DETERMINING THE ROLES OF WATER LEVEL AND FISH PREDATION ON SUBMERGED PLANT GROWTH IN SHALLOW LAKES USING MESOCOSM EXPERIMENT

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ABSTRACT

DETERMINING THE ROLES OF WATER LEVEL AND FISH PREDATION ON SUBMERGED PLANT GROWTH IN SHALLOW LAKES USING MESOCOSM EXPERIMENT

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Four-month mesocosm experiment from June 1^{st} to September 25^{th}, 2009, was conducted to determine the effect of water level difference in combination with fish predation pressure, on submerged macrophyte development, in an eutrophic shallow lake. Effect of water level fluctuation was simulated by placing enclosures to the different water depths that included 0.8 m, 1.6 m and 2.3 m on Lake Eymir. These enclosures having a cylindirical shape and 1.2 m diameter, were open to sediment and atmosphere interaction. The highest water level mesocosms were cancelled after fifth sampling due to rapture in the bags, hence this thesis does not include the results of 2.3 m. At each depth, half of the enclosures were stocked with planktivo-omnivorous fish (*Tinca tinca*, *Alburnus spp.*) which are natural fauna of Lake Eymir. Before stocking of fish, ten shoots of *Potamageton pectinatus* were added to all of the enclosures in order to observe submerged macrophyte development.

Sampling for physico-chemical parameters, zooplankton, chlorophyll *a*, PVI% and periphyton was conducted weekly for the first five weeks, last six samplings were done biweekly. Macrophyte harvesting for dry weight estimation was done at the end of the experiment. Throughout the experiment water level decreased 0.41 ± 0.06 m in each enclosures.

Water level was so critical for macrophyte development that no significant macrophyte growth was observed in enclosures located at 1.6 m (HW). However, fish predation did not prevent the growth of macrophyte in enclosures located at 0.8 m (LW) but it was important in HW enclosure for affecting water clarity. Fish predation affected chlorophyll *a*, zooplankton and nutrient concentrations and the effect was mostly pronounced at LW enclosures. They had high chlorophyll *a* and nutrient concentrations but it did not repress macrophyte growth as in temperate lakes. Despite high water clarity in HW fishless enclosures, very low macrophyte biomass may be attributed to enhanced periphyton development. Zooplankton community shifted to small sized ones under fish predation while fishless enclosures had higher zooplankton/phytoplankton ratio for each depth. Hence, regarding these results it can be stated that decrease in water level can compensate the negative effects of fish predation on macrophyte growth in warm Mediterranean lakes.

Keywords: hydrology, macrophyte, top-down control, bottom-up control, mesocosm

ÖZ

SIĞ GÖLLERDE SU SEVİYESİ VE BALIK AVLANMA BASKISININ SUİÇİ BİTKİ GELİŞİMİNDEKİ ROLLERİNİN MEZOKOZM DENEYİYLE BELİRLENMESİ

Bucak, Tuba
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Balık avlanma baskısıyla beraber su seviyesi farkının ötrofik sığ göllerdeki etkilerini belirlemek için 1 Haziran ve 25 Eylül 2009 tarihleri arasında, 4 aylık bir mezokozm deneyi gerçekleştirilmiştir. Su seviyesi değişimi benzeşimi oluşturabilmek için Eymir Gölü'nde 0.8 m, 1.6 m ve 2.3 m derinliklere sahip mezokozmlar oluşturulmuştur. Deney düzenekleri 1.2 metre çapında silindirler olup, sedimana ve atmosfere açık ve etkileşim halindedirler. En yüksek su seviyesine sahip düzenek, beşinci örneklemenin sonunda oluşan yırtık sebebiyle iptal edilmiştir ve bu tez 2.3 metrenin sonuçlarını içermemektedir. Her su seviyesinde, mezokozmların yarısına Eymir gölü faunasından planktivo-omnivor balıklar (*Tinca tinca*, *Alburnus spp.*) eklenmiştir. Balık eklenmeden önce ise bitki gelişimini gözleyebilmek için her mezokozma on adet *Potamageton pectinatus* bitkisi ekilmiştir.

Su kimyası, klorofil *a*, zooplankton ve PVI% için örnekleme periyodu, ilk 5 örnekleme için haftalık, kalan 6 örnekleme için iki haftalık olarak devam etmiştir. Kuru ağırlık hesaplaması için suiçi bitkileri deneyin sonunda toplanmıştır. Deney süresince su seviyesi 0.41 ± 0.06 kadar düşmüştür.

1.6 m (HW) derinliğe yerleştirilen mezokozmlarda kayda değer bir bitki gelişimi görülmemiş olması sebebiyle, su seviyesinin makrofit gelişimi için çok kritik olduğu söylenebilir. Bununla birlikte, balık avlanması, 0.8 m (LW) derinliğe yerleştirilmış mezokozmlarda makrofit gelişimini engellememiş olmasına rağmen, yüksek derinlikli düzeneklerde (HW) su berraklığını önemli şekilde etkilemiştir. Balık avlanması, klorofil a, zooplankton ve besin tuzu yoğunluklarını etkilemiştir ancak bu etki düşük derinlikli (LW) düzeneklerde daha fazla olmuştur. Yüksek klorofil a ve besin tuzu derişimlerine sahip olmalarına rağmen, bitki gelişimi, düşük su seviye mezokozmlarında engellenememiştir. Yüksek seviye balıksız mezokozmlarında ise su berraklığı yüksek olmasına rağmen, çok az bitki biyokütlesi görülmesi, perifiton büyümesinden kaynaklanmış olabilir. Balık baskısı altında zooplankton topluluk yapısının da daha küçük boylu zooplanktonlara doğru kaydığı görülmüştür. Balıksız mezokozmlarda ise zooplankton/fitoplankton oranının daha yüksek olduğu gözlenmiştir. Bu sonuçlar değerlendirildiğinde sıcak Akdeniz iklim kuşağı göllerinde, su seviyesindeki düşüşün, balık avlanmasının bitki gelişimi üzerindeki olumsuz etkilerini telafi edebileceği öne sürülebilir.

Anahtar Kelimeler: hidroloji, suiçi bitkileri, yukardan asağıya kontrol, asağıdan yukarıya kontrol, mezokozm

To Oğuz and Şehnaz

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CHAPTER 1

INTRODUCTION

1.1 Introduction to Shallow Lakes and Structuring Role of Macrophytes

Freshwaters have a vital role for all living things (Bailey et al., 2004; Naiman et al., 1995), make up a small portion (%0.01) of the world water resources (Dudgeon et al., 2006; Wetzel, 2001). They provide habitat and essential source for many organisms. Despite its cruciality, extensive usage of freshwater for agriculture, industry and domestic purposes are becoming a great problem throughout the world. Beside extreme consumption, increasing nutrient loading from settlement and agricultural fields create threats of eutrophication to freshwater habitats (Moss, 2010). According to WWF Living planet index (WWF, 2010), freshwater systems of warmer regions were highly affected for the last 30 years. Hence, they are one of the most degraded ecosystems by humankind (Dudgeon et al., 2006).

Until the second half of the 1950s, freshwater ecology was concentrated on deep lakes which are characterized by thermal stratification during summer and concurrently importance of shallow lakes were ignored in scientific arena. However, small and shallow lakes constitute most of the freshwater source of the world (Williamson et al., 2009; Moss, 2010). Shallow lakes are characterized by extensive littoral zone with dense submerged macrophyte beds and no regular thermal stratification pattern in summer. Because of large area of littoral zone, benthic- pelagic coupling is high if compared to deep lakes and they serve a complex habitat for organisms (Scheffer, 1998). Thus the overall productivity of organisms are higher in shallow lakes (Jeppesen et al., 1998).

Until 1990s, it was hypothetized that turbid water state and nutrient amount has a linear relationship (Philips et al., 1978). Mainly depending on nutrient concentrations, shallow lakes can be found in two alternative stable states namely macrophyte dominated clearwater state and phytoplankton dominated turbid water state. The switch between these can be explained by alternative stable state (ASS) hypothesis demonstrating the probability of ecosystem to be found between two states (Scheffer et al., 1993). Figure 1.1 indicates the nutrient thresholds and probability of ecosystem switching between these states. The lake can switch to these situations at intermediate nutrient levels abruptly and its whole community can change (Scheffer et al., 1993, 2001; Jeppesen et al., 1998). Increase in nutrient concentrations and consequent phytoplankton production cause a lake to reach critical turbidity which result in loss of macrophytes. While forward shift to turbid water state takes place at higher nutrient concentrations, backward shift to clear water state is a tough issue. Hence, in order an eutrophic lake to recover, very low nutrient concentrations must be achieved. As alternating to turbid state, phytoplankton gain advantage for light and submerged macrophytes decline. Turbid state is generally defined as presence of high primary productivity of phytoplankton, low primary grazers and dominance of plankti-benthivorous fish, low macrophyte growth and low biodiversity, while clearwater state is typified as dense macrophyte beds, large-bodied zooplankton and piscivorous fish control on planktivorous fish. As macropyte dominance serves complex habitat, biodiversity is high in clearwater state (Jeppesen et al., 2000; Scheffer, 1998).

Having prominent role in lake ecosytems, submerged macrophytes operate on lake dynamics through several mechanisms (Figure 1.2). As they are central in alternative stable state hypothesis, there is a synergistic relationship between submerged macrophyte development and water clarity. While water clarity triggers macrophyte growth through enabling increase in light penetration, submerged macrophytes stimulate the mechanisms, which enhance water clarity. One of the direct effect of submerged macrophytes is reducing the wind-driven resuspension by stabilizing the sediment through their roots (Barko and James, 1998; James and Barko, 1990). Hence, internal nutrient release from sediment decreases in macrophyte dominated system (Søndergaard et al., 1992). They also serve as comlex habitat for many organisms

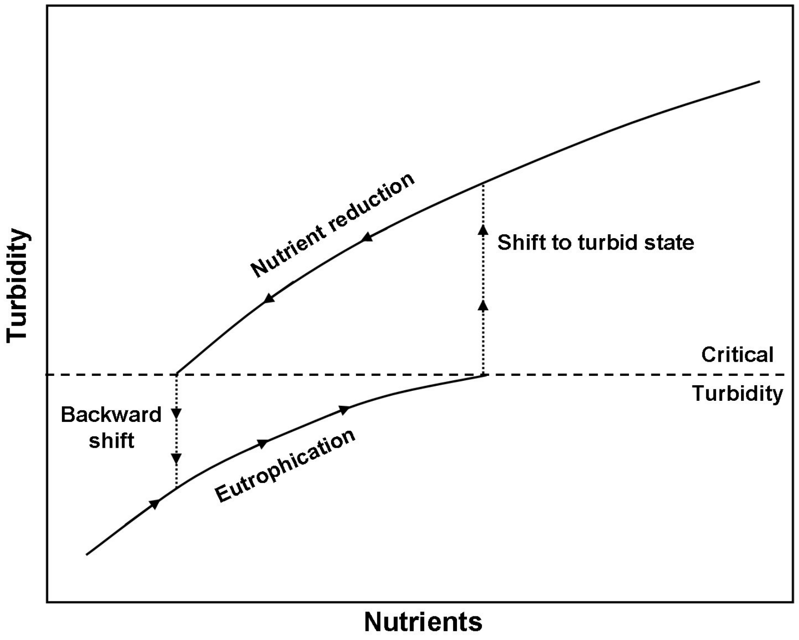


Figure 1.1: Alternative stable states hypothesis: Schematic view of the ecosysem shifts corresponding to nutrient-turbidity relationship, taken from Scheffer (1998)

like fish, birds, macroinvertebrates (Meerhoff, 2003; Meerhoff et al., 2007b). Most fish use dense plant beds for spawning and as a refuge in order to hide from predators. They also act as a refuge for zooplankton against planktivorous fish predation. This behaviour of zooplankton is prevalent in temperate lakes whereas in warmer-climate lakes high amount of fish accumulate in macrophyte beds. Hence, zooplankton in low latitude lakes do not use submerged macrophyte as a refuge mechanism (Meerhoff et al., 2007a,b).

Being a primary producer, macrophytes compete with phytoplankton for light. They gain advantage in low nutrient concentrations as they can take the nutrients from the sediment (Lacoul and Freedman, 2006). Macrophytes also have allelopathic mechanisms to compete with phytoplankton through secreting chemicals to inhibit the growth of phytoplankton (van Donk and van de Bund, 2002). They serve attached surfaces for epiphyton development. In addition, they provide habitat for macroinvertebrates which are periphyton grazers, control the growth of periphyton and so benefit macrophyte development (Jones and Sayer, 2003).

Macrophytes can also trigger nitrogen reduction in lakes by enhancing denitrification through providing surfaces for denitrifying bacteria (Weisner et al., 1994). Within dense macrophyte beds, excessive respiration during night give rise to anoxic conditions which enhance denitrification and loss of nitrogen in the form of N_2 (Frodge et al., 1990).

