ROLE OF HYDROLOGY, SEWAGE EFFLUENT DIVERSION AND FISH ON MASS BALANCE OF NUTRIENTS IN A SYSTEM OF SHALLOW LAKES MOGAN AND EYMİR, TURKEY

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ABSTRACT

ROLE OF HYDROLOGY, SEWAGE EFFLUENT DIVERSION AND FISH ON MASS BALANCE OF NUTRIENTS IN A SYSTEM OF SHALLOW LAKES MOGAN AND EYMİR, TURKEY

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In this study, annual total phosphorus (TP) budget and dissolved inorganic nitrogen (DIN) load were constructed for Lakes Mogan and Eymir for the period of eight years from 1997 to 2004 and the period of ten years covering from 1993 to 1995 and 1997 to 2004, respectively.

Lake Mogan experienced seasonal and interannual water level fluctuations. Low water level experienced in 2001 led to decrease in the in-lake TP amount whereas 2-fold increase in the in-lake DIN amount was recorded. Also, high hydraulic residence time resulted in high TP and DIN amount in the lake. Increase in hydraulic residence time was due to management of the lake level. It seems that this practice deteriorates the water quality of Lake Mogan.

In Lake Eymir, sewage effluent diversion undertaken in 1995 resulted in 2-fold and 11-fold decrease in TP and DIN amounts in the lake, respectively. High biomass of carp and tench were halved through selective removal during 1998-1999. A 2.5-fold and 1.5 fold decrease in the in-lake TP and DIN amounts, respectively, were recorded after the biomanipulation. In low water level years, the in-lake TP increased and the in-lake DIN amounts were high despite the fact that TP and DIN loads via inflows were significantly low. Therefore, the results showed that the in-lake phosphorus and nitrogen amount were controlled by internal processes rather than external loading in the years with low water levels which coincided with the high hydraulic residence times.

Key words: phosphorus, nitrogen, water level, submerged plants.

ÖZ

MOGAN VE EYMİR SIĞ GÖLLERİNDE HİDROLOJİ, EVSEL ATIK UZAKLAŞTIRILMASI VE BALIĞIN BESİN BÜTÇESİNDEKİ ROLÜ

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Bu çalışmada, Mogan Gölü için 1997-2004 arası sekiz yıllık ve Eymir Gölü için 1993-1995 ve 1997-2004 arası on yıllık toplam fosfor bütçeleri ve çözünmüş inorganik azot yükleri yapılmıştır.

Mogan Gölü mevsimsel ve yıllık su seviyesi değişimleri yaşamaktadır. 2001 yılındaki düşük su seviyesi, göldeki toplam fosfor miktarının azalmasına neden olurken çözünmüş inorganik azot miktarında iki kat artış kaydedilmiştir. Ayrıca, yüksek hidrolik kalma süresi, gölde yüksek toplam fosfor ve çözünmüş inorganik azot miktariyla sonuçlanmıştır. Hidrolik kalma süresindeki artış, göl seviyesinin işletiminden kaynaklanmaktadır. Bu uygulamanın, Mogan Gölü'nün su kalitesinin bozulmasına yol açtığı görülmüştür.

Eymir Gölü'nde 1995'te evsel atıkların uzaklaştırılmasıyla göldeki toplam fosfor miktarı iki ve çözünmüş inorganik azot miktarı 11 kat azalmıştır. Seçici uzaklaştırmayla yüksek biyokütledeki sazan ve kadife balıkları 1998-1999 döneminde yarıya indirilmiştir. Biyomanipulasyondan sonra göldeki toplam fosfor miktarında 2,5 ve çözünmüş inorganik azot miktarında 1,5 kat azalma kaydedilmiştir. Düşük su seviyesi yıllarında, derelerden gelen toplam fosfor ve çözünmüş inorganik azot yüklerinin düşük olmasına rağmen göl içi toplam fosfor artmıştır ve göl içi çözünmüş inorganik azot miktarları yüksektir. Bu yüzden, düşük su seviyesiyle birlikte yüksek hidrolik kalma süreli yıllarda, göl içi fosfor ve azot miktarlarının dışardan gelen yüklemelerden ziyade göl içindeki mekanizmalar tarafından kontrol edildiği gösterilmiştir.

Anahtar kelimeler: fosfor, azot, su seviyesi, suiçi bitkiler.

To My Little Niece, Ceren

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DIN	Dissolved Inorganic Nitrogen
E	Eymir
EIE	General Directorate of Electrical Power, Resource Survey & Development Administration
HWL	High Water Level
IBA	Important Bird Area
LWL	Low Water Level
M	Mogan
RWL	Regular Water Level
SED	Sewage Effluent Diversion
STW	Sewage Treatment Work
TEAS	Turkey Electricity Associated Company
TP	Total Phosphorus

CHAPTER 1

INTRODUCTION

1.1. Ecology of Shallow Lakes:

Shallow lakes, where the entire water column is frequently mixed, are largely colonized by submerged plants when water clarity allows. The intense sediment-water interaction and the potentially large impacts of submerged plants makes the functioning of shallow lakes be different from that of deep lakes (Jeppesen, 1998; Scheffer, 1998).

Shallow lakes are known to switch between two alternative stable states, a clearwater state dominated by abundant submerged vegetation and a turbid water state dominated by high phytoplankton abundance and other suspended solids (Scheffer, 1989; Moss, 1990; Scheffer et al., 1993). Two alternative equilibria exist over a range of intermediate nutrient levels (Jeppesen, 1998). In addition to nutrients, increase in water level or benthi-planktivorous fish might cause a shift from macrophyte-dominated clearwater state to phytoplankton-dominated turbid water state when a critical turbidity is exceeded (Scheffer et al., 1993).

Submerged macrophytes play a crucial role for maintaining clearwater state in shallow lakes since they provide useful stabilizing mechanisms. They cause reduction of sediment resuspension (Boström et al., 1982), nutrient limitation of algae through nitrogen uptake and enhancement of denitrification (Ozimek et al., 1990; van Donk et al., 1993), release of allelopathic substances by plants that inhibit the growth of algae (Wium-Andersen, 1987), refuge for zooplankton against fish predation

(Timms & Moss, 1984) and spawning grounds and refuge against cannibalism of piscivorous fish (Grimm, 1989).

1.2. Hydrology:

The balance of water in lakes is expressed by the basic hydrological relationship in which change in water storage is governed by inputs from all sources less water losses (Wetzel, 1983).

Water input to the lakes includes several sources:

Precipitation directly on the lake surface: Although most lakes, largely in exorheic regions, receive a relatively small proportion of their total water input from direct precipitation, this percentage increases in very large lakes. (Wetzel, 1983).

Water from surface influents of the drainage basin: The amount of the total water input to a lake from surface influents is highly variable. Lakes of endorheic regions receive nearly all their water from surface runoff. The rate of runoff from the catchment and corresponding changes in lake level are strongly influenced by the nature of the soil and vegetation cover of the catchment (Wetzel, 1983).

Groundwater seepage below the surface of the lake through the sediments or as discrete subsurface springs: Seepage of groundwater is commonly a major source of water for lakes in rock basins and lake basins in glacial till that extend well below the water table. Springs from groundwater occur frequently in hard-water lakes of calcareous drift regions, where the basin is effectively sealed from groundwater seepage by deposits within the basin (Wetzel, 1983).

Losses of water from lakes occur by:

Flow from an outlet or seepage into the groundwater through the basin walls: Deposition of clays and silts commonly forms a very effective seal in drainage lakes, from which most or all of the outflow leaves by the outlet. In seepage lakes, losses to groundwater usually occur from the upper portions of the basin (Wetzel, 1983).

Direct evaporation from the lake surface: The extent and rates of evaporative losses are highly variable according to season and latitude, and are greatest in endorheic regions. Lakes of semi-arid region commonly have no outflow and lose water only by evaporation (Wetzel, 1983).

Evapotranspiration from emergent and floating-leaved aquatic plants: In most situations, transport of water from the lake to the air is greatly increased by a dense stand of actively growing littoral vegetation, as compared to evaporation rates from open water. Further, plant growth and evapotranspiration are predominantly seasonal in lakes of exorheic regions; in tropical lakes, many of the large hydrophytes are perennials and grow more or less continually (Wetzel, 1983).

Thus, each of these inputs and losses varies seasonally and geographically and is governed by the characteristics of the lake basin, its catchment and the climate (Wetzel, 1983).

1.3. Nutrients:

Nitrogen and phosphorus are key and essential nutrients for living organism because their natural supply is lower than the amounts that organisms need. Therefore, they are regarded as key or limiting nutrients (Moss et al., 1996a; Moss, 1998).

Although there is a huge global reserve of atmospheric nitrogen gas, it is accessible in this form to only a few nitrogen-fixing bacteria. All other organisms must use combined nitrogen, which has previously been fixed from the atmosphere into ammonium and nitrate ions. Phosphorus is, on average, the scarcest element in the earth's crust. It is found in small quantities in rocks and is also relatively insoluble. It is easily bound to clays in soils and hence dissolves, as phosphates, only at low rates. Both nitrogen and phosphorus, in a variety of forms, enter the water that runs off from land into lakes. These forms include dissolved inorganic compounds, such as nitrite, nitrate, ammonium or reactive phosphate ions, and dissolved organic compounds, such as nitrogen containing amino acids or the sugar-phosphates. There are also small particles, called colloids, such as clays and iron minerals, that contain adsorbed phosphate, and fragments of organic matter including detritus. All of these dissolved and particulate forms of nitrogen and phosphorus may become available for growth of algae and plants in the lake, either directly or following simple chemical reactions or transformation by bacteria. These all possible forms in water are collectively called as total phosphorus and total nitrogen. In pristine waters, total phosphorus concentration will be of order of a few micrograms to a few tens of micrograms per litre. Total nitrogen concentration will be a few tens to a few hundreds of micrograms per litre. These same nutrients are required also by land ecosystems, which conserve these scarce nutrients for continual cycling and re-use so there is very little nutrients that escapes to lakes from vegetation in the catchment. Therefore, nitrogen and especially phosphorus frequently limits algal growth in a lake (Moss et al., 1996a; Moss, 1998).

Catchment has a great impact on trophic state of a lake. Water that drains a catchment with poorly weathered rocks and vegetated land contains little nitrogen and phosphorus so lake is in an oligotrophic state. In this state, lake water is clear so light availability is high in the water column. This allows growth of submerged plants. A catchment that is composed of more reactive rocks and soils produce relatively more fertile water. (Moss et al., 1996a; Moss, 1998).

Lake sediment may become important source for phosphorus. In aerobic conditions, phosphorus is immobilized with Fe(III). If anaerobic conditions arise, Fe(III) is reduced to Fe(II). This leads to phosphorus release from sediment. This can be referred to as internal phosphorus loading (IPL). Sediment plays a significant role in nutrient dynamics due to mixing since thermal stratification does not occur in shallow lakes. Other factors in addition to oxygen and iron can influence phosphorus release from sediment. High pH and temperature decrease iron-phosphorus binding. Also, wind and benthivorous fish (such as carp and bream) by resuspension cause phosphorus release from sediment (Søndergaard et al., 2003).

Phosphorus concentration in the lake water is determined by as a result of the balance between external and internal phosphorus loading. External loading is affected by soil type, land use and surface flows of catchment. In deep lakes, external loading is a key factor in control of lake phosphorus whereas in shallow lakes, sediment is a key factor for the phosphorus (Boström et al., 1982; Marsden, 1989).

Nitrogen differs from phosphorus. It doesn't accumulate in the sediment as much as phosphorus. It can be released to atmosphere by denitrification process. Some cyanobacteria can use atmospheric nitrogen gas directly. This process is called as nitrogen fixation. Organic nitrogen in detritus can be converted to ammonium by some bacteria. In the aerobic top layer of sediment, ammonium can be transformed to nitrate. If anaerobic conditions exist, nitrate is reduced to ammonium. Then, ammonium is converted to nitrogen gas, which is released to atmosphere. This process is called as denitrification (Scheffer, 1998).

1.4. Relationship between Hydrology and Nutrients:

Hydrology is a crucial factor for nutrients especially for shallow lakes. Previous studies mostly focused on external nutrient loading that depends on water input. The relationship between in-lake nutrient concentration and hydraulic residence time has shown already by Vollenweider, (1975). However, the significance of hydrology on internal nutrient dynamics of shallow lakes has been understood recently.

Water levels in shallow lakes naturally fluctuate intra- and interannually depending largely on regional climatic conditions. Through global climate change, water level fluctuations may become as significant as nutrients on functioning of shallow lakes (Coops et al., 2003). Water level fluctuations may be a catastrophic disturbance that may cause shifts between the turbid and the clear, macrophyte-dominated state that is independent of nutrient enrichment and top-down effects (Wallsten & Forsgren, 1989; Blindow, 1992; Beklioglu et al., 2004).

Water level seems to be a major factor influencing summer thermal stratification, nutrient dynamics and submerged plant development. Decrease in summer water level results in lack of thermal stratification. This, in turn, enhances phytoplankton growth by continuous supply of nutrients through increased internal loading (Naselli-Flores, 2003). On the other hand, high water levels in spring may limit submerged plant expansion inducing a shift to a sparsely vegetated state, whereas a low spring lake level may enhance macrophyte abundance and richness (Blindow, 1992; Gafny & Gasith, 1999; Beklioglu et al., 2004; Havens et al., 2004; Van Geest et al., 2005).

1.5. Eutrophication:

Human activities in the catchment also affect the water chemistry of a lake. Sewage effluent, animal farming, agriculture with intensive usage of fertilizers are the main sources of phosphorus and nitrogen. Human settlement and agriculture also lead to loss of natural vegetation and forests. The amounts of phosphorus and nitrogen reaching lakes increase. This is called as eutrophication. Eutrophication causes increase in phytoplankton growth, which makes the water turbid. Shading by these organisms ultimately leads to a collapse of the vegetation due to light limitation. Biodiversity declines in lakes (Moss, 2001). Algal blooms especially cyanobacteria lead to serious problems because they produce toxic substances, which are harmful for aquatic organisms and people (Skulberg et al., 1984; Carmichael, 1991).

