PALEOLIMNOLOGICAL ASSESSMENT OF PAST AQUATIC VEGETATION DYNAMICS AND ECOSYTEM STATE IN TURKISH SHALLOW LAKES

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ABSTRACT

PALEOLIMNOLOGICAL ASSESSMENT OF PAST AQUATIC VEGETATION DYNAMICS AND ECOSYTEM STATE IN TURKISH SHALLOW LAKES

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Since submerged macrophytes are a key primary producer of shallow lakes and are sensitive to environmental changes, macrofossils of them can be used in investigations of past environmental conditions, to infer human introduced environmental impacts (e.g. eutrophication) and to determine past macrophyte communities.

The present study includes twenty six shallow lakes, which were chosen along a latitudinal gradient ranging from the North (41°52´N, 27°58´E) to the South (37°06´N, 29°36´E) in Turkey. Sampling for environmental variables and sediment was carried out using a snap-shot sampling protocol (developed within the framework of the EU FP6 project 'Eurolimpacs') during the summers of three consecutive years (2006-2008). Surface sediment, short core and long core samples were retrieved from the lakes. The aims of this study were i. to compare the surface sediment plant macrofossils with present day macrophyte taxa of the lakes, ii. to determine the environmental variables potentially influencing the temporal changes in macrophyte communities, and iii. to assess vegetation community dynamics in dated short and long cores. Comparison of plant macrofossil assemblages in surface sediment with present day macrophyte coverage revealed that approximately 41% of the modern taxa were represented among the surface sediment macrofossils. Redundancy analysis (RDA) was carried out for surface macrofossil data with corresponding environmental data. RDA revealed relation of plant species and environmental variables (e.g. Salinity and *Najas marina* L.). Changes in plant species assemblages in short and long cores from eight lakes chosen along a latitudinal gradient ranging from North to South Turkey is discussed in relation to the RDA results.

Key words: eutrophication, short/tall growing macrophytes, RDA

ÖZ

ÜLKEMİZ SIĞ GÖLLERİNDEKİ GEÇMİŞ SUCUL BİTKİ DİNAMİĞİNİN VE EKOSİSTEM DURUMUNUN PALEOLİMNOLOJİK YÖNTEMLER KULLANILARAK DEĞERLENDİRİLMESİ

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Göller için çok önemli bir yeri olan suiçi bitkiler çenvresel değişikliklere karşı da hassas olduklarından bu bitkilerin makrofosilleri geçmiş çevresel koşulların ve insan etkisinden kaynaklanan çevresel değişimlerin araştırılmasında ayrıca geçmişteki bitki örtüsünün belirlenmesinde de kullanılmaktadırlar.

Bu çalışma süresinde, 2006-2008 yıllarının yaz aylarında, Kuzeyden (41°52´N, 27°58´E) Güneye (37°06´N, 29°36´E) doğru enlemsel bir hat boyunca yirmialtı göl örneklenmiştir. Çevresel değişkenlerin örneklenmesinde EU FP6 (Eurolimpacs) projesi kapsamında geliştirilen anlık fotoğraf çekme yöntemi kullanılmış, ayrıca bu yöntem kullanılarak göllerden uzun ve kısa karotlar alınmıştır. Çalışmanın amaçları, i. yüzey çökelinde bulunan bitki makrofosili örnekleri ile güncel bitki örtüsünün karşılaştırılması, ii. Bitki örtüsünde değişimlerin meydana gelmesine neden olan olası etmenlerin belirlenmesi ve iii. Yaşlandırılması yapılan kısa ve uzun karotlarda geçmişten günümüze meydana gelmiş bitki örtüsü değişiminin belirlenmesi. Yüzey çökellerindeki bitki makrofosilleri ile güncel bitki örtüsünün karşılaştırılması sonucunda yaklaşık %41 oranında bir örtüşme olduğu kaydedilmiştir. Yüzey çökelindeki makrofosil verileri ile arazi çalışmalarından elde edilen çevresel veriler için Fazlalık analizi (RDA) yapılmış ve sonucunda bitkilerin hangi çevresel etmene karşı daha duyarlı olduğu belirlenmiştir (örnek; Tuzluluk ve *Najas marina* L.). Ayrıca sekiz gölden alınan kısa ve bir gölden alınan uzun karotlardaki bitki değişimleri elde edilen RDA sonuçlarına göre yorumlanmıştır.

Anahtar kelimeler: ötrofikasyon, uzun/kısa boylu suiçi bitkiler, RDA

To my beloved family and friends

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CHAPTER 1

INTRODUCTION

1.1 Shallow Lakes

Being a strategic resource in the world, freshwater ecosystems play a key role in biosphere. They are sources of energy, habitat for numerous organisms; they support complex ecological communities and often determine the structure and function of the surrounding terrestrial ecosystem. Therefore, these ecosystems are essential for life (Bailey et al., 2004; Naiman, 1995). Together with these important functions, freshwaters are crucial for the establishment of human communities and for the conservation of terrestrial wildlife (Moss, 1998, Beklioğlu, 2007). More than 90% of the world's freshwater ecosystems are shallow, mostly small individual lakes dominated by littoral communities (plant dominated). Unfortunately, with the increasing human population the use of freshwaters have increased, resulting to a decrease in healthy and clear natural aquatic habitats (Naiman, 1995).

As part of the freshwater ecosystems, the effect of development activities on shallow lakes is incontrovertible, because shallow lakes also are one of the most delicate ecosystems on earth (Barbier et al., 1997; Iscen et al., 2008). Many people live near the shallow lakes and their lives depend on these lakes conditions. Moreover, since the situation of shallow lakes is on the farmable lowlands they are more vulnerable to human disturbances (Güneralp and Barlas, 2003).

Due to the complex ecological structures and high productivity rate of shallow lakes, they have a great amount of diversity (Jeppesen et al., 1997b). Considering the increasing nutrient concentrations, change in hydrology and climate like factors, shallow lakes respond to these changes in two alternative equilibria: macrophyte dominated clear water state and phytoplankton dominated turbid water state (Alternative Stable State Hypothesis) (Scheffer et al., 1993; Scheffer, 1998; Naselli- Flores et al., 2003; Kagalou et al., 2008; Karabulut Doğan et al., 2009). The switch between these two equilibria depend on the factors, like nutrient release from sediment, duration and magnitude of nutrient loading, trophic structure etc. All of these factors have an important effect on shallow lake management (Scheffer et al., 1993. Güneralp and Barlas, 2003).

1.1.1 Macrophytes in Shallow Lakes

Being quite diverse and playing pivotal role in frehswater ecosystems, macrophytes are found in aquatic systems (both in lentic-standing water- and lotic-running water-) and they are defined as large vascular flowering plants (angiosperms). Most of them are rooted in the sediment and they may be emergent, floating or fully submerged. Some of them have more then one type of leaves, like both floating and submerged. Moreover, some macrophyte species do not have any roots and they float freely in the water (Figure 1-1) (Dopirak, 2002).

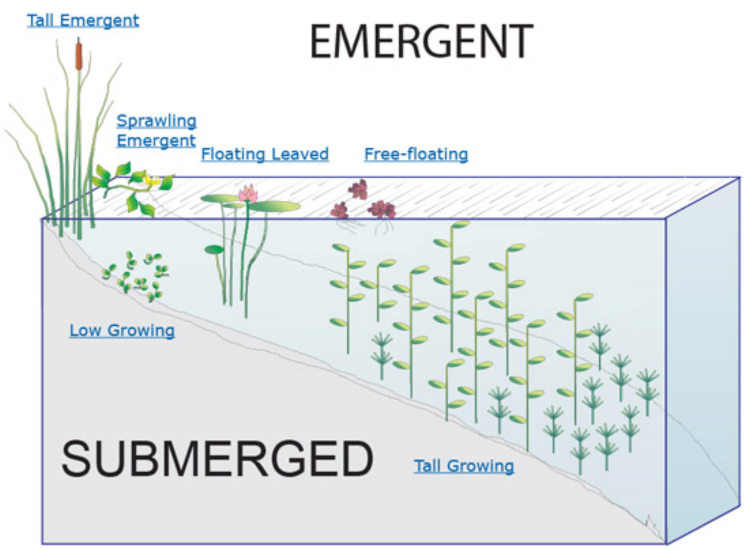

Figure 1-1 Aquatic plants in a lake ecosystem (http://www.niwascience.co.nz)

1.1.2 Factors that Affect Macrophytes Growth

Aquatic plants are primarily influenced by factors inherent in the limnology of water bodies, including geomorphology, sediment, climate, and hydrology. The quality of waterbodies and terrestrial elements of the catchment affect these factors. Furthermore, aquatic plants are influenced by biological interactions, like competition, predation and disease (Lacoul and Freedman, 2006a).

The key climatic factors that affect macrophyte growth are ambient temperature (of water and sediment), ice cover and hydrology. Wind, precipitation, latitude and altitude are other elements which have influences on aquatic plants. Wind and waves may have positive or negative effects on aquatic plants, depending on their intensity and frequency (Lacoul and Freedman, 2006a). The effect of the wind and waves on the dispersal of propagules, nutrient cycling and uprooting, and scouring is very strong (Andersson 2001; Madsen et al. 2001; Havens et al. 2004). The extreme climatic conditions of higher latitudes limit the species richness of aquatic plants (Virola et al. 2001). However, the effect of latitude is much higher in wider gradients (Lacoul and Freedman, 2006a). Another factor that affects macrophyte growth is altitude. Due to the severe climatic conditions in higer altitudes, species richness decrease at higher elevations (Heegaard et al. 2001; Lacoul and Freedman 2006b).

Hydrology, being related to changes in water depth, sediment characteristics, water clarity and chemistry, affects species composition, distribution, abundance and succcessional community dynamics of aquatic plants (van der Valk 1987; Mitsch and Gosselink 2000; Gafny and Gasith 1999).

Geomorphology is another factor that affects essential aquatic factors for macrophytes; such as hydrology, water chemistry and habitat area (number of species increases with increasing suitable area) (Canfield et al. 1985; Mitsch and Gosselink 2000; Bernez et al. 2004).

Being one of the most important factors light availability is affected by water colour and turbidity. Due to this reason and being the cause of competition between species, availability of light affects community structure (Canfield et al. 1985; Middelboe and Markeger 1997, Perrow and Davy, 2002). Moreover, sediment characteristics also affect macrophytes. Although some bottom types, such as the ones composed of mixture of inorganic particulates and rich humidified organic matter are hospitable, some bottom types; like bedrocks are inhospitable (Lacoul and Freedman, 2006a).

Aquatic plants can obtain dissolved nutrients either from sediment or from water column (Lacoul and Freedman, 2006a). Nutrient availability, especially the availability of nitrogen (N) and phosphorus (P), is one of the main factors that influence the abundance and composition of aquatic plant communities (Van et al., 1999; Thomaz et al., 2007). Robach et al. (1995) showed that shifts in aquatic plant compositions may be observed along a nutritional gradient and they also added that the distribution of macrophytes are determined by N and P (Thomaz et al., 2007). Moreover, nutrient concentrations also have indirect effects on macrophytes. High nutrient concentrations cause an increase in phytoplankton and periphyton biomass which in turn deteriorate light availability causing the suppression of macrophyte growth by shading (Jeppesen, 1998; Jeppesen et al. 2000, Merhoff and Jeppesen, 2009).

Alkalinity and pH are other elements that are important for the composition of aquatic plants. Depending on the alkalinity and pH conditions structure of aquatic plants can change. For example, some species, like charophyes, prefer hardwater lakes while some others prefer softwater habitats. In general aquatic plant richness is higher in hardwater habitats than in acidic or dilute ones (Lacoul and Freedman, 2006a).

The influence of salinity on aquatic plants is significant especially in lakes, salt marshes etc (Lacoul and Freedman, 2006a). According to Lacoul and Freedman

(2006a) some studies on the effect of salinity showed that most aquatic plants cannot tolerate high (>10 g/L) dissolved salt conditions.

Besides geomorphology and hydrology, biological interactions also affect the structure of aquatic plants. Species life history characteristics and tolerance of environmental conditions are the basic factors that affect the community structure of plants. Environmental conditions which influence aquatic plants are related to disturbance, competition and stress (Perrow and Davy, 2002; Lacoul and Freedman, 2006a). For example grazing by invertebrates, fish, waterfowl, and mammals (herbivory) and diseases are the important factors that influence the abundance and structure of macrophytes (Lacoul and Freedman, 2006a).

1.1.3 Importance of Macrophytes in Shallow Lakes

Macrophytes are an important primary producer, not least in shallow lakes. They play an important role in lake ecosystem functioning and in carbon and nutrient cycling (Koff and Vandel 2008) and trophic dynamics (Jeppesen et al., 1998). Therefore, the important effects of submerged macrophytes on numerous biological, physical and chemical processes are well documented (Jeppesen et al., 1997a; Davidson et al., 2005). Submerged aquatic macrophytes provide refuge, habitat and food for various plankton and invertebrates species. Also, they are refuge for zooplankton, small and predator fish. Their effect on fundamental physical and chemical processes, such as stabilizing sediment, reducing resuspension and removing nutrients (nutrient recycling), are essential. Therefore, being in the center of many biological, physical and chemical mechanisms, submerged macrophytes promote water clarity and help maintain the clear water state in the lakes. Furthermore, since they contribute to aquatic biodiversity (ex; increase the number of waterfowl) they are very important in conservation studies (Timms and Moss, 1984; Burks, et al., 2006; Jeppesen et al., 1998; Muhammetoğlu and Soyupak, 1999; Vestergaard and Sand Jensen, 2000; Gulati et al., 2002; Jeppesen et al., 2005; Ayres et al., 2008).

Due to their key role in shallow lakes, submerged macrophytes have been subject of many researches. Large body of information can be found especially on their growth, reproduction and physiology. Interactions between submerged macrophytes and other autotrophic components, also the effects of plants on nutrient dynamics, dissolved organic and inorganic carbon, oxygen and pH have been the focus of various studies. Also, recently, there is a significant increase in the amount of studies on the structuring role of submerged macrophytes in food web. The results of these studies showed the importance of submerged macrophytes on the food web interactions and on the environmental quality of lakes (Jeppesen et al., 1998).

Unfortunately, the effect of global climate change, with increasing anthropogenic impact on lakes and their catchments altered lake ecosystems (e.g. nutrient enrichment namely eutrophication, water quality changes, shift in biological communities) (Jeppesen, 1998; Scheffer et al., 2001; Jeppesen et al., 2003). Over a range of nutrient concentrations, shallow lakes can switch between a macrophyte dominated clear water state and a phytoplankton dominated turbid water state (Scheffer etal., 1993; Scheffer, 2001). If the increase in nutrient supply reach the threshold (>0.150 mgl^{-1} TP), system break down and abrupt changes will occur causing a turbid water state with high phytoplankton biomass. As the nutrient concentration increases, aquatic macrophyte species shift from short (eg. Charophytes) to tall growing forms (eg. *Potamogeton pecinatus.*) (Moss 1988; Ayres et al., 2008). It has also been observed that in most cases species richness decreased significantly (Balls et al., 1989; Ayres et al., 2008). Furthermore, this transition to a species poor community might be followed by the disappearance of all macrophyte vegetation (Balls et al., 1989; Scheffer, 2001; Ayres et al., 2008). Because submerged macrophytes are very important in maintaining clear water state, after a moderate increase in nutrient concentrations (TP range: 0.05-0.150 mgl^{-1}), lakes without or with a few submerged macrophytes will lose their ecological importance (Moss, 1998; Burnak and Beklioglu, 2000; Jeppesen, 1998, 2005).

1.2 Paleolimnology

As the interactions in a stable ecosystem become unbalanced, the character of the ecosystem will alter. These significant or small changes may occur in a short period of time (sudden changes) or over a longer period (slowly). Although regular observations can be used to monitor rapid changes occuring at present, they cannot be used for long-term changes proceeding over a long period (impossible observation) and for some sudden and extensive changes that have occured far back in the past. In order to reconstruct past ecosystems and biotic responses, the record of changes in fossil organisms and sediment characteristics ('proxy' data) can be used. Therefore, looking back into the past enables to study dynamics of these ecosystems (Birks and Birks, 2006). Paleolimnology, which is an interdisciplinary science, is basically the study of lake histories (Frey, 1988). With paleolimnological studies so much can be interpreted from the so little that is preserved (Frey, 1988).

Even the scientific investigation of the history of lake basins was important in the early 1800s, paleolimnology was developped slowly as a science (Last and Smol, 2001; Douglas, 2007). Early studies on paleolimnology were mostly descriptive and these studies date back to around 1920s (Frey, 1988; Douglas 2007). Nevertheless, paleolimnological studies showed a tremendous improvement over the following decades (approximately after mid-1970s) and the science is trasformed into one that is quantitative, applied, and still expanding (Birks, 1998; Douglas, 2007; Smol, 2008). This improvement is mostly due to the acidification problem which occured around the same time with the development of personal computers (PCs) in end of 70s and begining of 80s (Batterbee, 1999; Douglas, 2007). During the last thirty years, The development and application of new paleolimnological approaches have improved our possibilities of differentiating the effect of natural and anthropogenical changes (Birks and Birks, 2006; Douglas, 2007). Furthermore, recently in palaeolimnological studies, a multi-proxy approach is the norm, but the aims of investigating ecosystem dynamics have turned more towards the reconstruction of past environments and climate changes (Lotter 2003).

Lakes accumulate sediments that can be used as archives as sediment remains provide information about the ecological status of a lake at different timescales. Paleolimnology, the study of chemical, biological (cladoceran, ostracoda, pollen, plant macrofossil etc.) and physical lake sediment remains, provides information on past limnogical changes, which can be used to reconstruct past environmental conditions (Figure 1-2) (Frey, 1988; Smol et al. 2004). In this way, historical changes in the hydrological, physical and ecological regime of the lakes from the past until the present and their probable causes can be determined (Frey, 1988; Last and Smol, 2001).

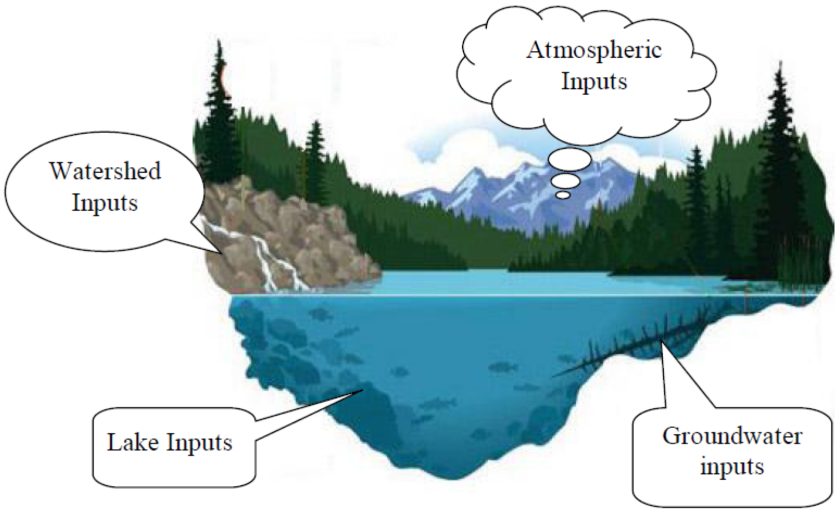

Figure 1-2 Composition of lake sediments. Sources can be divided to allochthonous-originates outside from lake and autochtonous-originates from the lake. Modified from Smol, 2008 and http://www.bthompson.net/lake.html

Atmospheric inputs: Radioactive nuclides (^{210}Pb, ^{137}Cs etc.), flyash particles, charcoal, inorganic ash spheres, spherical carbonaceous particles, trace metals (eg. Pb, Cu), pollen grains and spores, volcanic ash, toxics (e.g. Hg), pesticids, sulfates, nitrates etc., dust

Catchment inputs: Inorganic mineral material, nutrients (eg. P, N, Si), organic detritus, plant and other biogenic remains, toxics (e.g. pesticids, heavy metals etc.),

Groundwater inputs: Solutes (e.g. Ca, Mg, Na), nutrients (e.g. P, N), toxics (e.g. pesticides)

Lake inputs: Diatoms, Chrysophytes, other algae and pigments, bacteria, aquatic macrophytes, Cladocera, Ostracods, Chironomids, Other insects, fish scales etc. (Smol, 2008)

Information on paleoenvironmental conditions including paleoclimates and other past environmental conditions can be acquired from both physical structures (ex. grain size) and the chemistry of the sediment (ex. stable isotopes) (Frey, 1964; Douglas, 2007). Furthermore, physical structures of the lake sediment provide information about abiotic factors that affect sedimentation and its chemistry on general limnological conditions (Frey, 1964). The information on change in biota and biological communities can be derived from numerous biological indicators, such as algae, plants, zooplankton, insects and algal pigments (Birks, 1998; Douglas, 2007). Moreover, while water chemistry can be reconstructed throughout the core sequence by using algae and zooplankton as proxies, pollens and insects can be used to get information on vegetation shifts and past temperatures (Douglas, 2007).

1.2.1 Some of the Basic Steps of Paleolimnological Studies

1.2.1.1 Selection of coring site(s)

Choice of the coring site is an important step for paleolimnological studies. Due to the time consuming processes in paleolimnological analyses, generally a few or single sediment core is analyzed thoroughly (Smol, 2008). Continuous, undisturbed and representative sediment sequences are very important for paleolimnology studies (Smol, 2008). The object in selecting coring sites is that the retrieved sediment profile should be the most representative sample for the research subject and should also reflect the entire basin as much as possible. Another factor that affect this selection is basin morphometry (steep sites should be avoided) (Smol, 2008; Koff and Vandell, 2008). Also, because shallower areas may be more prone to mixing processes, usually deeper sites (flat central basins) are preferred (Smol, 2008). However, for some indicators (e.g. plant macrofossils) more information can be acquired by collecting multiple cores from nearshore parts of the lakes (Hannon and Gaillard, 1997; Birks, 2001).

1.2.1.2 Collection of Sediment Core(s)

Retrieval of the sediment core is the most critical process in paleolimnological work, due to the difficulties of collecting an unmixed and continuous sediment core (Glew et al., 2001; Douglas, 2007). Also, it is important that the retrieved core should represent the entire lake (Douglas, 2007). A variety of sediment corers are available and each one of them is suitable for a particular type of lake and/or sediment. Although there are various types of corers, gravity, freeze (frigid finger) and piston corers are the three main types that are used in paleolimnological works (Glew et al., 2001; Douglas, 2007; Smol, 2008). Depending on the corer's type, sediment cores can be retrieved from either a boat or from a platform (Douglas, 2007). Gravity and piston corers were the two types of corers which were used during this study.

Gravitiy corers use the gravity force to enter the uppermost sediment (Figure 1-3). Therefore, these are especially used for studies focusing from recent past to present day (~150 years) (Douglas, 2007; Smol, 2008). These cores are subdivided according to the method used to seal the core top. Messenger-operated samplers (core top sealed by a messenger) are the common ones (Smol, 2008).

Longer sedimentary sequences are obtained with piston coring (Figure 1-4). The piston and cable assembly, the core tube, and the drive head and drive rods are the three components of the typical piston corer (Smol, 2008).

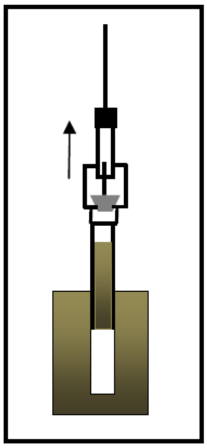

Figure 1-3 A Messenger-operated gravity corer (Kajak Corer) (modified from Douglas, 2007)

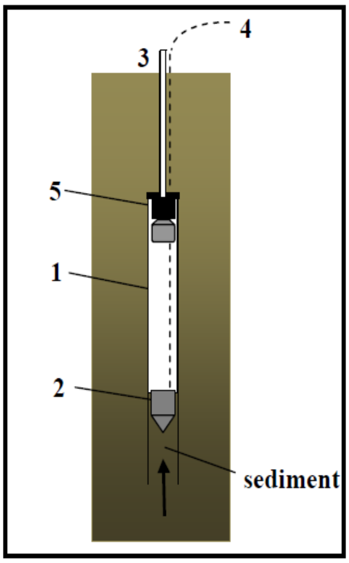

Figure 1-4 Livingstone-type piston corer (1, Core tube, 2. Piston, 3. Push rods, 4. Piston cable, 5. Locking drive head) Modified from Glew et al., 2001

1.2.1.3 Dating the Sediment Profiles

To be able to use the age-depth relationship in paleolimnological studies, it is important to be assured that the core represents an unmixed stratigraphic column of sediments (Douglas, 2007). The basis of relative age dating is "younger sediments will overlie older sediments" (Law of Superposition). Dating techniques in paleolimnological studies differ depending on the sediment type and age range (Last and Smol, 2001). Usually, measuring the decay of naturally occurring radioisotopes is used for dating of sediment cores (Douglas, 2007). Since natural radioactive isotope ^{210}Pb has a half life of 22.3 years and unnatural radioactive isotope ^{137}Cs (manufactured by nuclear industry) pinpoints certain time periods in sedimentary sequences, they are generally used for dating layers accumulated during the last 150 years (Smol, 2008). Another radioactive isotope that is used in dating is radiocarbon (^{14}C) which is formed by cosmic ray bombardement in the atmosphere. Because it has a half life of 5730 ± 40 years, ^{14}C is essential in dating lake sediments up to approximately 50 kyr of age, so that for dating longer sedimentary sequences (Douglas, 2007; Hajdas, 2008; Smol, 2008).

