COMPARING ECOLOGICAL STRUCTURE OF TURKISH SHALLOW LAKES BETWEEN THE SEASONS, AND WET & DRY YEARS

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ABSTRACT

COMPARING ECOLOGICAL STRUCTURE OF TURKISH SHALLOW LAKES BETWEEN THE SEASONS, AND WET & DRY YEARS

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Due to global climate change, lakes in Mediterranean climate face the problem of reduced precipitation and enhanced evaporation along with increased water abstraction for irrigation that are largely causing changes in water level, salinity and nutrient dynamics. In this study 22 Turkish shallow lakes were investigated in the Mediterranean climate zone. All lakes were sampled with a well-established snapshot sampling protocol. There are 19 lakes, which were sampled once during both spring and summer seasons within the same year and 9 lakes that were sampled once during both drought and wet years. Also, data of 1997 - 2012 period from Lake Eymir and Mogan were used to investigate the effects of drought in a longer term period.

Environmental data were tested for normality and variables that do not follow normal distribution were transformed. Principal Component Analysis (PCA) was applied to the environmental data, including surface water temperature, salinity, pH, mean air temperature, Secchi depth, alkalinity, total phosphorus, total nitrogen, net evaporation, net precipitation and chlorophyll a (spring – summer) and without total nitrogen (Lake Eymir - Mogan) and additionally number of fish and total zooplankton biomass (for wet – dry years).

Lakes sampled during spring seasons were associated with high Secchi and maximum depth, dissolved oxygen and precipitation. So, in spring seasons lakes can be characterized as in a clear water state, whereas lakes sampled in summer seasons were identified with high chlorophyll a, total nitrogen and total phosphorous concentration and salinity. Thus, lakes sampled during summer seasons could be considered as eutrophic. Furthermore, lakes sampled in drought years show increased salinity and nutrient concentrations. According to Procrustes analyses of lakes sampled in drought and wet years, the southern lakes displayed small environmental variable differences except Lake Gölcük Ödemiş, and Lake Saka, Poyrazlar and Hamam which were all northern lakes in our dataset of lakes sampled in wet and dry years. Also, Lake Gölcük Ödemiş displayed a low degree of similarity. In northern lakes, Secchi depth and precipitation decrease higher than in southern lakes and total phosphorus and number per unit effort of fish increase due to the effect of eutrophication. On the other hand, in Lake Eymir and Mogan, the internal loading of nutrients and salinity change were explained by high evaporation and increase of water residence time in drought years. Since climate change enhances the drought events and frequency in the Mediterranean climate zone, our results suggest that shallow lakes will turn to eutrophic condition in the future like in drought periods.

Keywords: precipitation, seasonality, PCA, drought, eutrophication

ÖZ

TÜRKİYE SIĞ GÖLLERİNİN EKOLOJİK YAPILARININ MEVSİMSEL VE KURAK – ISLAK YILLAR BAKIMINDAN KARŞILAŞTIRILMASI

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Küresel iklim değişikliğiyle, Akdeniz iklim kuşağındaki göller, yağış miktarındaki azalma, buharlaşmadaki artış ve sulama için su kullanımının artması ile su seviyesinde, tuzlulukta ve besin tuzu dinamiğinde büyük değişimlere neden olan sorunlar ile karşı karşıya kalmaktadır. 2006 ve 2012 yılları arasında, Türkiye de Akdeniz iklim kuşağında bulunan 53 adet sığ göl araştırılmıştır. Tüm göller birçok araştırmalarda kullanılan, anlık örnekleme protokolü ile örneklenmiştir. Bu çalışmada, aynı yılın bahar ve yaz dönemlerinde bir defa örneklenmiş 19 göl ve kurak ve ıslak yıllarda bir kez örneklenmiş 9 adet göl yer almaktadır. Ayrıca 1997 ile 2012 yılları arasında Eymir ve Mogan Gölü'nün uzun dönemli verileri kuraklığın göller üzerindeki etkilerini araştırmak için kullanılmıştır.

Çevresel değişkenlere normal dağılma testi uygulanmış, normal dağılım göstermeyen değişkenler dönüştürülmüştür. Çevresel değişkenlere Temel Bileşenler Analizi (PCA) uygulanmıştır ve bu değişkenlerden, yüzey su sıcaklığı, tuzluluk, pH, ortalama hava sıcaklığı, Secchi derinliği, alkalinite, toplam fosfor, toplam azot, net buharlaşma net yağış miktarı ve klorofil-a (ilkbahar – yaz örnekleri için) toplam nitrojen olmadan

(Eymir – Mogan Gölü için) ayrıca ağ başına düşen balık miktarı ve toplam zooplankton biyokütlesi de (ıslak – kurak yıllar için) kullanılmıştır.

Bahar sezonunda örneklenen göller yüksek Secchi derinliği, maksimum derinlik, çözünmüş oksijen ve yağış miktarı ile ilişkili olup, bundan dolayı bu göller berrak su durumunda yer almakta, oysa yaz sezonunda göller yüksek klorofil a, toplam azot ve toplam fosfor konsantrasyonu ve tuzluluk ile ötrofik göl olarak yapılanmaktadır. Üstelik kurak yıllarda örneklenen göllerde tuzluluk ve besin tuzları artışı görülmekte ve kuzey göllerinde yağış miktarındaki değişimlerden dolayı yüksek çevresel değişimler görülmektedir. Kurak ve ıslak yıllardaki göller Procrustes analizi ile incelendiğinde, güney gölleri birbirleriyle uyum göstermiş ancak kuzey gölleri Saka, Hamam ve Poyrazlar Gölü ve Gölcük Ödemiş Gölü az derecede benzerlik göstermişlerdir. Kuzey göllerinde Secchi derinliği ve yağış miktarında azalma ile ötrofikasyonun etkisi nedeniyle toplam fosfor ve ağ başına düşen balık miktarında artış gibi değişimler gözlemlenmiştir. Ayrıca, Eymir ve Mogan Gölleri için yapılan analizlerde, göl içi besin tuzunun yükselmesi ve tuzluluktaki artış, kurak yıllardaki yüksek miktardaki buharlaşma ve su yenilenme süresinin artışı ile açıklanabilir. İklim değişikliği Akdeniz iklim kuşağında kuraklık olaylarının görülmesini ve sıklığını artırmaktadır ve eğer koruma önlemleri alınmaz ise sonuç olarak göller kuraklık dönemlerinde olduğu gibi gelecekte de iklim değişikliği ile ötrofik hale dönüş göstereceklerdir.

Anahtar Kelimeler: yağış, mevsimsellik, , PCA, , kuraklık, ötrofikasyon

To My Parents and My Lovely Niece

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PCA	Principal Component Analysis
GLM	Generalized Linearized Model
SD	Secchi Depth
Prec	Precipitation
Mdepth	Maximum Depth
DO	Dissolved Oxygen
S	Salinity
AirT	Air Temperature
WaterT	Surface Water Temperature
Evap	Evaporation
Chla	Chlorophyll a
Alk	Alkalinity
Zoo	Number of Zooplankton
Npue	Number per unit effort of fish
TP	Total Phosphorous
TN	Total Nitrogen

CHAPTER 1

INTRODUCTION

1.1 Freshwaters and Shallow Lakes

Water does not only play an important role for human beings but also for all living things in the world. Although 70% of our planet is covered with water, freshwater is a limited resource and only makes up 3% of the water of the Earth. However, much of this freshwater is in the ice caps, glaciers and ground water. The remainder is in lakes, streams and soil moisture, and an estimated 68% of the fresh liquid surface water is in 189 large lakes with surface areas greater than 500 km^2 (Reid et al., 1998).

The lakes on the global scale play an important role in the global water cycle although they are considered a small component of the biosphere (Downing et al., 2006). However, they compose land surface heterogeneity and influence the water and energy exchange between land and atmosphere (Adams et al., 2000). Additionally, lakes play active role in climate systems through the carbon cycle. Thus, they are sensitive to change of water cycle driven by climate variability and changes in hydrologic conditions such as drought and floods, are critical for lakes (Sobek et al., 2003).

Shallow lakes numerically constitute a large part of the world’s lakes (Moss, 2012). They are very important for food supply and recreation and as well as providing richness for natural habitat. In shallow lakes, littoral zones where submerged and floating leaved plants are living is more productive (per unit of surface area) than deep lakes. Moreover, biodiversity is much higher in shallow lakes. In our country, nearly

200 small and large lakes are located in 26 big river basin (Kazancı et al., 1995). However, increasing anthropogenic activity, arid and semi-arid Mediterranean climate causes disappearance of some of these lakes and/or change in the ecological structure of the lakes (Beklioğlu et al., 2007).

In many lakes, temporal and spatial changes in the physical and chemical parameters are common in response to surface water runoff, direct precipitation, ground water recharge, rate of evaporation and human interference. These changes have impacts on structure and function of the ecosystems (Kemdirim, 2005). The maintenance of water quality standards in lakes and reservoirs is necessary in order to avoid problems affecting aquatic biota and humans.

1.2 Drought Types and Effects

The origin of drought is a reduced precipitation over an extended period, usually one season or more. Drought is a normal, recurrent feature of climate, although often erroneously considered an unexpected and extraordinary event. Increasing world population, urbanization, climate change, forest destruction and desertification lead to drought and it threatens society and natural habitats of the countries. The effects of drought increased in the world in the last decade, however its effects are not yet sufficiently well understood (Sen, 1998).

As a consequence of climate change, rising temperatures and decreasing precipitation, frequency and severity of drought events increased in many parts of the world (IPCC, 2014) especially in Mediterranean climatic regions. Drought is a natural hazard that differs from other events in that it has a slow onset, and typically causes substantial economic, environmental, and social impacts in large regions or entire countries (WWF Report, 2006), (Figure 1.1). There are two main causes of drought in the Mediterranean region. First one is natural that drought and wet periods oscillate naturally maybe in a decadal fashion. Since most inland water resources are sustained by precipitation, a temporal decrease in precipitation generally is the major initial cause of the drought. Studies show that a meteorological drought has never been the result of a single cause, however it is the result of many synergetic causes. In addition to precipitation, there are other factors that play a role in the development and characterization of drought are temperature and humidity, evapotranspiration, wind velocity and pressure, geography of the region and vegetation (Yevjevich, 1967). All of these factors determine the efficiency of precipitation and the severity of drought. The anthropogenic cause of the drought is man-made aggravations through the actions contributing to climate change, the current policies of water, agriculture and energy, securing the water supply and actual water consumption. Droughts may develop from cumulative effects from year to year, depending on the precipitation, water demand and consumption (Clark, 2012).

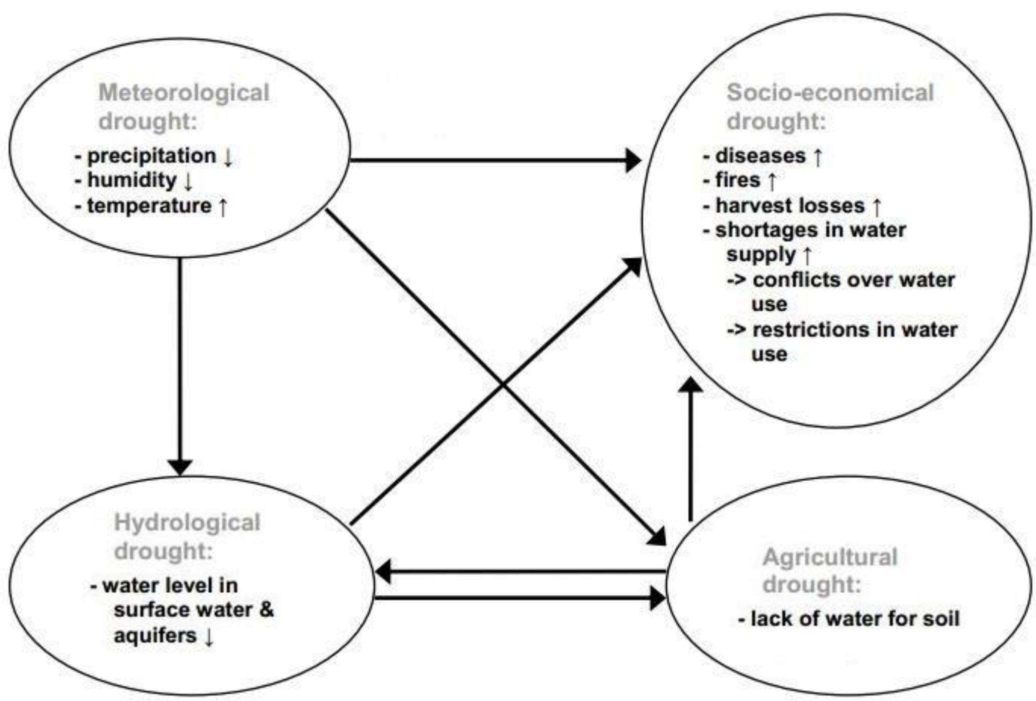

Figure 1.1 The various types of drought and their relations (taken from WWF Report, 2006)

There are several types of that include meteorological, agricultural, hydrological and socioeconomical droughts. Meteorological drought is defined on comparison to normal or average amount of precipitation or the degree of dryness, and the duration of the dry period. Moreover, meteorological drought trigger other type of droughts (Van Loon and Laaha, 2014). Such as agricultural drought links various characteristics of meteorological drought to agricultural impacts, focusing on precipitation shortages, differences between actual and potential evaporation and transpiration, soil water deficits, reduced groundwater or reservoir levels. After the meteorological drought, agricultural drought occurs. Plant water demand depends on prevailing weather conditions, biological characteristics of the specific plant, the stage of growth, and the physical and biological properties of the soil. Agricultural drought is primarily effective in the economic sector (Wang, 2005).