In order to predict the effects of nitrogen and phosphorus inputs on receiving waters, it is necessary to be able to predict how water body nutrient concentrations vary as the external inputs are changed. The development of quantitative models that relate external nutrient inputs to the resulting water column concentrations of nutrients in the water body itself was a second key development in eutrophication research. This conceptual advance resulted from the introduction of mass-balance approaches to aquatic ecosystems. A rigorous quantitative framework has developed to predict the responses of freshwater lakes to eutrophication since Vollenweider (1968). Essential to this framework are the calculations of mass budgets for both phosphorus and nitrogen and the parallel calculations of a hydraulic budget for the water body (Smith et al., 1999).

1.6. Restoration:

External nutrient loading can be the largest source of nutrients to lakes. The reduction of external phosphorus loading, which is a point source from sewage effluent, has been accepted as the first crucial step for restoration of eutrophic shallow lakes. Long resilience due to internal phosphorus loading was anticipated in early studies (Marsden, 1989; Søndergaard et al., 2003). Phosphorus release from the phosphorus pool accumulated in lake sediments during the time when loading was high may counteract the reduction of external loading. The duration of resilience depends on conditions such as the magnitude and duration of loading, hydrological residence time and iron input (Cullen & Forsberg, 1988; Sas, 1989; Jeppesen et al., 1991; Jensen et al., 1992). Biological homeostasis is another factor affecting internal phosphorus loading. Benthivorous fish such as bream (*Abramis brama)* and carp (*Cyprinus carpio*) have a significant impact on the resuspension of sediment (Breukelaar et al., 1994) as well as on the concentration phosphorus and its release from the sediment (Havens, 1991; Søndergaard et al., 1992; Søndergaard et al., 2003).

On the other hand, results from long-term studies have also shown that decrease in the in-lake phosphorus upon reduction has been achieved in some lakes (Beklioglu et al., 1999; Jeppesen et al., 2002; Villena & Romo, 2003; Jeppesen et al., 2005). This reduction has reflected on a recovery in density of daphnids, piscivorous fish biomass, etc. (Jeppesen et al., 2002 & 2005).

Although the role of nitrogen in shallow lakes is less explored, several recent studies showed that high nitrogen loading reduces the chances of obtaining a clearwater state at intermediate phosphorus concentration (Moss, 2001; González Sagrario et al., 2005; James et al., 2005). Also, Moss (2001) argued that macrophyte communities are particularly sensitive to total nitrogen loading and will exhibit low species diversity at high concentration.

Understanding and exploiting trophic cascades provides a successful basis for managing the water quality of eutrophic systems. First application of manipulation of upper trophic level consumers to control lower trophic levels was done by Shapiro et al., (1975). It is based on top-down control of phytoplankton. This can be achieved by either adding piscivorous fish or removal of benthi-planktivorous fish or together. This change in fish community leads to increase in large-bodied zooplankton, causing reduction in phytoplankton. The reduction of benthi-planktivorous fish stock can also trigger clearwater through the processes such as reduced sediment resuspension and internal loading of nutrients and in turn, re-establishment of submerged plants (Hansson et al., 1998). Low in-lake nutrient concentrations may be achieved owing to either increased top-down control on phytoplankton or increased abundance of submerged macrophytes (Søndergaard et al., 1990) since re-development of submerged plants is very crucial for the success and maintenance of biomanipulation. Since, submerged vegetation provides useful stabilizing buffer mechanisms (see previous section, ecology of shallow lakes). Therefore, biomanipulation is a useful tool for lake restoration and has been employed with varying degrees of success in many parts of the world (Shapiro & Wright, 1984; Benndorf, 1990; Jeppesen et al., 1990; De Melo et al., 1992; Moss et al., 1996b; Meijer et al., 1999; Beklioglu et al.; 2003). However, long-term stability of clearwater without stringent nutrient control appears to be less possible (Søndergaard et al., 2003; Jeppesen et al., 2005).

1.7. Resilience & Re-oligotrophication:

Planktivorous and benthivorous fish seem to contribute significantly to biological resilience in shallow eutrophic lakes. By feeding on large zooplankton and stirring up sediment when foraging on benthic invertebrates, they prevent efficieny grazing on phytoplankton, thereby keeping the lake in the turbid water state despite reduction in external loading (Hosper & Jagtman, 1990; Jeppesen et al., 1990; Scheffer, 1990; Scheffer et al., 1993).

Moreover, resuspension of the sediment with high organic matter and water content accumulated during eutrophication may also delay or even prevent a shift to the clearwater state in large, shallow, wind-exposed lakes (Bachmann et al., 1999; Meijer et al., 1999). Continuous resuspension of detritus reduces the light penetration to prevent growth of submerged macrophytes (Bachmann et al., 2001) or that the sediment in the reoligotrophication phase is too loose and therefore unsuitable for establishment of rooted plant communities (Meijer et al., 1999). However, Jeppesen et al., (2003) found that resuspension of sediment did not prevent a shift to clearwater state during reoligotrophication following reduction in external nutrient loading for 15 shallow Danish lakes. Resuspension may, however, indirectly influence the recovery process, as resuspended sediment can release nutrients for phytoplankton growth (Søndergaard et al., 1992).

A further factor contributing to resilience following a reduction in nutrient loading is grazing by waterfowl, in particular coot (*Fulica atra)* and mute swan (*Cygnus olor*), which has been reported to hinder successful colonization by submerged macrophytes (Lauridsen et al., 1993; Van Donk et al., 1994; Søndergaard et al., 1996).

Based on an analysis of 18 case studies from European lakes, Sas (1989) argued that four-stage response of phytoplankton to nutrient loading reduction. At the first stage, no response is found, as the phosphate concentration is too high throughout the growing season to limit the phytoplankton growth. At the second stage, P limitation occurs during part of the summer, leading to lower phytoplankton biomass per unit of volume but only small or no changes in biomass per unit area, due to a deepening of the photic zone because of the improved water clarity. At the third stage, biomass of per unit area is affected and the fourth stage, changes in phytoplankton community composition also occur. Other hypotheses are resistance to changes in nutrients increases up through the food web, thus reflecting the overall increase in size and turnover rates of keystone-species populations (Carpenter et al., 1992; Reynolds, 2000) and that the resistance increases with increasing length of food chains (Pimm & Lawton, 1977).

The scarcity of long reoligotrophication time-series covering multiple trophic levels including fish has rendered it difficult to validate the different hypotheses of lake responses in the transient phase following nutrient loading reductions. For 11 year study of 23 Danish lakes, Jeppesen et al., (2002) found that the biomass and structure of phytoplankton and fish responded rapidly to an in-lake TP reduction. Major changes occurred in the relative abundance of phytoplankton community composition in TP-reduced lakes, with a gradual reduction in the share of non-heterocyctous cyanobacteria. In addition, the share of dinophytes, cryptophytes and chlorophytes increased. A significant reduction in the abundance of planktivorous fish and an increase in the share of potential piscivores at reduced TP. Comparatively minor changes occurred at the zooplankton level in the TP-reduced lakes, while zooplankton also responded markedly in the biomanipulated lakes.

In biomanipulated lakes, removal of benthi-planktivorous fish can also have indirect effects on reoligotrophication process. First, decreased predation by benthivorous fish may enhance the abundance of benthic invertebrates (Andersson et al., 1978) and thereby indirectly oxidization of sediment and reducing phosphorus release. Second, enhanced light penetration of the water stimulates benthic algae production, which, in turn, reduces the risk of resuspension (Delgado et al., 1991). Also, benthic algae form a barrier to diffusion between sediment and water and oxygenate the upper sediment layer (Scheffer, 1998).

1.8. Variation in Theme - Low Latitude Lakes:

Experience with lake restoration in warm-temperate, subtropical and tropical lakes is limited compared with the northern temperate lakes. Few studies have shown that nutrient loading reduction may lead to decrease in TP and chlorophyll a levels (Lowe et al., 2001; Beklioglu et al., 2003; Villena & Romo et al., 2003; Beklioglu & Tan, submitted). Jeppesen et al., (2000) suggested that the TP concentration has been reduced to below 0.05-0.1 mgl^{-1} to obtain clearwater state dominated by submerged plants for shallow temperate freshwater lakes. However, Romo et al., (2004) found that lower threshold of phosphate loadings ($\leq$ 0.05 mgl^{-1}) than those reported from temperate shallow lakes was required for Mediterranean shallow lakes. If hydrological changes through global warming in shallow lakes located especially in semi-arid or arid Mediterranean lakes are taken into consideration (Loaiciga et al., 1996), even lower thresholds of nutrient loading may be necessary for obtaining submerged vegetation dominated clearwater state.

Food web manipulations have mostly been carried out on shallow northern temperate lakes (Perrow et al., 1997; Hansson et al., 1998; Meijer et al., 1999; Mehner et al., 2002). Climate and hydrological regimes are likely to affect lake communities differently in warmer regions (Jeppesen et al., 2005). However, a successful biomanipulation led to switch from turbid state to clearwater state in a warm temperate Mediterranean Lake Eymir. This might have resulted from presence of strong piscivorous pike and prominent winter ice cover as opposed to subtropical and tropical lakes (Beklioglu & Tan, submitted). In warmer lakes, zooplankton may have weaker control of algal biomass (Fernando, 1994; Lazzaro, 1997; Benndorf et al., 2001) as high annual temperatures increase fish growth and predation rates on large-bodied zooplankton (Bachmann et al., 1996). Moreover, high planktivore biomass and small-bodied zooplankters may enhance nutrient cycling and algal growth (Fernando, 1994; Lazzaro, 1997; Lazzaro et al., 2003; Beklioglu et al., 2003). Furthermore, higher temperatures and mild winters favour presence of cyanobacteria all the year round (Romo & Miracle, 1993). In addition to higher annual water temperatures than in temperate lakes, Mediterranean shallow lakes also have significant seasonal water level fluctuations and smaller seasonal changes of light and temperature (Coops et al., 2003; Beklioglu et al., submitted; Beklioglu & Tan, submitted). Lowering of water levels may improve light conditions for macrophytes, which in combination with over wintering of submerged macrophytes due to higher temperatures could stabilise macrophyte dominance and clearwater phases (Romo et al., 2004).

The mass balance studies on total phosphorus (TP) and dissolved inorganic nitrogen (DIN) have focused on north temperate lakes. However, only few studies were present for Mediterranean lakes (Jossette et al., 1999; Romero et al., 2002). Moreover, there was a limited number of study about the effects of water level fluctuations on nutrient dynamics and ecology of shallow lakes located in Mediterranean or semi-arid to arid region (Gafny & Gasith, 1999; Coops et al., 2003; Naselli-Flores, 2003; Beklioglu et al., 2004; Beklioglu et al., submitted; Beklioglu & Tan, submitted).

1.9. Scope of the Study:

One of the scopes of the present study was to construct the water and total phosphorus (TP) budget and dissolved inorganic nitrogen (DIN) load to evaluate impacts of water level fluctuation on the nutrient dynamics in a Mediterranean Lake Mogan.

In addition to hydrological changes, roles of external nutrient reduction and biomanipulation are very crucial on nutrient dynamics in shallow lakes. In Lake Eymir, sewage effluent diversion was undertaken in 1995 and biomanipulation took place between August 1998 and December 1999. Therefore, this study was also aimed to construct water and TP budgets and DIN load for ten-year data to evaluate impacts of sewage effluent diversion, biomanipulation and hydrology on the nutrient dynamics in a Mediterranean Lake Eymir.

CHAPTER 2

STUDY SITES

Lake Eymir and Lake Mogan are located 20 km south of Ankara, within the Gölbasi Municipality. Lakes Eymir and Mogan are alluvial dam lakes formed by damming of Imrahor River at the beginning of last century. The basin was formed by tectonic depression and has been named as Gölbasi formation (Görgün, 1994).

The region has the Central Anatolian climatic conditions (semi-arid), with most of the rain falling during late winter and spring. The summers are hot with an average temperature of 22.0±0.7ºC and relatively dry with an average precipitation of 58.7±41.9 mm. Both lakes are important recreational sites of Ankara. Besides Gölbasi Municipality, there are TEAS settlement, ten villages and Police Academy in the catchment area of both lakes, and they are affected by agricultural practices, recreation, as well as small-scale industries in the catchment.

2.1. Lake Mogan:

Lake Mogan (39°47′N 32°47′E) is a shallow lake with of a mean depth 2.1 m and a maximum depth of 3.5 m. It is a large lake with a surface area of 5.4–6 km^2 and a total of 925 km^2 drainage area situated 20 km south of Ankara. The lake is mainly fed by four main inflows, the Sukesen brook in the north, the Gölcük and Yavrucak brooks in the west and the Çölovasi brook in the east. These brooks first run through agricultural lands and then through reed beds before reaching the lake. The outflow of the lake empties into downstream Lake Eymir through a canal and a wetland in the north. Gölbasi town located north of the lake has a population of 62,602 people (census data of 2000, State Institute of Statistics). Sukesen brook, which runs through the town before reaching the lake, used to receive sewage effluent discharge until 1999. Since then, the effluent has been connected to a collector. However, the west catchment of the lake was recently opened to settlement and the sewage effluent of the houses was discharged into Gölcük and Yavrucak brooks, which were connected to the collector later.