Other dating techniques include: Electron Spin Resonance (ESR), paleomagnetism, luminescence dating, varve chronology, amino acid racemization, tephrochonology, and marker beds of pollen (from Douglas, 2007).

1.2.1.4 Gathering Proxy Data

The most important part of paleolimnological studies is searching the paleoenvironmental information contained in the sedimentary sequence, because the data that will be used in reconstructions is provided from sediment core (Smol, 2008). In sediment matrix there are many proxy indicators that can be used to infer past environmental conditions. These indicators can be divided into three classes which include physical, chemical and biological proxies (Douglas, 2007).

1.2.1.5 Physical and Chemical Proxies

Physical and chemical indicators of the retrieved sediment core can be used to determine paleoenvironmental conditions, like paleoclimate. The main physical and chemical proxies are percent loss on ignition (LOI %), grain size, magnetic susceptibility, X-ray diffractometry (XRD), fluid inclusions, fly-ash particles, the $^{18}O/^{16}O$ and $^{13}C/^{12}C$ isotope ratios.

The most widely used physical proxy in paleolimnology is percent loss on ignition (LOI %), which indicates the percentage of organic carbon, carbonate and mineral matter in the sediment (Dean, 1974, Birks and Birks 2006). Moreover, the percentage water of the sediment can be calculated with this weight loss technique (Heiri et al., 2001). Suggesting higher organic sediment accumulation, the increase in the amount of organic carbon (LOI 550) in a sediment sample might indicate nutrient enrichment and/or a decrease in water level (Kauppila and Valpola, 2003; Korhola et al., 2005). Moreover, processes such as, sediment focusing and mire development may also influence the LOI results (Shuman, 2003). Therefore, due to these within-lake processes, changes in LOI in a single core may be difficult to interpret thus it is likely that multiple core approach increase the interpretability of the LOI record (Birks and Birks, 2006). The base procedure of LOI analyses is to weigh a known amount of sediment, and drying it in an oven or a muffle furnace and afterwards to use arithmetic operations, subtraction and division (Heiri et al., 2001). Percent water content can be calculated by drying the sample at 105 °C in an oven and this enables to determine the amount of the increase in the sediment density (Smol, 2008). The ignition of the weighted dried samples in the muffle furnace at 550 °C enables the calculation of organic matter content in the sediment (Nesje and Dahl, 2001; Heiri et al., 2001). Also, carbonate content can be determined by burning the known amount of sample in the muffle furnace at 925 °C (Heiri et al., 2001).

Measurements of the magnetic properties of materials, such as rocks, soils, sediments, and atmospheric particulates enable to acquire very important knowledge for various fields of work (Thompson et al., 1980). Since lake sediments preserve a magnetic signal, information on the magnetic properties of the sediment can be gathered (Smol, 2008). The origins of most magnetic minerals found in lake sediments are catchment erosion and bedrock, subsoil and topsoil in the drainage basin of the lake. Furthermore, atmosphere is another source of magnetic minerals in lake sediments. Some of these sources are aerosols emitted from volcanoes and particles produced by anthropogenic activities (Sandgren and Snowball, 2001). Magnetic susceptibility, which is related to magnetization and magnetic field, enables to estimate magnetic mineral concentration in samples (Thompson et al., 1980; Sandgren and Snowball, 2001). Magnetic susceptibility measurements can be used in gathering information on sedimentation history and in dating recent sediments (Thompson et al., 1980; Nowaczyk, 2001). Also, multiple cores taken from the same lake basin can be correlated using magnetic susceptibility measurements (see results) (Nowaczyk, 2001).

LOI % and magnetic susceptibility are the two proxies, used in this study.

1.2.1.6 Biological Proxies

One of the advantages of biological approaches is that changes in limnological variables can be integrated by organisms in longer time periods than periodic water chemistry sampling (Smol, 2008).

The animal and plant remains that are used as biological indicators in paleolimnological studies are fairly diverse, such as crysophytes, pigments, cladocera, ostracoda, diatom, pollens and plant macrofossils (Table 1-1) (Douglas, 2007; see Rosen et al., 2001 for an example). These proxies are either originated from within the lake (authochthonous) or transported from outside the lake (allochthonous). Reconstruction of water chemistry and microhabitat availability throughout the core sequence can be made by using authochthonous proxies, such as zooplankton, while allochthonous ones, like insects, can be used to determine vegetation changes and to infer past temperatures (Doulglas, 2007). In order to be a good proxy of environmental changes, a proxy indicator must have several characteristics. Most importantly, they must be identifiable, their ecological requirements should be known and they should be sensitive to environmental changes (Douglas, 2007; Smol, 2008). Quick reproduction, high abundancy and good preservation are other characteristics that an organism should have to be a good biological indicator (Douglas, 2007).

Table 1-1 Animal and Plant remains that can be found in lake sediments (modified from the Quaternary Terrestrial Paleoecology course notes prepared by Prof. Dr. Bent Vad Odgaard)

Biological Remains in Lake Sediments
Pollen and spores
Algae
• Diatoms
• Chrysophytes
• Biogeochemical fossils/pigments
Crustaceae
• Cladocerans
• Foraminiferans
• Ostracods
Aquatic insects
• Chironomids
• Chaoborus
Remains of submerged macrophytes
Fish scales

Microfossils

Macrofossils

Being a part of the class Branchiopoda Cladocerans are microscopic crustaceans with the size between 300 and 3000 μm (Heiri and Lotter, 2005), and their length are rarely larger than 1 mm (Smol, 2008). In most of the freshwater lakes they form an important component of zooplankton and benthos (Heiri and Lotter, 2005). Especially three chitinized body parts, head-shields, shell or carapace, and post abdominal claws of cladocerans are preserved well in the lake sediment (Smol, 2008). Cladocera remains are used in reconstruction of anthropogenic impacts, in trophic dynamics and eutrophication studies, also in assessment of lake acidification, metal contamination, salinity changes and water level fluctuations (Korhola and Rautio, 2001; Jeppesen et al., 2001; Smol, 2008). Moreover, calibration sets, which are used to explain the value of an environmental variable as a function of biological data can be generated using cladocerans (Birks, 1995). Afterwards the calibration sets that are generated with sub-fossil cladocera found in surface sediment can be used to construct transfer functions to infer past changes in physical and chemical conditions, and biological parameters (e.g. Amsinck et al., 2003, 2005; Seppa et al, 2008).

Plant macrofossils is the only biological proxy that is used during this thesis study.

1.2.1.6.1 Plant Macrofossils

Plant macrofossils are the plant remains with a median size of 0.5-2 mm. Aquatic plant macrofossils and terrestrial plant macrofossils derived from the catchment are the two main components of the plant remains in lake sediments (Koff and Vandel 2008). Plant remains used to elucidate past environmental conditions are, for instance, seeds, fruits, leaves, bud scales and tree branches (see Figures 1-5, 1-6 for some examples) (Birks and Birks, 2000; Birks 2007; Koff and Vandel 2008). Paleoecological studies that use macrofossils which found in lake sediments are reviewed for the last glaciation, the Holocene and previous interglacials (Birks, 1980a).

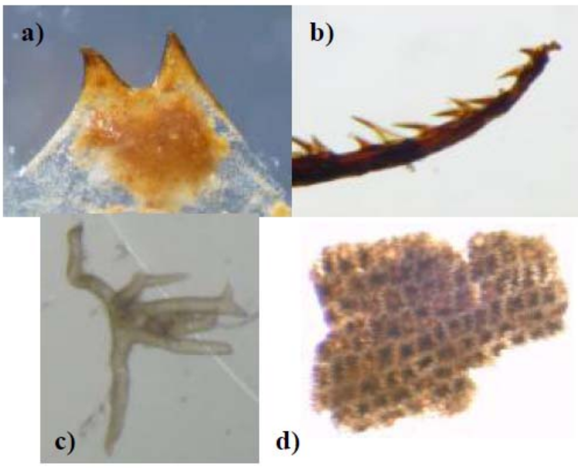

Figure 1-5 Examples of floating-leaved plant remains. a) Trapa natans L. leaf spine, b) Trapa natans L. seed spine c) Nymphaceae trichosclereid d) Nymphaea alba L. seed fragment (Photos are taken by Eti Levi)

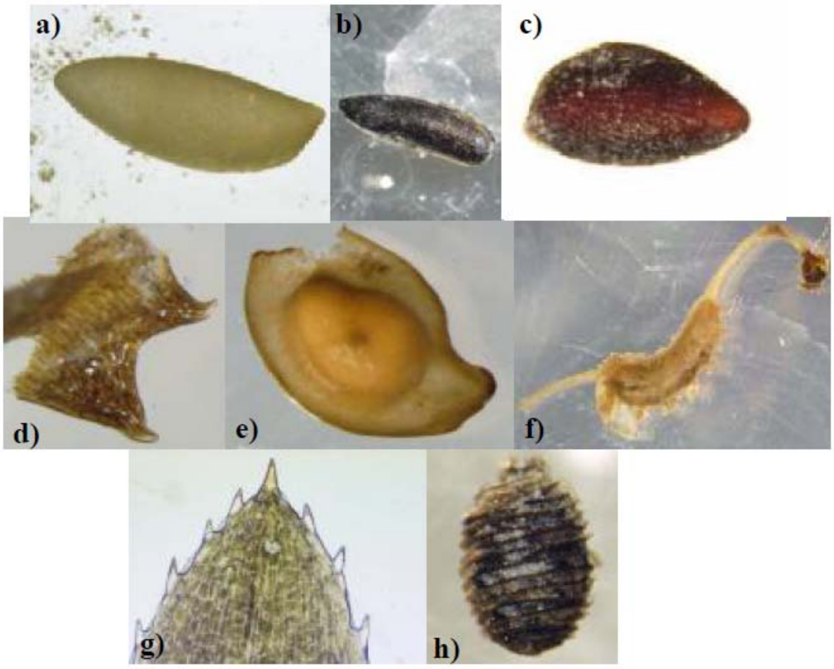

Figure 1-6 Examples of submerged plant remains. a, b, c) Najas marina L. seeds, d) Potamogeton crispus L. turion spine e) Potamogeton sp seed f) Zannichellia palustris L. seed g) Elodea canadensis Michaux. leaf tip) Chara sp oospore (Photos are taken by Eti Levi)

A. Brief History of Plant Macrofossil Studies

At the beginning of 20th century plant macrofossil studies were more common than the pollen analysis. Moreover, around that time these fossil plants were used in determining vegetational history studies, but not for understanding past environmental conditions. Earliest comprehensive Quaternary macrofossil studies were concentrated on obtaining species lists from different areas (e.g. Reid 1899, Reid and Reid, 1908). Although the standards of plant remain identification were high, the fossils were not counted and their stratigraphic context was not clearly defined. Even though plant macrofossils were used in pioneer vegetation studies in Quaternary sediments, with the development of pollen and spore studies they became less important in vegetational history studies. Birks (1980) stated that when valuable quantitative pollen analyses was developed by Von Post (1916) and refined by Jessen (1935) and Iversen (1954) plant macrofossils tended to be ignored. She also added that the cause of this decline may be due to the fact that pollen studies do not require as much sediment sample as macrofossils and narrow cores with 1-2 cm diameter is enough for pollen analyses. The studies of Jessen and Milters (1928) on interglacial deposits in Ireland and Jessen (1949) on late-glacial and post-glacial deposits demonstrated the importance of combined pollen and macrofossil studies. However, first modern macrofossil diagram was made approximately ten years later than Jessen (1949)'s studies, by West (1957) and the techniques was developed by W.A. Watts (e.g. Watts 1970). Therefore, with the development of quantitative format the usefulness of that plant macrofossil studies in the reconstruction of past environments has been demonstrated. Moreover, many studies, like Hannon and Gaillard (1997), Shuman (2003), and Koff and Vandell (2008) pointed out that multiple core approach in plant macrofossil research is very important for increasing the reliability and the interpretability of the results.

Nowadays, due to the key role and sensitivity to environmental changes of aquatic plants, macrofossils of them are used in investigations of past environmental conditions, to reconstruct lake level changes, to infer temperature and obtain knowledge of human impacts, such as eutrophication and pollution (Hannon and Gaillard, 1997; Davidson et al., 2005; Birks, 2007; Koff and Vandel 2008), on lake ecosystems. Most recently, plant macrofossils have been employed in determining the structure, composition and dynamics of past macrophyte communities (Brodersen et al., 2001; Davidson et al., 2005; Valiranta, 2006; Valiranta et al.; 2006; Koff and Vandel 2008). They, also, are used in archeological studies (e.g. Maler, 1995). Therefore, since aquatic plant macrofossils represent submerged plant-dominated alternative equilibrium state in shallow lakes and because they are important in understanding changes in aquatic biota, the number of paleolimnological research including aquatic plant macrofossil studies is increasing (Birks and Birks, 2006; Birks, 2007).

B. Advantages and Disadvantages of Plant Macrofossil Studies

In studying lake ecosystems, it is important to have the knowledge of former plant communities both to establish baseline conditions and to determine the need for active management. Unfortunately, only a few lake sites have a continuous long-term (more than a century) macrophyte record. Therefore, in most cases paleolimnology is the only way to determine the composition of submerged vegetation in the past (Birks and Birks, 2001; Davidson et al., 2005; Zhao et al., 2006; Ayres et al., 2008).

Plant macrofossil studies from surface sediment samples may provide insight into the factors affecting the relationship between plant remains assemblages and present-day plant communities (Koff and Vandel 2008). Moreover, short and long core studies of aquatic plant macrofossils from lakes provide information on the vegetational and environmental changes over time. Due to the anthropogenic activities many aquatic systems have shown significant changes (Moss, 1977; Jeppesen, 1998; Davidson et al., 2005). Because plant communities are highly sensitive to environmental changes, their diversity may decline with deteriorating conditions (Farmer, 1990; Riis and Sand- Jensen, 2001; Davidson et al., 2005) and may in extreme cases (e.g. eutrophication) completely disappear (e.g. Davidson et al., 2005). Therefore, knowledge of the ecological requirements of plant species may elucidate the ecological conditions of the lake environment (Kienast et al., 2001; Birks 2007).

One of the advantages of applying plant macrofossils is the possibility of obtaining high taxonomic resolution, which increases the amount of information on environmental conditions that can be gathered. Another advantage of macro plant remains is that they give an indication of local vegetation diversity, since they do not disperse far from the mother plants (Kienast et al., 2001; Birks 2007). Together with its advantages, the disadvantages of macrofossil studies are the requirement of larger amount of sediment samples (Birks, 1980a) and the strong bias in the representation of each taxon (Odgaard and Rasmussen, 2001). Even mother plants of the different plant groups may be equally common, some taxa, such as *Chara*, may have abundant remains while others, such as many species of *Potamogeton*, may have only few (Odgaard and Rasmussen, 2001).

Seeds and fruits are well preserved identifiable fossils as macro remains (Birks 1980a). In contrast, leaves and flowers, being more fragile, have a low frequency of preservation (Dieffenbacher-Krall, 2007). In lake sediments fragile plant remains tend to be broken down by benthos and microorganisms. Also, during overturns, currents erode these soft remains (Birks, 1980a). Even though seeds and fruits are more resistant, they also tend to be broken down by physical forces or parts of them can be eaten by animals, such as birds. Therefore, for easier and more correct identification it is important to know which parts of the identified species are preserved as macrofossils (Davidson et al., 2005; Koff and Vandel 2008).

Plant macro-remains can be preserved in environments other than lake sediments. However, depending on the sediment conditions their preservation might be poor or good. For example, macrofossil preservation in mesotrophic fen peats is often poor due to the oxidizing alkaline or neutral conditions (Birks, 1980a).

C. Multi Proxy Studies with Plant Macrofossils

Birks and Birks (2006) stated that ecosystem can be regarded as an almost infinite network of interactions between biotic and abiotic elements. They also added that small or substantial changes in an ecosystem may occur suddenly or in a long period of time. Since in the present it is not possible to observe all the changes (e.g. rapid changes which have occurred in the past), to be able to understand ecosystem dynamics, record of the alterations in fossil organisms and sediment characteristics can be used to reconstruct past ecosystems and biotic responses (Birks and Birks, 2006). Due to the complex interactions in an ecosystem, studying with many proxies (multiproxy study) provide better understanding of the situation than studying only with a single proxy (Birks and Birks, 2006; Smol, 2008). Therefore, Multi proxy studies, which use various animal (e.g. Ostracoda, Cladocera) and plant remains (e.g. plant macrofossils, pollens) as proxies, enable to determine the past structure and function of aquatic ecosystems (Birks and Birks, 2006; Bennion and Battarbee, 2007). Since plant macrofossils are used to understand the shifts in aquatic species and in lake ecosystem, they continue to come into prominence in multi proxy studies (e.g. Sayer et al., 1999; Birks et al., 2001; Brodersen et al., 2001; Odgaard and Rasmussen 2001; Davidson et al., 2005). By using both plant macrofossils and fossil Cladocerans as indicators Valiranta (2006) was able to gather important information on the water level fluctuations in Lake Mezhornoe (Valiranta, 2006; Koff et al., 2005). Moreover, in another study, in nine CASSARINA project lakes, Birks et al. (2001) used various fossils; such as aquatic plant remains, cladocera and diatoms. They showed that the shift in Cladocera, diatom and plant communities were compatible (Birks et al., 2001). For instance, in Sidi Bou Rhaba Lake, which is located in Morocco, the appearance of *Ceratophyllum* (submerged plant) and increase in *Chydorus sphaericus* (Cladocera) indicate increasing nutrient concentrations in the lake (Birks et al., 2001). Therefore, as it can be seen in various research, multiproxy studies enable to test particular hypotheses on the development of the lakes and biotic responses to specific factors (Birks and Birks, 2006).

1.3 Shallow Lakes and Paleolimnological Research in Turkey

Turkey is a rich country in freshwater resources with approximately 900 natural lakes and ponds (Coops, et al., 2003). There are 200 lakes covering about 10000 km^2 surface area with high level of endemism and species diversity of fauna and flora (Seçmen and Leblebici, 1982; Karabulut Doğan et al., 2009). Most of these lakes, which are located in a semi-arid to arid Mediterranean climate, are shallow. However, since these lakes are used for agricultural and domestic purposes their ecosystem dynamics is threatened and they are subjected to nutrient enrichment (eutrophication) and strong water level fluctuations (Coops et al., 2003; Çelik, 2006; Beklioglu, 2007). Global climate change with hydrological alterations (water level fluctuations) and eutrophication in Turkish shallow lakes affect the ecology, thus species diversity of the lakes (Külköylüoğlu et al., 2007). Furthermore, besides water level fluctuations, eutrophication may also lead the loss of submerged plants due to the turbidity caused by benthi-planktivorous fish feeding and increased phytoplankton production (Naselli-Flores, 2003; Beklioğlu et al., 2006; Iscen et al., 2008; Beklioğlu and Tan, 2008)

The ecology of semi-arid to arid Mediterranean shallow lakes (e.g. Turkish shallow lakes) are not as much explored as the ecology of north temperate ones. It is demonstrated that north temperate shallow lakes alternate between clear and turbid water states (Beklioğlu et. al., 2007; Kagalou et al., 2008). Studies in north temperate lakes showed that with increasing total phosphorous (TP) concentrations submerged plants disappeared, resulting the occurance of turbid water state (Jeppesen, 1998). Similar response was also recorded in warm temperate lakes (Tan and Beklioğlu, 2005). Due to the possibility of being persistence all year around, submerged macrophytes in Mediterranean climate regions are more advantageous in the competition for nutrient and light than algae. Therefore, macrophytes in warmer locations may be more effective in maintaining water clarity than the ones in northern regions (Alvarez-Cobelas et al., 2005).

Although there in an increase in limnological research, paleolimnological studies are relatively limited in Turkey. Paleolimnological research in Turkey mostly comprised of climate change studies carried out by non-Turkish scientists (e.g. Eastwood et al., 2007; Jones et al., 2007). There are also studies on paleohydrological changes (Leng et al., 2001) and environmental changes, like vegetation shifts (Wright et al., 2003). As an example of climate change studies in Turkey, Nishimura et al. (1997) studied fatty acids and terrestrial plant residues (> 250 μm) as a paleoclimatic indicator in Lake Kestel. Furthermore, pollen and stable isotopes of Lake Gölhisar were studied by Eastwood (2007) to provide Holocene climate change record and Jones et al. (2007) used oxygen isotope

($\delta_{18}O$) values recorded in Lake Eski Acıgöl' s sedimentary archive by means of combined hydrological and isotope mass balance modelling to reconstruct past climatic conditions. Reed et al (1999) studied the effect of environmental change on diatom composition in two different lake systems, which are Lake Süleymanhacı and Lake Pınarbaşı located in Konya basin. Moreover Eastwood (1999) studied the pollen, diatom and non-siliceous microfossil data to understand the effect of Holocene environmental change in south-west Turkey. There are studies in the eastern parts of Turkey as well, for instance Wright et al. (2003) investigate the change in terrestrial vegetation by using pollen records from Lake Van. However, non of these studies use aquatic plant macrofossils to reconstruct past vegetation composition in lakes.

1.4 Introduction to Project TÜBİTAK ÇAYDAG-105Y332

This thesis is a part of a larger project (TÜBİTAK-CAYDAG 10Y332), which is in the scope of a European Union project called EUROLIMPACS (Work Package 3) (www.eurolimpacs.ucl.ac.uk). The aim of the project is to determine the effects of eutrophication and climate change on Turkish shallow lakes using space for time substitution conducted in the Limnology Laboratory of Biology Department in Middle East Technical University (METU). Twenty six lakes from very north to the south of Turkey to fulfil space for time substitution approach were sampled for current limnological (including physical, chemical and biological) and paleolimnological parameters (e.g. aquatic plant macrofossils) using a snap shot sampling protocol developed and tested in EU-FP6 Eurolimpacs project.

1.5 Aim of the Present Study

In this study aquatic plant macrofossils of surface sediment samples taken from 25 shallow lakes are examined and compared with present-day data of Plant Volume Inhabited (PVI) in order to improve the understanding of the relationship between present aquatic vegetation and plant remains. Surface sediment samples were also used to determine the environmental variables potentially influencing the temporal changes in macrophyte communities. Moreover, eight short cores and a long core were analysed to assess the past vegetation cover and vegetation dynamics from the recent past to present.

CHAPTER 2

METHODOLOGY & STUDY SITES

2.1 Snap-shot Sampling Protocol

Throughout the summers 2006, 2007 and 2008, 26 shallow lakes were sampled along a latitudinal gradient from North (41°52′N, 27°58′E) to South (37°06′N, 29°36′E) (Figure 2-2). Sampling for environmental variables and sediment was carried out using a snap-shot sampling protocol (developed within the framework of the EU FP6 project 'Eurolimpacs') (Figure 2-1). This invaluable method is based on taking samples from several research areas with the same methodology. The samples for various physical, chemical and biological proxies of each research area are taken only during the peak of growing season (Stemberger et al., 2001). To determine general chemical characteristics of the lakes, such as total phosphorous (TP), soluble reactive phosphorus (SRP), total nitrogen (TN), alkalinity and chlorophyll-a (Chl-a), water samples (40 liters) were taken using a Schindler sampler comprising the entire water column from the deepest part where also Secchi depth was measured, together with conductivity (µS), pH, salinity (g/l), temperature (^{o}C) and dissolved oxygen (mg/l) using a YSI multiprobe. From the water samples taken with the Schindler sampler, both phytoplankton samples, directly into a 50 ml brown glass bottle, and zooplankton samples, after filtering 20 mililiters of water with a 20 µm filter, were taken as biological proxies. Zooplankton samples were also taken, by filtering 20 mililiters of water, from the littoral part of the lake using a Plexiglas pipe sampler. Furthermore, being one of the biological proxies fish were sampled using 1-5 m deep and 30 m long multi-mesh gillnets comprised 12 mesh-sizes, 43.0 – 19.5 – 6.25 – 10.0 – 55.0 – 8.0 –

12.5 – 24.0 – 15.5 -5.0 – 35.0 – 29.0 mm, respectively. The nets were set overnight, for an average duration of 12 hours, on the two determined locations at the pelagic and the littoral parts of the lake. Also, being a part of snap-shot sampling method sediment samples were retrieved with a Kajak Corer and a Livingstone Piston Corer (see sections 2.3.2 and 2.3.3 in Field methods-Chapter 2). Another proxy, which were investigated is aquatic plants, including submerged, floating leaved and emergent species (see section 2.3.1 in Field methods- Chapter-2).