Whereas hydrological drought refers to a persistently low discharge and volume of water in streams and reservoirs, lasting months or years. The lack of precipitation occurred in a long time with a reduction in surface and ground water resources. Then, hydrological drought will occur. Hydrological drought is a natural phenomenon, but it may be exacerbated by human activities. Hydrological droughts are usually related to meteorological droughts. Changes in land use and land degradation can further effect the magnitude and frequency of hydrological droughts.

Lastly all these droughts have socioeconomic consequences that refer to socioeconomical drought, which is associated with changes in the supply and demand of some economic goods with elements of meteorological, hydrological, and agricultural drought. It differs from the other types of drought in that its occurrence is influenced by human activities. Socioeconomic drought occurs with the start of the water shortages affecting human being when the demand for an economic good such as water, forage, food grains, fish or hydroelectric power causing social and economic impacts (Wilhite, 1996).

1.2.1 Effects of Drought on Lakes Ecosystems Including Water and Nutrient Budgets and Ecology

Drought primarily has an impact on the water budget of lakes then consequently impact the nutrient availability or nutrient budgets. High altitude lakes proportionally receive more input from precipitation and thus may be not severely impacted by the drought; whereas lakes at lower altitudes and that proportionally receive more groundwater may be responsible for drought. However, drought impacts the overall hydrologic cycle (Coops et al., 2003). Therefore, drought conditions increase periods of low flow duration, so lakes water level drops, hydrological retention time or the flushing rate prolongs dramatically or lakes completely dry. Such conditions enhance the internal release of nutrients from the sediments of especially in the eutrophic lakes (Özen et al., 2010). Moreover, combination of high temperature and evaporation lead to nutrient enrichment and salinity increase at low water level (Beklioğlu et al., 2007).

Changes in availability of nutrients are firstly through increased water retention time and evapotranspiration causing nutrients and cations remain longer in the water column and can become eventually more up-concentrated. Secondly, decreased groundwater causes decrease in nutrient concentration with transferring with ground water because of less dissolved cations inputs (Allen and Ingram, 2002).

Many organisms are impacted by drought. While some are more resilient and capable of immediate stressors, some sessile organisms are less tolerant. Wetland and littoral species often dry out (Lake, 2003). Plants communities may shift from submerged vegetation to emergent plants. Fish can be particularly susceptible depending on the degree of drawdown. The low water levels expose and reduce spawning areas, killing eggs and fry, and consequently reducing reproductive success. There is often a decrease in dissolved oxygen availability, which is compounded by the high water temperature that may lead to fish-kills (Kangur et al., 2005). The early warm spring and the highly variable water budgets have created ripe conditions for algal blooms. Many algae, particularly some cyanobacteria, thrive in high temperatures (Michalak et al., 2013).

1.3 Eutrophication

As a result of rapid and uncontrolled population growth in recent years, need for energy and food and shelter have been increasing inevitable. The last 30 years, increasing urbanization in the waste water discharge, the use of wetlands and increasing agricultural activities have increased the amount of nutrients entering shallow lake in the world (Coops et al., 2003, Beklioğlu et al., 2011). Dramatically change of nutrients of lakes which enter to lakes from catchment with precipitation and point and nonpoint sources leads to increase primary production of phytoplankton and consequently causes a change in the relations of the trophic level (Jeppesen, 1998). Eutrophication is caused by excessive phosphorus and nitrogen nutrient inputs to the lake. Change of land use and agricultural irrigation cause the variation of hydrological flow regime. Also eutrophication results in the lake i) increased phytoplankton biomass, ii) detects an increase in the frequency and intensity of extreme growth, iii) reduce the macrophyte diversity, iv) decrease in biomass, especially oxygen sensitive fish species, v) decrease in species diversity, vi) a decrease in water clarity, vii) decrease in quality of drinking water taste and odor, and viii) cause losses as aesthetic and ecosystem values (Jeppesen et al., 2009, 2010, 2011; Beklioğlu et al., 2011; Dokulil et al., 2011).

Sharp increase of lake primary production is explained by average temperature increase and average light amounts. Combining with increased nutrient inputs and eutrophication cellular activity of phytoplankton is increasing logarithmically. The highest increase is seen between 25 and 40°C (Reynolds, 1984). The amount of cyanobacteria shows increase with rising summer air temperature because cyanobacteria have higher optimum temperature range compare to other algal groups (Jeppesen et al., 2011). Also cyanobacteria blooms need less light energy and storage capacity of the cyanobacteria provides a competitive advantage relative to other algal groups (Dokulil et al., 2011). Cyanobacteria cause unpleasant condition and food source for organisms. With the dominance of cyanobacteria, biodiversity and water clarity decline, and the production of toxins increases. Thus, these changes can cause high primary production and oxygen depletion as a result of the negative effects of mass fish deaths (Scheffer et al., 1997). Moreover, algal bloom rise leads to negative effects on lake services such as drinking water, fishing and biodiversity (Dokulil et al., 2000).

On the other hand, hydrological alterations in shallow lakes can lead or enhance eutrophication through reduced flushing rate, volume of water through major water level drop (Özen et al., 2010; Jeppesen et al., 2015). Thus hydrological alterations can also be a trigger to shift shallow lakes to turbid water conditions (Scheffer et al., 1993; Scheffer, 2001).

1.4 Impacts of Global Climate Change on Shallow Lakes

As a result of global climate change, the end of the 21st century in Europe average temperature will increase at least 2°C. Due to changes in average temperature of the Northern Hemisphere winter is expected to be warmer and humid whereas summer is expected to be hotter and dry (IPCC, 2014). Moreover, future climate change projections suggests that Mediterranean region will experience 20-23% lower precipitation and higher evaporation whereby it would lead to extreme drought conditions (Lelieveld et al., 2012; Giorgi, 2006). The worldwide percent of terrestrial area affected by serious drought events were doubled from the 1970s to the early 2000s. In freshwaters, prolonged drought may also induce eutrophication and salinization (Beklioğlu & Tan, 2008; Beklioğlu et al. 2011; Özen et al., 2010; Jeppesen et al., 2015).

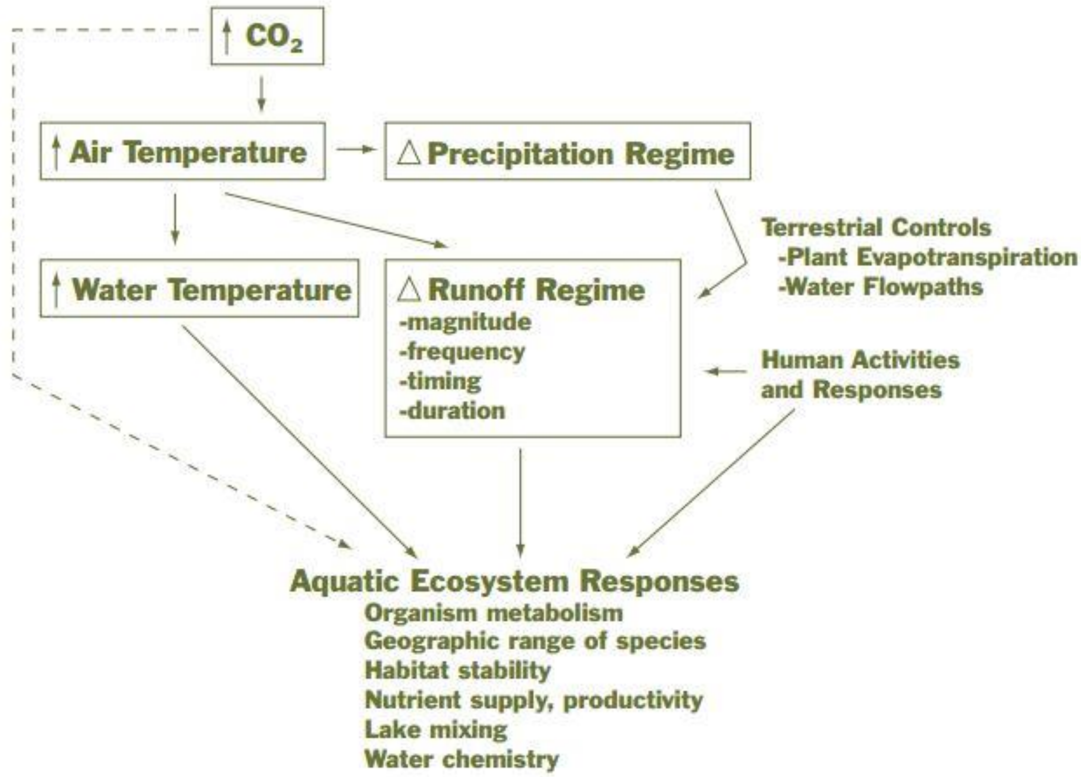

Figure 1.2 Linkages between CO2, climate and ecological processes (solid arrow: direct responses, dashed arrow: direct effects of lesser known importance) (taken from Poff et al., 2002)

The ecological consequences of climate change will largely depend on the rate and magnitude of change in two critical environmental drivers, which are temperature and water availability from precipitation and runoff. These factors regulate many ecological processes in aquatic ecosystems, both directly and indirectly (Figure 1.2). Linkages between atmospheric increases in CO2 and environmental drivers of temperature and precipitation that regulate many ecological processes and patterns in inland freshwater ecosystems. Seasonal variation in water volume strongly influences what kinds of species can flourish in an aquatic system. Therefore, a change in regional climate that alters the existing hydrologic regime has the potential to greatly modify habitat suitability for many species and cause significant ecological change (Poff et al., 2002).

1.5 Aim of the Study

In this study environmental data of the 22 Turkish shallow lakes are analyzed to understand;

1) How do differences in meteorological conditions as wet and drought periods, and spring and summer seasons affect the ecosystem structure of shallow lakes sampled through using space for time substitute approach

2) Effects of drought/wet periods on ecosystem structure of Lakes Eymir and Mogan using long term monitoring data

We hypothesized that increasing effects meteorological drought would trigger hydrological drought that will affect the structure of lakes and may trigger eutrophication and salinization.

To determine these aims, 19 lakes were used for showing the effects of differences between seasons that were sampled both in spring and summer, further 9 lakes were sampled during dry and wet years. Lastly Lakes Eymir and Mogan data from 1997 to 2012 were used for long term data impact of dry and wet periods.

CHAPTER 2

MATERIALS AND METHODS

2.1 Study Sites

Turkey is located in the Mediterranean climate zone. Its climatic conditions differ along a latitudinal gradient from semi-arid in north (41° 52´ N, 27° 58´E) to arid in south (37° 06´ N, 29° 36´ E). According to the Koeppen-Geiger classification, Turkey is divided into 3 climate zones and 14 different biogeoclimatic zones (Evrendirek et al., 2007) (Figure 2.1). Coastal areas are milder, whereas inland areas have hot summers and cold winters with much less rainfall. The mountainous regions have snowy climate with dry summers. Most of the precipitation is in the winter season and less evaporation is observed but in summer seasonal rainfall is limited.

In this study, 19 of the lakes were sampled both in spring in April and summer seasons in the same year during the peak of growing period in August. Furthermore, 9 of the lakes out of 19 lakes were sampled once during summer of both dry and wet years (Figure 2.2). For determining their ecological structures, well-established snap- shot sampling method is used for physical, biological and chemical proxies (Levi et al., 2014; Çakıroğlu et al., 2014). The physical, chemical and biological data were taken from METU, Limnology Laboratory data set. The data set have been used with METU, Limnology Laboratory members and METU, Limnology Laboratory members had sampled the studied lakes. The drought and wet years were identified according to Standardized Precipitation Index (SPI) (Guttman, 1998). The studied lakes are located across a wide range of altitude (between 0 m to 1423 m) and latitude (from 37, 73513 N to 42, 01416 N). Maximum depth of the lakes are between 0.95 cm to 7.30 cm.

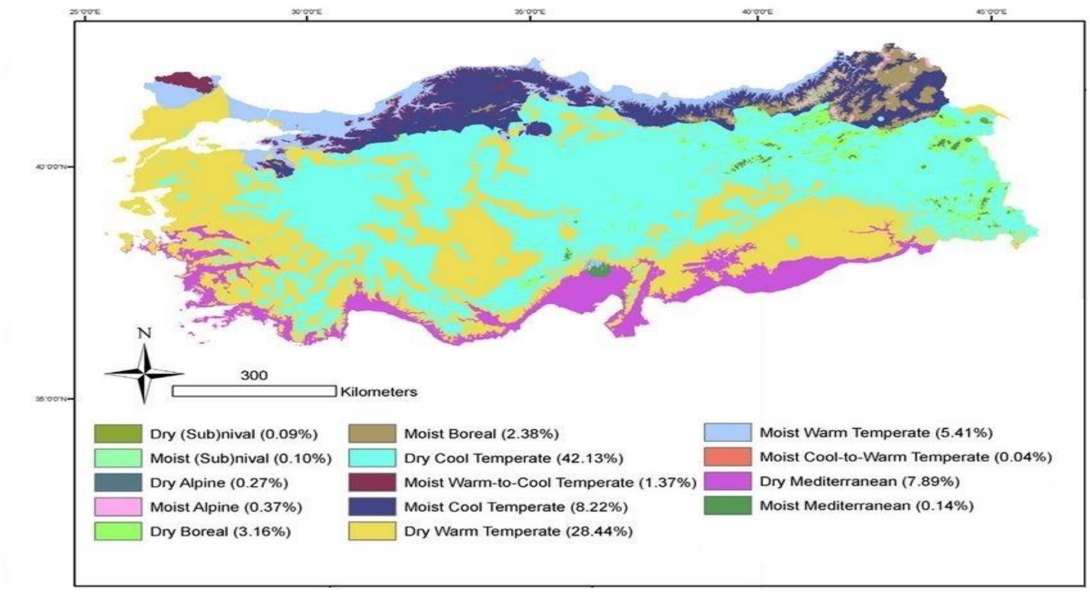

Figure 2.1 Biogeoclimatic zones in Turkey (map modified from Evrendilek et al., 2007)

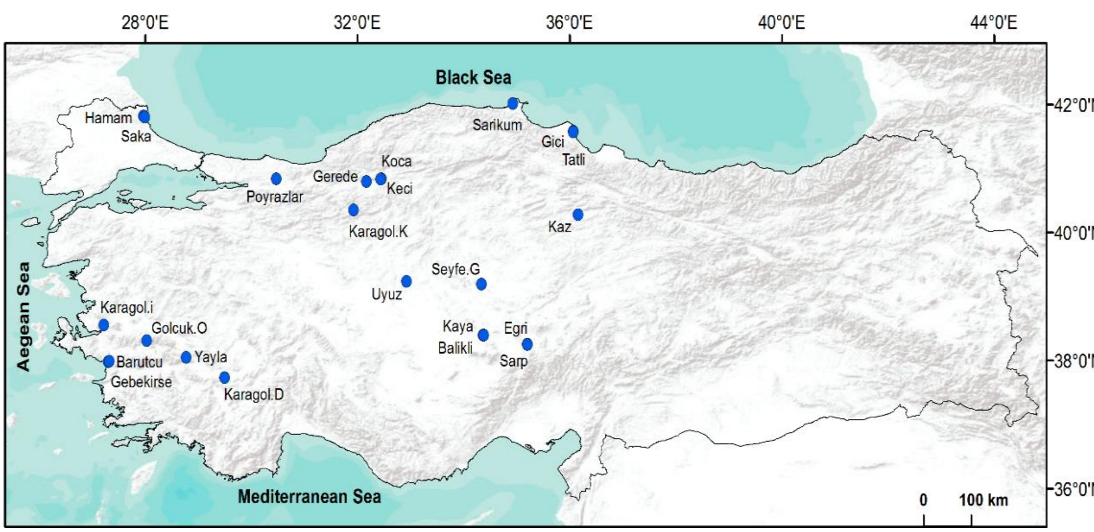

Figure 2.2 Location of studied lakes.