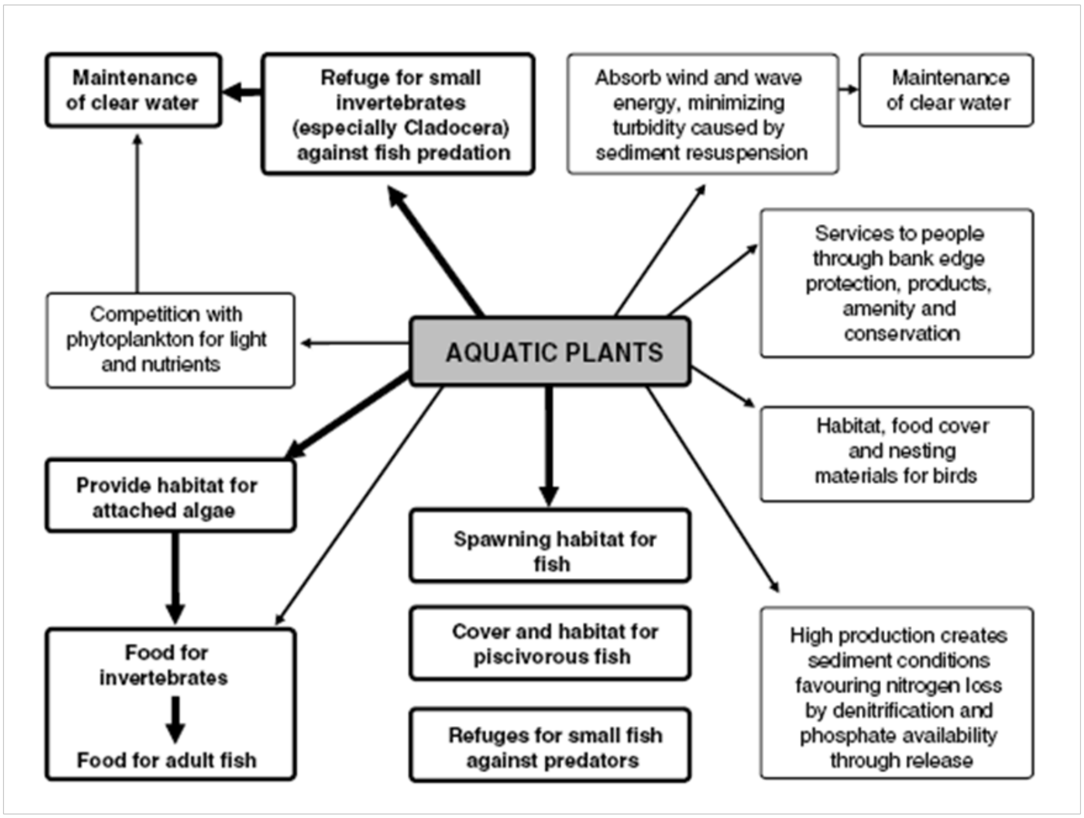


Figure 1.2: Diagram summarizing the role of macrophytes in shallow lake ecosytems, taken from Meerhoff (2003)

The roles stated above mainly confirmed in temperate lakes. The mechanisms in other climatic regions may be different since temperature is very important agent for metabolisms of organisms. There are many studies showing that the role of macropytes do not follow the same pattern in low latitudes as in temperate ones (Meerhoff et al., 2007a; Bachmann et al., 2002; Özen et al., 2010). For instance a study pooling lakes from Florida having a warm climate, indicated that there is no significant relationship between macrophyte growth and water clarity (Bachmann et al., 2002).

1.2 Factors Affecting Submerged Macrophyte Growth

Primary factors affecting submerged macrophyte development are the physical factors like geology of the basin, sediment characteristics, climate and hydrology. After suitable physical conditions are set, chemical and biological interactions play the role (Lacoul and Freedman, 2006).

Nutrients may trigger macrophyte development up to some level but generally nutrient is not considered as a limiting factor for macrophytes. However, high nutrient concentrations in water column stimulate phytoplankton production which in turn negatively affects macrophyte growth by decreasing light availability because of the organic turbidity caused by high phytoplankton density (Moss, 2010; Jeppesen et al., 1998). Light is the primary agent for primary production. Availability of light depends on the turbidy and water colour. These are function of suspended solid concentrations, biological productivity and chemical characteristics of water. Shading effect of phytoplankton reduce the availability of light for macrophyte. There are many other chemical factors act on macrophyte production, such as alkanility, pH, salinity which determine the community structure of aquatic plants (Lacoul and Freedman, 2006).

Water level is another factor affecting the state of lake ecosystems and growth of submerged macrophytes especially for the lakes in arid and semi-arid regions. Water level can determine the threshold which macrophyte can grow and seasonality of fluctuations acts on lake ecosystems in a complex manner. Vulnurability of macrophyte to turbidity may increase during high water level because of decreasing light penetration to the lake bottom whereas low water levels during summer can enhance macrophyte growth (Tan and Beklioglu, 2006; Beklioglu et al., 2006). Its effects on lake ecosystems will be discussed further in section 1.2.1.

Competition with other primary producers (e.g. phytoplankton and periphyton) for light availability also affects the macrophyte growth. As periphyton attached to plant negatively affect plant development, cascade over it act upon submerged macrophytes (Jones and Sayer, 2003). Waterfowl can also affect macrophyte density by feeding on them (Noordhuis et al., 2002). Fish predation which can be regarded as trophic cascade effect will be discussed in section 1.2.2.

1.2.1 Water Level Fluctuations

Hydrology is another factor affecting the ecosystem dynamics of lakes. Precipitation regime and morphometry of lake affect the magnitude of water level fluctuations (Beklioglu et al., 2006). Water level fluctuations (WLF) are a function of morphology of the lake, climate and anthropogenic factors, act on a nonlinear way through the lake ecosystems (Beklioglu et al., 2006; Van Der Valk, 2005; Coops et al., 2003). Importance of the role of WLF on lake dynamics is a relatively new topic and has not been fully exploited. Its impact can be observed on whole lake ecosystem such as through light penetration, nutrient, growth dynamics, primary production, fish spawning and biodiversity (Wallsten and Forsgren, 1989; Blindow, 1992; Beklioglu et al., 2001, 2006; Tan and Beklioglu, 2006). Several studies showed that WLF may play a role in shifting between clear water state and turbid water state (Havens et al., 2004; Coops et al., 2003; Gafny and Gasith, 1999; Engel and Nichols, 1994; Blindow, 1992).

Mediterranean climate is a semi-arid climate which characterized with warm-rainy winter and hot-dry summer. Since extreme precipitation pattern exists, there are water level differences between seasons. Most of the lakes in this region faces desiccation during summer with strong loss of water by evaporation. Especially for manmade and regulated lakes it is crucial to determine the optimum ”dewatering” threshold considering ecosystem changes (Naselli-Flores and Barone, 2005; Beklioglu et al., 2007). In Mediterranean climatic region, WLF has the most prominent factor because of climatic characteristics.

Low water levels in summer may trigger submerged macrophyte development (Nõges and Nõges, 1999; Coops et al., 2004; Beklioglu et al., 2006, 2007, 2011) through increasing light levels reaching up to bottom whereas high water level can give advantage to phytoplankton tolerant to low light (Beklioglu et al., 2006; Nõges et al., 2003). Low water levels during winter can be a perturbation shifting to turbid water state. This is because low water levels can cause littoral sediment to be frozen and it can prevent recolonizing of the macrophyte. Complete desiccation can also cause loss of macrophyte (Scheffer, 1998; Blindow, 1992; Blindow et al., 1993; Hargeby et al., 1994; Beklioglu et al., 2007).

At low water levels when light is not a limiting factor, nutrient level determines the primary production in some lakes (Nõges et al., 2003) but not in all: especially warm Mediterranean lakes (Özen et al., 2010). Temperature and water level can act together on primary production by inreasing nutrients; high temperature and low water level can trigger nutrient release from sediment (Haldna et al., 2008) in addition to direct up-concentrating of nutrients because of enhanced evaporation and high temperature(Özen et al., 2010).

Lower precipitation pattern can also reduce the external nutrient loading from the catchment and may cause a decrease in lake nutrient levels(Vollenweider, 1976); but for lakes which are exposed to high external nutrient loading for years, even no nutrient input coming from the catchment during dry years, nutrient levels can increase by the processes called internal nutrient loading. No flush out of lake during drought years result in increasing water retention time and it may bring out enhanced salinity and internal nutrient loading which can (Özen et al., 2010) deteriorate the conditions for healthy vegetation.

A recent study by Özkan et al. (2010) showed that nutrient- phytoplankton- macrophyte relationship may be different in warmer lakes considering water level fluctuations. With increase in nutrient levels, they found no significant relationship between high nutrient and macrophyte loss, however, nutrient triggered periphyton growth. The results indicated that decrease in water level through their experiment (40 cm in 3 months) may have overriden the effect of eutrophication in warmer shallow lakes.

1.2.2 Fish Predation

Trophic cascade theory is defined as the effect of zooplankton on phytoplankton triggered by fish predation pressure (Carpenter et al., 1985). According to the size efficiency hypothesis (Brooks and Dodson, 1965) planktivorous fish prefer large bodied zooplankton in their diet. Hence, ecosystem can shift to dominance of small-bodied zooplankton which cause a reduction in grazing effect of zooplankton and result in increased algal growth (Shapiro and Wright, 1984; Seda and Duncan, 1994; Hambright, 1994).

Presence of piscivorous fish in the system can control the planktivorous fish and can decrease the negative consequences of planktivory on shallow lakes. Planktivorous fish community can shift from small sized ones to large-sized ones in the presence of piscivorous fish. As large planktivorous fish prefer large macroinvertebrates instead of zooplankton prey which small fish have a high predation pressure on, zooplankton able to control the phytoplankton in the system having piscivore fish at the top of the pyramid (Scheffer, 1998; Carpenter et al., 1987).

A recent study by Mazzeo et al. (2010) provided further support for the trophic cascade hypothesis in warmer climates with the experiment they conducted in Uruguay. Designing experiments with two to four trophic levels showed that with three trophic level (absence of the piscivorous fish) enclosures showed high chlorophyll *a* and lower water clarity. However, enclosures that have four trophic levels (phytoplankton, zooplankton, planktivorous, piscivorous) showed high zooplankton abundance and low chlorophyll *a* which suggest that stocking of piscivorous fish can be an alternative for lake restoration in order to shift submerged plant dominated clear water state. Impact of trophic cascade is in action that can be an efficient restoration method in Mediterranean region as well (Beklioglu et al., 2003).

1.3 Changing Lake Dynamics Considering Global Climate Change

Climate change is regarded as a global change in meteorological pattern in long term scale and accelerated after the industrial revolution. Increased carbon emissions are giving rise to elevated mean temperatures of Earth and its impacts are various on ecosystems and society. Freshwaters are one of the vulnerable system regarding climate change as they depend on meteorological cycle. It is predicted that climate change worsens the effects of urbanization and population growth on water resources. Expected outcome of climate change differs among different latitudes as it is predicted that precipitation will increase at high latitudes (Parry et al., 2007). However, increase in temperature decreases precipitation regime and enhance evapotranspiration in low latitude dry regions, such as Mediterrranean region (Giorgi, 2006).

Mediterranean region is one of the hot-spot area (Giorgi, 2006) from climate change perspective, expected to have a decrease in precipitation 25%-30% and warm up to 4-5 °C during warmer seasons with highly inter annual variation that resulted in extreme drought events (Giorgi and Lionello, 2008). The most comprehensive study (Önol et al., 2009) conducted in Turkey for future climate scenarios states that most dramatic change is predicted in the western part of Turkey in summer season. While the southern regions of Turkey will suffer from drought by 34% precipitation drop in winter seasons, Blacksea region of Turkey will have an increase in precipitation. In addition, it is expected that fall precipitation will increase in the south-eastern of Turkey by 50% (Önol et al., 2009). Hence, warmer parts of Turkey will have even dryer summers which may possibly deteriorate and result in loss of many freshwater ecosystems.

As climate change has become a hot topic for last two decades, there are many studies conducted to predict future impacts of climate change on freshwater ecosystems (Moran et al., 2010; Winder and Schindler, 2004; Carvalho and Kirika, 2003). A study conducted by METU Limnology Laboratory (TUBITAK project, 105Y332) indicated that southern lakes of Turkey which experience higher temperature and lower precipitation during summer, had higher salinity compared to northern lakes. Fish fauna is characterized with small sized ones and very high number in warmer lakes which result in deterioration of lake water quality by high TP, chlorophyll *a* and low water transperancy (Beklioglu et al., unpublished data). Furthermore, Meerhoff et al. (2007a) also showed that warmer lakes because of higher fish biomass are so sensitive to external factors since expected warming pattern will worsen the lake quality conditions more.

Since global climate change affect hydrological cycle of lake and trophic interactions indirectly, current experiment is conducted in eutrophic lake to determine the effect of WLF and top-down control on macrophyte growth in the light of climate change.