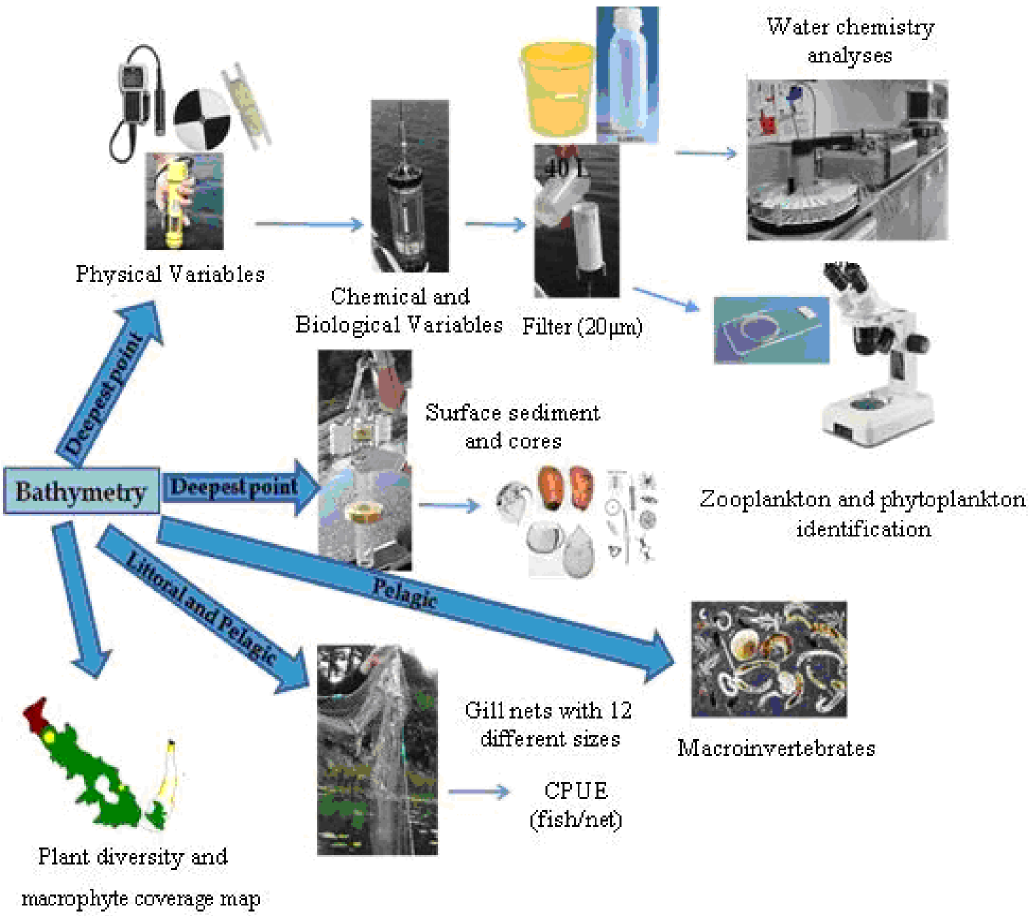

Figure 2-1 Snapshot sampling process in the studied lakes according to Eurolimpacs project (This figure prepared by Ayşe Idil Çakıroğlu and Nihan Tavşanoğlu)

2.2 Study Sites

The 26 study lakes (Figure 2-2, Table 2-1) are mostly shallow, except Lake Abant and Büyük Göl with maximum depth 17.4 m and 15.2 m respectively. Also, they are small and mostly freshwater lakes, except brackish lakes Mert and Erikli, and saline lakes Akgöl (Barutçu) and Gebekirse with mean salinities of 14.5, 5.8, 4.76 and 4.18 gl^{-1}, respectively. The lakes can be classified as mesotrophic and hypertrophic with total phosphorous (TP) concentrations ranging from around 30 to 250 μgl^{-1} and chlorophyll-a (Chl-a) concentrations ranging from ca. 5 to 60 μgl^{-1} (Table 2-1). From these 26 lakes four of them (Abant, Büyük, Derin and Nazlı) do not have percent plant volume inhabited (PVI %) data. Mean PVI data of the 22 lakes is approximately 29% and six of the lakes has no macrophytes today.

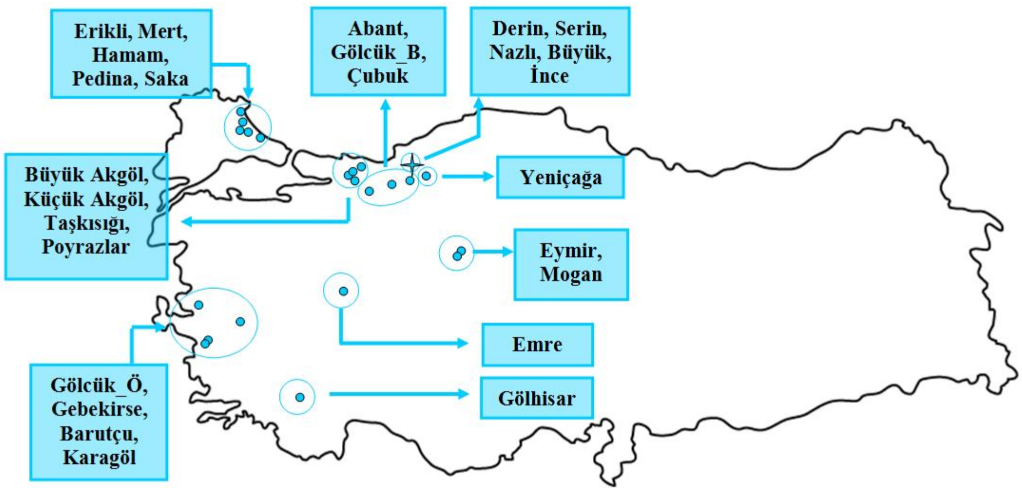

Figure 2-2 Map of Turkey, showing the main study sites (Map of Turkey taken from Google Earth and this figure modified from TÜBİTAK 105Y332 final project report)

Table 2-1 General Characteristics of the study Lakes

Lakes	Coordinates N	Coordinates E	Altitude (m)	Max Depth (cm)	Secchi Depth (cm)	TP (µg/l)	TN (µg/l)	Alkalinity (meq l-1)	Chl-a (µg/l)	Suspended solid (mg/l)	Salinity (g/l)	Conductivity (mics)	pH	PVI (%)
Erikli	41 52 03.3	27 58 40.0	0	100	80	43,70	361,80	6,30	15,44	26,80	5,82	10261,00	8,02	53,33
Mert	41 52 03.3	27 58 40.0	0	75	45	85,17	662,80	6,30	6,89	41,37	14,50	24391,83	9,11	57,67
Pedina	41 49 53.8	27 55 54.6	30	130	50	44,90	338,50	5,80	6,00	55,00	0,10	250,00	7,50	13,85
Hamam	41 49 40.0	27 57 93.6	5	190	70	29,90	328,30	2,20	16,30	9,20	0,06	122,00	8,98	11,30
Saka	41 48 10.0	27 59 36.3	1	250	80	83,20	276,10	5,90	11,57	11,60	0,21	435,00	7,62	61,00
B. Akgöl	41 02 45.6	30 33 50.3	10	370	35	80,50	658,70	5,60	10,18	75,00	0,11	233,00	8,51	55,61
K. Akgöl	40 52 42.8	30 25 55.4	22	95	20	226,70	2096,40	8,90	60,72	50,80	0,14	296,00	8,70	1,25
Taşkısığı	40 52 25.9	30 24 02.8	33	340	50	68,90	457,00	7,00	36,74	40,00	0,15	303,00	8,68	0,00
Poyrazlar	40 50 32.8	30 28 12.3	36	470	220	21,00	238,80	5,10	2,35	12,80	0,08	172,00	7,84	40,45
Serin	40 56 45.3	31 44 50.6	987	150	150	33,90	54,10	8,30	5,70	4,00	0,15	310,00	8,06	5,50
Büyük	40 56 35.6	31 44 44.8	784	1520	230	27,40	410,90	8,60	7,44	6,40	0,09	184,00	7,78	–
Derin	40 56 30.1	31 44 51.7	987	970	255	95,30	189,20	4,60	34,65	24,40	0,09	325,95	7,65	–
İnce	40 56 22.6	31 44 27.1	987	100	110	113,40	112,00	4,20	5,76	4,80	0,13	279,33	7,60	0,00
Nazlı	40 56 15.8	31 44 30.7	987	550	150	84,90	193,70	7,80	5,98	72,40	0,05	273,33	7,75	–
Yeniçağa	40 46 45.5	32 01 44.3	990	440	90	266,20	271,10	9,50	7,68	72,40	0,16	330,00	9,10	20,00
Gölcük_B	40 39 16.9	31 37 35.9	1380	520	100	52,50	219,10	4,70	13,26	24,40	0,08	247,38	8,45	35,38
Abant	40 36 45.4	31 16 91.7	1328	1740	900	15,00	81,10	6,30	4,42	4,80	0,06	104,00	7,69	–
Çubuk	40 28 51.9	30 50 05.3	1058	560	300	37,50	231,80	5,20	4,66	6,40	0,06	130,00	8,08	45,83
Eymir	39 49 37.1	32 49 57.7	971	350	20	260,20	1605,90	25,80	62,15	16,78	2,13	4008,86	8,98	11,08
Mogan	39 46 08.7	32 47 27.1	975	350	100	110,00	1278,50	47,40	6,54	7,80	2,86	5277,71	9,49	43,00
Emre	39 06 29.7	30 26 16.2	1154	430	80	88,00	1802,60	1,50	24,50	56,80	0,13	269,89	7,79	24,29
Karagöl	38 33 28.7	27 13 05.1	813	250	20	246,00	1795,50	1,20	28,60	22,00	0,14	299,80	7,69	0,00
Gölcük_Ö	38 18 52.6	28 01 37.1	1049	370	25	326,00	2028,40	1,90	14,50	33,30	0,12	168,00	9,64	0,00
Barutçu	37 59 29.8	27 19 08.0	0	250	20	410,90	1374,70	1,20	21,40	66,40	4,76	8582,67	8,52	0,00
Gebekirse	37 59 07.2	27 18 15.5	0	540	50	59,60	570,20	1,20	14,70	17,50	4,18	7608,82	8,19	0,00
Gölhisar	37 06 50.0	29 36 22.6	949	1600	50	67,30	351,30	26,20	12,67	34,00	0,31	629,00	9,16	20,25

2.3 Field Methods

2.3.1 Aquatic Plant Investigation

Aquatic macrophytes, including, emergent, floating leaved and submerged plants, were investigated at each lake. Percent plant cover of the lakes were calculated using the information gathered on floating leaved and submerged plants, whereas only submerged plant data were used to calculate percent plant volume inhabited (PVI %). Moreover, the presence or absence of emergent plants was recorded.

The observations on aquatic plants were made along paralel transect lines spaced at even intervals on the lake (see Figure 2-3 for an example). The numbers of these lines were determined according to the lake area (Table 2-2). GPS coordinates, water depth, plant species, which were sampled with a rake, average plant heights and plant cover of each submerged and floating leaved plant species were recorded at each sampling site which are located at even intervals on the transect lines (see Figure 2-3 for an example).

Percent PVI were calculated using the information on percent plant coverage (c%), average plant height (p) and water depth (wd).

PVI% = (c% x p)/wd

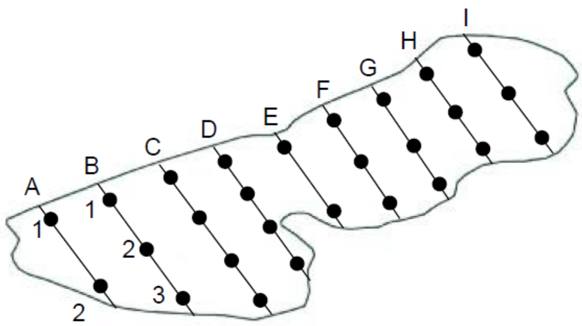

Figure 2-3 An example of Plant Volume Inhabited Studies in a Lake. (Letters, A-I, show the transect lines and numbers,1-3, represent the sites where plant samples were taken)

Table 2-2 Minimum Transect numbers for a lake according to its area

Lake Area (ha)	Number of Transects
0 – 20	10
21 – 50	15
51 – 100	15-20
101-300	20
>301	>20

2.3.2 Retrieving Sediment Samples

Surface and short core sediment samples were obtained with a Kajak Corer, while Long core samples with a Livingston Piston Corer, from or around the deepest part of the lakes.

A. Using Kajak Corers

The general operation of the messenger-operated gravity corers (e.g. Kajak Corer) includes four basic steps (Figure 2-4). As the corer is slowly lowered through the water column, water passes freely through the open coring tube (Figure 2-4 A and B). This free water flow prevent the formation of a pressure wave (bow wave), that would disturb the sediment–water interface, below the lower end of the core. When the corer settled into the sediment, the messenger is released to close the corer (Figure 2-4 C). The strike of the messenger to the corer activates closure mechanism of the core and a plunger seals the top of the core tube and allows recovering the sediment sample to the surface (Figure 2-4 D) (Douglas, 2007; Smol, 2008). The corer and the core tube must not be overshoot and completely burried in the sediment while recovering a sediment sample with a gravity corer (Douglas, 2007).

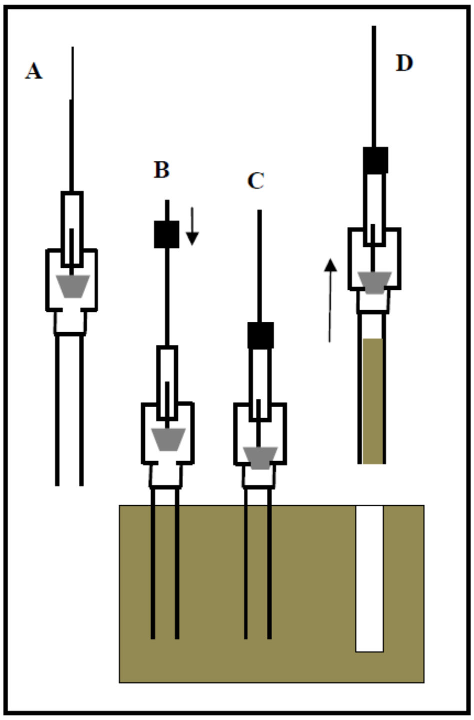

Figure 2-4 The general operation of a Gravity corer (modified from Douglas, 2007 by Ayşe İdil Çakıroğlu)

B. Using Piston Corers

Longer sedimentary sequences from Lakes Poyrazlar and Hamam were obtained with piston coring (Figure 2-5). Inside the core tube there is a piston connected to the top of the device by a strong wire cable and this piston can be positioned both at the bottom and the top ends of the core tube. Rods are used to push the corer into the sediment with the piston at the bottom of the core tube. Piston, which is located at the bottom, prevents sediment from entering the tube until the intended depth of the sediment sequence is reached. The piston is then held stationary and the core tube pushed one meter down past the piston. After the core tube filled with sediment sample, the corer is recovered by pulling the rods. The collected core sample is extruded from the core tube or the core tube containing sediment sample is exchanged with another tube and then the process is repeated for the next depth interval (Douglas, 2007; Smol, 2008).

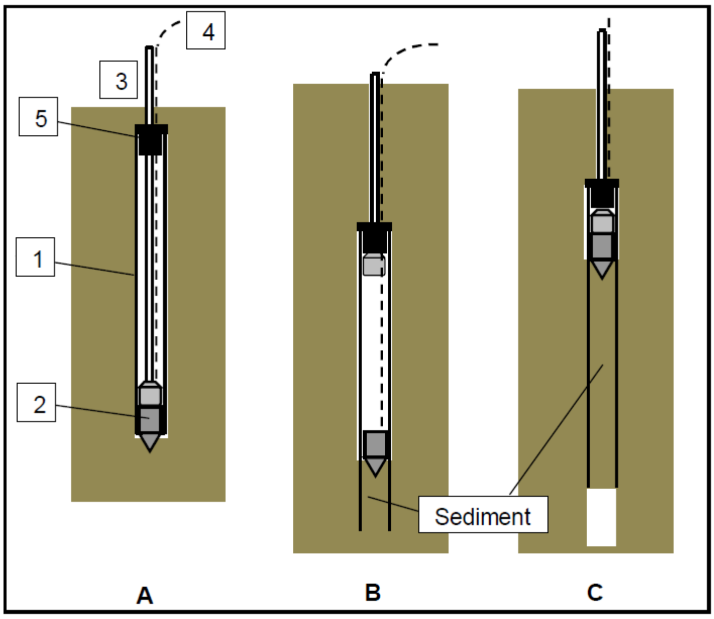

Figure 2-5 The general operation of Livinstone piston corer, showing the lowering (A), sampling (B), and withdrawal (C) of a sediment core sample. (1, Core tube, 2. Piston, 3. Push rods, 4. Piston cable, 5. Locking drive head). Modified from Glew et al., 2001

2.3.3 Sediment Coring in the Study Lakes

Surface sediment and short core samples were retrieved with one of the Gravity Corers, Kajak Corer (internal diameter 5.2 cm), from 26 lakes and from 24 lakes respectively (Table 2-3). In addition, long core samples were retrieved with a Livingstone Piston Corer from two of the lakes (Table 2-3). Surface sediment samples (0-2 cm) were taken from seven different parts (around the deepest point) of the lakes and pooled (Figure 2-6). Both short core (at around 30-60 cm long) and long core (approximately 2 m and 4 m long) samples were taken around the deepest part of the lakes. After retrieving the cores, short core samples were cut in 1 cm thick layers (subsectioning) in the field. Long cores were cut into two vertically, placed in PVC pipes and wrapped with plastic film. While short core samples were kept frozen (-18 °C), long core samples were preserved in a cold room (4 °C) prior to analysis.

Table 2-3 Lakes, from which surface sediment, short core and long core samples were retrieved (┼, shows the lakes with sediment samples)

Lake	Surface Sediment	Short Core	Long Core
Erikli	┼	┼	
Mert	┼	┼	
Pedina	┼		
Hamam	┼	┼	┼
Saka	┼	┼	
Büyük Akgöl	┼	┼	
Küçük Akgöl	┼	┼	
Taskısığı	┼		
Poyrazlar	┼	┼	┼
Serin	┼	┼	
Buyuk	┼	┼	
Derin	┼	┼	
İnce	┼	┼	
Nazlı	┼	┼	
Yenicağa	┼	┼	
Gölcük _B	┼	┼	
Abant	┼	┼	
Cubuk	┼	┼	
Eymir	┼	┼	
Mogan	┼	┼	
Emre	┼	┼	
Karagol	┼	┼	
Gölcük _Ö	┼	┼	
Barutcu	┼	┼	
Gebekirse	┼	┼	
Gölhisar	┼	┼	

2.4 Laboratory Methods

2.4.1 Magnetic Susceptibility

Correlation of the cores retrieved from Lake Hamam was made according to the Magnetic Susceptibility (MS) signal, measured using a Bartington Magnetic Susceptibility System at the Plymouth State University, USA, by Assist. Prof. Lisa Doner.

2.4.2 Dating

In order to obtain information on the change rates of lake ecosystems, samples from short cores have been substituted for ^{210}Pb-dating and samples from long core for ^{14}C-dating.

2.4.2.1 ^{210}Pb Dating

^{210}Pb Dating of the short cores from 14 lakes (in total) were made in Flett Research Ltd Environmental Laboratory, Canada (http://www.flettresearch.ca/) and in Gamma Dating Center, University of Copenhagen, Denmark (http://geo.ku.dk/english/gdc/). Two grams of wet sediment from every two cm depth interval were dried using Labconco FreeZone 6 liter Benchtop Freeze Dryer (Model 77520), in the Biology Department of Middle East Technical University as a preparation procedure before dry weights of the samples were recorded.

2.4.2.2 ^{14}C (Radiocarbon) Dating

Age measurements of the long cores taken from Lakes Hamam and Poyrazlar were made in the Department of Geology and Quaternary Science of Lund University, Sweden (http://www.geol.lu.se/c14/en/). Terrestrial plant parts, sediment samples with high organic material and crustaceans were used for radiocarbon dating. These samples were chosen from known depths of the cores and were dried in a drying oven in 105^{o}C prior to sending for analysis. In this study only radiocarbon dating results of Lake Hamam were given. Samples taken from 66, 106, 161 and 174 cm depth below sediment surface were sent for radiocarbon dating.

2.4.3 Loss on Ignition (LOI)

Water content, organic matter and carbonate content of the sediment samples are estimated in every five cm intervals. Loss on ignition (LOI) method is based on measuring weight loss of the samples after burning. LOI of sediment samples was determined at the Limnology Laboratory of Middle East Technical University.

Subsamples (around 1 cc) were placed in weighed crucibles and weighed. Weight loss was measured after each heating step; 12 hours at 105 ºC to estimate water content, two hours at 550 ºC to estimate organic matter content and, finally, four hours at 925 ºC for carbonate content. Before the weighing, crucibles were placed in a desiccator to cool completely (Nesje and Dahl, 2001; Heiri et al., 2001; Smol, 2008).

2.4.4 Plant Macrofossil Sample preparation

In this study, 25 lakes were chosen for surface sediment macrofossil analysis. Among these, short core from 8 lakes and long cores from two of the lakes were analysed. To facilitate macrofossil countings, sediment samples were washed through sieves with mesh sizes of 500 µm and 200 µm (Figure 2-6) (Brodersen et al., 2001; Odgaard and Rasmussen, 2001). Afterwards, the entire residue on the 500 µm sieve and, depending on sample size, a quantitative subsample of the residue (approx. 25%) on the 200 µm sieve were identified and both counted under LEICA MZ 16 stereo-microscope at 10-90x magnification. Fossils are presented as numbers per 100 cm^3 fresh sediment or using 4-level frequency scale (see Statistical Analysis).

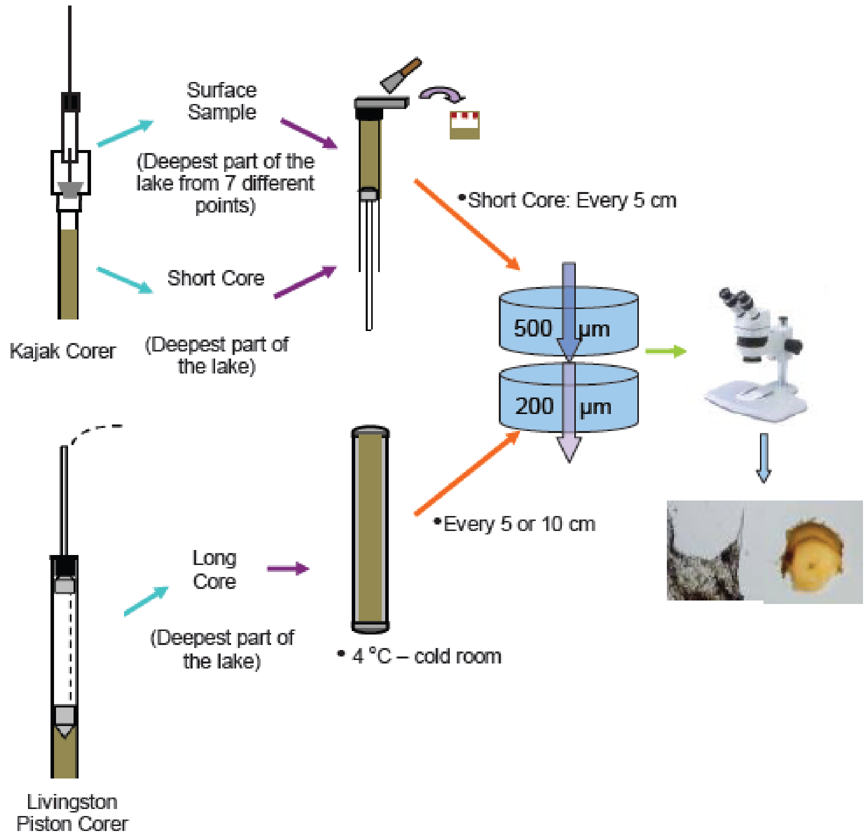

Figure 2-6 Sediment Coring and preparation of plant macrofossil samples

Identification was made with the valuable assistance of Prof. Bent Odgaard and the use of key literature (Beijerinck, 1947; Nilsson, 1961; Berggren, 1969; Birks, 1980; Berggren, 1981; Jacomet 1986; Haas, 1994; Birks, 2007; Mauquoy and Van Geel, 2007), and according to recent reference material elaborated by the Aarhus University Herbarium (see Figure 2-7, 2-8 for some examples). With the purpose of comparing fossil samples retrieved from the lake sediment and the recent reference material (from the University's herbarium), like seeds and leaves, herbarium samples were heated using a water bath in 40 ^{o}C for approximately two hours. Therefore, recent material soaked into water and swelled look like fossil ones. Following the heating procedure, to be able to compare the recent material and the fossil ones (cell structures, spines etc.), slides of the recent vegetative parts that are soaked with water, were prepared using glycerine jelly. The same procedure (except preparing slides) were applied to seed samples taken from the herbarium and their surface structures, shapes and characteristic features (if there is any) were compared with the fossil ones (see Figure 2-7, 2-8 for some examples).