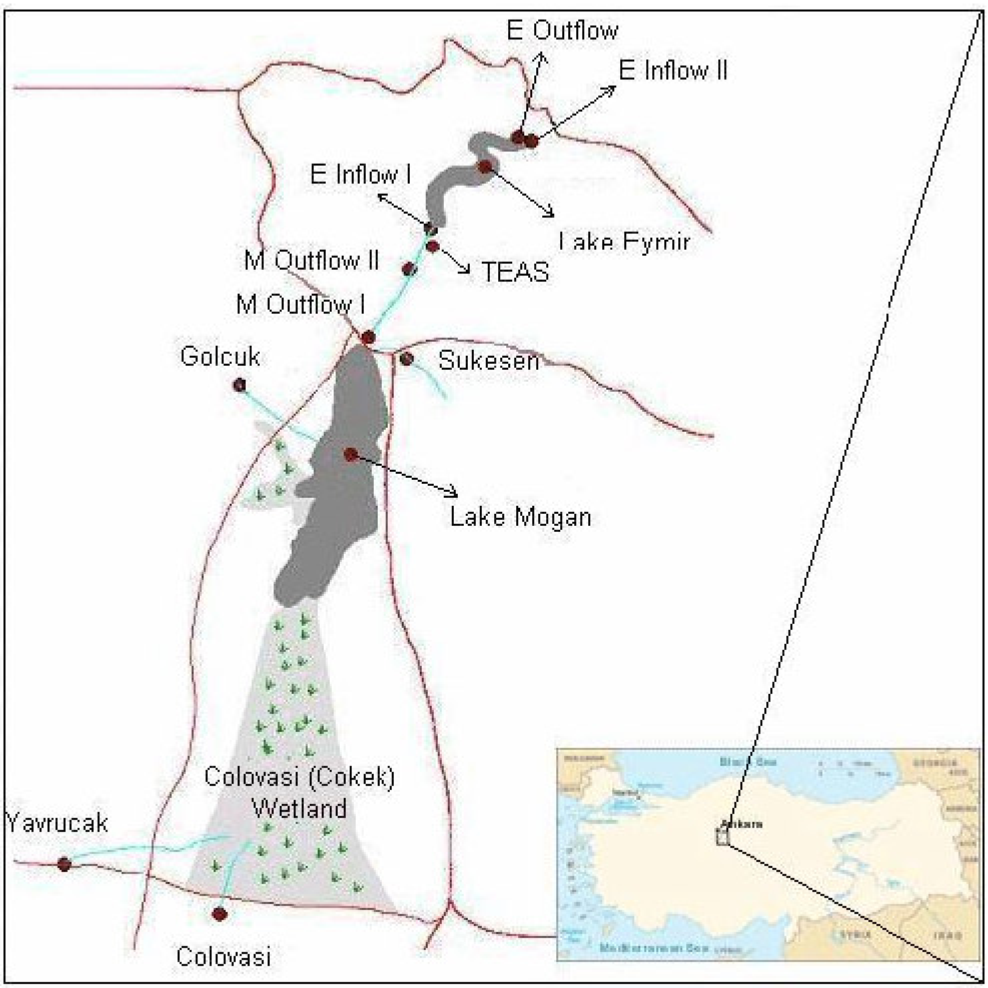


Figure 2.1: Lakes Mogan and Eymir.

The earliest limnological survey, which was carried out during 1971-1972, recorded a turbid water state (Secchi disc transparency: 39 ± 7 cm) with limited distribution of submerged plants confined to the very shallow areas, as a belt of 8-10 m width on the shores (Tanyolaç & Karabatak, 1974). The subsequent survey, which was carried out after the implementation of new water regime using the sluice gate, recorded an improvement in the water clarity (Secchi depth of 90 ± 6 cm), and a slight increase in the vegetation coverage (Obali, 1978). Furthermore, a submerged plant dominated clearwater state was recorded, with a very high vegetation cover in 1991 (80%) and a high Secchi disc transparency (168 ± 56 cm) (DSI, 1993).

Burnak & Beklioglu (2000) reported that the lake was in macrophyte-dominated clearwater state at moderate TP (63 ± 5 µg l^{-1}), low DIN (166 ± 58 µg l^{-1}) and chlorophyll-a (8.8 ± 2 µg l^{-1}), very high Secchi depth transparency and 70-80% macrophyte coverage. The lake experienced regular intra- and interannual water level fluctuations. Tan (2002) found that an increase in the spring water level compared to the previous years resulted in disappearance of macrophytes in 2000, regardless of the low nutrient concentrations. Moreover, in the consecutive year a decrease in the spring water level led to re-colonization of the submerged macrophytes to 90% of the lake surface area (Table 2.1) (Tan, 2002). In 2002, the annual and spring water levels increased again and the submerged macrophyte coverage decreased to 19% (Table 2.1) (Kisambira, 2003). During these state shifts in the lake, deteriorations in the chlorophyll-a concentrations and Secchi depth transparency were observed.

A study carried out on Lake Mogan to investigate role of waterfowl and fish on growth of submerged macrophytes revealed their effects were low in Lake Mogan with abundant submerged vegetation (Sandsten et al., 2005).

Table 2.1: The changes (mean ± standard deviation) in the variables measured from 1997 to 2004 in Lake Mogan. The spring lake level and the spring Secchi depth included the measurement of the variable from March to May. (m a.s.l: meters above sea level).

Year	1997	1998	1999	2000	2001	2002	2003	2004
Lake level (m a.s.l)	972.81 ± 0.24	972.89 ± 0.19	972.85 ± 0.18	972.71 ± 0.41	972.40 ± 0.31	972.94 ± 0.30	973.05 ± 0.31	972.91 ± 0.21
Spring lake level (m a.s.l)	973.10 ± 0.11	973.04 ± 0.09	973.07 ± 0.10	973.25 ± 0.16	972.73 ± 0.03	973.16 ± 0.23	973.40 ± 0.02	973.09 ± 0.04
Salinity (‰)	1.12±0.01	1.11±0.09	1.19±0.04	1.04±0.05	1.21±0.06	1.11±0.04	1.04±0.05	1.16±0.27
Secchi depth (cm)	229 ± 99	216 ± 53	211 ± 76	184 ± 55	212 ± 86	113 ± 15	119 ± 46	110 ± 68
Suspended solid (mg l^{-1})	-	-	11.5 ± 8.5	6.0 ± 4.3	8.1 ± 6.6	10.0 ± 3.0	9.6 ± 5.2	16.4 ± 10.2
Total phosphate (µgl^{-1})	73 ± 30	82 ± 18	77 ± 35	99 ± 29	55 ± 28	73 ± 32	93 ± 43	122 ± 46
Nitrite & Nitrate (µg l^{-1})	97 ± 118	69 ± 78	74 ± 54	59 ± 52	148 ± 88	91 ± 136	211 ± 172	135 ± 64
Ammonium (µg l^{-1})	100 ± 222	101 ± 201	65 ± 116	77 ± 69	155 ± 163	198 ± 240	462 ± 553	190 ± 177
Chlorophyll a (µg l^{-1})	7.1 ± 6.5	12.7 ± 11.0	11.7 ± 11.6	18.1 ± 8.1	8.9 ± 9.3	18.7 ± 6.9	12.4 ± 13.2	15.7 ± 21.3
Submerged plant coverage (%)	present	present	present	absent	90	19	30	24

Lake Mogan and the surrounding wetlands have been famous for the high density of waterfowl and mostly host >20,000 waterfowl in winter (Kiraç et al., 1995; Özesmi, 1999). In 1990 Lake Mogan was given the status of "Specially Protected Area" by the Ministry of Environment. Furthermore, the lake also obtained the status of the IBA and internationally important wetland due to the rich and diverse community of waterfowl.

2.2. Lake Eymir:

Lake Eymir is located 20 km south of Ankara (area: 1.05-1.25 km^2, Zmax: 4.3-6 m, Zmean: 2.6-3.2m) with a catchment of 971 km^2 and a long shoreline (13 km). The upstream Lake Mogan empties into Lake Eymir at the southwest corner, forming the main inflow of Lake Eymir, named Inflow I. Inflow II is located at the northern end, which usually dries up in summer.

The lake was originally in a clearwater state summer Secchi disk transparency being >4 m and a submerged plant community mainly dominated by Charophytes whose outer depth of colonization was 6-7 m (Geldiay, 1949). The lake was eutrophicated onward late 1970s as a consequence of discharge of untreated sewage effluent from nearly 25,000 inhabitants of a nearby town into the main inflow of the lake, Inflow I. In 1995 sewage effluent was diverted via a bypass to the outflow of the lake. The prediversion concentrations of total phosphorous (TP), dissolved inorganic nitrogen (DIN), chlorophyll-a, and suspended solids were very high and Secchi depth transparency was low (727 ± 43 µg l^{-1}, 1.49 ± 0.82 mg l^{-1}, 27 ± 7 µg l^{-1}, 38 ± 18 mg l^{-1} and 56 ± 6 cm, respectively) (Table2.2) (Altinbilek et al., 1995). The eutrophication of Lake Eymir resulted in an increase in the suspended solids concentration, largely as a result of benthivorous fish feeding induced resuspension and an increase in algal biomass. This, in turn, led to a decline in submerged plants. The sewage effluent diversion undertaken in 1995 to control eutrophication of the lake from Inflow I led to a major reduction in the TP and DIN areal loads (88%

Table 2.2: The changes (mean ± standard deviation) in the variables measured from 1993-1995 to 1997-2004 in Lake Eymir. The spring lake level and the spring Secchi depth included the measurement of the variable from March to May. (m a.s.l: meters above sea level).

Year	**1993-1995**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Lake level (m a.s.l)	968.26 ± 0.32	968.44 ± 0.30	968.66 ± 0.27	968.57 ± 0.22	968.64 ± 0.41	967.62 ± 0.30	968.12 ± 0.39	968.34 ± 0.41	968.04 ± 0.29
Spring lake level (m a.s.l)	968.54 ± 0.23	968.74 ± 0.10	968.92 ± 0.19	968.87 ± 0.21	969.04 ± 0.15	967.88 ± 0.05	968.46 ± 0.45	968.68 ± 0.49	968.24 ± 0.14
Salinity (‰)	-	1.09±0.03	1.15±0.05	1.12±0.06	1.07±0.07	1.20±0.00	1.04±0.07	1.06±0.10	1.11±0.12
Secchi depth (cm)	56 ± 6	120 ± 45	127 ± 53	305 ± 149	310 ± 114	218 ± 95	237 ± 168	198 ± 170	216 ± 127
Suspended solid (mg l^{-1})	38.0 ± 18.0	-	-	9.4 ± 6.2	6.1 ± 3.1	9.6 ± 4.9	8.1 ± 5.8	12.8 ± 10.9	11.3 ± 5.0
Total phosphate (µg l^{-1})	727 ± 43	372 ± 89	249 ± 48	426 ± 71	166 ± 59	314 ± 108	238 ± 145	150 ± 43	516 ± 135
Nitrite & Nitrate (µg l^{-1})	680 ± 50	63 ± 81	29 ± 32	118 ± 133	101 ± 95	278 ± 256	179 ± 107	207 ± 126	136 ± 85
Ammonium (µg l^{-1})	860 ± 47	68 ± 90	199 ± 381	94 ± 151	78 ± 68	199 ± 152	266 ± 209	340 ± 220	278 ± 218
Chlorophyll a (µg l^{-1})	27.0 ± 7.0	17.4 ± 12.8	17.2 ± 11.1	11.4 ± 12.4	14.5 ± 11.8	11.0 ± 11.3	21.8 ± 37.0	29.2 ± 33.1	33.2 ± 51.2
Submerged plant coverage (%)	-	-	2.5	6	50	90	60	45	5

and 95%, respectively). Subsequently, the in-lake concentrations of TP halved, and DIN concentration decreased 14-fold. However, the submerged plant coverage remained low, it being 2.5% of the lake's total surface area (Beklioglu et al., 2003). The same study also included the period of fish manipulation during August 1998 – December 1999, resulting in 45% and 83% reductions in the abundance of the dominant omnivorous fish, tench (*Tinca tinca* L.) and carp (*Cyprinus carpio* L.), respectively, which was a 57% reduction of the total fish stock. Furthermore, the biomass of piscivorous pike (*Esox lucius)* greatly increased probably due to the stop of pike angling introduced in May 1998 (Beklioglu et al., 2003). During the 1999 growth season, the fish removal led to a significant improvement of several variables. The Secchi depth transparency and the density of largebodied grazer *Daphnia pulex* increased 2.5- and 4.4–fold, respectively, and the concentrations of suspended solids and chlorophyll-a decreased about 4- and 2-fold. Despite a significant recovery in 1999, the submerged plants did not re-establish and their coverage remained very low, 6% of the lake surface area. Colonization of submerged plants began in 2000 and reached 50% coverage of the lake area.

In addition, Inflow I also received the poorly treated nutrient rich effluent (TP: 2579 ± 310 µg l^{-1}, soluble reactive phosphate (SRP): 1522 ± 534 µg l^{-1} and DIN: 3.7 ± 1.4 mg l^{-1}) of the sewage treatment work of the TEAS residency with a population of 5000 people (TEAS, STW) until the end of 2000, when it was connected to the main sewage collector.

Lake level drop in 2001 increased submerged vegetation cover to 90% (Beklioglu & Tan, submitted). In Lake Eymir, clearwater state with macrophyte coverage ranging from 40-90% until 2004 was observed. Fish community of the lake also deteriorated over the time since the biomanipulation. In 2004, the lake shifted to turbid water state (Ozen et al., unpublished data).

CHAPTER 3

MATERIAL & METHODS

Water samples were collected from March 2004 to September 2004. Data for the period of 1997-2003 was obtained from Burnak (1998), Tan (2002), Beklioglu & Tan (submitted) and Beklioglu et al. (submitted). Sampling was conducted fortnightly in spring, summer and fall, and with monthly intervals in winter. Prior to our study, the lake was sampled with a limited number of occasions between 1993-1995 for water chemistry (Altinbilek et al., 1995).

In Lake Mogan, depth-integrated water samples were taken from a fixed buoy at a mid-lake station using a 1.6 m long plastic tube sampler, which sampled a water column of about 1.5 m. Water samples were also taken from Sukesen brook just before reaching the lake Mogan, Gölcük, Yavrucak and Çölovasi brooks, which had about 1, 0.9 and 3 km distances to the lake Mogan, respectively, as well as from the outflow just after leaving the lake. In Lake Eymir, water samples were taken from the epilimnion using a weighted length of polyethylene hose, and from Inflows of Lake Eymir (I and II), just before reaching to the lake Eymir and the outflow of the lake.

Water for chemical analyses was stored in acid-washed 1-l Pyrex bottles. TP and nitrite & nitrate (NO2-N+NO3-N) were analysed using the methods described by Mackereth et al., (1978) to precisions of ± 8%. Ammonium-nitrogen (NH4-N) was determined according to Chaney & Morbach (1962) to precisions of ± 4%.

The major components of a water budget include inflow, precipitation, surface runoff, groundwater fluxes, outflow and evaporation. A balance can be constructed as:

$$\frac{\Delta V}{\Delta t} = I + P + R + G - O - E$$

V : lake volume,

ΔV/Δt : change in lake volume per unit time, (t),

I : surface inflows,

P : precipitation,

R : surface runoff,

G : net groundwater flux (in-out),

O : surface outflows,

E: evaporation.

