - |
| *Dinobryon divergens* O.E.Imhof | - | - | + | - |
| *Eudorina elegans* Ehrenberg | - | - | - | + |
| *Euglena acus* (O.F.Müller) Ehrenberg | - | - | - | + |
| *Eunotia tenella* (Grunow) Hustedt | - | - | - | + |
| *Fragilaria capucina* Desmazières | - | - | + | + |
| *Fragilaria ulna* var. *acus* (Kützing) L-Bertalot | - | + | + | + |
| *Geminella interrupta* Turpin | + | + | - | + |
| *Gomphonema gracile* Ehrenberg | - | - | - | + |
| *Gomphonema mammilla* Ehrenberg | - | - | - | + |
| *Gomphonema parvulum* Kützing | - | - | - | + |
| *Gomphonema truncatum* Ehrenberg | - | - | + | - |
| *Gyrosigma acuminatum* (Kützing) Rabenhorst | - | - | - | + |
| *Gyrosigma attenuatum* (Kützing) Rabenhorst | - | - | + | - |
| *Hantzschia distinctepunctata* Compère | - | - | + | - |
| *Melosira lineata* (Dillwyn) C.Agardh | - | - | + | - |
| *Melosira varians* C.Agardh | - | - | + | - |
| *Merismopedia glauca* (Ehrenberg) Kützing | + | - | - | + |
| *Microcystis aeruginosa* (Kützing) Kützing | - | + | - | - |
| *Microcystis flosaquae* (Wittrock) Kirchner | - | - | - | + |
| *Navicula phyllepta* Kützing | + | - | - | - |
| *Navicula radiosa* Kützing | - | - | + | - |
| *Navicula slesvicensis* Grunow in van Heurck | - | - | - | + |

**Appendix K** Continue

| Species | Su14 | Fa14 | Sp15 | Su15 |
|---|---|---|---|---|
| *Navicula trivialis* Lange-Bertalot | - | - | + | - |
| *Nitzschia flexa* Schumann | - | - | + | - |
| *Nitzschia solita* Hustedt | - | - | + | - |
| *Oscillatoria limosa* C.Agardh ex Gomont | - | - | - | + |
| *Pandorina morum* (O.F.Müller) Bory | - | - | - | + |
| *Pediastrum simplex* Meyen | - | + | - | - |
| *Peridinium willei* Huitfeldt-Kaas | - | - | - | + |
| *Phacus longicauda* (Ehrenberg) Dujardin | - | - | - | + |
| *Pseudanabaena catenata* Lauterborn | - | - | + | - |
| *Scenedesmus communis* E.Hegewald | + | - | + | + |
| *Spirogyra elongata* (Vaucher) Kützing | - | - | - | + |
| *Trachelomonas scabra* Playfair | - | - | - | + |
| *Trachelomonas zorensis* Deflandre | - | - | + | - |
| *Zygnema pectinatum* (Vaucher) Agardh | - | - | - | + |

Su14= summer 2014; Fa14=fall 2014; Sp15= spring 2015; Su15= summer 2015; + and - represent occurrence and absence respectively

