SALINITY INFERENCE IN INLAND TURKISH SHALLOW LAKES BASED ON PALEOECOLOGY USING SUB-FOSSIL CLADOCERA

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

AYŞE İDİL ÇAKIROĞLU

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
DOCTOR OF PHILOSOPHY
IN
BIOLOGY

JANUARY, 2013

Approval of the thesis:

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ABSTRACT

SALINITY INFERENCE IN INLAND TURKISH SHALLOW LAKES BASED ON PALEOECOLOGY USING SUB-FOSSIL CLADOCERA

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January 2013, 109 pages

In the current study, sub-fossil Cladocera collected from the surface sediment of 44 shallow lakes spanning over five latitudes from north to south of Turkey using snap-shot methodology revealed strong impact of salinity on cladoceran community structure. To see the whole picture, sediment cores collected from six of the lakes and long-term monitoring data from two of the lakes were also investigated.

Contemporary cladocerans and sub-fossil assemblages were compared to reveal that their responses to salinity changes were highly similar. This lead us to use sub-fossil cladocerans and salinity data from water column together while generating the calibration data set using ordination techniques. Salinity transfer function models were developed utilising weighted averaging techniques. The developed salinity transfer function was applied to cladocera assemblages from dated sediment cores. Hindcasting of the salinity inference model was performed using monitoring data and the reconstructed salinities from two central Anatolian lakes and reflected good linear correlation with the known lake salinity history.

This thesis has confirmed that sub-fossil Cladocera is a valuable indicator of historical salinity change and marker for the monitoring of lakes. For the first time, the lake environmental variables and sub-fossil cladoceran species composition from the surface sediments of Turkish shallow lakes were studied and a salinity transfer function was developed to elucidate past salinity change. The approach of the current study has been proven to be reliable while interpreting past salinity conditions. Since monitoring programmes are scarce in Turkey, paleolimnological analyses would be beneficial especially when defining effective restoration strategies.

Keywords: Paleolimnology, Calibration set, Transfer function, Surface sediment, Sediment core.

ÖZ

TÜRKİYE İÇ SIĞ GÖLLERİNDE PALEOEKOLOJİ TEMEL ALINARAK ALT-FOSİL CLADOSER KULLANILARAK TUZLULUK TAHMİNİ

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Bu tezde Türkiye'nin beş farklı enleminden kuzeyden güneye 44 sığ gölden alt fosil Cladocera örnekleri "zaman yerine mekan" yöntemiyle toplanmıştır. Tuzluluğun Cladocera kommünitesi üzerinde güçlü bir etkiye sahip olduğu bulunmuştur. Bu sonuç paleolimnolojik çalışmalarda uygulanabilirliği altı gölden alınan kısa karotlar ve iki göldeki uzun dönemli izleme verileri kullanılarak karşılaştırılmıştır.

Güncel Cladocera ile çökelden elde edilen alt fosil Cladocera karşılaştırıldında tuzluluğun her iki grupta da aynı etkiye sahip olduğu ortaya çıkmıştır. Bu sonuç, alt fosil Cladocera ile güncel tuzluluk verilerinin bir arada kullanılarak ordinasyon yöntemleriyle bir kalibrasyon kümesi oluşturulabileceğini göstermiştir. Ağırlıklı ortalama yöntemi kullanılarak tuzluluk için transfer fonksiyonu hazırlanarakaltı gölden alınan kısa karotlardaki alt fosil Cladocera ile geçmiş tuzluluk tahmini yapılmıştır.

Geçmişe yönelik tuzluluk çıkarım modelinin doğruluğunun ıspatı için iki İç Anadolu gölünden elde edilen uzun dönemli izleme veri seti kullanıldı. Buna göre, her iki gölde de tahmin edilen geçmişten günümüze değişen tuzluluk ile uzun dönemli veriden elde edilen tuzluluk arasında anlamlı bir ilişki olduğu bulunmuştur.

Bu tez alt fosil Cladocera'nın geçmiş tuzluluk değişiminin belirlenmesinde ve uzun dönemli izlemeler için önemli bir değişken olduğunu ortaya koymuştur. Türkiye'de ilk defa göl yüzey çökelinden elde edilen alt fosil Cladocera kullanılarak geçmiş tuzluluk değişiminin ortaya konulabileceği güvenilirliği ıspatlanmış bir transfer fonksiyonu hazırlanmıştır. Türkiyede uzun dönemli izleme çalışmalarının yeterli olmamasından dolayı paleolimnolojik yöntemler özellikle restorasyon çalışmalarında kullanılabilecek önemli bir araçtır.

Anahtar Kelimeler: Paleolimnoloji, Kalibrasyon seti, Transfer fonksiyonu, Yüzey çökeli, Karot.

ACKNOWLEDGEMENTS

I extend my sincere graditude and appreciation to many people who made this PhD thesis possible.

I would like to thank my supervisors, Prof. Dr. Meryem Beklioğlu Yerli and Prof. Dr. Erik Jeppesen for providing me the opportunity to be a part of their precious projects. I also would like to thank them for their encouragement, constructive critism and editorial remarks during the development of this thesis.

I want to thank Dr. Thomas A. Davidson for his guidance and help in improving the Chapters 2 and 3. I also want to express my gratitude to Dr. Susanne Lildal Amsinck and Mrs. Liselotte Sander Johansson for helping me during the identification of sub-fossil Cladocera. I also acknowledge Dr. Lisa Doner for sharing her field experiences with me.

I want to express my gratitude to my dear lab mates, Korhan Özkan, Dr. Arda Özen, Dr. S. Banu Akkaş, Tuba Bucak, Şeyda Erdoğan, Gizem Bezirci, Nur Filiz, Dr. Damla Beton, Ece Saraoğlu and Jan Coppens for their help in the field work and laboratory analyses as well as their friendship. Eti E. Levi, thank you for your scrutinize perspective of the endless statistical analyses and be my "paleo partner". Very special thank goes to "my body" Dr. Ü. Nihan Tavşanoğlu for being the other half in every single moment of this thesis work. I also want to express my gratitude to Dr. S. Banu Akkaş for her precious friendship and for being my late night study and chat partner.

I wish to express my appreciation to my dear friends, Öznur, Nazlım, Aslı, Seçkin, İştar, Zeynep and Havva for their valuable support throughout this thesis.

I would like to extend my hearthfelt appreciation for my mother Gülseren and my sister Şirincan for their endless support and their patience during this journey.

This work was supported by the Environmental, Atmospheric, Earth and Marine Sciences Research Group (ÇAYDAG-105Y332 and ÇAYDAG-110Y125) of the Scientific and Technical Research Council of Turkey (TÜBİTAK), METU-BAP (BAP-07-02-2010-00-01) and EU-FP-7 REFRESH (No: 244121).

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ABBREVIATIONS

CA: Correspondance Analysis
CCA: Canonical Correspondance Analysis
CPUE: Catch Per Unit Efford
DCA: Detrenden Canonical Analyses
EU: Europenian Union
METU: Middle East Technical University
PVI: Plant Volume Inhabited
RDA: Redundancy Analysis
PLS: Partial Least Squares
RMSE: Root Mean Square Error
RMSEP: Root Mean Square Error Prediction
SD: Standart Deviatation
TÜBİTAK: Türkiye Bilimsel ve Teknolojik Araştırma Kurumu
WA: Weighted Averaging
WA-PLS: Weighted Averaging Partial Least Squares

CHAPTER 1

INTRODUCTION

Paleolimnology is the interpretation of past limnology from changes that occurred in the ecosystem of the lake, and their probable causes. It is interested in knowing how the lake functioned how it produced organic matter and processed it or organic matter produced elsewhere; how the ecosystem of the lake responded to external changes in climate, hydrology, fires, floods, volcanism, tectonic events, etc.; how the functioning of the lake became more sophisticated over time as the different groups of organisms evolved and differentiated (Frey, 1988). Paleolimnology is a captivating field of study, in part because so much can be interpreted from the so little that is preserved (Frey, 1988). Early paleolimnological studies, started about 1920, were descriptive; although, remarkable advancements have been made over the following decades and still expanding (Birks, 1998).

Palaeolimnological studies can present long time series data for assessing past values and natural diversity from annual, decadal to millennia. Chemical, physical, and biological parameters of lake sediment can supply a substantial amount of information on past lake ecosystems (Birks and Birks, 1980; Smol, 1990; Smol et xal., 1991, 1994). The lake sediments' physical structure provide data on the currents and abiotic factors other than currents. The sediment chemistry provides information of the sources of sediment, past climate changes, and past lake conditions (Frey, 1964). The biological remains such as, algal, plant or animal can be derived from the sediment, and their quantitative analyses elucidate the biota and biological community change through time. Thus, valuable new knowledge of the whole limnological relationships can be obtained, and paleolimnology has the potential to solve limnological and environmental questions and to test hypotheses considering the affect of climate changes in lake ecosystems (Birks, 1998).

Paleolimnology from the zoological point of view began as an offshoot of palynology and investigations of lake sediments by geographers. The classic works of von Post (1862) and Lundquist (1924, 1927) on lake sediment types and sediment succession sowed the seed of a new era in limnology. Messiatsev (1924) was perhaps the first to engage in any extensive work on the identification of animal remains in lake sediments, but this was only qualitative in nature. Later, Gams (1927) first used animal remains as typological indicators in lake sediment succession. Also in 1927, Rossolimo published his atlas of animal remains in sediments, which contains much valuable information concerning several lakes near Moscow and includes sketches of the species found. Since then various articles have been published on almost all freshwater groups that leave remains in lake sediments. A summary of the animal remains in lake sediments has been given by Frey (1964).

Previous work on sub-fossil Cladocera started in 1942 with the investigation of Cladocera in addition to other groups in Linsley Pond, Connecticut in North America by Deevey. Many of the European Cladocera have been described as microfossils by Frey (1958, 1959, 1962a, 1962b), these works being of major importance in the identification of remains from lake sediments. The taxonomic guidelines that were set by these pioneer studies are still valid and for many species still present the best drawings of the remains. Frey (1958, 1961, 1962a) interpreted past population density changes and climatic conditions during the Late-glacial and Aemian Interglacial. Also, Frey (1962a) presented evidence that the ecology of the Chydoridae family had been unchanged at least for the last 100000 years. This study demonstrated that the close correlation between the fossil and living assemblages of chydorids.

During the 1960-1980s the use of cladoceran remains in paleolimnological research increased rapidly. De Costa (1964) investigated the latitudinal distribution of Cladoceran remains in the Mississippi Valley by analysing the surface sediments of lakes and calculating the abundance and percentage composition of the subfossil Cladocera. He concluded that the most abundant species may be placed in groups with northern, southern, or eurytopic affinities. With such data it was possible to infer paleotemperatures from past cladoceran distributions (Harmsworth, 1968). Megard (1967) used cosmopolitan, northern and southern species to interpret climate changes from 22500 years to present in Lake Zeribar, Iran.

Till 1970 very little effort had been made to examine the regional relations between Cladoceran species and lake types and also no attempts had been made to apply results of a regional study to paleolimnological interpretations of lake sediments from the same region. The study of Whiteside (1970) explored some of the ecological relationships found between cladoceran species and lake types in order to interpret sediment cores from two Danish lakes. First Whiteside (1970) dealed with cladocera populations from surface sediment of 80 Danish lakes to infer lake trophic states such as highly oligotrophic or ultra-eutrophic then he choosed two lake with different ontogeny in order to apply the results from surface sediment studies. This study was followed by Frey (1976), Bradbury (1981), Hofmann (1983), Binford (1986), Hofmann (1986), Hofmann (1987), U-Simola and Tolonen (1987), Simola et al. (1989), and Hofmann (1989) with the analyses of Late-Quaternary environmental histories of lakes from Canada, Venezuela, Finland and Germany.

These studies linked cladocerans to environmental variables such as temperature (climate), pH (acidification), and nutrients (eutrophication), initializing the use of cladocerans as indicators of the past. Instead of the ecological indicator value of individual cladoceran species, interpretations should be based on the overall structure and composition of the community assemblage. The development of transfer functions in the 1990s resolved this problem (Rautio, 2007). Transfer functions quantitatively reconstruct past environmental conditions in lakes. They are generated from a set of surface sediment samples (0–1cm depth) usually collected from more than 20 lakes representing a large gradient of environmental conditions. Statistical correlations of the sub-fossil remains to environmental parameters that quantitatively identify the community response to changes in a certain environmental variable are obtained using multivariate analysis techniques. From the study of Binford (1986), during the last two decades, transfer function approach has developed. Binford (1986) took to first step for calibrating lakewater pH with chydorid species using multiple regression models. Since then past changes in physical conditions (e.g. temperature: Lotter et al., 1997), chemical conditions (e.g. total phosphorus: Brodersen et al., 1998; salinity: Bos et al., 1999) and biological parameters (e.g. planktivorous fish abundance: Jeppesen et al., 1996) have being determined.

Before Jeppesen et al (1996) no one has employed the surface sediment calibration technique to reconstruct lake trophic structure. Fish have been shown to have a key top-down effect on food webs structure and lake water quality, and thus affect zooplankton communities in many ways (Jeppesen et al., 2001a). Thus, it is possible not only to reconstruct past fish abundance changes but also fish community composition changes. Jeppesen et al. (1996) used a weighted-averaging transfer function to relate the relative proportion of five pelagic zooplankton taxa preserved in surface sediments to present day planktivorous fish abundance (expressed as mean catch per unit effort (CPUE) in multiple mesh size gill nets) in shallow freshwater Danish lakes. This inference model has now been used to reconstruct the changes in planktivorous fish abundance in lake Skanderborg, Denmark, for last two centuries (Jeppesen et al., 2001b). After Jeppesen et al. (1996), reconstruction of past lake trophic structure calibration set researches continued with the studies of Amsinck et al. (2003, 2005a) in brackish lakes; Jeppesen et al (2003) in 135 lakes covering a latitude gradient from Greenland in the north to New Zealand in the south and Davidson et al (2007) in 39 shallow lakes in U.K. and Denmark. Established transfer functions from these studies were used to infer past trophic structure in the studies of Amsinck et al. (2005b) in brackish lakes and Johansson et al. (2005) in Dallund Lake, Denmark.

Many cladocerans show a unimodal response over a gradient of salinity because they have poor ability to osmoregulate (Frey, 1993). A preliminary study of the zooplankton from lakes in British Columbia agree with Frey’s (1993) conclusion that zooplankton species composition varies greatly with salinity, as well as with brine composition (Bos et al., 1996). The study of Bos et al. (1999) recovered cladoceran and anostracan remains from the surficial sediments of 33 lakes in the Interior Plateau of British Columbia. They used cladoceran and anostracan remains to develop paleoecological inference models of invertebrate response to lakewater salinity and depth. This study provided information on the optima and tolerance of individual cladoceran species to lake water salinity and showed the potential that these organisms have for paleoenvironmental and paleoclimatic research.

Lotter et al. (2007) studied diatom, chrysophyte cyst, benthic Cladocera, planktonic Cladocera, and Chironomid communities from the surface sediments of 68 lakes along an altitudinal gradient from 300 to 2350 m in Switzerland. Moreover, environmental variables such as geography, physical water parameters, catchment characteristics, water chemistry, and climate were measured. This study aimed to measure the power of using many aquatic organisms, such as Cladocera, diatoms, chrysophytes, and Chironomids, in quantitative reconstructions between Late-Glacial and Holocene times in Central Europe. They presented surface sedimentary cladoceran assemblages creating the first modern quantitative cladoceran calibration set and as a result they showed that Cladocerans have potential to be used as quantitative indicators.

Brodersen et al. (1998) have re-done the study of Whiteside (1970). Assuming total phosphorus (TP) to be a good indicator of trophic state in Danish lakes, they used the indirect cladoceran response to increased nutrient richness as a proxy by inferring TP from subfossil assemblages. They provided the opportunity to re-evaluate the lake trophic state after 27 years with a complete replication of methods and subfossil identification done by the same person. Modern ordination techniques such as, non-metric multidimensional scaling made it possible to describe the degree of changes in species compositions between 1965 and 1992. Canonical Correspondance Analysis (CCA) found a strong relationship between the 1992 species data and lake TP concentrations which allowed them to reconstruct a model to infer TP by weighted average (WA) regression and calibration techniques. The WA model was used to infer TP levels for the 1965 data set, and the results suggested that several “clear-water” lakes have declined, and a few have increased in water quality since 1965. This study had confirmed that sub-fossil cladocerans were used as a valuable tool for trophic state constructions and were markers for the “long-term” monitoring of lakes. They showed that the application of surface-sediment assemblages in monitoring filled the gap in the time frame between traditional monitoring and palaeoecological core studies, i.e., years and decades. These comparative analyses are rare (e.g. Jankowski and Straile, 2003; Davidson et al., 2005; Bunting et al., 2007; Manca et al., 2007) but necessary since as they allow tests of the reliability of using sediment records as indicators of past human impacts and climate changes (Battarbee et al., 2005).

In Canada, Bos et al. (1999) studied cladoceran and anostracan remains recovered from the surficial sediments of 33 lakes to develop paleoecological inference models of invertebrate response to lake-water salinity and depth. Their models for inferring lake depth had shown that the ratio of planktonic/littoral microcrustaceans was a reasonable proxy for depth, and certainly useful if other measures were not available. Moreover, weighted-averaging models of salinity and depth showed greater predictive abilities and were more easily interpretable. In addition, Sarmaja-Korjonen and Alhonen (1999), and Sarmaja-Korjonen (2001) discussed Holocene fluctuations of lake levels indicated by the ratio of planktonic/littoral Cladocera. Quantitative lake-level and sub-fossil Cladoceran research has been done by Sweetman and Smol (2006) in 51 freshwater sites in Alaska, USA and by Amsinck et al. (2006) in 29 Faroese islands’ lakes. Transfer function approach for lake-level constructions first started by Korhola et al. (2000) in 53 lakes in Finnish Lapland. Korhola et al. (2000) developed modern cladocera – lake depth transfer model and applied it to subfossil cladocerans analysed from three small and shallow (<6 m) kettle-hole lakes in north-western Finnish Lapland to provide estimates of the amplitudes of long-term lake-level changes in the region.

From the beginning of the 2000’s multiproxy paleolimnological studies gained the importance. Mutiproxy studies use more than one of biological parameters with physical and chemical variables. The Krakenes Project (Birks et al., 2000) was an example of how a variety of proxies could be used together to reconstruct the lake ecosystem, including the catchment, and climate changes over the late-glacial and early Holocene. Other than Cladocera, Chironomids, diatoms, pollens, plant macrofossils, Oribatid mites, and Trichoptera had all been extracted from the same master sediment core and studied as a proxy to reconstruct paleoenvironment. This multidisciplinary study, with proxies for changes in the lake and in the catchment, highlighted the dependence of lake biota and processes not only on regional climatic changes but also on changes in the lake catchment and on internal processes within the lake. In the same project, cladoceran microfossil remains were analysed from a sediment core taken from a lake basin at Krakenes, western Norway (Duigan and Birks, 2000). The sequence included immediate post-glacial conditions (ca. 12,300 14C BP), the Allerød, Younger Dryas, and early Holocene to approximately 8,500 14C BP. The interpretation of changes in the cladoceran assemblages was based on the known ecology of the taxa, the documented environmental history of the study sequence, the variations in the organic content of the sediment, the radiocarbon dates, and the results of analyses of other biotic groups, including diatoms, macrophytes, and chironomids. In addition, a quantitative reconstruction of changes in air temperature was presented for the study period based on transfer functions developed from a separate Swiss surface-sediment cladoceran data set. They indicated that cladocera could provide reliable data for quantitative climate-change studies if more extensive and more relevant calibration data-sets were obtained. Similar studies were conducted by Hofmann, (2000, 2001), Lotter et al. (2000) in Switzerland; Batterbee et al.

(2002) in seven European lakes; Catalan et al. (2002) in Spain; Koinig et al. (2002) in Austria; Kultti et al. (2003) in Eastern Russia.

Multiproxy paleolimnological studies continued with the EU funded project Mountain Lake Research (MOLAR) (http://www.mountain-lakes.org/molar/). In this project several new independent proxy sources, such as chrysophycean cysts, chironomids, cladocerans, plant pigments, and various sediment quality indices along with a more detailed diatom analysis are used to examine the environmental history of the lakes and the extent of the ecosystem change since the pre-industrial period (Lotter et al., 2002; Brancelj et al., 2002; Korhola et al., 2002). Other than the MOLAR project Hakala et al., 2004 studied a sediment core from Lake Vaha -Pitkusta, Finland using multi-proxy biostratigraphical methods (pollen, diatoms, Cladocera), grain size and loss-on-ignition analyse and radiocarbon dating. In addition, Bigler et al. (2006) analysed surface sediments from 30 mountain lakes in south-eastern Switzerland (Engadine, Grisons) for subfossil diatom, chironomid, and cladoceran assemblages. Ordination techniques were used to identify relevant physical and chemical environmental parameters that best explain the distribution of these biota in the studied lakes.

Past two decades, either single variable or multi-proxy paleolimnological researches have been occupied with developing transfer functions to reconstruct a single environmental variable. Today, paleolimnology plays a pivotal role in paleoclimatic and global change investigations, in many fields of environmental science, and hydrocarbon and mineral resource exploration and exploitation (Last and Smol, 2001). Lake sediments are valuable archives of environmental changes, because lakes are geographically widespread and their sediments are often continuous and datable (Wolfe et al., 2004; Brinner, 2006). Gaining insight into the development of lakes, their past conditions and future trends are important to assess the adaptation of environments to global processes such as global warming (Punning et al., 2003).

Paleolimnological methodology include several samplings and analyses. First retrieving the sediment core. Second, sectioning the core, either at the field or in a laboratory, into subsections for a variety of analyses including dating, chemical, and biological analyses.

1.1. Coring

The first and the important step is the collection of the sediment core. It needs great care since this step is the base of the paleolimnological studies. An undisturbed core collection is very important because sediment core represents the depositional environment. There are three kind of sediment corers, gravity corer, freeze corer, and piston corer (Glew et al., 2001).