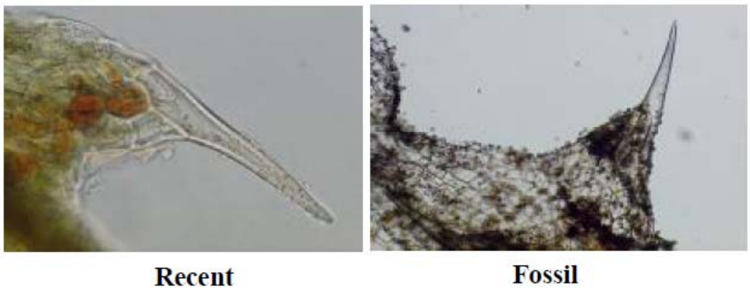

Figure 2-7 Ceratophyllum leaf spine

Figure 2-8 Callitriche brutia seeds

2.4.5 Statistical Analysis

The representation of each taxon in fossil macrophyte remains found in lake sediments are biased towards plants leaving numerous, persistent and identifiable fossils (Birks, 1980; Odgaard and Rasmussen, 2001). For example, while *Chara* may have abundant remains, some *Potamogeton* species may have only few, even their mother plants are equally common. Therefore, to be able to reduce this bias in comparing macrofossil records between lakes, the frequencies of fossils were standardised against the maximum abundance of each fossil using "4-level frequency scale" method (Odgaard and Rasmussen, 2001). Plant remain concentrations in each surface sediment sample were transformed into a 4-level frequency scale (abundant, common, rare and absent) (Table 2-4). Afterwards, fossil records of taxa with two or more fossil remains such as, *Ceratophyllum* leaf fragments and spines were edited, so that each taxon was only represented once in each sample and given the abundance of the fossil type with the highest frequency (from Odgaard and Rasmussen, 2001).

Table 2-4 4-level Frequency scale (from Odgaard and Rasmussen, 2001)

abundant	$x \geq \bar{m}$
common	$\bar{n} \leq x \leq \bar{m}$
rare	$0 \leq x \leq \bar{n}$
absent	$x = 0$

x: square root concentration of a plant remain in a sample (number in 100 cm^3 fresh sediment)
$\bar{m}$: mean square root concentration of fossils of this type in **all samples containing this type**
$\bar{n}$: mean square root concentration of this type in **all samples with plant remains**

Following the transformation to 4-level frequency scale Detrended Cannonical Correspondance Analyses (DCCA) were carried out by using surface sample plant macrofossil from 22 lakes, with environmental parameters sampled in these lakes. In DCCA, the value of “length of gradient”, which is an estimate of turover rate of species, were smaller than four. Therefore Redundancy Analyses (RDA), which is the method based on the linear model, were used (Leps and Smilauer, 2003; Bleeker and van Gestel, 2007). RDA was conducted by using CANOCO 4.5 program (ter Braak and Smilauer, 2002). Moreover, because the relationship of most organisms with environmental variables is unimodal, Canonical Correspondence Analysis (CCA), also, was conducted for comparison with RDA results.

CHAPTER 3

RESULTS

3.1 Macrophyte Species and Coverage in Study Lakes

During summers 2006, 2007 and 2008, percent plant volume inhabited (PVI) and plant species distribution were determined in 22 shallow lakes Submerged, floating leaved and emergent plants were recorded and in total twenty aquatic plant families were found (Table 3-1). Also filamentous green algae, Characeans, such as *Chara* sp. also was recorded. Even though Characeans are freshwater algae, in this study they will be mentioned as a part of the vegetation cover (Schwarz et al., 1996). From these 22 lakes submerged macrophytes were observed in 16 of them (Figure 3-1 and 3-2). It is recorded that towards the southern latitudes, between the lakes Karagöl_İzmir and Gölhisar aquatic plant diversity were lower and no submerged plants were found (Figure 3-1). Plant volume inhabited (PVI) studies of these 22 lakes showed that PVI % of northern lakes were higher then that of the southern ones. The highest PVI percentage was recorded in Lake Büyük Akgöl (55.61%), no submerged plants were observed in two of the northern lakes (Lakes Taşkısığı and İnce) (Figure 3-1).

Table 3-1 Identified plant species in Present-day aquatic plant survey

Plants		LAKES																					
		Erikli	Mert	Pedina	Hamam	Saka	B. Akgöl	K. Akgöl	Taşkısığı	Poyrazlar	Serin	İnce	Yeniçağa	Gölcük_B	Çubuk	Eymir	Mogan	Emre	Karagöl	Gölcük_Ö	Barutçu	Gebekirse	Gölhisar
Submerged Plants	*Ceratophyllum demersum* L.					+				+	+							+					
	Ceratophyllum sp.	+		+	+		+								+	+							
	Chara sp.						+				+				+			+					
	Myriophyllum spicatum L.													+	+			+					
	Myriophyllum sp.					+	+							+									+
	Elodea canadensis MICHAUX																	+					
	Vallisneria spiralis L.									+													
	Najas marina L.	+	+				+	+					+				+						
	Potamogeton crispus L.																	+					
	Potamogeton lucens L.												+		+								
	Potamogeton pectinatus L.															+	+						
	Potamogeton perfoliatus L.						+			+													
	Potamogeton sp.																						
	Ranunculus sp.														+								
	Ruppia maritima L.		+																				
	Zannichellia palustris L.																+						
Floating leaved	*Hydrocharis morsus-ranae* L.						+																
	Nuphar lutea (L.) SM.						+		+					+									
	Nymphaea alba L.				+		+		+	+													
	Polygonum amphibium L.													+	+			+		+			
	Trapa natans L.			+	+		+	+		+													
Emergent Plants	*Sagittaria sagitifolia* L.									+													
	Butomus umbellatus L.							+	+					+									
	Carex sp.													+									
	Juncus inflexus L.													+									
	Juncus sp.					+	+		+					+				+					
	Phragmites australis (Cav.) Trin. Ex. Steud.								+	+								+		+	+	+	
	Phragmites sp.	+	+			+	+	+					+	+									+
	Sparganium sp.								+														
	Verbascum sp.													+									
	Typha latifolia L.									+													
	Typha sp.	+				+	+	+	+				+	+									+

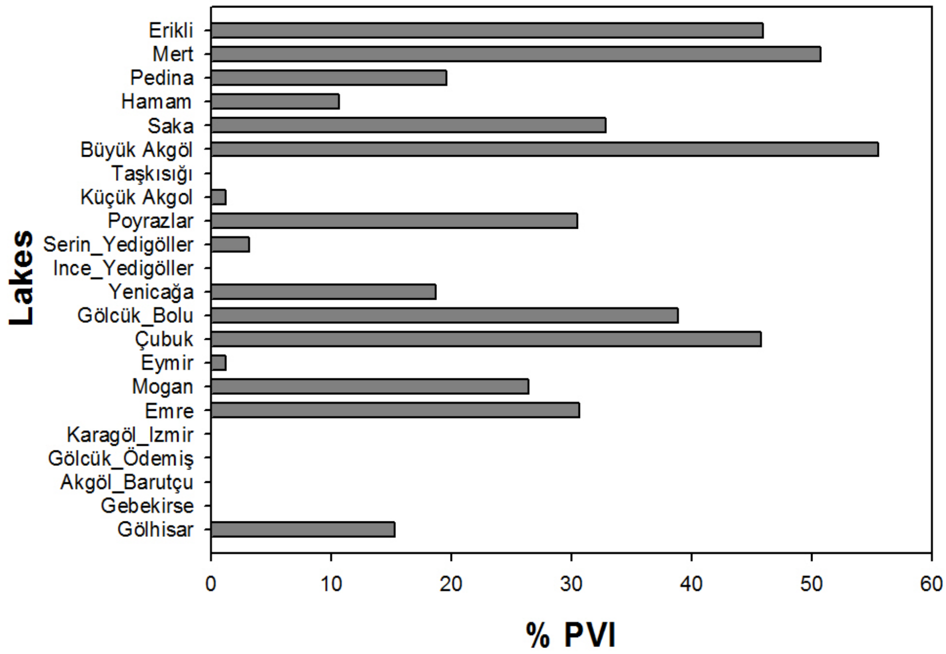

Figure 3-1 PVI percentages of the study lakes

It is recorded that *Ceratophyllum* were dominant in seven lakes. Other prevalent species were *Najas marina* in six lakes, *Myriophyllum* spp. in five lakes and *Potamogeton* spp. in six lakes. Also, species such as, *Zannichellia palustris* and *Ruppia maritima,* which can tolarate more saline conditions were observed (Figure 3-2).

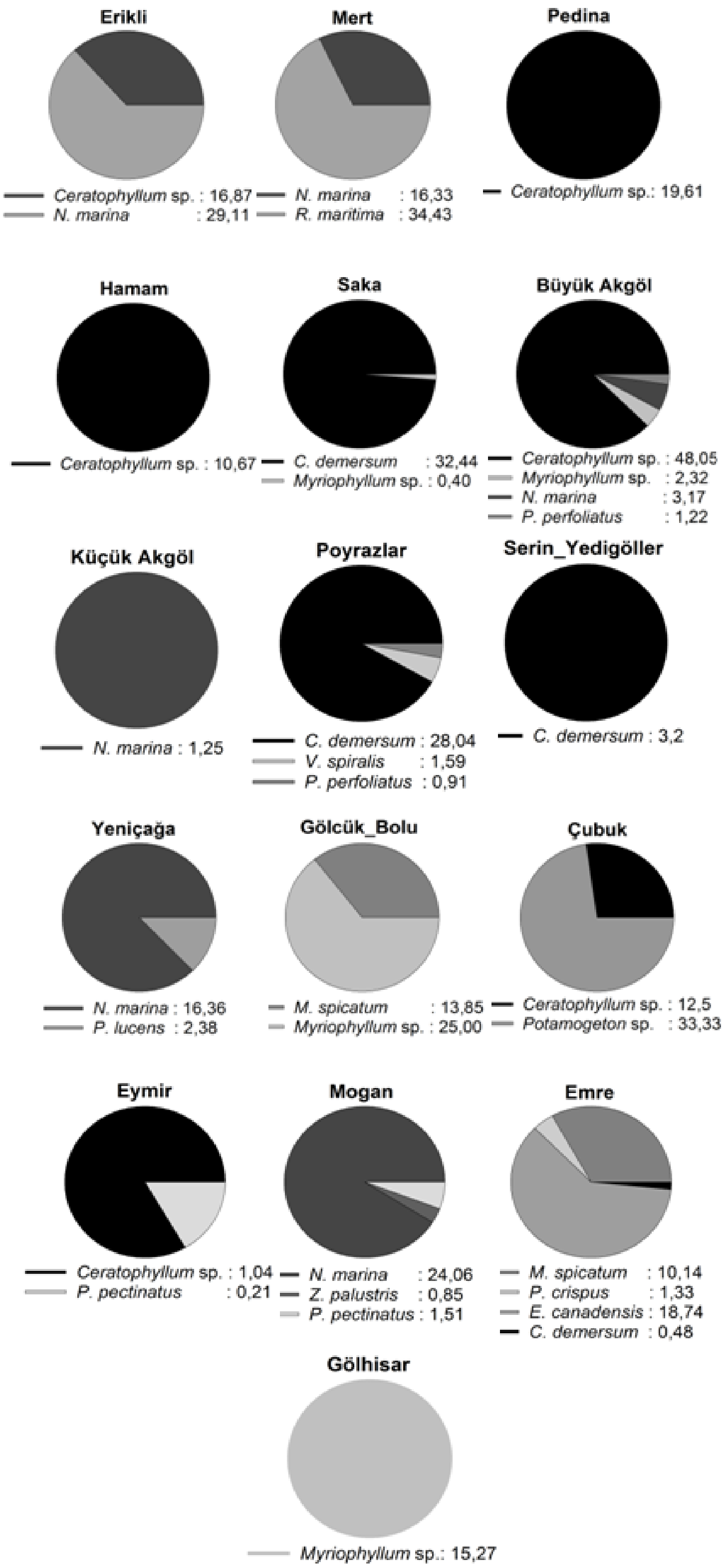

Figure 3-2 Plant PVI Percentages of the study lakes

3.2 Surface Sediment Macrofossils and Comparison with Modern Vegetation

From 12 submerged and floating leaved plant families, which were found during present-day studies, 8 species were represented as macrofossils in the form of leaf fragments, leaf spines, seeds etc. in the surface sediments (Table 3-2 and Figure 3-3). Eleven taxa that were found as macrofossils, but not as part of the modern vegetation (Table 3-2). Some of these taxa were *Zannichellia palustris* L., *Potamogeton crispus* L., *Ceratophyllum* (in lakes Gölhisar, Mert, Küçük Akgöl and Erikli), Characeae (in lakes Pedina, Taşkısı, Eymir, Mogan, Mert and Erikli), *Callitriche*, *Lemna minor* L., *Najas marina* L. (in Lakes Ince, Gölhisar and Gölcük_Bolu), *Ranunculus sceleratus* L. and *Ruppia maritima* L. (in Lake Mert) (Table 3-2). Being the most abundant modern taxa of submerged plants, the amount of spines and leaf fragments of *Ceratophyllum* were the most frequently occurring plant remains. In addition, Characeae species were present in the macrophyte vegetation in Lakes Erikli, Büyük Akgöl, Çubuk and Emre and were represented as macrofossils in Büyük Akgöl and Çubuk. Percent Plant Volume Inhabited (PVI %) identified another abundant modern species, *Najas marina* L. which was found in seven lakes. This taxon was represented in four of these lakes as plant remains (e.g. seeds, seed fragments and leaf spines) in the surface sediment (Table 3-2, Figure 3-3). *Ranunculus* spp. was found as macrofossil in Lakes Mert and Karagöl, whereas it was found as a part of modern vegetation in Lake Çubuk. However, in Lake Çubuk it was not represented as macrofossils. The remains of floating leaved species *Trapa natans* L. and *Nymphaea alba* L. were found in 3 and 2 lakes, respectively (see Table 3-2).

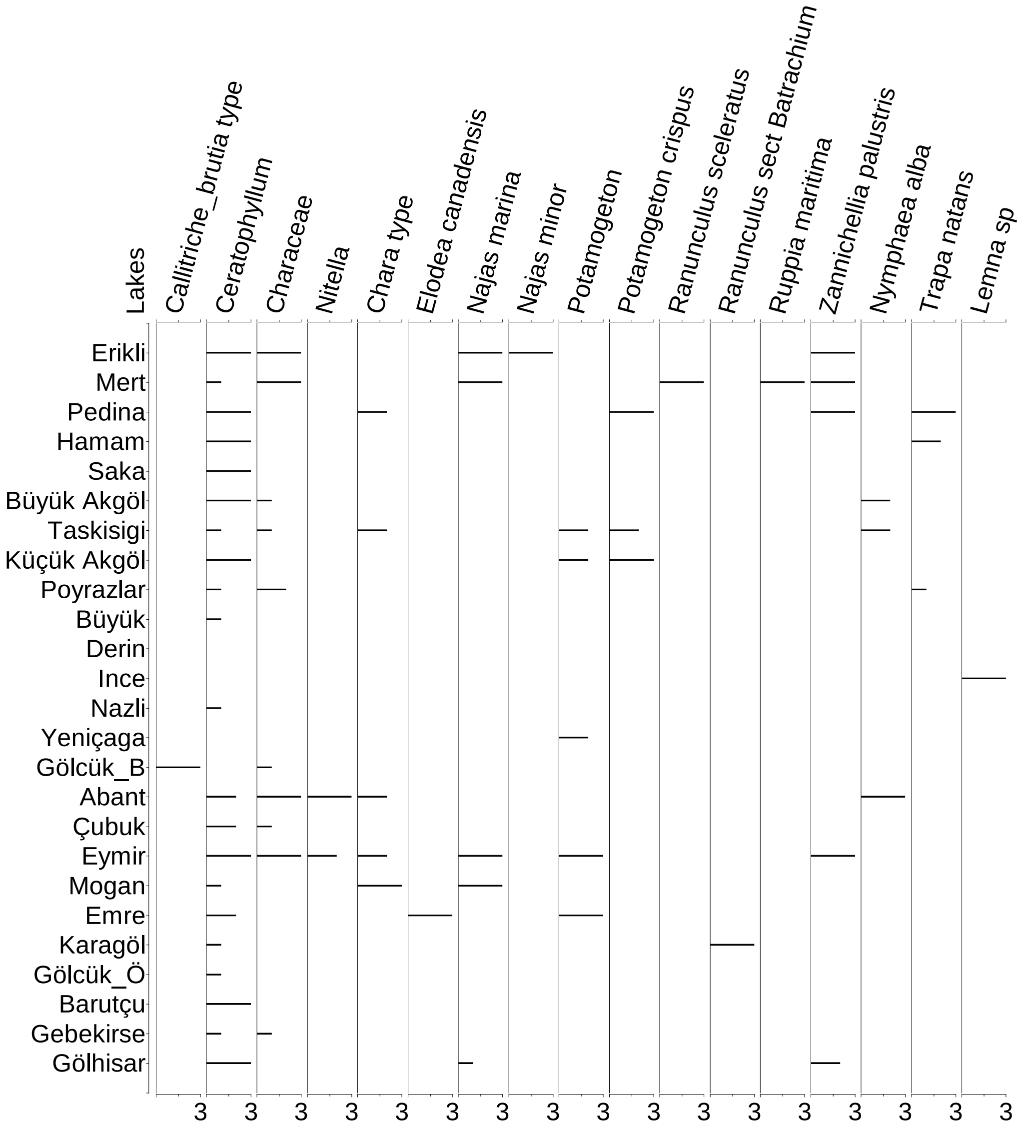

Figure 3-3 Surface sample counting results. Results are presented using 4-level frequency scale method (Odgaard and Rasmussen, 2001)

Table 3-2 Comparison of present-day submerged and floating leaved macrophyte data obtained during the snap-shot sampling with plant macrofossils from surface sediment [+, Present day-modern-plants (M); o, Plant remains (F). Gray boxes show modern vegetation represented as macrofossils]

Plants	Lakes																																									
	Erikli		Mert		Pedina		Hamam		Saka		B. Akgöl		Taşkısı		K. Akgöl		Poyrazlar		Ince		Yeniçağa		Gölcük_B		Çubuk		Eymir		Mogan		Emre		Karagöl		Gölcük_Ö		Barutçu		Gebekirse		Gölhisar	
	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
Callitriche_brutia type																								o																		
Ceratophyllum spp	+	o		o	+	o	+	o	+		+	o		o		o	+								+	o		o		o		o		o		o		o		o		o
Ceratophyllum demersum										o								o													+											
Elodea canadensis																															+	o										
Myriophyllum spp									+		+												+		+						+										+	
Najas marina	+	o	+	o							+				+						+						+	o	+	o												o
Najas minor	+																																									
Potamogeton spp														o		o		o				o					+	o				o										
Potamogeton crispus						o								o		o															+											
Potamogeton lucens																					+				+																	
Potamogeton pectinatus																											+		+													
Potamogeton perfoliatus											+						+																									
Ranunculus spp																									+																	
Ranunculus sceleratus				o																																						
Ranunculus sect Batrachium																																		o								
Ruppia maritima			+	o																																						
Valisneria spiralis																	+																									
Zannichellia palustris		o		o	+																							o														o
Hydrocharis morsus-ranae											+																															
Nymphaea alba								o			+	o	+	o			+																									
Nuphar lutea											+		+										+																			
Polygonum amphibium																							+		+						+				+							
Trapa natans					+	o	+	o			+				+		+	o																								
Lemna cf minor																				o																						
Characeae	+			o							+			o				o				o		o	+			o												o		
Chara spp						o						o		o												o		o		o	+											
Nitella spp																												o														

3.3 Relationship Between Surface Sample Plant Macrofossils and Environmental Parameters

The comparison of RDA and CCA results showed that Redundancy Analysis (Table 3-3, Figure 3-4) gave a better explanation on the relationship between plants and environmental variables. Therefore, as in the study of Sondergaard et al. (2005) RDA results were used to explain this relationship. On the other hand, Lougheed et al. (2001) used CCA to determine environmental factors that affect aquatic macrophytes. Result of the RDA showed that among eight environmental variables first axes was related to alkalinity, salinity, and Secchi depth explaining 57.2% of variance and second axis was to TN and chlorophyll-a (Chl-a) explaining 22.9% of variance (λ_1= 0,240 ve λ_2=0,096) (Figure 3-4 and Table 3-3). Lakes, which have had higher salinity concentrations, including Lakes Mert, Erikli, Mogan, Geberkirse and Barutçu are clustered around the 1st axis as they had high salinity. Since Lake Gölhisar has a high Alkalinity value, it is positioned near the 1st axis. Moreover, present-day studies showed that Chl-a and Alkalinity values of Lake Eymir, which is located in between the 1st and 2nd axis, is relatively high. Also, having high Chl-a concentrations Lakes Taşkısığı and Küçük Akgöl are clustered close to the 2nd axis.

Table 3-3 Redundancy Analyses (RDA) Results

Axes	1	2	3	4	Total variance
Eigenvalues	0.240	0.096	0.032	0.028	1.000
Species-environment correlations	0.889	0.808	0.721	0.581	
Cumulative percentage variance of species data	24.0	33.6	36.9	39.7	
Cumulative percentage varianceof species-environment relation	57.2	80.1	87.8	94.5	
Sum of all eigenvalues					1.000
Sum of all canonical eigenvalues					0.420

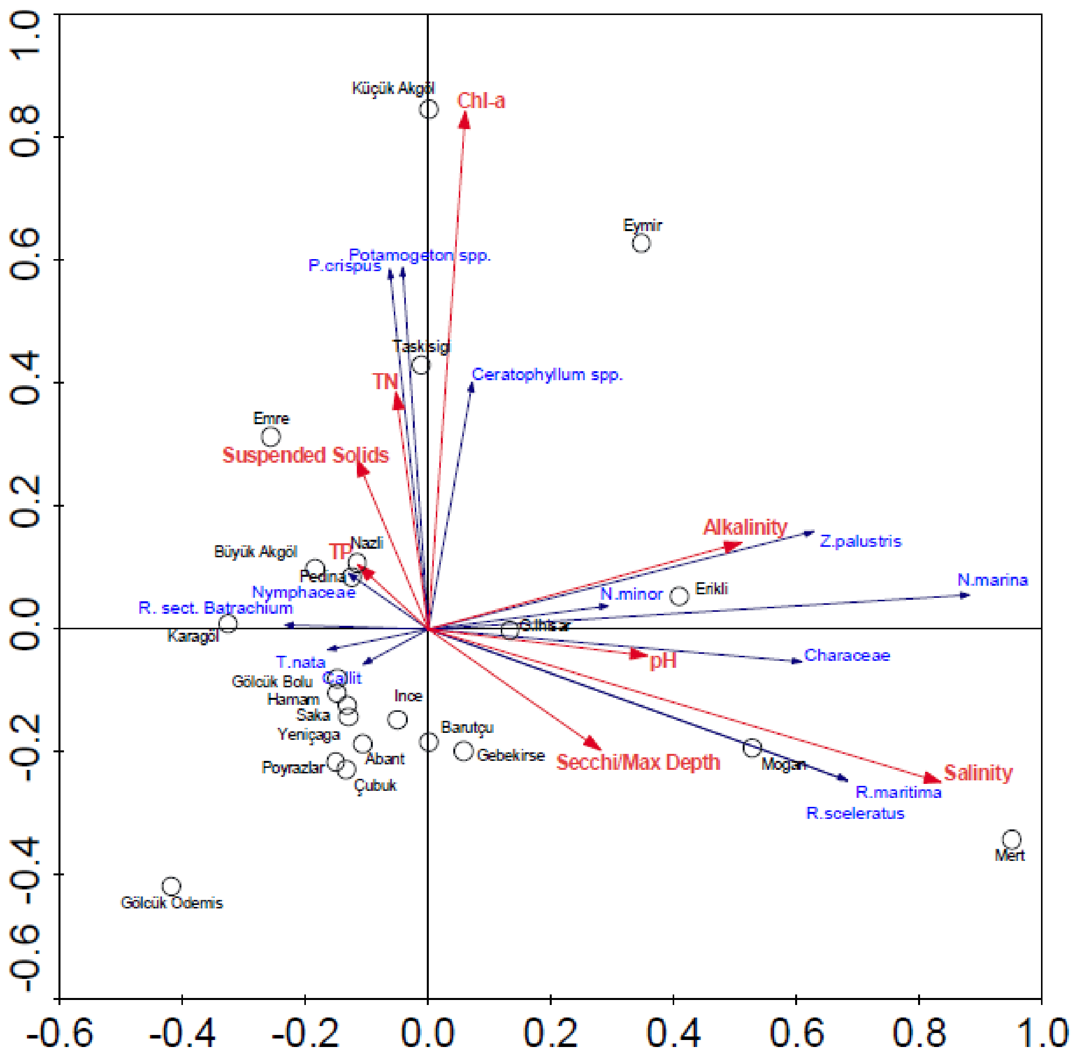

Figure 3-4 RDA result in surface sediment plant macrofossils and environemental variables of 23 lakes (Red arrows show environmental variables, triangles show species that found as macrofossils and circles indicate the lakes)

3.4 Sediment Analyses of Long and Short Cores

3.4.1 Magnetic Susceptibility, Loss on Ignition and Correlation of the Long Core from Lake Hamam

In Lake Hamam long core samples were taken deeper down the sediment at three different sites around the deepest point of the lake. Thus, in this lake cores were sampled at 99 cm length (T1) at site 1, at 110 cm length (T2) and 37 cm length

(T3) at site 2, and the last one at 88 cm length (T5) at site 3. Correlation of these cores was made according to the Magnetic Susceptibility (MS) signal, measured (Figure 3-5). MS signal graphs showed significant peaks including α, β and γ (Figure 3-5). Comparison of these peaks enables correlation of the long cores (Figure 3-6). On the other hand, LOI results of Lake Hamam did not show any clear peaks or drops except the peaks in LOI (550) and LOI (925) at around 165-166 cm (Figure 3-7, 3-8). Therefore the results indicated that both organic and inorganic carbon, determined from LOI (550) and LOI (925) results respectively, were more or less stable throughout the core (Figure 3-7, 3-8). In addition, for more reliable results, the MS correlation of these cores (Figure 3-7, 3-8) was compared with the LOI results of the long core segments, but they could not be verified due to the lack of significant peaks and drops in LOI results (Figure 3-7, 3-8). Moreover, short core (~45 cm) of Lake Hamam is assumed to be correlated with the upper parts of the long core, so the upper 45 cm of the long core (T1) was not counted for plant macrofossils.