**Appendix L** List of species found at Toptaş reservoir

| Species | Su14 | Fa14 | Sp15 | Su15 |
|---|---|---|---|---|
| *Botryococcus braunii* Kützing | - | - | - | + |
| *Clevamphora ovalis* (Kützing) Mereschkowsky | + | + | + | + |
| *Ceratium furcoides* (Levander) Langhans | - | - | - | + |
| *Chlamydomonas debaryana* Goroschankin | - | - | - | + |
| *Cocconeis placentula* Ehrenberg | - | + | + | + |
| *Coelastrum microporum* Nägeli in A.Braun | - | - | - | + |
| *Cryptomonas marssonii* Skuja | - | - | + | - |
| *Cryptomonas ovata* Ehrenberg | + | + | + | + |
| *Cryptomonas rostratiformis* Skuja | - | - | + | - |
| *Cyclotella ocellata* Pantocsek | - | + | + | + |
| *Cymatopleura solea* (Brébisson) W.Smith | - | - | + | - |
| *Cymbella affinis* Kützing | - | + | - | + |
| *Cymbella amphicephala* Näegeli in Kützing | + | - | - | - |
| *Cymbella naviculiformis* (A ex Heiberg) Cleve | - | - | - | + |
| *Denticula elegans* Kützing | - | - | - | + |
| *Diatoma vulgaris* Bory | - | + | - | - |
| *Euglena chlamydophora* Mainx | - | - | - | + |
| *Euglena oblonga* F.Schmitz | - | - | - | + |
| *Euglena oxyuris* Schmarda | - | + | + | - |
| *Euglena proxima* P.A.Dangeard | + | - | - | - |
| *Eunotia glacialis* Meister | - | - | - | + |
| *Eunotia tenella* (Grunow) Hustedt | - | - | - | + |
| *Fragilaria capucina* Desmazières | - | - | + | + |
| *Fragilaria dilatata* (Brébisson) L-Bertalot | - | - | + | + |
| *Fragilaria ulna* (Kützing) L-Bertalot | + | - | - | - |
| *Gomphonema parvulum* Kützing | - | + | + | - |
| *Gyrosigma attenuatum* (Kützing) Rabenhorst | - | - | + | - |
| *Microcystis aeruginosa* (Kützing) Kützing | + | + | - | - |
| *Navicula capitatoradiata* H.Germain | - | - | - | + |
| *Navicula cryptonella* Lange-Bertalot | - | - | - | + |
| *Navicula expecta* S.L.VanLandingham | - | - | + | - |
| *Navicula lanceolata* (C.Agardh) Kützing | - | + | - | - |
| *Navicula pupula* Kützing | - | - | - | + |
| *Navicula slesvicensis* Grunow | - | - | - | + |
| *Navicula veneta* Kützing | - | - | + | - |
| *Nitzschia calida* Grunow | + | - | - | - |
| *Nitzschia flexa* Schumann | - | - | - | + |
| *Oscillatoria cortiana* Meneghini ex Gomont | - | - | - | + |
| *Pediastrum boryanum* (Turpin) Meneghini | - | - | - | + |
| *Pediastrum duplex* Meyen | - | + | - | + |
| *Pediastrum simplex* Meyen | + | + | + | + |
| *Peridinium cinctum* (O.F.Müller) Ehrenberg | + | - | - | + |

**Appendix L** Continue

| Species | Su14 | Fa14 | Sp15 | Su15 |
|---|---|---|---|---|
| *Phacus longicauda* (Ehrenberg) Dujardin | - | - | - | + |
| *Pseudanabaena catenata* Lauterborn | - | - | - | + |
| *Scenedesmus communis* E.Hegewald | - | - | + | - |
| *Scenedesmus dimorphus* (Turpin) Kützing | - | - | + | - |
| *Scenedesmus ellipticus* Corda | - | - | - | + |
| *Staurastrum chaetoceras* (Schröder).Smith | - | + | - | - |
| *Staurastrum cingulum* (West & West) Smith | - | - | - | + |
| *Stauroneis nobilis* Schumann | - | - | + | - |
| *Trachelomonas cervicula* Stokes | - | - | - | + |
| *Trachelomonas pseudofelix* Deflandre | - | - | + | - |

Su14= summer 2014; Fa14=fall 2014; Sp15= spring 2015; Su15= summer 2015; + and - represent occurrence and absence respectively