The lake level given in meters above sea level (m. a. s. l.), was recorded daily from a fixed gauge positioned at the southwest corner of the lake Mogan, and at the south shore of the lake Eymir. Flow rates of inflows and outflow were measured with a Gurrly current meter by the General Directorate of Electrical Power, Resource Survey & Development Administration (EİE) (EİE, 2004). Lake volume was calculated by using the bathymetric map constructed in 2000. Monthly air temperature, rainfall and evaporation data were recorded by meteorological station located in Golbasi town, which is within the catchment of Lake Eymir. Surface runoff was calculated from the rainfall over the near catchment, corrected for evapotranspiration. Evapotranspiration over the near catchment was calculated using the Thornwaite equation.

$$ET_P = 16.N_m \left[\frac{10.T_m}{I} \right]^a \qquad 0 \leq T_m \leq 26.5ºC$$

ET_P: potential evaporation (mm/month),
m: months of the year,

N_m: monthly adjustment factor related to hours of daylight,
T_m: monthly mean temperature (ºC),
I: heat index of the year, given by

$$I = \sum_{i=1}^{m} \left(\frac{T_m}{5} \right)^{1.514}$$

$a = (6.75\text{x}10^{-7}.I^3) - (7.71\text{x}10^{-5}.I^2) + (1.7975\text{x}10^{-2}.I) + 0.49$

Average groundwater input to the lake was approximately 17 l s^{-1} and groundwater output from the lake was 2 l s^{-1} (Çamur, 1997). The hydraulic residence time was also estimated from dividing the lake volume (V_{lake}) by the volume of water flowing into the lake (I) per unit of time (Vollenweider, 1975).

The following equation was used for nutrient budget.

ΔLake = Inputs – Outputs ± Internal sources/sinks

All volume terms were multiplied with concentration. In-lake, inflow and outflow concentrations were measured directly. TP concentration of precipitation was negligible, therefore, it was not included. DIN concentration for precipitation was 80 μgl^{-1} (Tuncer et al., 2001). Concentrations of TP and DIN in groundwater were 24 μgl^{-1} and 3423 μgl^{-1}, respectively (Altinbilek et al., 1995). To estimate loading from surface runoff, the monthly mean nutrient concentration of Çölovasi and Inflow II was used for Lakes Mogan and Eymir, respectively. These streams drain an area with a very similar land usage to that of the catchments of Lakes Mogan and Eymir, respectively and so give a reasonable estimate of loadings. The internal sources include the release of nutrients from sediment while the sinks include sedimentation of particulate matter and denitrification by bacteria. They were not measured. However, the net internal source/sink was calculated by balancing Equation (2).

Fish stock was estimated using multiple mesh-sized gill nets (18, 36, 40, 50, 60, 70 mm). The length and the depth of each section of the net measured 100 m and 3.5 m, respectively. The nets were placed along the shoreline in the littoral zone and perpendicular to the shoreline from the littoral zone to open water and left them overnight to then collect on the following morning. To cover the whole lake, each fishing effort lasted a week. The number and weight of the fish species were recorded. Fish abundance was expressed as catch per unit effort (CPUE). During biomanipulation, planktivorous fish tench and benthivorous common carp were selectively removed (Beklioglu et al., 2003).

Statistical analyses:

Monthly lake level data was available for each year. Z-scores of water level were used to determine the trends in long-term data. The data was standardized by subtracting the mean and dividing by the standard deviation (Gerten & Adrian, 2000). Z-score transformation places variables on a common scale for easier visual comparison. By using one-way ANOVA, z-scores were compared for significant differences among years. If p value is less than 0.05, years are significantly different. Once differences existed among the years, pairwise multiple comparisons test the difference between each pair of means. In the study, Tukey's honestly significant difference test was used to determine which means differ. Years were grouped in homogeneous subsets as low, regular and high water level.

CHAPTER 4

RESULTS

4.1. Lake Mogan

The lake level fluctuated both annually and interannually with a mean amplitude of 0.78±0.24 m a.s.l. throughout the study period (Figure 4.1). Z-scores were calculated to standardize the water level data. Firstly, one-way ANOVA test was applied to z-scores of spring water levels. The results showed that years were significantly different in terms of water levels (F: 7.9, p: 0.000). Then, Tukey's test was used to determine which years were different than the others. As a result of, water levels in 2001 was significantly lower than years 2000, 2002 and 2003 ($p < 0.05$). Using the z-scores values of the water levels for the study period, Tukey's test constructed three hydrologically different periods. Years were grouped in homogeneous subsets as low, regular and high water level. Year 2001 was referred to low water level (LWL) year whereas years 2000, 2002 and 2003 were referred to high water level (HWL) years and the remaining study period is regarded as regular water level (RWL) years (Figure 4.1). On the other hand, if hydraulic residence time was also taken into account, year 2004 could be referred to dry year because it had the highest hydraulic residence time throughout the study period.

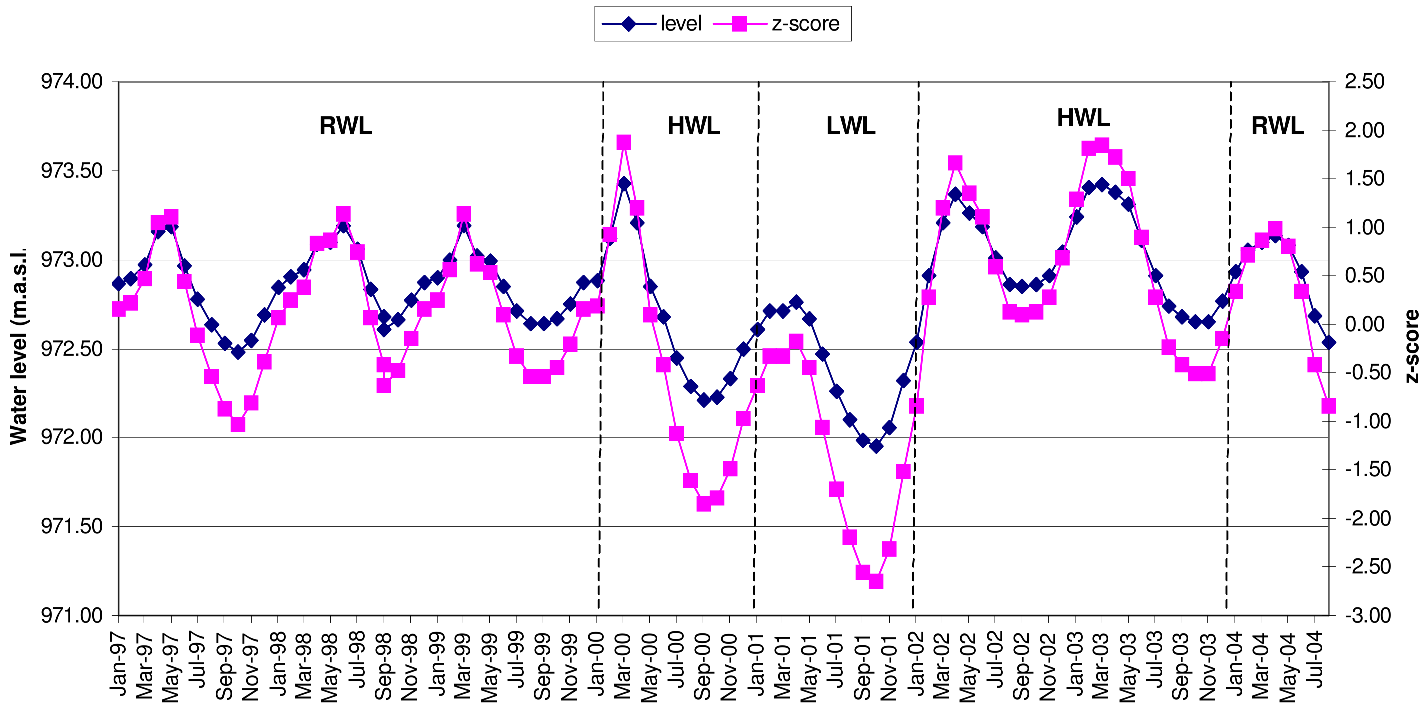


Figure 4.1: Water level fluctuations recorded from 1997 to 2004 in Lake Mogan. (RWL: regular water level, HWL: high water level, LWL: low water level).

4.1.1. Annual Water Budget:

Table 4.1 shows annual water budget between 1997 and 2004. The lake volume changed markedly from the minimum volume of $11.47 \pm 1.56 \times 10^6$ recorded in 2001 to the maximum volume of $15.02 \pm 1.89 \times 10^6$ m^3 recorded in 2003. The total inputs by inflows had critical contribution to the budget that varied between 26.3%-70.3%. Precipitation had also contribution to the water budget that accounted for 8.5% to 18.3% of the total input, in 2000 and 2004, respectively. Surface runoff from the land contributed to the budget varied from 19.8% to 56.1% of the total. Groundwater's contribution to the budget varied from 1.2% to 3.3% in 1998 and 2004, respectively depending on the total inputs from other sources. For the outflow of the lake, the highest flow was 16.56×10^6 m^3 recorded in 2000 and it completely dried out in 2004. Hydraulic residence time increased from 0.7 yr to 4.9 yr recorded in 2000 and 2004, respectively. Evaporative loss was a major source of water loss that it varied between 44% and 48.5% of the lake volume for 1999 and 2001, respectively. All balances were found to be negative throughout the years.

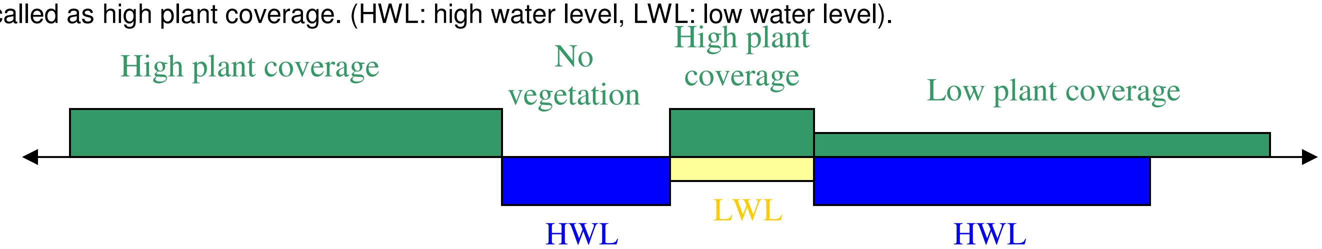
4.1.2. Annual Total Phosphorus Budget:

Annual total phosphorus budget constructed for eight years is presented in Table 4.2. The total external inputs varied largely throughout the study. The highest input via the inflows was 6213.6 kg recorded in 2000 and the lowest value was 768.2 kg recorded in 2004 (Figure 4.2). The contribution made by the inflows to the TP budget varied from 94.5% to 54.6% in 2000 and 2004, respectively. The surface runoff accounted for 4.5% to 42% of the total input, in 2000 and 2004, respectively. The contribution of groundwater varied between 0.8% and 3.5% of the total input. Also, the outflow changed markedly from 1858.9 kg in 1998 and completely dried out in 2004.

Table 4.1: Annual water budget calculated for the period of 1997 and 2004 in Lake Mogan. Values given are 10^6 m^3. Values in brackets are % contribution of total input except evaporation [% of lake volume].

Year	1997	1998	1999	2000	2001	2002	2003	2004
Lake volume (m^3)	13.58 ± 1.25	13.97 ± 0.97	13.82 ± 0.94	13.15 ± 2.28	11.47 ± 1.56	14.35 ± 1.68	15.02 ± 1.89	14.07 ± 1.04
Inflow (m^3)	10.84 [48.4]	17.54 [64.6]	10.74 [53.4]	18.51 [70.3]	3.78 [26.3]	11.03 [67.1]	10.68 [63.0]	2.85 [29.3]
Precipitation (m^3)	3.40 [15.2]	3.11 [11.5]	3.32 [16.5]	2.25 [8.5]	2.22 [15.4]	1.84 [11.2]	2.02 [11.9]	1.78 [18.3]
Net Groundwater (m^3)	0.32 [1.4]	0.32 [1.2]	0.32 [1.6]	0.32 [1.2]	0.32 [2.2]	0.32 [1.9]	0.32 [1.9]	0.32 [3.3]
Surface runoff (m^3)	7.85 [35.0]	6.18 [22.8]	5.72 [28.5]	5.25 [19.9]	8.07 [56.1]	3.26 [19.8]	3.93 [23.2]	4.79 [49.2]
Total input (m^3)	22.41	27.15	20.1	26.33	14.39	16.45	16.95	9.74
Outflow (m^3)	9.24	14.74	7.81	16.56	0.36	1.02	3.16	0.00
Evaporation (m^3)	6.37 [46.9]	6.51 [46.6]	6.08 [44.0]	5.85 [44.5]	5.56 [48.5]	6.60 [46.0]	7.14 [47.5]	6.23 [44.3]
∂ Lake volume (m^3)	0.65	0.39	-0.15	-0.67	-1.68	2.88	0.67	-0.95
Balance (m^3)		-5.51	-6.37	-4.59	-10.15	-5.95	-5.97	-4.47
Hydraulic residence time (yr)	1.3	0.8	1.3	0.7	3.0	1.3	1.4	4.9

Table 4.2: Annual TP budget calculated for the period of 1997 and 2004 in Lake Mogan. Values in brackets are % contribution of total input. Plant coverage was classified among years. Equal or less than 30% surface coverage was called as low plant coverage and greater than 30% surface coverage was called as high plant coverage. (HWL: high water level, LWL: low water level).