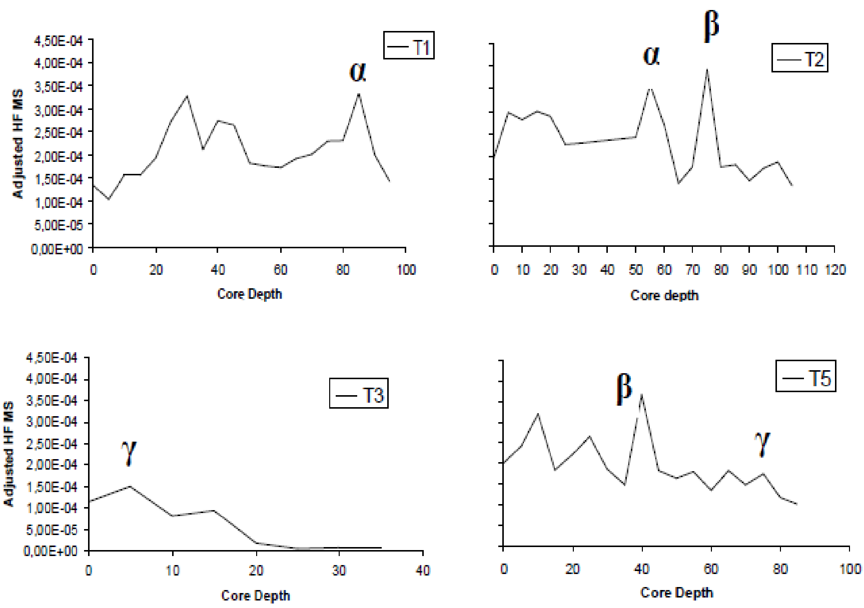

Figure 3-5 Magnetic Susceptibility (MS) results and correlation of long core segments (α, β and γ show correlated peaks of the cores T1, T2, T3 and T5)

T1 Core Depth (cm)	T1 Adjusted Depth (cm)	T2 Core Depth (cm)	T2 Adjusted Depth (cm)	T3 Core Depth (cm)	T3 Adjusted Depth (cm)	T5 Core Depth (cm)	T5 Adjusted Depth (cm)	
0	0							
5	5							
10	10							
15	15							
20	20							
25	25							
30	30	0	30					
35	35	5	35					
40	40	10	40					
45	45	15	45					
50	50	20	50					
55	55	25	55					
60	60	30	60					
65	65	35	65			0	65	
70	70	40	70			5	70	
75	75	45	75			10	75	
80	80	50	80			15	80	
85	85	55	85			20	85	α
90	90	60	90			25	90	
95	95	65	95			30	95	
		70	100			35	100	
		75	105			40	105	β
		80	110			45	110	
		85	115			50	115	
		90	120			55	120	
		95	125			60	125	
		100	130			65	130	
		105	135	0	135	70	135	
				5	140	75	140	γ
				10	145	80	145	
				15	150	85	150	
				20	155			
				25	160			
				30	165			
				35	170			

Figure 3-6 Correlation of Long core retrieved from Lake Hamam according to MS results (α, β and γ show correlated peaks of the cores T1, T2, T3 and T5)

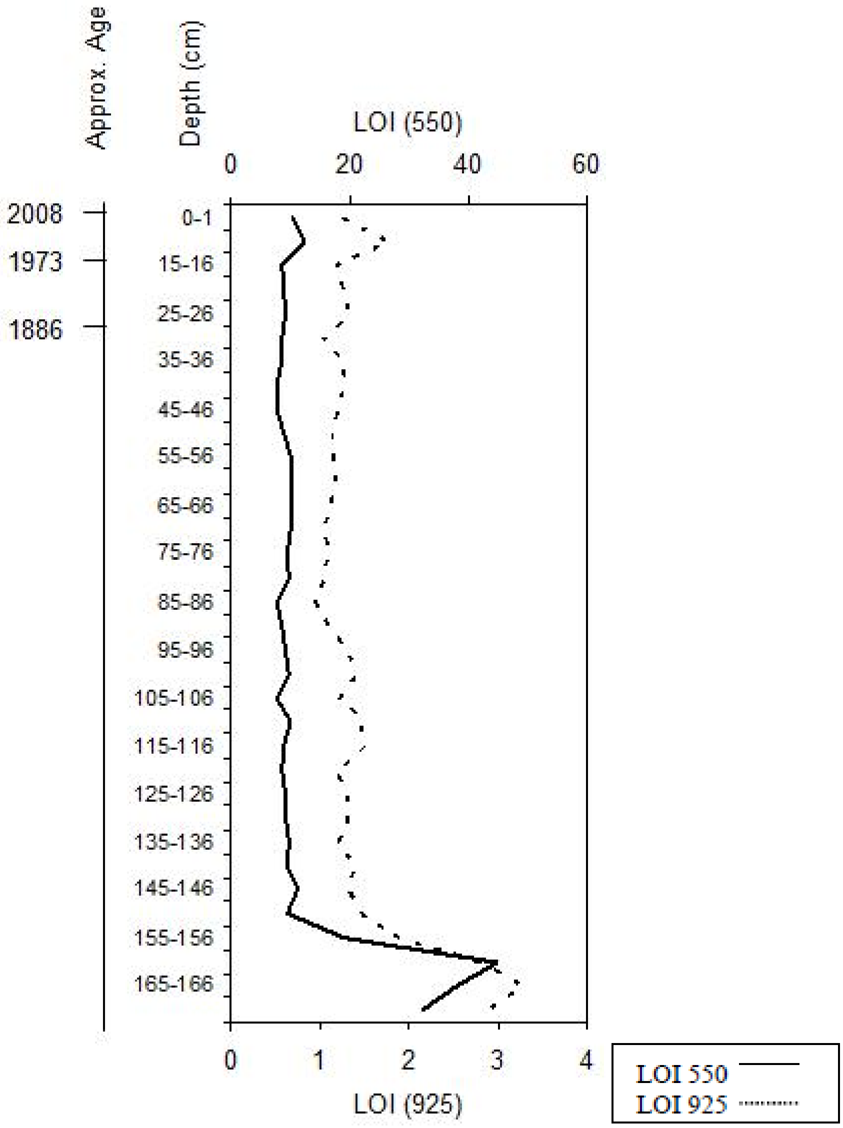

Figure 3-7 LOI results of Lake Hamam's correlated long core (dotted lines show LOI (925) and solid lines show LOI (550). Approx. Age shows the results of ^{210}Pb (0-27 cm)

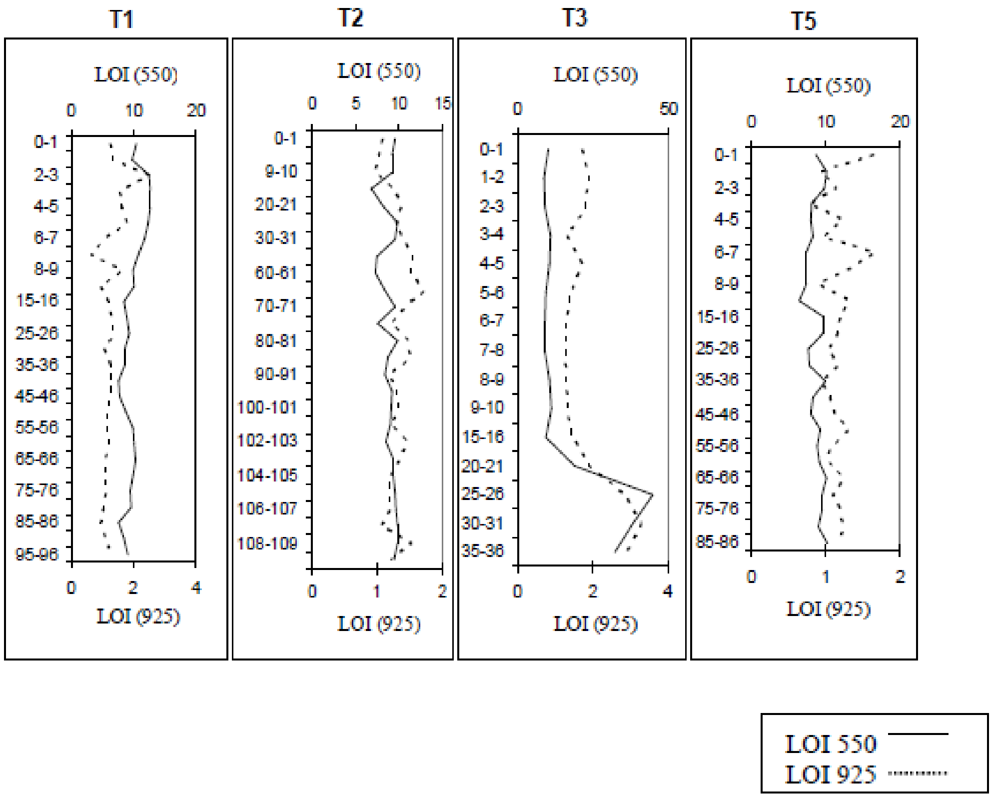

Figure 3-8 LOI results of Lake Hamam's long core segments (dotted lines show LOI (925) and solid lines show LOI (550)

3.4.2 Loss on Ignition (LOI) Results of the Short Cores

LOI results of the short cores retrieved from three lakes (Hamam, Yeniçağa and Gölcük_Ö) did not show major peaks and drops, while the results of the rest five lakes signified some distinctive peaks and drops (Figure 3-9). For example, the LOI (925), which is the carbonate (inorganic carbon) content, of Lake Mert showed two peaks at 5-6 cm and 20-22 cm among which first was bigger. Later on recently organic carbon content LOI (550) increased. LOI analyses results of Lakes Mogan, Emre and Gölhisar also showed slight changes all over the short cores, while in Lake Poyrazlar both organic and carbonate (inorganic carbon) content were fluctuating throughout the core. It is observed that both organic and inorganic carbon content of Lake Mogan were more or less stable from the bottom of the core until around 11-12 cm depth. Afterwards an increase was recorded in both of the results. However towards the surface while the amount of organic carbon was stayed constant, inorganic carbon content started to decrease. In the LOI results of Lake Emre a continuous increase in both LOI (550) and LOI (925) were recorded from 31-32 cm depth towards the bottom of the core, while from surface to 31-32 cm depth the results did not show significant changes. The organic carbon content of Lake Gölhisar showed two substantial peaks at around 15-16 and 25-26 cm respectively, whereas the amount of inorganic carbon decreased slightly throughout the short core.

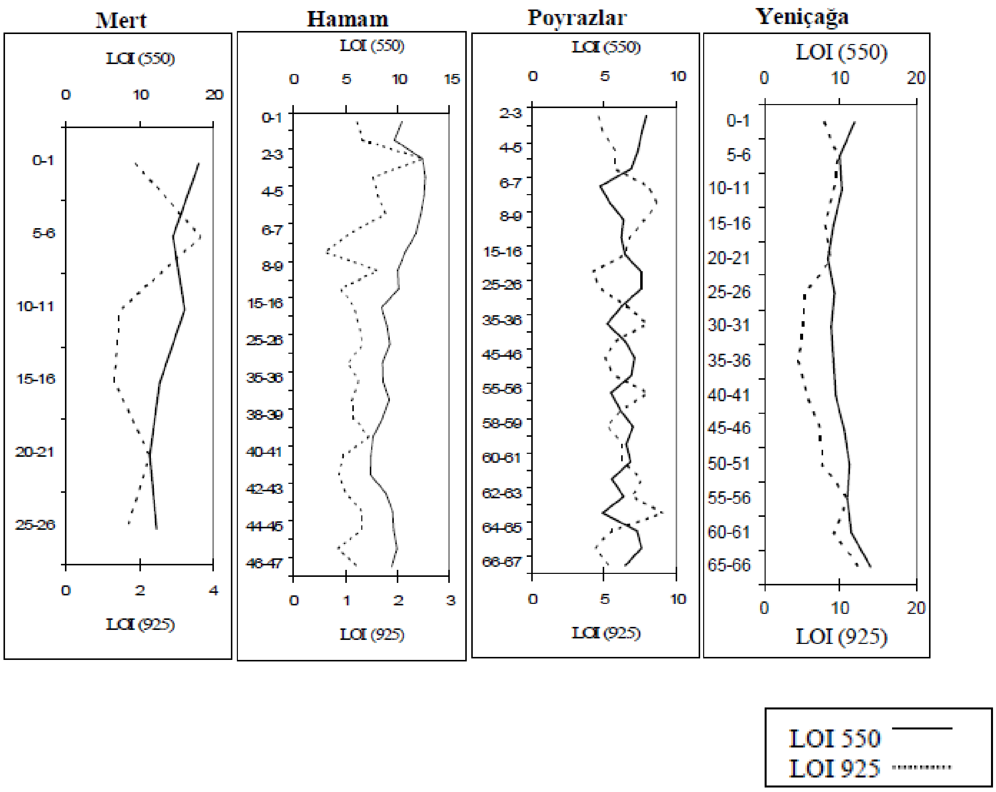

Figure 3-9 LOI results of short cores from eight different lakes (dotted lines show LOI (925) and solid lines show LOI (550)

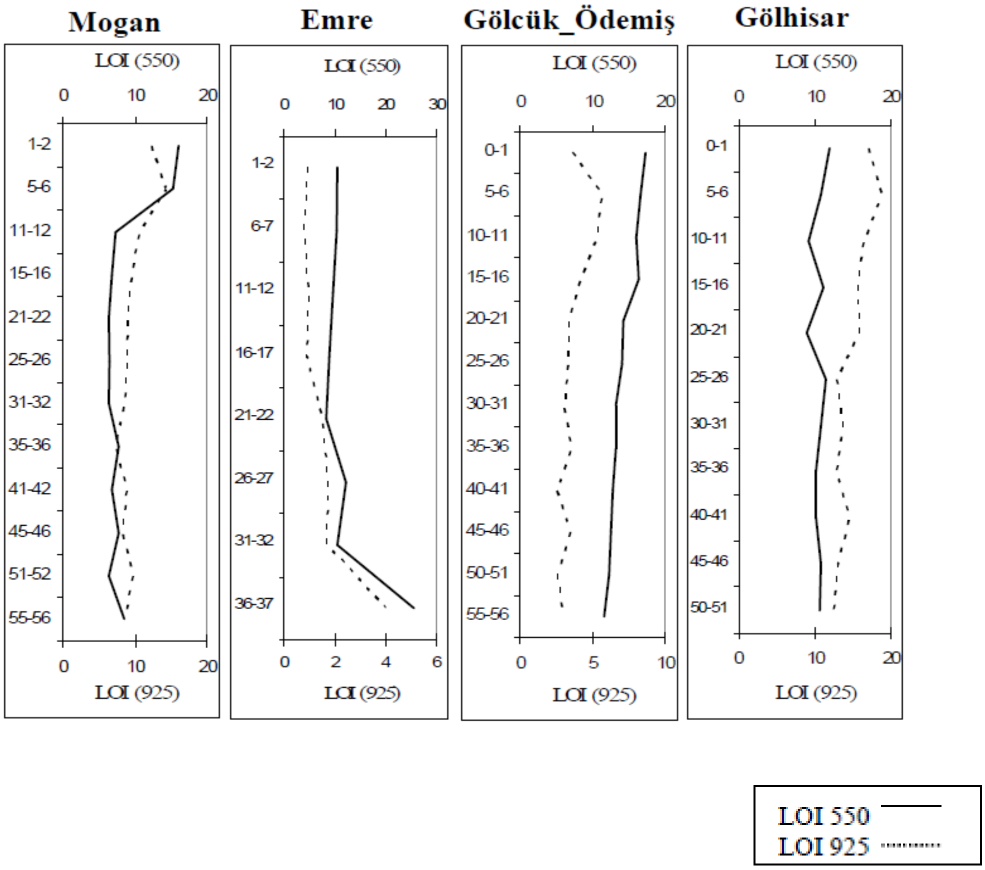

Figure 3-9 (continued) LOI results of short cores from eight different lakes (dotted lines show LOI (925) and solid lines show LOI (550)

3.4.3 ^{210}Pb Dating Results of the Shorts Cores Taken from Eight Lakes

^{210}Pb Dating of the short cores from Lakes Poyrazlar, Yeniçağa, Gölcük and Gölhisar were made in Flett Research Ltd Environmental Laboratory, Canada and from Lakes Hamam and Mogan in Gamma Dating Center, University of Copenhagen, Denmark. Due to the very high sedimentation rate, which causes uniform activities of Pb-210 and Cs-137 in the entire core it was not possible for Gamma Dating Center to date the short core from Lake Emre. However, according to the dating center the deepest part of the core might be around 10 years old. Also, due to the limited budget of the TÜBİTAK project the short core of Lake Mert could not be dated yet.

3.4.3.1 ^{210}Pb Results of Lake Poyrazlar

According to the interpretation of the "Pb-210" dating report of Lake Poyrazlar, from the two models which is used for dating, linear regression model (based on depth) is considered more reliable than the one based on cumulative dry weight. Moreover, it is stated in the report that the average sediment accumulation rate of the core is 0.36 cm/year and the corresponding year of deepest point (31 cm) is 1908 (Figure 3-10).

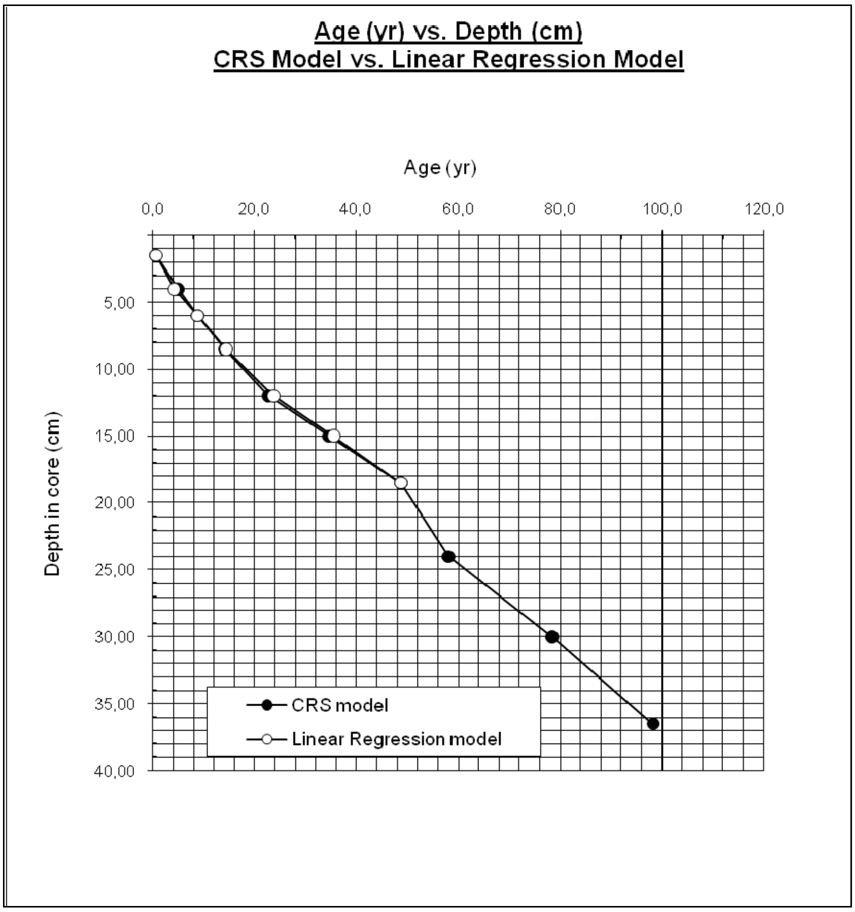

Figure 3-10 ^{210}Pb dating results of the short core of Lake Poyrazlar based on the lineer regression and CRS models

3.4.3.2 ^{210}Pb Results of Lake Yeniçağa

According to the interpretation of the "Pb-210" dating report of Lake Yeniçağa, from the two models which is used for dating, linear regression model (based on depth) is considered more reliable than the one based on cumulative dry weight. Moreover, it is stated in the report that the average sediment accumulation rate of the core is 0.93 cm/year and the corresponding year of deepest point (66 cm) is 1939 (Figure 3-11).

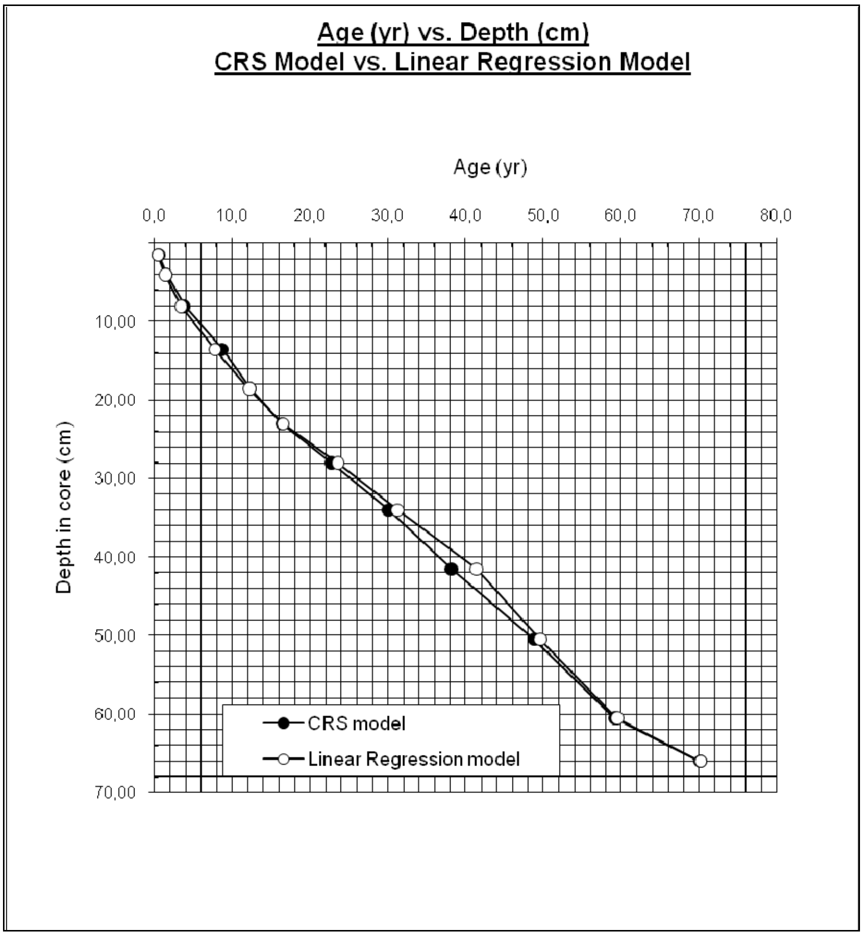

Figure 3-11 ^{210}Pb dating results of the short core of Lake Yeniçağa based on the lineer regression and CRS models

3.4.3.3 ^{210}Pb Results of Lake Gölcük

In the interpretation report of the "Pb-210" dating of Lake Gölcük it is indicated that from the two models which are used for dating, the CRS model, which is based on cumulative dry weight is preferred. Moreover, according to the report the sediment accumulation rates are increasing toward the surface of the core and the average sediment accumulation rate is 0.19 gr/cm^2/year and the corresponding year of deepest point (60 cm) is 1942 (Figure 3-12).