**Appendix M** List of species found at Yapraklı reservoir

| Species | Su14 | Fa14 | Sp15 | Su15 |
|---|---|---|---|---|
| *Aulacoseira granulata* (Ehrenberg) Simonsen | + | - | - | - |
| *Botryococcus braunii* Kützing 1849 | - | - | - | + |
| *Botryosphaerella sudetica* (Lemmermann) Silva | - | + | - | - |
| *Clevamphora ovalis* (Kützing) Mereschkowsky | - | - | - | + |
| *Ceratium hirundinella* (O.F.Müller) Dujardin | - | + | - | - |
| *Chroococcopsis chroococcoides* (Fritsch) K & A | - | + | - | - |
| *Chroococcus turgidus* (Kützing) Nägeli | - | + | - | + |
| *Closterium aciculare* T.West | - | + | - | - |
| *Closterium dianae* Ehrenberg ex Ralfs | - | + | - | - |
| *Cocconeis placentula* Ehrenberg | - | + | + | + |
| *Cryptomonas marssonii* Skuja | - | - | + | - |
| *Cryptomonas ovata* Ehrenberg | + | + | + | + |
| *Cyclotella cyclopuncta* Håkansson &Carter | - | + | + | - |
| *Cyclotella fottii* Hustedt in Huber-Pestalozzi | - | - | - | + |
| *Cyclotella iris* Brun & Héribaud-Joseph | + | - | - | - |
| *Cyclotella ocellata* Pantocsek | - | + | + | + |
| *Cymatopleura solea* (Brébisson) W.Smith | - | - | - | + |
| *Cymbella affinis* Kützing | - | - | - | + |
| *Cymbella aspera* (Ehrenberg) Cleve | - | - | - | + |
| *Cymbella gracilis* (Rabenhorst) Cleve | - | - | - | + |
| *Cymbella tumida* (Brébisson) van Heurck | - | - | + | - |
| *Diatoma tenuis* C.Agardh | - | - | - | + |
| *Diatoma vulgaris* Bory | - | - | - | + |
| *Dinobryon divergens* O.E.Imhof | - | - | - | + |
| *Euglena oxyuris* Schmarda | - | + | - | - |
| *Eunotia tenella* (Grunow) Hustedt | - | - | - | + |
| *Fragilaria capucina* Desmazières | - | + | - | + |
| *Fragilaria leptostauron* (Ehrenberg) Hustedt | - | - | - | + |
| *Fragilaria ulna* var. *acus* (Kützing) L-Bertalot | + | - | + | + |
| *Geminella interrupta* Turpin | - | - | - | + |
| *Gomphonema gracile* Ehrenberg | - | - | - | + |
| *Gomphonema parvulum* Kützing | - | - | + | + |
| *Gomphonema truncatum* Ehrenberg | + | - | - | - |
| *Merismopedia glauca* (Ehrenberg) Kützing | + | - | - | + |
| *Microcystis flosaquae* (Wittrock) Kirchner | - | - | - | + |
| *Monoraphidium arcuatum* (Korshikov) Hindák | - | - | - | + |
| *Mougeotia boodlei* (West & G.S West) Collins | - | - | - | + |
| *Mougeotia parvula* Hassall | - | - | - | + |
| *Navicula cryptocephala* Kützing | + | - | - | - |
| *Navicula halophila* (Grunow) Cleve | - | + | - | - |
| *Navicula lanceolata* (C.Agardh) Kützing | - | + | - | + |
| *Navicula radians* Héribaud-Joseph | - | - | - | + |

**Appendix M** Continue

| Species | Su14 | Fa14 | Sp15 | Su15 |
|---|---|---|---|---|
| *Navicula radiosa* Kützing | - | - | + | - |
| *Navicula slesvicensis* Grunow | - | - | - | + |
| *Navicula tripunctata* (O.F.Müller) Bory | - | - | - | + |
| *Oocystis borgei* J.W.Snow | + | - | - | - |
| *Pediastrum boryanum* (Turpin) Meneghini | - | - | - | + |
| *Pediastrum duplex* Meyen | - | + | - | + |
| *Pediastrum simplex* Meyen | - | + | - | - |
| *Peridiniopsis cunningtonii* Lemmermann | - | - | + | + |
| *Peridinium cinctum* (O.F.Müller) Ehrenberg | + | - | - | - |
| *Peridinium willei* Huitfeldt-Kaas | - | - | - | + |
| *Pseudanabaena catenata* Lauterborn | - | - | - | + |
| *Rhopalodia gibba* (Ehrenberg) Otto Müller | - | - | - | + |
| *Scenedesmus communis* E.Hegewald | - | + | - | + |
| *Scenedesmus dimorphus* (Turpin) Kützing | - | - | - | + |
| *Scenedesmus ellipticus* Corda | + | - | - | - |
| *Staurastrum cingulum* (West & G.S.West) Smith | - | - | - | + |
| *Staurastrum crenulatum* (Nägeli) Delponte | - | + | - | - |
| *Stephanodiscus rotula* (Kützing) Hendey | - | - | + | - |
| *Tetraëdron minimum* (A.Braun) Hansgirg | + | - | - | - |
| *Trachelomonas hispida* (Perty) F.Stein | - | - | - | + |

Su14= summer 2014; Fa14=fall 2014; Sp15= spring 2015; Su15= summer 2015; + and - represent occurrence and absence respectively