Since 1997 Lakes Mogan and Eymir have been continuously monitored, and thus, the data from Lakes Eymir and Mogan between 1997 - 2012 have been used for showing the long-term effects of drought and wet periods on lake ecosystem dynamics. Lake Eymir and Mogan were two interconnected shallow lakes. They were located 20 km south of Ankara. Both lakes were alluvial dam lakes on Imrahor River. Lake Mogan was larger and higher than Lake Eymir and outflow of Lake Mogan through a canal constitute the main inflow of Lake Eymir. Lake Mogan had four main inflows, which were Sukesen, Gölcük, Yavrucak and Çölovası brooks. Mean depth of Lake Mogan was 2,1 m, the maximum depth was 3,5 m and surface area of Lake Mogan was 5,4-6 km^2, whereas Lake Eymir had 3,1 m mean depth, 5,5 m of maximum depth and surface area of Lake Eymir was relatively small with 1,20-1,25 km^2. Lake Eymir had two main inflows, Lake Mogan and Kışlakçı creek. In summer seasons, all inflow of Lake Eymir dry out or do not flow. Lake Eymir received raw sewage from Gölbaşı region over 25 years. Then, in 1995 sewage control was started. Moreover, first biomanipulation project was performed during 1998-1999. During this period (1998-1999) half of the benthic-planktivorous fish were removed. This provided an improvement of lake water quality. However, extended drought years led to water clarity change after the biomanipulation. Five year later, lake's water clarity turned to previous year and nutrient concentration increased with internal mechanisms. Therefore, during 2006 and 2007 second biomanipulation was performed and the results of water quality turned to good condition and chlorophyll a concentration decreased twofold, Secchi depth increased 50%, after biomanipulation (Özen et al., 2010). Moreover, from 1997 to present day, both Lake Mogan and Eymir have been monitored with snap-shot sampling protocol. Water samples of lakes were analyzed for total phosphorous, soluble reactive phosphate, alkalinity, zooplankton, phytoplankton and chlorophyll a, whereas after 2007 total nitrogen was added to analyses and *in situ* salinity, conductivity, pH and dissolved oxygen concentration and water temperature were measured by YSI multiprobe.

2.2 Snap-shot Sampling

Nineteen lakes that were studied sampled for environmental variables following snap-shot sampling protocol. It was standardized by Moss et al. (2003). All sampling procedures used for physical, chemical and biological variables were the same for all sampled lakes (Figure 2.3). Before sampling water for physical, chemical and biological variables of the lakes, the deepest part of the lakes were determined by carrying out depth profiling measurements along transects whose numbers were dependent on lake size. The deepest point of the lake was used for sampling point of the pelagic measurements.

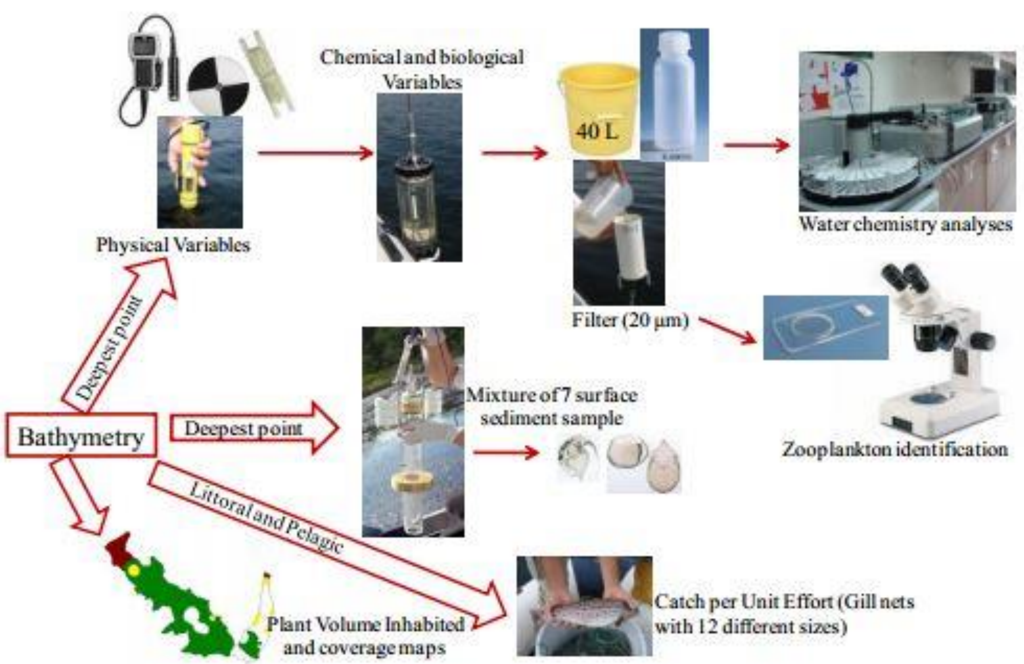

Figure 2.3 Schematic description of snap-shot sampling method (taken from Tavşanoğlu, 2012)

Depth measurement was performed with a Laylin SM5 depth meter (Laylin Associates, Unionville, USA) and Secchi depth (Secchi, B. 1989) was measured from the deepest point using Secchi disc which is 20 cm in diameter. To determine general characteristics of the lakes, water quality parameters such as pH, salinity, temperature, conductivity and dissolved oxygen were measured by using an YSI 556 MPS multiprobe field meter (YSI Incorporated, O.H., U.S.A.). KC Denmark water sampler was used for taking water samples from first 0.5 m depth to the bottom of a lake with every half meter water increment at the deepest point. In overall 40 liters water samples were collected and mixed in a large barrel. For total phosphorous (TP), total nitrogen (TN), soluble reactive phosphorous (SRP), alkalinity and chlorophyll a (Chla), 1 liter of water sample was taken and stored in acid-washed 1 liter Pyrex bottle. The samples were kept frozen until analyses. Moreover, 20 liter of water from the mixed water sample was filtered with a 20 μm mesh filter for zooplankton and sample was stored in 100 ml brown glass bottle which was previously filled with 4% Lugol's solution. Furthermore, fish, were sampled using 1-5 m deep and 30 m long Lundgren gill nets. The gill nets included 12 mesh-sizes ranging from 5 to 55 mm (43.0 - 19.5 - 6.25 - 10.0 - 55.0 - 8.0 - 12.5 - 24.0 - 15.5 - 5.0 - 35.0 - 29.0). The number of nets used per lake was proportional to the lake area, the maximum number being eight (Moss et al., 2003; Jeppesen et al., 2010b). The nets were set overnight, for an average duration of 12 hours, on the two determined locations at the pelagic and along the littoral zone of the lake. Fish abundance was obtained from overnight catches in multiple mesh-sized gill nets

2.3 Laboratory Analyses

Chlorophyll a pigment content were determined by ethanol extraction in triplicate (Jespersen and Christoffersen, 1987) and measurements were performed with a Lambda 35 UV/VIS spectrophotometer (PerkinElmer Inc., MA, USA). For total phosphorus (TP) and soluble reactive phosphate (SRP) the acid hydrolysis method and molybdate reaction methods were used (Mackereth et al., 1978). For alkalinity (Alk) titration method was used with adding precise quantities of sulfuric acid (the reagent) to the sample until the sample reaches a certain pH. For total nitrogen (TN) and ammonium (NH4) analysis Scalar Autoanalyzer Method was used (San++ Automated Wet Chemistry Analyzer, Skalar Analytical, B.V., Breda, Netherlands). Silicate was measured following Golterman et al. (1978). Zooplankton samples were identified to species level and counted in a Leica MZ 16 stereomicroscope (Tavşanoğlu et al., 2012). Hundred individuals of the most abundant taxa were counted and body size of 25 individuals of each taxon was measured.

2.4 Drought Analyses

Since there are wide variety of disciplines affected by drought and drought operates on many different scales with diverse geographical and temporal distribution, it is difficult to develop an index to measure drought effectively (National Oceanic and Atmospheric Administration, 2013). Drought has different meanings to different users such as water managers, agricultural producers, hydroelectric power plant operators and wildlife biologists (World Meteorological Organization, 2012). The Standardized Precipitation Index (SPI) is a tool, which was developed for defining and monitoring drought. It is used to determine the rarity of a drought at a given time scale of interest for special data of geographical location. SPI was a probability index that considers only precipitation. All precipitation data was taken from Turkish State Meteorological Services and SPI value calculation and analyses were realized by online program

Drought Monitoring System 2.1. In this system, the SPI calculation for specific location was based on the long-term precipitation record for a desired period. The first step was to find the probability density function that best describes the precipitation distribution over the chosen time scales. Each of the data sets is fitted to gamma probability density function. The gamma distribution was defined by its probability density function.

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{-x/\beta} \qquad \text{for } x>0$$

where:

$\alpha > 0$ α is a shape parameter

$\beta > 0$ β is a scale parameter

$x > 0$ x is the precipitation amount

$\Gamma(\alpha) = \int_0^{\infty} y^{\alpha-1} e^{-y} dy$ $\Gamma(\alpha)$ is the gamma function

$$G(x) = \int_0^x g(x)dx = \frac{1}{\hat{\beta}^{\hat{\alpha}}\Gamma(\hat{\alpha})} \int_0^x x^{\hat{\alpha}-1} e^{-x/\hat{\beta}} dx$$

The cumulative probability distribution function is described as follows by using gamma distribution;

$$H(x) = q + (1-q)G(x)$$

Then, the cumulative probability distribution function was converged into the standard normal cumulative distribution function Z with mean zero and variance of one, which was the value of the SPI (Edwards and McKee, 1997).

$$Z = SPI = -\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right) \qquad \text{for } 0 < H(x) \leq 0.5$$

$$Z = SPI = +\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right) \qquad \text{for } 0.5 < H(x) < 1.0$$

The probabilities were standardized so that zero showed the median precipitation amount. Negative SPI values represented rainfall deficit, whereas positive PSI values indicted rainfall surplus (Table 2.1), (Kumar et al., 2009).

Table 2.1 SPI values (taken from World Meteorological Organization, 2012)

SPI value	**Condition**
2.0 and more	extremely wet
1.5 to 1.99	very wet
1.0 to 1.49	moderately wet
(-0.99) to 0.99	near normal
(-1.0) to (-1.49)	moderately dry
(-1.5) to (-1.99)	severely dry
(-2.0) and less	extremly dry

For SPI index, precipitation was the only parameter and this provided less complex index for drought analyses. Timescales of the data reflected the impact of drought on different water sources. McKee and others (1993) originally calculated the SPI for 3 – 6 – 12 – 24 and 48 months timescales. For example, 1- 2 month SPI is used for meteorological drought, 1 – 6 month for agricultural drought and 6 – 24 month SPI for hydrological drought analyses and applications. To define dry and wet years that the study lakes were sampled, 12 month SPI was used for drought analyses (Figure 2.4). 9 of the lakes were also sampled in different years ranging between 2006 and 2012. These different sampling years for the same lakes were analyzed weather there were drought or wet conditions prevailing. Drought analysis was carried out by using SPI index analysis. Twelve month precipitation data of the nearest meteorological station was used for the drought analysis of the lakes. Furthermore, drought and wet year decision for Lake Eymir and Lake Mogan were used by SPI index of Ankara.