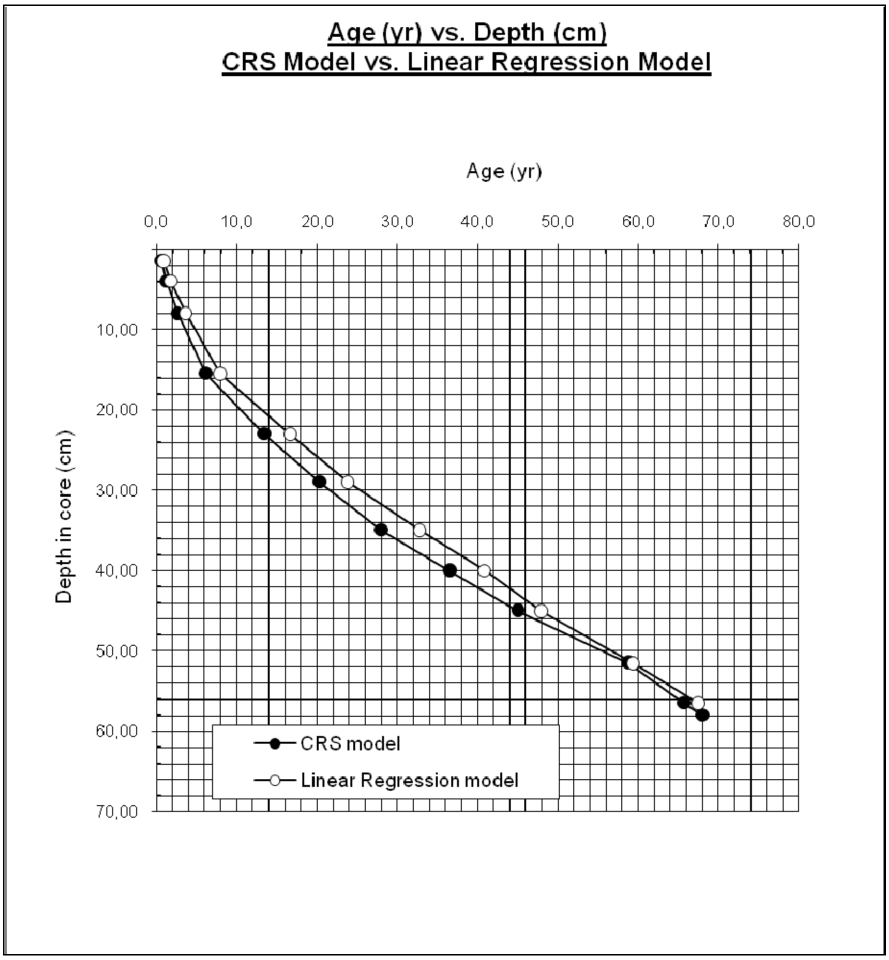

Figure 3-12 ^{210}Pb dating results of of the short core Lake Gölcük based on the lineer regression and CRS models

3.4.3.4 ^{210}Pb Results of Lake Gölhisar

In the interpretation report of the "Pb-210" dating of Lake Gölhisar it is concluded that due to the equal reliability of the lineer regression and CRS models, the true ages of the sediment samples lie somewhere between the two model estimates. According to the report the average sediment accumulation rate is 0.71 cm/year and the corresponding year of deepest point (26 cm) is 1939 (Figure 3-13).

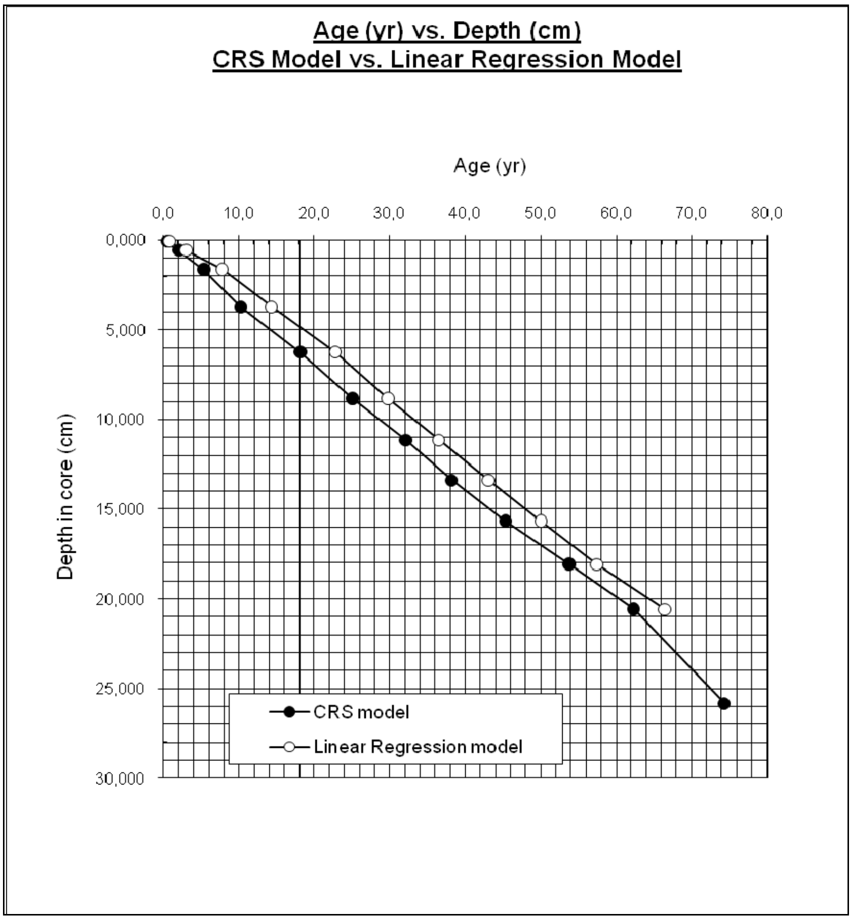

Figure 3-13 ^{210}Pb dating results of the short core of Lake Gölhisar based on the lineer regression and CRS models.

3.4.3.5 ^{210}Pb Results of Lake Hamam

According to the Pb-210 dating result report, CRS-modeling has been applied for the analyses. It is stated in the report that the average sediment accumulation rate of the core is 0.22 g/cm^2/year and the corresponding year of deepest point, that could be dated (27,5 cm) is 1886 (Figure 3-14).

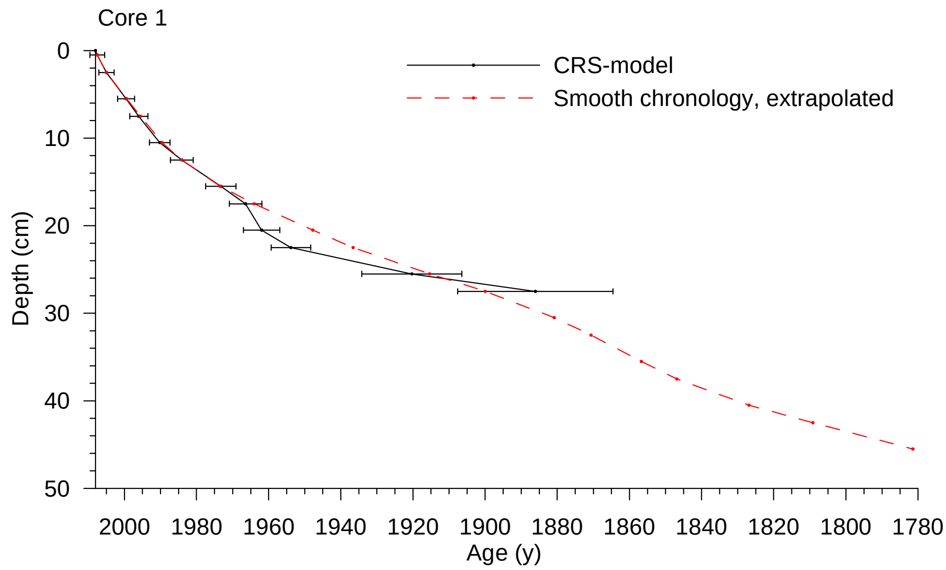

Figure 3-14 ^{210}Pb dating results of the short core of Lake Hamam based on the CRS model

3.4.3.6 ^{210}Pb Results of Lake Mogan

According to the Pb-210 dating result report, CRS-modeling has been applied for the analyses. It is stated in the report that the average sediment accumulation rate of the core is 0.17 g/cm^2/year and the corresponding year of deepest point, that could be dated (34,5 cm) is 1917. It is also indicated in the report that due to the irregular profile of ^{210}Pb precise dating of the core was not possible and therefore ^{210}Pb the chronology can only be regarded as indicative. Moreover, because the dating results of the layers deeper than 34.5 cm was absent in the report, the age of these parts could not be given in this study (Figure 3-15).

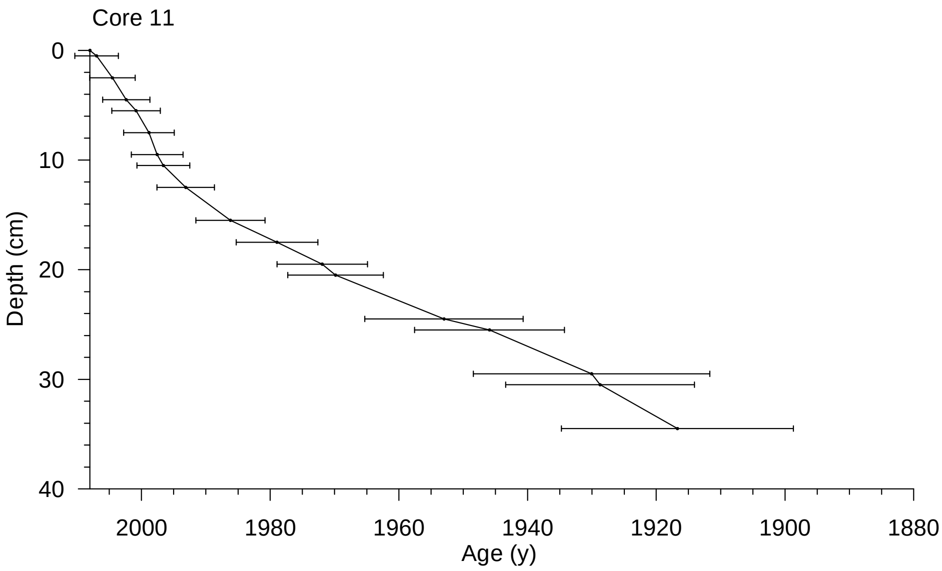

Figure 3-15 ^{210}Pb dating results of the short core of Lake Mogan based on the CRS model

3.4.4 ^{214}C Dating Results of the Long Core Taken from Lake Hamam

Age measurement results of the long core taken from Lake Hamam showed that the depths 66 and 106 cm correspond to years between 500-330 before present (BP; present = 1950 AD) with 95.4 % possibility and 470-265 BP with 73.1 % possibility, respectively. It was also shown that the age range of the samples taken from 161 and 174 cm is the same, from 155 to -6 BP, with 54.6 % and 61.4 % probabilities respectively. The reverse order of the ages (from older to younger) might be due to the difficulties in dating very young samples (from the last few centuries) with ^{14}C dating method. Moreover, a reason for the older calibrated age of the sample from 66 cm, which is a gyttja, might be the "reservoir effect" of the hard water lakes with pH more than 7.5 (Last and Smol, 2001). If the $^{14}C/^{12}C$ ratio of the carbon, from which the aquatic plants built up their tissue was lower than the $^{14}C/^{12}C$ ratio in the CO_2 of the contemporaneous atmosphere, the dating of such plant material is regarded to have been affected by the so-called "lake reservoir effect" (Last and Smol, 2001). Due to this uncertainty radiocarbon dating results were not used while giving the results of Lake Hamam's long core.

3.4.5 Plant Macrofossils Identification and Density in the Short and Long Cores

Short cores of eight lakes, including Lakes Mert, Hamam, Poyrazlar, Yeniçağa, Mogan, Emre, Gölcük and Gölhisar, and a long core from Lake Hamam were counted for submerged and floating leaved fossil macrophyte remains. Plant macrofossils found in sediment samples were counted under a stereo-microscope at 10-90x magnification. Initially, samples from deep and shallow levels were selected, if large differences occurred between these, intermediate samples were analysed. Therefore, counting of short and long cores were done mostly between 5 and 10 cm intervals considering the change in plant remains between the selected sediment layers. Since in a sediment sample a species may have various preservable fragments (e.g. *Potamogeton crispus* turion spines and *Potamogeton crispus* seeds/seed fragments) counting results of plant macrofossils were given separately to show all preserved remains.

^{210}Pb dating results of the short cores from Lakes Hamam, Yeniçağa, Poyrazlar, Mogan, Gölcük and Gölhisar were received, however dating result of Lake Mert is not ready yet. Moreover, since Lake Emre is a set lake, it has a quite fast sedimentation rate preventing the dating of the short core.

3.4.5.1 Lake Mert

In the short core of Lake Mert (counted in 10 cm intervals), the presence of vegetation was relatively stable, although there were slight changes in the density of plant remains (Figure 3-16). Moreover, *Potamogeton* seed fragments, were found around 20 cm depth, did not appear at the upper depths. In contrast, *Ranunculus sceleratus* L. remains were found just at the surface of the core. Other plant taxa remains like, *Ceratophyllum*, *Najas marina* L. and *Ruppia maritima* L. were found throughout the core though in decreasing density. Also *Zannichellia palustris* L. decreases towards the top and at the surface where only a few seeds appeared. Furthermore, the number of Characeae oospores decreases slightly upward the core (Figure 3-16).

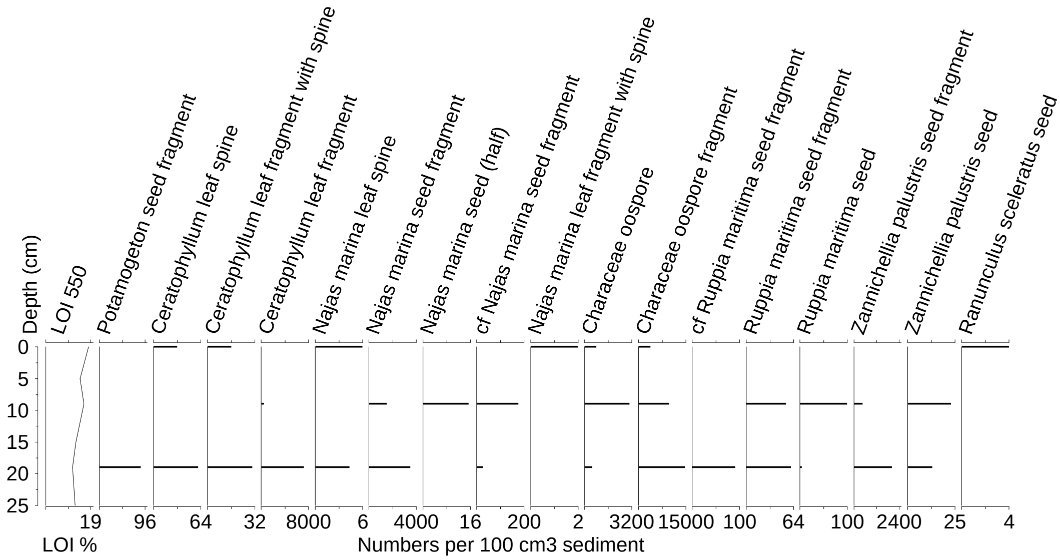

Figure 3-16 Plant macrofossils, their density distribution and percent Loss on Ignition (LOI%) results throughout of a short core taken in Lake Mert

3.4.5.2 Lake Hamam

Short (counted in 10 cm intervals) and long core (counted in 20 cm intervals) macrofossil records of Lake Hamam showed a shift from a Characeae remains dominated state to a floating leaf plant remains, *Trapa natans* L., dominated state which started around 20 years earlier from present (zone 1). In Zone 5, at the base of the long core, *Chara*-type and *Nitella* oospores were common (Figure 3-17, 3-18). In Zone 4, there was a change from Characeae oospores to *Nymphaea* seed fragments around 140 cm deep. After the *Nymphaea* state, there was Zone 3 without remains (Figure 3-17). In zone 2, at around 1890-1970, *Trapa natans* L. remains, such as leaf spines and leaf fragments, appeared (Figure 3-17, 3-18). Furthermore, towards the end of this zone there was an increase in the number of *Trapa natans* L. remains and *Chara*-type oospore fragments occur. In Zone 1, approximately between the years 1970-2008, towards the surface, the number of

Trapa natans L. remains increased (Figure 3-17, 3-18). In addition, in this zone *Ceratophyllum* macrofossil remains appeared and an increase in their number was recorded upwards, to present time. Moreover, Seçmen and Leblebici (1991) also were identified *Trapa natans* and *Ceratophyllum demersum* species which support the plant remain results around 1990's.

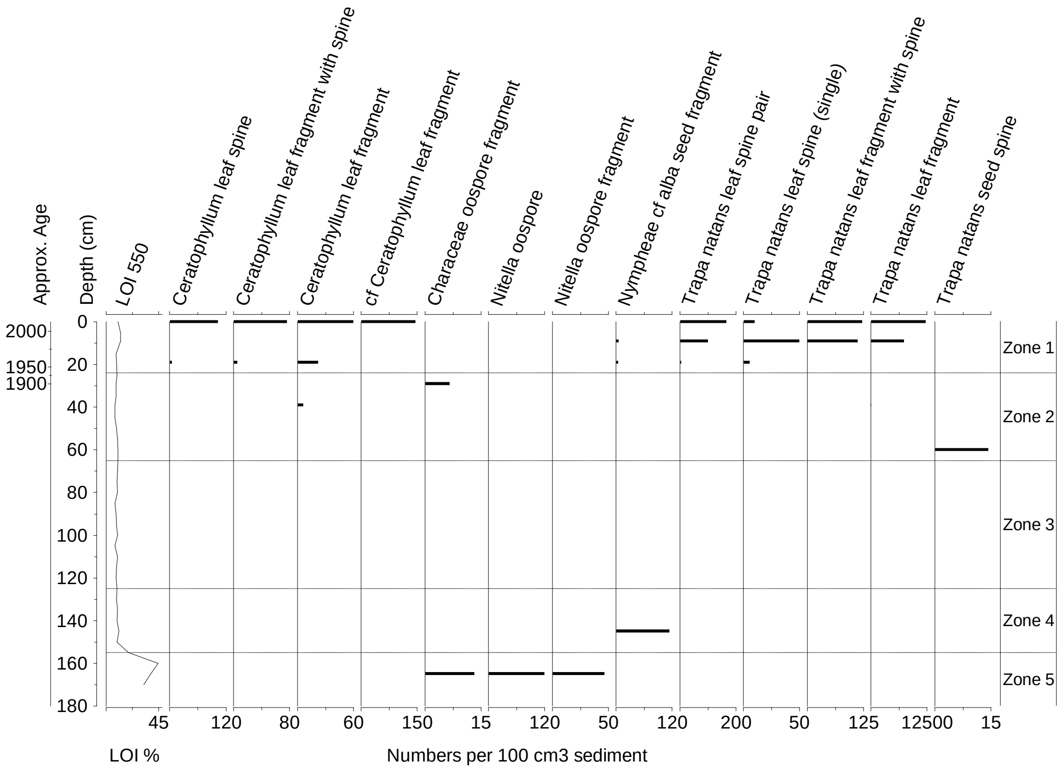

Figure 3-17 Plant macrofossils, their density distribution and percent Loss on Ignition (LOI%) results throughout of a long core taken in Lake Hamam

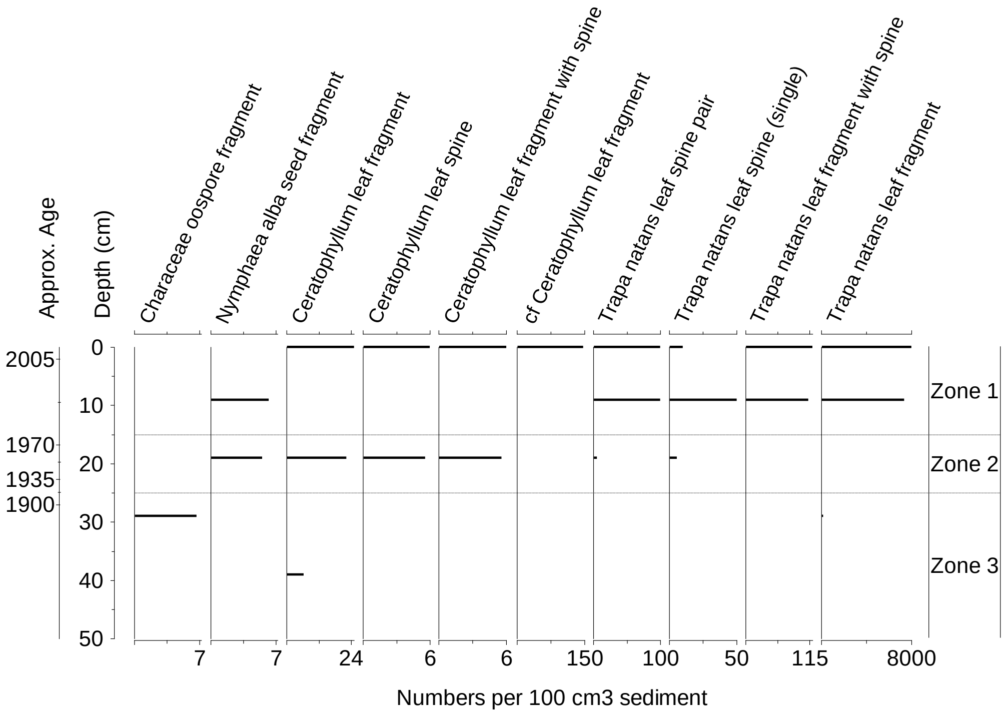

Figure 3-18 Plant macrofossils and their density distribution throughout of a short core taken in Lake Hamam and ^{210}Pb dating results

3.4.5.3 Lake Poyrazlar

Macrofossil remains in the short core (counted in 5 cm intervals) of Lake Poyrazlar showed a change from floating leaved species, such as *Nymphaea alba* and *Trapa natans* to a submerged genus *Ceratophyllum* (Figure 3-19). In the second zone (between 10-65 cm) *Trapa natans* leaf fragments were found at the bottom layer for the first time and towards the upper parts, in 54-55 cm remains of *Nymphaea alba* appeared. A fluctuation in the numbers of these plant remains were recorded throughout zone-2. Between the years 1970 and 2008 (zone-1) *Ceratophyllum* remains appeared, while *Nymphaea alba* and *Trapa natans* fragments disappeared. At around 1-2 cm depth an increase in the number of *Ceratophyllum* remains and the appearance of both Characeae oospore fragments and *Trapa natans* leaf fragments were recorded.

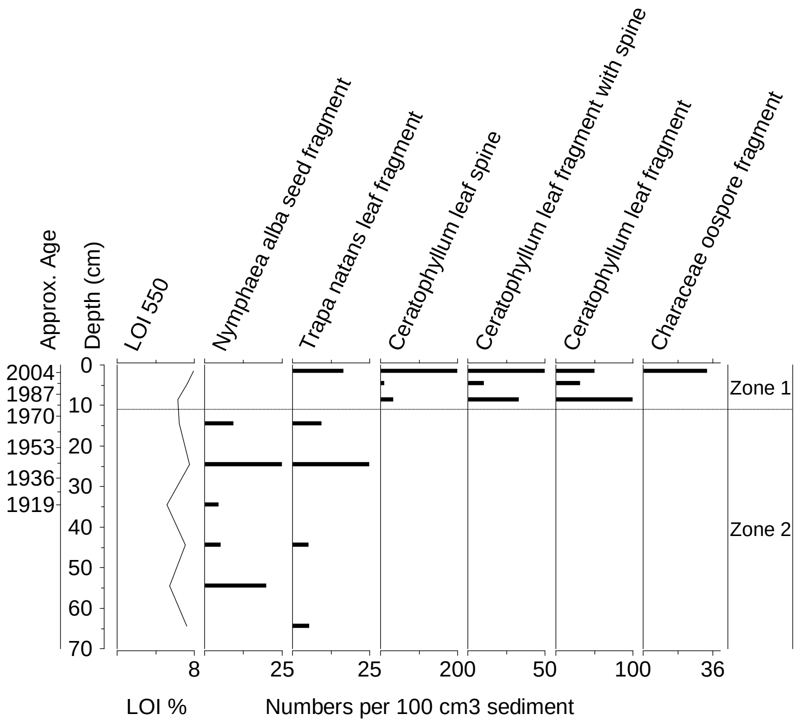

Figure 3-19 Plant macrofossils, their density distribution and percent Loss on Ignition (LOI%) results throughout of a short core taken in Lake Poyrazlar and ^{210}Pb dating results (Dating analysis of the core were started from 35 cm depth)

3.4.5.4 Lake Yeniçağa

In the short core (counted in 10 cm intervals) of Lake Yeniçağa *Ceratophyllum* remains prevailed at the bottom corresponding to year 1943, whereas few or no plant remains were found at the top though the lake had 18.7% PVI (Figure 3-1 and 3-20). In the deepest part of the core, in Zone 2 around 40-60 cm (between the years 1943 and 1965) *Ceratophyllum* was the most frequently encountered remains with up to 300 fossil leaf fragments per 100 cm^3. In Zone 1, around the year 1975 (at 30 cm depth) a few *Potamogeton* spp seed fragments were found, whereas no *Ceratophyllum* plant remains occurred. Towards the upper parts of the core, around 20 cm depth (corresponding approximately to year 1986), *Ceratophyllum* reappeared, together with some *Potamogeton crispus* remains, while at the top only two *Potamogeton* sp. seed fragments were found. Although during the present-day PVI studies *Najas marina* L. appeared, it was absent from the surface sediment cores (Figure 3-20).