**Appendix N** List of species found at Osmankalfalar reservoir

| Species | Su14 | Fa14 | Sp15 | Su15 |
|---|---|---|---|---|
| *Achnanthes impexa* Lange-Bertalot | - | - | - | - |
| *Aulacoseira granulata* (Ehrenberg) Simonsen | - | - | - | + |
| *Botryococcus braunii* Kützing | - | - | + | + |
| *Ceratium furcoides* (Levander) Langhans | - | - | - | + |
| *Ceratium hirundinella* (O.F.Müller) Dujardin | - | - | - | + |
| *Chlamydomonas crassa* H.R.Christen | - | - | - | + |
| *Cocconeis placentula* Ehrenberg | - | - | + | + |
| *Coelastrum microporum* Nägeli in A.Braun | + | - | - | - |
| *Cyclotella iris* Brun & Héribaud-Joseph | - | + | - | + |
| *Cyclotella krammeri* Håkansson | - | - | + | - |
| *Cyclotella ocellata* Pantocsek | + | - | + | + |
| *Cyclotella radiosa* (Grunow) Lemmermann | - | - | - | + |
| *Cymbella affinis* Kützing | + | - | - | + |
| *Cymbella minuta* Hilse in Rabenhorst | - | + | - | - |
| *Diatoma vulgaris* Bory | - | - | - | + |
| *Dinobryon divergens* O.E.Imhof | - | + | - | - |
| *Eudorina elegans* Ehrenberg | - | - | - | + |
| *Euglena acus* (O.F.Müller) Ehrenberg | + | - | - | - |
| *Euglena chlamydophora* Mainx | - | - | + | + |
| *Euglena oxyuris* Schmarda 1846 | - | - | - | + |
| *Euglena viridis* (O.F.Müller) Ehrenberg | - | + | - | - |
| *Ulnaria biceps* (Kützing) Compère | - | - | + | - |
| *Fragilaria capucina* Desmazières | - | - | - | + |
| *Fragilaria dilatata* (Brébisson) L-Bertalot | - | - | + | - |
| *Fragilaria parasitica* (W.Smith) Grunow | - | - | - | + |
| *Geminella interrupta* Turpin | - | - | - | + |
| *Gomphonema parvulum* Kützing | - | - | - | + |
| *Microcystis aeruginosa* (Kützing) Kützing | + | - | + | - |
| *Navicula angusta* Grunow | - | - | - | + |
| *Navicula cari* Ehrenberg | - | - | + | - |
| *Navicula cryptocephala* Kützing | + | + | - | - |
| *Navicula expecta* S.L.VanLandingham | - | - | - | + |
| *Navicula phyllepta* Kützing | - | - | - | + |
| *Navicula porifera* Hustedt | - | - | + | - |
| *Navicula veneta* Kützing | - | - | - | + |
| *Peridiniopsis cunningtonii* Lemmermann | - | - | + | + |
| *Phacus caudatus* Hübner | + | - | - | + |
| *Pseudanabaena catenata* Lauterborn | - | - | - | + |
| *Scenedesmus communis* E.Hegewald | + | + | - | + |
| *Scenedesmus dimorphus* (Turpin) Kützing | + | - | + | - |
| *Scenedesmus ellipticus* Corda | - | + | - | - |
| *Scenedesmus falcatus* Chodat | - | - | + | - |

**Appendix N** Continue

| Species | Su14 | Fa14 | Sp15 | Su15 |
|---|---|---|---|---|
| *Tetraëdron minimum* (A.Braun) Hansgirg | - | + | - | - |
| *Trachelomonas hispida* (Perty) F.Stein | - | - | - | + |
| *Trachelomonas pseudofelix* Deflandre | - | - | + | - |

Su14= summer 2014; Fa14=fall 2014; Sp15= spring 2015; Su15= summer 2015; + and - represent occurrence and absence respectively