Gravity corers, use the gravity force to penetrate into the sediments. The corer is slowly soped in to the water column, and the weight of the corer push the tube into the sediment. “Care must be taken not to overshoot and completely bury the corer and core tube in the sediment, as the sediment–water interface represents the present-day conditions and is an important reference point for the core” (Douglas, 2007). When the corer settled into the sediment, a messenger is sent down the core line to trigger the plunger. The plunger closes the top of the core tube thus, the corer and the sediment in the core tube can be pulled up to the lake surface (Figure 1.1). Before removing the corer to the surface of the water, a bung must be inserted at the base of the core tube to plug it. As a result, an undamaged sediment–water interface and the sediment below can be collected. Gravity cores are mostly used for studies focusing on the recent (~150 years) past (Smol, 2008).

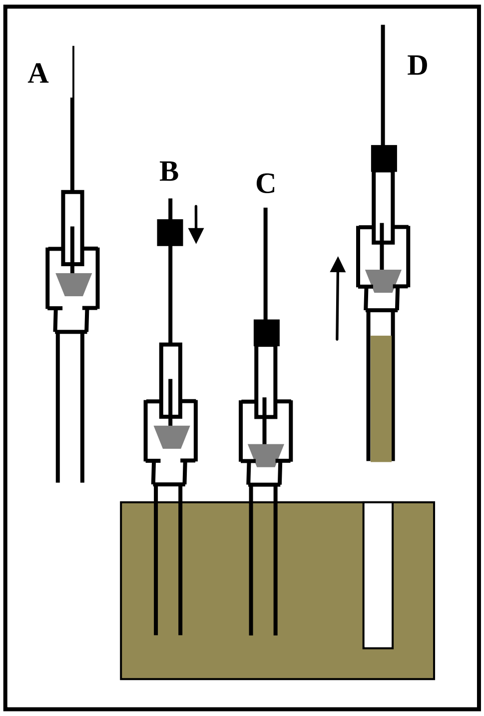

Figure 1.1. (A) A gravity corer with openning is lowering down through the water column into the lake sediment. (B). A weighted messenger is dropped down the coring line in order to seal the top of the core (B and C). (D) The sealed gravity core holds the lake sediment within the sampling tube by creating a suction until the core is retrieved to the lake surface (modified from Douglas, 2007).

Freeze coring is specialized and more complicated than gravity coring. In this case, sediment is brought to the surface after having been frozen *in situ* (Douglas, 2007). The corer consists of a box that has been sealed at one end. This end is either wedge shaped or conical and has been weighted, often with lead. The corer is then filled with dry ice and ethanol and lowered gently into the sediment where it remains for roughly five to seven minutes, while the sediment freezes on the outside of the corer (Figure 1.2). Upon retrieval on the surface, the corer and frozen sediment are separated and the frozen sediment is transported and stored in a freezer, prior to analyses. This kind of coring does not recover large amounts of sediment, but it is especially useful in lakes where the sediment is very loosely consolidated yet finely structured. Depending on the nature of the sediment and length of the coring apparatus, it is possible to retrieve sediment cores up to 2 m or more in length (Smol, 2008). A major advantage of this corer is that the sediment profile is frozen *in situ* so the integrity of the stratigraphy is retained (Smol, 2008).

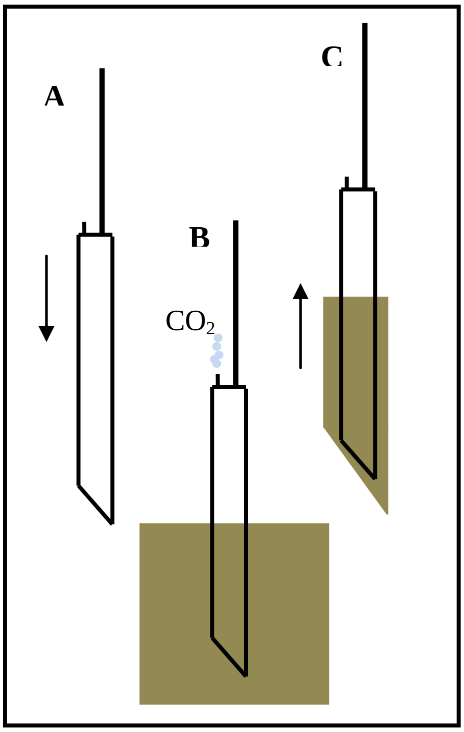

Figure 1.2. Lowering down to a freeze corer into the sediment (A–B). Removing the frozen sediment (C) (modified from Douglas, 2007).

Piston corer is choosen to collect longer sediment cores. The coring equipment includes a tube, connecting to the handle at the top with rods. A piston is inside the tube, and the piston is connected to the top by a wire cable. While holding the piston positioned at the bottom of the core tube, the corer is pushed into the sediment with the help of the rods, until the whole sediment sequence collected. Then the piston is fixed by grasping its wired cable in place. Afterwards, the corer is pushed one meter down. As a result the core tube filled with sediment stratigraphy and the tube is brought up to the surface by pulling the rods one by one (Figure 1.3). In order to reach the deeper interval, another core tube is used and the whole procedure is repeated. According to Douglas (2007) "generally, a researcher will work downwards through the lake sediment, sequentially recovering one meter of core at a time until an impenetrable layer is met. In order to ensure that a continuous sediment sequence is obtained, and no depths remain unsampled, the researcher must overlap the core intervals so that there are a few centimetres of overlap between the bottom of one core section and the top of the next lower interval. Because of problems with rigidity and strength of the rods, casing is often used to guide and constrain them and the attached corer back to the same core hole".

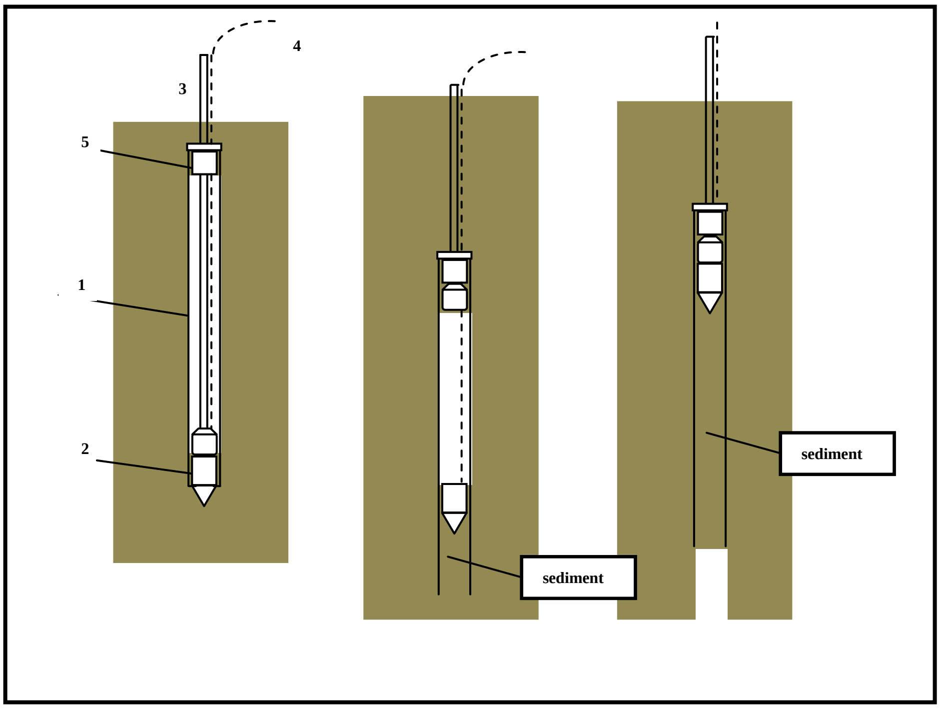

Figure 1.3. The general operation of Livinstone-type piston corer, showing the lowering (A), sampling (B), and withdrawal (C) of a sediment core sample. The operator uses the push rodes to push the corer into the sediment to the known depth. A cable, keeps the piston in place. 1, Core tube, 2. Piston, 3. Push rods, 4. Piston cable, 5. Locking drive head. Modified from Glew et al., 2001.

Several modifications have been proposed for the original corer designs in order to address some of coring problems (Smol, 2008). Most of the changes aim to increase the operating capacity of the corer (Glew et al., 2001). For instance, a corer designed for shallow lake sampling can be modified to use in deep lakes with an automated closing mechanisms.

The addition of some weight on top of the corer to increase penetration of the tube is one of the most common modifications for gravity and piston corers (Glew et al., 2001). In this type of coring, the corer is lowered into the sediment where it penetrates by its own weight. At this point the driving weight can be lifted from the top of the corer and then released to drive the core tube into the sediment (Glew et al., 2001). Moreover, in deep water or in situations where control of the coring device may be difficult, one method of providing the device with artificial stabilization is to use a parachute at the lower end of the recovery line (Cushing et al., 1997). This provides the descending sampling device with a controlled rate of fall through the water column and a degree of vertical stability as it enters the sediment. Another example can be chamber-type samplers (e.g. Russian peat corers). These types of corers were developed as an alternative to vertically driven corers. In these corers, the sample is cut and enclosed in a rotating chamber of half-cylindrical form (Glew et al., 2001). Vibra corers, which use a vibrating device to impart high-frequency, low amplitude standing waves along the length of a coring tube, are especially useful in collecting sediment sequences in metrial that may be difficult to penetrate using standard push rods, such as profiles containing sand (Smol, 2008).

1. 2. Sub-sectioning

After collecting the core, sediment is removed from the tube and sub-sectioned into intervals thus the sediment can be used for different succeeding analyses. There is little chance of transporting the core to the laboratory without some significant disturbance since high water content cores are recovered (Glew et al., 2001). For this reason, these cores can be sub-sectioned in the field as soon as after retrieval of the core. “The decision is based upon the nature of the sediment, the kind of core, as well as the location of the coring site” (Douglas, 2007). Frozen cores are transported in one piece to a freezer and to the laboratory, until further analyses. Gravity cores can be sub-sectioned at the field, especially if the sediment condition is wobbly and unconsolidated and if there is a probability of the sediments getting mixed during the transportation to the laboratory. Piston cores are usually trasferred to the laboratory in 1 m segments where they are divide lengthwise. One half is kept for the archives and the other half is sub-sectioned for analyses (Douglas, 2007). Sub-sectioning processes for long cores in the field is considered important, because it provides an important confirmation of the performance of the corer and a chance for look at the core for some initial logging (Glew et al., 2001).

1.3. Core Chronology

The age–depth relationship can be used in palelimnological reconstructions when a sediment core represents an unmixed stratigraphic column of sediments. The Law of Superposition, pointed out the younger sediments will overlie older sediments. This law is the foundation of age dating. In most cases, an absolute chronology is advantageous because specific dates can be connected to past events (Douglas, 2007). In paleolimnology there is a number of dating techniques to help determine depth with respect to time. Each dating technique is suitable for a definite age range and sediment type. The most commonly used dating techniques measure the decay of naturally occurring radioisotopes (Douglas, 2007). For dating recent sediments (past 150 years), ^{210}Pb and ^{137}Cs radioactive isotopes are commonly used (Appleby, 2001). With a half life of 22.3 years, ^{210}Pb is ideal for establishing depth-time scales over the past century (Smol, 2008). The total ^{210}Pb activity in sediments has two components: supported ^{210}Pb, which is derived from the *in situ* decay of the parent radionuclide ^{226}Ra; and unsupported ^{210}Pb, which is derived from the atmospheric flux (Appleby, 2001). The methodology based on the assumptions that (i) the rate of deposition of unsupported ^{210}Pb from the atmosphere has been and is constant; (ii) the ^{210}Pb in water is quickly absorbed by suspended particulate matter so that unsupported ^{210}Pb activity in sediments is essentially due to atmospheric fallout; (iii) post depositional processes are not redistributing ^{210}Pb activity in the sediments and (iv) ^{210}Pb decays exponentially with time, in accordance with the law of radioactive decay (Krisnaswami et al., 1971). In practice things are little more complicated: the supply of unsupported ^{210}Pb to the lake may include a small but significant fraction of ^{210}Pb deposited on the catchment and then transported to the lake (Smol, 2008). However, two simple models used to calculate sediment dates – the constant rate of ^{210}Pb supply (CRS) and the constant initial concentration (CIC) of ^{210}Pb (Appleby, 2001). The CRS model has been the most successful and is most frequently used, but under certain conditions for example, where primary sedimentation rates have been constant and the core has been impacted by episodic slump events, the CIC model is more appropriate (Appleby, 2001).

In paleolimnology other than naturally occurring ^{210}Pb, isotopes that are not natural, but have been manufactured by nuclear industry can also be used (Smol, 2008). These can be used to pinpoint certain time periods in sedimentary sequences. The most commonly used isotope is ^{137}Cs which was released for the first time in 1945 with the dawning of nuclear age (Smol, 2008). ^{137}Cs was also released in the 1986 Chernobyl nuclear power plant accident.

^{210}Pb activity in lake sediments is usually determined either by alpha spectrometry, or by gamma spectrometry (Appleby, 2001). In most cases the choice will be governed by what is available. Until recently, alpha spectrometry was the most widely used method, though increasing numbers of laboratories are now equipped with gamma spectrometers. Alpha spectrometry is more sensitive and most suitable for small samples of very low activity (Appleby, 2001).

1.4. Proxy Analyses

Various proxies can be retrieved from the sediment and analyzed to infer past environmental conditions. These proxies can be biological, physical, or chemical. Table 1.1 shows some important proxies for each group.

Examinating the chemical and physical properties of sediment reveals a vast amount of data for inferring past environmental conditions like paleoclimate. Several biological proxies such as algal pigments, algae, plant macrofossils, zooplankton, and invertebrates have been used in paleolimnology. Some of these biological variables are authoctonous which live within the lake (algae, aquatic plants, invertebrates, zooplankton) and they are useful for reconstructing water chemistry throughout the core from past to present. Some of them are allochthonous which transported into the lake from the surrounding of the lake by means of wind and water movements and these biological proxies such as pollen can help to identify vegetation changes of the surroundings of the lakes and also estimate past temperature changes (Douglas, 2007).

The animal and plant remains in lake sediments are various such as, Cladocera, Chironomidae, Ostracoda and constitute important part of the functional groups in lakes (Frey, 1964; Smol, 1992). Sometimes the whole body part of the animal is preserved, but usually only some body parts of the whole animal can only be analysed, for example Chironomid head capsules (Frey, 1964; Warwick, 1980; Hofmann, 1988), *Chaoborus* mandibles (Johnson et al. 1990; Uutala, 1990) or cladoceran carapace and head shields (Frey, 1986; Whiteside and Swindoll, 1988). In this thesis only Cladocera was used as biological proxy.

Table 1.1. Physical, geochemical and biological variables in paleolimnology (from Douglas, 2007).

Group	**Application**
Physical	
Grain Size	Sediment supply, sedimentation, and turbulance
Loss-on-ignition	Inorganic and organic composition of sediment matrix
Mineralogy and elemental composition	Sediment supply, water chemistry
Magnetic properties	Sedimentation, dating, erosion
Fluid inclusions	Aquatic paleoclimate and paleochemisitry
Fly ash and charcoal	Industrialization, fires
Geochemical	
Organic matter	Paleoproductivity
C:N	Paleoproductivity
Stable isotopes	
$^{18}O/^{16}O$ $^{2}H/^{1}H$, $^{13}C/^{12}C$, $^{15}N/^{14}N$,	Paleoclimate, paleoproductivity, paleotemperature
Biological	
Algae	
Diatoms	Aquatic chemistry and microhabitats
Chrysophytes, scales and cysts	Aquatic chemistry and microhabitats
Desmids	Aquatic chemistry and microhabitats
Pigments	Aquatic chemistry and algae classes
Insects	
Coleoptera	Aquatic chemistry and microhabitats
Chironomids	Aquatic chemistry and microhabitats
Zooplankton	
Crustaceans	
Ostracods	Aquatic chemistry and microhabitats
Cladocera	Aquatic chemistry and microhabitats
Copepods	Aquatic chemistry and microhabitats
Sponges	Aquatic chemistry and microhabitats
Pollen	Terrestrial vegetation, aquatic macrophytes
Phytoliths	Terrestrial catchment vegetation, especially grasses

1.5. Cladocera

Cladocerans are small (300-3000 µm) crustaceans, part of the class Branchiopoda. The most abundant animal remains in freshwater sediments are the various skeletal fragments of cladoceran which may be one of the dominant components of the sediments (Frey, 1986). Skeletal fragments are composed of chitin and they are chemically inert (Korhola and Rautio, 2001). Thus not all chitinous body parts are equally resistant to biological degradation. Some certain crystalline polymers in the chitin are more hydrated and as a result they preserved better in the sediment (Korhola and Rautio, 2001). Among the species, there are great differences in the number of body parts that are preserved in sediment. Hard and chitinized shelled forms of cladocerans, such as chydorids, are well preserved, whereas soft-shelled chitinous taxa are not as well preserved (Figure 1.4).

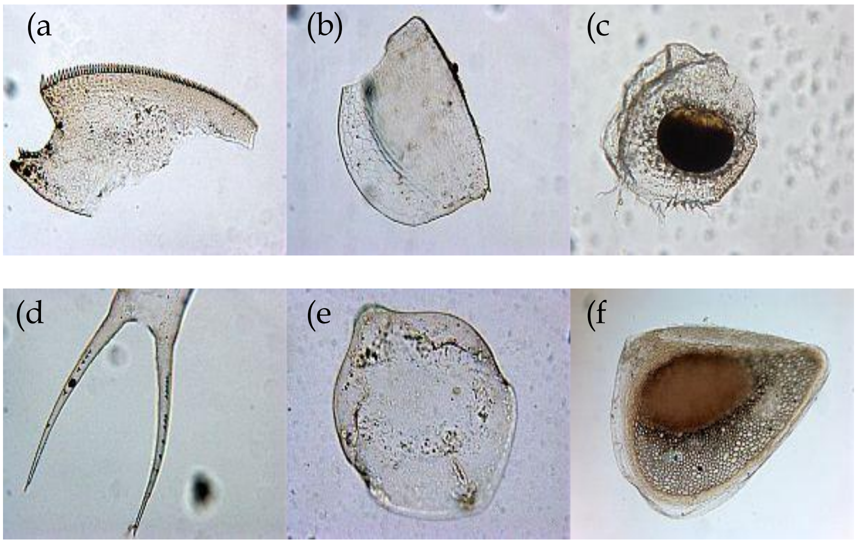

Figure 1.4. Examples of different cladoceran remains from Turkish shallow lakes' sediments. (a) Eurycercus post-abdomen, (b) Graptoleberis carapace, (c) Ilyocryptus ephippia, (d) Leptodora caudal cerca, (e) Leydigia acanthocercoides head shield, and (f) Simocephalus ephippia. Photographs have been taken by A. İdil Çakıroğlu, Limnology Laboratory, Biology Dept, METU, Ankara.

The Cladocerans can be grouped basically into two, pelagic associated species such as, *Bosmina*, *Daphnia*, and *Ceriodaphnia* and littoral associated species such as Chydorids (Whiteside and Swindoll, 1988). Then, they also can be grouped according to their primarily association with macrophytes and with sediments (Frey, 1986). The pelagic species are generally filter-feeders and feed on phytoplankton, detritus and bacteria but there are also predator species exist, such as *Leptodora* and *Bythotrephes* (Korhola and Rautio, 2001). The littoral species are mostly scrapers and they feed mainly on algae and detritus at the sediment-water interface (Figure 1.5) (Korhola and Rautio, 2001).

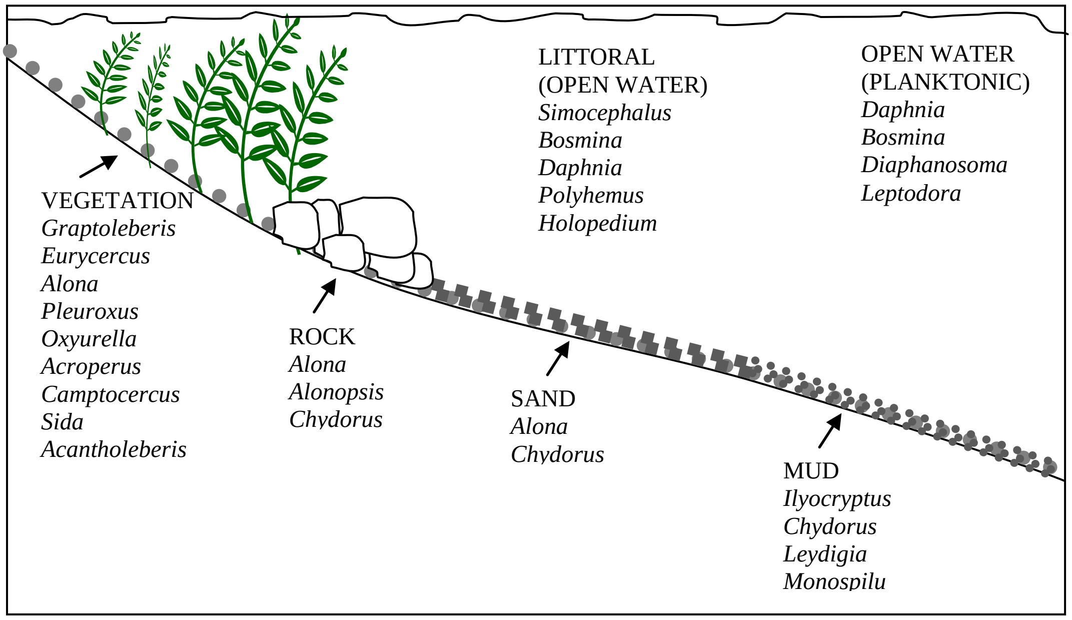

Figure 1.5. Habitats of Cladocerans (modified from Hann, 1980).

Cladocerans are a group of arthropods, and they grow by moluting by shedding their exoskeleton. Their skeletal body parts are then rapidly disarticulated into components such as, head shields, carapace, post-abdomen, post-abdominal claws and mandibles via biological activity. These body parts not the whole animal body can preserve in to the sediment.