Year	1997	1998	1999	2000	2001	2002	2003	2004
Sukesen (kg)	904.7 [39.0]	467.2 [18.8]	261.9 [10.1]	1207.8 [18.4]	87.8 [5.2]	244.2 [10.0]	270.2 [14.4]	431.6 [30.6]
Gölcük (kg)	32.4 [1.4]	159.7 [6.4]	107.6 [4.1]	40.6 [0.6]	183.7 [11.0]	328.5 [13.5]	14.8 [0.8]	13.0 [0.9]
Yavrucak (kg)	630.3 [27.2]	1190.2 [48.0]	967.6 [37.2]	4364.4 [66.6]	587.4 [35.1]	1414.0 [58.0]	888.8 [47.2]	292.5 [20.8]
Çölovası (kg)	208.7 [9.0]	348.5 [14.1]	460.5 [17.7]	600.8 [9.2]	193.1 [11.5]	191.1 [7.8]	276.3 [14.7]	31.1 [2.2]
Total inflow (kg)	1776.1 [76.6]	2165.6 [87.3]	1797.6 [69.1]	6213.6 [94.5]	1052.0 [62.8]	2177.8 [89.3]	1450.1 [77.1]	768.2 [54.6]
Net Groundwater (kg)	49.2 [2.1]	49.2 [2.0]	49.2 [1.9]	49.2 [0.8]	49.2 [2.9]	49.2 [2.0]	49.2 [2.6]	49.2 [3.5]
Surface runoff (kg)	493.6 [21.3]	265.3 [10.7]	753.0 [29.0]	293.5 [4.5]	573.8 [34.3]	210.9 [8.7]	381.9 [20.3]	590.8 [42.0]
Total input (kg)	2318.9	2480.1	2599.8	6556.3	1675	2437.9	1881.2	1408.2
Mogan out (kg)	1149.3	1858.9	1538.9	967.0	55.5	156.6	318.5	0.0
TP Lake (kg)	1011 ± 479	1128 ± 250	1032 ± 432	1264 ± 313	626 ± 323	1063 ± 442	1426 ± 623	1961 ± 789
ΔTP Lake (kg)		118	-97	233	-638	438	362	535
Balance(kg)		-504	-1158	-5357	-2258	-1844	-1201	-873

Low water level recorded in 2001 decreased the in-lake TP to 626±323 kg, which was the lowest TP amount, from 1264±313 kg in 2000, which was a high water level year especially in spring. During high water level years, TP amount in the lake increased significantly especially in 2003. The highest in-lake TP was 1961±789 kg recorded in 2004 despite the fact that TP load was the lowest in the same year. TP balance was varied from net sedimentation –5357 kg in 2000 to the value of -504 kg in 1998 (Figure 4.3). This implied that there was no phosphorus release from the sediment.

4.1.3. Annual Dissolved Inorganic Nitrogen Load:

Table 4.3 shows the annual dissolved inorganic nitrogen load for the period of 1997 and 2004. The highest input via inflows was 20,773 kg recorded in 1998 and the lowest was 2048.4 kg recorded in 2004 (Table 4.3 & Figure 4.4). The contribution of inflows to the budget varied from 95% of total input in 2002 to 65.9% in 2004. Surface runoff accounted for 2.6% to 20.5% of the total input, in 2002 and 2004, respectively. The contribution made by precipitation was insignificant and constituted between 0.8% and 4.6% of the total input. The contribution by groundwater was also insignificant and varied between 1.3% and 9.0% of the total input. Furthermore, the outflow changed markedly from 2027.1 kg y^{-1} in 2000 and completely dried out in 2004.

DIN amount in the lake increased from 1654±1024 kg in 2000, which was the lowest value throughout the study period to 3635±1944 kg in 2001 in spite of low DIN load. The latter was associated with low water level. In high water level years, there was a further increase in the in-lake DIN amount especially in 2003, which had the highest value. In 2004, DIN amount in the lake decreased to 4157±3199 kg due to low DIN load. DIN balances were negative, changing between -21,472 kg and -1379 kg for the study period (Figure 4.5).

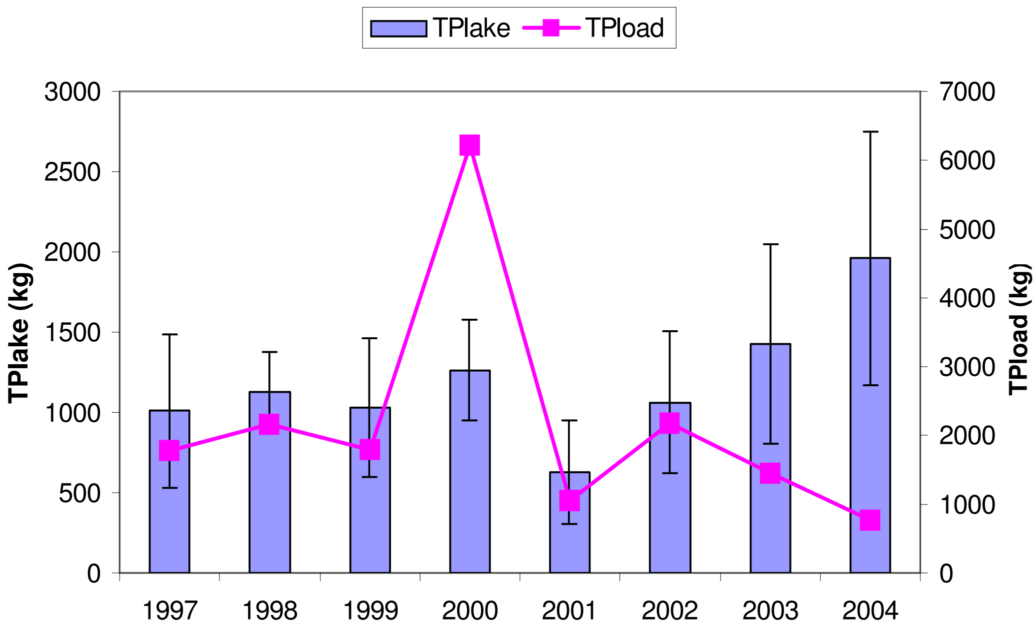


Figure 4.2: Changes in the TP amount in Lake Mogan and TP load via inflows from 1997 to 2004.

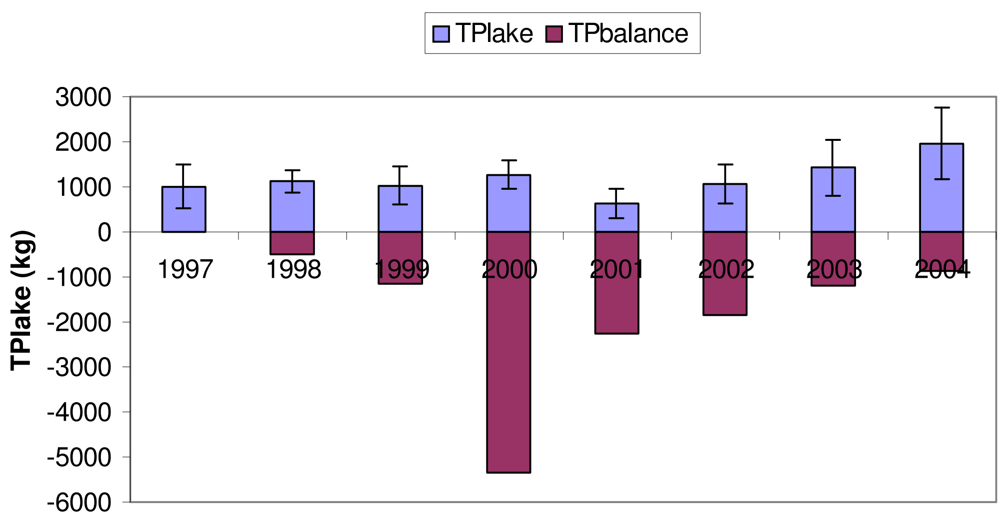
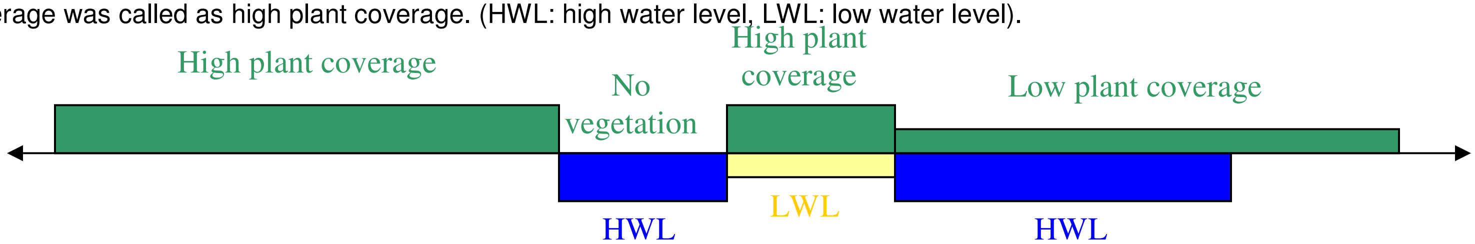


Figure 4.3: Changes in the TP amount and TP balance in Lake Mogan from 1997 to 2004.

Table 4.3: Annual DIN load calculated for the period of 1997 and 2004 in Lake Mogan. Values in brackets are % contribution of total input. Plant coverage was classified among years. Equal or less than 30% surface coverage was called as low plant coverage and greater than 30% surface coverage was called as high plant coverage. (HWL: high water level, LWL: low water level).



Year	1997	1998	1999	2000	2001	2002	2003	2004
Sukesen (kg)	2825.2 [29.2]	2065.0 [9.3]	1470.1 [12.1]	723.8 [6.6]	1780.5 [25.5]	2278.4 [12.5]	1208.9 [15.3]	613.4 [19.7]
Gölcük (kg)	401.4 [4.1]	2290.1 [10.3]	880.2 [7.3]	712.4 [6.5]	895.0 [12.8]	1408.6 [7.7]	462.1 [5.8]	175.3 [5.6]
Yavrucak (kg)	5061.0 [52.3]	16032.7 [72.2]	7835.2 [64.7]	5310.5 [48.8]	2606.6 [37.3]	13398.6 [73.2]	3334.2 [42.2]	1237.0 [39.8]
Çölovası (kg)	248.8 [2.6]	385.2 [1.7]	376.1 [3.1]	2585.8 [23.8]	434.6 [6.2]	307.3 [1.7]	1751.0 [22.1]	22.7 [0.7]
Total inflow (kg)	8536.4 [88.2]	20773 [93.5]	10561.6 [87.2]	9332.5 [85.7]	5716.7 [81.8]	17392.9 [95.0]	6756.2 [85.4]	2048.4 [65.9]
Precipitation (kg)	272.2 [2.8]	248.6 [1.1]	265.5 [2.2]	179.8 [1.7]	177.9 [2.5]	147.5 [0.8]	161.5 [2.0]	142.8 [4.6]
Groundwater (kg)	281.3 [2.9]	281.3 [1.3]	281.3 [2.3]	281.3 [2.6]	281.3 [4.0]	281.3 [1.5]	281.3 [3.6]	281.3 [9.0]
Surface runoff (kg)	589.6 [6.1]	917.5 [4.1]	999.6 [8.3]	1093.6 [10.0]	809.0 [11.6]	477.6 [2.6]	709.9 [9.0]	638.2 [20.5]
Total input (kg)	9679.5	22220.4	12108	10887.2	6984.9	18299.3	7908.9	3110.7
Mogan out (kg)	1955.2	972.7	901.6	2027.1	163.3	667.2	710.1	0.0
DIN Lake (kg)	2558 ± 2918	2333 ± 3560	2148 ± 2348	1654 ± 1024	3635 ± 1944	3851 ± 3669	9671 ± 8834	4157 ± 3199
ΔDIN Lake (kg)		-224	-185	-494	1981	216	5820	-5514
Balance(kg)		-21472	-11392	-9354	-4841	-17416	-1379	-8624

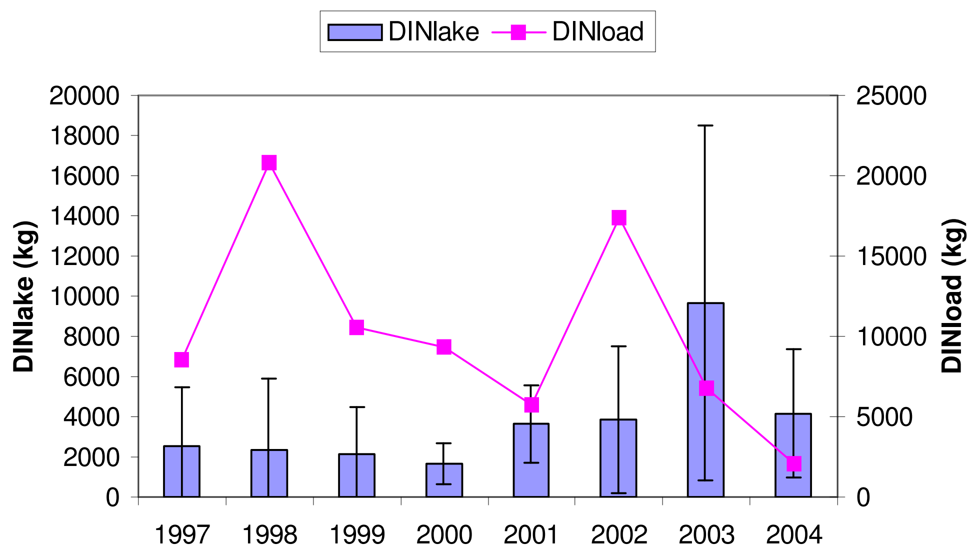


Figure 4.4: Changes in the DIN amount in Lake Mogan and DIN load via inflows from 1997 to 2004.

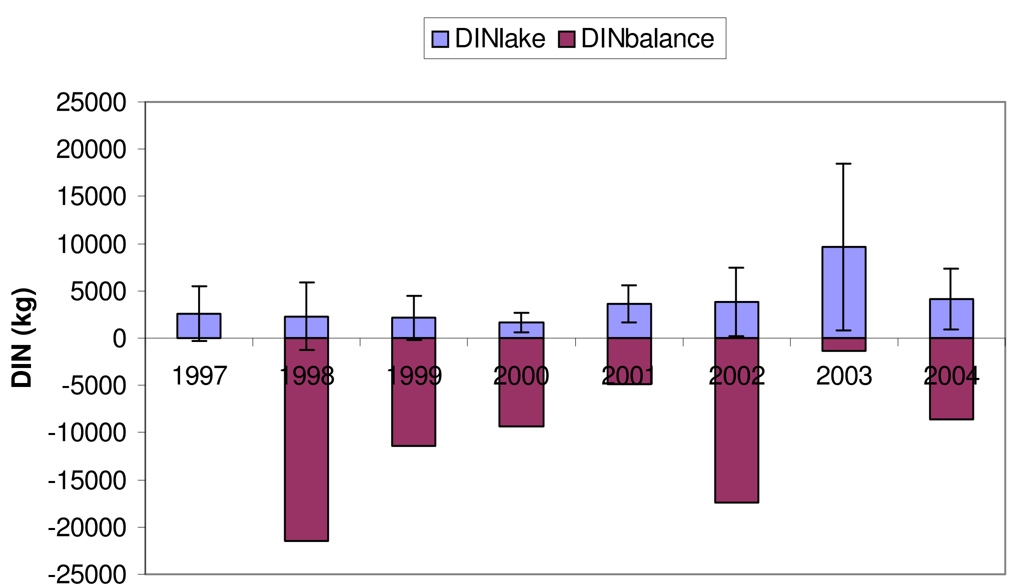


Figure 4.5: Changes in the DIN amount and DIN balance in Lake Mogan from 1997 to 2004.