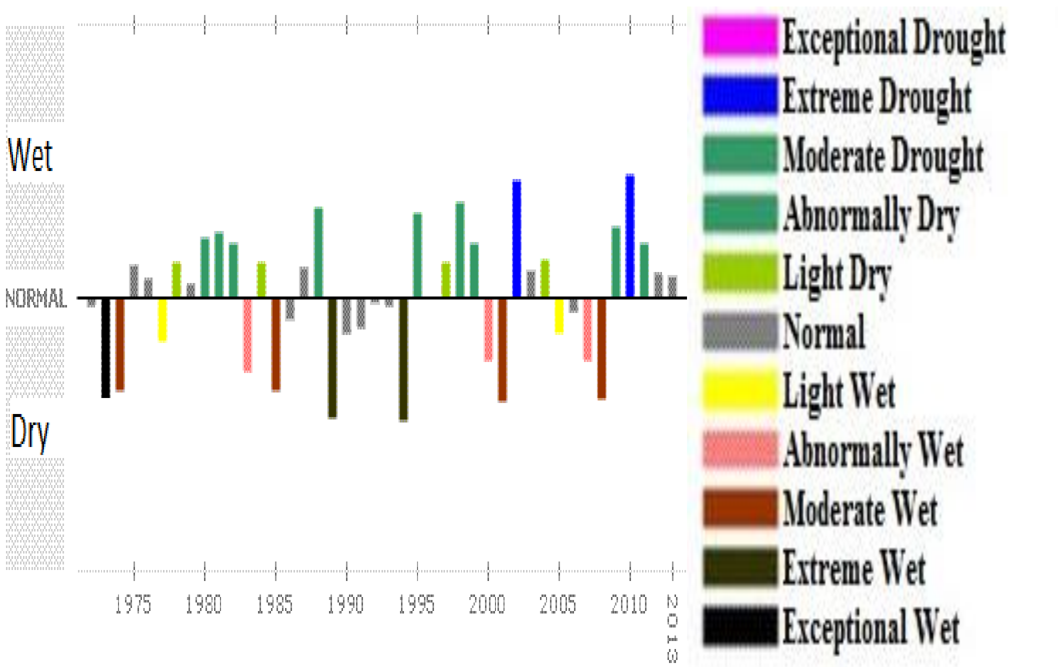

Figure 2.4 12 months SPI results of Turkey (taken from Turkish State of Meteorological Service)

2.5 Statistical Analyses

For statistical analyses, mean value of sampled seasons meteorological data of the lakes (precipitation, net evaporation and air temperature) were used. Other environmental data of the lakes were used single measuring data of deepest point (sampling point) of the lakes. Environmental data in each group was tested for normality using Kolmogorov-Simirnov test in SigmaStat 3.5 (Systat software Inc. 2014). If environmental data could not pass the normality test, data was transformed (log10, square root, log(x+1)) (Table 2.2).

Table 2.2 Transformed variables of summer & spring and wet & dry groups

Variables	**Summer & Spring**	**Wet & Dry**
Conductivity	log	log(x+1)
Salinity	square root	square root
Secchi Depth	log	log
Total Nitrogen	log(x+1)	log(x+1)
Silicate	log	log
Alkalinity	square root	square root
Precipitation	log(x+1)	log(x+1)
Net Evaporation	square root	square root
Number per unit effort of fish	no transformed	log(x+1)
Total Zooplankton Biomass	no transformed	log(x+1)
Surface Water Temperature	no transformed	square root

For explaining the variance and co-variance among environmental variables of the study lakes, Principal Component Analysis (PCA) was employed as it concerns with explaining the variance- covariance structure of the data set through a few linear combinations of the original variables (Afifi and Clark, 1996). This technique compresses the data by reducing the number of dimensions and explained most of the variance of the system without much more loss of information (Smith, 2003). The purpose of PCA is to identify the dependence structure of multivariate observations in order to obtain a compact representation and to preserve the relationships present in the original data (Ahmadi-Nedushan et al., 2006).

Procrustes rotation and the associated Protest permutation test were applied to the ordination results of the PCA analyses of the data. Procrustes rotation identifies the degree of correlation association between two or more ordination results by using a procrustean superimposition approach. The results of the ordinations are scaled and rotated in a procrustean superimposition approach in order to find an optimal superimposition for maximizing their fit (Davidson et al., 2006). The sum of the squared residuals between configurations in optimal superposition fit can be used as a metric of correlation (Gower, 1971). Procrustes sum of squares were referred to as m_{12} value and associated the likelihood of the relationship occurring by chance representing p value.

Generalized linear models (GLM) were used to assess the effect of independent environmental variables on biological dependent variables (chlorophyll a, total zooplankton biomass and number per unit effort of fish). Backward stepwise regression procedure was performed by removing the weakest predictor based on Akaike's Information Criteria (AIC) points and best model was selected by excluding collinear (Pearson $r > 0.6$) predictors.

T-test is known as a hypothesis test that is used for making a statistical examination of two samples mean. T-test evaluate the means of two variables or groups, providing to whether the means of groups differ.

The analyses were carried out using R statistical program (Version 2.12.2) using the vegan package and multivariate partitioning package, SigmaStat 3.5 and Statistica 8.0 (R Core Team, 2013; Oksanen et al.., 2012; StatSoft. Inc., 2008; Systat Software, 2006; De'ath, 2002).

CHAPTER 3

RESULTS

3.1. Lakes Sampled During Spring and Summer Seasons

Mean value of the variables sampled both during spring and summer seasons in the 19 of the lakes showed that during spring season lakes had low nutrients and higher Secchi depth than that of summer season, but Lake Koca, Keçi and Karagöl Bolu had higher Secchi depths during summer season. During summer season, the lakes' salinity and conductivity were higher, while dissolved oxygen concentration was lower than spring season. Moreover, chlorophyll a concentration increased from spring to summer with respect to temperature. Lake surface areas decreased with evaporation so during summer season small decreases were seen for lake surface areas, whereas small increase was observed for lakes' alkalinity and silicate concentration. During summer, mean pH was higher than spring because of the increase of biological productivity during summer. Total phosphorous concentration showed increasing trend from spring to summer seasons, especially in Lake Lake Tatlı, Gıcı, Barutcu and Balıklı, but Lake Gerede, Kaz and Yayla showed opposite trend. In addition, from spring to summer total nitrogen concentration increased same as total phosphorous, but only total nitrogen concentration decreased in Lake Seyfe. For chlorophyll a concentration, most of the lakes showed increase from spring to summer, but Lake Barutçu, Gebekirse, Gölcük Ödemiş, Karagol Denizli showed opposite trend. When the meteorological parameters and maximum depth changes were compared between the seasons for the 19 lakes sampled during both spring and summer, the mean air temperature and net evaporation increased from spring to summer season, while precipitation and maximum depth reduced in summer season (Table 3.1). In addition, simple t-test showed that total nitrogen, net evaporation, surface water and air temperature, pH and precipitation were significantly different between spring and summer (Figure 3.1).

Table 3.1 General characteristics of the lakes sampled in summer and spring seasons. (* significant)

		Spring		**Summer**	
Variables	**Unit**	**Mean**	**SD**	**Mean**	**SD**
Air Temperature *	°C	12,0	3,7	23,9	3,3
Alkalinity	meq L^{-1}	5,1	3,7	5,9	6,7
Area	ha	43,2	51,8	40,4	47,2
Chlorophyll a	µg L^{-1}	22,9	21,7	41,7	44,0
Conductivity	mS cm^{-1}	1714,5	2489,6	2237,5	3519,2
Dissolved Oxygen	mg L^{-1}	7,4	3,0	6,4	3,9
Maximum Depth	m	3,7	2,3	3,2	1,9
Net Evaporation *	mm	195,2	107,3	598,9	169,4
pH *	pH unit	7,2	1,4	8,2	0,9
Precipitation *	mm	156,6	52,2	60,7	55,8
Salinity	‰	0,9	1,4	1,2	2,0
Secchi Depth	m	1,4	0,7	1,1	1,0
Silicate	µg L^{-1}	4470,9	3596,2	4992,6	2912,1
Surface Water Temperature *	°C	16,6	5,4	25,3	1,8
Total Nitrogen *	µg L^{-1}	800,1	767,1	1215,7	636,6
Total Phosphorous	µg L^{-1}	95,8	58,9	167,1	120,4

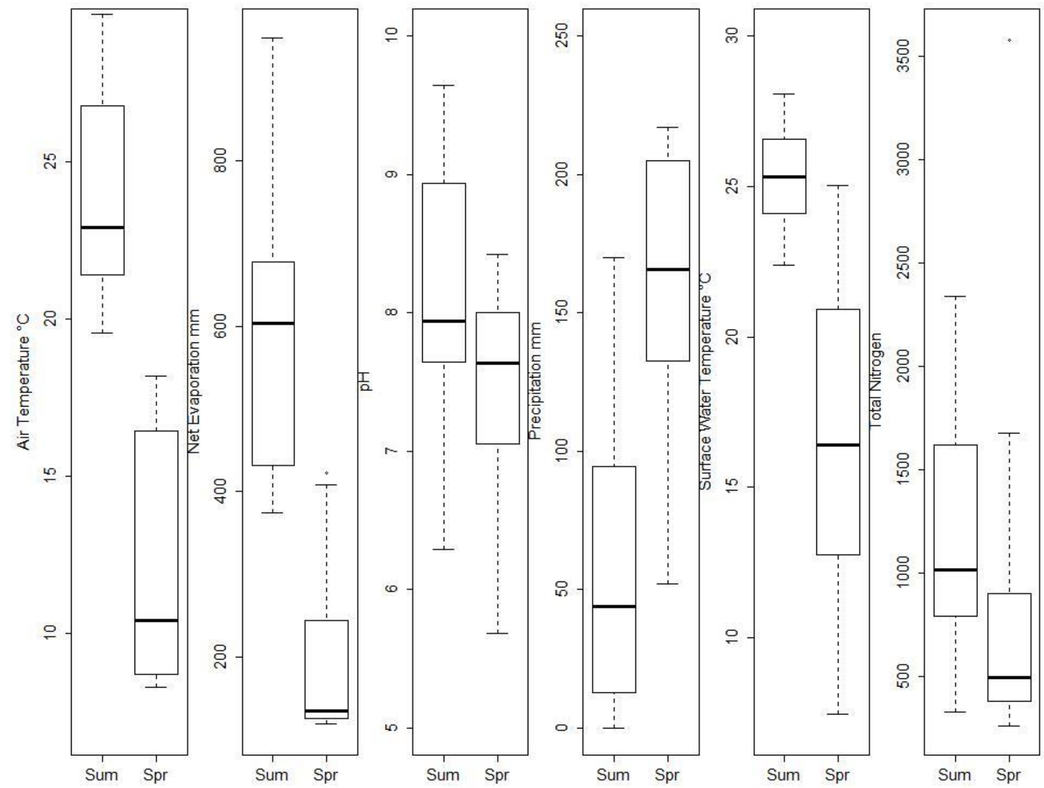

Figure 3.1 Boxplots of significant variances of lake sampled summer and spring seasons (Air temperature, net evaporation, pH, precipitation, surface water temperature and total nitrogen)

Among the studied lakes, environmental variables including precipitation, surface water temperature, maximum depth, air temperature, evaporation, salinity, alkalinity, pH, dissolved oxygen concentration, total phosphorous, total nitrogen and chlorophyll a were used for Principal Component Analyses (PCA). The first four axes were significant and the first two axes explained 49% of the variance observed (Figure 3.2). The first axis was positively related with mean air temperature, evaporation and surface water temperature and was negatively related with precipitation and Secchi depth. The second axis was positively related with alkalinity and chlorophyll a concentration whereas negatively with dissolved oxygen concentration and salinity. Summer sampling data of the lakes were located on the positive side of the PC1 axis of the PCA plot where the lakes had higher surface water and air temperatures, higher nutrients and chlorophyll a concentrations. However, spring sampling data of the same lakes were located on the negative side of the PC1 axis of the PCA plot. On the negative side of the PC1 axis, spring sampling data of the lakes had higher Secchi and maximum depth, precipitation and dissolved oxygen concentration. However, summer values of variables in Lakes Keçi, Koca and Gerede were located at middle part of the box axis of PCA plot. However, their spring values were located in more negative side of the PC1 axis of the PCA plot relatively, and data from these lakes showed some changes from spring to summer season.

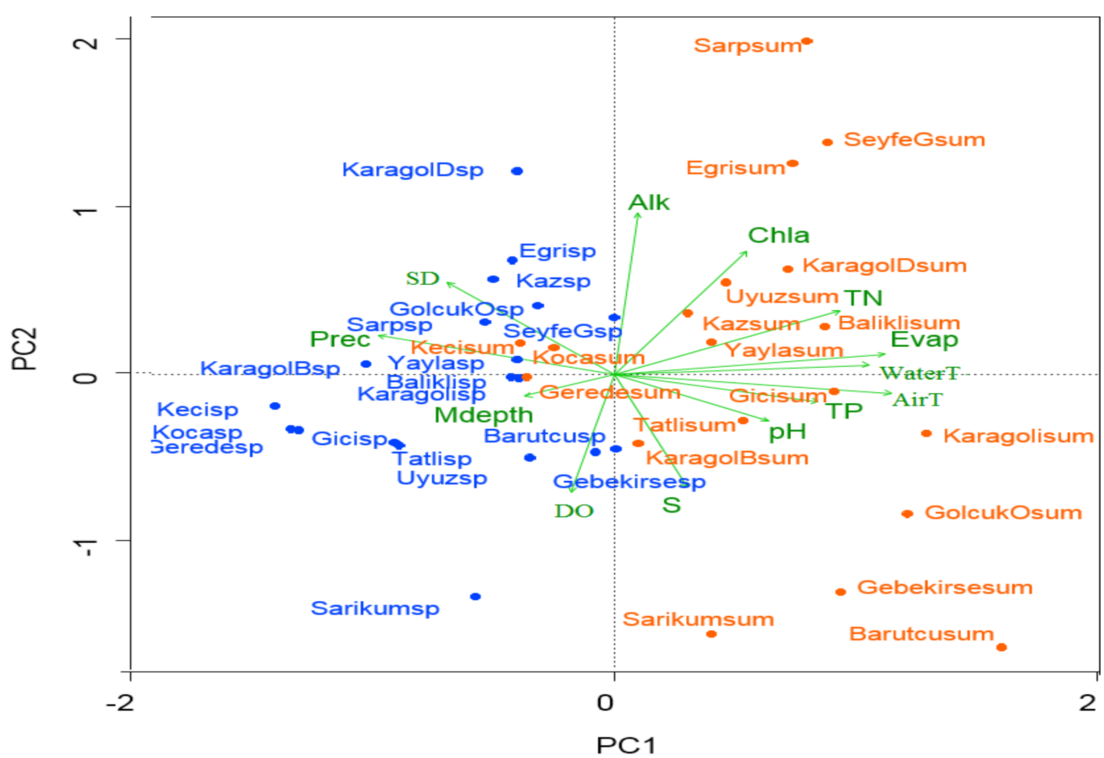

Figure 3.2 PCA plot of lakes with spring and summer samplings' variables (blue color: value of the variables form spring sampling of the lakes, orange color: summer sampling of the lakes, green color: variables)