The Chydoridae and Bosminidae families are well preserved in the sediment and the preservation of their skeletal components can be used quantitatively because their relative abundance in the sediments are in relation with their original water column alive population (Korhola and Rautio, 2001). The rest of the families sometimes do not leave any remains to identify or they are very selectively preserved. *Daphniidae*, a key component of aquatic ecosystems, is one of the rare preserved planktonic family. In the sediment, their remains are are only represented by post-abdominal claws, mandibles and ephippia (Jeppesen et al. 2001a).

1.6. Identification of Cladocera remains

There are large number of taxonomic keys available for contemporary Cladocera whereas the identification of cladoceran remains still relies on individual research papers, faunistic summaries, and illustrated reports (Rautio, 2007).

The most common remains in sediments are headshields, carapaces, postabdomens and postabdominal claws. *Daphnia* spp.remains are predominantly postabdominal claws and ephippia. *Simocephalus* spp., *Moina* spp. and *Ceriodaphnia* spp. are mostly identified by their ephippia. The headshields of Bosminidae are characterized by large antennae and different species can be identified on the basis of appearance and location of the lateral pores (Figure 1.6).

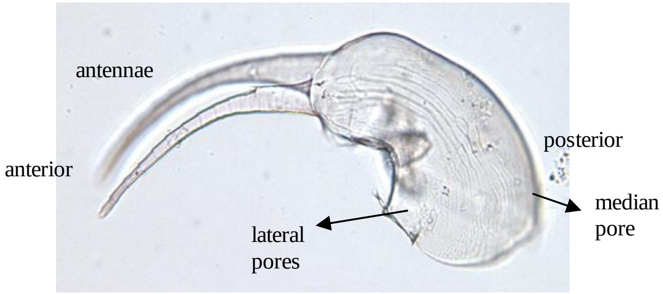

Figure 1.6. Headshield of *Bosmina* spp. from Lake Derin, Yedigöller-Bolu.

Remains of the Chydoridae preserve very well in lake sediment and it is possible to identify most of them to species level (Szeroczynska and Sarmaja-Korjonen, 2007). Chydorid headshields have a species-specific shape and the head pores in the posterior part give important clues for identification. In the subfamily Aloninae, there are usually 2-3 median pores and two small lateral pores and the pore system is usually situated close to the posterior margin (Figure 1.7,1). Headshields of the sub-family Chydorinae have a different pore configuration than Aloninae. There are two separate median pores on the middle of the headshield (Figure 1.7,2). The carapaces of sub-family Aloninae are attached together at a long dorsal margin (Figure 1.7,3). The dorsal region of the anterior margin is quite short inorder to accommodate headshield. Whereas, the carapaces of sub-family Chydorinae are attached at the short dorsal margin. Because of the species of Chydorinae are globular in shape and elongated headshields, the anterior margin of the shell is very long (Figure 1.7,4).

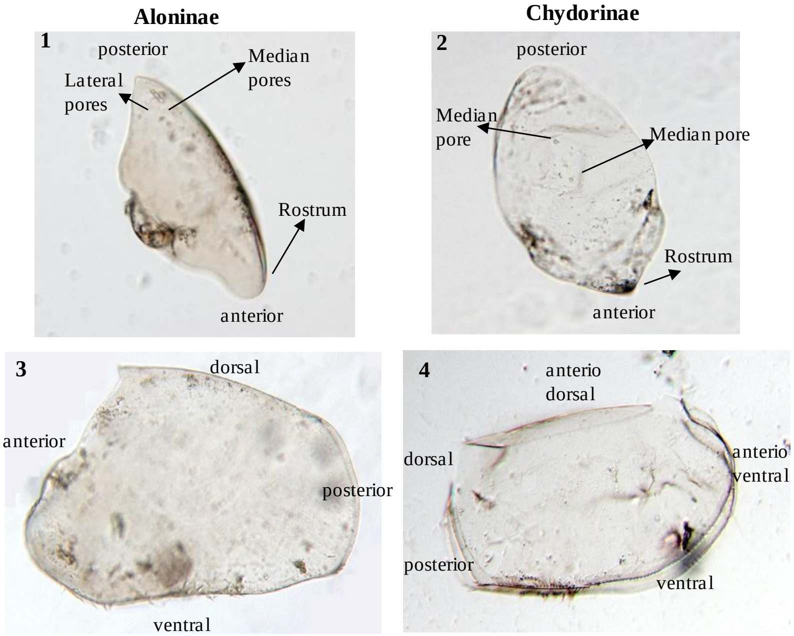

Figure 1.7. Chydoridae family head shields and carapaces. 1. Headshield of Aloninae sub-family (*Alona quadrangularis* – Lake Derin), 2. Headshield of Chydorinae sub-family (*Pleuroxus* sp. – Lake Gölhisar), 3. Carapace characteristics of Aloninae sub-family (*Camptocercus rectirostris* – Lake Abant) and 4. Carapace characteristics of Chydorinae sub-family (*Pleuroxus trigonellus* – Lake Büyük).

1.7. Data Analyses in Paleolimnology

Douglas, (2007) stated that “one of the greatest advances in paleolimnology has been in data analyses leading to the quantification of environmental change and paleoenvironmental assessment. This big step brought paleolimnology forward from a descriptive to a quantitative science”. Now testing hypotheses and quantifying environmental responses are possible in paleolimnology. Modelling the modern surface sediment calibration sets gave insight to paleolimnological researches (Birks, 1998 and Smol, 2008). Creating data matrix including biological communities and related environmental data, it is now possible to identify relationships between species data and environmental data. A calibration set is created by using data from approximately 50 lakes. From each lake, the surface sediment (1-2 cm-thick) is collected and the contemporary chemical, physical and biological data from water column are measured. Then, the two data sets are developed from these samplings. One of the data set consists of the relative abundance of the biological communities from the surface sediment from each lake, for example, sub-fossil Cladocera species. Another data set includes the chemical, physical and biological parameters from each lake. By means of ordination analyses, for instance, principal component analyses (PCA) and detrended correspondence analyses (DCA), finding the most important environmental variables contributing the species’ distribution is possible. After calculating the environmental optima and tolerance of each species, a transfer function can be construct. Then in that transfer function it is possible to use species’ abundance from the stratigraphic profile in order to reconstruct interested environmental variable (Birks, 1998).

Surface-sediment calibration sets

Species prefer to live in a limited range of habitats and they are abundant at their particular environmental optimum (ter Braak and Prentice, 1988), thus the species composition differs along environmental gradients. Species replacements occur successively because of the difference in the environment or time. “The primary aim of quantitative reconstructions is to express the value of an environmental variable as a function of biological data (e.g. chironomid assemblages)” (Birks, 1995). The most widely used approach for quantitative environmental reconstructions involves “surface sediment calibration sets”, or “training sets”. These calibrations sets involve sampling a range of lakes for a suite of environmental variables, which are then related to the indicators preserved in the surface sediments using statistical techniques (Smol, 2008). These data are very crucial since the final goal is to use the known present-day ecology of organisms to infer past conditions.

The first step for generate a calibration set is to choose a group of reference lakes that cover the environmental variables of interest, and the range of environmental conditions is likely to encounter in the limnological history of the lake that wish to reconstuct. Most importantly, the taxa that will eventually be encountered in the cores must be well represented in the modern, surface-sediment samples. For each of the lakes, relevant limnological data must be available because these present-day environmental data will be used to estimate the environmental optima and tolerances of the taxa (Smol, 2008). As a result of this step a data matrix of lakes and the relevant environmental data is produced.

The second step is to construct another data matrix including the lakes with the associated biological data. From the deepest part of each lake, the surface 1-2 centimeter of sediment is collected using corer. These sediment samples are prepared for microscopic examination, identification and enumeration. As a result, the second data matrix including lakes and the abundances of species data is produced.

The final step is to combine these two matrices, identify the most significant environmental variable which explains the biological assemblege and develop a quantitative transfer function of that environmental variable, so that the taxa can be used to infer environmental variables from fossil assemblages.

Development of quantitative transfer functions

The development of powerful statistical methods has allowed quantitative past lake ecosystem reconstruction (ter Braak et al., 1993; Birks, 1995; Livingstone and Lotter, 1998). These reconstructions involve the estimation of species optima and tolerances to an environmental variable by quantitatively using surface sediment – contemporary environment calibration sets (Birks, 1995). The design and methodology of quantitative environmental reconstructions are summarized as below:

In order to reconstruct past environmental variable (E_0) from fossil assemblage data (B_0) including c taxa and l samples, the responses of the c taxa in present day to the environmental variable of interest (E) need to be modelled. This procedure needs a present day biological sample (species matrix) B, of c taxa at n sites, with an contemporary present day environmental variable (E) for the same n sites. The relationship between these two data set are created using statistical methods and this quantitative relationship is used as a transfer function to transform the fossil assemblage (B_0) into unknown past environmental variable (Table 1.2).

Table 1.2. Schematic description of quantitative paleolimnological reconstructions. Modified from Birks (1995).

	Biological Data	**Environmental Data**
Present	Modern (B) c taxa - n sites	Modern (E) n sites
Past	Fossil (Bo) c taxa - l samples	Eo l samples

In order to use organisms to reconstruct a specific environmental variable, their distributions have to be influenced by that variable (Smol, 2008). Multivariate ordination and regression techniques have to be applied to the calibration set in order to find the environmental variable strongly influencing the distribution of species data. The most common approach has been the use of indirect (correspondance analysis, CA) and direct (canonical correspondance analysis, CCA) analysis techniques if taxa are responding to the measured environmental gradients in a unimodal distribution. If taxa are responding linear relationship with measured environmental variables, principal component analysis (PCA) or redundancy analysis (RDA) are required (ter Braak 1994). The selection of unimodal versus linear techniques can often be decided by running a detrended correspondance analysis (DCA) to determine the length of the gradient, estimated in standard deviation (SD) units (Hill, 1973; Hill and Gauch, 1980). This is an estimate of the turnover rate of species because distribution of most species will rise and fall over four SD units. If the gradient is shorter than about 3 SD units, linear techniques are more appropriate (Birks, 1998).

After determining which of the environmental variables influence species distributions, a transfer function can be constructed. In order to create transfer function, this environmental variable is taken as the response variable and the responses of the species as the explanatory variable. This regression equation is then directly used for prediction.

In order to make a transfer function, weighted averaging (WA), weighted averaging partial least squares (WA-PLS) and partial least squares (PLS) models will be created using C2 version 1.4 (Juggins, 2004). There are also some assumptions in order to reconstruct quantitatively (Imbrie and Kipp, 1971; Birks, 1995):

1. The biological data and the environmental data in calibration set should be related to each other.
2. The reconstructed environmental variable should linearly related to an ecologically important parameter in the ecosystem.
3. The biological variable (**B**) in the calibration set should be the same as in the sedimentary data $\mathbf{B_0}$ and also the ecological responses should not changed over the time. Thus, the relationship between modern taxon abundance with the environmental variable **E** can be used to reconstruct changes in **B** from past to present.
4. The statistical methods, regression and calibration, are effectively model the biological reactions to the interested environmental variable.
5. The other environmental variables do not influence our interested environmental variable, or it is the same as in the training set.

1.8. Turkish Shallow Lakes

Having 200 natural lakes, 75 dams, and 700 ponds, Turkey is a rich country in freshwater resources (Kazancı et al, 1995). The surface area of these lakes is 10,000 km^2. Turkish lakes are mostly shallow and some of them have large surface areas such as, Lakes Beysehir, Marmara, Işıklı, Uluabat. These shallow lakes have high biodiversity and also important aquatic vegetation community (Beklioğlu et al., 2006). Turkish shallow lakes are influenced by the nutrient enrichment resulting eutrophication and also under the influence of strong water level fluctuations (Beklioğlu et al., 2006). These water level changes effect lakes differently according to their trophic status.

Beklioğlu et al. (2006) stated that "ecology of Turkish shallow lakes and their associated species diversity are very sensitive to hydrological alterations, namely water level fluctuations and hydraulic residence time". In oligotrophic lakes, submerged plant grows in low water levels conditions with increasing the size of the littoral zone with associated species diversity. The Increase of nutrient concentration in lake ecosystem also direct the decrease of submerged plants development via turbidity which is a result of planktivorous fish feeding and high phytoplankton production. Moreover, global climate change complicates these processes with the salinity increase and thus, decrease of species diversity. Increased urbanization, sewage disposal, regulation of wetlands and more intensive farming practices have also increased the nutrient loading to many shallow lakes world-wide increasing salinity as shown by the predictive models (Coops et al., 2003; Naselli-Flores, 2003; Talling, 2001; Beklioğlu et al.,2006; Beklioğlu and Tan, 2008).

Climate change will further affect the physical, chemical and biological properties of freshwater lakes and rivers, with predominantly adverse impacts on many individual freshwater species, community composition and water quality (IPCC, 2007). From 1900 to 2005 precipitation declined in the semi-dry Mediterranean climatic region and the areas have already been affected by drought whose intensity increased since 1970s (IPCC, 2007). As part of the Mediterranean climatic region, Turkey is highly susceptible to impacts of climate change. Many studies revealed a recent warming trend which extends from early 1990s to the present day in Turkey (Türkeş et al. 1995; Kadıoğlu 1997; Türkeş et al., 2002). Furthermore, recent studies reported general decreasing precipitation trend over western and southern parts of Turkey (Türkeş et al. 2009). Turkish shallow lakes especially Central Anatolian lakes' functions and services are very susceptible to hydrological changes, such as hydraulic residence time and water level fluctuations (Beklioğlu et al., 2006; Ozan et al. 2010; Bucak et al. 2012) and regional precipitation. Hydrologoical alterations and regional climate changes have shown to lead salinization and eutrophication of Turkish shallow lakes (Beklioğlu et al., 2006; Beklioğlu and Tan, 2008; Beklioglu et al. 2010; Ozan et al. 2010; Bucak et al. 2012). Salinity shows particularly great temporal variability in response to climate (Talling, 2001). It increases annually during dry summers that can return to regular level as the season changes. However, during prolonged dry periods, salt accumulates interannually and make lakes shift to saline conditions (Beklioğlu and Tan, 2008).

1.9. Paleolimnological Research In Turkey

In Turkey, paleolimnologist mostly study the effects of climate change on lake and its catchment. These studies have been focusing on the climatic changes in Late Quaternary period. Paleolimnological surveys were mostly conducted by the co-operation with Mineral Research & Exploration (MTA) and researchers from U.K., France, Germany and Japan. At first, in 1967 German researchers studied postglacial vegetatinoal history of Northern Turkey by retrieving a sediment core from Lake Yeniçağa and Lake Abant, Bolu in 1957 (Beug, 1967). This research was followed by a detailed vegetational history study of northern and northwestern Turkey. This project was a joint project of the Faculty of Forestry of İstanbul University and Palaeobotanical Department of Groningen University (Woldring et al., 1986). At the second half of 1990's English researchers collected sediment cores from Gölhisar Lake, Burdur; Süleymanhacı and Pınarbaşı Lakes, Konya to study the Late-Holocene environmental change in Southern Turkey (Roberts et al., 1997, Eastwood and Pearce, 1998, Reed et al., 1999, Eastwood et al., 1999a, Eastwood et al., 1999b, Roberts et al., 1999, Jones et al., 2002).

Kashima (2003) studied climatic changes during the Late Quaternary using three sediment cores from closed and semi-arid lacustrine basins in central Anatolia, Turkey, based on diatom assemblages of sediments. In their research, they used diatoms from 38 lakes and rivers and living and fossil diatoms indicated that palaeolimnological studies using diatom remains can provide quantitative reconstruction of water salinity for Turkey.

Jones et al. (2005) sampled varved sediment core from Nar Lake, Nevşehir and studied oxygen isotope records. They compared oxygen isotope record from the lake sediment with instrumental records of temperature, precipitation, wind speed, relative humidity and calculated values of evaporation. They showed that the isotope record followed the same trends in the temperature and evaporation records.

The most recent study used oxygen isotope records from lake sediments from three lakes namely, Zeribar, Iran; Van and Eski Acıgöl, Turkey (Jones and Roberts, 2008). The Turkish lake records had been interpreted as controlled by changes in precipitation to evaporation ratio. Furthermore, England et al. (2008) coupled stable isotope, pollen and charcoal from Nar Lake sediment core in order to investigate land use in Cappadocia region. They indicated that Cappadocia has been a predominantly open landscape throughout the last two millennia. They also found the first significant cultural landscape transformation occurrence during the Bronze Age. Woodbridge and Roberts (2010) used the same laminated sediments to investigate the link between modern and fossil diatom assemblages. Thereafter, Woodbridge and Roberts (2011) compared sedimentary diatom record with stable isotope and pollen record from the same core over last 1720 years and they investigated that Nar lake water was much more saline and the climate of central Anatolia was significantly more arid during the decades prior to AD 540. Recently, Reed et al. (2012) developed conductivity transfer functions using diatoms and ostracods from Turkish lake training sets using weighted averaging techniques to confirm the potential for diatoms and ostracods to strengthen palaeoclimate inferences by quantitative multi-proxy reconstruction. Results of paired diatom-ostracod analysis indicated that the most important ecological threshold occurs at a conductivity boundary of ~3 $mScm^{-1}$.

1.10. Objectives

In this thesis, the limnological characteristics of sub-fossil Cladocera from surface sediment are outlined by comparison of the present day environmental variables. The 44 shallow lakes of Turkey were sampled using snap-shot methodology.

The objectives of this thesis are:

1. to determine the concurrence of contemporary and sub-fossil Cladocera in relation with environmental factors;
2. to establish the relationship between the distribution of sub-fossil cladoceran species and environmental variables to produce a calibration set;
3. to hindcast the reliability of salinity transfer functions using long-term monitoring data from two interconnected shallow lakes;
4. to construct a transfer function for inferring past salinity and delineate the effects of climate change from the recent past (100-150 years) to the present using transfer function.

CHAPTER 2

RELATEDNESS BETWEEN CONTEMPORARY AND SURFACE SEDIMENT SUB-FOSSIL CLADOCERA ASSEMBLAGES IN TURKISH SHALLOW LAKES

2.1. Introduction

Zooplankton are important indicators of the structure and function of freshwater lake ecosystems and their ecological status (Jeppesen et al., 2011). They are considered as a key component of the trophic web and are sensitive to anthropogenic impacts (Caroni and Irvine, 2010). Zooplankton community structure changes along an eutrophication gradient. Zooplankton biomass increase with increasing total phosphorus (TP) and their size decrease the latter reflecting mainly an increase in fish predation (Jeppesen et al., 2000; Haberman and Laugaste, 2003). A study of 81 shallow European lakes Gyllström et al. (2005), showed that the fish:zooplankton ratio increased however, zooplankton:Chl-*a* ratio decreased from north to south resulting increased top-down (fish predation) effect. Cladocera species are sensitive to increasing salinities because of their limited osmoregulating capacity (Aladin, 1991; Frey, 1993). Zooplankton species richness and diversity decrease with increasing salinity (Frey, 1993; Jeppesen et al., 1994; Bos et al., 1999, Boronat et al., 2001, Brucet et al., 2009).

Zooplankton sedimentary remains also provide information on ecosystem state and change through time (Jeppesen et al., 2001a; Davidson et al, 2011). The surface sediment includes pelagic, benthic and macrophyte associated zooplankton remains and they are well represented and the species richness and diversity are generally higher than for contemporary samples (Davidson et al., 2007; Nevalainen, 2010). Exoskeletons of planktonic and littoral Cladocera can be found in the sediment. The chitinous outer body parts, such as carapaces, head shields, ephippia, post-abdomens and claws, preserve selectively in lake sediments, whereas soft tissues decompose (Frey, 1986). Preservation is known to be the best for the families Bosminidae and Chydoridae (Frey, 1986, Korhola and Rautio, 2001), while other Cladocera families such as Daphniidae and Sididae are less well preserved in the sediments and are represented, for instance, by ephippia, postabdominal claws, antennal segments and mandibles (Frey, 1991). It is considerably more difficult to identify these small, detached body parts than shells, headshields and post-abdomens (Frey 1986). Frey (1960) suggested that all Cladocera species should leave some kind of remains in lake sediments, but due to some difficulties in precise identification, palaeolimnology researchers have generally found that cladocerans are poorly represented in the sediment record (Frey, 1958, 1988). Several factors affect the deposition of cladoceran remains. Cladocerans grow by periodically shedding their exoskeletons at the end of each instar. Molting rates differ among the species and are strongly influenced by temperature (Vijverberg, 1980). The proportions of shed exuviae and disarticulated animals in the sediment depend on the age structure characteristics of the population (Kerfoot, 1981), which, in turn, are affected by varying food conditions and size-selective predation (Boersma et al., 1996; Hülsmann and Mehner, 1997). Mechanical, chemical and biological agents can all decompose exoskeletal fragments and chitin, thus affecting their preservation (Kerfoot, 1995). However, Ephippia of many species preserve well (Frey, 1986; Hofmann 1987; Hann, 1989; Rautio et al., 2000). “Interpretation of the sub-fossil cladoceran data is based on the assumption that a close contemporary-fossil relationship exists” (Davidson et al., 2011).

Because several processes determine the production and distribution of cladoceran remains, the reliability of this assumption is widely discussed by palaeolimnologists (Davidson et al., 2007, Kattel et al., 2007, Nykanen et al., 2009). Some previous studies have analysed how well the sediment cladoceran remains reflect the living community. Jeppesen et al. (2003) identified a good correlation between the relative involvement of the *Daphnia* spp. population occurring in the water column and its percentage abundance in the surface sediments. However, the higher presence of *Ceriodaphnia* spp. in the littoral than in the pelagial demonstrated less correlation between water column and relative abundance of ephippia and it was found more frequently in the sediment than in the water column. Davidson et al. (2007) focused on external forces shaping cladoceran communities (e.g. macrophytes and fish) in a set of Danish and UK lakes and found that these were essentially the same for contemporary and subfossil assemblages. Kattel et al. (2007) used cladoceran samples from deep sediment traps, surface sediment samples and seasonally collected Cladocera from the water column to identify difference between them and concluded that sediment samples should not only cover the pelagic but also the area in between the pelagic and the littoral. Nykanen et al. (2009) estimated annual cladoceran body part production in the water column for each species and compared it with the net accumulation in the sediment.