4.2. Lake Eymir:

The lake level fluctuated both annually and interannually with mean amplitude of 0.93±0.21 m a.s.l. throughout the study period (Figure 4.6). Z-scores were calculated to standardize the water level data. Firstly, one-way ANOVA test was applied to z-scores of water levels. The results showed that years were significantly different in terms of water levels (F: 13.9, p: 0.000). Then, Tukey's test was used to determine which years were different than the others. As a result of, water levels in 2001 and 2004 were significantly lower than those of recorded in 1998, 1999 and 2000 ($0.00 \leq p \leq 0.01$). Using the z-scores values of the water levels for the study period, Tukey's test constructed three hydrologically different periods. Years were grouped in homogeneous subsets as low, regular and high water level. Years 2001 and 2004 were referred to low water level (LWL) years whereas years 1998, 1999 and 2000 were referred to high water level (HWL) years and the remaining study period is regarded as regular water level (RWL) years (Figure 4.6).

4.2.1. Annual Water Budget:

Table 4.4 shows annual water budget for the periods of 1993-1995 and 1997-2004. The lake volume changed markedly from the maximum volume of $4.09 \pm 0.34 \times 10^6$ m^3 recorded in 1998 to the minimum volume of $2.84 \pm 0.34 \times 10^6$ m^3 recorded in 2001. Inflows were the major sources of water in the high water level and regular years whereas surface runoff, precipitation and groundwater became significant in the low water level years. Contribution made by inflows to the budget varied from 19.2% to 92.5%. The surface runoff contributed to the budget by 2.6%-36%. Precipitation had also a critical contribution to the water budget and it accounted for 2.2% to 27.4% of the total input, in 2000 and 1997, respectively. Although there was no change in the amount of groundwater, its percent contribution to the budget varied from 2.6% in 2000 to 28.5% in

2004. For the outflow of the lake, the highest flow was recorded in 2000 and it completely dried out in 2004. Evaporative loss was between 27% and 34% of the lake volume for 2000 and 2001, respectively. Hydraulic residence time increased from 0.2 yr recorded in 2000 to 7.4 yr recorded in 2004. The high hydraulic residence times were recorded during low water level years. However, 1997 was an exceptional year with the highest hydraulic residence time (9.1 yr) since lake volume remained high despite of low inflows.

4.2.2. Annual Total Phosphorus Budget:

Annual total phosphorus budget for ten years is in Table 4.5. The total external inputs largely varied throughout the study. Before the sewage effluent diversion undertaken in 1995, the load from the Inflow I, which was the major source of TP, was 6280 kg and the in-lake TP amount was 2759±1986 kg (Table 4.5 & Figure 4.7). Following the effluent diversion, the TP load via Inflow I and the in-lake TP amount significantly decreased (Table 4.5 & Figure 4.7). Moreover, diversion of the minor sewage effluent from the Inflow I undertaken at the end of 2000 led to further reduction in the TP load to the lake. This, however, did not result in further decrease in the in-lake TP level. Following the fish removal, TP amount in the lake significantly declined and net sedimentation of TP increased (Table 4.5 & Figure 4.8). Hydrological changes also strongly affected TP budget. During high water level years, TP loads via inflows were high. In-lake TP amount increased from 666±224 kg in high water level year 2000 to 875±284 kg in low water level year 2001. In low water level years, TP loads via inflows were lower. However, TP amount in the lake and net phosphorus release from the sediment increased especially in 2004 (Figure 4.8).

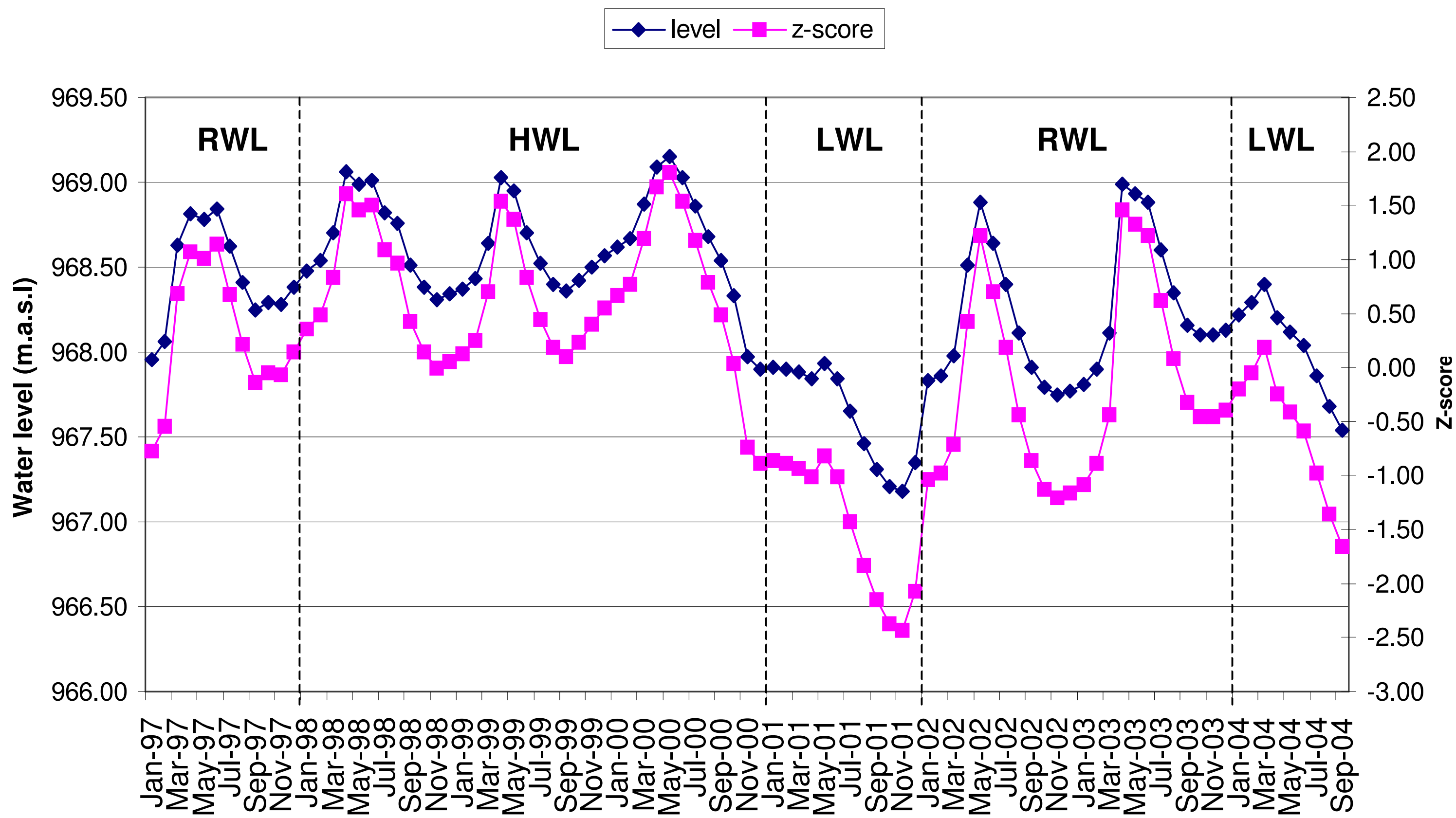
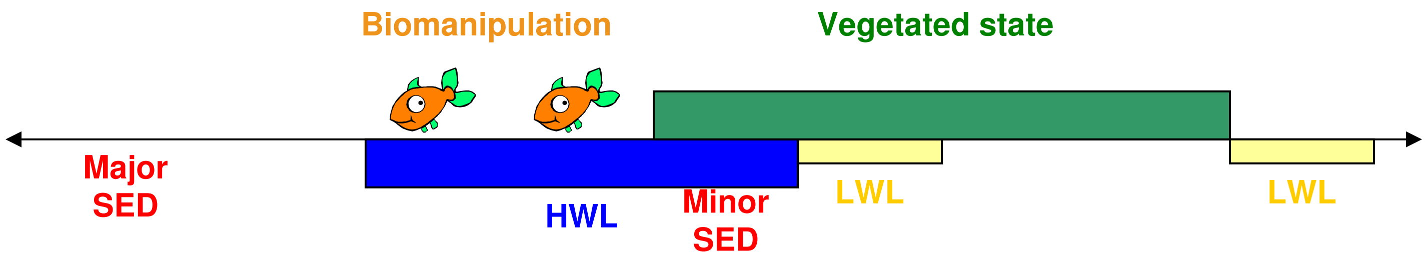


Figure 4.6: Water level fluctuations recorded from 1997 to 2004 in Lake Eymir. (RWL: regular water level, HWL: high water level, LWL: low water level).

Table 4.4: Annual water budget calculated for the period of 1993-1995 and 1997-2004 in Lake Eymir. Values given are 10^6 m^3. Values in brackets are % contribution of total input except evaporation (% of lake volume).

Year	1993-1995	1997	1998	1999	2000	2001	2002	2003	2004
Lake volume (m3)	3.59 ± 0.39	3.82 ± 0.37	4.09 ± 0.34	3.98 ± 0.28	4.08 ± 0.51	2.84 ± 0.34	3.43 ± 0.47	3.70 ± 0.51	3.33 ± 0.34
Inflow (m3)	2.12 [59.7]	0.42 [19.2]	2.29 [59.3]	8.58 [84.6]	16.64 [92.5]	0.41 [20.5]	2.11 [66.6]	3.29 [73.9]	0.45 [27.3]
Precipitation (m3)	0.44 [12.4]	0.60 [27.4]	0.55 [14.2]	0.58 [5.7]	0.40 [2.2]	0.40 [20.0]	0.30 [9.5]	0.34 [7.6]	0.30 [18.2]
Surface runoff (m3)	0.52 [14.6]	0.70 [32.0]	0.55 [14.2]	0.51 [5.0]	0.47 [2.6]	0.72 [36.0]	0.29 [9.1]	0.35 [7.9]	0.43 [26.1]
Net Groundwater (m3)	0.47 [13.2]	0.47 [21.5]	0.47 [12.2]	0.47 [4.6]	0.47 [2.6]	0.47 [23.5]	0.47 [14.8]	0.47 [10.6]	0.47 [28.5]
Total input (m3)	3.55	2.19	3.86	10.14	17.98	2.00	3.17	4.45	1.65
Outflow (m3)	1.79	0.91	1.34	8.17	16.09	0.41	1.20	0.26	0.00
Evaporation (m3)	1.09 [30]	1.13 [30]	1.15 [28]	1.09 [27]	1.09 [27]	0.96 [34]	1.08 [31]	1.20 [32]	1.01 [30]
∂ Lake volume (m3)			0.27	-0.11	0.10	-1.23	0.59	0.27	-0.37
Balance (m3)			-1.10	-1.00	-0.71	-1.86	-0.31	-2.72	-1.00
Hydraulic residence time (yr)	1.6	9.1	1.8	0.5	0.2	7.0	1.6	1.1	7.4

Table 4.5: Annual TP budget calculated for the period of 1993-1995 and 1997-2004 in Lake Eymir. Values in brackets are % contribution of total input. (SED: sewage effluent diversion, HWL: high water level, LWL: low water level).



Year	1993-1995	1997	1998	1999	2000	2001	2002	2003	2004
Inflow1 (kg)	6280.0 [61.7]	36.2 [2.7]	1270.8 [42.4]	4510.3 [94.7]	3340.0 [93.2]	220.7 [83.1]	1004.8 [83.1]	490.7 [87.8]	0.0 [0]
Inflow2 (kg)	2119.4 [20.8]	286.9 [21.8]	1307.1 [43.6]	141.3 [3.0]	31.2 [0.9]	2.1 [0.8]	145.6 [12.0]	13.2 [2.4]	40.9 [44.9]
Surface runoff (kg)	1769.0 [17.4]	984.4 [74.6]	406.3 [13.6]	98.6 [2.1]	201.3 [5.6]	31.7 [11.9]	48.0 [4.0]	43.9 [7.9]	38.9 [42.7]
Net Groundwater (kg)	11.2 [0.1]	11.2 [0.8]	11.2 [0.4]	11.2 [0.2]	11.2 [0.3]	11.2 [4.2]	11.2 [0.9]	11.2 [2.0]	11.2 [12.3]
Total input (kg)	10179.6	1318.7	2995.4	4761.4	3583.7	265.7	1209.6	559.0	91.0
Eout (kg)	776.2	261.7	409.1	5920.1	2889.9	52.7	361.8	41.8	0.0
TP Lake (kg)	2759 ± 1986	1469 ± 412	994 ± 121	1683 ± 232	666 ± 224	875 ± 284	847 ± 602	556 ± 159	1516 ± 332
ΔTP Lake (kg)	-	-	-475	689	-1017	209	-28	-291	960
Balance (kg)	-	-	-3061	1847	-1710	-4	-876	-808	869

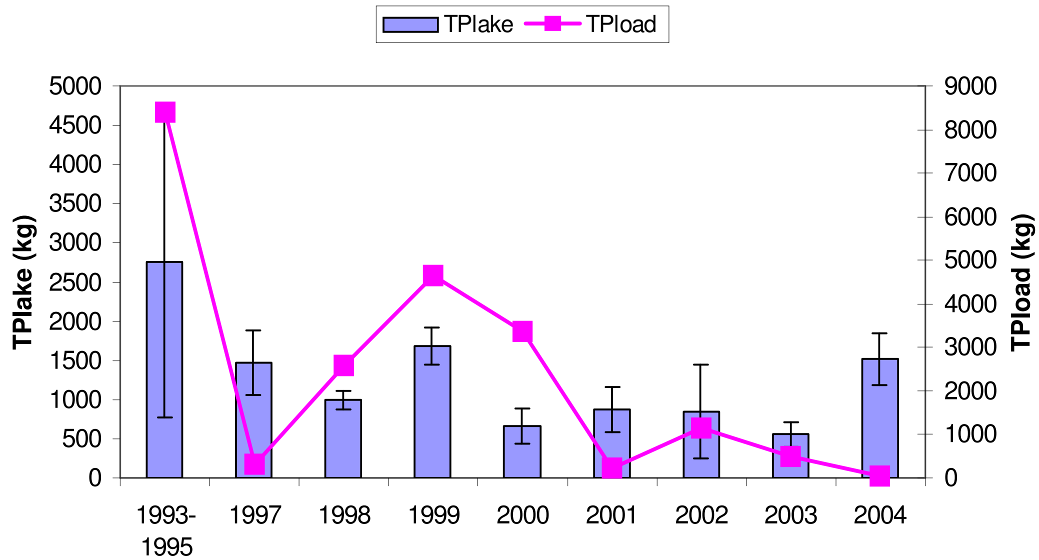


Figure 4.7: Changes in the TP amount in Lake Eymir and TP load via inflows from 1993-1995 to 1997-2004.