To determine extend of the difference between spring and summer values of the lakes for variables, the Procrustes rotation analyses was carried out (Figure 3.3). The scores of PCA of the summer and spring samplings were used. The sum of squares was 27.9, root mean squared error was 1.21 and the correlation diagnostic value (m_{12}) was high (0.91) and p value was 0.44. Thus, Procrustes rotation test using PCA score of lakes with summer variables and PCA score of lakes with spring variables were not fit to each other and analysis was not significant. Black dots represent values of the lakes with spring sampling data and arrow represent lakes with summer sampling data. The distance between points and arrows showed Procrustes residuals. The high residuals means a longer distance between spring and summer data all lakes. This indicated a weak agreement or a large dispersion between two data sets of the lakes as they departed from each other as summer months preceded. However, Procrustes rotation plot indicated that, Lakes Karagöl Denizli (KaragolD), Eğri, Uyuz, Kaz, Karagöl Bolu (KaragolB), Gıcı and Yayla showed low differences between summer and spring season. On the other hand, Lakes Koca, Gebekirse, Gölcük Ödemiş (GolcukO), Tatli, Barutçu, Baklıklı, Karagöl İzmir (Karagoli), Gerede, Sarıkum, Sarp, Seyfe and Keçi showed high residual distance. Moreover, the direction of arrows between the lakes with spring data (circle) and summer data (arrow) was related to change of environmental variables from PCA analyses. According to arrow direction, summer data measured in Lakes Karagöl İzmir, Gölcük Ödemiş, Gebekirse and Barutçu reflected to a high change in surface water temperature and pH. Total phosphorus, total nitrogen and evaporation increased from spring to summer season especially in Lakes Koca, Keçi and Gerede. Other examples of higher residual lakes included Lakes Sarıkum and Tatlı showed direction to higher salinity and pH, whereas Lakes Balıklı, Sarp and Seyfe showed to direction to higher chlorophyll a concentration and alkalinity.

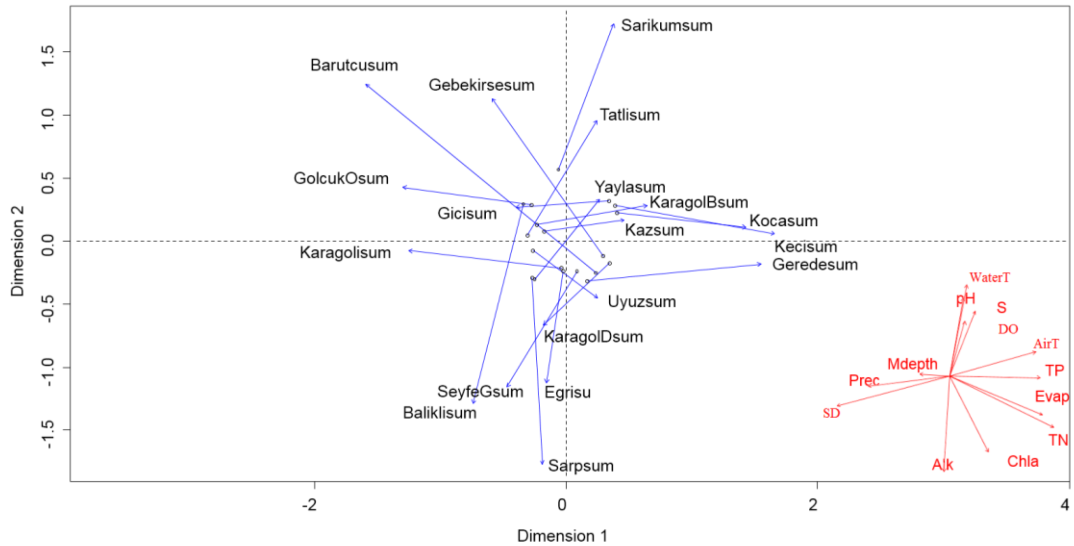

Figure 3.3 Procrustes plot of summer and spring sampled lakes (Black dots: spring data arrow: summer data, distance between points and arrows: Procrustes residuals)

The collinear (Pearson r>0.6) predictors for the lake with both summer and spring values of the variables were showed on Table 3.2 and value which was larger than 0.6 represented correlation between variables. Mean air temperature was correlated with surface water temperature, evaporation and precipitation. Surface temperature correlated with evaporation. Precipitation was correlated with air temperature and evaporation. To investigate the effects of the physical, chemical variables on chlorophyll a concentration, General Linearized Model of multiple regression (GLM) analyses was performed. Total phosphorus, total nitrogen and water temperature variables were chosen for the GLM analyses. The final best model of GLM analysis was showed that chlorophyll a was significantly related to total nitrogen concentration in both spring and summer season, but the significance level decrease from spring to summer season (Table 3.3).

Table 3.2 Results of Pearson correlation for the environmental variables from the lakes sampled both in summer and spring seasons

	Oxy	Stemp	pH	Sal	Secchi	Mdepth	TP	TN	Alk	Chla	Atemp	Prec	Evap
Oxy	1,0000	-0,2221	-0,0351	0,1586	-0,2582	-0,0195	0,0502	-0,0224	-0,3068	-0,0486	-0,2455	0,1150	-0,1521
Stemp	-0,2221	1,0000	0,5313	0,2619	-0,1668	-0,2612	0,3573	0,4456	0,0845	0,2602	0,7708	-0,5058	0,7480
pH	-0,0351	0,5313	1,0000	0,2490	-0,1876	-0,4216	0,1797	0,1619	-0,0012	-0,0547	0,4948	-0,1756	0,3005
Sal	0,1586	0,2619	0,2490	1,0000	-0,2879	-0,1895	-0,0036	-0,0172	-0,0472	-0,1435	0,1677	-0,3054	0,0135
Secchi	-0,2582	-0,1668	-0,1876	-0,2879	1,0000	0,2835	-0,5559	-0,4047	0,1521	-0,1427	-0,3460	0,4098	-0,2618
Mdepth	-0,0195	-0,2612	-0,4216	-0,1895	0,2835	1,0000	-0,0735	-0,2177	-0,4231	-0,0588	-0,1844	0,0177	0,0586
TP	0,0502	0,3573	0,1797	-0,0036	-0,5559	-0,0735	1,0000	0,5304	-0,1163	0,3010	0,4315	-0,4162	0,5100
TN	-0,0224	0,4456	0,1619	-0,0172	-0,4047	-0,2177	0,5304	1,0000	0,2721	0,5468	0,4610	-0,4619	0,5769
Alk	-0,3068	0,0845	-0,0012	-0,0472	0,1521	-0,4231	-0,1163	0,2721	1,0000	0,3624	-0,0947	0,0460	-0,0073
Chla	-0,0486	0,2602	-0,0547	-0,1435	-0,1427	-0,0588	0,3010	0,5468	0,3624	1,0000	0,2097	-0,1239	0,4158
Atemp	-0,2455	0,7708	0,4948	0,1677	-0,3460	-0,1844	0,4315	0,4610	-0,0947	0,2097	1,0000	-0,7092	0,8514
Prec	0,1150	-0,5058	-0,1756	-0,3054	0,4098	0,0177	-0,4162	-0,4619	0,0460	-0,1239	-0,7092	1,0000	-0,6603
Evap	-0,1521	0,7480	0,3005	0,0135	-0,2618	0,0586	0,5100	0,5769	-0,0073	0,4158	0,8514	-0,6603	1,0000

Table 3.3 Generalized Linear Model of Chlorophyll a concentration in spring and summer seasons

```
Model:  Spring Season
Chla ~ Stemp + TP + TN
       Df Deviance    AIC scaled dev. Pr(>Chi)
<none>      4959.9 169.65
Stemp   1   5133.7 168.30      0.6542  0.41861
TP      1   5094.7 168.16      0.5093  0.47544
TN      1   6730.2 173.45      5.7991  0.01603 *

Model:  Summer Season
Chla ~ Stemp + TP + TN
       Df Deviance    AIC scaled dev. Pr(>Chi)
<none>       24308 199.85
Stemp   1    24962 198.35      0.5046  0.47750
TP      1    25126 198.48      0.6286  0.42787
TN      1    31917 203.02      5.1742  0.02293 *
```

3.2 Drought Analyses

Lake Poyrazlar was sampled in both 2006 and 2008. The results showed that year 2006 emerged as relatively less dry than 2008. Thus 2006, was regarded as a wet and 2008 regarded as a dry year (Figure 3.4). Lake Hamam was sampled in 2006 and 2008; whereas Lake Saka was sampled both in 2007 and 2008. Thus, the wet years for Lakes Hamam and Saka were assigned as 2006 and 2007, respectively; whereas 2008 was the dry year for both of them (Figure 3.5). Lakes Gebekirse and Barutcu, GolcukO, Karagoli, were all sampled in same years 2008 and 2012, for all of the lakes 2008 emerged as a dry year and 2009 as wet year (Figure 3.6, 3.7, 3.8, 3.9). However, Lakes Yayla and KaragolD from the same region were also sampled in both 2008 and 2012, the SPI index analyses showed that the both years were wet. (Figure 3.9)