1.4 Aim of The Study

Özkan et al. (2010) explicitly showed that effect eutrophication, which was achived through nitrogen (N) and phosphorus (P) enrichment on macrophyte growth, was overridden through significant water level drop in a mesocosm experiment carried out in Lake Pedina, İğneada, Turkey,

Following the footsteps of Özkan et al. (2010), the major goal was to test the effect of water level fluctuation and top down control of fish in a eutophic lake separately and together on macrophyte growth using *in situ* mesocosms with three different depths reflecting a possible water level fluctuation. Lake Eymir was chosen to test if water level effect is also significant at eutrophic lake which was given raw sewage for many years. Mesocosms with a height of 0.8m, 1.6 m and 2.3 m depths in the presence/absence of fish, it was hypothesised that, at shallowest depth, the effect of water level on macrophyte growth override the negative effects of eutrophication and top-down control on underwater light climate, whereas at higher depths opposite can be the case.

CHAPTER 2

MATERIALS AND METHODS

2.1 Study Site

Lake Eymir, Ankara, located at town Gölbaşı, is a shallow lake, has a mean depth of 3.1 m and with a surface area of 125 ha. Main inflow of Lake Eymir is outflow of Lake Mogan which was inactive for the past 6 years including the experiment period. Second inflow of Lake Eymir is Kışlakçı creek which enters the lake from the northern part is mostly active in late winter and spring.

Through the history, Lake Eymir was characterized by clear water and dense macrophyte beds. Secchi disc depth was >4 meter at deepest point and Charophytes was observed at 6-7 m. depth (Geldiay, 1949). However, after 1970s lake received raw sewage effluents that resulted in deterioration of water quality by increasing total phosphorus and observation of low Secchi disc depth. In 1995, sewage effluent diversion was conducted to recover the lake. While lake total phosphorus (TP) levels were reduced, there was still low Secchi disc depth and absence of macrophytes. In 1998-1999 biomanipulation program was started that including the removal of bentiplanktivorous fish fauna (*Tinca tinca*, *Cyprinus carpio*) of Lake Eymir. Biomanipulation caused a decrease in suspended solids, chlorophyll *a* and nutrient levels, and enhanced water clarity. Increase in water clarity brought about submerged macrophyte development up to 40% and 90% of the surface area (Beklioglu et al., 2003; Tan and Beklioglu, 2006; Beklioglu and Tan, 2008). Dry years also enhanced macrophyte development as in year 2001. However after five years from biomanipulation, lake shifted back to turbid state by increasing suspended solids via phytoplankton

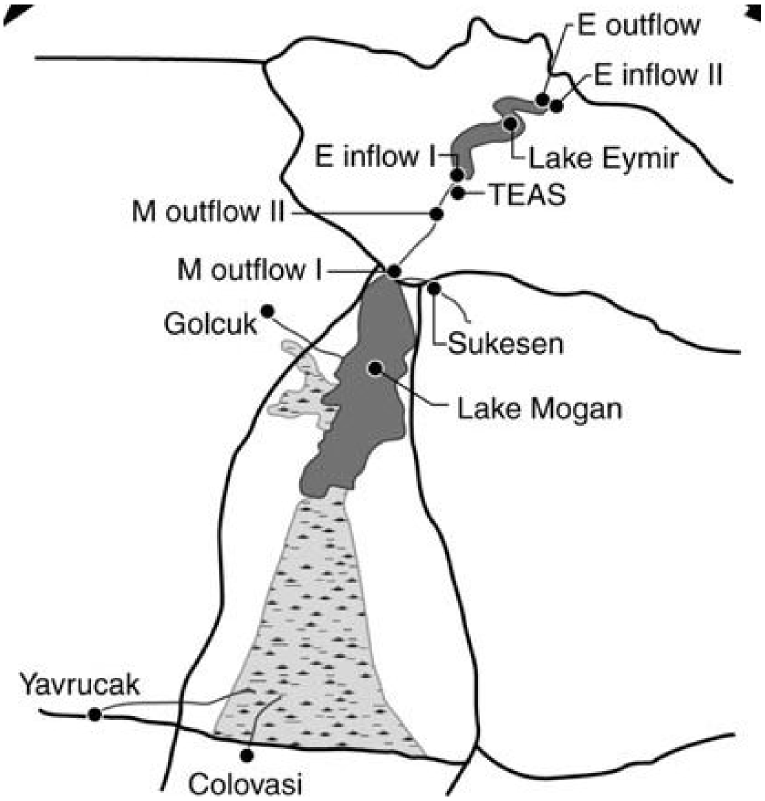


Figure 2.1: Figure showing the inflows and outflows of Lake Eymir and its upstream: Lake Mogan, taken from Özen et al. (2010). Eymir and Mogan is abbreviated as E and M respectively.

production due to drought, and increased nutrient availability initiated by increased fish density. Second biomanipulation program was implemented between 2006-2007 which result in improvement of lake quality (Özen et al., 2010).

2.2 Experimental Design

Mesocosm experiment was conducted in Lake Eymir (Figure 2.2), Ankara from June 1^{st} to September 25^{th}, 2009 (Table 2.1) in order to observe the effects of water level and fish predation on submerged macrophyte development.

Mesocosm enables to design replicable and controlled experiments under natural conditions. They were designed as isolated enclosures within lake, open to atmosphere and sediment interaction. They were big enough to reflect the natural ecosystem of lake and small enough to enable to design replicable experiments. In this study, conducting enclosures at different water depth enable to simulate the effect of water level fluctuations on lake ecosystem whereas fish predation was tested within enclosures having fish and no fish at each depth.

Mesocosm were placed in to 0.8 m, 1.6 m and 2.3 m to simulate the critical water depths for submerged macrophyte development. In each water level, 8 mesocosms were placed; half of which had fish, half of them was fishless. In total, there were 24 enclosures with 4 replicated block design. However, after 5th week the deepest treatment (2.3 m.) had to be cancelled because of rapture in the enclosures. The enclosures were placed at 0.8 m were regarded as Low Water (LW) and the ones were placed at 1.6 m were regarded as High Water (HW). To indicate the fish treatment +/- signs are used as (+) sign indicates presence of fish while (-) sign indicates absence of fish.

Figure 2.2: Google earth image of Lake Eymir, 2009: Image shows the location of the enclosures. Enclosures at 2.3 m was cancelled, so they were not assessed through the thesis

Enclosures were designed as to have cylindrical shape to have a diameter of 1.2 m. that were open to the sediment and atmosphere. Isolating walls were composed of transparent polyethylene nylon have a thickness of 180 nm provide sunlight to pass through enclosure. One side of the cylindirical transparent polyethylene nylon was

Table 2.1: Sampling dates

# of sampling	1	2	3	4	5	6	7	8	9	10	11
Date of sampling	1 Jun	9 Jun	15 Jun	22 Jun	30 Jun	13 Jul	27 Jul	6 Aug	17 Aug	10 Sep	24 Sep

attached to circular PVC tube (r = 1.2 m) with the aid of a Duck tape and cable ties. Bottom of the polyethylene tube was attached to the iron circle tube to bury them to the sediment.

To enable enclosures to be stable in water column, they were attached to floating aluminum frame. Aluminum frame was designed as to have dimensions of 1.2 x 1.2 x 0.3 m for each enclosure (Özkan, 2008). Buoyancy of frame was provided by polyurethane foams attached to the lower parts of the frame. Aluminum frame was fixed within lake with heavy bricks from each corner. Then enclosures were lowered to the water column, top rings of enclosures were attached to upper part of the frame and bottom rings were buried in sediment approximately 15-30 cm (see Figure 2.3 and Figure 2.4).

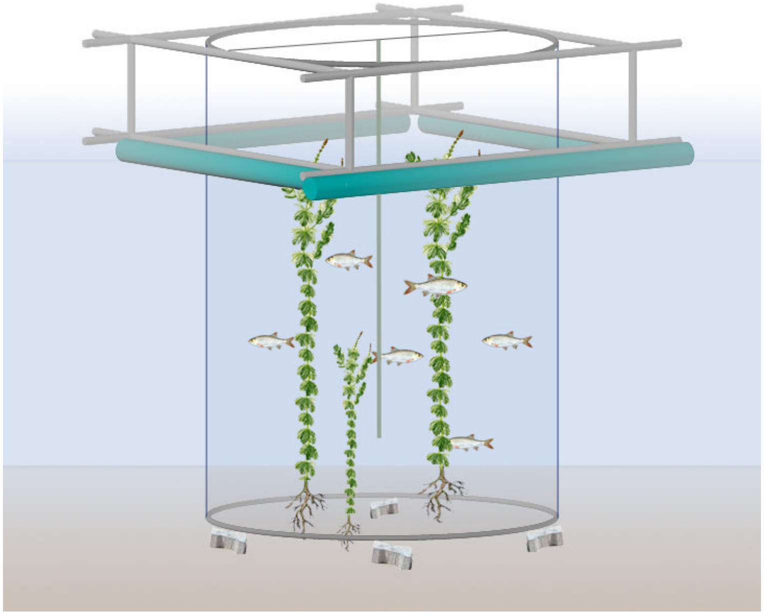


Figure 2.3: Schematic view of the enclosures; taken from Özkan (2008)

Before placing the enclosures, sediment was cleared from the macropyhtes by sub-aqua divers using hand rake. After placing aluminum frame and enclosures, they were left there for 1 week for the water column to be stable and suspended material to settle out.

Figure 2.4: Pictures summarizing the steps for constructing experimental blocks

Figure 2.5: Enclosures used in present study

2.3 Initial Conditions

Lake Eymir was surveyed for *Potamageton pectinatus*, which is a dominant macrophyte of the lake. Ten shoots of *Potamageton pectinatus* that have similar lenghts were added to each encloure. Small pebbles within a plastic bag was attached to each shoot of *Potamageton pectinatus* in order to sink through the water column. Zooplankton collected with 50 μm zooplankton net were inoculated to each enclosure.

Polyethylene (PE) strips with 3 cm width and have a length equal to the water depth were attached to the string adhering the diameter of the aluminium frame. Six PE strips were hanged with the weight attached to bottom of the strip for each enclosure.

After taking first samples from the enclosures, fish were introduced. *Tinca tinca* and *Alburnus spp.* were stocked into the mesocosm. To imitate the natural fish density of Lake Eymir, 12 fish with six *Tinca tinca* and six *Alburnus spp.* (<10 cm) were stocked to half of the enclosures at each depth .

2.4 Sampling Procedures

Sampling was conducted weekly for the first five weeks of the sampling period. Remaining samplings from July to September 25th were performed biweekly. First sampling was conducted before fish introduction as a control sampling to see if initial conditions were similar among enclosures. In each sampling, water depth, Secchi disc depth, plant volume infested (PVI%) were recorded. PVI% was calculated using surface coverage, plant height and water depth (Canfield et al., 1984). Using YSI 556 MPS sensor, temperature, dissolved oxygen, conductivity, total dissolved solids, salinity and pH were measured at surface and 0.5 m intervals through the water column.

At each enclosure 4 liter composite sample from the water column was taken with tube sampler for water chemistry (0.5 *l*), chlorophyll *a* and suspended solids (0.4 *l*) and phytoplankton (0.05 *l*) analysis. Three liters of water was filtered through 20 μm net for zooplankton identification. Phytoplankton and zooplankton samples were preserved in 2% and 4% Lugol respectively.

First periphyton sampling was performed at the third week of the sampling and then was taken biweekly. Strip of 10 cm was cut between 10-20 cm below the surface of the water and 10-20 cm above the sediment kept in zip-lock bags. Remaining strips were preserved if needed for further analysis.

At the end of the experiment, all the macropytes grown in the enclosure were harvested with the hand rake. They were kept in zip lock bags and taken to the laboratory. They were washed and washing water was filtered through 212 μm mesh to collect the macrophyte attached macroinvertebrates. Detailed study on macrophyte-periphyton interaction affecting macrophyte growth was the scope of another MSc study conducted by Ece Saraoğlu concurrently. So this thesis does not include assessment of macroinvertebrates.

2.5 Laboratory Analysis

All water chemistry samples were frozen until analysis. For determination of total phosphorus (TP) in water sample, acid hydrolysis method was used (Mackereth et al., 1978). For soluble reactive phosphorus (SRP), filtered water was processed with molybdate reaction method. Alkalinity analysis was done with acid titration with phenolphtelene and BDH indicator (Mackereth et al., 1978). Silicate was determined with a method of molibate reaction (Golterman et al., 1978). Nitrogen analysis including total nitrogen (TN) and Nitrite- Nitrate (NO_2-N and NO_3-N) analysis were carried out using Scalar Autoanalyzer Standart Methods (Houba et al., 1987; Krom, 1980; Kroon, 1993; Searle, 1984).

Chlorophyll *a* pigment content of phytoplankton was done with ethanol extraction method (Jespersen and Christoffersen, 1987) with three replicates and measured at 663 and 750 nm. For chl-a pigment concentration of periphyton, the same methodology was employed. Suspended solid amount is estimated as mg/L(Standard Methods, 22. Edition. American Health Association, 1996).

For determination of macrophyte dry weight at the end of the experiment, washed macropytes were dried at 105 °C for 24 hours for dry weight estimation.

Zooplankton identification was performed to genus level for Cladocera. Copepoda were identified as naupli, cyploploid and calanoid Copepoda. First, second, fifth and eleventh samples were processed to observe the variation during experiment. In laboratory, zooplankton samples were filtered through 140 μm filter and species >140 μm was counted. Cladocera (Scourfield and Harding, 1966) and Copepoda (Harding and Smith, 1974) species were counted under Leica MZ16 Stereo microscope with 50x magnification. In order to calculate biomass (McCauley, 1984), body length was measured to represent the whole population at each sample and measurement was done at least 25 individuals for dominant species.