This study focused on the reliability of contemporary-fossil relationship by comparing contemporary pelagic and littoral zooplankton populations with surface sediment assemblages from 40 shallow Mediterranean lakes. We also sought to find a similarity between contemporary and sedimentary assemblages with environmental factors shaping the cladoceran community.

2.2. Materials and methods

2.2.1. Study Sites and field sampling

Environmental variables and surface sediments were sampled in 40 Anatolian shallow lakes spanning over 5 latitudes from semi-arid north (41°52´N, 27°58´E) to arid south (37°06´N, 29°36´E) Turkey during August and September 2006 - 2011 (Figure 2.1; Appendix A).

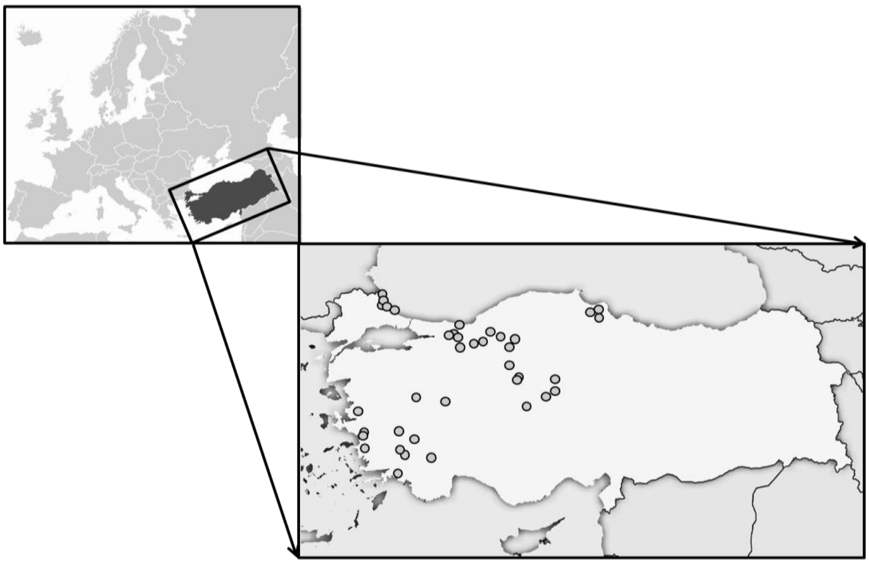

Figure 2.1. Studied 40 shallow lakes in Turkey.

Snap shot sampling methodology was used for sampling the lakes (Figure 2.2). Depth-integrated, mixed water samples from the whole water column were taken at the deepest part of the lake using a 3.5 L KC-Denmark Ruttner sampler and analysed for total phosphorus (TP), soluble reactive phosphate (SRP), nitrate, nitrite, total nitrogen (TN) and chlorophyll *a* . Lake water temperature (°C), conductivity (±1 µS cm^{-1}), salinity (‰),maximum depth (m), dissolved oxygen (ml L^{-1}), and pH were determined *in situ* using a YSI 556 MPS multiprobe and Secchi disc transparency was measured using a depth gauge with a 20 cm diameter.

Zooplankton samples were taken from both the littoral and pelagic parts of each lake and a 40 L water depth-integrated sample from the pelagic and 20 L from the littoral zone. From each sample

20 L water were filtered through a 20 µm mesh size filter and the remains were fixed using 4 % Lugol's solution.

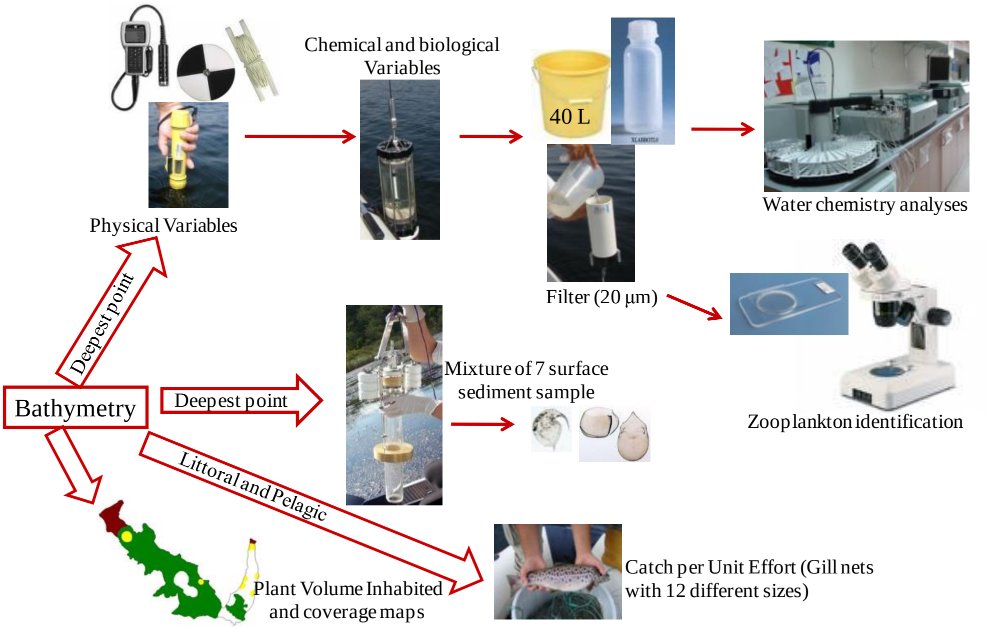

Figure 2.2. Schematic description of snap shot sampling.

The composition and abundance of fish (Catch per unit effort - CPUE) were determined by overnight fishing with Lundgren gill nets with multiple mesh sizes: 6.25, 8, 10, 12.5, 16.5, 22, 25, 30, 33, 38, 43, 50, 60 and 75 mm, with the length of 3 m and depth of each section being 1.5 m. The nets were set overnight for an average duration of 12 hours in the littoral and pelagic part of the lake.

Percent plant volume inhabited (PVI %) of the lakes was calculated based on data on submerged plant sampled at evenly spaced intervals along parallel transect lines. The number of lines was determined relative to the lake size. Plant species, average plant height, plant coverage, GPS coordinates, and water depth were recorded at each sampling point which were located along the transect lines.

PVI % at each sampling point (n) was calculated using the percent plant coverage (c %), average plant height (p) and water depth (wd). Average lake PVI was determined as the sum of all PVI divided by the sum of all water depths:

$$PVI_n = (c\ \%\ x\ p)/wd$$

$$PVI_{lake} = \sum PVI_n x depth_n / \sum depth$$

From each lake, seven surface sediment (0–2 cm) mud were taken using a KC-Denmark Kajak Corer (5.2 cm diameter) at the deepest point of each lake. The seven surface sediment samples were mixed together and kept frozen (-18 °C) prior to analysis for sub-fossil Cladocera remains.

2.2.2. Laboratory analyses

All water samples were kept frozen prior to chemical analyses in the laboratory. For analysis of total phosphorus (TP) and soluble reactive phosphate (SRP) analyses we used the acid hydrolysis (Mackereth, Heron and Talling, 1978) and molybdate reaction methods (Mackereth et al., 1978), respectively. Total nitrogen (TN), ammonium (NH_4) and nitrite-nitrate (NO_2 - NO_3) were analysed by the Scalar Autoanalyzer Method (San++ Automated Wet Chemistry Analyzer, Skalar Analytical, B.V., Breda, The Netherlands). For chlorophyll *a*, the ethanol extraction method by Jespersen and

Christoffersen (1987) was used and suspended solids were determined by weighing the dried GF/C Whatman filters after filtering ~500 mL water through weighted filters.

For sub-fossil cladoceran taxonomical analysis 5 g wet homogenised sediment were boiled in 100 mL 10% KOH for 50 minutes and afterwards all material kept in Lugol's solution until microscopic analysis. Before to the counting under the microscope, the samples were sieved. Remains bigger than 45 µm were all identified and counted using a stereomicroscope (LEICA MZ 16) and an inverted light microscope (LEICA DMI 4000). For the counting process, sub-fossils were separated into two size fractions: >140 and 45–140 µm. All remains >140 µm were counted, while remains in the 45–140 µm size fraction were sub sampled and approximately 20 % were counted. For species identification, the keys developed by Frey (1959); Flöβner (2000) and Szeroczyńska and Sarmaja-Korjonen (2007) were used. Carapaces, head shields, post abdomens, post abdominal claws and resting eggs of each sub-fossil Cladocera were counted and the most abundant body part was used in analyses. Sometimes, taxonomic species separation of *Alona rectangula* Sars, 1862 and *Alona gutata* Sars, 1862 could not be conducted when organic material stuck into the head shields covering the head pores which are used for identification. Thus, these two *Alona* species are used as *Alona rectangula/gutata* in statistical analyses.

Contemporary zooplankton species were identified to species level and individuals were counted at 40X magnification in a LEICA MZ 16 stereomicroscope (Tavşanoğlu, 2012). For taxonomical identification, the keys in Scourfield and Harding (1966), Ruttner-Kolosko (1974), Pontin (1978), Einsle (1993), Segers (1995), Smirnov (1996), Flöβner (2000), and Smith (2001) were used.

2.2.3. Data analyses

Prior to statistical analyses, environmental data was tested for normality using the Kolmogorov-Simirnov test in SigmaStat 3.5. Environmental variables that did not pass the normality test were either $\log_{10}$, $\log_{10}(x+1)$ or square root transformed to obtain the best approximation to normal distribution (Table 2.1), and species data were Hellinger transformed (Legendre and Gallagher, 2001).

Ordination is an effective method when investigating the patterns and causes of variation in multivariate datasets (ter Braak and Prentice, 1988). An arrangement of ordination techniques including detrended correspondence analysis (DCA), canonical correspondence analysis (CCA) and redundancy analysis (RDA), was employed. In DCA, rare species were downweighted and detrending was carried out, and non-linear rescaling was applied. Detrended Correspondence Analysis (DCA) was performed on Hellinger transformed species data in order to determine whether unimodal or linear ordination techniques were suitable. DCA is an indirect ordination method that summarizes the variation in species assemblages along the DCA axis. Linear ordination (Redundancy Analysis – RDA) or unimodal ordination (Canonical Correspondence Analysis – CCA) were applied when the gradient length of axis 1 in DCA was less than or higher than 3.00 standard deviation (SD) units (ter Braak, 1995). Monte Carlo permutation tests were applied in order to test the significance of each environmental variables used in ordination analyses. Environmental variables, which did not explain a significant portion of species variance after Monte Carlo permutations ($p<0.005$; 999 random permutations), were removed from ordination analysis. A series of partial RDA ordinations using only the significant environmental parameters was run to determine the % variance explained by each single variable.

In order to explore the similarities between the Cladocera community and environment relationship for both contemporary and surface-sediment data and also to test the significance of found relationship, Procrustes rotation and the related PROTEST permutation test were applied to the ordination results (Jackson, 1995; Peres-Neto and Jackson, 2001). Procrustes rotation considers the general degree of correlation between two or more ordination results by using a "Procrustean superimposition approach", in which the results of the ordinations are scaled and rotated to find an optimal superimposition maximising their fit (Davidson et al., 2007). "The sum of the squared residuals between configurations in their optimal fit can be used as a metric of correlation" (Gower, 1971). PROTEST measures the degree of concordance between two matrices and it is a permutation-based procedure (Jackson, 1995). PROTEST produces "a correlation-like statistic derived from the symmetric Procrustes sum of squares", referred to as "correlation in a symmetric procrustes rotation

(m_{12}) and an associated significance (p value)” indicating the likelihood of the relationship occurring by chance (Davidson et al., 2007). All analyses were done with R version 2.12.2 (R Core Development Team, 2011) using the vegan (Oksanen, et al., 2008) R packages.

The physical, chemical, biological and sedimentary data were obtained from Beklioğlu et al., (in preperation) and TÜBİTAK Project no: 110Y125. Thus, the same data excluding sub-fossil Cladocera will be used in the several PhD thesis who have carried out their thesis at METU, Biology Department (Şeyda Erdoğan, Gizem Bezirci, Eti Ester Levi) and was used in completed PhD thesis (Ü. Nihan Tavşanoğlu and ArdaÖzen).

2.3. Results

The 40 lakes studied were generally small and shallow with maximum depth ranging from 0.55 to 17.4 m (Table 2.1). Surface water temperature averaged 24.4 ^{0}C and the lakes were well oxygenated (average=6.7 ml L^{-1}). Except for four with salinities between 3.1 and 5.8‰ all were freshwater lakes. Most of the lakes had pH close to neutral, were eutrophic with an average chlorophyll *a* concentration of 19.2 µg L^{-1} and an average Secchi depth of 1.3 m. Planktivorous fish dominated the fish catches, the average catch per net per night being 106.9 per net. The PVI % varied from 0 to 94%.

Table 2.1. Summary statistics of environmental variables from the 40 Turkish shallow lakes.

	Size (ha)	**Depth (cm)**	**Temp (°C)**	**Oxygen g/L**	**Chl-a µg/L**	**pH**	**TP (µg/L)**	**TN (µg/L)**	**Salinity (‰)**	**Secchi (cm)**	**PVI (%)**	**Fish (cpue)**
min	0.1	55	18.3	0.58	0.66	6.3	15	238.8	0.06	20	0	0
max	635	1740	32.4	15.3	62.1	9.6	632.6	2340	5.8	900	94.2	644.2
mean	74.9	409.8	24.4	6.7	19.2	8.2	138.1	1024.7	0.7	130	17.5	106.9

A total of 20 and 27 taxa were identified in the water column and surface sediment samples, respectively (Table 2.2, Appendix 2 and 3). The occurrence, maximum, mean and median values of the relative abundance for all identified taxa showed that some of the frequently occurring taxa in the water were not found in the sediment assemblages. These include *Diaphanosoma* sp., *Macrothrix* sp., *Scapholeberis mucronata* (Müller) and *Polyphemus pediculus* (Linnaeus, 1761) (Table 2.2). All other pelagic taxa were represented in the surficial sediments. However, *Bosmina longirostris, Chydorus sphaericus* and *Leydigia leydigi* were over represented in sediment assemblages; only few or none were found in contemporary samples.

Table 2.2. Contemporary and surface sediment percent abundances of all Cladoceran taxa.

	Sediment				**Water column**			
	Occurence	**Median**	**Mean**	**Max**	**Occurence**	**Median**	**Mean**	**Max**
Leptodora kindtii (Focke, 1844)	2	0.0	0.0	0.3				
Sida crystallina (O.F.Müller, 1776)	4	0.0	1.2	42.6				
Diaphanasoma sp.					10	0.0	9.4	100.0
Daphnia spp.	15	0.0	0.2	3.4	19	0.0	10.2	93.0
Ceriodaphnia spp.	28	0.1	0.6	5.9	22	0.4	17.8	100.0
Simocephalus spp	6	0.0	0.0	0.7	4	0.0	0.8	20.8
Moina spp.	9	0.0	0.1	1.0	9	0.0	3.9	76.5
Bosmina longirostris (O. F. Müller, 1785)	33	50.4	46.8	99.3	19	0.0	23.3	99.9
Macrothrix sp.					1	0.0	0.0	0.1
Ilyocryptus spp.	6	0.0	0.0	0.4	1	0.0	0.0	0.1

Table 2.2 (continued)

Eurycercus lamellatus (O.F. Müller, 1785)	2	0.0	0.0	0.3				
Camptocercus spp.	6	0.0	0.0	0.8				
Acroperus harpae (Baird, 1835)	14	0.0	0.7	7.6	2	0.0	0.4	8.9
Kurzia latissima Kurz,1874	3	0.0	0.0	0.2				
Oxyurella tenuicaudis (Sars, 1862)	2	0.0	0.2	5.8				
Alona quadrangularis (O.F.Müller, 1785)	19	0.0	1.4	35.3	5	0.0	3.4	97.4
Alona rectangula/gutata	36	6.1	22.1	96.4	15	0.0	3.3	56.8
Alona affinis Leydig, 1860	7	0.0	0.0	0.5	1	0.0	0.0	0.6
Leydigia leydigi (Schoedler, 1863)	26	0.1	2.9	20.2	3	0.0	2.6	100.0
Leydigia acanthocercoides (Fischer, 1854)	16	0.0	1.1	19.2				
Graptoleberis testudinaria (Fischer, 1848)	16	0.0	1.8	49.4				
Alonella excisa (Fischer, 1854)	11	0.0	0.5	8.3				
Alonella exigua (Lilljeborg, 1853)	9	0.0	0.7	9.5	3	0.0	1.1	21.0
Allonella nana (Baird, 1850)	6	0.0	0.6	15.2	2	0.0	0.2	8.7
Disparalona rostrata (Koch, 1841)	8	0.0	0.2	2.4				
Pleuroxus spp.	22	0.0	1.0	19.3	9	0.0	1.3	20.8
Chydorus sphaericus (O. F. Müller, 1776)	37	6.8	17.6	86.0	23	0.9	14.1	100.0
Scaptoleberis mucronata (O. F. Müller, 1785)					1	0.0	0.2	7.9
Polyphemus pediculus (Linnaeus, 1761)					1	0.0	0.4	16.0

DCA indicated a first axis length of 1.41 SD units for the contemporary data whereas 2.03 SD units for the sub-fossil data. According to ter Braak and Prentice (1988) both linear (RDA) and unimodal (CCA) methods can be used where the first axis length falls between 1.5 and 3 SD units. Thus, linear methods were chosen for the both contemporary and sedimentary assemblages and only RDA was used for both data sets to compare the results of the ordinations (Figure 2.3). Lakes Hamam, Pedina and Baldımaz did not contain any cladocera taxa in their contemporary zooplankton assemblages and therefore not included in the RDA and Procrustes analyses. Significance test showed the first two axis for contemporary RDA to be significant ($p<0.01$) whereas, only the first axis was significant ($p<0.01$) for sedimentary RDA. As indicated in Figure 2.3, Monte Carlo permutation test showed that TP and salinity were significant for the contemporary assemblage ($p<0.05$), while only salinity ($p<0.01$) was significant for the sub-fossil assemblage. Thus, in both RDAs salinity was the most significant variable and it was negatively correlated with axis 1 (Figure 2.3).

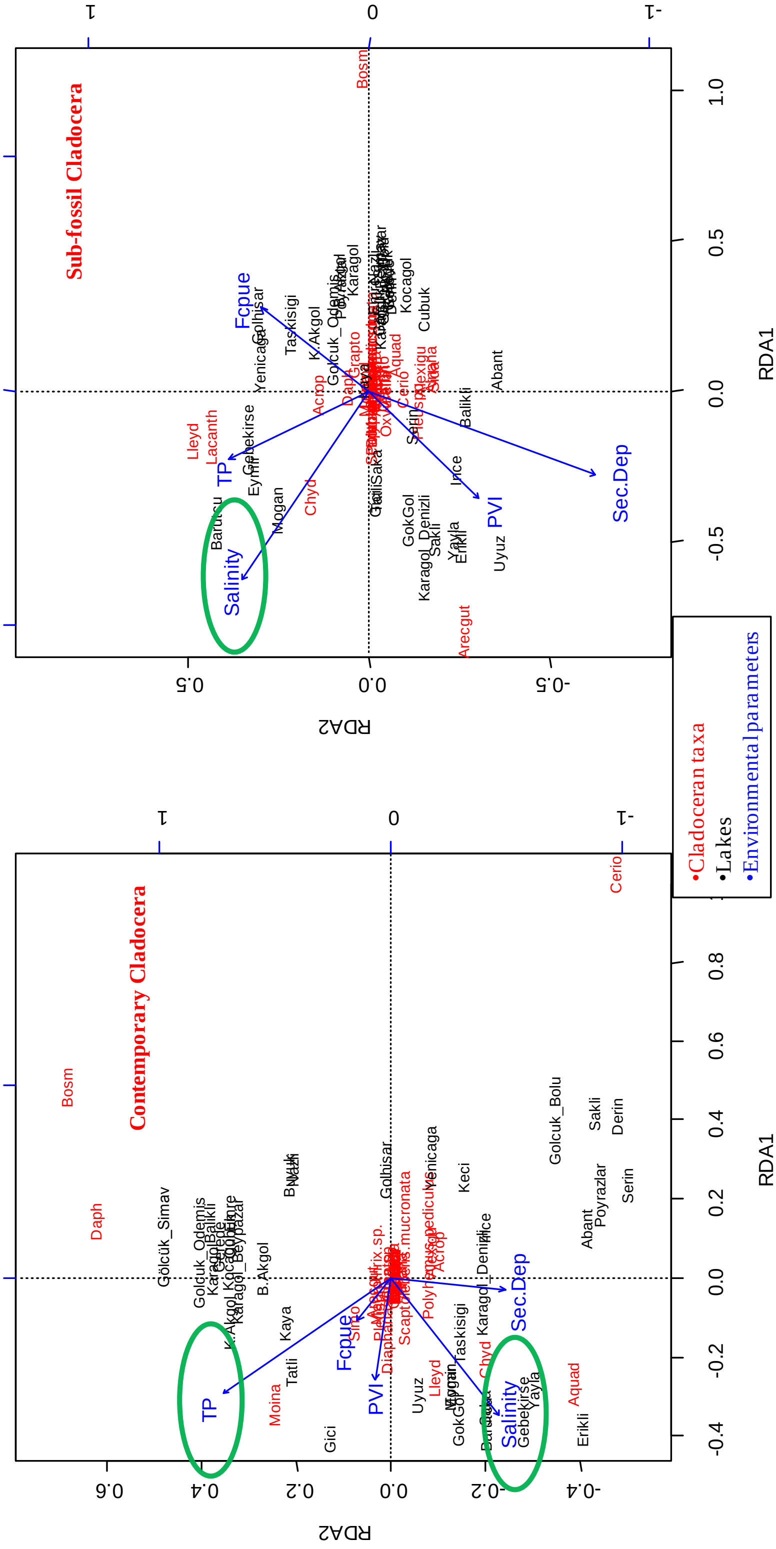

Figure 2.3. RDA plot of contemporary and sub-fossil Cladocera assemblages.