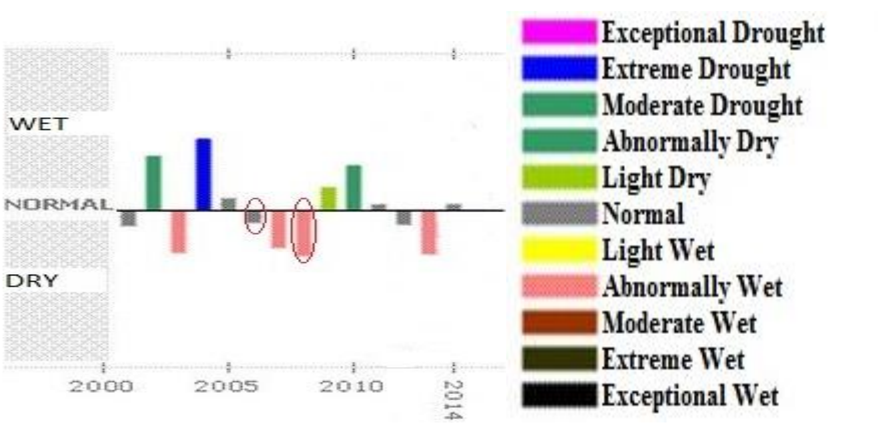

Figure 3.4 SPI index analysis result for Lake Poyrazlar

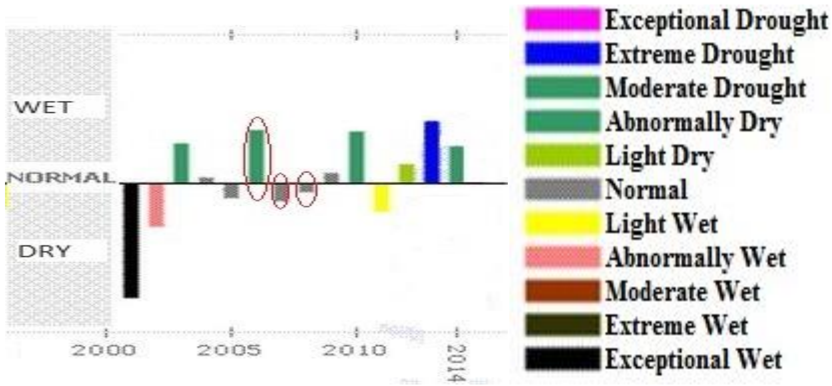

Figure 3.5 SPI index analysis result for Lake Hamam and Saka

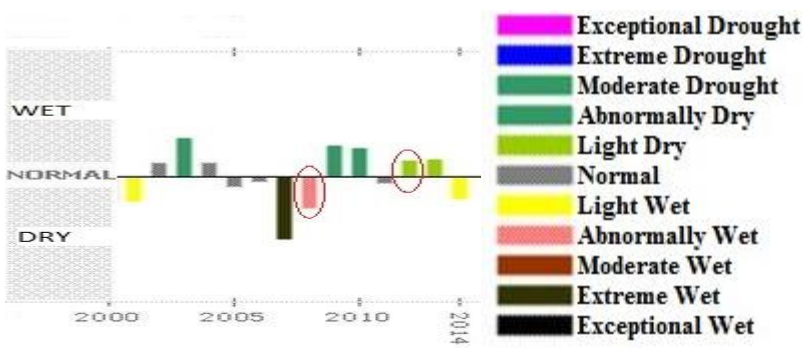

Figure 3.6 SPI index analysis result for Lake Gebekirse and Barutçu

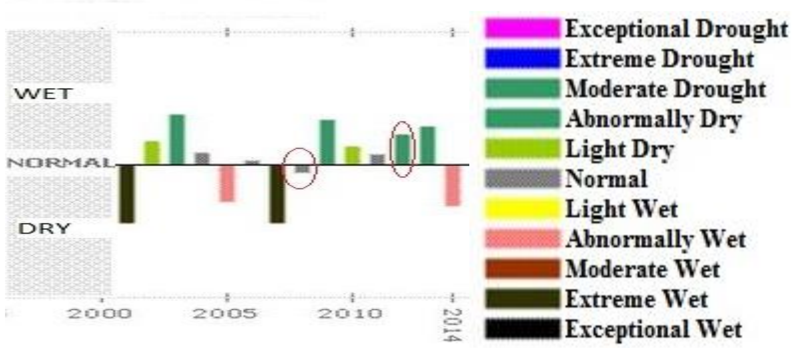

Figure 3.7 SPI index analysis result for Lake Gölcük Ödemiş

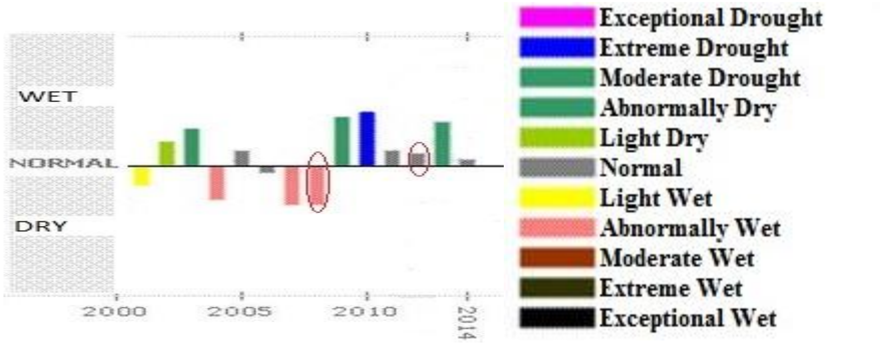

Figure 3.8 SPI index analysis result for Lake Karagol İzmir

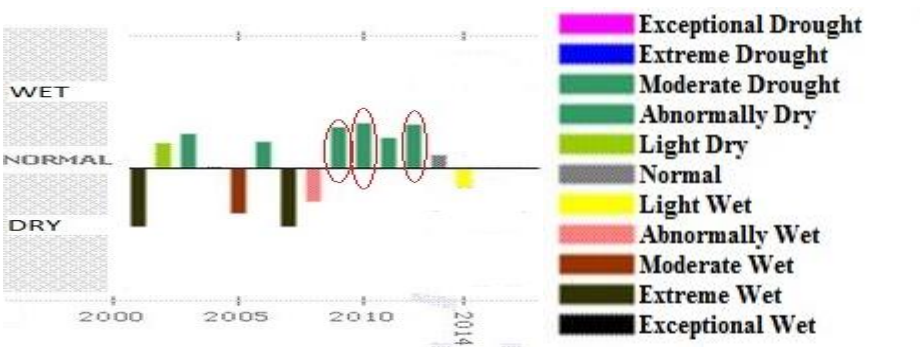

Figure 3.9 SPI index analysis result for Lake Yayla and Karagöl Denizli

3.3. Characteristics of the Lakes Sampled in both Wet and Dry Years

9 of 19 lakes showed above were sampled in different years which were further assigned as dry or wet years according to the SPI index analysis. The lakes had high concentrations of nutrients and low Secchi depth in drought year though chlorophyll a concentration was not high during drought year. In wet year, dissolved oxygen concentration was higher and salinity was lower than that of drought year. Total phosphorous concentration increased for all the lakes from wet to dry period. However, for total nitrogen concentration small increasing trend was seen from wet to dry. Alkalinity were high during wet year. Lakes' areas were same both wet and drought

years, but maximum depth decreased from wet to drought period. When the meteorological parameters were compered, the mean air temperature, and net evaporation increased, whereas precipitation amount decreased between the wet and dry years (Table 3.4). On the other side, simple t-test explained that precipitation, total phosphorous and Secchi depth were significantly different between wet and dry periods (Figure 3.10).

Table 3.4 General characteristics of the lakes sampled in wet and drought periods (* significant)

		Wet		**Dry**	
Variables	**Unit**	**Mean**	**SD**	**Mean**	**SD**
Air Temperature	°C	16,5	1,9	17,0	2,0
Alkalinity	meq L^{-1}	8,5	9,2	1,5	1,1
Area	ha	44,7	32,1	44,7	32,1
Chlorophyll a	µg L^{-1}	15,9	11,0	33,2	23,1
Conductivity	mS cm^{-1}	2030,5	3633,8	2060,5	3437,1
Dissolved Oxygen	mg L^{-1}	6,3	1,7	5,3	3,3
Maximum Depth	m	395,6	159,5	354,4	134,6
Net Evaporation	mm	611,2	153,8	636,0	168,3
pH	pH unit	8,0	0,7	8,3	0,8
Precipitation *	mm	732,1	92,8	535,3	163,6
Salinity	‰	1,1	2,0	1,2	1,9
Secchi Depth *	m	122,2	59,1	67,8	59,5
Silicate	µg L^{-1}	5203,5	3662,3	4795,8	3062,6
Surface Water Temperature	°C	25,6	3,4	25,2	1,8
Total Nitrogen	µg L^{-1}	1111,5	632,3	1183,2	543,7
Total Phosphorous *	µg L^{-1}	87,0	72,0	187,8	160,7

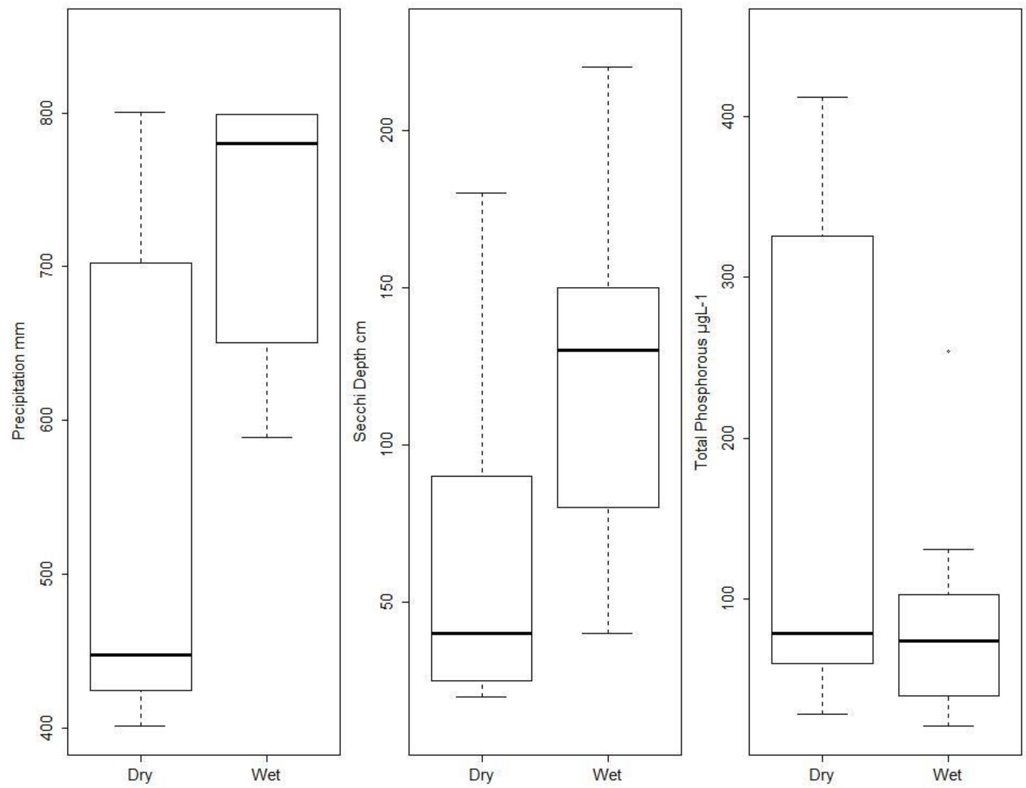

Figure 3.10 Boxplots of significant variances of lake sampled wet and dry years (Precipitation, Secchi depth and total phosphorous)

Environmental variables including precipitation, surface water temperature, maximum depth, air temperature, evaporation, salinity, alkalinity, pH, dissolved oxygen concentration, total phosphorous, total nitrogen, chlorophyll a and as well as zooplankton and number per unit effort of fish data were used for PCA analysis. According to the PCA, the first eight axes were significant and the first two axes explained 51% of the variance (Figure 3.11). The first axis positively related with number of fish, and negatively related with total nitrogen, net evaporation, alkalinity and water temperature. The second axis positively related with total phosphorous, whereas negatively with Secchi depth and precipitation. Variables that were obtained during the dry year located on positive side of the PC2 axis of the PCA plot, Wet period sampled lakes on the negative side of the PC2 axis of the PCA plot. However, Lakes Poyrazlar and Hamam were showed different pattern. Total phosphorous, salinity and pH increased from wet period to dry years, Furthermore, number per unit of number of fish was high in dry period.

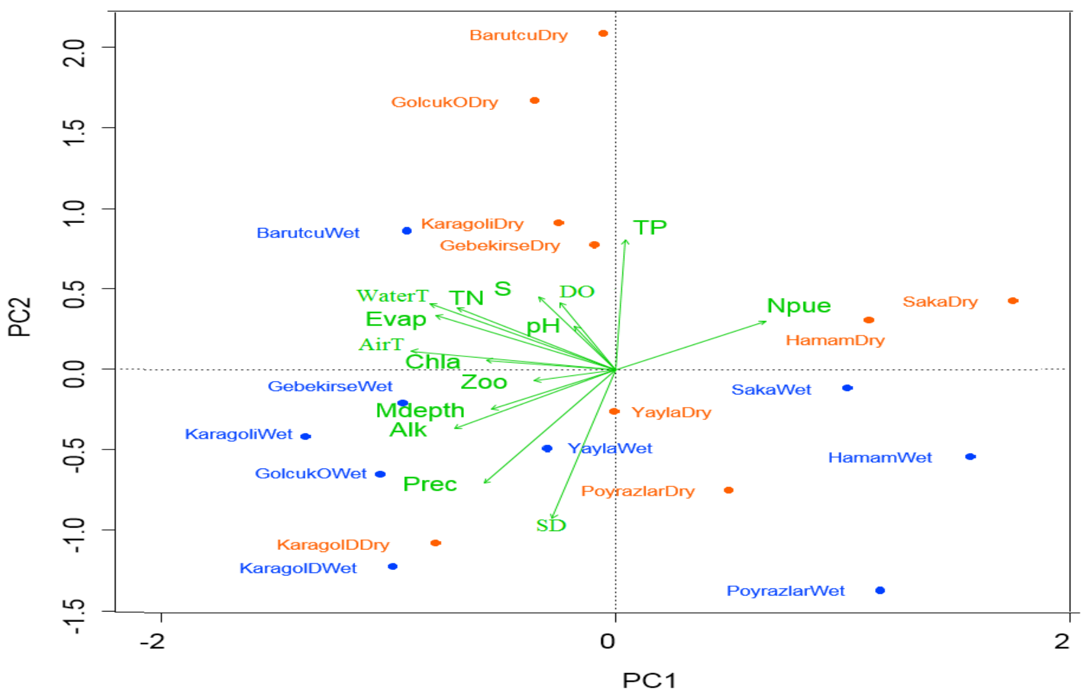

Figure 3.11 PCA plot of wet and dry period sampled lakes (blue: wet period sampled lakes, orange: dry period sampled lakes, green: variables)

For the Procrustes rotation analyses, the scores of PCA of the wet and dry year data were used and the results of protest were shown that sum of squares was 7.59, root mean squared error was 0,92. Furthermore, the correlation diagnostic (m12) was low value (0.35) and p value = 0.004 showed that Procrustes rotation test using PCA of summer sampled lakes and PCA of spring sampled lakes were fit to each other and Protest was statistically significant. Black dots represent wet period sampled data and arrow represent data of dry period sampled. The distance between points and arrows showed Procrustes residuals. The distance between wet and dry data of lakes show amount of the residuals. This indicated the level of agreement between two data sets of lakes. Procrustes rotation plot indicated that, only Lakes Poyrazlar, Hamam, Saka and Gölcük Ödemiş (GolcukO) occurred in low agreement between the wet and dry periods. As these lakes had high residual distance. Moreover, the direction of arrows between spring sampled (circle) and summer sampled (arrow) was related to change of environmental variables from PCA analyses (Figure 3.12). In Lake Golcuk Ödemiş total phosphorous concentration significantly increased and Secchi depth and precipitation significantly decreased. For Lake Saka number per unit effort of fish and total phosphorous significantly increased from wet to dry years. Furthermore, precipitation and Secchi depth negatively change and salinity positively change is seen for Lakes Poyrazlar and Hamam.