2.6 Statistical Analysis

SAS 9.2 Statistical Software was used for statistical analysis. Pre-treatment values tested with one way ANOVA to see if any difference existed among enclosures. To provide the assumptions of ANOVA, log(x+1) transformation was used if necessary. If there a was significant difference, Tukey HSD was applied to see the differences among treatments. To see the trend and change in treatments during experiment Repeated Measures of Two Way ANOVA method was applied (RM two way ANOVA). First factor was water level (LW and HW) and second factor was presence/absence of fish (+/-). In RM two way ANOVA, time effect, water level, fish, water level-fish interaction and time interaction with these factors were run. If there was difference, Tukey HSD was applied to data. 95% confidence level was used for all statistical tests to show statistical difference. For macrophyte dry weight which was collected at the end of the experiment two way ANOVA was used.

CHAPTER 3

RESULTS

3.1 Physico-chemical Parameters

During the experiment a large water level drop was observed for all the mesocosms. Water depths at the low & high water mesocosms (LW and HW) ranged between 0.80-1 and 1.6-1.7 m, respectively prior to the experiment; at the end of the experiment, there were 0.41 ± 0.06 m drop in the water levels. After 5th sampling; at the end of the June 2009 water level started to decrease sharply (Figure 3.1) when surface water temperatures exceeded 26 °C in all enclosures. There was a great stratification pattern observed in the HW mesocosms. Difference between surface and one meter depth can be up to 3-4 °C during sampling period (Figure 3.2).

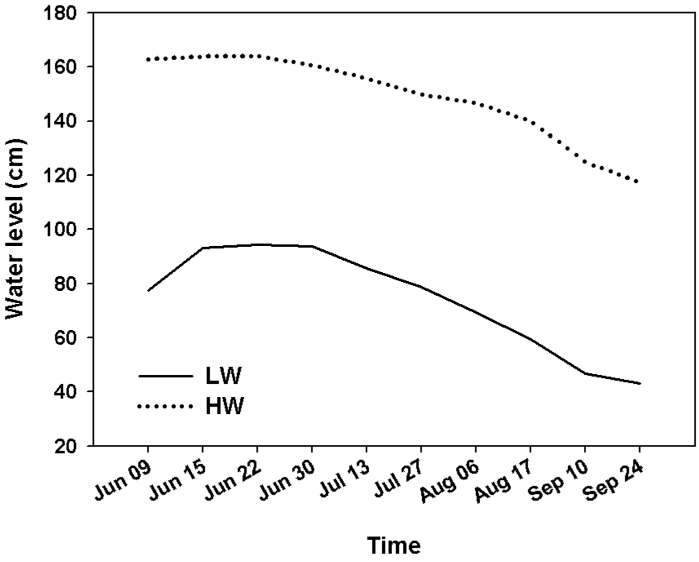


Figure 3.1: Water levels in the enclosures LW and HW throughout the study period

Table 3.1: Mean values ± standart errors of parameters measured across treatments and in-lake values. Last 3 columns give the results of Repeated measures of two way ANOVA. *p* values greater than 0.05 as defined as ns (nonsignificant). Only for dry weight which did not have time series data, p values are results of two way ANOVA

Variables	LW+	LW-	HW+	HW-	Lake	WL	Fish	WL x Fish
Conductivity (μs/cm)	2802.1 ± 14.9	2862.2 ± 20.0	2716.8 ± 28.4	2721.4 ± 32.38	2806.4 ± 22.9	<0.0001	ns	0.001
Suspended solids (mg/L)	34.02 ± 3.14	15.56 ± 1.24	25.18 ± 2.25	12.21 ± 1.36	22.14 ± 3.47	0.0114	<0.0001	ns
Dissolved oxygen (mg/L)	6.74 ± 0.47	8.08 ± 0.40	5.38 ± 0.39	5.82 ± 0.54	4.65 ± 0.94	0.0005	ns	ns
Secchi disk depth/WL	0.73 ± 0.21	0.92 ± 0.14	0.44 ± 0.21	0.84 ± 0.25	-	0.004	0.0001	ns
pH	8.81 ± 0.02	9.04 ± 0.03	8.88 ± 0.02	8.93 ± 0.02	8.79 ± 0.04	ns	0.0011	0.0202
Total phosphorus (μg/L)	269.8 ± 10.28	237.4 ± 11.37	179.2 ± 11.17	128.2 ± 10.34	235.5 ± 22.27	<0.0001	0.0128	ns
Soluble reactive phosphorus (μg/L)	114.2 ± 9.93	114.7 ± 7.59	41.0 ± 4.70	30.5 ± 2.64	115.0 ± 28.21	<0.001	ns	0.0424
Total Nitrogen (μg/L)	1506.8 ± 88.9	1312.3 ± 67.2	1214.6 ± 83.48	1176.3 ± 94.7	1244.2 ± 174.6	<0.001	0.0256	ns
NO_3-NO_2 μg/L	49.25 ± 9.16	31.88 ± 6.75	9.85 ± 1.87	10.13 ± 1.70	62.68 ± 53.58	0.0005	ns	ns
Chlorophyll *a* (μg/L)	89.53 ± 14.26	15.58 ± 3.71	47.87 ± 7.31	19.35 ± 6.40	55.32 ± 15.34	0.025	<0.001	ns
Periphyton upper (μg/cm^2)	5.76 ± 0.75	4.87 ± 0.85	5.05 ± 0.89	4.24 ± 0.72	-	ns	ns	ns
Periphyton bottom (μg/cm^2)	4.17 ± 0.58	3.74 ± 0.51	2.09 ± 0.38	6.014 ± 0.62	-	0.0003	0.0197	0.0046
PVI%	24.33 ± 5.05	43.18 ± 5.16	0.40 ± 0.22	1.47 ± 0.34	-	<0.0001	0.0001	ns
Macrophyte dry weight (g)	58.73 ± 6.95	121.45 ± 22.64	1.74 ± 1.74	0.18 ± 0.11	-	<0.0001	0.0243	0.019
Zooplankton (μg/L)	295.03 ± 98.98	938.14 ± 146.63	248.96 ± 52.33	1404.29 ± 408.17	-	ns	0.002	ns

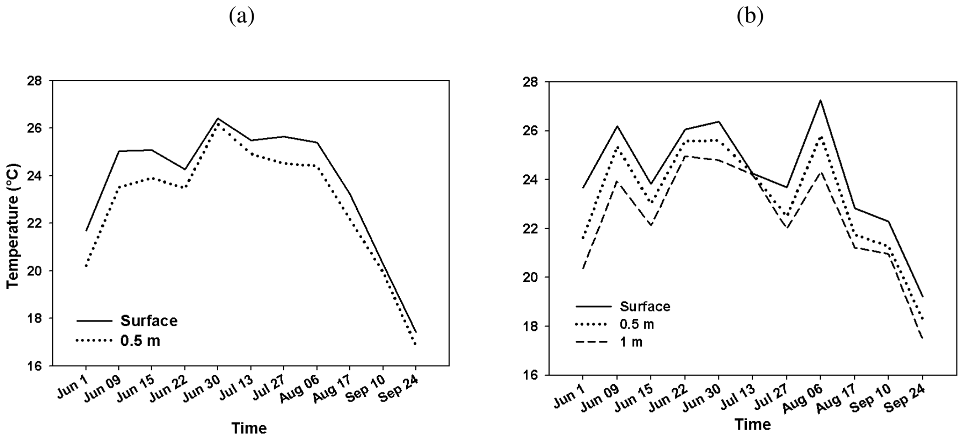


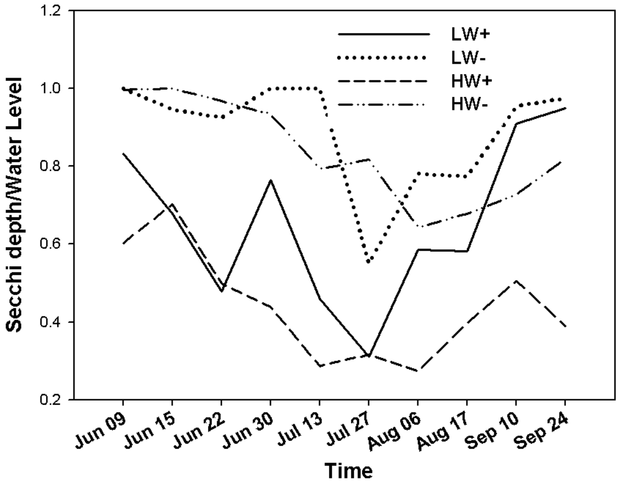
Figure 3.2: Changes in temperature profile during the experiment a) Mean water temperatures at surface and 0.5 m depth in LW enclosures, b) Mean water temperatures at surface, 0.5 m and 1.0 m depth in HW enclosures

Comparing the Secchi disc depth through all treatments Secchi depth/water level ratio (S/W) was used as Secchi depth was almost equal to the water depth in the fishless LW mesocosms. The S/W ratio differed significantly with the fish treatment and water level (Repeated Measures of two way ANOVA; p=0.0001, p=0.004, see Table 3.1). Fishless mesocosms had the highest Secchi disc depth/water level ratio corresponding to high under water light climate. At the end of the experiment the S/W ratio of LW fishless (LW+) mesocosms was close to 1 which meant that Secchi disc depth equal to the water depth because of the decrease in water depth (Figure 3.3).

Initial conditions for conductivity, one way ANOVA among water levels indicated a difference ($p<0.05$). Repeated measures of ANOVA (Rm-ANOVA) revealed that effect of water level was significant ($p<0.0001$). Also, time had a significant impact on conductivity and ($p<0.001$), it increased throughout the experiment, it is because temperature change. According to Tukey test, conductivity in the HW mesocosm significantly differed until 7th sampling period but after this period, there was no significant difference among treatments (Figure 3.4).

There was no significant difference among water depths for pre-treatment period (one-way ANOVA, p=0.051) for pH. Difference in water levels had no effect on pH (rm-ANOVA, $p>0.1$) while fish treatment decrease the pH levels (rm-ANOVA, p=0.001, see Table 3.1). Water level and fish treatment interaction gave rise to significant difference (p=0.020) which resulted in the highest pH in LW-. In addition, increasing

(a)



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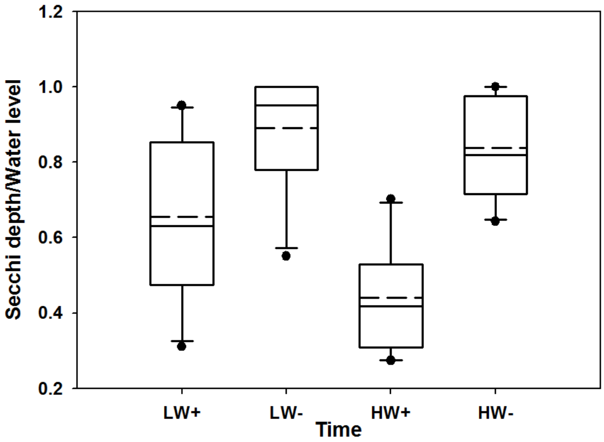


Figure 3.3: Secchi disk depth/Water level ratio for all treatments a) Change in time b) Boxplot demonstration (dashed lines show mean, and solid line show median values)

trend in pH was observed through the experiment (Figure 3.5).

For bottom dissolved oxygen (DO) concentrations there was no difference among fish treatments ($p>0.1$), however water level effect was significant ($p<0.001$, see Table 3.1) according to rm-ANOVA. Water level differences were increased after 8^{th} week when there was a sudden decrease in dissolved oxygen concentrations as shown in Figure 3.6.