Furthermore, RDA ordinations specified that a similar percentage of variance was explained for water column (16.7 %) and sub-fossil Cladocera (13.6 %) data when all environmental variables were included in the analysis (Table 2.3). When using single variable in each analysis, salinity again had the highest percent variance explained in both datasets (Table 2.3).

Table 2.3. Summary results of variance explained by RDA analyses for contemporary and sedimentary Cladocera from 37 lakes.

Environmental Variable	**% RDA Variance** **Contemporary Cladocera**	 **Sedimentary Cladocera**
Secchi:Max.Depth, TP, Salinity, PVI, Fish$_{cpue}$	16.7	13.6
Salinity&TP	10.8	8.4
TP	5.6	1.6
Salinity	5.5	7.6

The location of most common species in the two RDAs differed. For instance, *Bosmina longirostris*, *Chydorus sphaericus*, and *Leydigia leydigi* distributions in ordination space were quite similar and they exhibited a parallel degree of reaction to the same environmental variables in both ordinations (Figure 2.3). *Chydorus sphaericus* was positively associated with salinity; otherwise *Bosmina longirostris* was negatively associated with salinity when comparing contemporary and sedimentary RDAs. *Moina* spp. was positively linked with TP in contemporary dataset.

Species diversity and evenness of the two communities showed some response to salinity and TP (Figure 2.4). With increasing TP only species evenness of contemporary community showed decrease because sedimentary cladocerans did not significantly correlated with TP as seen in RDA. There was a clear separation between low and high salinity in diversity patterns in the contemporary cladoceran data however, in sub-fossil cladocera data this separation was not clear (Figure 2.4). Sub-fossil Cladocera species diversity decreases with increasing salinity whereas evenness did not change with increasing salinity.

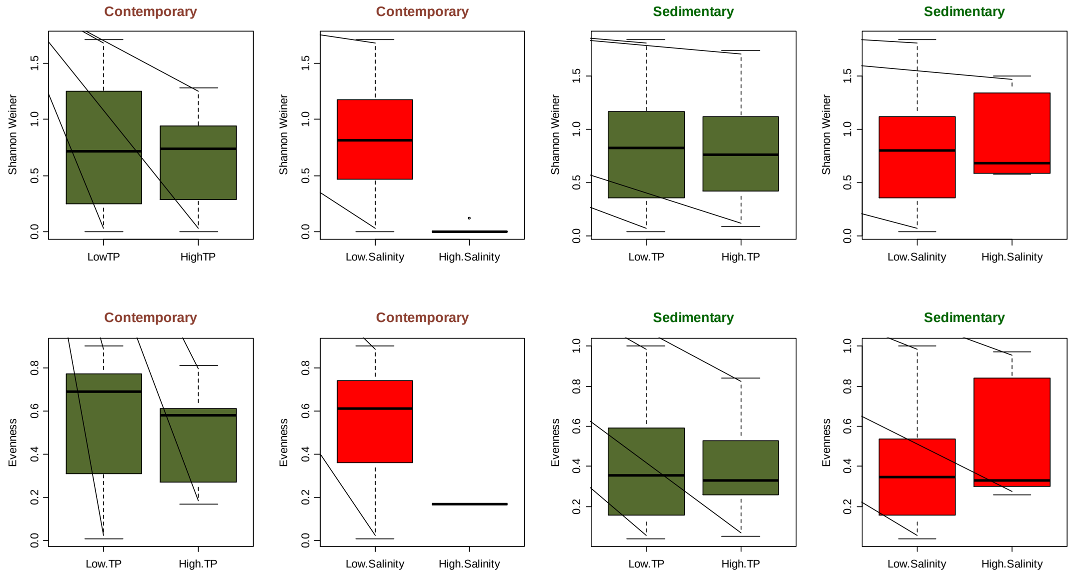

Figure 2.4. Species diversity (Shannon-Weiner index H') and evenness (Pielou index) between contemporary and sedimentary communities and the effect of salinity and TP.

For the Procrustes rotation analysis, the scores of PCA of the species data and the scores of RDA of 37 lakes were employed and the results were shown in Table 2.4. The lower values of rotation sum of squares and root mean square error (RMSE) shows better aggrement between the two dataset. Thus, lower rotation sum of squares (6.43) and RMSE (0.41) values showed that Procrustes analyses with using PCA scores had better explanation. However, the correlation diagnostic (m_{12}) showed relatively higher value (0.4501) in analysis using RDA scores. Furthermore, the significant p value = 0.002 suggested that Procrustes rotation test using both PCA and RDA scores of the contemporary and sedimentary Cladocera gave optimal fit and a high degree of correspondence between contemporary and sedimentary cladocera assemblages (Table 2.4).

Table 2.4. PROTEST diagnostics for fossil and contemporary data of 37 lakes.

Test	Procrustes rotation sum of squares	Procrustes RMSE	PROTEST m_{12}	p value
Fossil RDA & Contemporary RDA	12.73	0.58	0.4501	0.002
Fossil PCA & Contemporary PCA	6.43	0.41	0.4019	0.002

In graphical description of procrustes results for the two datasets, their arrangements of optimal fit offered a signal of the difference (procrustes residuals) between the contemporary and surface sediment scores for each lake (Figures 2.5 and 2.6). Black circles in the plots represent contemporary data and point of the arrows represent sedimentary data. The distance between the points and arrows shows procrustes residuals. Low residuals (short arrows) indicate a good agreement, and high residuals (long arrows) indicate a weak agreement between data sets.

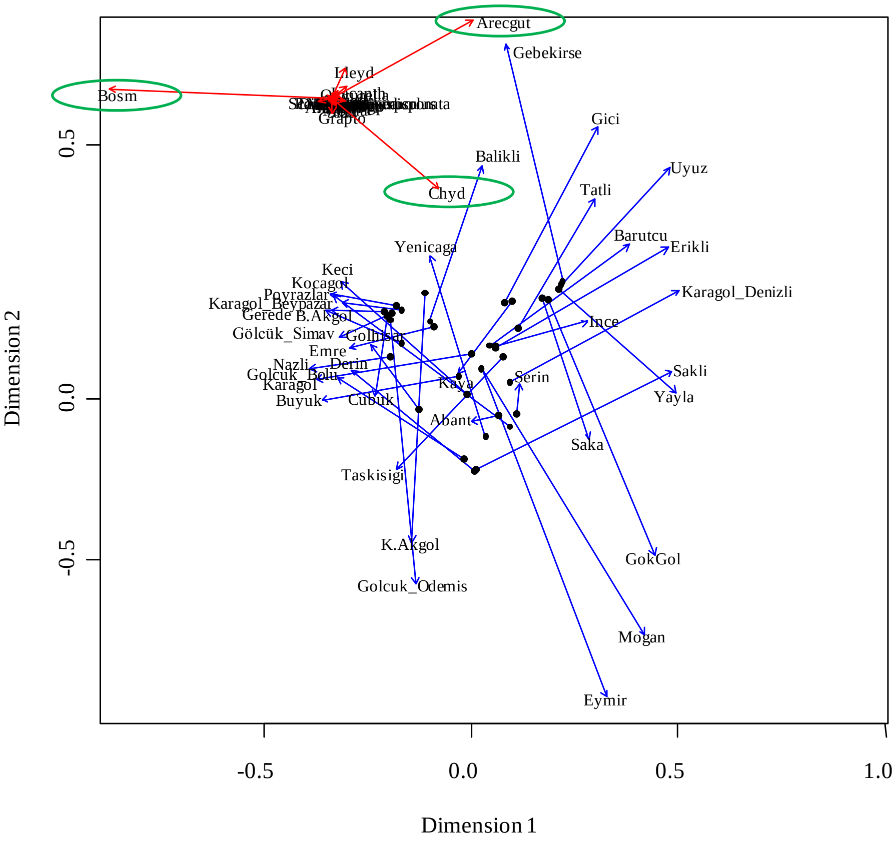

Figure 2.5. PROTEST plot generated from PCA scores. Circles represent contemporary samples and point of the arrows represent sedimentary samples, the distance between the two shows procrustes residuals. The overlaid species PCA plot were retained from sedimentary PCA.

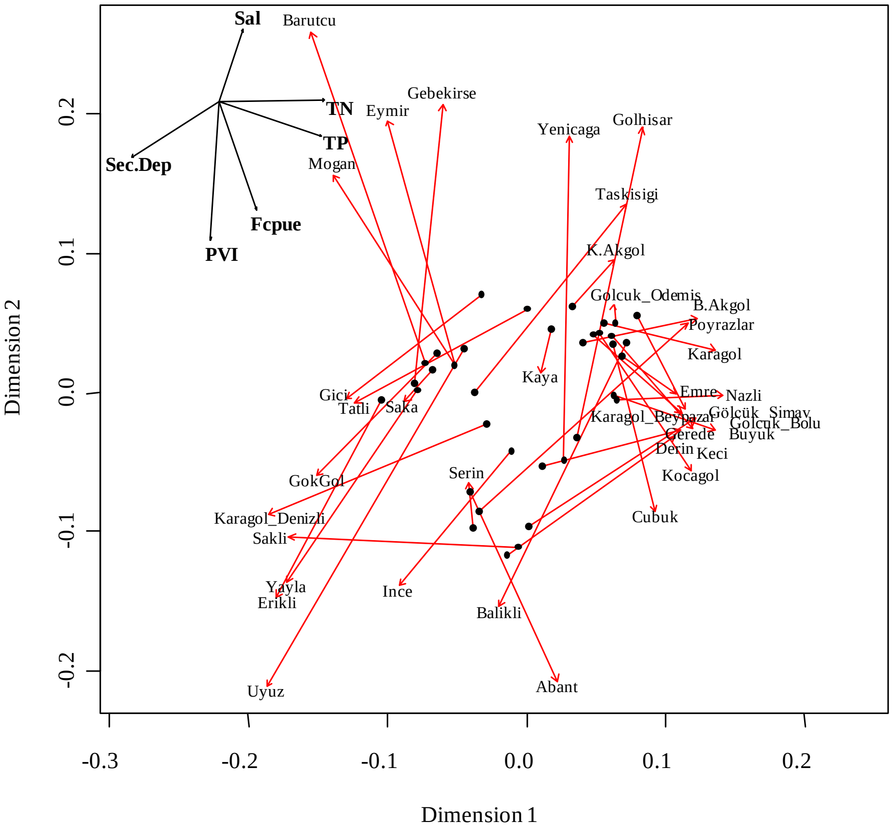

Figure 2.6. PROTEST plot generated from RDA scores. Circles represent contemporary samples and point of the arrows represent sedimentary samples, the distance between the two shows procrustes residuals. Environmental variables were retained from PCA.

PCA-Procrustes rotation plot showed several sites such as, Abant, Serin and Poyrazlar to have low residuals, indicating a high concordance between their ordinations. However, a number of lakes such as, Eymir, Mogan, K.Akgol, Gokgol and Golcuk_Odemis displayed low degree of similarity (Figure 2.5). The direction of the movement between the base and the end of the arrow of lakes Eymir, Mogan, K.Akgol, Gokgol and Golcuk_Odemis were related to the PCA ordination results and they were affected by *Chydorus sphaericus* (Figure 2.5). The sedimentary community of these lakes were dominated by *Chydorus sphaericus* exoskeletal remains, whereas other lakes either did not have or include very low abundance of this species. Similar results were observed for *Alona rectangula/gutata* with high residual lakes Gıcı, Uyuz, Erikli, Karagol_Denizli and Saklı (Figure 2.5).

RDA-procrustes rotation plot indicated several sites with low residuals. For instance, Lakes Kaya, Serin, Saka and Golcuk_Odemis revealed high correlation between the two datasets (Figure 2.6). However, a number of lakes such as Eymir, Mogan, Gebekirse, Barutcu, Yenicaga, Golhisar, Uyuz, Yayla, Erikli, and Balıklı displayed high procrustes residuals (Figure 2.6). The direction of movement between the circle and the direction of the arrow is related to environmental variables from RDAs. Accordingly, the point of the arrow (sub-fossil assemblage) for Eymir, Mogan, Gebekirse, Barutcu, Yenicaga and Golhisar reflects higher salinity concentrations than the the contemporary assemblages. The sub-fossil community for these lakes were dominated by *Chydorus sphaericus* which was positively associated with high salinity. Thus, not only the direction of the movement is a indication of the environmental relationships of the species in the lake but also the assemblage composition indicates the discrepancy between contemporary and sub-fossil data. Other examples are the high procrustes residuals of lakes Uyuz, Yayla and Erikli. Sedimentary assemblages of these lakes showed directions towards high PVI and high Secchi:Max depth ratio (Figure 2.6). Uyuz and Yayla had PVI of 57.4 and 69.3, respectively also Uyuz and Erikli had 1 and 0.8 Secchi:Max depth ratio respectively. The sub-fossil cladocera assemblage of these three lakes include high abundance of *Alona rectangula/gutata* which relate to high PVI and Secchi:Max depth ratio in the sedimentary RDA (Figure 2.3 and 2.5).

2.4. Discussion

Sedimentary Cladocera have been used to discover the changes in aquatic ecosystems. Elucidation of the sub-fossil cladoceran reconstruction is stands on the hypothesis that a modern-fossil cladoceran relationship. We recorded slightly more cladoceran species in the surface sediment samples (27 species) than in the contemporary samples (20 taxa). There was a strong correspondence in the response of the cladoceran community to the changing environment between the late summer modern community samples and the surface sediment samples. Salinity and TP explained most of the variation in contemporary communities, while only salinity did for the sub-fossil communities. Salinity was not only the major structuring variable in both data matrix, but also described very similar percent variance in the different assemblages.

In our sedimentary dataset *Diaphanosoma* sp., *Macrothrix* sp., *Scapholeberis mucronata* and *Polyphemus pediculus* were absent. Likewise in a study of Nykanen et al. (2009) in Lake Vesijärvi, Finland no large body parts of *Diaphanosoma* sp. was found. These authors used a 50 µm sieve and found that most cladoceran species were well represented, except for *Diaphanosoma* sp., reflecting the small claw size of this species. Kattel et al. (2007) compared species diversity and mean percentage composition of live Cladocera in littoral and pelagic with the percentage composition of remains deposited in the surface sediment of Loch Coire Fionnaraich, UK. As in our lakes, *Macrothrix* sp. and *Polyphemus pediculus* were recorded only in the contemporary samples and these authors suggested that these two taxa should not be taken into account in the comparison.

The dissimilarity in the incidence of species number between the contemporary and sedimentary data could be influenced by differences in the time period the samples represent. Contemporary assemblages were sampled in late summer whereas the surface sediment samples represent accumulation of approximately 1 and 3 years of sedimentation. Furthermore, the habitat preference of the species, together with sampling strategy, could be the reason for their absence in the contemporary dataset. For instance, some lakes had high abundances of the pelagic species *Moina* spp. in their contemporary assemblages. Since *Moina* spp. are identified by ephippia in sedimentary samples, the difference may be caused by ephippia floating from the pelagic to the littoral or favourable environmental conditions for sexual reproduction (Frey, 1982).

RDA ordinations indicated a similar proportion of variance to be explained for contemporary and sub-fossil Cladocera assamblages when all environmental variables were used. Monte Carlo permutation test in RDAs specified that for contemporary assemblage TP and salinity and for sub-fossil assemblage only salinity were the significant variables. Phosphorus indirectly affects Cladocera by changing their food quality and habitats. Studies from temperate and Mediterranean lakes showed that cladoceran richness was significantly unimodally related to TP (Jeppesen et al., 2000; Bos and Cumming, 2003; Gyllström et al., 2005).

Contemporary species, *Leydigia leydigi, Chydorus sphaericus,* and *Alona quadrangularis* were found to be related to salinity. This agrees with previous studies for instance, *Chydorus sphaericus* is euryhaline species and was found high range of salinities, *Alona quadrangularis* was found in Danish lagoons (Brucet et al., 2009) and *Leydigia leydigi* was found in lakes with moderate to high salinity (Bos et al., 1999). A declining trend of species diversity with increasing salinity was found in contemporary data whereas an increasing trend was found in sedimentary data. For the contemporary data this trend is in agreement with other observations (Boronat et al., 2001; Amsinck et al., 2005a).

Procrustes rotations and the associated PROTEST permutation tests using PCA and RDA revealed that a number of lakes displayed high residuals showing low similarity. These marked differences were mainly a result of differential deposition of cladoceran remains in the sediment. The spatial distribution and areal coverage of contemporary littoral and pelagic cladoceran populations, together with transport-sedimentation processes in the lake when they disarticulated, affect the composition of species assemblages in lake sediment (Nykanen et al., 2009). Another explanation could be that the contemporary assemblages were sampled in late summer whereas the surface sediment samples represent accumulation of disarticulated cladocera. Besides different species composition between these two data sets, environmental parameters were also caused high residuals shown in RDA-Procrustes plot.

Apart from some difficulties with comparing modern and sub-fossil data, we found high correspondence in the cladoceran community reaction to the changing environment between the modern, water column community sampled in late summer and the sub-fossil assemblages from surface sediment sample collected from the deepest part of the lake.

CHAPTER 3

SURFACE SEDIMENT SUB-FOSSIL CLADOCERA CALIBRATION AS INDICATORS OF SALINITY IN FORTY FOUR TURKISH SHALLOW LAKES

3.1. Introduction

Climate change is expected to intensify current stresses on water resources. Changes in precipitation and temperature lead to changes in runoff and water availability. Runoff expected to decrease by 30 % in some dry regions at mid-latitudes and dry tropics, suffering a decrease in water resources (IPCC, 2007).

Climate change will further affect the physical, chemical and biological properties of freshwater lakes and rivers, with predominantly adverse impacts on many individual freshwater species, community composition and water quality (IPCC, 2007). From 1900 to 2005 precipitation declined in the semi-dry Mediterranean climatic region and the areas have already been affected by drought whose intensity increased since 1970s (IPCC, 2007). As part of the Mediterranean climatic region, Turkey is highly susceptible to impacts of climate change. Many studies revealed a recent warming trend which extends from early 1990s to the present day in Turkey (Türkeş et al. 1995; Kadıoğlu 1997; Türkeş et al., 2002). Furthermore, recent studies reported general decreasing precipitation trend over western and southern parts of Turkey (Türkeş et al. 2009).

Turkish shallow lakes and their functions and services are very susceptible to hydrological changes, such as hydraulic residence time and water level fluctuations (Beklioğlu et al., 2006; Ozan et al. 2010; Bucak et al. 2012). Hydrologoical alterations have shown to lead salinization and eutrophication of Turkish shallow lakes (Beklioğlu et al., 2006; Beklioğlu and Tan, 2008; Beklioglu et al. 2010; Ozan et al. 2010; Bucak et al. 2012). Moreover, global climate change complicates the lake processes with the salinity increase and thus, decrease of species diversity (Naselli-Flores and Barone, 2003; Coops et al., 2003; Talling, 2001; Beklioğlu et al., 2006; Beklioğlu et al., 2007; Beklioğlu and Tan, 2008).

Paleolimnology, one of the methods for understanding climate change affects, plays a pivotal role in paleoclimatic and global change investigations, in many fields of environmental science, and hydrocarbon and mineral resource exploration and exploitation (Last and Smol, 2001). Lake sediments are valuable archives of environmental changes, because lakes are geographically widespread and their sediments are often continuous and datable (Wolfe et al., 2004; Brinner, 2006). Gaining insight into the development of lakes, their past conditions and future trends are important to assess the adaptation of environments to global processes such as global climate change (Punning et al., 2003).

Sub-fossil Cladocera is one of the biological proxies helping to understand climate driven effects on lake ecosystems. The importance of Cladocera in both contemporary and paleolimnological studies comes especially from their position in the food web (Jeppesen et al., 2011, Davidson et al., 2011). Being herbivorous they occur as a link between algae and zooplanktivorous fish indicating their sensitivity to ecosystem change (Jeppesen et al., 1997, Moss, 1998; Abrantes et al., 2006). Furthermore, increasing their importance in paleolimnological studies is because cladocerans are small (300-3000 μm) crustaceans, their hard and chitinized shelled forms are well preserved in the sediment and the preservation of their skeletal components can be used quantitatively because their relative abundance in the sediments are in relation with their original water column alive population (Korhola and Rautio, 2001; Szeroczynska and Sarmaja-Korjonen, 2007). Cladocera remains can be used to inferboth quantitatively and qualitatively trophic structure, plant composition, fish population, climatic change, eutrophication, salinity, and water-level fluctuation (Jeppesen et al., 1996; Hofmann, 1998; Lotter et al., 1998; Bos et al., 1999; Jeppesen et al., 2003; Johansson et al., 2005; Amsinck et al., 2005; Korhola et al., 2005). Most of the published literature on sub-fossil Cladocera comes from Europe (Korhola and Rautio, 2001; Bjerring et al., 2009; Davidson et al., 2010, 2011). To the best of our knowledge there has been no study so far carried out on sub-fossil Cladocera from Turkish lakes.

Here with the current study first time, 44 shallow Turkish lakes were thoroughly studied for the lake environmental variables and cladoceran species composition in the surface sediments. The aim was to investigate the key environmental factor that was related with climate change structuring cladoceran community composition.

3.2. Materials and methods

3.2.1. Study sites

The 44 study lakes were all shallow, small and spanning over 5 latitudes from the semi-arid north (41°52´N, 27°58´E) to the arid south (37°06´N, 29°36´E) of Turkey (Figure 3.1, Appendix A). Environmental variables and surface sediments were sampled during July, August and September 2006 - 2012.