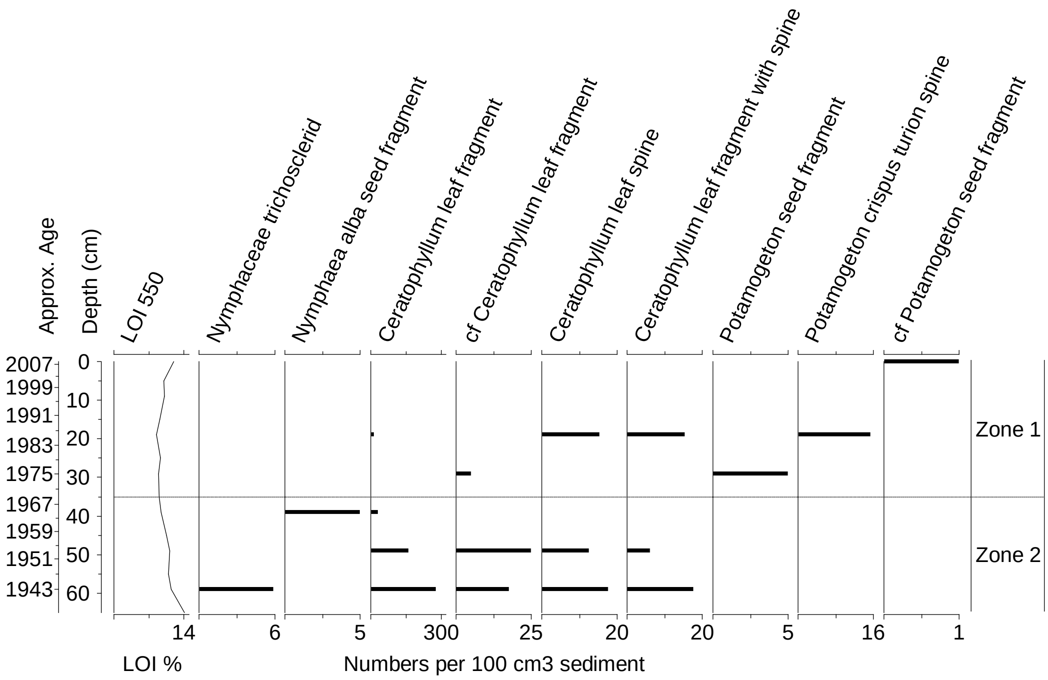

Figure 3-20 Plant macrofossils, their density distribution and percent Loss on Ignition (LOI%) results throughout of a short core taken in Lake Yeniçağa and ^{210}Pb dating results

3.4.5.5 Lake Mogan

Short core of Lake Mogan (counted in 5 cm intervals) showed significant changes especially between *Najas marina* L., which was dominant towards the surface at Zone 2, *Ceratophyllum* and Characeae remains (e.g. leaf spines of *Ceratophyllum, Chara* oospores) (Figure 3-21). At the bottom of the core, at 53-54 cm (in Zone 4) *Chara* type oospores were the most frequent ones with up to 1700 remains per 100cm^3. Both of the frequent species (*Chara* type oospores and *Najas marina* L.) remains showed a significant decrease towards the third zone, whereas the number of *Zannichellia palustris* L. seed fragments did not change. Other macrofossils found in this zone were *Potamogeton* seed and seed fragments, which were disappeared towards zone 3 and did not occur in other zones. In Zone 3, possibly around the years 1910-1980, Characeae and *Ceratophyllum* remains prevail alternately (Figure 3-21, 3-22). This zone started with the dominance of Chara type oospore fragments in 39-40 cm. Afterwards, in 33-34 cm (approx age is 1917), Characeae remains showed a significant decrease with the substantial increase in *Ceratophyllum* remains with up to 489 leaf fragments. Although *Ceratophyllum* macrofossils were dominant in the third zone towards the second zone, at around 1985-2003, there was a decrease in their number. At the beginning of the third zone *Najas marina* fossil remains showed a decrease compared to Zone 4, however, towards Zone 2 fragments of *Najas marina*, especially fossil leaf remains, started to increase. Second zone started with the prevalence of *Chara* type oospore remains. Even though there was an increase in Characeae fragments, the increase in *Najas marina* L. macrofossils was much higher. Therefore, at the last part of Zone 2, in 3-4 cm (approximately corresponding to year 2003), there was *Najas marina* dominance with around 13500 fossil leaf remains per 100 cm^3. In zone 1, between the years 2003 and 2007, at the surface of the core there was another Characeae remains dominant period. In this zone *Ceratophyllum* fragments started to increase one more time, whereas there was a decrease in the number of *Najas marina* remains.

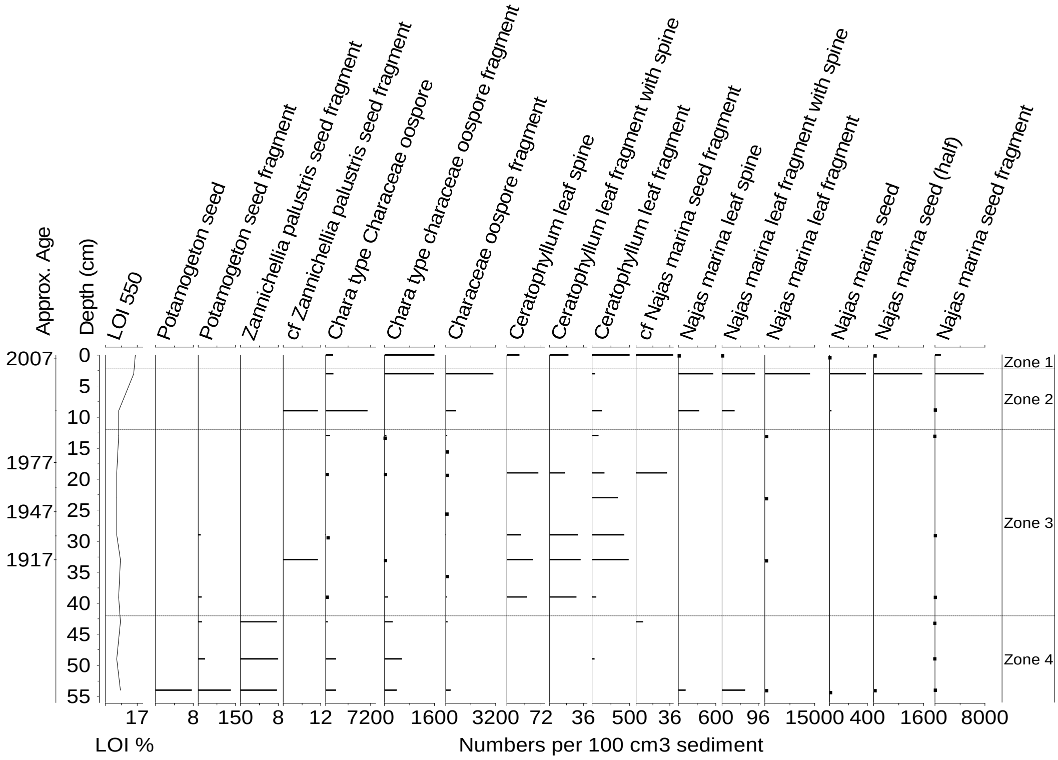

Figure 3-21 Plant macrofossils, their density distribution and percent Loss on Ignition (LOI%) results throughout of a short core taken in Lake Mogan and ^{210}Pb dating results

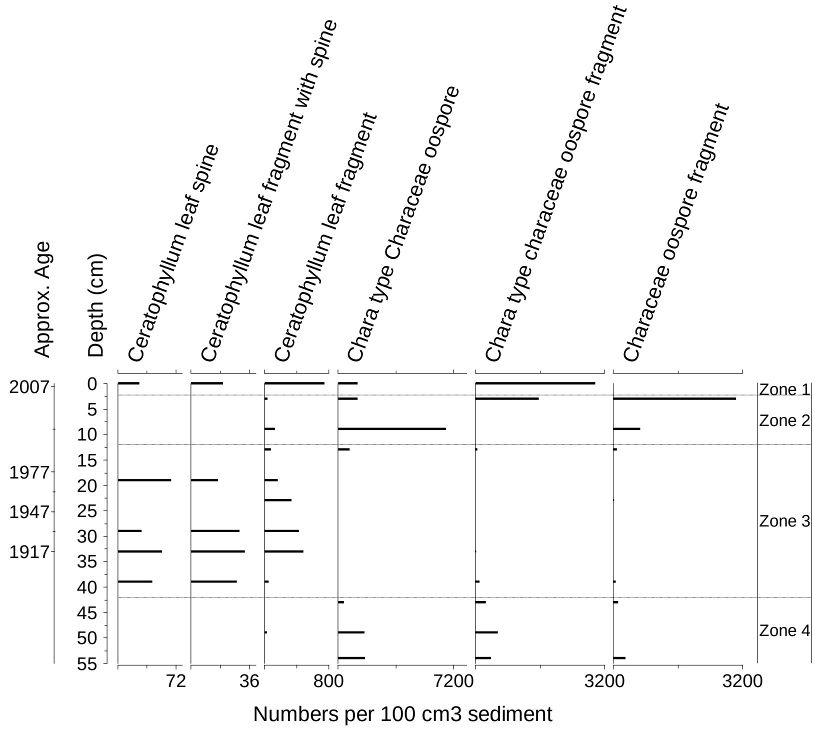

Figure 3-22 ^{210}Pb dating results and counting of Ceratophyllum and Characeae remains in the Short core of Lake Mogan (close up view)

3.4.5.6 Lake Emre

Short core macrofossil records of Lake Emre (counted in 5 cm intervals) showed that plant macrofossil diversity in Zone-2 was higher than in the first zone due to the disappearance of *Nitella* spp. and *Ranunculus* sect *Batrachium* fragments in Zone-1 (Figure 3-23). *Ceratophyllum* being the most frequent remain with up to 8000 fossil leaf fragments per 100 cm^3 at the deepest part of the core (in 34-35 cm) were the prevalent macrofossil in both zones. Also, *Nitella* oospores, *Ranunculus* sect *Batrachium* seed fragments and *Potamogeton* seed fragments were recorded in 34-35 cm (Zone-2). Towards the upper parts of this zone, a decrease in all plant remains was observed and in 14-15 cm *Ranunculus* sect *Batrachium* and *Potamogeton* remains disappeared. Moreover, solely *Ceratophyllum* remains were recorded at the deeper layer of the first zone, while with the reappearance of

Potamogeton remains, both *Ceratophyllum* and *Potamogeton* fragments were observed at the surface sediment sample.

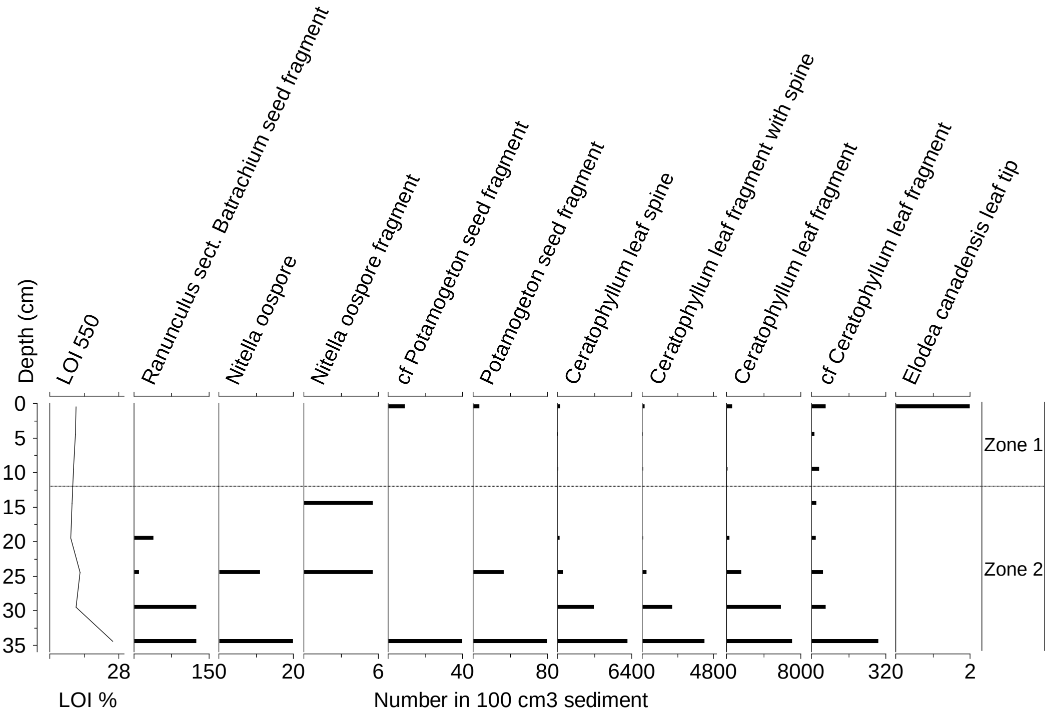

Figure 3-23 Plant macrofossils, their density distribution and percent Loss on Ignition (LOI%) results throughout of a short core taken in Lake Emre

3.4.5.7 Lake Gölcük_Ödemiş

The short core of Lake Gölcük (counted in 5 and 10 cm intervals) can be divided to three zones. In Zone 2 and Zone 3, between the years 1945 and 1990, Characeae and *Ceratophyllum* species were dominant, whereas, in Zone 1, from around 1990 to 2008, there was a decrease in the percent number of these species (Figure 3-24). In the third zone, from around 50 to 60 cm depth (corresponding to year 1950), *Najas marina* and *Ranunculus* sect. *Batrachium* seed fragments were found together with Characeae oospores and *Ceratophyllum* plant remains. However, in Zone 2 no *Najas marina* L. and *Ranunculus* sect. *Batrachium* plant remains were encountered. Moreover, in this zone there was a slight increase in the number of

Characeae oospore fragments and *Nitella* oospores, whereas a decrease were observed in *Ceratophyllum* plant remains. Towards the upper parts of the core, in Zone 1, around 25 cm depth, approximately in 1994, as *Chara*-type species appeared, *Nitella* oospore fragments disappeared. Although around 5 cm depth, together with the occurance of *Potamogeton* seed fragments, there was an increase in the number of *Chara*-type oospores with 40 oospore remains per 100 cm^3, in the surface sample neither oospore remains nor *Potamogeton* remains were found. Only a few *Ceratophyllum* plant remains were found on the surface sample.

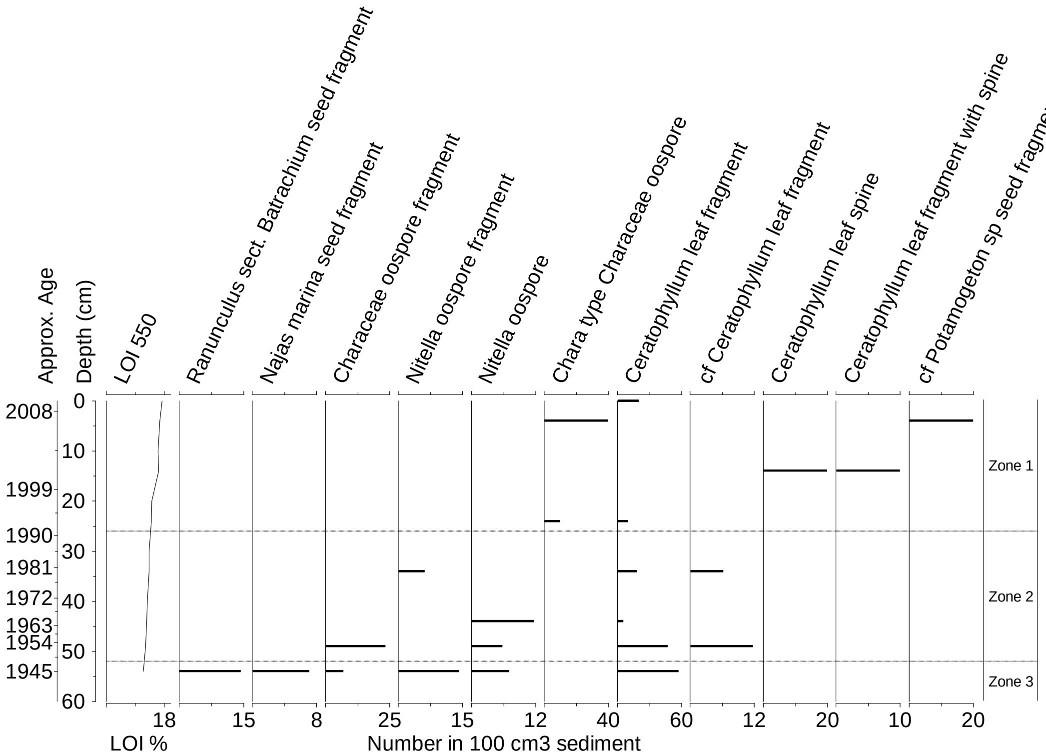

Figure 3-24 Plant macrofossils, their density distribution and percent Loss on Ignition (LOI%) results throughout of a short core taken in Lake Gölcük and ^{210}Pb dating results

3.4.5.8 Lake Gölhisar

In the short core of Lake Gölhisar (counted in 5 cm intervals), *Ceratophyllum* remains prevailed at the top (Zone 1 at around 1996 to 2008) and at the bottom (Zone 4 corresponding to years 1935-1940), while in the middle part of the core (Zone 2) *Najas marina* L. and *Zannichellia palustris* L. remains were dominant (Figure 3-25). In Zone 4 (43-50 cm) there were a few Characeae oospores together with *Nuphar lutea* (L.) SM. remains. *Ceratophyllum* was the most frequent remain with up to 114 fossil leaf fragments per 100 cm^3. In Zone 3, (around 1945 and 1970) between 25 and 43 cm, *Nuphar lutea* (L.) SM. remains disappeared, whereas Najas marina (L.) seed fragments appeared. In addition, between 45 and 35 cm, no Chara type oospores found, but at around 30 cm oospores were occured. In comparison to Zone 4 Ceratophyllum remains decreased significantly to about six fossil leaf fragments per 100 cm^3. *Najas marina* (L.) were the prevalent species in the second zone, between 12 and 25 cm. Moreover, in this zone *Zannichellia palustris* (L.) remains occured and showed a slight increase towards the top of Zone 2 (towards 1990's). The occurrence of *Zannichellia palustris* in Lake Gölhisar was confirmed with the findings of Seçmen and Leblebici (1982). On the other hand, compared to Zone 3 *Ceratophyllum* remains increased slightly in this zone. Towards the top of the core, in Zone 1 (0-12 cm) *Ceratophyllum* remains showed a substantial increase especially at around 5 cm. At the surface of the core some species remains, like *Ceratophyllum*, decreased and the other ones disappeared.

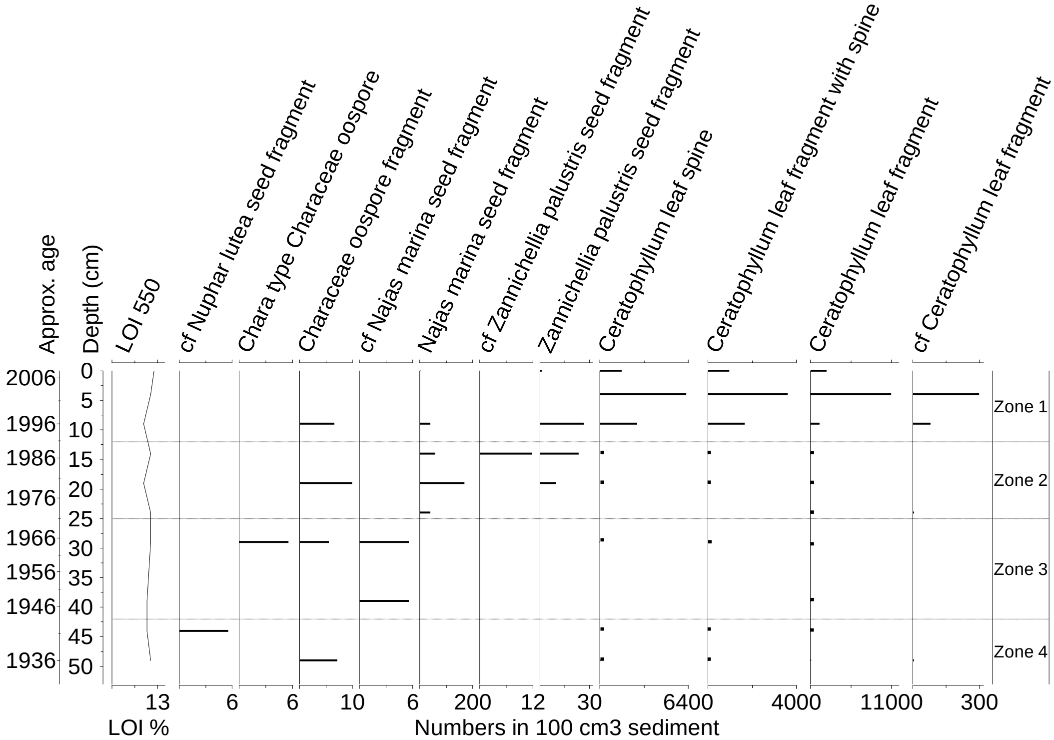

Figure 3-25 Plant macrofossils, their density distribution and percent Loss on Ignition (LOI%) results throughout of a short core taken in Lake Gölhisar and ^{210}Pb dating results

CHAPTER 4

DISCUSSION

Since macrophytes, a key primary producer of freshwaters, are sensitive to environmental changes and because they have direct and indirect effects on biological, physical and chemical processes, they play an essential role in shallow lake ecosystems (Jeppesen et al., 1998; Davidson et al., 2005; Birks, 2007; Koff and Vandel 2008). Therefore, aquatic plants are used in investigations of past environmental conditions (Koff and Vandel 2008). Most recently, plant macrofossils have also been employed in determining the structure, composition and dynamics of past macrophyte communities (Brodersen et al., 2001; Valiranta et al., 2006).

Besides plant macrofossils, as part of the TÜBİTAK ÇAYDAG 105Y332 project Cladocerans also were used as biological proxies. Sub-fossil Cladocera studies were carried out by Ayşe İdil Çakıoğlu, in Limnology Laboratory, METU. First of all, a calibration set is generated with sub-fossil Cladocera found in surface sediments of the study lakes. According to the ordination analyses, which is applied to the generated calibration set, being two of the environmental variables, Secchi/Max. Depth and Conductivity were found statistically significant. Therefore, for Lakes Mogan and Gölcük, transfer functions were constructed to infer past Secchi/Max. Depth and Conductivity changes. However, transfer functions could not be constructed for Lakes Mert, Hamam, Poyrazlar, Yeniçağa, Emre and Gölhisar.

The aims of the present study were to compare the surface sediment plant macrofossils with present day macrophyte taxa of the lakes, and to determine environmental variables potentially influencing the temporal changes in macrophyte communities, in addition, to assess vegetation community dynamics in dated short and long cores.

4.1 Comparison of modern plant coverage and surface sample plant remains

The relationship between aquatic plant remains in surface sediment and the present vegetation is influenced by macrofossil dispersal, production and loss (such as decomposition), location of sampling site and basin characteristics (Dieffenbacher-Krall, 2007; Koff and Vandell 2008). In the present study the lack of macrofossil records for some taxa and an apparent over-representation for other taxa were discussed.

Depending on the species features, macrofossils, especially vegetative parts, are usually found close to the vegetation, which is generally found in the littoral zone of the lakes (Birks, 1980b; Koff and Vandel 2008). However, in this study cores were retrieved from deepest part of the lakes that might be in the pelagic, and depending on the maximum depth, lake area and availability of light, plant remains might not be found near the coring sites and some of the plants may therefore not be represented as macrofossils. An example is the absence of *Najas marina* L. remains in lakes Yeniçağa, Küçük Akgöl and Büyük Akgöl. Another reason can be the characteristics of the seeds, such as size, buoyancy etc. Unlike small seeds (ex. *Typha*) *Najas marina* L. seeds are quite large and can not move too far from the source plant (Cappers et al., 2006; Koff and Vandel 2008).

Nympheaceae are poor seed producers (Dieffenbacher-Krall, 2007). It is therefore likely that water lily did not occur in macrofossils despite being present in Lakes Hamam and Gölcük_B. However, water lilies contain trichosclereid cells that can be found as macrofossils; thus, their absence may be due to the mid-lake coring site as they are confined to the wind-proof littorals (Nurminen, 2003; Davidson et al., 2005). In a study of two Estonian Lakes Koff and Vandell (2008) showed the importance of lake topography for the distribution of plant macrofossils. They found that the inclination of lake bottom and exposition to dominant wind direction affects post-sedimentation processes and, therefore, the distribution of plant remains. This might be another reason for the lack of remains of some plants such as Nympheaceae, *Najas marina* L. etc. Also, during the sampling process of Lake Poyrazlar it was observed that wind were quite dominant in the area. Another observation was that PVI % of Lake Poyrazlar was relatively high (40,45 %) compared to other lakes (see also Sarı et al., 2004). However, in surface sediment sample both the frequency and diversity of remains were low in comparison to present day survey. The reason of the lack of remains might be strong wind effect on the dispersal of plant macrofossils (Andersson 2001; Madsen et al. 2001; Havens et al. 2004; Lacoul and Freedman, 2006a).