One way ANOVA results for suspended solid concentrations indicated that there was no significant difference for the initial conditions ($p>0.1$). Throughout the experi-

(a) (b)

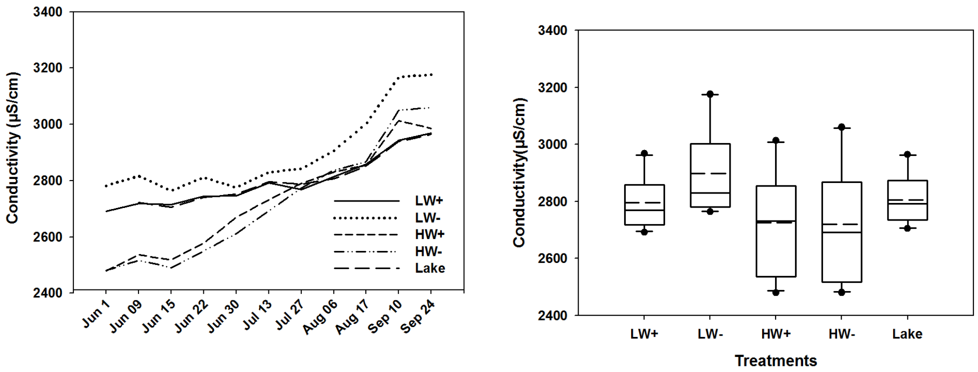


Figure 3.4: Changes in conductivity among treatments and in-lake through the experiment a) Change in time b) Boxplot demonstration (dashed lines show mean, and solid line show median values)

(a) (b)

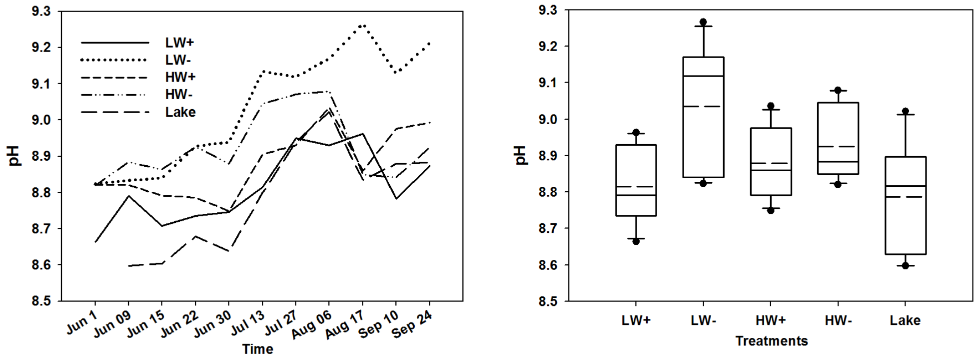


Figure 3.5: Changes in pH among treatments and in-lake through the experiment a) Change in time b) Boxplot demonstration (dashed lines show mean, and solid line show median values)

(a) (b)

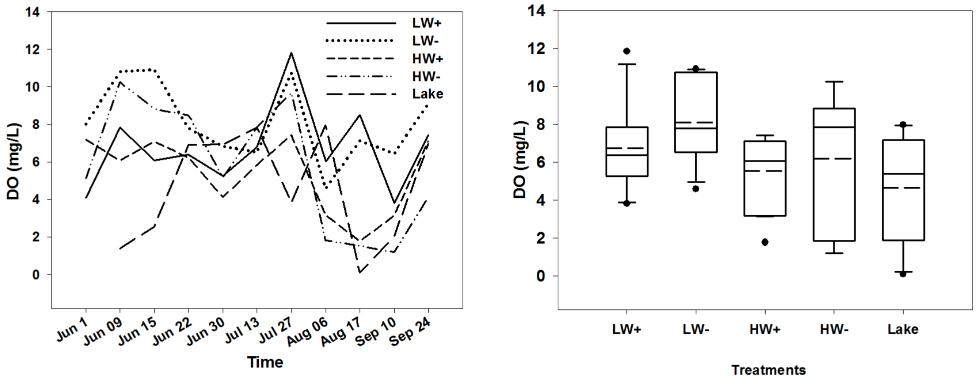
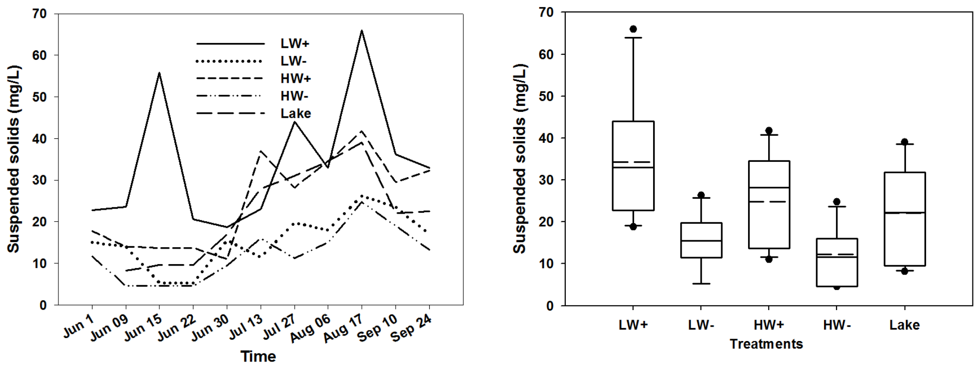


Figure 3.6: Changes in dissolved oxygen concentrations among treatments and in-lake a) Change in time b) Boxplot demonstration (dashed lines show mean, and solid line show median values)

ment, rm-ANOVA results showed that both the water level and fish had significant effect on suspended solid amount (p=0.011, p<0.001, respectively, see Table 3.1). Lower water level and fish treatment yielded the higher suspended solids. While fishless enclosures (LW- and HW-) showed a similar pattern, the differences among LW+ and HW+ were more pronounced; LW+ gave several peaks through the experiment (Figure 3.7).

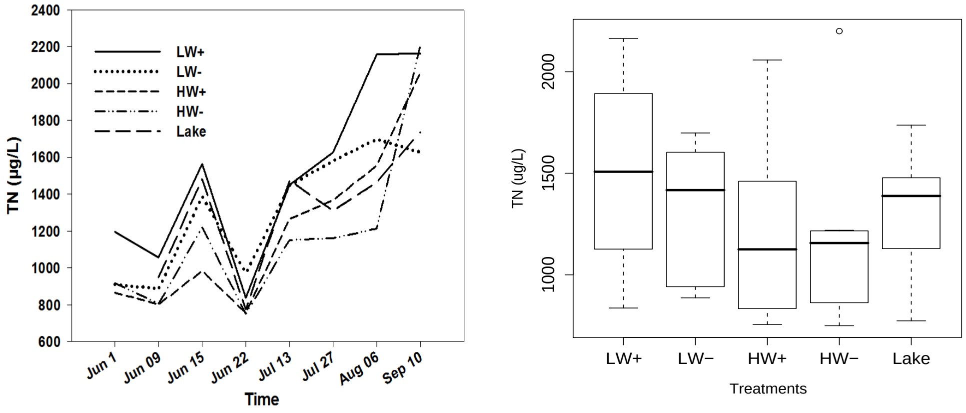

(a)

(b)

Figure 3.7: Changes in suspended solids among treatments and in-lake through the experiment a) Change in time b) Boxplot demonstration (dashed lines show mean, and solid line show median values)

For total nitrogen (TN) initial conditions, there was no significant differences between treatments except low water level with fish (LW+ fish) mesocosms (p=0.033). Moreover, the water level and fish treatment had significant effect on TN concentrations (p<0.001 & p=0.0256 respectively, rm-ANOVA, see Table 3.1). With decreases in water levels, TN concentrations increased onward 4th sampling week. Throughout the experiments the LW mesocosms especially with the presence of fish had higher TN concentration (Figure 3.8).

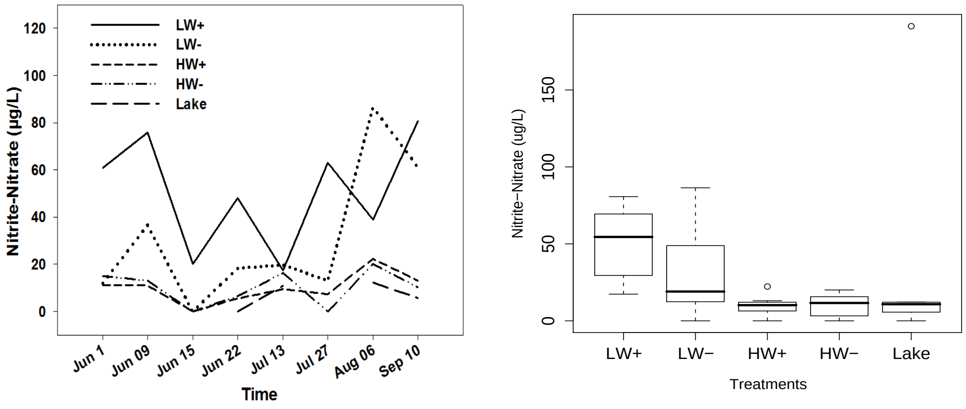
One-way ANOVA showed no difference between LW and HW mesocosms (p>0.1) for NO_3-N + NO_2-N concentrations for the initial conditions. Throughout the experiment, water level had statistically significant impact (p<0.001) on NO_3-N + NO_2-N concentrations as LW had higher NO_3-N + NO_2-N concentration than that of HW. Fish treatment did not result in significant effect (p>0.1, see Table 3.1). The concentrations of NO_3-N + NO_2-N in both fish and fishless HW remained similar whereas in the the LW enclosures, it showed a fluctuatuation pattern (Figure 3.9).


(a)

(b)

Figure 3.8: Changes in total nitrogen among treatments and in-lake through the experiment a) Change in time b) Boxplot demonstration (dashed lines show mean, and solid line show median values)

Pearson correlation analysis was done to see the dissolved oxygen and nitrogen relationship. According to Pearson correlation, TN concentrations in HW+ and HW- were inversely correlated with dissolved oxygen concentrations (R= -0.74, R= -0.67, respectively) while relationship among LW was not so strong. NO_3-N + NO_2-N and DO were also inversely correlated for HW+, HW- and LW- having a R values of -0.74, -0.53 and -0.75 respectively.


(a)

(b)

Figure 3.9: Changes in Nitrate-Nitrite among treatments and in-lake through the experiment a) Change in time b) Boxplot demonstration (dashed lines show mean, and solid line show median values)

Total phosphorus (TP) concentrations differed significantly among the water levels for the initial conditions (p=0.003) as HW had lower TP at the first sampling. Water level effect was significant (p<0.001, rm-ANOVA) and differences were more pronounced up to end of July. Fish treatment also had a significant effect on TP concentrations (p=0.0128, rm-ANOVA, Table 3.1) as fishless mesocoms had lower TP concentrations than that of presence of fish (Figure 3.10).

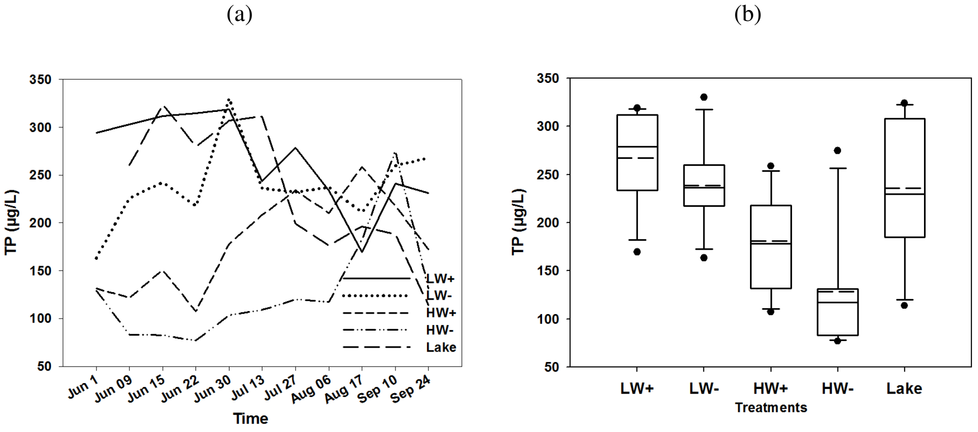


Figure 3.10: Changes in total phosphorus among treatments and in-lake through the experiment a) Change in time b) Boxplot demonstration (dashed lines show mean, and solid line show median values)

Soluble reactive phosphate (SRP) concentrations significantly differed for initial conditions (p<0.001). While water level was significant (p<0.001, rm-ANOVA), effect of fish was not (p>0.1, rm-ANOVA, see Table 3.1). As in TP concentration, the LW mesocosms had higher SRP concentration. However, July onward the differences among treatment became less pronounced (Figure 3.11). In addition, SRP concentrations significantly changed with the combined effects of the water level and fish (p=0.042).

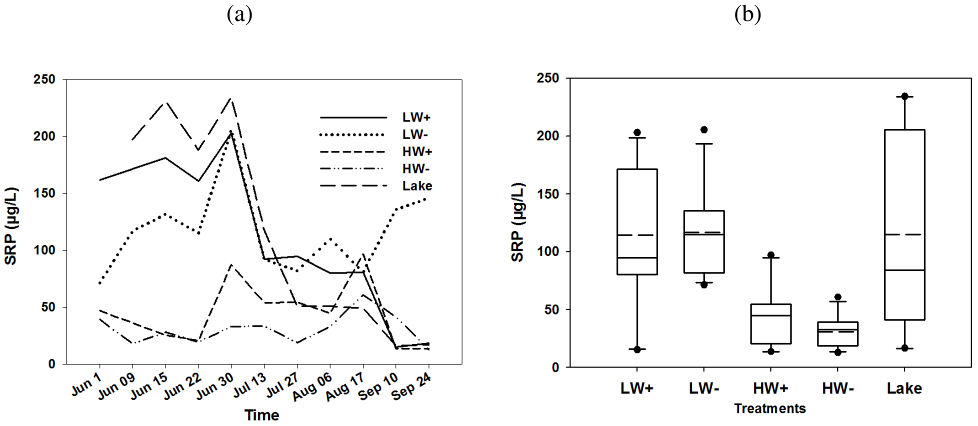
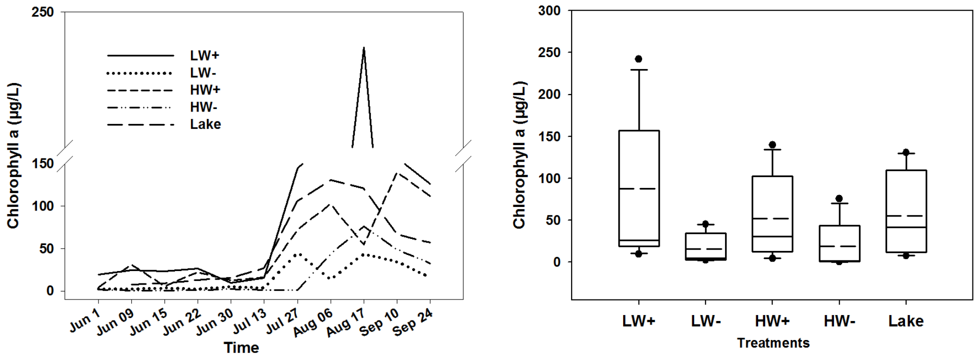


Figure 3.11: Changes in soluble reactive phosphorus among treatments and in-lake through the experiment a) Change in time b) Boxplot demonstration (dashed lines show mean, and solid line show median values)

3.2 Biological Parameters

3.2.1 Phytoplankton chlorophyll *a* & Periphyton chlorophyll *a*

Comparing initial conditions for chlorophyll *a* concentrations indicated there was not any difference among treatments ($p>0.05$, One Way ANOVA). Throughout the experiment both water level and the fish treatment had a significant effect on chlorophyll *a* concentrations in overall (rm-ANOVA, $p=0.0250$ and $p<0.001$ respectively, see Table 3.1) as water level effect was more pronounced in fish enclosures: LW+ mesocosms were higher than the LW- as shown in Figure 3.12.