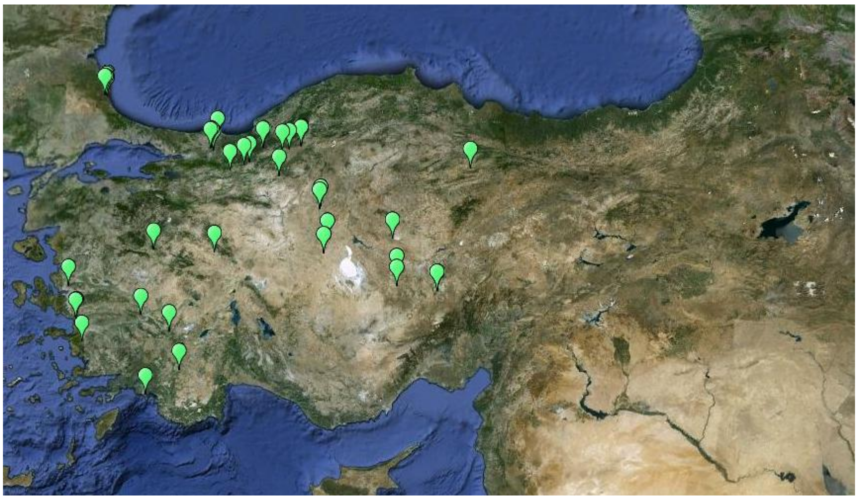

Figure 3.1. Location of studied 44 shallow lakes (map taken from Google Earth, July, 2012).

3.2.2. Fieldsampling and laboratory analyses

A standardized snap shot sampling procedure was employed for sampling of 44 lakes sediment samples, physicochemical and biological variables as given in Chapter 2. Also, sub-fossil Cladocera sediment samples were analyzed according to the method given in the Chapter 2.

3.2.3. Data analyses

Environmental data and species data were transformed prior to statistical analyses following the same procedures given in Chapter 2. In addition, for the weighted averaging methods, species data were square root transformed.

As explained in Chapter 2, DCA was first performed on Hellinger transformed species data in order to determine whether unimodal or linear ordination techniques were suitable for the data of the current study. Then, linear ordination method RDA was applied and after Monte Carlo permutations non-significant environmental variables were removed from ordination analysis. Finally, a series of partial RDA ordinations using only the significant environmental parameters was run to determine the % variance explained by each single variable.

Weighted averaging (WA), weighted averaging with tolerance down weighting (WA_{tol}) with both inverse and classical deshrinking and weighted averaging partial least squares (WA-PLS) regression models were applied to calibration data set including cladoceran and environmental data to infer salinity using the program C2 (Juggins, 2003). The optimal model was selected using their coefficients of determination (r^2), root mean square error (RMSE) and by the root mean square error of prediction (RMSEP). Predicted values and RMSEP were obtained by bootstrapping cross-validation for WA and WA_{tol} models and by leave one out cross-validation for WA-PLS model (Birks, 1995). Additional components for WA-PLS models were considered useful if they gave a reduction in the prediction error of at least 5 % (ter Braak and Juggins, 1993, Birks, 1998).

The physical, chemical, biological and sedimentary data were obtained from Beklioğlu et al., (in preperation) and TÜBİTAK Project no: 110Y125. Thus, the same data excluding sub-fossil Cladocera will be used in the several PhD thesis who have carried out their thesis at METU, Biology Department (Şeyda Erdoğan, Gizem Bezirci, Eti Ester Levi) and was used in completed PhD thesis (Ü. Nihan Tavşanoğlu and ArdaÖzen).

3.3. Results

3.3.1. Environmental data

The 44 study lakes were generally small and shallow with maximum depth ranged from 55 to 1740 cm and located from sea level to 1453 m altitude (Appendix A). Most of the lakes had freshwater excluding seven lakes whose salinity measures between 1.4 and 5.8 ‰. Surface water temperature were relatively warm (average=24.49^{0}C) of all 44 lakes as a result of warm sampling season and were well oxygenated (average=6.56 ml L^{-1}). Most of the lakes had pH values close to neutral. Lakes were generally eutrophic (average TP=139 µg L^{-1}, TN=1088 µg L^{-1}, Chla=25 µg L^{-1}). Thus, water clarity was low with average Secchi/Maximum depth ratio of 0.4.

Among 44 study lakes, the abundance of planktivorous fish was much higher than that of piscivorous in fact most of the southern lakes had no piscivorous fish. The study lakes had PVI %ranging from 0 to 100 % (Table 3.1).

Table 3.1. Summary statistics of environmental variables from the 44 Turkish shallow lakes.

Variables	Min.	Max.	Mean	Transformation
Altitute (m)	1	1423	747	$\log_{10}$
Lake size (ha)	0.10	635	67.09	$\log_{10}$ (x+1)
Maximum depth (cm)	55	1740	393	$\log_{10}$
Temperature (°C)	18.30	32.37	24.49	$x^{1/2}$
Salinity (‰)	0.06	5.82	0.73	$\log_{10}$
Dissolved Oxygen (mg L^{-1})	0.56	15.32	6.56	$\log_{10}$
pH	6.29	9.64	8.12	-
Suspended Solids (mg L^{-1})	4.00	208.6	40.90	$\log_{10}$
Total Dissolved Solids (mg L^{-1})	0.07	6.66	0.91	$\log_{10}$ (x+1)
Secchi Depth/Maximum Depth	0.05	1.00	0.39	$\log_{10}$ (x+1)
Total Phosphorus (µg L^{-1})	15.04	632.57	139.70	$\log_{10}$
Soluble Reactive Phosphate (µg L^{-1})	3.38	187.89	37.00	$\log_{10}$
Total Nitrogen (µg L^{-1})	238.80	2340.02	1088.67	$\log_{10}$
NH_4 (µg L^{-1})	2.45	565.07	109.91	$\log_{10}$
NO_2+NO_3 (µg L^{-1})	1.50	1721.98	67.92	$\log_{10}$
Silicate (µg L^{-1})	1096	15652	4921	$\log_{10}$
Alkalinity (meq L^{-1})	0.50	24.50	4.16	$\log_{10}$ (x+1)
Chlorophyll-*a* (µg L^{-1})	0.66	163.28	24.79	$\log_{10}$
Plant Volume Inhabited (%)	0.00	100.00	22.20	$x^{1/2}$
Total Fish (gr net^{-1} $night^{-1}$)	0.00	3965.73	1125.73	$x^{1/2}$
Total Fish (number of fish net^{-1} $night^{-1}$)	0.00	1425.00	140.97	$x^{1/2}$

These 44 study lakes could be grouped into three namely, eutrophic lakes, clear water lakes and saline lakes (31 lakes from Beklioğlu et al., in prep. and 13 lakes from unpublished data). Eutrophic lakes were characterized by having high concentrations of TP and chlorophyll-*a*, while clear water lakes were characterized by high Secchi/Max depth and PVI % which are mostly located in the higher latitudes. Furthermore, among clear water lakes high fish biomass was observed when PVI % was high. Finally, the third group consisted of saline lakes which are located in the south.

3.3.2. Species data

Cladocera sub-fossils were collected in all 44 lakes' surface sediments and a total 26 species were identified (Table 3.2; Appendix B-C). *Bosmina longirostris* and *Chydorus sphaericus* were the most common and dominant species. Chydoridae family with 18 taxa had the highest diversity. In ordination analyses *Pleuroxus* and *Daphnia* species added together and used as total *Pleuroxus* spp. and *Daphnia* spp. taxa.

Table 3.2. Cladoceran sub-fossils collected from the 44 study lakes, with number of occurance (Count), maximum abundance, predicted salinity optimum and tolerance values using weighted averaging methods.

Family	Species	Count	Maximum abundance (%)	Salinity Optimum (‰)	Salinity Tolerance (‰)
Sididae	*Sida crystallina* (O.F.Müller, 1776)	4.00	9.53	0.22	0.31
Daphniidae	*Daphnia* spp.	21.00	4.56	0.64	0.62
Daphniidae	*Simocephalus* sp.	7.00	1.41	0.75	0.69
Moinidae	*Moina* sp.	10.00	2.41	0.54	0.57
Ilyocryptidae	*Ilyocryptus* spp.	6.00	1.41	0.09	0.03
Bosminidae	*Bosmina longirostris* (O.F.Müller, 1785)	38.00	88.48	0.24	0.37
Chydoridae	*Eurycercus lamelatus* (O.F.Müller, 1785)	2.00	1.18	0.10	0.04
Chydoridae	*Pleuroxus* spp.	26.00	9.22	0.45	0.35
Chydoridae	*Alonella exigua* (Lilljeborg, 1853)	13.00	4.49	0.26	0.37
Chydoridae	*Alonella excisa* (Fischer, 1854)	13.00	4.77	0.40	1.13
Chydoridae	*Alonella nana* (Baird, 1850)	8.00	7.50	0.13	0.19
Chydoridae	*Disparalona rostrata* (Koch, 1841)	8.00	2.45	0.10	0.04
Chydoridae	*Chydorus sphaericus* (O.F.Müller, 1776)	42.00	34.38	0.74	1.20
Chydoridae	*Alona quadrangularis* (O.F.Müller, 1785)	21.00	5.29	0.21	0.26
Chydoridae	*Alona rectangula/gutata*	41.00	28.11	0.84	1.44
Chydoridae	*Alona affinis* Leydig, 1860	8.00	2.05	0.18	0.16
Chydoridae	*Acroperus harpae* (Baird, 1835)	16.00	4.71	0.82	1.68
Chydoridae	*Camptocercus* sp.	7.00	2.45	0.23	0.22
Chydoridae	*Ceriodaphnia* spp.	33.00	4.00	0.48	0.60
Chydoridae	*Graptoleberis testudinaria* (Fischer, 1848)	20.00	12.17	0.32	0.44

Table 3.2. (continued)

Chydoridae	*Kurzia latissima* Kurz, 1875	4.00	1.00	0.12	0.06
Chydoridae	*Oxyurella tenuicaudis* (Sars, 1862)	3.00	8.37	0.49	0.18
Chydoridae	*Leydigia leydigi* (Schoedler, 1863)	28.00	12.81	0.66	1.10
Chydoridae	*Leydigia acanthocercoides* (Fischer, 1854)	18.00	4.75	1.16	1.46
Leptodoridae	*Leptodora kindtii* (Focke, 1844)	2.00	2.28	0.17	0.04

3.3.3. Ordination

Sub-fossil cladocerans from the surface sediment and contemporary environmental variables were used together in order to generate a calibration data set using ordination techniques.

As the DCA first axis length had 2.21 standard deviation units, the linear direct ordination method, redundancy analysis (RDA) was consequently employed. These environmental variables from 44 lakes captured 32.9 % of the total variation in the species composition of sub-fossil (Figure 3.3). The eigenvalues of the RDA for the 1st and the 2nd axis were λ_1=0,110 and λ_2=0.011, respectively. The first axis accounts for 81 % of the constrained variability and the second axis explained 8 % of the discerned variation. According to significance test only axis 1 was the significant axis ($p<0.001$). Axis 1 was correlated with salinity and PVI whereas axis 2 was positively correlated with Secchi/Max Depth and negatively correlated with fish abundance and total phosphorus (Figure 3.3). *A.rectangula/gutata* (Arecgut) was positively correlated with axis 1 in contrast *B.longirostris* (Bosm) was negatively correlated with axis 1. It was suggest that *A.rectangula/gutata* tolerates high salinity whereas *B.longirostris* prefers low salinity environment. *C.sphaericus* (Chyd), *L.leydigi* (Lleyd) and *L.acanthocercoides* (Lacanth) were negatively correlated with axis 2. Thus, these species can be found in eutrophic lakes with high TP and low Secchi/Max Depth.

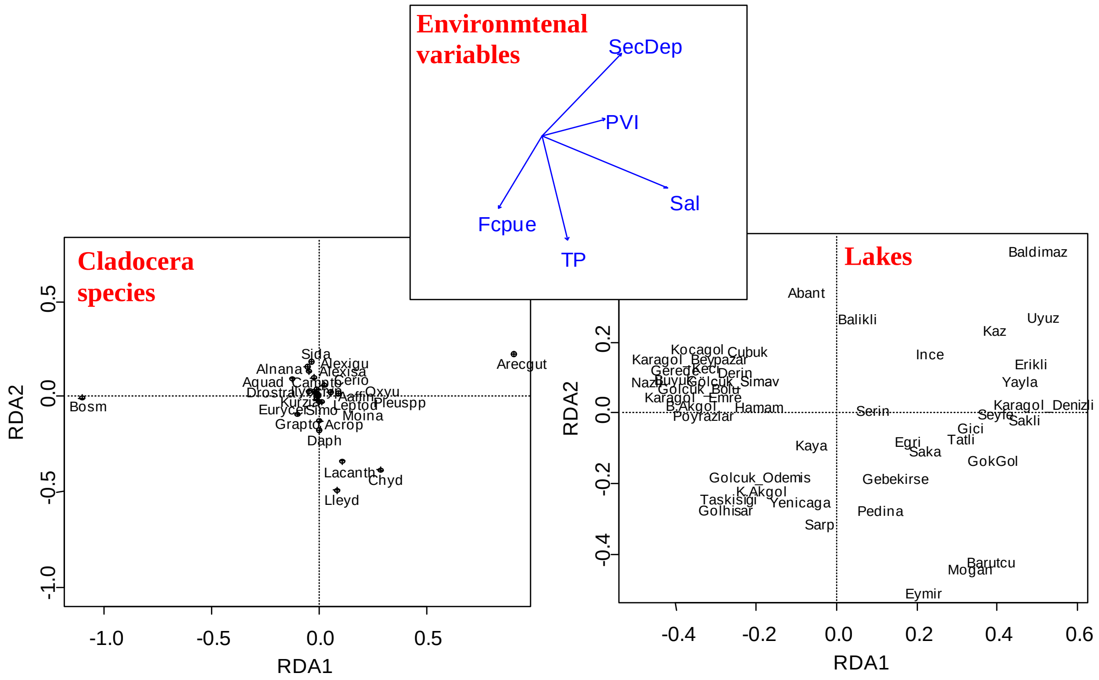

Figure 3.2. RDA of 44study lakes and sedimentary cladoceran samples with the environmental variables.

Monte Carlo permutation test for RDA revealed that salinity ($p<0.001$) and Secchi/MaxDepth ($p<0.05$) were the minimum set of environmental variables that could explain the greatest amount of variation in the data set (Table 3.3).

Table 3.3. Results of Monte Carlo permutation test of RDA for the 44 study lakes.

	p-value	% variance explained
Salinity	<0.001	17
Secchi/MaxDepth	<0.05	8

As a result, salinity explained the most variance, suggesting that Cladocera sub-fossils can be used to develop strong inference models to reconstruct lake past water salinity.

The species distribution in the RDA ordinations showed that *L.leydigi*, *L.acanthocercoides*, *Daphnia* spp., *C.sphaericus*, *Moina* spp. and *A.harpae* appeared to prefer conditions with high salinity (Figure 3.3). The macrophyte and benthic associated species *A.rectangula/gutata* seemed to prefer clear water conditions with low nutrient concentrations. The relatively large-sized species *E.lamellatus*, *Simocephalus* sp., *Daphnia* spp., *E.lamellatus*, and *G.testudinaria* appeared to choose turbid waters even these lakes had high fish abundance.

3.3.4. Calibration set

Calibration data set with square-root transformed biological and untransformed salinity data were used for developing sub-fossil Cladocera based transfer functions in order to infer past salinity change of the Turkish shallow lakes. The whole data set with 44 lakes were used for inference models. Summary statistics of fourth component weighted averaging partial least squares (WA-PLS-4), weighted averaging tolerance down weighting (WA_{tol}), inverse deshrinking models based on 44 lakes were given in Table 4. WA_{tol} model did not contribute 5 % improvement of RMSEP although; WA-PLS-4 model resulted in an optimal performance with $r^2$of 0.74 and RMSEP of 1.02 ‰ (Table 3.4). Thus, WA-PLS-4 model had better predictability and higher coefficient of determination than the models using WA. However, WA method was used to estimate the salinity optima and tolerance values for 26 cladocera taxa. Among the 26 taxa, *Ilyocryptus* spp., *Disparalona rostrata*, and *Eurycercus lamellatus* had the lowest salinity optima of 0.09, 0.10 and 0.10, respectively whereas *Leydigia acanthocercoides*, *Alona rectangula/gutata*, *Acroperus harpei*, *Simocephalus* sp. *Chydorus sphaericus*, and *Leydigia leydigi* had the highest salinity optima of 1.16, 0.84, 0.82, 0.75, 0.74 and 0.66, respectively (Table 3.2). All other taxa had an average optimum salinity of 0.32 ‰.

Table 3.4. Root mean square error (RMSE), root mean square error of prediction (RMSEP), coefficient of determination (r^2) and % reduction in root mean square error of prediction (% Change) of 44 lakes data sets.

Model	**RMSE**	**RMSEP**	r^2	**% Change**
WA_{tol}- Inverse deshrinking	0.14	0.18	0.53	
WA-PLS-4	**0.65**	**1.02**	**0.74**	**8.4**

3.4. Discussion

The environmental variables collected from 44 study lakes and cladoceran species composition in the lake surface sediments demonstrated that salinity is the most significant parameter to discern surface sediment cladoceran assemblages.

Lakes were grouped into three according to Beklioglu et al. (in prep). The first group was composed of lakes characterized as eutrophic and had high concentrations of TP and chlorophyll-*a*, while the second group included lakes with clear water and high PVI %. Some of the second group of lakes were characterized by having high fish biomass while having high PVI %. Among which one of the group was characterized by being saline which were all southern inland lakes. Because of higher evaporation than precipitation ought to be the reason for these lakes becaming saline (Moss, 1994; Jeppesen et al., 1997) along with human hydrological alterations (Beklioğlu et al., 2011). For instance, inland southern lakes had been under the influence of anthropogenic affects such as, low underground water table as a result of intense irrigation (Yağbasan et al., 2012).

Salinity and water clarity (Secchi/MaxDepth) were important variables influencing sub-fossil Cladocera assemblages in Turkish shallow lakes. Salinity explained the most variance, suggesting that Cladocera sub fossils can be used to develop strong inference models to reconstruct lake water salinity. Cladocerans are sensitive to salinity unlike other zooplankton they are largely restricted to freshwater habitats (Dodson 2001). An increase in salinity in freshwater ecosystems affects the dynamics and abundance of cladocerans (Bos et al., 1999, Amsinck et al., 2005, Brucet et al., 2009) because of their physiological intolerances (Jeppesen et al., 2011).Salinity controls both cladoceran species richness and species composition (Hobaek et al. 2002, Green, 2005).

Our findings support those of Bos et al. (1999) who showed salinity to be a key predictor of Cladocera species composition in Interior Plateau of British Columbia. Moreover, in coastal brackish lakes cladoceran species richness also declined with increasing salinity (Amsinck et al., 2005, Brucet et al., 2009). RDA ordinations showed that *L.leydigi*, *L.acanthocercoides*, *Daphnia* spp., *C.sphaericus*, *Moina* spp. and *A.harpae* appeared to prefer conditions with high salinity. These taxa were similar with previous studies on cladoceran community structure with salinity in both fresh and brackish water lakes (Amsinck 2005; Bjerring 2009; Bos et al. 1999). Furthermore, high salinity preference of *L.acanthocercoides* and *L.leydigi* were shown by Amsinck et al. (2005) this is in accordance with our findings.

The macrophyte associated species *S.crystallina*, *A.nana*, *Camptocercus* sp., *G.testudinarius*, and *A.harpei* seemed to prefer clear water conditions with low nutrient concentrations. Bjerring et al. (2009) also stated that macrophyte associated taxa were found in lakes with low nutrient concentrations in their 54 Pan-European lakes comparisions' study.

The large-sized species *E.lamellatus*, *Simocephalus* sp., and *Daphnia* spp. appeared to choose turbid waters even these lakes had high fish abundance. This situation contradicts with size-selective fish predation (Brooks and Dodson, 1964; Kitchell and Kitchell, 1980). Although these lakes had high fish abundance, water turbidity became as refuge for cladocerans against fish predation (Horppila et al., 2004; Nurminen et al., 2008). Furthermore, turbidity seems to be a critically important refuge for large cladocrans from high fish predation in Turkish shallow lakes (Tavşanoglu, 2012).

Results from the inference model suggested that cladocera assemblages from lake surface sediment were potentially well suited for reconstructing salinity in Turkish shallow lakes.WA-PLS-4 model based on 44 lakes produced more reliable inference model having low RMSE and higher r^2.These values were stronger than Cladocera-salinity inference model (Bos et al., 1999) of 33 British Columbian lakes in Canada and 36 shallow coastal brackish lakes study in Denmark (Amsinck et al., 2005).

In conclusion, to the best of our knowledge the current study proceed the inference models with the better predictability and reliability compared to the earlier approach by Bos et al. (1999) in freshwater lakes. Our results indicated that Cladocera assemblages preserved in lake sediments were reliable and sensitive indicators of lake salinity. Cladoceran sub-fossils can be a useful tool in the paleolimnological reconstruction of salinity in shallow lakes, which may help interpret past changes in climate.

CHAPTER 4

HINDCASTING OF CLADOCERA-BASED SALINITY TRANSFER FUNCTION USING LONG TERM MONITORING DATA IN TWO INTERCONNECTED SHALLOW ANATOLIAN LAKES

4.1. Introduction

Lake levels change via precipitation and temperature fluctuations. Recent studies reported a decreasing trend of precipitation in Turkey (Türkeş, 1996; Türkeş et al., 2009). Small, closed-basin lakes are sensitive to lake level fluctuations driven by climatic changes along with anthropogenic use. Turkish shallow lakes are influenced by Mediterranean climatic conditions and lake water levels change annually from 1 m to 3 m depending on local conditions and also anthropogenic uses (Beklioğlu et al., 2001; Beklioğlu et al., 2006 and 2007). Moreover, according to global climate change predictions, Mediterranean region will receive 20-23 % lower precipitation and extreme drought will be expected as a result of high evaporation (Giorgi, 2006). In addition to global climate change effects, water level decline in lakes triggered through long term drought periods may result in salinization (Beklioğlu and Tan, 2008). Furthermore, water level fluctuation has a crucial effect on lake ecosystems through changes in nutrient level, light availability, biological relationships and primary production (Blindow, 1992; Beklioğlu et al., 2001; Tan and Beklioğlu, 2006).