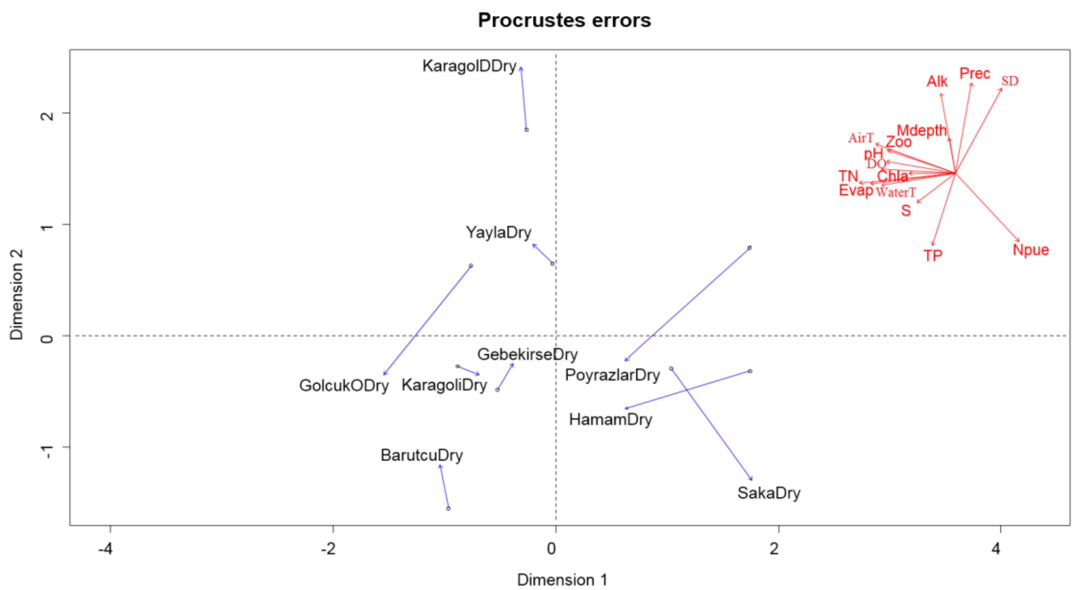

Figure 3.12 Procrustes plot of wet and dry period sampled lakes (black dots: wet period sampled data, arrow: dry period sampled data, distance between points and arrows: Procrustes residuals)

For determining effect of the water quality variables on biological variables, General Linearized Model of multiple regression (GLM) analyses was performed. Correlation among the variables for the lakes were showed that collinear (Pearson r>0.6) predictors for dry and wet years data (Table 3.5). Salinity was correlated with water temperature, Secchi depth was correlated with total phosphorous, precipitation, air temperature was correlated with total nitrogen, evaporation and precipitation and alkalinity were correlated with each other. Thus, surface water temperature, salinity, total phosphorous concentration, and total biomass of zooplankton were chosen as independent variables for the GLM analyses of chlorophyll a. Surface water temperature, salinity, total phosphorous concentration, and chlorophyll a concentration were chosen as independent variables for the GLM analyses of total biomass of zooplankton. Surface water temperature, salinity, total phosphorous concentration, total biomass of zooplankton and chlorophyll a concentration were chosen as independent variables for the GLM analyses of number per unit effort of fish. Therefore, the final best model was showed that chlorophyll a concentration was significantly related to total biomass of zooplankton and total phosphorous in wet years, but in dry years significant differences turned to surface water temperature and number per unit effort of fish (Table 3.6 and 3.7). Total biomass of zooplankton was significantly related to total phosphorous and chlorophyll a concentration. Then, total phosphorous lost significance and chlorophyll a concentration decrease its significance level in dry period (Table 3.8 and 3.9). The number per unit effort of fish was significantly related to total nitrogen, total biomass of zooplankton and surface temperature in wet period, whereas in dry period only total biomass of zooplankton was significantly related (Table 3.10 and 3.11).

Table 3.5 Results of Pearson correlation for the environmental variables from the lakes sampled in dry and wet periods

	Oxy	Stemp	pH	Sal	Secchi	Mdepth	TP	TN	Alk	Chla	Zoo	Npue	Evap	Temp	Prec
Oxy	1,0000	0,4877	0,5169	0,3802	-0,1111	0,1378	0,0123	0,2927	0,0884	-0,1678	-0,2780	0,0878	0,2734	0,0627	-0,0519
Stemp	0,4877	1,0000	0,1261	0,7140	-0,0658	0,3151	0,1197	0,5768	0,3295	0,4190	-0,2643	-0,2076	0,4353	0,5705	0,2572
pH	0,5169	0,1261	1,0000	0,0123	-0,1370	0,0520	0,0995	0,0653	-0,0674	0,0260	0,1183	-0,1965	0,0976	0,2341	-0,0565
Sal	0,3802	0,7140	0,0123	1,0000	-0,2333	0,1534	0,1936	0,2210	0,0519	0,1332	-0,3567	-0,1811	0,1782	0,2285	-0,0073
Secchi	-0,1111	-0,0658	-0,1370	-0,2333	1,0000	0,4790	-0,7618	-0,1920	0,4650	-0,0416	-0,0043	-0,3230	-0,0529	0,1308	0,7953
Mdepth	0,1378	0,3151	0,0520	0,1534	0,4790	1,0000	-0,1894	0,1539	0,4545	-0,1985	-0,0914	-0,3293	0,5457	0,4600	0,2722
TP	0,0123	0,1197	0,0995	0,1936	-0,7618	-0,1894	1,0000	0,2552	-0,1687	0,0710	-0,0136	0,2029	0,2940	0,0826	-0,5274
TN	0,2927	0,5768	0,0653	0,2210	-0,1920	0,1539	0,2552	1,0000	0,4268	0,5414	0,4753	-0,3125	0,8325	0,7230	0,1410
Alk	0,0884	0,3295	-0,0674	0,0519	0,4650	0,4545	-0,1687	0,4268	1,0000	0,2927	0,1110	-0,4399	0,4213	0,4204	0,6552
Chla	-0,1678	0,4190	0,0260	0,1332	-0,0416	-0,1985	0,0710	0,5414	0,2927	1,0000	0,2981	-0,3155	0,2399	0,5120	0,4626
Zoo	-0,2780	-0,2643	0,1183	-0,3567	-0,0043	-0,0914	-0,0136	0,4753	0,1110	0,2981	1,0000	-0,4958	0,4323	0,4197	0,0353
Npue	0,0878	-0,2076	-0,1965	-0,1811	-0,3230	-0,3293	0,2029	-0,3125	-0,4399	-0,3155	-0,4958	1,0000	-0,2919	-0,4826	-0,5063
Evap	0,2734	0,4353	0,0976	0,1782	-0,0529	0,5457	0,2940	0,8325	0,4213	0,2399	0,4323	-0,2919	1,0000	0,7251	0,0506
Temp	0,0627	0,5705	0,2341	0,2285	0,1308	0,4600	0,0826	0,7230	0,4204	0,5120	0,4197	-0,4826	0,7251	1,0000	0,3579
Prec	-0,0519	0,2572	-0,0565	-0,0073	0,7953	0,2722	-0,5274	0,1410	0,6552	0,4626	0,0353	-0,5063	0,0506	0,3579	1,0000

Table 3.6 Generalized Linear Model of chlorophyll a concentration in wet year

Model: Wet year

Chla ~ TP + WaterT + S + Zoo

	Df	Deviance	AIC	scaled dev.	Pr(>Chi)	
<none>		481.29	73.354			
TP	1	2117.95	84.690	13.3356	0.0002604	***
Stemp	1	481.29	71.354	0.0000	0.9957337	
Sal	1	563.20	72.769	1.4145	0.2343130	
Zoo	1	1674.03	82.573	11.2187	0.0008098	***

Table 3.7 Generalized Linear Model of chlorophyll a concentration in dry year

Model: Dry year

Chla ~ TP + WaterT + S + Zoo

	Df	Deviance	AIC	scaled dev.	Pr(>Chi)	
<none>		4115.1	160.86			
TP	1	4123.7	158.90	0.0374	0.84670	
Stemp	1	5562.0	164.28	5.4231	0.01987	*
Sal	1	4243.9	159.41	0.5548	0.45638	
Zoo	1	5035.6	162.49	3.6336	0.05662	.

Table 3.8 Generalized Linear Model of total biomass of zooplankton in wet year

Model: Wet year

Zoo ~ Chla + TP + WaterT + S

	Df	Deviance	AIC	scaled dev.	Pr(>Chi)	
<none>		0.78867	15.629			
Chla	1	2.74317	24.848	11.2187	0.0008098	***
TP	1	1.97888	21.909	8.2794	0.0040096	**
Stemp	1	0.78888	13.632	0.0023	0.9614800	
Sal	1	0.94338	15.241	1.6121	0.2041997	

Table 3.9 Generalized Linear Model of total biomass of zooplankton in dry year

Model: Dry year

Zoo ~ Chla + TP + WaterT + S

	Df	Deviance	AIC	scaled dev.	Pr(>Chi)	
<none>		4.2931	37.281			
Chla	1	5.2534	38.915	3.6336	0.05662	.
TP	1	4.2983	35.303	0.0218	0.88252	
Stemp	1	4.5290	36.244	0.9629	0.32645	
Sal	1	4.3952	35.704	0.4229	0.51548	

Table 3.10 Generalized Linear Model of number per unit effort of fish in wet year

Model: Wet year

Npue ~ Chla + TP + WaterT + S + Zoo + TN

	Df	Deviance	AIC	scaled dev.	Pr(>Chi)	
<none>		0.87615	20.576			
Chla	1	0.93648	19.175	0.5993	0.438853	
TP	1	0.89921	18.810	0.2338	0.628738	
Stemp	1	1.60139	24.004	5.4278	0.019819	*
Sal	1	0.87636	18.578	0.0021	0.963341	
Zoo	1	2.04548	26.207	7.6306	0.005739	**
TN	1	1.45116	23.117	4.5412	0.033089	*

Table 3.11 Generalized Linear Model of number per unit effort of fish in dry year

Model: Dry year

Npue ~ Chla + TP + WaterT + S + Zoo + TN

	Df	Deviance	AIC	scaled dev.	Pr(>Chi)	
<none>		2.2862	29.939			
Chla	1	2.2906	27.974	0.0349	0.851892	
TP	1	2.4089	28.880	0.9413	0.331949	
Stemp	1	2.5537	29.931	1.9920	0.158134	
Sal	1	2.4059	28.858	0.9186	0.337838	
Zoo	1	3.6624	36.421	8.4822	0.003586	**
TN	1	2.5562	29.949	2.0096	0.156304	

3.4 Lakes Mogan and Eymir

Wet and dry years of the Lakes Mogan and Eymir were assigned according to SPI index of the meteorological data that were obtained from Ankara main Station. Before 2001 the period was regarded as wet periods according to SPI index analysis. The years between 2003 to 2008 were regarded as dry years. Moreover, onward 2009 to 2012 was wet years (Figure 3.13). Furthermore, 2011 was the wettest year and 2008 was the driest year.

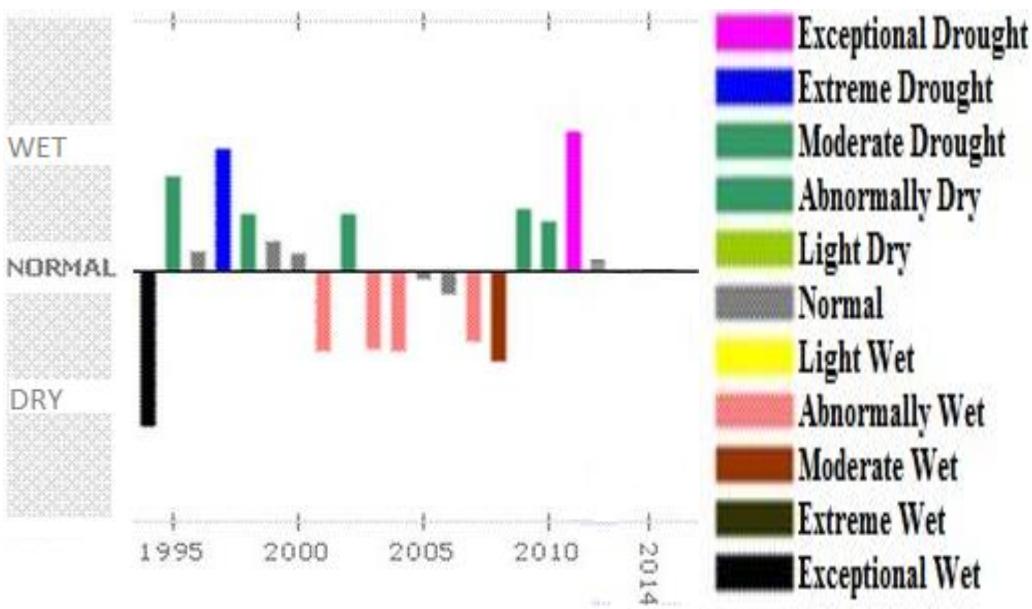

Figure 3.13 12 months SPI results of Ankara

According to Lake Mogan principal component analysis result, the first four axes of the principal component analysis (PCA) were significant and explained 75% of the observed variances. Salinity and conductivity were significant though negatively related, while Secchi depth was significant positively related to the first axis. Dissolved oxygen concentration and pH were significant and positively related to the second axis, whereas total phosphorous was significant though it was negative on the second axis. Dry years were associated high with conductivity, salinity, chlorophyll a concentration and air temperature. On the other hand, the wet years were associated with lower total phosphorous, Secchi depth, dissolved oxygen and mean precipitation (Figure 3.14).

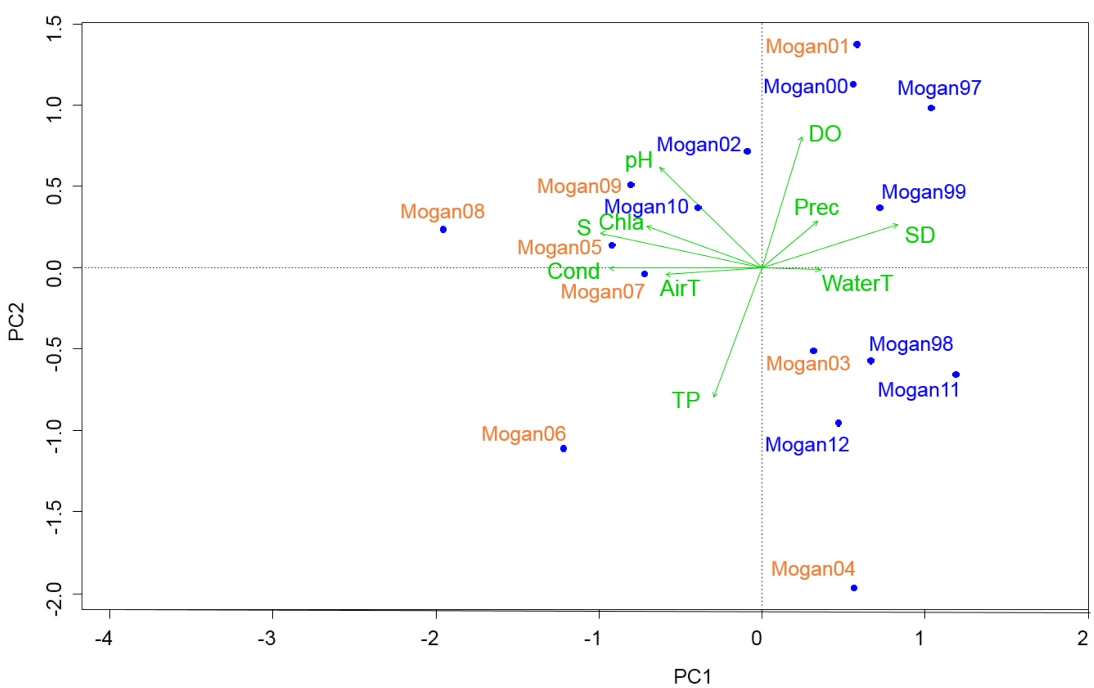

Figure 3.14 PCA plot of Lake Mogan (blue: wet years, red: dry years, green: variables)

Lake Eymir results of the principal component analysis was shown in Figure 3.15 The first three axes of the PCA were significant and explained 69% of the observed variances. For the first axis, salinity and conductivity were positively related whereas the maximum depth was negatively related. For the second axis, pH, Secchi depth and dissolved oxygen concentration had the significant positive contribution, and chlorophyll a concentration had significant negative contribution. Dry years were associated with high conductivity, salinity, surface water temperature and total phosphorous. On the other hand, the wet years were associated with high maximum depth, chlorophyll a, Secchi depth and mean precipitation.