(a)

(b)

Figure 3.12: Changes in Chlorophyll *a* among treatments and in-lake through the experiment a) Change in time b) Boxplot demonstration (dashed lines show mean, and solid line show median values)

Water level and fish did not cause a significant effect on upper periphyton (10-20 cm below water surface) chloropyll *a* concentrations (rm-ANOVA $p>0.1$ for both, see Table 3.1 and Figure 3.13).

Periphyton chlorophyll *a* concentrations measured between the 10-20 cm depth above the sediment whose actual depth differed for LW and HW. Water level and fish treatment had a significant impact on bottom periphyton (rm-ANOVA, $p=0.0003$ and $p=0.0197$, respectively). Furthermore, combined effect of water level and fish treatments also had a significant effect (rm-ANOVA, $p=0.0046$, see Table 3.1) as HW+ had the lowest periphyton chlorophyll *a* (Figure 3.14). Impact of water level was also time dependent and time x water level interation was significant ($p=0.0359$).

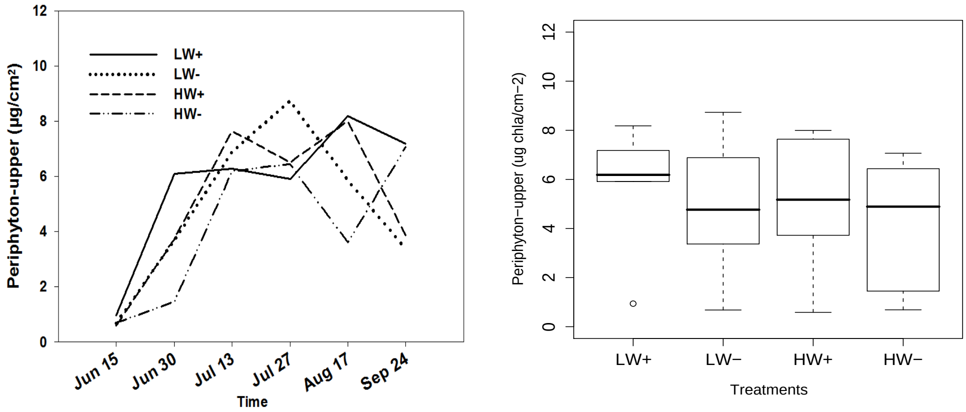

(a)
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Figure 3.13: Changes in periphyton chlorophyll *a* taken from the 10-20 cm below the surface a) Change in time b) Boxplot demonstration (dashed lines show mean, and solid line show median values)

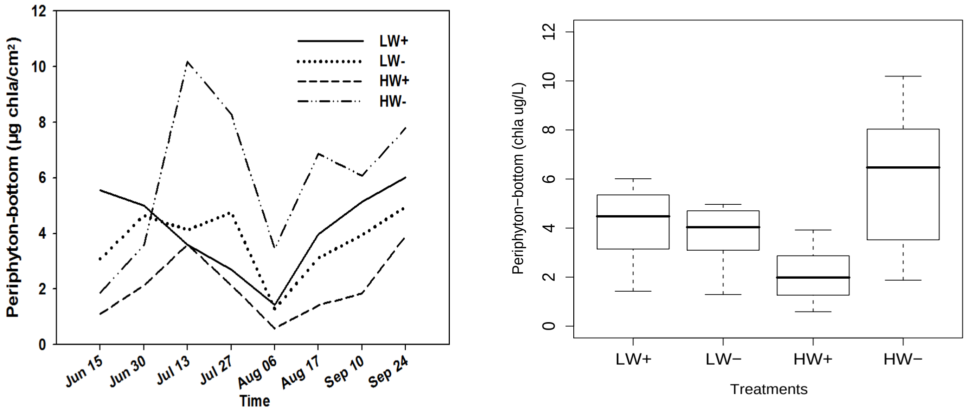
(a)
(b)

Figure 3.14: Changes in periphyton chlorophyll *a* taken from the 10-20 cm above the sediment a) Change in time b) Boxplot demonstration (dashed lines show mean, and solid line show median values)

3.2.2 Macrophyte

Macrophyte development, which was the target of the study, was measured as surface coverage and PVI% (Percent plant volume infested). According to rm-ANOVA both water level and fish had a significant effect on PVI% ($p<0.0001$, $p=0.0001$). Among treatments macrophyte growth was higher in LW than that of HW as very little growth (0.40 ± 0.22 and 1.47 ± 0.34 PVI% for HW+ and HW- respectively) was detected in HW treatments. In the LW mesocosms, macrophyte growth was observed both fish and fishless (24.33 ± 5.05 and 43.18 ± 5.16 PVI% for LW+ and LW- respectively, see

Table 3.1). In LW+ and LW- treatments PVI% ratios got closer towards the end of the experiment (Figure 3.15). Figure 3.16 shows the surface coverage of plants in one of the LW- enclosures.

At the end of the experiment macrophytes were harvested in order to estimate the dry weight. There was also significant difference for dry weights as LW- enclosures were significantly higher than LW+ (p = 0.038) while there was no significant differences among HW+ and HW- according to two way ANOVA (Figure 3.17, see Table 3.1).

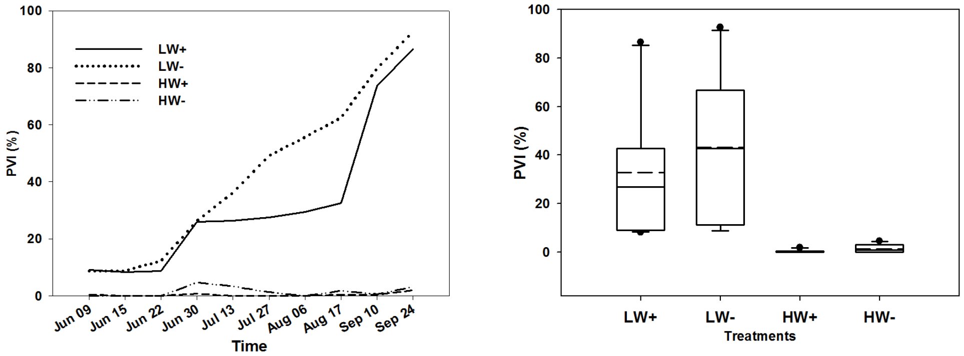
(a) (b)

Figure 3.15: Macrophyte growth as PVI% of the enclosures a) Change in time b) Boxplot demonstration (dashed lines show mean, and solid line show median values)

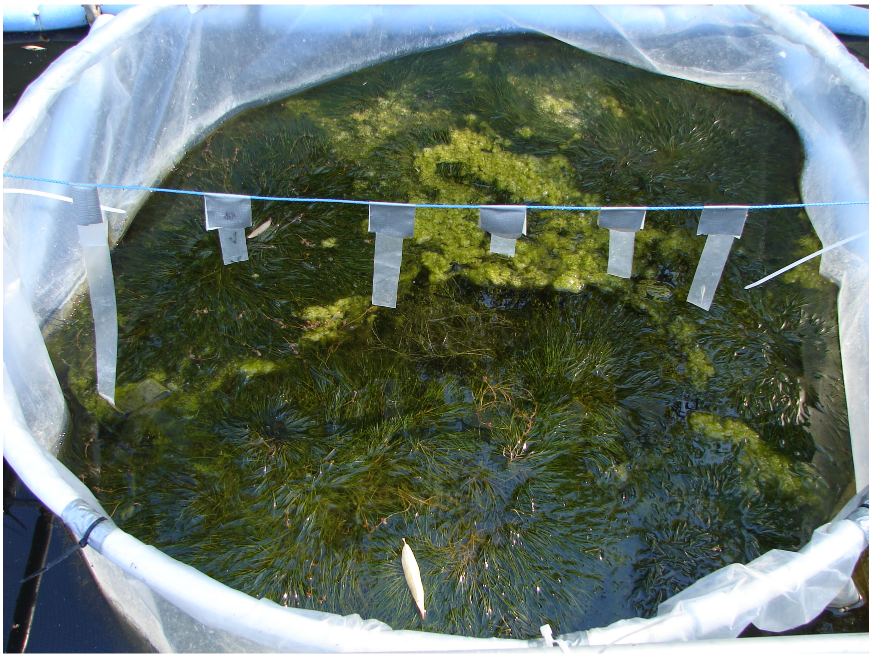

Figure 3.16: Surface macrophyte coverage at LW- enclosure at the end of the experiment: light green color indicates filamentous algae development

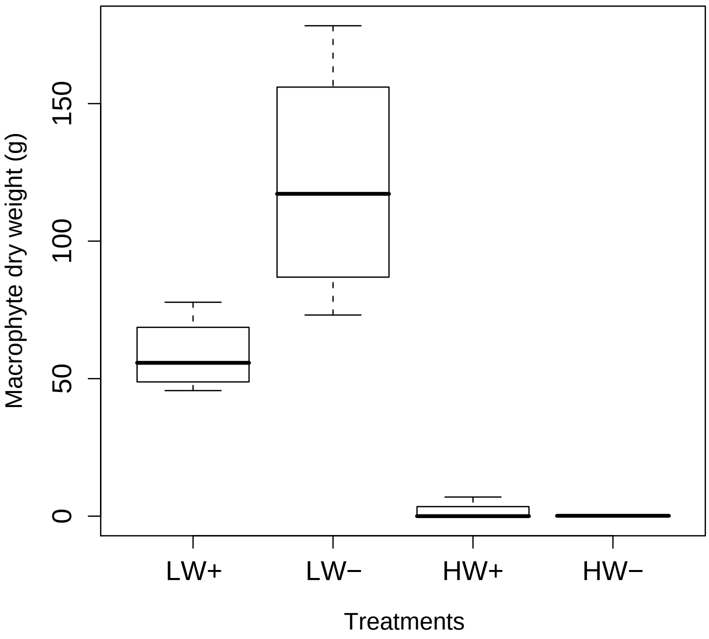

Figure 3.17: Dry weight of macrophyte at the end of the experiment

3.2.3 Zooplankton

Zooplankton community mostly dominated by Calanoid copepoda, nauplii, *Daphnia spp*, small cladocerans and Cyploploid copepoda. Identified Cladoceran genus included *Daphnia*, *Megafenestra*, *Chydorus*, *Diaphanosoma*, *Pleuroxus*, *Scapholeberis*, *Alona*, *Ceridaphnia*, *Bosmina*, *Macrothrix*. For the first sampling there was no significant differences among treatments (Figure 3.18 a) according to one way ANOVA for total zooplankton biomass and total copepoda ($p>0.1$for both) while total cladocera biomass differed ($p=0.020$).

For Copepoda, Cladocera and total zooplankton biomass, rm-ANOVA was conducted seperately for a difference among treatments. For Copepoda, water level did not have a significant effect ($p>0.1$) but fish effect was significant ($p=0.0269$). The same results were also found for Cladocera as water level effect was insignificant ($p>0.1$, rm-ANOVA), fish had a significant impact on Cladoceran biomass ($p=0.001$, rm-ANOVA). Cladoceran biomass was high in fishless enclosures. Total zooplankton biomass differed for fish treatments ($p=0.0020$) but no effect of water level was observed ($p>0.1$).

Zooplankton composition and trend in time is shown in Figure 3.18. The effect of fish treatment caused a significant decrease immediately at second sampling (Figure 3.18 b). Total zooplankton biomass of LW+ was reduced to 254.3 ± 140.1 μg/L from 761.5 ± 252.3 μg/L. HW+ biomass was also reduced to 229.2 ± 74.3 from 479 ± 138.9 μg/L. At the fifth sampling (Figure 3.18 c) the total LW+ biomass was very low ($8.0 + 1.7$ μg/L). Towards the end of the experiment LW+ biomass started to increase but these levels was not high as initial conditions (156.9 ± 176.5 μg/L at the end, see Figure 3.18 d). Throughout the experiment, fishless mesocosms (LW- and HW-) were mostly characterized with high contribution of Cladocera to total zooplankton biomass.