Cladocerans are sensitive to anthropogenic and natural forces in lakes and their catchments (Manca et al., 2007). Therefore, sub-fossil remains of the cladocerans in lake sediment are indicators of past environmental changes (Frey, 1986; Jeppesen et al., 2001; Korhola and Rautio, 2001). Thick chitinous-shelled forms (i.e. Chydorids) of Cladocera are well preserved in lake sediments whereas thin-shelled taxa (i.e. Daphnids) are preserved as small particles such as post abdominal claws and resting eggs. Body length and habitat preferences of Cladocera are important properties to infer changes in size-selective predation, changes in trophic structure, habitat alterations (Frey, 1986; Jeppesen et al., 2000; Barnett et al., 2007). Salinity is an important ecological controlling factor for zooplankton (Amsinck et al., 2005). In general, species richness and diversity decline with salinity increase (Frey, 1993; Bos et al., 1999; Boronat et al., 2001, Brucet et al., 2009) because of their limited osmoregulation capacity (Aladin, 1991). Moreover, contemporary studies showed that top-down effect on zooplankton is higher in high saline lakes compared to freshwater lakes (Jeppesen et al., 1997; Tavşanoğlu, 2012).

Monitoring programs can provide valuable information on the development of water bodies as well as their response to environmental changes, but are usually restricted to the past few decades. Especially in Turkey monitoring programs are scarce. Paleolimnological data can provide useful information about lake ecosystems prior to the monitoring programs (Anderson and Battarbee, 1994). However, validation of paleolimnological research is rarely tested. There are two ways, direct and indirect, for hindcasting the paleolimnological inference models (Hauptfleisch et al., 2012). Indirect way uses surface sediment microfossils to correlate contemporary biota of the lake as in Chapter 2 then uses this relationship in down-core microfossil assemblages. Direct way uses long term monitoring of the biota and dated sediment sequence (Anderson, 1995). For instance, Manca et al. (2007) described the changes in trophic structure in Lake Maggiore, Italy from 1943 to 2002 by studying sub-fossil cladoceran assemblages and body size distributions. They validated their results with long-term plankton studies in the lake and found a good correlation between inferred trophic changes and contemporary data. Furthermore, Hauptfleisch et al. (2012) used Chironomid and Cladocera microfossils in sediment cores from Lake Myvatn, Iceland to examine food web fluctuations and biomonitoring data since 1975. This study showed good correspondence between these two dataset and gave the opportunity to explore the long term food web history of the lake ecosystem.

The present study reveals the results of a paleolimnological investigation of two interconnected shallow lakes in Central Anatolia, Lake Mogan and Lake Eymir. The objective was to elucidate whether sub-fossil cladoceran species in sediment cores could be used to describe the historical changes in the salinization of the two lakes. Moreover, changes in ^{210}Pb-dated sediment records of the sub-fossil cladoceran community and cladoceran inferred salinity data compared with existing long term monitoring data including physical (water level, etc.), chemical (total phosphorus, etc.) and biological variables (zooplankton, fish, etc.) of Lakes Mogan and Eymir. These lakes are two ideal interconnected sites for conducting a comparative study of paleolimnological and limnological data because of the availability of 15 years monitoring data.

4.2. Materials and Methodologies

4.2.1. Study Sites

Lake Mogan (39^{o}46'05"N; 39^{o}47'33"E) and Lake Eymir (39^{o}49'32"N ;39^{o}49'54"E;) are two shallow lakes located in the Central Anatolia, 20 km south of the metropolitan city of Ankara, Turkey (Figure 4.1, Appendix A). Lake Mogan occupies an area of 5.4 km^2 with elevation of 973 m. The mean depth of Lake Mogan is 2.8 m with maximum depth reaching 4 m. Lake Eymir, located downstream from Lake Mogan, is relatively small with a surface area of 1.25 km^2 with elevation of 968.5 m. The mean depth of Lake Eymir is 3.1 m with maximum depth reaching 6 m. The surface and ground water runs through a wetland located at the northeast of Lake Mogan through Lake Eymir. The main inflows of Lake Mogan are Gölcük, Sukesen, Çölovası and Yavrucak brooks and also, İkizce and Dikilitaş reservoirs are situated at the upstream. Furthermore, Kışlakçı brook, flows into the Lake Eymir and the Lake Eymir runs out to the İmrahor Creek from the northeast part of the lake. All the inflows of Lake Eymir mostly dries out in summer seasons (Beklioğlu et al., 2003; Özen et al., 2010) in addition; groundwater levels have been decreasing according to EİE (2009). Furthermore, in both lakes majority of the lake volume were lost per year as a result of evaporation (Özen et al., 2010) resulting salinity increase.

Semi-arid climate conditions exist in the study sites and it is characterized as high precipitated winters and hot and dry summers. The driest period is from June to September. According to Gölbaşı meteorological station, average precipitation is 405±80 mm and average temperature is 11.9±8.4°C obtained from the data between 1980 and 2011(Turkish State Meteorological Service, 2011). According to water level, there were two periods were observed in both Eymir and Mogan (Özen et al., 2010; Tavşanoğlu, 2012). The dry years 2001 and between 2005 and 2009 resulted the low water level (LWL) period and the years in between resulted the high water level (HWL) period in both lakes.

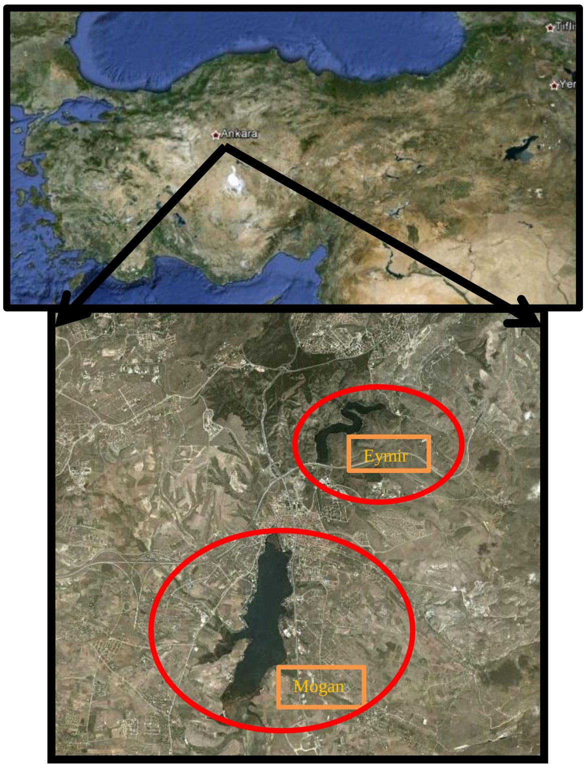

Figure 4.1. The location of Lakes Eymir and Mogan.

Lake Eymir received raw sewage effluents over 25 years until the sewage diversion was carried out in 1995 (Altınbilek, 1995; Beklioğlu et al., 2003). The diversion reduced the external loading of total phosphorus by 89 %. However; water clarity was not recovered fully. During the period of 1998 to 1999, fifty percent of planktivorous fish (*Tinca tinca,* Linnaeus 1758 and *Cyprinus carpio,* Linnaeus 1758) were taken out and pike fishing was banned (Beklioğlu et al. 2003). After the first fish removal year, the water clarity recovered and submerged macrophytes coverage increased from 2.5 % to 30-80 %. Five years later, the recovery started to decline through extended drought with increasing nutrient concentrations through internal mechanisms and increasing fish biomass to the pre-biomanipulation level (Beklioglu and Tan, 2008; Özen et al. 2010). After that, the second biomanipulation started in 2006 and still continues.

Previous studies found that Lake Mogan was a clear water lake with high macrophyte coverage (Burnak and Beklioğlu, 2000) and very sensitive to hydrological changes (Zhang et al., 2003a; Zhang et al., 2003b). In Lake Mogan, though there was no biomanipulation afford, lake's fish community of lake shifted from *Esox lucius*, Linnaeus 1758, *Tinca tinca*, *Cyprinus carpio*, , and *Siluris glanis*, Linnaeus 1758 to exotic and invasive species *Pseudorasbora parva* (Temminck and Schlegel, 1846) and dominated with dissaperance of pike (Beklioğlu et al., unpubl data; DSI, 1993; ÖÇKK, 2002; Akbulut and Akbulut, 2002; Manav and Yerli, 2008). According to monitoring data the the most abundant cladocerans are large sized *Daphnia magna* and *D. longispina* also *Ceriodaphnia* sp. and *Diaphanasoma lacustris* (Korinek, 1981) whereas the small sized *Chydorus sphaericus*, *Bosmina longirostris* and *Alona* spp. (*A. rectangula* Sars, 1862 and *A. affinis* Leydig, 1860) had very low biomass (Tavşanoğlu, 2012). Moreover, in 2008, the highest salinity year, *D. magna*, *D. longispina* and *Diaphanasoma* achieved the maximum biomass (Tavşanoğlu, 2012).

In Lake Eymir, the dominant cladoceran taxa were the large-sized *D. pulex* and *D. magna* during the low fish predation years. In addition, *Diaphanasoma brachyurum*, *Ceriodaphnia* sp. and small sized *Chydorus sphaericus*, *B. longirostris*, *Alona* sp. and *Pleuroxus* sp. were identified in the lake (Tavşanoğlu, 2012). According to monitoring data since 1997, during the low water level period

D. magna exhibited major increase in accordance with the high salinity values and less fish abundance as a result of the fish biomanipulation afford in contrast *D. pulex* did not display similar trend. Furthermore, *Ceriodaphnia* were found in high water level periods while *Diaphanasoma* and small cladocerans did not show this relationship (Tavşanoğlu, 2012).

4.2.2. Monitoring

From 1997 to present day, water samples for total nitrogen (TN), total phosphorus (TP), soluble reactive phosphate (SRP), alkalinity analyses and zooplankton, phytoplankton; chlorophyll *a* were taken at the deepest point of each lake from depth integrated, from the water column by using water sampler (between 2007 and present day) and tube sampler (between 1997 and 2007) and conductivity and salinity were measured by using Orion conductivity meter in the laboratory. After 2007, salinity (‰), conductivity ($\mu S\ cm^{-1}$), pH, dissolved oxygen ($mg\ L^{-1}$) and temperature (◦C) were measured *in situ* by using YSI 556 multiprobe field equipment.

Percent plant coverage were estimated by doing parallel transects along the each lake and collecting submerged macrophyte data. Moreover, Plant Volume Inhabited (PVI %) was calculated by using the equation below.

% PVI= (%coverage * average plant height) /water depth.

In Lake Eymir, fish surveys were completed using multi-mesh gill nets (100m length and 3.5m height nets with 7, 9, 12, 16, 22, 25, 36, 42, 55 and 65 mm mesh sizes) between 1997 to 2007. After 2007, in both lakes, fish surveys were performed with multi-mesh Lundrens gill nets with dimensions of 30 m length and 1.5 m height and mesh sizes of 5.0, 6.25, 8.0, 10.0, 12.5, 15.5, 19.5, 24.0, 29.0, 35.0, 43.0 and 55.0 mm. The nets were set parallel to the littoral and pelagic zone overnight with average duration of 12 hours. Fish data were measured as total length and weight.

Water level change data were taken from the General Directorate of Electrical Power, Resource Survey and Development Administration (EİE, 2011). In order to identify the water level periods, z-scores were calculated. Z-score is a statistical method which indicates how many standard deviations are below the mean (negative scores), above the mean (positive scores) or equal to the mean (Gerten and Adrian, 2000). Subtracting the mean value from the observed data and dividing the residual to the standard deviation z-scores were calculated. Positive z-score represent “high water level (HWL)” whereas negative z-scores values represent “low water level (LWL)”.

The meteorological data were obtained from Turkish State Meteorological Service (MGM, 2011).

METU Limnology Laboratory have accomplished the monitoring of lakes Eymir and Mogan since 1997 by under the supervision of Prof.Dr. Meryem Beklioğlu Yerli. As a result, for this chapter, monitoring data were retained from the METU, Limnology Laboratory database. This monitoring database were already used and will be used for different studies and thesis by M.Sc. and PhD students of METU Limnology Laboratory.

4.2.3. Paleoecology

In 2008, sediment coring was conducted using a KC-Denmark Kajak Corer with 100 cm Plexiglas tube. The sediment cores were sectioned in the field at 1 cm intervals. Sub-fossil cladocerans were analyzed very five centimetres along the core and every centimetre at the top 10 cm to infer past salinity, using weighted averaging regression and calibration as described in Chapter 3.

The sediment cores were dated by measuring the constant rate of ^{210}Pb supply (CRS). The samples have been analysed for the activity of ^{210}Pb, ^{226}Ra and ^{137}Cs via gamma spectrometry at the Gamma Dating Center, Institute of Geography, University of Copenhagen. The measurements were carried out on a Canberra low-background Germanium well-detector. ^{210}Pb was measured via its gamma-peak at 46,5 keV, ^{226}Ra via the granddaughter ^{214}Pb (peaks at 295 and 352 keV) and ^{137}Cs via its peak at 661 keV.

4.2.4. Data Analyses

In order to identify major zones in the two cores, Detrended Correspondance Analysis (DCA) and Principal Component Analysis (PCA) were performed using sub-fossil Cladocera abundance data from each depth to identify the changes in the cladoceran records. PCA was used if the first axis gradient length in DCA ordination was < 2 standard deviations (ter Braak and Prentice, 1988). The scores of PCA were plotted against each depth along the core. Zones were distinguished with the changes of the scores along the core. Ordinations were carried out using the vegan package (version 2.0-1) in R program (Version 2.12.2).

Weighted averaging (WA), weighted averaging with tolerance down weighting (WA_{tol}) with both inverse and classical deshrinking and weighted averaging partial least squares (WA-PLS) regression models were applied to calibration data set which explained in Chapter 3 to infer past salinity changes using the program C2 (Juggins, 2003). The optimal model was selected using their coefficients of determination (r^2), root mean square error (RMSE) and by the root mean square error of prediction (RMSEP). Predicted values and RMSEP were obtained by bootstrapping cross-validation for WA and WA_{tol} models and by leave one out cross-validation for WA-PLS model (Birks, 1995). Additional components for WA-PLS models were considered useful if they gave a reduction in the prediction error of at least 5% (ter Braak and Juggins, 1993; Birks, 1998). After the determination of the inference model, the model was applied to the cladoceran species abundance data from the core to identify salinity changes from past to present.

Fish predation pressure index on cladocerans was estimated using the ratio of *B. longirostris* to sum of *Daphnia* spp. and *B. longirostris* according to Kitchell and Kitchell (1980). The ratio of pelagic/littoral cladoceran species was used to qualitatively reconstruct past changes in lake levels (Alhonen, 1970; Hofmann, 1998).

Detrended correspondence analysis (DCA) was applied to determine whether linear or unimodal ordination techniques was the most appropriate to qualitatively estimate the historical changes in environmental variables such as, salinity, $fish_{(cpue)}$, plant volume inhabited (PVI), total nitrogen (TN), total phosphorus (TP), and Secchi/Maximum depth. The analysis compared species abundances from the sediment core with the sub-fossil cladoceran abundances from the surface sediment calibration set from 40 lakes. The sub-fossil cladoceran abundances from surface sediment were used as active samples in the ordination whereas sub-fossil cladoceran abundances from sediment core were used as supplementary (passive) samples. Therefore, the sediment core samples were arranged in a line on an ordination plot in order to estimate past environmental conditions of Lakes Mogan and Eymir. All ordination analyses were completed using CANOCO version 4.5 with Hellinger transformed cladoceran and transformed environmental data.

Pearson correlation analyses were performed between monitoring and paleolimnological datasets. SigmaStat 3.5 was used for correlation analyses and the pairs with p-values lower than 0.05 accepted as significant correlation.

4.3. Results

4.3.1. Long term monitoring of Lakes Eymir and Mogan

There were two periods observed according to z-scores in both lakes, low water level (2001, 2005-2009) and high water level (1997-2000, 2010-present) years (Figures 4.2 and 4.3). During the low and high water level periods, there were changes in physical, chemical and biological variables in both lakes.

Lake Mogan

According to Pearson correlation, annual precipitation was positively correlated whereas salinity was negatively correlated with the water level changes in Lake Mogan (p=0.01; Table 4.1). Decrease in water level triggered the salinity increase of the lake; for instance, except the first low water level period in 2001, salinity was low from 1997 to 2005 since the water levels were high (Figure 4.2). However, in the second low water level period salinity increased almost two fold. Then, with the increase of water level, salinity decreased again (Figure 4.2).

Table 4.1. Pearson correlation of long term monitoring data of Lake Mogan. The numbers are correlation coefficients and the bolds are the significantly correlated variables (*: $p<0.05$ and **: $p<0.01$).

	Annual prec.(mm)	Water level (m)	Fish (CPUE)	Salinity (‰)
Zscores	**0.52***	**1.00****	-0.47	**-0.62***
Annual prec.(mm)		**0.53***	-0.37	-0.19
Water level (m)			-0.44	**-0.61***
Fish (CPUE)				0.54

In Lake Mogan, fish survey started in 2007. The highest cpue (481 individual net^{-1} night^{-1}) was found in the low water level period in 2009 (Figure 4.2). After 2009 it decreased to 24 individual net^{-1} night^{-1} and again it increased to 121 individual net^{-1} night^{-1} in 2011. When the fish cpue was high in 2008 and 2009, the abundance of large Cladocera decreased whereas small Cladocera increased (Figure 4.2).

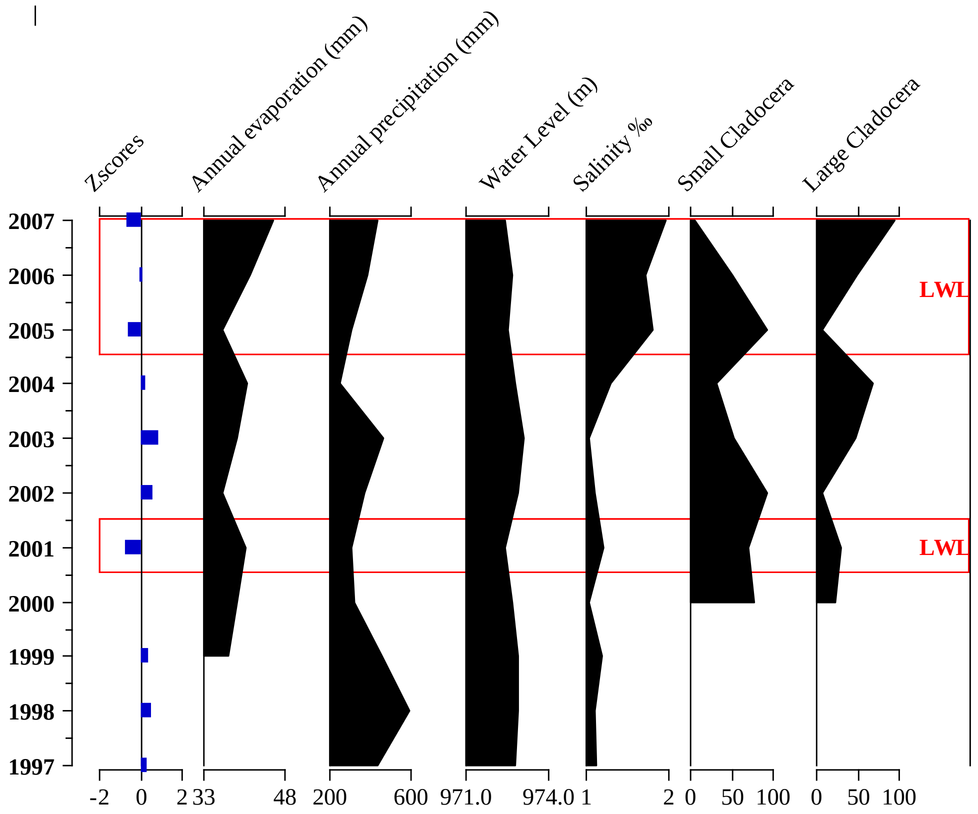

Figure 4.2. Environmental parameters of Lake Mogan from 1997 to present.

Zooplankton survey in Lake Mogan started in 2000. Small-sized Cladocera assemblage (*Alona* sp., *Chydorus sphaericus* (O.F. Müller, 1776), *Moina* sp., *Bosmina longirostris* (O.F. Müller, 1785), *Diaphanasoma lacustris* (Korinek 1981) and *Diaphanosoma* sp.) was generally abundant in LWL years except in 2007 when cpue was 0.3 individual net^{-1} night^{-1} (Figure 4.2). Whereas in high water level years, large bodied Cladocera (*Daphnia longispina* O.F. Müller, 1875, and *Daphnia magna* (Straus, 1820)) dominated the cladoceran community.

Lake Eymir

According to Pearson correlation, evaporation and salinity were negatively correlated with water level in Lake Eymir ($p=0.04$; Table 4.2). Water level decrease triggers an increase in salinity of the lake; for instance, except the first low water level period in 2001, salinity was low from 1997 to 2005 since the water levels were high (Figure 4.3). However, in the second low water level period salinity increased almost two fold. Then, with the increase of water level, salinity declined (Figure 4.3).

Table 4.2. Pearson correlation of long term monitoring data of Lake Eymir. The numbers are correlation coefficients and the bolds are the significantly correlated variables (*: $p<0.05$ and **: $p<0.01$).