**Appendix O** List of species found at Lake Yazır

| Species | Su14 | Fa14 | Sp15 | Su15 |
|---|---|---|---|---|
| *Botryococcus braunii* Kützing | - | - | + | + |
| *Chlamydomonas lapponica* Skuja | + | - | - | - |
| *Closterium moniliferum* E. ex Ralfs | - | - | - | + |
| *Cocconeis placentula* Ehrenberg | - | - | + | + |
| *Cocconeis placentula* var. *placentula* | - | - | - | + |
| *Cryptomonas marssonii* Skuja | - | - | + | - |
| *Cryptomonas ovata* Ehrenberg | + | - | + | + |
| *Cyclotella iris* Brun & Héribaud-Joseph | + | - | - | - |
| *Cyclotella ocellata* Pantocsek | - | - | + | + |
| *Cymatopleura solea* (Brébisson) W.Smith | - | - | + | - |
| *Cymbella affinis* Kützing | - | + | - | + |
| *Cymbella cistula* (Ehrenberg) O.Kirchner | - | - | - | + |
| *Cymbella cymbiformis* C.Agardh | - | - | - | + |
| *Cymbella elliptica* Prudent | - | - | - | - |
| *Cymbella gracilis* (Rabenhorst) Cleve | - | + | - | - |
| *Denticula elegans* Kützing | - | - | + | + |
| *Dinobryon divergens* O.E.Imhof | - | - | + | - |
| *Epithemia sorex* Kützing | - | - | - | + |
| *Epithemia turgida* (Ehrenberg) Brun | - | - | - | + |
| *Eudorina elegans* Ehrenberg | - | - | + | - |
| *Euglena chlamydophora* Mainx | - | - | + | - |
| *Euglena oxyuris* Schmarda | - | - | - | + |
| *Fragilaria capucina* Desmazières | - | - | + | + |
| *Fragilaria crotonensis* Kitton | - | - | - | - |
| *Fragilaria dilatata* (Brébisson) Lange-Bertalot | - | - | + | + |
| *Fragilaria ulna* var. *acus* (Kützing) L-Bertalot | + | + | + | + |
| *Geminella interrupta* Turpin | - | - | + | - |
| *Gomphonema angustatum* (Kützing) Rabenhorst | - | - | + | - |
| *Gomphonema gracile* Ehrenberg | - | - | - | + |
| *Gomphonema parvulum* Kützing | - | - | + | + |
| *Gomphonema truncatum* Ehrenberg | - | - | - | + |
| *Microcystis aeruginosa* (Kützing) Kützing | - | - | + | - |
| *Monoraphidium arcuatum* (Korshikov) Hindák | - | - | - | + |
| *Navicula bryophila* J.B.Petersen | - | + | - | - |
| *Navicula cryptocephala* Kützing | + | - | - | - |
| *Navicula gregaria* Donkin | - | - | - | + |
| *Navicula lanceolata* (Agardh) Kützing | - | - | + | + |
| *Navicula pseudomutica* Hustedt | - | + | - | - |
| *Navicula radiosa* Kützing | + | - | + | - |
| *Nitzschia flexa* Schumann | - | - | - | + |

**Appendix O** Continue

| Species | Su14 | Fa14 | Sp15 | Su15 |
|---|---|---|---|---|
| *Oscillatoria limosa* Agardh ex Gomont | - | - | - | + |
| *Oscillatoria tenuis* Agardh ex Gomont | - | - | - | + |
| *Pandorina morum (O.F.Müller) Bory* | - | - | + | - |
| *Pediastrum boryanum* (Turpin) Meneghini | - | - | - | - |
| *Pediastrum duplex* Meyen | - | - | - | - |
| *Pediastrum integrum* Nägeli | - | - | - | - |
| *Pediastrum simplex* Meyen | - | - | - | - |
| *Pediastrum tetras* (Ehrenberg) Ralfs | - | - | - | - |
| *Peridiniopsis cunningtonii* Lemmermann | - | - | + | - |
| *Peridinium cinctum* (O.F.Müller) Ehrenberg | + | - | - | + |
| *Peridinium lomnickii* Woloszynska | - | - | - | - |
| *Peridinium willei* Huitfeldt-Kaas | - | - | + | - |
| *Pleurosigma angulatum* (Queckett).Smith | - | - | - | + |
| *Pseudanabaena catenata* Lauterborn | + | - | + | - |
| *Rhopalodia gibba* (Ehrenberg) Otto Müller | - | - | - | + |
| *Scenedesmus abundans* (O.Kirchner) Chodat | - | - | + | - |
| *Scenedesmus communis* E.Hegewald | - | - | + | - |
| *Scenedesmus dimorphus* (Turpin) Kützing | - | - | + | - |
| *Scenedesmus falcatus* Chodat | - | - | + | + |
| *Scenedesmus obliquus* (Turpin) Kützing | - | - | + | - |
| *Staurastrum cingulum* (West & West) Smith | - | - | + | - |
| *Trachelomonas pseudofelix* Deflandre | - | - | + | - |