For estimating grazing pressure of zooplankton on phytoplankton, zooplankton/ phytoplankton ratio was used. Phytoplankton biomass was estimated from chlorophyll a content. For the beginning of the experiment, second and fifth sampling, there were significant difference among treatments ($p=0.023$, $p=0.009$, $p=0.005$, respectively, Kruskal-Wallis one way ANOVA) while no significant difference was detected at the end of the experiment ($p>0.1$, Kruskal-Wallis one way ANOVA). Zooplankton-phytoplankton ratio was high in fishless enclosures; however, the ratio was very low for fish mesocosms. The highest ratio was observed in LW- treatment where the highest zooplankton biomass was detected (Figure 3.20).

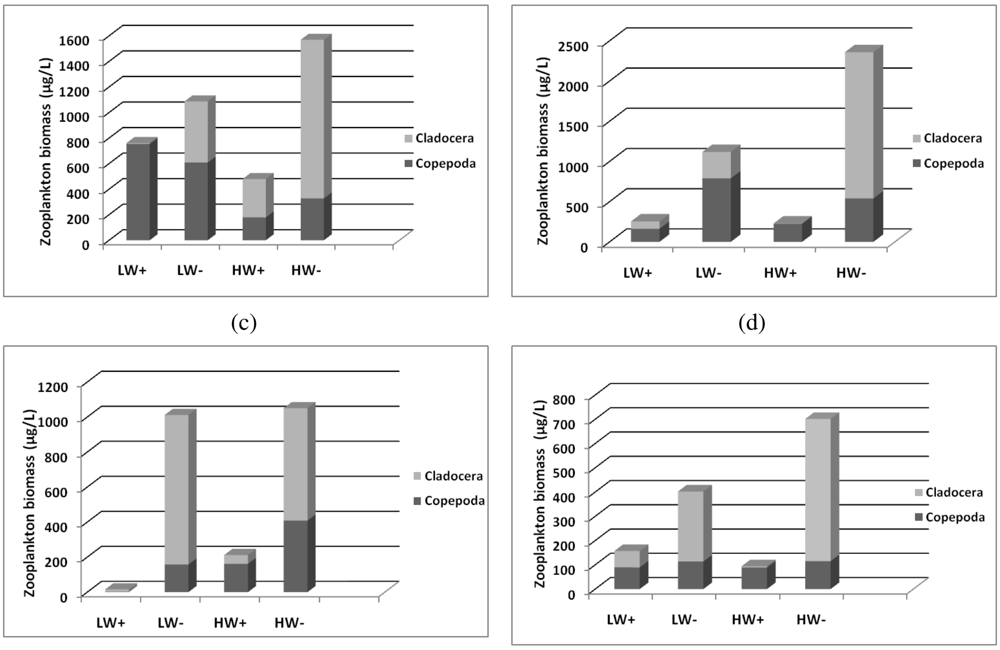
(a)
(b)
(c)
(d)

Figure 3.18: Zooplankton biomass: a) At the beginning of the experiment b) At second sampling c) At fifth sampling d) At eleventh sampling (the end of the experiment)

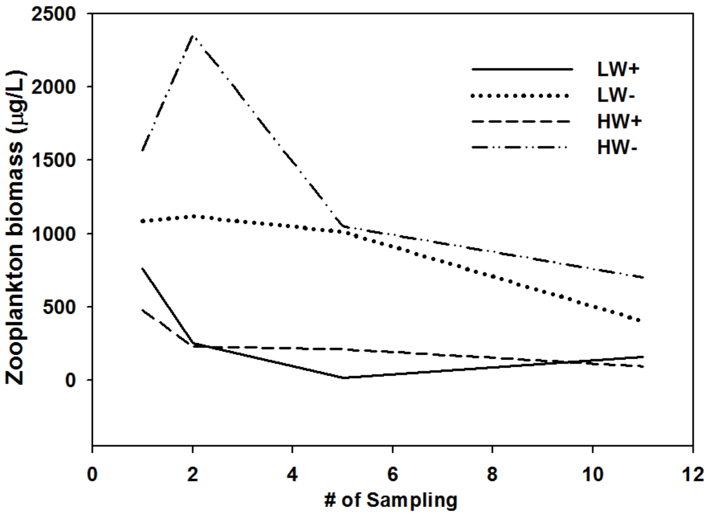

Figure 3.19: Total grazing zooplankton biomass throughout the experiment including sum of Copepoda and Cladocera

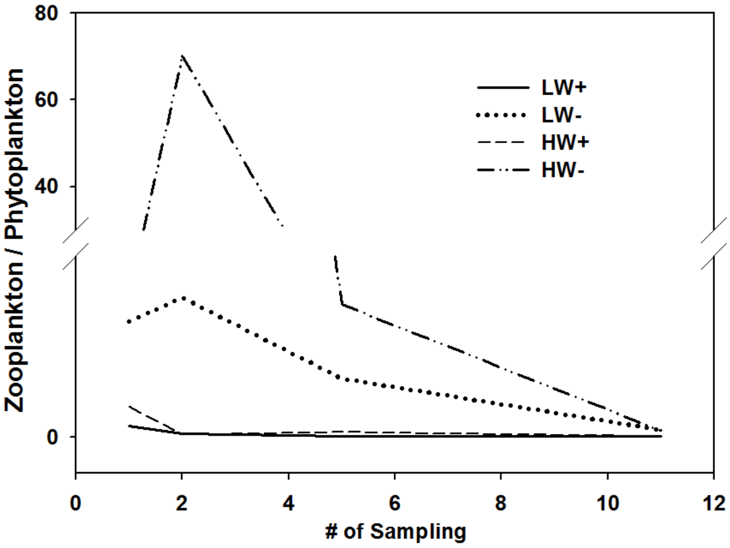

Figure 3.20: Zooplankton/Phytoplankton ratio indicating grazing potential of zooplankton

Table 3.2: Summary table showing the effects of treatments on water quality and biological variables: * p <0.05, ** p <0.01, *** p <0.001, ns = not significant,

Variables	WL	Fish	WL x Fish
SS (mg/L)	*	***	ns
Secchi disk depth/WL	**	***	ns
Total phosphorus	***	*	ns
Total nitrogen (μg/L)	***	*	ns
Chlorophyll *a* (μg/L)	*	***	ns
Periphyton bottom (μg/cm^2)	***	*	**
PVI%	***	***	ns
Macrophyte dry weight (g)	***	*	*
Zooplankton (μg/L)	ns	**	ns

CHAPTER 4

DISCUSSION

Climate change is a hot topic in scientific arena and its impacts are globally concerned. As functioning of ecosystems can not be interpreted without meteorological events, understanding its impacts is vital. Effects of climate change are diverse and do not follow a linear pattern since expected scenarios show a great divergence for different regions (Parry et al., 2007). Regarding global climate change, the south-western part of Turkey is expected to have a climate pattern of hotter (2-4 °C increase) and dryer (34% less precipitation) summers (Önol et al., 2009) which can have a significant effect on hydrology of aquatic ecosystems especially on shallow lakes.

Even in general characteristics of Mediterranean climate, most of the precipitation occurs in winter season and summers are dry; which leads to an extreme change in hydrology especially in water level fluctuation throughout the year. Furthermore, the region is known for decadal oscillations of drought and wet period that also enhances the water level fluctuations (Beklioglu et al., 2006, 2011). As water level fluctuations are characteristics of Mediterranean lakes, their role in determining ecological structure is crucial. Submerged macrophytes, which are central elements of shallow lakes, highly depend on hydrology since their major limiting factor is light. A study conducted by Beklioglu et al. (2006) on five shallow lakes of Turkey explicitly showed that the role of WLF as a significant driver of plant growth under the effect of Mediterranean climatic zone.

Lake Eymir located in Ankara, experiences high water level during rainy winters and decreasing water levels in the hot summer season. Studies showed that fluctuation of water can exceed to 1.25 m during the year (Özen, 2006) and magnitude of fluctuation can have a profound effect on the lake ecosystem dynamics: especially macrophyte growth. PVI% results of long term monitoring of Lake Eymir and Lake Mogan indicated that there is a relation with water level and macrophyte development in the upstream Lake Mogan; however, such relationship was weakened with the effect of eutrophication induced in Lake Eymir as the morphometry, depth profile is steeper than that of Lake Mogan (Özen et al., 2010). Figure 4.1 points out the relationship between water level and submerged macrophyte development in Lake Eymir. There was an increasing macrophyte development pattern after 1998 which was the period after biomanipulation. In 2001 with the nearly a meter drop in water level, large increase in submerged plant coverage was observed (90%). Until 2003 with increase in water level, PVI% declined. However, after 2003, low water did not trigger macrophyte development. These results indicated that positive effect of water level was masked by eutrophic conditions along with increased fish predation and high nutrient availability on macrophytes.

Indirect effects of nutrients on submerged plant growth by reduced water clarity through high N availability at intermediate P level has been explicitly shown for north temperate shallow lakes with both experimental and monitoring studies (James et al., 2005; Gonz´alez Sagrario et al., 2005). The role of submerged plant growth was first time experimentally tested in a mesocosm experiment with N enrichment at intermediate P availability in Lake Pedina, İğneada, Turkey (Özkan et al., 2010). Contrary to the expectation, submerged plant growth remained very high owing to a significant drop in water level. Thus low water level overrid the negative effect of eutrophication induced turbidity. Current study followed the study of Özkan et al. (2010) to test the water level and fish predation effects on submerged plants growth using enclosures at different depths which simulate potential water level fluctuation.

4.1 Physico-chemical Parameters

As a general trend of Mediterranean climate, during the 4 month of sampling period mean 0.41 ± 0.06 m of water level reduction was detected. Significant decrease pattern

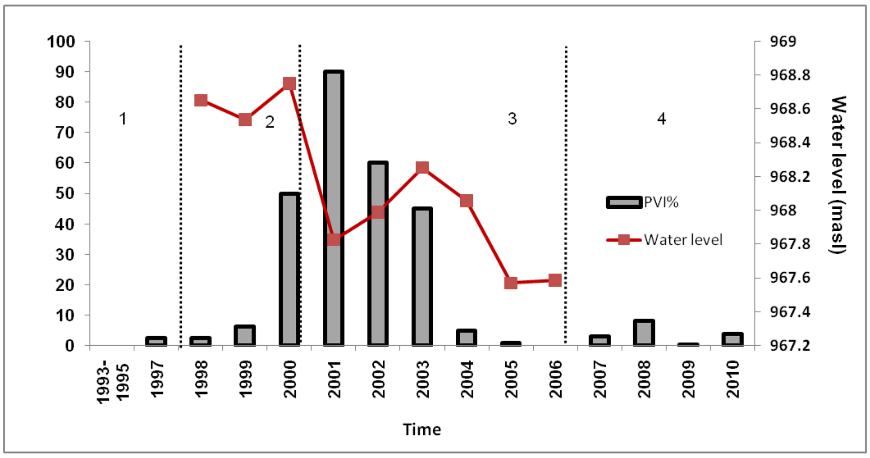

Figure 4.1: PVI% and Water Level relationship of Lake Eymir for period of 1997-2010: During this period Lake Eymir was found in different states. 1^{st} period shows the turbid water state before manipulation. 2^{nd} period is clearwater period after biomanipulation. 3^{rd} is the period between two biomanipulation application. As this period starting with clear water, after 2004, lake shifted to turbid water state. 4^{th} period shows the period after 2^{nd} biomanipulation, characterized with turbid water(Özen et al., 2010). Masl is the abbreviation of meters above sea level

started after 4^{th} sampling corresponding at the end of June. Early weeks of the June of 2009 was rainy whereas after July, drought period started resulted in water level reduction. When surface water temperatures exceeded 26 °C, this gave rise to increase in evaporation which triggered drop in water level.

For some of the variables analyzed during the experiment, initial conditions among mesocosms were not equal. HW mesocosms differed significantly from LW mesocosms. This might have been due to the disturbance created during removal of plants and the placement of the mesocosms.This situation can complicate the interpretation of the results. Even though Lake Eymir is a small and shallow lake, the horizontal variation in physico-chemical variables especially for the littoral zone which all of the depths located can be high.

Suspended solid (SS), amount in the water column is important for affecting underwater light penetration which in turn affect submerged macrophyte growth (Søndergaard, 2007). Amount of SS was significantly controlled by both water level and fish, thus it was high in LW+ treatment which shows the fish driven turbidy was more pronounced in shallower depths than that of high water levels. While there was no difference among fishless enclosures at different depths, water level effect was significant among fish mesocosms (LW+ and HW+). High amount of SS in LW+ may be the result of increased sediment-water column interaction triggered by fish. It‘s known that macrophyte beds decrease the wind driven turbidy and enhance the water clarity but in this experiment suspended solid concentration was high even in the LW enclosures which were covered by dense macropytes. Macrophyte beds may also have a negative effect on resuspension in eutrophic lakes that preventing water to be mixed and may result in relesease of iron bound phosphorus because of anoxic conditions (Søndergaard, 2007). Another reason of observing high SS in LW enclosures could be the outcome of difficulty in sampling LW because high macrophyte density obstructed to take water samples without any interaction of plant beds. In addition, high decomposition rate may be triggered from the high productivity because of complex ecosystem created by macrophyte beds may have affected suspended solids.