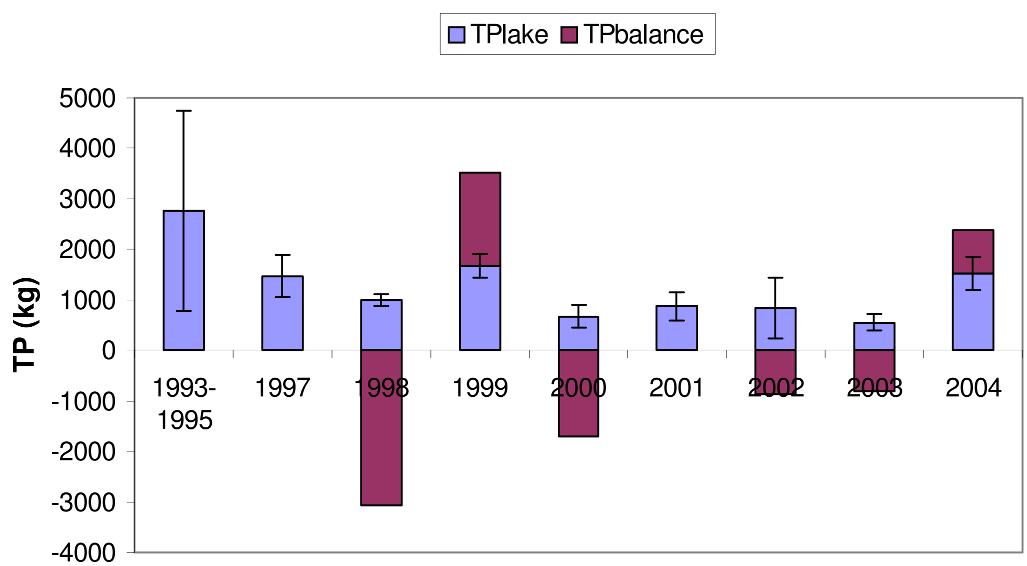


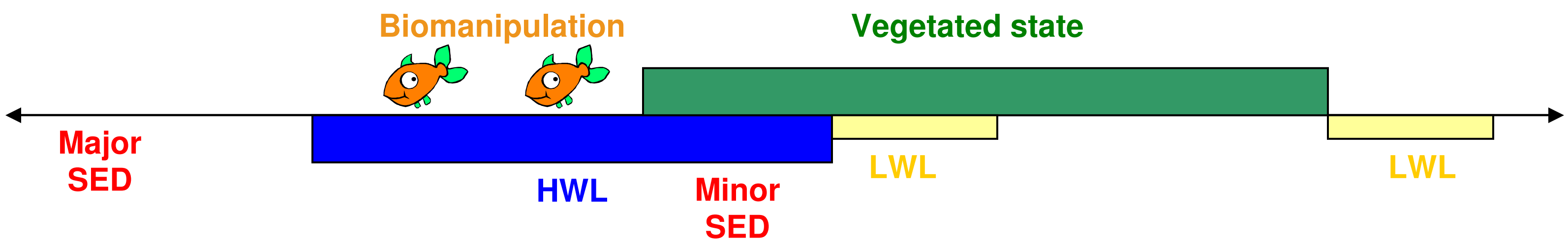
Figure 4.8: Changes in the TP amount and TP balance in Lake Eymir from 1993-1995 to 1997-2004.

Moreover, multiple stepwise regression for summer total phosphorus concentration in the lake revealed that first, second and third predictor of summer total phosphorus were water level (p: 0.000), concentration of chlorophyll-a (p: 0.001) and the hypolimnetic dissolved oxygen concentration (p: 0.026), (r: 0.763).

4.2.3. Annual Dissolved Inorganic Nitrogen Load:

Table 4.6 shows the annual dissolved inorganic nitrogen load for the period of 1993-1995 and 1997-2004. Both the DIN load via Inflow I and the in-lake DIN amount were the highest (31,521 kg and 5838±3511 kg, respectively) before sewage effluent diversion. The DIN load via Inflow I and DIN amount in the lake significantly decreased following the effluent diversion (Figure 4.9). Moreover, diversion of the minor sewage effluent led to further reduction in the DIN load via Inflow I. This, however, did not result in further decrease in the in-lake DIN level. Furthermore, the fish removal resulted in significant reduction in the DIN amount in the lake. During high water level years, DIN loads via inflows were high. Although DIN load via inflows was low in the low water level year 2001, the in-lake DIN amount was high (1416±607 kg). DIN load via inflows was the lowest in the low water level year 2004 and DIN amount in the lake decreased to 1277±774 kg. All the balances for DIN were negative, varying between –2004 and –5638kg (Table 4.6 & Figure 4.10).

Table 4.6: Annual DIN budget calculated for the period of 1993-1995 and 1997-2004 in Lake Eymir. Values in brackets are % contribution of total input. (SED: sewage effluent diversion, HWL: high water level, LWL: low water level).



Year	1993-1995	1997	1998	1999	2000	2001	2002	2003	2004
Inflow1 (kg)	31521.0 [86.5]	74.0 [2.1]	2101.7 [36.0]	5189.2 [69.6]	4393.6 [69.9]	795.7 [26.7]	330.9 [12.5]	2094.1 [51.8]	0.0 [0]
Inflow2 (kg)	1797.9 [4.9]	486.9 [14.1]	1455.0 [25.0]	265.5 [3.6]	35.5 [0.6]	33.4 [1.1]	554.0 [20.9]	87.3 [2.1]	249.9 [11.7]
Rain (kg)	35.5 [0.1]	47.7 [1.4]	43.8 [0.8]	46.7 [0.6]	31.7 [0.5]	31.7 [1.1]	24.3 [0.9]	27.1 [0.7]	23.7 [1.1]
Surface runoff (kg)	1455.5 [4.0]	1227.0 [35.5]	611.9 [10.5]	329.8 [4.4]	209.2 [3.3]	498.6 [16.7]	125.7 [4.7]	214.1 [5.3]	237.4 [11.1]
Net Groundwater (kg)	1619.2 [4.4]	1619.2 [46.9]	1619.2 [27.8]	1619.2 [21.7]	1619.2 [25.7]	1619.2 [54.4]	1619.2 [61.0]	1619.2 [40.1]	1619.2 [76.0]
Total input (kg)	36429.1	3454.8	5831.6	7450.4	6289.2	2978.6	2654.1	4041.8	2130.2
Eout (kg)	4359.1	192.6	467.6	1556.4	1657.6	189.6	482.0	85.0	0.0
DIN Lake (kg)	5838 ± 3511	508 ± 622	850 ± 1472	1106 ± 1020	742 ± 461	1416 ± 607	1584 ± 670	2204 ± 975	1277 ± 774
ΔDIN Lake (kg)			342	256	-364	674	168	620	-927
Balance(kg)			-5023	-5638	-4995	-2115	-2004	-3337	-3057

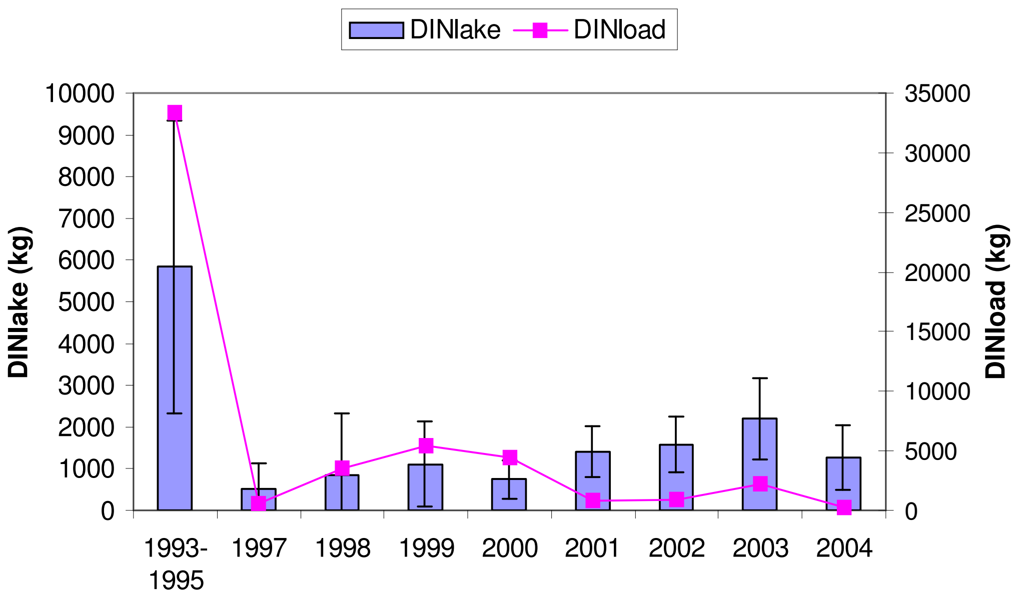


Figure 4.9: Changes in the DIN amount in Lake Eymir and DIN load via inflows from 1993-1995 to 1997-2004.

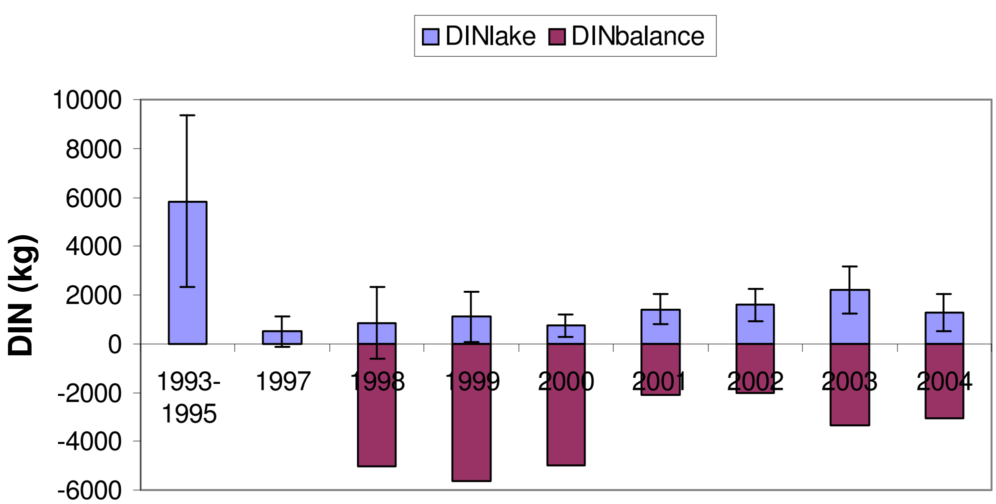


Figure 4.10: Changes in the DIN amount and DIN balance in Lake Eymir from 1993-1995 to 1997-2004

CHAPTER 5

DISCUSSION

5.1. Lake Mogan:

Shallow lakes especially located in semi-arid to arid region are very dependent on the balance of inflows and evaporation and very sensitive to change in either. The degree of lake level fluctuations affect the lake ecosystem varies according to local conditions of the lake and its catchment (Hulme et al., 2003). In Lake Mogan, inflows were the major sources of water budget in wet and regular years while the importance of inflows decreased significantly in dry years. Significant decrease in lake volume and increase in hydraulic residence time (3 yr) took place in 2001 due to low inflows. However, highest hydraulic residence time was recorded in 2004 because the water level was kept higher by closing sluice gate for maintaining the lake volume high to not allow the reduction in lake level despite of low inflows.

In arid tropical shallow lakes, sensitivity to hydrological conditions also has dramatic costs especially for salinity (Talling, 2001). In Lake Mogan, the salinity was high throughout the study especially in the low water level year 2001. The salinity level was close to the threshold of 2 ‰ at which the major shifts in lake trophic structure and dynamics are supposed to occur (Jeppesen et al., 1994; Moss, 1994).