Although data on the buoyancy of macrofossils other than seeds is limited, buoyancy may have a significant effect on the dispersal of the plant remains (Dieffenbacher-Krall, 2007). For example, Davis (1985) demonstrated that *Potamogeton* seeds, which have a lower settling velocity, can float and therefore potentially be well-distributed. However, because *Potamogeton* plants are perrenials they produce less seeds than annual plants, which may explain the absence of *Potamogeton* seeds and leaf macrofossils in Lakes Büyük Akgöl and Çubuk. In addition, *Potamogeton* leaves indicated the presence of source plants, which was not encountered during the present day plant survey. The absence of vegetative plant remains may be due to the rapid decomposition of the vegetative parts (Dieffenbacher-Krall, 2007). Despite decomposition of vegetative parts, especially soft leaves, is rapid, some of the taxa fragments, such as *Ceratophyllum* leaf spines, may be well preserved in the sediment (Dieffenbacher-Krall, 2007).

In contrast, some macrofossils were recorded in lakes where the plants were no longer present in the present day survey. Examples are Characeae oospores, *Ruppia maritima* L., *Potamogeton crispus* L. and *Zannichellia palustris* L. seed fragments. Dieffenbacher-Krall (2007) claimed that, as seed production, the production of Characeae oospores can significantly differ from one year to another. Even though during present day survey characeaens were not present in some of the study lakes, the macrofossil records were found, like in the case of Koff and Vandel's (2008) study. Findings by Zhao et al. (2006) in a shallow lake in Green Plantation Ponds (England) yielded to further support to this. They found that when charophytes were absent or rare characeaen oospores were present, indicating a regenerative potential, but not actual presence of the plants. *Najas marina* L. is another example of a plant detected as macro plant remains, but not in the current plant community. The absence of actual macrophytes but their presence as remains in surface sediments may also reflect the difficulties in making complete surveys of the lake flora. Especially some of the study lakes (e.g. Lakes Büyük Akgöl, Mert) were too big to have had very fine sediment survey in a day field work. Furthermore, lack of a specialist on plant systematic may have also been another reason for these findings.

Depending on the environmental conditions, such as wind and wave actions causing resuspension of the sediment, bioturbation etc., plant remains in surface samples generally reflect the plant community further back in time than just the present-day vegetation. As Dieffenbacher Krall and Halteman (2000) mentioned in their study, it is not possible to determine the exact age of the plant remains found in surface sediment.

As indicated in other studies (Zhao et al., 2006; Dieffenbacher-Krall, 2007; Koff and Vandel 2008), relationship between the present day plant community structure and surface plant macrofossils, is complicated and, concordingly, no clear pattern was found. In order to obtain more certain results, application of a multiple core approach or a detailed examination of one plant species is recommended.

4.2 RDA Results, Plants and Environmental Variables

As it is indicated in chapter 3 the results of RDA (linear model) gave better explanation about the relationship between aquatic plants and environmental variables than CCA (unimodal model) results. The reason of better explanation with linear model might be due to the significant difference between the values of environmental variables (lack of intermediate values) of the study lakes. It is also stated that the the first two axes of redundancy analysis explained 80 % of the variables in total. Salinity tolerant species *Ruppia maritima* and *Najas marina* remains found in Lakes Mert and Erikli having the highest salinity concentrations (Comin and Alonso, 1988; Khedr, 1997; Velasco et al., 2006). Although *Ceratophyllum* prefer moderate or low salinity conditions the remains of this genus were also observed in these lakes (Comin and Alonso, 1988). However, because findings of this plant were quite frequent among the study lakes, both in saline and freshwater ones, in RDA result graph it is not clustered near the environmental variable salinity supporting its moderate salinity tolerance. Although Characeans prefer freshwaters some of them are found in saline habitats (Winter and Kirst, 1990; Winter et al., 1996). The reason why Characeans located near the salinity variable in RDA analysis might be due to the species characteristics. Moreover, being positively related to alkalinity conditions Characeans were clustered near the alkalinity variable (Kufel, 2002; Wehr and Sheath, 2003). As it is observed in RDA results, *Ceratophyllum*, which is more tolerant to relatively higher total nitrogen (TN) and Chlorophyll-a (Chl-a) concentrations, was clustered near the Lake Küçük Akgöl (TN: 2096, 4 μgl^{-1} and Chl-a: 60, 72 μgl^{-1}) (Beklioğlu et al., 2003; Stephen et al., 2004). Water lilies (Nymphaceae), which can tolerate relatively higher nutrient concentrations were clustered near total nitrogen (TN) and total phosphorus (TP) variables (Stephen et al., 2004; Ayres et al., 2008)

4.3 Short and Long Cores Retrieved from Eight Lakes

The variables potentially influencing the temporal changes in macrophyte communities include changes in temperature (e.g. climate change), nutrient concentrations, alkalinity, pH, dissolved oxygen, light conditions, competition and grazing pressure etc. (see introduction) (Hannon and Gaillard, 1997; Birks et al., 2000; Heegard et al., 2001).

The plant communities of Lake Mert did not change much over the time interval covered by the core. However, towards the top of the sediment core all the plant remains showed a tendency to decrease in concentrations. The cause of this decrease can be a reduction in plant vegetation frequency or, alternatively, that sediments are less compacted in the top part of the core, implying that a top sample can represent fewer years than a sample from deeeper layers. Another reason of this decrease towards the surface of the core, can be the increase in the LOI (550) (organic carbon content), which may be an evidence of nutrient enrichment or eutrophication (Figure 3-9) (Kauppila and Valpola, 2003). Findings of *Ruppia maritima*. and *Najas marina* support the saline condition of the lake (Comin and Alonso, 1988; Khedr, 1997; Velasco et al., 2006). However, *Zannichellia palustris* and *Ceratophyllum* are normally found in lakes with moderate salinity (Comin and Alonso, 1988). Besides saline conditions, the prescence of *Zannichellia palustris*, which requires medium to high phosphorus conditions, and *Ceratophyllum*, which can be found at a wide range of TP concentrations, indicated that this lake might have been in mesotrophic-eutrophic conditions (Sayer et al., 1999; Heegard etal 2001). As it is widely known and shown in many studies; such as Romo et al. (2004) and Beklioğlu et al. (2003), Characeae species can be found at low or moderate TP concentrations. Studies from Spanish Lake Xeresa showed that Characeans started to decrease at phosphorus concentrations equivalent to 60µgl^{-1}, which is lower than the present day TP concentration recorded in Lake Mert (Table 2-1) (Romo et al., 2004). The reduction in Characeae oospores towards the surface might therefore be indicative of an increasing phosphorus concentration.

In Lake Hamam plant remains showed a significant shift of macrophyte communities, even in the short core. Characeans, which are negatively affected from factors like high amount of TP, TN and suspended solids (poor light conditions) (Blindow, 1992; Caffrey et al., 1996; Coops, 2002) were dominant in Zone 5. Therefore, this Characeae dominated state indicates clear water conditions with low nutrient concentration (Moss, 1998; Romo et al., 2004; Lacoul and

Freedman 2006). According to this interpretation, the reason of the significant peak in organic carbon content of the sediment (LOI 550) at zone 5 is unlikely a nutrient enrichment; however it might be the decrease in water depth which may favor better light conditions for Characeans (Blindow, 1992; Korhola et al., 2004). In Zone 4 the disappearence of Characeae oospores and the increase in *Nymphaea alba* seed fragments indicated *Nymphaea alba* development. Replacement of characeans with the floating leaved plant *Nymphaea alba* might have been due to increased nutrient levels or decrease in Secchi depth (Van Dijk and Van Donk, 1991; Blindow, 1992; Romo et al., 2004; Ayres et al., 2008). Furthermore, floating leaved *Nymphaea alba* prefers more quite conditions and sheltered sites being confined to the shallow littoral (Nurminen, 2003). Thus dominace of this species may also indicate shallower as well as nutrient enriched conditions (Hannon and Gaillard, 1997; Paillison and Marion, 2006) In Zone 3, from around towards 1900's; the disappearance of all the plant remains might be related to further nutrient enrichment. However, because LOI results did not show any significant changes around the same period, there is no further support to this. Zone 2 was characterized by dominance of *Trapa natans* L. plant remains. As indicated in the statistical analysis results and evidenced by Lacoul and Freedman (2006) *Trapa natans* L. can grow in lakes with low transparency. RDA analysis also revealed that the plant was encountered at low Secchi depth condition. In Zone 1 *Trapa natans* L. fragments increase towards the surface. Also, high number of *Ceratophyllum* remains in this zone suggested higher nutrient concentrations than that of at the bottom of the core, where characeans were dominant (Brodersen et al., 2001). However, as shown in Table 2-1, although the present-day TP concentration of this lake was lower than that of the threshold for characeans (60µg/l) to disappear (Romo et al., 2004), it might have been higher at the time that the shift took place. Furthermore, disappearance of Characeans and an increased frequency of occurrence of *Ceratophyllum* might also be due to increased nitrogen or Chl-a concentrations, which were positively related to *Ceratophyllum* and negatively related to Characean (Beklioglu et al., 2003).

Macrofossil records of Lake Poyrazlar showed that there was a shift from floating leaf plants, *Trapa natans* and *Nymphaea alba*, to submerged *Ceratophyllum*. The RDA results showed that *Ceratophyllum* can tolerate high TP and TN concentrations. Therefore, there might have been a change in TN/TP ratio. Moreover, since *Ceratophyllum* species can grow in deeper waters than *Trapa natans* and *Nymphaea alba*, another reason of this possible vegetation shift might be increased water depth conditions (Hannon and Gaillard, 1997; Nurminen, 2003).

The aquatic plant communities of Lake Yeniçağa in the study period, corresponding to the time between 1943 and 2007, were probably species poor. In Zone 2 (from 1943 to 1970), since RDA results showed that the plant community including species; such as *Ceratophyllum,* were positively related to chlorophyll-a (Chl-a), total nitrogen (TN) and total phosphorus (TP), and negatively related to Secchi depth the plant macrofossil data gathered from the short core suggests that at the time represented by Zone 2 (from 1943 to 1970), the lake was likely nutrient rich and turbid (Sayer et al., 1999; Lacoul and Freedman 2006). Also as a support to this suggestion an example of a floating-leaved plant that can tolerate more turbid waters, water lily (Nympheaceae), found in Zone 2 (Lacoul and Freedman 2006). However, because these are the results acquired from present day survey and surface sediment samples, precise interpretation of the past conditions it is not possible. The shift from a *Ceratophyllum* dominated state to, first, reduced *Ceratophyllum* abundance and then almost absence (Zone 2 to Zone 1) was likely due to a further increase in nutrient concentrations (Külköylüoğlu et al., 2007). According to present-day measurements this hardwater lake had a TP concentration of 266 μgl^{-1} (Table 2-1), which is well above the estimated threshold of a shift from a clear water state to turbid conditions, which is typically 90-100µg/l for Mediterranean hardwater lakes (Romo et al., 2004; 2005). In another study, Beklioğlu et al. (2003) showed that in Lake Eymir (Turkey) PVI of the lake was 2.5%, which was lower than the present-day PVI percentage of Lake Yenicaga (~19%). Also, its TP level was higher, nearly 324 μgl^{-1} (Beklioğlu et al., 2003).

In Lake Mogan, significant changes in the plant remains were observed, especially among the species of *Ceratophyllum,* Characeae and *Najas marina*. The results suggested that over the time interval covered by the core there were several periods with the dominance of one of these species. In Zone-4 macrofossil record of plant species, Characeae and *Najas marina,* which prefer relatively clearer water conditions started to decrease towards the third zone, while in zone-3, probably around 1910's to 1980's, the dominance of *Ceratophyllum* remains were observed (Bootsma et al., 1999; Hilt et al., 2006). This shift in plant remains indicates that there was a possible increase in turbidity which might have resulted from increased nutrient concentrations or water level fluctuations. However, LOI 550 did not show any significant change around this period of time (Figure 4-1). Thus, organic carbon content results did not give support to nutrient enrichment and resultant increase in productivity. Moreover, Beklioğlu et al. (2006) and Tan and Beklioğlu (2005) showed that water level fluctuations in Lake Mogan has an important role for vegetation development. Secchi/Max. Depth transfer function (Çakıroğlu unpublished data) indicates that in zone-3 (approximately between 1910's to 1990's) there was a decrease in Secchi-disc Depth and/or an increase in water level. Therefore, increase in water level might have shifted the system from vegetation dominated state to sparse vegetation cover with turbid water condition since Secchi-disc Depth also decreased (Beklioğlu et al., 2006). Towards the upper parts of the third zone, *Ceratophyllum* remains started to decrease together with increasing *Najas marina* fragments. This change suggests an increase in salinity concentration (Comin and Alonso, 1988; Khedr, 1997; Velasco et al., 2006; Wasylikowa et al., 2006). Inferred conductivity results also confirmed that around the upper parts of the third zone conductivity started to increase indicating higher salinity concentrations (Figure 4-1) (Çakıroğlu unpublished data). The observations during the monitoring programme confirmed the findings of the Characeae species in the second zone (2-12 cm). Approximately in the year 2001, at around 5-6 cm, LOI 550 showed a substantial increase, which might indicate higher nutrient concentrations and/or lower water depth (Kauppila and Valpola, 2003; Korhola et al., 2004). Also, as a support to this interpretation Özen (2006) showed that in 2001 water level of Lake Mogan was relatively low. Since Characeae species are sensitive to changes in Secchi Depth, decreasing numbers of Characeae remains towards the surface might indicate lower Secchi Depth conditions. Transfer function results (Figure 4-1) together with the results of monitoring programme of Lake Mogan (lower Secchi Disc transparency after the year 2001) supported this interpretation (Blindow, 1992; Korhola et al., 2004; Özen, 2006; Çakıroğlu unpublished data). Although in zone 1 (between the years 2003 and 2008) Characean remains were prevailed, *Ceratophyllum* fragments started to increase towards the surface and no Characeans found during the present day survey (Table 3-1). These results might indicate increasing nutrient concentrations. Furthermore, nutrient budgets constructed using data from ongoing monitoring programme of Lake Mogan also revealed a significant increase in availability of TP and DIN (Özen et al., submitted). Therefore, the change in plant remains over the entire core suggested that during the corresponding time interval the conditions of the lake alternate between turbid and clearer water conditions. It is likely that these changes might be the result of water level fluctuations and/or changing nutrient concentrations.

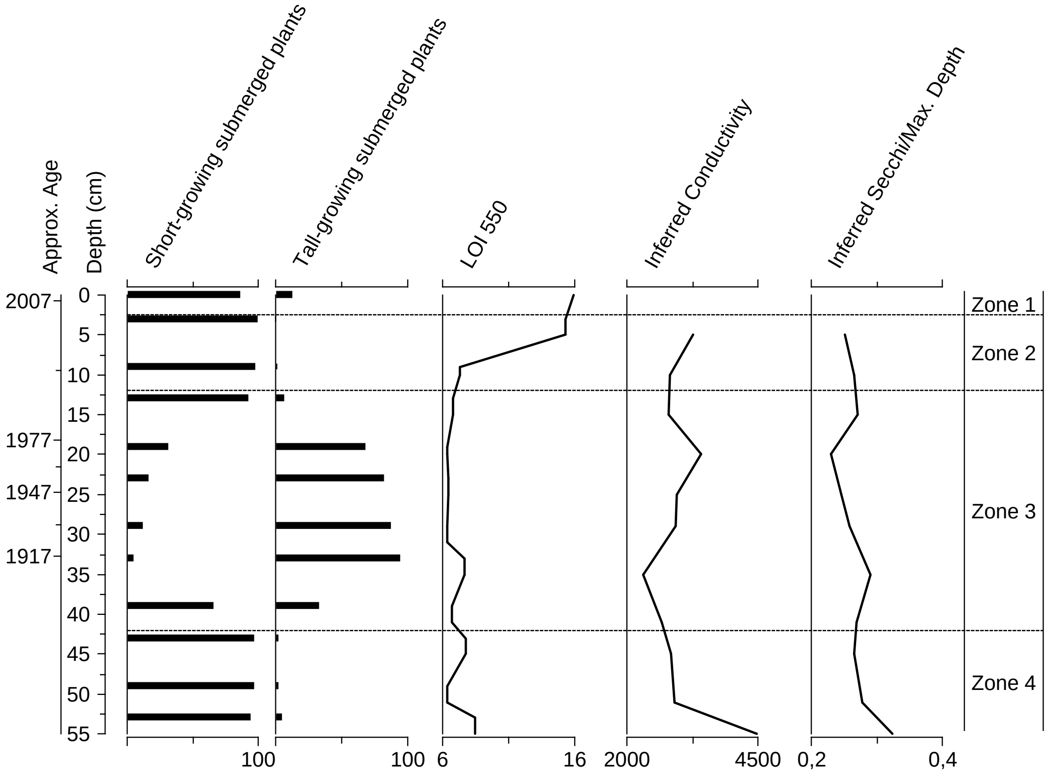

Figure 4-1 Plant macrofossil counting results of the short core of Lake Mogan. Plant remains found in this core were divided into basic sub-groups and compared with LOI 550 (organic carbon content) and transfer function results (Secchi/Max. Depth and Conductivity) (Transfer functions were constructed by Ayşe İdil Çakıroğlu)

Plant remains that are found in the short core of Lake Emre indicated that there was a possible plant community shift from a state with higher species diversity (Zone-2) to a state where *Nitella* and *Ranunculus* sect. *Batrachium* species disappeared and a significant decrease in *Ceratophyllum* was observed. Nutrient enrichment in Lake Emre may be the cause of this shift (Beklioğlu et al., 2003; Romo et al., 2004). Moreover, Birks (2000) observed that *Ranunculus* sect. *Batrachium* species decrease with the increasing turbidity conditions. Therefore, the disappearance of *Nitella* and *Ranunculus* sect. *Batrachium* was probably the result of reduced Secchi depth and/or increased suspended solid concentration. Also, the decrease in LOI 550 results (organic carbon content) suggested that another reason of the *Ranunculus* sect. *Batrachium* absence might be due to the higher water level conditions (Birks et al., 2001a).

During the time represented by the short core of Lake Gölcük, from around 1945 to present, a reduction in plant macrofossils were observed. This decrease denotes that there might be an increase in the nutrient concentrations of Lake Gölcük. *Ceratophyllum* is found at a wide range of TP concentrations and since in the second and third zones it was found with other macrophytes (*Najas marina* and Characeae), that prefer clear water conditions and which is likely to occur with low TP concentrations, the suggestion is that approximately between the years 1945 and 1980 nutrient concentrations were low or moderate (Sayer et al., 1999; Heegard etal 2001) and/or Secchi depth was relatively high (Çakıroğlu unpublished data). Towards the first zone a shift in Characean species, from Nitella remains to Chara type ones, were observed indicating a probable increase in alkalinity (Kufel, 2002; Wehr and Sheath, 2003). Moreover, increasing LOI 550 results, which indicated higher organic carbon concentration, towards the present support the interpretation of higher nutrient concentrations (Figure 4-2) (Cirik, 1993; Kauppila and Valpola, 2003). Although, this slight increase in LOI 550 results might also have indicated that there was a decrease in water depth (Korhola et al., 2004), the change in plant remains found in the entire core and Secchi/Max. Depth transfer function results did not confim decreasing water level conditions (Figures 3-24, 4-2) (Çakıroğlu unpublished data). On the contrary, transfer function results indicate decreasing Secchi Depth and/or increasing water level, which also supported by plant macrofossil records (e.g. disappearance of *Ranunculus* sect. *Batrachium* remains) (Birks et al., 2001a; Çakıroğlu unpublished data). Therefore, it is unlikely that there was a decrease in water depth towards the surface.

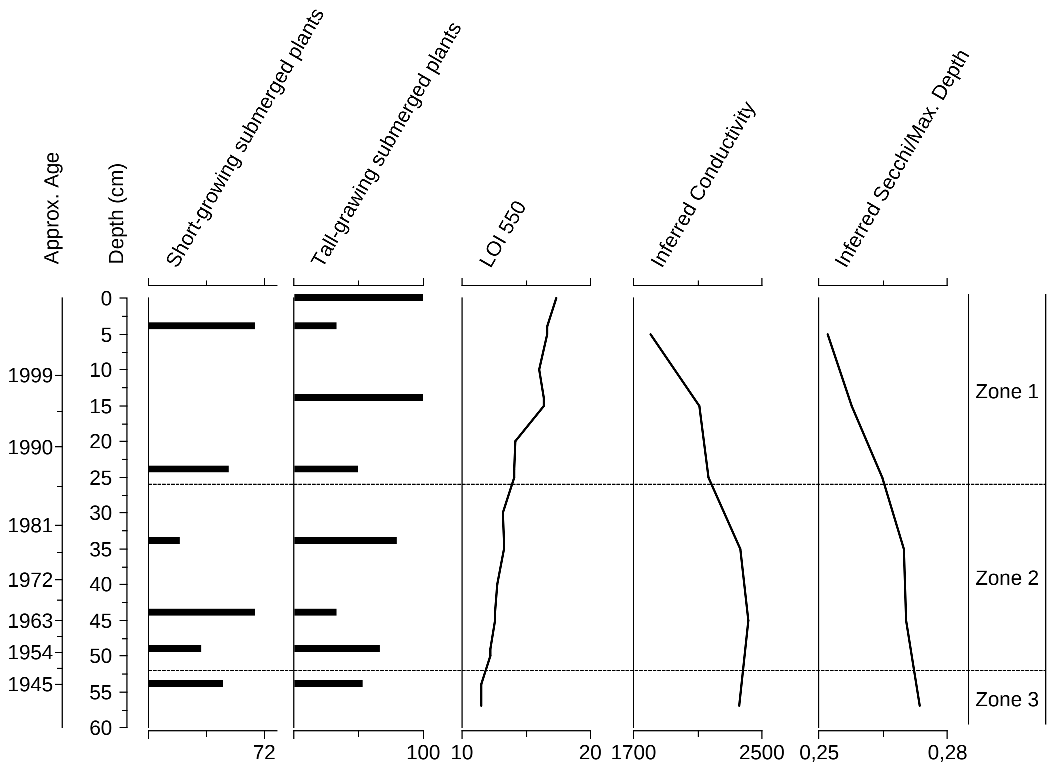

Figure 4-2 Plant macrofossil counting results of the short core of Lake Gölcük. Plant remains found in this core were divided into basic sub-groups and compared with LOI 550 (organic carbon content) and transfer function results (Secchi/Max. Depth and Conductivity) (Transfer functions were constructed by Ayşe İdil Çakıroğlu)

Macrofossil records of Lake Gölhisar might indicate that there were substantial changes over the time interval covered by the core (1936-2008). The change in plant remains between the zones three and four (reduced *Ceratophyllum* plant fragments and increased *Najas marina* remains) indicate a probable increase in the salinity concentrations, while there was a decrease in nutrient concentrations (Comin and Alonso, 1988; Khedr, 1997; Sayer et al., 1999; Heegard etal 2001; Velasco et al., 2006). Another reason of this shift can be the change in water level conditions. While *Najas marina* species are restrictred to lower water level (around 0,5-2 m), *Ceratophyllum* mostly grow at water depths more than 2 meters (Hannon and Gaillard, 1997). According to the macrofossil records in zone-2, approximately from 1970 to 1990, because dominant species were *Najas marina*, which prefers higher salinity and clearer water conditions, in both zone-2 and zone-3 there might be a slight improvement in the conditions of Lake Gölhisar (Comin and Alonso, 1988; Velasco et al., 2006). However, towards the upper parts of the core, at around 5 cm depth, the fast increase in *Ceratophyllum* plant remains indicated a possible deterioration of the conditions.

In this part of the discussion, an attempt was made to explain the possible causes of vegetation shifts in eight shallow Turkish lakes, using the RDA results obtained from surface sediment studies, LOI results, transfer functions constructed with sub-fossil Cladocerans and also using the literature on vegetation shifts.

4.4 Conclusion

- For the first time in Turkey, aquatic plant macrofossils of surface sediment samples were compared with present day macrophyte coverage

- As a result of comparison of plant macrofossil assemblages in surface sediments with present day macrophyte coverage 41% of representation were observed.

- Redundancy analysis (RDA) were carried out by using submerged and floating leaved plant remains found in surface samples with environmental parameters sampled in these lakes. The results showed that among eight environmental variables first two axes were related to alkalinity, salinity, Secchi/Max. Depth, total nitrogen (TN) and Chlorophyll-a (Chl-a), explaining 80% of variance.

- Since plant macrofossils give an indication of local vegetation diversity, information on the qualitative changes in aquatic plant cover were acquired from the results obtained in short and long core studies

- Ecological requirements of identified aquatic plants were used together with the results of loss on ignition and redundancy analysis in the interpretation of qualitative changes, enabling the discussion of the variables potentially influencing the temporal changes in macrophyte communities.

- The changes in plant remains found in the short cores of Lakes Mogan and Gölcük were compatible with the inferred Secchi/Max. Depth and conductivity changes obtained with the sub-fossil Cladocera based transfer functions.

4.5 Future Study Suggestions

In order to obtain more certain results, counting with closer intervals, application of a multiple core approach or a detailed examination of one plant species is also recommended. Moreover, by increasing the number of study lakes, plant macrofossil present-day macrophyte comparison studies can be multiplied and it may provide better understanding of the relationship between environmental variables and plant species. Since plant macrofossils which are used in multi-proxy studies are important in understanding human impacts on lake ecosystems (e.g. eutrophication), aquatic plant remains should be used in multi-proxy studies with for example, cladocerans, diatoms and chironomids.

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