Fish (Kitchell et al., 1979; Søndergaard et al., 2008) and water level (Özen et al., 2010; Özen, 2006; Beklioglu et al., 2006) have indirect effects on nutrient supply of the lake. There are many experiments conducted to explain the mechanisms of nutrient dynamics (Moss et al., 2004; Romo et al., 2004). For P, there are many studies showing increasing trend in P with high planktivo-benthivorous fish (Scheffer, 1998; Søndergaard et al., 2008; Jeppesen et al., 2007). Study by Søndergaard et al. (2008) showed that for 37 Danish lakes, fish removal ended up with 50-70% reduction in nutrient concentrations like TP, TN and SS. Fish removal study conducted in Lake Eymir also resulted in significant reduction in TP levels (Beklioglu and Tan, 2008).

In this study both water level and fish had significant effects on TP concentrations. Fish species used in this experiment are planktivo-benthivorous fish having feeding behaviour which were expected to stir up the sediment and this may cause the resuspension of sediments. TP in HW enclosures were lower than LW which was interesting. TP concentrations of all water depths were not different according to survey conducted 10 days before the sampling period started. However, for the first sampling TP concentrations of HW enclosures were significantly low. These enclosures (HW) were characterized by clear water and enhanced benthic algae development prior to first sampling. In addition, higher stratification pattern was observed up to 4-4.5 °C in 1.5 m for HW enclosures which may cause nutrients to be locked up at the hypolimnion; bottom layer of the water column. Furthermore, high benthic algae development may have reduced the resuspension of sediment while covering the surface sediment. They can also use nutrients from the sediment. Hence activity of benthic algae may have reduced the TP and SRP of the HW enclosures. Low SRP concentrations in higher water may also be attributable to the reasons for TP as SRP may be retained in hypolimnion in HW enclosures.

A study analyzing data set of 782 lakes from North America, South America and Europe representing diverse climatic regions indicated that macrophyte growth declined sigmodially within the P range of 0.05-0.2 mg/L. They also observed that above the TN concentration of 1-2 mg, macrophyte growth was very restricted (Kosten et al., 2009). Among lakes having high TN, macrophyte growth was observed in Florida, Netherland and Argentina. Although in LW enclosures avalibility of N and P were much higher than that of the suggested thresholds throughout the experiment, contrary to the expectations this did not prevent the growth of submerged plants only in the LW enclosures but not in the HW enclosures. This is in accordance with the findings of Özkan et al. (2010) as a half a meter drop in the enclosures allowed macrophytes to grow and overcome the effects of nutrient encrichment induced turbidty.

On the other hand presence of macrophytes can have a significant affect on the nitrogen avalability. A general opinion in warmer shallow lakes states that nitrogen loss would be higher than that of temperate shallow lakes because of the enhanced denitrification resulting from the higher temperatures (Eriksson and Weisner, 1999; Reddy and De Busk, 1985; Eighmy and Bishop, 1989). Submerged macrophytes are known for enabling surfaces and creating deoxygenating area for denitrification. Contrary to this, in LW enclosures with high macrophyte growth, N availability remained very high compared to HW enclosures without macrophyte. In addition, TN concentrations had an increasing trend throughout the experiment. These results are consistent with the study on two warmer Mediterranean shallow lakes where macrophyte growth did not reduce the nitrogen availability (Özen et al., 2010). In the enclosures, low oxygen concentration near the surface may have decreased the conversion of ammonium to nitrate which kept nitrate concentrations relatively low to TN. Another explanation with high evaporation and decreasing water level, nutrients may have upconcentrated. The Nitate-Nitrite concentrations inversely correlated with oxygen concentrations in the bottom of the mesocosms especially in HW enclosures compared to LW enclosures which may be indicator of denitrification as denitrification occurs in anoxic environments. This may have a significant consequences for maintaining clearwater in warmer regions that not only phosphorus but also stringent nitrogen control at the catchment level might be critical.

4.2 Biological Parameters

Productivity of a lake in terms of phytoplankton is highly dependent on top-down and bottom processes. Planktivo-benthivorous fish presence was expected cause an increase in phytoplankton biomass due to decrease in control of zooplankton grazing pressure on phytoplankton (Moss et al., 2004; Scheffer, 1998; Jeppesen et al., 1998). Present experiment verified the effect of fish on phytoplankton. Highest chlorophyll *a* concentrations were detected in fish mesocosms which was the result of zooplankton community shift under fish predation. Since fish is a visual predator, it prefers the largest zooplankton while feeding which causes zooplankton community to be dominated by small zooplankton rotifers (Brooks and Dodson, 1965). In this study Rotifera group were not counted but it was observed that samples taken from fish mesocosms were highly dominated by Rotifera. Water level did not cause any difference on total Cladocera and Copopoda biomass, but in fish mesocosms composition reduced significantly after second week. At fifth week total zooplankton biomass of LW+ mesocosms was very low which indicated high predation pressure of fish. Zooplankton/Phytoplankton ratio was high in fishless mesocosms showing that there was a significant herbivory on phytoplankton which result in low chlorophyll *a* and high water clarity. The composition of zooplankton was also diverse and changed throughout the experiment. At the beginning of the experiment Calanoid copepod and *Daphnia* dominated the community and, fish presence resulted in dominance of small sized zooplankton as *Chydorus spp.*, *Alona spp.* and nauplii which was consistent with the size efficiency hypothesis of Brooks and Dodson (1965). With the growth of macrophytes toward to the end of the experiment, the composition of LW enclosures were changed. Littoral *Macrothrix spp.* species dominated the system which did not exist at the beginning of the experiment and biomass of the Chydoridae was increased to the end of the experiment. Hence, reducing water level can shift zooplankton community to substrate attached (Fryer, 1974) fauna like *Macrothrix spp.* as in this case.

Role of periphyton on macrophyte growth has been highly neglected until recently (Carpenter et al., 1987; Vadeboncoeur et al., 2002). It has been shown that periphyton have a vital role for both benthic and pelagic productions (Burkholder and Wetzel, 1989; Vander Zanden and Vadeboncoeur, 2002) and controlled by both nutrients and fish predation (Liboriussen et al., 2005). The experiment conducted by Liboriussen et al. (2005) stated that fish predation and light availability had the primary role for periphyton development. Fish directly or indirectly favor periphyton growth by predating periphyton grazers. Another mesocosm study from Turkey indicated that increase in nutrient concentrations did not effect the phytoplankton biomass while increasing periphyton biomass (Özkan et al., 2010). In present study, periphyton samples taken from the 10-20 cm below the surface did not differ although water clarity did differ. In the fishless enclosures, despite low phytoplankton biomass and high light availability, macroinvertebrate community might have controlled the periphyton biomass. During samplings *Chaoborus spp.* and *Corixa spp.* (water boatman), which normally exert grazing pressure on periphyton biomass, were observed in fishless enclosures. Macroinvertebrate samples are being processed in another thesis study carried out by Ece Saraoğlu, detailed discussion about water level and fish predation effect on macroinvertebrate-periphyton interaction will be found in her thesis.

The bottom periphyton growth (10-20 cm above the sediment) results showed that, periphyton significantly controlled by water level and fish predation. The highest periphyton biomass was in HW- where water clarity was high due to low phytoplankton biomass which was result of mainly Cladocera grazing. While such condition favoured periphyton in the lower water column close to the sediment, such periphyton growth may have disfavoured planted shoots of *Potamageton pectinatus* through cutting off light since periphyton can reduce 67-82% of light available for macrophyte growth (Moss, 2010).

In the LW mesocosms, the periphyton growth was higher in LW+ which is consistent with Liboroussen et al. (2005); study that showed fish can enhance periphyton growth. In addition to this, dense macrophyte growth may have had a shading effect on periphyton. Because macrophyte density was high in LW-, they may have competed for light and macroinvertebrate community may have controlled the periphyton biomass in the case of absence of fish.

As macrophytes are vital for structuring shallow lakes, it is crucial to understand underlying mechanisms for their growth. This study clearly showed that water depth is the most significant factor for overriding the effect of eutrophication since dense macrophyte development was detected only in the LW enclosures. Submerged plants surface coverage and PVI% results suggested that macrophyte growth was the highest in LW- throughout the summer, however, towards the end the plant growth in the LW+ enclosures increased as indicated in Figure 4.2. In addition, macrophyte dry weight results clearly showed that the biomass in LW- enclosures was higher than that of LW+ which can be consistent with the theory that top-down control can negatively affect macrophyte development. However, fish control did not prevent macrophyte growth even at higher nutrient concentrations at the low water level. According to Bécares et al. (2008), macrophyte loss in the system was related to TP, chlorophyll *a* and periphyton concentrations whose critic concentrations to cause a 50 % loss in macrophyte growth are 270-900 μg/l, 30-150 μg/l and 0.5-9.2 μg/cm^2 respectively. Although for the both the LW+ and LW- enclosures, their concentrations were within the range of loss of macrophyte growth, enhanced macrophyte development was observed through the low water level. In addition, almost no significant submerged macrophyte development in HW- enclosures though presence of high water clarity resulted from high zooplankton grazing pressure, can be attributed to the high periphyton growth in the lower part of the mesocosms. As the highest periphyton biomass was detected in HW- and it was within the level that Bécares et al. (2008) suggested to cause a 50% reduction in macrophyte growth.

It has already been suggested that drop in water level can have a driver effect on macrophyte growth (Coops et al., 2005; Beklioglu et al. 2006). Current study is the first experimental demonstration which provided clear evidences that water level has

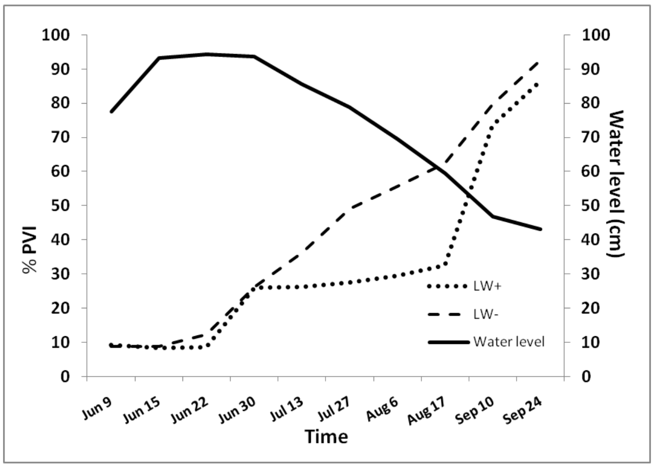

Figure 4.2: PVI% and water level relationship in LW enclosures

a structuring role for macrophyte growth in a warmer lake even at eutrophic conditions prevailing with deteriorated underwater light and high fish-mediated top-down control. Low water level being around 0.4-0.8 m based on the results of this study and Özkan et al. (2010) can overcome the negative effect of eutrophication. The results showed that the role of macrophyte and the factors affecting its development are not similar in warmer lakes compared to northern lakes since water level fluctuations are so critical in warmer climates and their impacts on shallow lake dynamics are so pronounced. As nutrients and fish effects were known to prevent macophyte development in norhern latitudes, low water level during growth season can override the effect of those and enabling macrophyte plant development.

CHAPTER 5

CONCLUSION

With current experiment it was aimed to determine the threshold that submerged macrophyte can grow with combining effect of fish. While there were 3 different water level at the beginning, the highest water level (2.3 m) had to be cancelled because of rapture in polyethilene tube of the enclosures. Experiment was carried on with two different water level (0.8 m and 1.6 m which were regarded as LW and HW) and presence/absence of fish (+/-). Through the experiment high water level reduction was observed up to 0.35-0.45 m in enclosures.

Water level had a significant effect on most parameters such as TP, TN, suspended solids, chlorophyll *a* as they had a higher trend in low water (LW) enclosures. Even though LW enclosures had high nutrients, macrophyte growth was irrepresibled on them. Presence of fish in LW+ caused a lag in macrophyte development but at the end of the experiment, with decrease in water levels their PVI% got close to LW-. High TN amounts in macrophyte dominated enclosures also contradicted with the common opinion that in warmer climates nitrogen loss would be high within plant beds. However, complex environment created by macrophyte beds and high productivity may have triggered high decomposition of organic matter leading to high nutrient level. Low nitrogen values in HW may be attributed to the low dissolved oxygen concentration as they were highly inversely correlated. However, significant macrophyte development was not detected in HW fishless enclosures despite their high water clarity and large-sized zooplankton fauna which may be the result of enhanced periphyton development cutting off the light availability for macrophyte growth.

These results may indicate that, low water level can compensate the impact of nutrients and fish on macrophyte development while at high water level periphyton and benthic algae may have taken over the advantage and outcompete macrophyte growth.

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