In Lake Mogan, TP amount in the lake was higher than previous years because TP load via inflows was significantly high and the lake was lack of submerged vegetation due to high spring level in 2000. However, TP amount in the lake declined a 2-fold in low water level year in 2001 owing to low TP loading from the catchment via the inflows. Moreover, the low spring level increased the submerged vegetation cover (90% surface coverage). This vegetation shift also lowered phosphorus amount by reduced resuspension and the phosphorus release from the sediment (Granéli & Solander, 1988). This is in accordance with Lake Võrtsjärv in Estonia that precipitation-poor period resulted in decline in external nutrient loading and lower water level year yielded better light conditions causing increase in growth of the submerged macrophyte (Nõges & Nõges, 1999). Furthermore, drops in spring lake level coupled with high evaporation in summer enhanced vegetation development leading to a large expansion of the littoral zone in Mediterranean and subtropical lakes (Gaffny & Gasith, 1999; Beklioglu et al., 2004; Havens et al., 2004). In addition to increase in abundance of submerged plants, Van Geest et al., (2005) found that drawdown in lake level caused higher species richness of submerged macrophytes. Upon increase in water level in 2002 and 2003, the in-lake TP increased again in Lake Mogan. These years were high water levels and low submerged plant cover. High water level periods were associated with decreased TP concentrations in temperate Lake Peipsi in Estonia (Kangur et al., 2003) whereas in subtropical Lake Okeechobee, TP amount within the nearshore region was higher at high water levels (James & Havens, 2005). This result is in concert with Lake Mogan. Furthermore, in 2004, the TP amount in Lake Mogan reached to a highest amount despite the lowest external TP load of the study period was recorded in this year. Possible explanation for high in-lake TP amount may be the hydraulic residence time being the highest in 2004 since long hydraulic residence times provide great opportunities for sediment-water contact (Saunders & Kalff, 2001). Thus, the in-lake phosphorus concentration becomes more dependent on internal processes rather than external loading. For the lake management point of view, increasing hydraulic residence time of the lake by closing the sluice gate to maintain high water level leads to increase in-lake TP concentration through internal processes.

In Lake Mogan, DIN amount increased 2-fold in 2001 which was a low water level year in spite of lower external DIN load to the lake and the high submerged plant cover. Several studies involving nitrogen budgets in freshwater systems support the idea that submerged macrophytes can enhance nitrogen removal by offering surfaces that can hold populations of both nitrifiers and denitrifiers (Reddy & Busk, 1985; Eighmy & Bishop, 1989; Korner, 1997; Eriksson & Weisner, 1997). However, Eriksson & Weisner, (1999) also found that about 40 times higher rates of nitrification than denitrification in the epiphytic communities and nitrification was greater in the macrophyte chambers (with or without sediment) than in the chambers with only sediment. The results indicated that the submerged vegetation, presumably by its photosynthetic O_2 production, stimulated biofilm nitrification in light. In Lake Mogan, DIN amount onward 2002 continued to increase because of high external load in 2002. In Lake Mogan, high water level years 2002 and 2003 were associated with high in-lake DIN amount and low submerged plant coverage. This result is similar with subtropical Lake Okeechobee, where DIN concentrations were higher at high water levels (James & Havens, 2005). Furthermore, lower submerged vegetation may lead to reduction in denitrification in the lake. In addition to less light availability due to high water levels, decrease in submerged vegetation abundance can be explained by negative effects of high external nitrogen loads (Moss, 2001). In 2004, low external DIN load to the lake led to a 2-fold decrease in the DIN amount in Lake Mogan.

Negative DIN balances were found throughout the study period in Lake Mogan. The balance does not only mean sedimentation/release since there were unmeasured extra sources or sinks for DIN. Denitrification or biological consumption by plant and algae can be responsible for the negative balance. In Lake Mogan, negative DIN balances were high in the years that chlorophyll a increased. Increase in consumption by algae may have resulted in decrease in the in-lake DIN and increase in negative balance. Also, in 2002, DIN amount in the lake did not change despite of high external DIN load. Probably, DIN was used by high phytoplankton populations because chlorophyll a increased in that year and high negative DIN balance implied the consumption by algae.

5.2. Lake Eymir:

Hydrology is a critical factor on functioning of shallow lakes especially located in dry climates. Variations in hydrology can have significant impacts on water chemistry of lakes (Talling, 2001). As a result, ecological changes in lakes should be evaluated in relation with hydrology and nutrient dynamics. Water and nutrient budgets provide useful information on trophic states of lakes. In Lake Eymir, inflows were the major sources of water budget in wet and regular years while the importance of surface runoff, precipitation and groundwater increased in dry years. Significant decrease in lake volume and increase in hydraulic residence time took place due to low inflows in 2001 and 2004.

In Lake Eymir, two years after the major reduction in external TP loading from Inflow I resulted in a 2-fold decrease in the in-lake TP amount. This is in accordance with Beklioglu et al., (1999), Jeppesen et al., (2002) and Villena & Romo, (2003) though long resilience to recovery owing to internal loading occurred in some other shallow lakes (Søndergaard et al., 2003). The duration of the period with excess internal loading after phosphorus loading reduction varies among lakes depending on loading history, chemical characteristics of the sediment, hydraulic residence time and water depth (Marsden, 1989).

Following about 50% benthi-planktivorous fish removal, a 2.5-fold decrease in the in-lake TP amount was observed. This can be attributed to the shift to clear water state with submerged plant domination. Vegetation cover increased from 6% cover of pre-biomanipulation period to 50% of the lake surface area (Beklioglu et al., 2003; Beklioglu & Tan, submitted). The major decrease in the in-lake TP and submerged plant dominated state coincided in Lake Eymir. This could be attributed to reduced algal crop, increased growth of benthic algae, nutrients uptake and storage by submerged plants. Moreover, net sedimentation of TP increased in Lake Eymir following the biomanipulation probably through the processes such as reduced fish resuspension and in turn, internal loading of phosphorus (Søndergaard et al., 2003). This demonstrated a strong coupling between the biological structure and nutrient processing, especially phosphorus in shallow lakes (Jeppesen et al., 1997).

Hydrology appears to be a significant factor affecting the nutrient dynamics both directly and indirectly in shallow lakes especially located in semi-arid to arid climates. In low water level years, TP amount in the lake was high despite the fact that the TP loads via inflows were significantly low. In subtropical Lake Okeechobee, TP amount within the nearshore region was lower at low water levels (James & Havens, 2005) whereas low water level periods were associated with increased TP concentrations in temperate Lake Peipsi (Kangur et al., 2003). This result is in concert with Lake Eymir. Longer hydraulic residence times provide great opportunities for sediment-water contact (Saunders & Kalff, 2001). Thus, in-lake phosphorus concentration becomes more dependent on internal processes rather than external loading. Significant reduction in the lake volume through high evaporation in summer may further concentrate the nutrients. Decrease in water level may also interfere with nutrient and phytoplankton dynamics, enhancing eutrophication phenomena (Naselli-Flores, 2003) whereas a substantial reduction in spring lake level may encourage expansion of submerged plants (Coops et al., 2003; Beklioglu & Tan, submitted). Low water level in 2001 led to not only higher submerged plant cover (90%), maintaining the clearwater state and but also increase in the in-lake TP (Beklioglu & Tan, submitted). Whereas in 2004, when the water level was significantly low, in-lake TP level was double of that of 2001. This was probably due to loss of submerged vegetation in 2004 resulted from huge phytoplankton concentration in spring despite the low water level prevailed in the lake. These two drought induced condition low water level years with contrasting ecological conditions show the significant role of vegetation for in-lake TP level. Low water level with no vegetation increased in-lake TP level through enhanced release from the sediment probably due to loss of stabilizing buffer mechanisms of vegetation (Jeppesen et al., 1997).

In Lake Eymir, a 11-fold decrease in the in-lake DIN amount occurred following the sewage effluent diversion. A fast decrease of nitrogen was expected after external loading reduction as little inorganic nitrogen accumulates in the sediment, perhaps due to denitrification (Jeppesen et al., 1991). N-limited conditions arose from sewage effluent diversion. Reduced available nitrogen seemed to severely limit phytoplankton crop in the lake (Beklioglu et al., 2003).

DIN amount in the lake further 1.5-fold decreased upon removal of cyprinids biomass by half and re-development of submerged plants with a surface cover ranging from 50% to 90%. Nitrogen retention increases with decreasing density of cyprinids. This can be achieved by increased denitrification through several mechanisms including reduced resuspension & sedimentation, lower algal biomass and increased growth of benthic algae and other sediment biota. In addition, by removing cyprinids, nitrogen is exported from the lakes (Jeppesen et al., 1998b). Furthermore, re-development of strong submerged plant beds probably reduced in-lake nitrogen availability directly, by uptake and, indirectly, by enhancing denitrification via the creation of alternately aerobic and anaerobic zones in the sediment (Carpenter & Lodge, 1986; Rysgaard-Petersen & Jensen, 1997).

DIN amount in the lake increased onward 2001 prevailing dry years despite the fact that the DIN loads via inflows were significantly low. Similar result was observed for the upstream Lake Mogan that in-lake DIN was 2-fold high in the low water level year 2001. Gokmen (2004) found that the higher water level was, the higher the N-retention was in the reed beds. This can be attributed to formation of suitable oxic-anoxic conditions for denitrification. This result was in line with the efficiency of denitrification, then the rate of NO_3-N retention, is enhanced in wetlands by occurrence of anoxic and oxic conditions with inundation at high lake levels (Saunders & Kalff, 2001; Sanchez-Carrillo & Alvarez-Cobeleas, 2001). High nitrogen loading may reduce the chances of obtaining a clear water state at intermediate phosphorus concentration (Moss, 2001). This might have been important for triggering a shift to turbid water in Lake Eymir in 2004. (Ozen et al., unpublished data).

Negative DIN balances were found throughout the study period in Lake Eymir. The balance does not only mean sedimentation/release since there were unmeasured extra sources or sinks for DIN. Denitrification or biological consumption by plant and algae can be responsible for the negative balance. Decrease in the in-lake DIN amount in 2004 may have resulted from high consumption rate by algae.

Jeppesen et al., (1997, 2000) suggested that the TP concentration should be reduced to below 0.05-0.1 mgl^{-1} to obtain clearwater state dominated by submerged plants for shallow north temperate freshwater lakes. However, Romo et al., (2004) found lower threshold of than that of Jeppesen et al., (1997, 2000) phosphate loadings ($\leq$ 0.05 mgl^{-1}) for Mediterranean shallow lakes. If hydrological changes through global warming in shallow lakes located especially in semi-arid or arid Mediterranean lakes are taken into consideration (Loaiciga et al., 1996), even lower thresholds of nutrient loading may be necessary for obtaining submerged vegetation dominated clearwater state in Mediterranean lakes since drought induced low water level years are associated with high TP and DIN amounts.

CHAPTER 6

CONCLUSION

Water levels in shallow lakes naturally fluctuate intra- and interannually depending largely on regional climatic conditions. Through global climate change, water level fluctuations may become as significant as nutrients on functioning of shallow lakes (Coops et al., 2003). Shallow lakes especially located in semi-arid to arid region are very dependent on the balance of inflows and evaporation and very sensitive to change in either. In Lake Mogan and Eymir, inflows were the major sources of water budget in wet and regular years while the importance of inflows decreased significantly in dry years.

Drops in spring lake level coupled with high evaporation in summer enhanced vegetation development leading to a large expansion of the littoral zone in Mediterranean and subtropical lakes (Gaffny & Gasith, 1999; Beklioglu et al., 2004; Havens et al., 2004). In Lake Mogan, TP amount in the lake was high and the lake lacked submerged vegetation due to high spring level in 2000. However, TP amount in the lake declined 2-folds in low water level year in 2001 owing to low TP loading from the catchment via the inflows and increased submerged plant coverage (90%). Upon increase in water level in 2002 and 2003, the in-lake TP increased again in Lake Mogan. These years were high water levels and low submerged plant cover. As a result, high hydraulic residence time resulted in high in-lake TP amount in Lake Mogan. Increase in hydraulic residence time is due to the new lake management, which manipulates the lake level. It seems that this management practice deteriorates the water quality of Lake Mogan.

Submerged macrophytes can increase nitrogen removal by enhancement of denitrification (Reddy & Busk, 1985; Eighmy & Bishop, 1989; Korner, 1997; Eriksson & Weisner, 1999). However, in Lake Mogan, DIN amount increased 2-fold in 2001 which was a low water level year in spite of lower external DIN load to the lake and the high submerged plant cover. Low water level in reed beds may decrease nitrogen retention (Gokmen, 2004). In Lake Mogan, high water level years 2002 and 2003 were associated with high in-lake DIN amount and low submerged plant coverage.

In Lake Eymir, a major reduction in external TP loading from Inflow I in 1995 resulted in a 2-fold decrease in the in-lake TP amount. This is in accordance with Jeppesen et al., (2002) though long resilience to recovery owing to internal loading occurred in some shallow lakes (Søndergaard et al., 2003). Moreover, a 11-fold decrease in the in-lake DIN amount occurred following the sewage effluent diversion. A fast decrease of nitrogen was expected after external loading reduction as little inorganic nitrogen accumulates in the sediment (Jeppesen et al., 1998b). In Lake Eymir, a 2.5-fold and 1.5 fold decreases in the in-lake TP and DIN amounts, respectively, were recorded after the biomanipulation, coincided with a shift to clear water-submerged dominated state. This could be attributed to reduced algal crop, increased growth of benthic algae, nutrients uptake and storage by submerged plants. Moreover, net sedimentation of TP increased in Lake Eymir following the biomanipulation probably through the processes such as reduced fish resuspension and in turn, internal loading of phosphorus (Søndergaard et al., 2003). In low water level years 2001 and 2004, TP and DIN amount in the lake increased despite the fact that TP and DIN loads via inflows were significantly low. Longer hydraulic residence times and low water levels provide great opportunities for sediment-water contact (Saunders & Kalff, 2001). Thus, in-lake phosphorus and nitrogen concentration becomes more dependent on internal processes rather than external loading.

The mass balance studies on total phosphorus (TP) and dissolved inorganic nitrogen (DIN) have focused on north temperate lakes. However, only a study was encountered for Mediterranean lakes (Jossette et al., 1999). Moreover, there were a limited number of studies about the effects of water level fluctuations on nutrient dynamics and ecology of shallow lakes located in Mediterranean or semi-arid to arid region (Gafny & Gasith, 1999; Naselli-Flores, 2003; Beklioglu et al., 2004). In Lakes Mogan and Eymir, high hydraulic residence time whether it is caused by high and low water level led to increase in the nutrients. Therefore, the present study provided useful information on strong impacts of sewage effluent diversion, submerged plant dominated clearwater state triggered by biomanipulation and hydrology on TP budget and DIN load in shallow Lakes Mogan and Eymir. If hydrological changes through global warming in shallow lakes located especially in semi-arid or arid Mediterranean lakes are taken into consideration (Loaiciga et al., 1996), even lower thresholds of nutrient loading may be necessary for obtaining submerged vegetation dominated clearwater state in Mediterranean lakes since drought induced low water level years are associated with high TP and DIN amounts.

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