Su14= summer 2014; Fa14=fall 2014; Sp15= spring 2015; Su15= summer 2015; + and - represent occurrence and absence respectively

**Appendix P** PTI, Med-PTI and Q index classes and boundaries

| **PTI based EQR class boundaries (Philips et al., 2013)** | | | | |
|---|---|---|---|---|
| Class limit | high – good | good – moderate | moderate – poor | poor – bad |
| EQR | 0.89 | 0.70 | 0.45 | 0.23 |

| **Med-PTI class boundaries and EQRs (Marchetto et al., 2009)** | | | | |
|---|---|---|---|---|
| Class limit | high – good | good – moderate | moderate – poor | poor – bad |
| Med-PTI | 2.77 | 2.45 | 2.13 | 1.81 |
| EQR | 0.89 | 0.79 | 0.69 | 0.59 |

| **Ecological status and Q index boundaries (Padisák et al., 2006)** | | | | | |
|---|---|---|---|---|---|
| Status | Poor | Tolerable | Medium | Good | Excellent. |
| Q index | 0–1 | 1–2 | 2–3 | 3–4 | 4–5 |

## CURRICULUM VITAE

### PERSONAL INFORMATION


| | |
|---|---|
| Name and Surname | : Assane Anabi TOUDJANI |
| Natioality | : Niger |
| Birth place and date | : Niger, 28/02/1982 |
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### EDUCATION

| | Graduate school | Year |
|---|---|---|
| Master | University of Maradi (Niger) | 2013 |
| Bachelor | University of Niamey (Niger) | 2011 |
| High School | CES Rive droite (Niamey/Niger) | 2005 |

### Work experience

| Year | Place | Enrollment |
|---|---|---|
| 2014-2016 | Turkey. Project (188.02.01) | Scholar-Research Assist. |
| 2012-2013 | Niger. High School Fogasso Maradi | Lecturer |
| 2012-2013 | Niger. High School Annur Maradi | Lecturer |
| 2011-2013 | Niger. University of Maradi | National service (Assistant) |
| 2011-2013 | Niger. High School LDB Maradi | Lecturer |

## PUBLICATIONS

**Toudjani, A. A.,** Issiaka, Y., Moustapha, A. M. (2013). Typologie de l’avifaune des zones humides de Madarounfa, région de Maradi (Niger). *Journal des Sciences de l’Environnement*, **2**, 1-9.

**Toudjani, A. A.**, Çelekli, A., Gümüş, E. Y., Kayhan, S., Lekesiz, H. Ö., Çetin, T. (2017). A new diatom index to assess ecological quality of running waters: a case study of water bodies in western Anatolia. *Annalles de Limnologie. - International Journal of Limnology*, **53**, 333–343.

**Toudjani, A. A.**, Çelekli, A., Gümüş, E. Y., Kayhan, S., Lekesiz, H. Ö., Çetin, T. (2018). Assessment of ecological status using phytoplankton indices and multivariate analyses in the West Mediterranean basin. *Fundamental and Applied Limnology*, https://doi.org/10.1127/fal/2018/1092.

Çelekli A, **Toudjani, A A**, Gümüş, E. Y, Kayhan S, Lekesiz H. Ö and Çetin T (2018). Determination of trophic weight and indicator values of diatoms in Turkish running waters for water quality assessment, *Turkish Journal of Botany,* doi:10.3906/bot-1704-40.

Çelekli, A., **Toudjani, A. A.**, Kayhan, S., Lekesiz, H. Ö., Çetin, T. (2018). Bioassessment of Ecological Status of Three Aegean Reservoirs Based on Phytoplankton Metrics. *Turkish Journal of Water Science and Management*, **2**, 76-99.

## FOREIGN LANGUAGES

- French : both writing and oral ;
- English : both writing and oral ;
- Turkish : both writing and oral ;
- Arabic: Writing and reading;

## HOBBIES

- Hobby 1: Sport ;
- Hobby 2: reading.