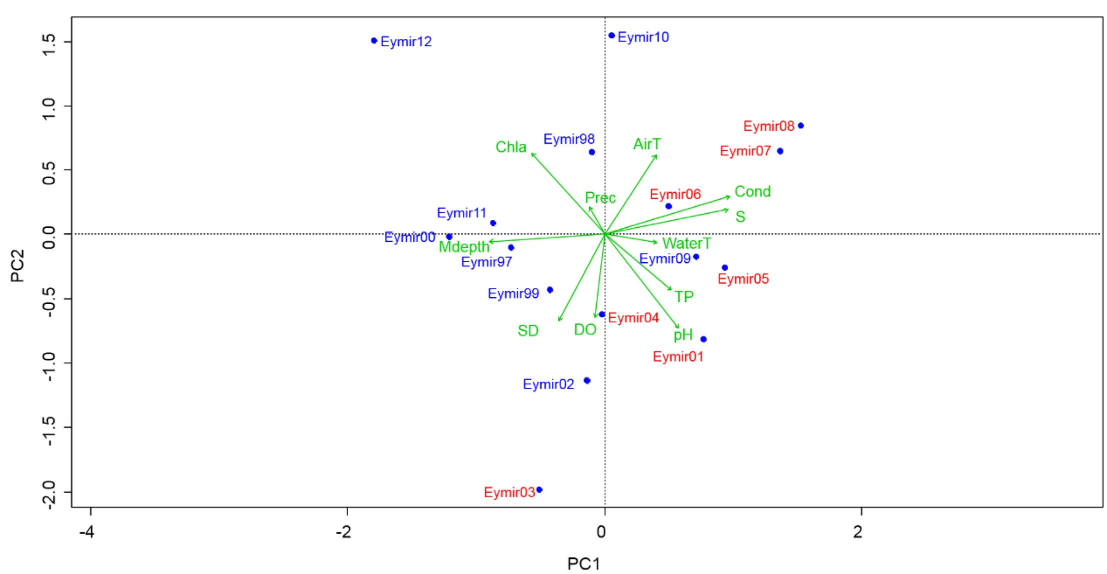

Figure 3.15 PCA plot of Lake Eymir (blue: wet period, red: dry period, green: variables)

CHAPTER 4

DISCUSSION

The results from this study showed that for the studied lakes, meteorological change especially temperature increase and precipitation decrease causes the rise of eutrophication effects and salinity. These were the key factors for determining the trophic structure of lakes. Increase of nutrient concentration combined with decrease of Secchi depth were observed in dry years and summer season. Effect of the drought periods on the lake dynamics led to water level change and increase in the water retention time. Thus, it is expected that salinity and evaporation will cause water scarcity and disappearance of lakes in the future. Lakes sampled in spring season were same as lakes sampled during dry years. These lakes were described as clear water state, because they showed strong correlation with high Secchi depth and low nutrient concentration than lakes sampled in summer season and dry years. Therefore, lakes sampled in summer season and dry years were associated with high nutrient and chlorophyll a concentrations, so they could be identified as in turbid water state conditions. Moreover, hydrological drought combined with physical condition of the lakes triggered the change to eutrophication and increased salinity problems.

4.1 Lakes with Spring and Summer Seasonal Environmental Variables

According to the results of lakes which were sampled both in spring and summer seasons, showed that seasonal difference in net evaporation, precipitation, and air temperature had significant effects on environmental variables measured in lakes especially in the concentration of total nitrogen, pH and water temperature. Lakes sampled during spring season received higher precipitation and their water level, maximum depth and Secchi depth were higher. Furthermore, lakes had lower nutrients (TP and TN) chlorophyll a and dissolved oxygen concentrations, and lower salinity and conductivity. They had relatively clearer water conditions with less phytoplankton. On the other hand, the same lakes' summer season environmental variables were associated with higher chlorophyll a total nitrogen and total phosphorous concentrations, higher salinity and surface water temperature. Because of high nutrient and chlorophyll a concentration, summer season data of the lakes showed that they were in eutrophic conditions.

Higher nutrient concentrations in summer associated with warmer condition would have triggered more phytoplankton production. Similar changes have also been found in other latitude gradient studies (Mazumder and Havens, 1998; Flannagen et al., 2003, Gyllström et al., 2005). A higher phytoplankton yield may result from a decrease in the grazing control of zooplankton on phytoplankton due to higher fish predation on large-bodied zooplankton (Jeppesen et al., 2009), though we did not measure role of top-down control during spring season.

Summer low oxygen concentration along with warmer conditions may have triggered to release phosphorous from lakes sediment (Sondergaard et al., 2003) this may partly explain why nutrient concentration higher in summers despite being used in phytoplankton crop. Moreover, from spring to summer increase evaporation, air temperature and major drop in precipitation were the important for lakes hydrology.

Such changes triggered decrease in water level, which may enhance up concentrations of nutrients through reduced volume (Özen et al., 2010; Jeppesen et al., 2015). Furthermore, such reduction in water level and volume may enhance evaporation water loss as a major avenue of water leaving the system. This in turn may lead to salinization (Beklioğlu & Tan, 2008; Beklioğlu et al., 2011; Jeppesen et al., 2015).

4.2 Lakes with Wet and Dry Years' Environmental Variables

SPI index successfully captured the wet and dry years for the study lakes. Wet years were associated with high precipitation and the dry years were associated with significant reduction in precipitation, which was below the tolerable level, thus it was regarded as drought. However, the lakes located in different region had different degree of wetness/dryness as the precipitation regime accords the lakes were not homogenous. For example, SPI index result for Lake Hamam and Saka show that wet condition was seen in 2006, while SPI index result for Lake Poyrazlar was below the tolerable level so dry condition was seen for Lake Poyrazlar.

Through global climate change increasing drought conditions with lower water availability and increased use of water for irrigation will cause more widespread hydrological problems in lakes and rivers. The comparisons of the environmental variables of the lakes from wet to dry years showed that there was an increase in eutrophication and salinity. When the duration of drought period increase, internal release of nutrients and increase in salinity will be triggered. Cyanobacteria and algal population will increase, causing eutrophication. Algal bloom, less submerged plants, increase in benthic and planktivorous fish and decreased water quality were observed (Moss, 1998).

The study lakes with wet and drought years' data showed that total phosphorous, total nitrogen concentrations and Secchi depth are important environmental variables for explaining differences between wet and dry years. Biological dependent variables chlorophyll a concentration, total biomass of zooplankton and number per unit effort of fish dependent on temperature, availability of nutrients concentration and interaction between trophic structure in wet periods, However, from wet period to dry period, trophic structure between the dependent variables keep their importance, but increase of the nutrient concentration and temperature lead to decrease dependence of biological variables on nutrients.

The study lakes did not react homogeneously to the changing condition that four of the study lakes, Lake Poyrazlar, Saka, Hamam and Gölcük Ödemiş showed large differences from wet to dry year. Lake Poyrazlar, Hamam and Saka are located in the north and the fourth lake Gölcük Ödemiş was located in the south that their Secchi depth decrease more than other sampled lakes, while total phosphorous concentrations and number per unit effort of fish increased more than that of the other study lakes. This may be explained with increased percentage of agricultural area in the catchment and increase use of lake water for irrigation (Mis and Ustaoğlu, 2009).

Lakes Saka, Hamam and Poyrazlar, had the lowest concentration of nutrients and chlorophyll a concentrations, and they were in clear water condition in wet periods. On the other hand, in dry period these lakes became eutrophic. Scheffer et al., (1993) assume that increase of total phosphorous and total nitrogen concentration caused decline and disappearance of submerged plant more in drought periods.

Furthermore, during the dry year most of the lakes especially southern lakes became also more saline and in addition to becoming more eutrophic because of higher evaporative water loss. This is in accordance with previous findings (Beklioğlu and Tan, 2008; Beklioğlu et al., 2011; Jeppesen et al., 2015). Moreover, in drought period lakes fish community was composed of mostly small sized fish, this might have caused decrease in zooplankton biomass and decrease the grazer control on phytoplankton (Jeppesen et al., 2000).

4.3 Lake Eymir and Mogan in Dry and Wet Years

Water level fluctuations are major drivers of Mediterranean especially shallow lakes. Their ecosystem structure and function change largely with hydrological alterations (Beklioğlu et al., 2006, 2011). In dry period of the Lakes Eymir and Mogan, salinity increased with water level change. Moreover, in dry years the external nutrients loading were lower because of less precipitation and less surface runoff (Özen et al., 2010), but total phosphorous concentration was higher than in wet years. This high nutrients level was explained by internal loading of nutrients during dry years and increased in-lake concentration due to high evaporation. Drought-induced decrease in water level and increase in water residence time may provide longer contact with sediment that may enhance internal release of nutrients, but it is opposite of cold temperate lakes in drought periods (Özen et al., 2010). During the dry periods, in-lake TP became more dependent on internal processes such as evaporation and internal loading than on the external loading. In contrast, when the water level increase in wet periods, salinity and conductivity decrease with high water level and decreased water residence time. Due to increasing nutrients and disappearance of submerged plants, algal blooms occurred in lake. Fish predation increase led to increase in grazing effect on large sized zooplankton, causing increase in phytoplankton.

Moreover, Lake Eymir was in turbid water state in 1997 with very low Secchi depth and high chlorophyll a concentration. After the first biomanipulation, light condition was improved. Removal of planktivorous fish between 1998 and 1999 led to decrease in the concentration of chlorophyll a. With the recovery of the lake hydrology in 2002 and 2003, salinity and conductivity decreased to their regular values. However, 5 years after the biomanipulation, the fish biomass increased again to the pre-manipulation level, and in 2004 the lake shifted back to a turbid state with scarce submerged vegetation cover and higher biomass of fish (Özen, 2006). On the other side, in turbid water state, Secchi depth was low compared to clear water state. Thus, submerged plants disappeared in turbid water state. Furthermore, water level change was one of the important mechanisms for submerged macrophytes, as well as change in meteorological variables and particularly increase of temperature. Water level change for Lake Eymir caused significant change in the lake.

In Lake Mogan, the clear water state dominated with submerged plants was very sensitive to water level change. However, in 2004, water level change caused increase in plant coverage. Following year in 2005, because of low Secchi depth, lake water level decline did not lead to shift to high macrophyte cover (Özen et al., 2010). Lake Mogan was only affected by natural changes in nutrient loading determined by variations in hydrology.

CHAPTER 5

CONCLUSION

In conclusion, salinity and eutrophication are the main parameters for determining the effects of precipitation and temperature change on shallow lakes. Climate change enhances occurrence and frequency of drought events in the Mediterranean climatic zone such as Turkey. Therefore, results show that lakes will shift to eutrophic condition in the future. So, water temperature, salinization, number of small fish and cyanobacterial activity will rise potentially.

Moreover, seasonal differences in meteorological variables had an effect on the trophic structure of lakes. Nutrient concentration, water temperature and pH have a significant relation to hydrological condition of the lakes. Lakes sampled in spring season had clear water state conditions because of low nutrient and chlorophyll a concentration. During summer season lakes had eutrophic conditions such as high concentration of total phosphorous and nitrogen and chlorophyll a. On the other hand, seasonality causes more complex effects on the lakes. However, for all lakes dissolved oxygen concentration, maximum depth and Secchi depth decrease from spring to summer seasons. Thus, in most of the lakes shift from clear water state to turbid water state and cyanobacteria blooms are observed.

During dry and wet period analyses, drought conditions with high air temperature caused hydrological problems and change in environmental variables. Duration of drought period was also important for lakes. Internal release of nutrients and salinity were correlated with duration of drought. Therefore, high nutrients concentration and salinity caused eutrophication and water quality decrease, because cyanobacteria and algal population increased. In addition, latitudinal gradient is particularly important for wet and dry period of the lakes. Northern lakes in drought years experienced important change in their structure. In northern lakes, number of small fish and total phosphorous concentration increase and Secchi depth and precipitation decrease significantly.

Furthermore, in Lakes Eymir and Mogan, concentrations of nutrients, chlorophyll a and salinity increased especially in drought years, which are caused by water level fluctuations and high hydraulic retention time. During the dry periods, in-lake TP became more dependent on internal processes such as evaporation and internal loading than on the external loading.

In order to obtain more certain results, increasing number of environmental variables and further studies are recommended and necessary. Global climate change is not only reason for causing environmental variables change on the lakes. Anthropogenic effects on lake are another important reason. Therefore, increasing the number of study lakes, and for drought and wet period analyses sampling in the same year for all lakes are also needed to understand the effect of drought on lakes clearly. On the other hand, catchment studies must be needed for providing another point of view for environmental changes of lakes, because physical and geological structure of catchment of the lakes are not homogeneous and cause differences in changes. Effects of land-use change and fish community structure of the lakes studies are needed to help for showing environmental change on the lake ecosystem. Furthermore, in order to gain a deep understanding of effects of drought related to climate change, research should be supported by more long term monitoring data and needed controlling or preceding studied lakes.

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