	Annual evap.(mm)	Annual prec.(mm)	Water level (m)	Fish (CPUE)	Salinity (‰)
Zscores	**-0.54***	0.36	**0.75****	0.11	**-0.76****
Annual evap.(mm)		-0.45	**-0.70***	-0.35	0.42
Annual prec.(mm)			0.43	0.05	-0.03
Water level (m)				0.33	**-0.53***
Fish (CPUE)					-0.40

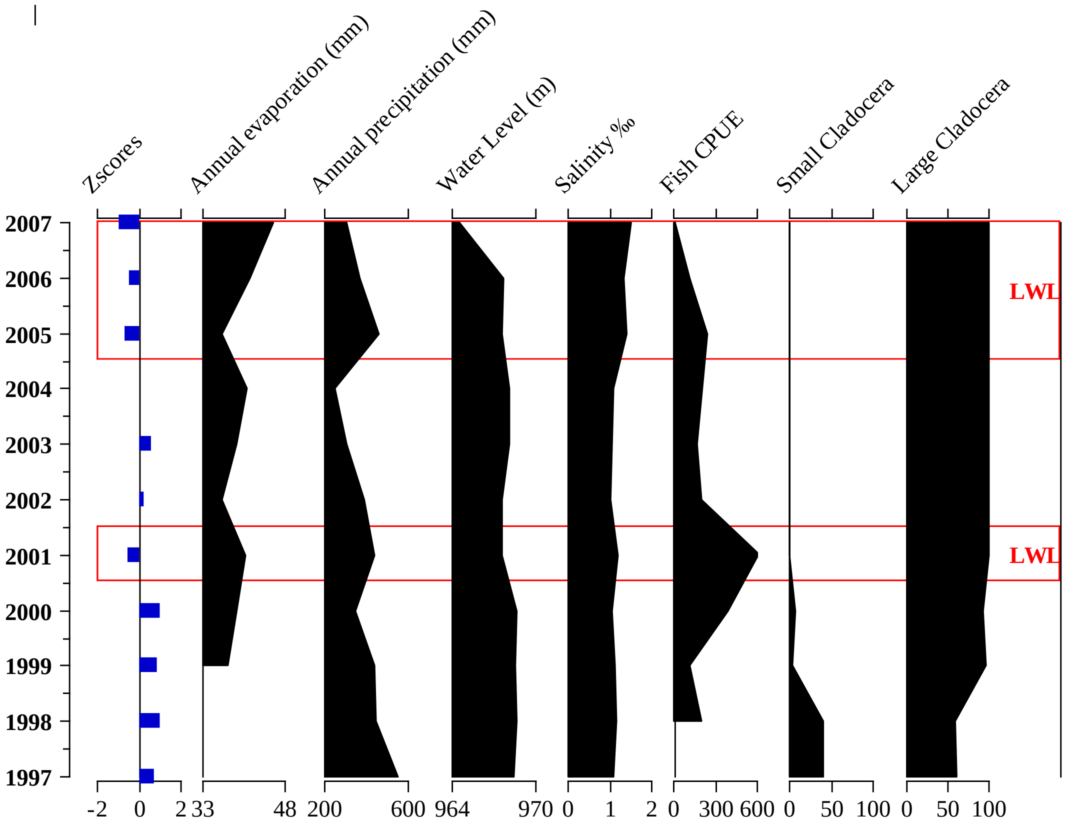

Figure 4.3. Environmental parameters of Lake Eymir from 1997 to present.

In Lake Eymir, there were two biomanipulation periods, in 1998-1999 and from 2006 to present day. In 1999, fish abundance net^{-1} night^{-1} was decreased, however; in 2001 fish abundance reached the highest value (613 individual net^{-1} night^{-1}). According to Tavşanoğlu (2012), the highest catch per unit was a result of the high number of small-sized bleak and the young of the year. After 2001, fish (cpue) decreased till 2005 and reached another peak (Figure 4.3). After this peak, the second biomanipulation started in 2006 and one year after, fish (cpue) reached the lowest value (6.8 individual net^{-1} night^{-1}; Figure 4.3).

Zooplankton distribution in Lake Eymir was mostly related to biomanipulation efforts. Small-sized cladocerans (*Diaphanasoma brachyurum*, *Ceriodaphnia* sp., *Chydorus sphaericus*, *Bosmina longirostris*, *Alona* sp. and *Pleuroxus* sp.) were abundant between 1997 and 1998, afterwards the abundance decreased following the biomanipulation in 1998-1999 (Figure 4.3). After 1999, large-sized Cladocera such as *D. magna* and *D. pulex* became dominant towards present day.

4.3.2. ^{210}Pb Dating

The core showed surface contents of unsupported ^{210}Pb of about 370 Bq kg^{-1} for Lake Mogan and 140 Bq kg^{-1} for Lake Eymir and the activity generally decreased exponentially with depth (Figures 4.4 and 4.5). However, the profile is quite irregular in both lakes. The calculated flux of unsupported ^{210}Pb was 164 Bq m^{-2} y^{-1} for Lake Mogan and 277 Bq m^{-2} y^{-1} for Lake Eymir which were higher than the estimated local atmospheric supply (based on data shown in Appleby, 2001). This shows that both sites were subject to sediment material movement from shallower to deeper zones of the lake by water turbulence.

In Lake Mogan significant activities of ^{137}Cs were found down to a depth of about 40 cm and a relatively high activity above 30 cm (Figure 4.4). The ^{137}Cs peak at around 15 cm related the

Chernobyl radioactive activity occurred in 1986. In Lake Eymir significant activities of ^{137}Cs were found in all samples. Precise dating of the core was hampered due to the irregular profile of unsupported ^{210}Pb. The profile of ^{137}Cs showed clear signs of leaching and the chronology based on ^{210}Pb can therefore not be verified by use of this isotope; however, the ^{137}Cs peak at 20 cm could correspond with Chernobyl activity in 1986 (Figure 4.5).

Precise dating of the core is hampered due to the irregular profile of unsupported ^{210}Pb. Sedimentation rates were calculated as 2.1 kgm^{-2}y^{-1} for Lake Mogan and 1.7 kgm^{-2}y^{-1} for Lake Eymir. CRS-modeling (Appleby, 2001) has been applied on both lakes profile and ^{210}Pb dates were calculated as in Figures 4.6 and 4.7. Based on this dating, the levels with significant ^{137}Cs activities were dated back to as early as the beginning of the 20th century. Thus, due to the irregular profile of unsupported ^{210}Pb the chronology and significant disturbance of the sediment, datings can only be regarded as indicative.

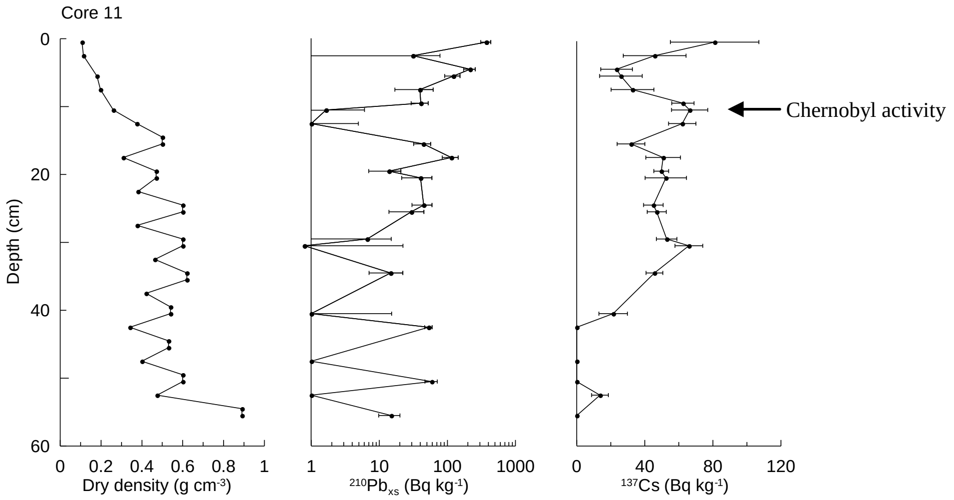

Figure 4.4. ^{210}Pb and ^{137}Cs profile of Lake Mogan short core.

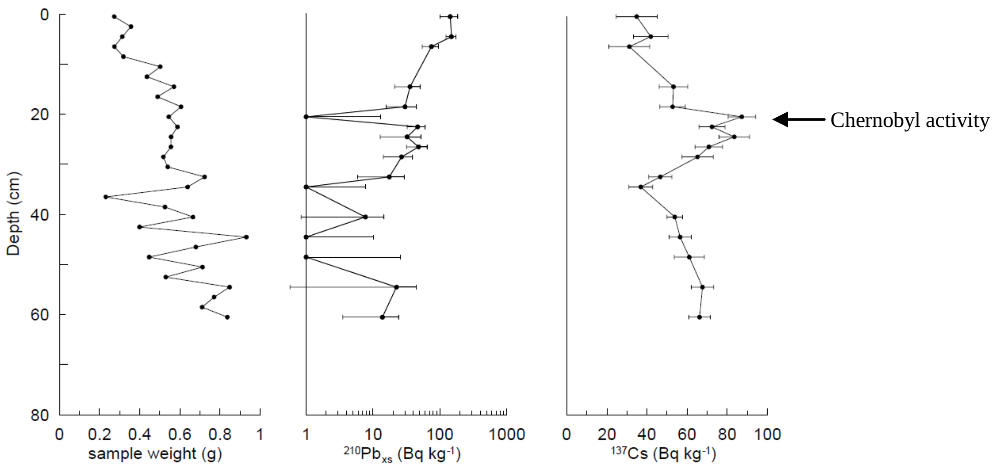

Figure 4.5. ^{210}Pb and ^{137}Cs profile of Lake Eymir short core.

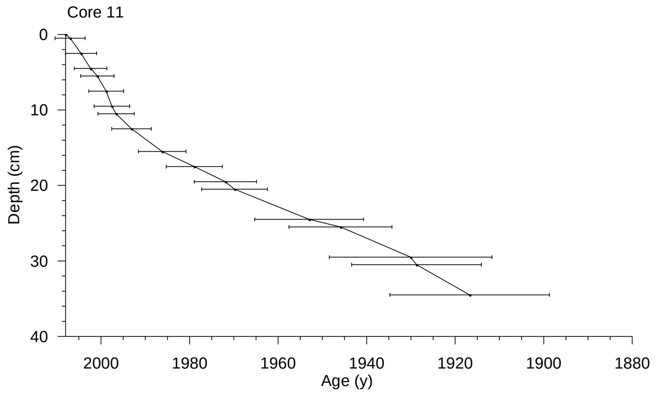

Figure 4.6. Age-depth model of Lake Mogan short core.

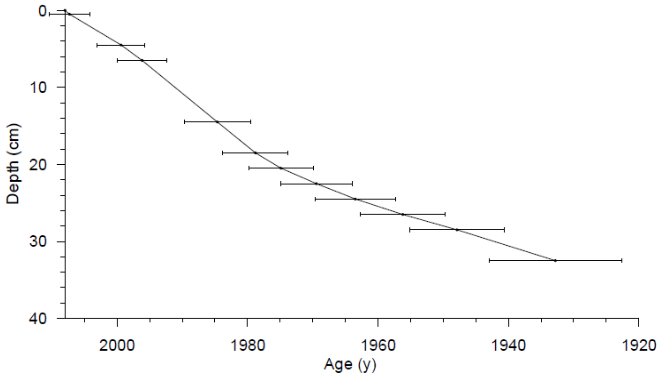

Figure 4.7. Age-depth model of Lake Eymir short core.

4.3.2. Cladoceran stratigraphy

Lake Mogan

12 cladoceran taxa were identified in the core. Based on the PCA analysis axis 1 scores, the record can be split into three distinct zones (Figure 4.8). Zone 1 (55 cm-31 cm; ca. 1860-1930) was dominated by macrophyte-sediment associated taxa and *Chydorus sphaericus* and *Alona rectangula/gutata* were the most abundant species. Pelagic taxa were rare in zone 1 and *Bosmina longirostris* increased at the onset of zone 2. The total cladoceran abundance of zone 1 was composed of the abundance of chydorids and it decreased after 45 cm (Figure 4.9 B). In addition to *B.longirostris*, in zone 2, pelagic species *Daphnia* spp. and *Moina* sp. were identified. Macrophyte-sediment associated taxa remained constant except the disappearance of *Camptocercus rectirostris, Pleuroxus* spp. and *Alonella exigua* (Figure 4.8). During zone 3, the abundance of total cladocera increased sharply at 5 cm (Figure 4.9). For the first time the macrophyte associated cladocera, *Simocephalus* sp. was identified and *Pleuroxus* spp. reappeared in zone 3 (Figure 4.8). In zone 1, benthic taxa were abundant whereas pelagic species were rare thus; pelagic/littoral ratio was low (Figure 4.10). In accordance with the increase of pelagic taxa in zone 2, pelagic/littoral ratio increased. In zone 3, at 3-4 cm there was a peak of pelagic species. This peak could be also observed in measured water level and pelagic/littoral ratio (Figure 4.10). The estimated fish predation pressure on cladocerans was higher in zone 2 and it decreased in zone 3 after 7 cm (Figure 4.10). The highest peak of the abundance of cladocera after 5 cm can be explained by that decrease of predation pressure.

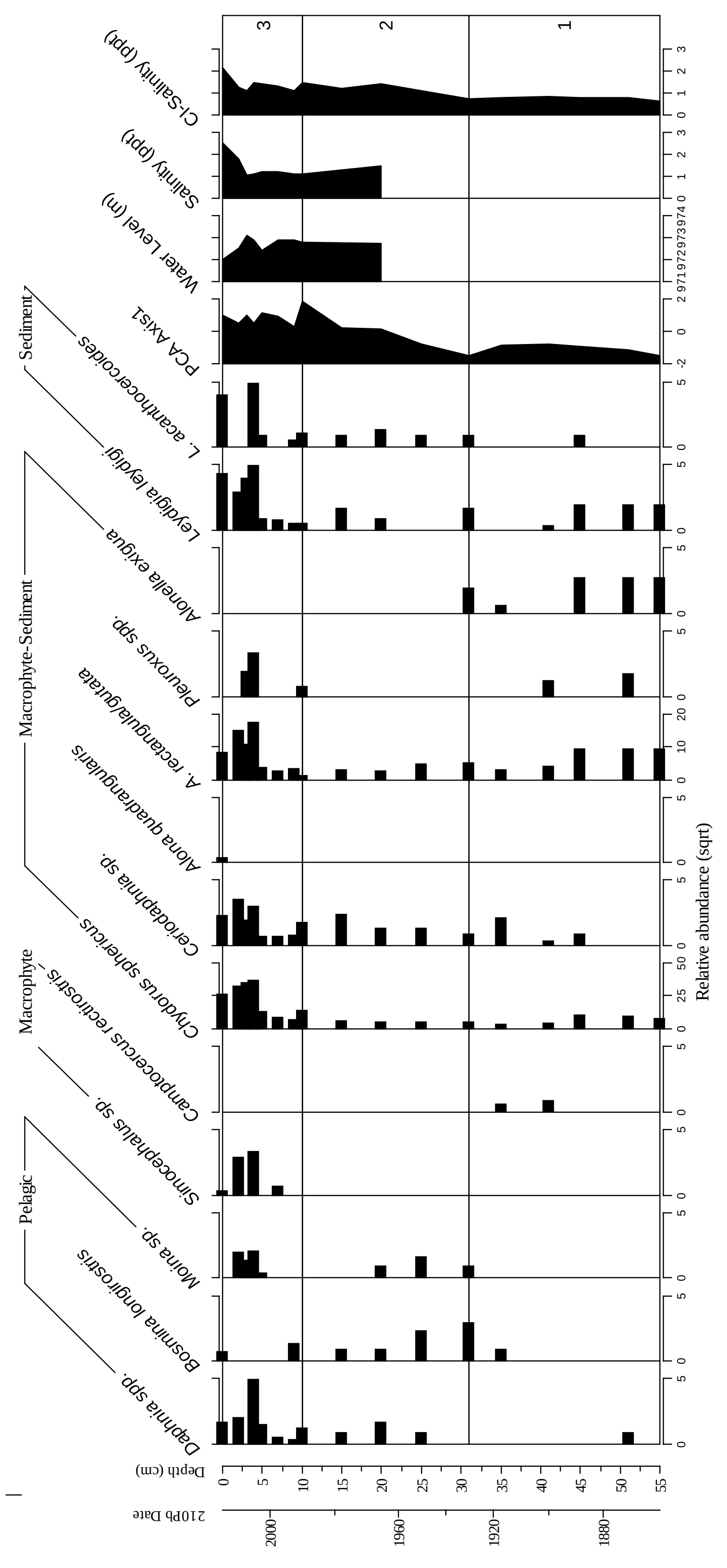

Figure 4.8. Cladoceran biostratigraphy of Lake Mogan for inferring salinity.

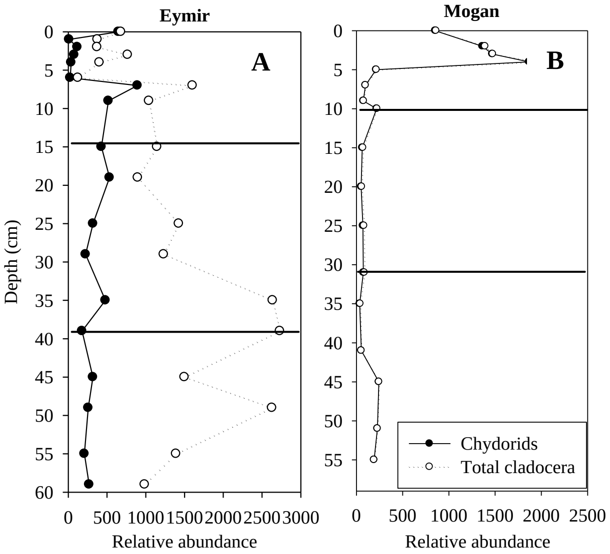

Figure 4.9. Profile of changes in the abundance of cladocerans in Lakes Eymir (A) and Mogan (B) short cores. Horizontal lines represent zones.

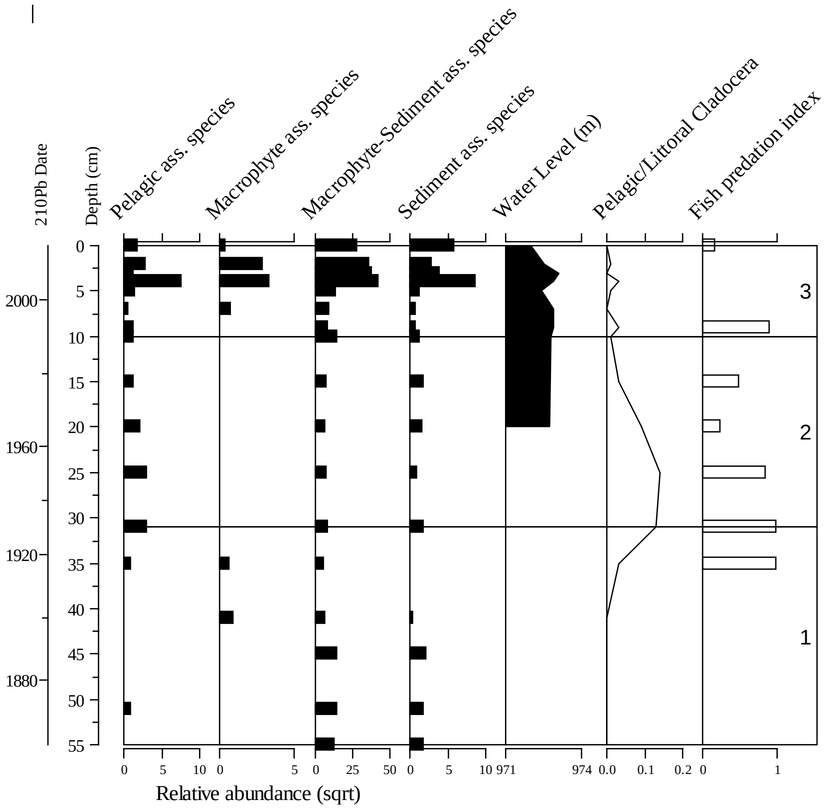

Figure 4.10. Cladoceran habitat groups of Lake Mogan. Habitat groups calculated as the sum of relative square root abundance of each taxon. A fish predation index value 1 indicates high predation.

Lake Eymir

A total of 11 cladoceran taxa were identified. Likewise in the Lake Mogan short core, three zones were determined by PCA analysis (Figure 4.11). Zone 1 (60 cm-39 cm; ca. 1860-1930) was dominated by pelagic taxa *B. longirostris* and *Moina* sp.; macrophyte and sediment associated *C. sphaericus, A. rectangula/gutata* and *Pleuroxus* spp. and sedimentary species *L. leydigi* while macrophyte associated taxa were absent. Furthermore, at the bottom of the core pelagic cladocera *Daphnia* spp. was identified then disappeared until zone 2 from around 1900 to 1980s (40 cm – 15 cm). Total cladoceran abundance was very high in zone 1 whereas chydorids were moderately abundant (Figure 4.9 A). Among pelagic cladocerans, *B.longirostris* and *Moina* sp. abundance decreased in the zone 2, in contrast *Daphnia* spp. abundance increased. For the first time macrophyte associated taxa, *Graptoleberis testudinaria* appeared in zone 2. During zone 2, macrophyte-sediment and sediment associated species remained the same as in the zone 1, and *Ceriodaphnia* sp. and *Leydigia acanthocercoides* appeared for the first time (Figure 4.11). The abundance of total cladocera decreased while the abundance of chydorids slightly increased (Figure 4.9 A). Cladoceran species richness remained the same along the zone 3 however; at 6th cm there was an abrupt decrease in total abundance and most of the chydorids were disappeared (Figures 4.11, 4.9A). Towards the present day total cladocera abundance increased. The fish predation pressure index indicated an overall higher predation on cladocerans during zone 1 and zone 2, followed by a distinct decline at the onset of zone 3 (Figure 4.12). In zone 3, from ca 1992 towards present day overall fish predation increased. Pelagic/littoral cladocera ratio suggested high water level periods in zone 1 then a gradual decline till 1970s in zone 2 when macrophyte associated species first appeared (Figure 4.12). Thereafter the pelagic/littoral ratio increased with a peak at 3-4 cm (late 1990s) and 1-2 cm (ca. 2005), followed by a decline in the top sediment core (Figure 4.12). Except the peak at 1-2 cm pelagic/littoral ratio followed the monitored lake level changes.

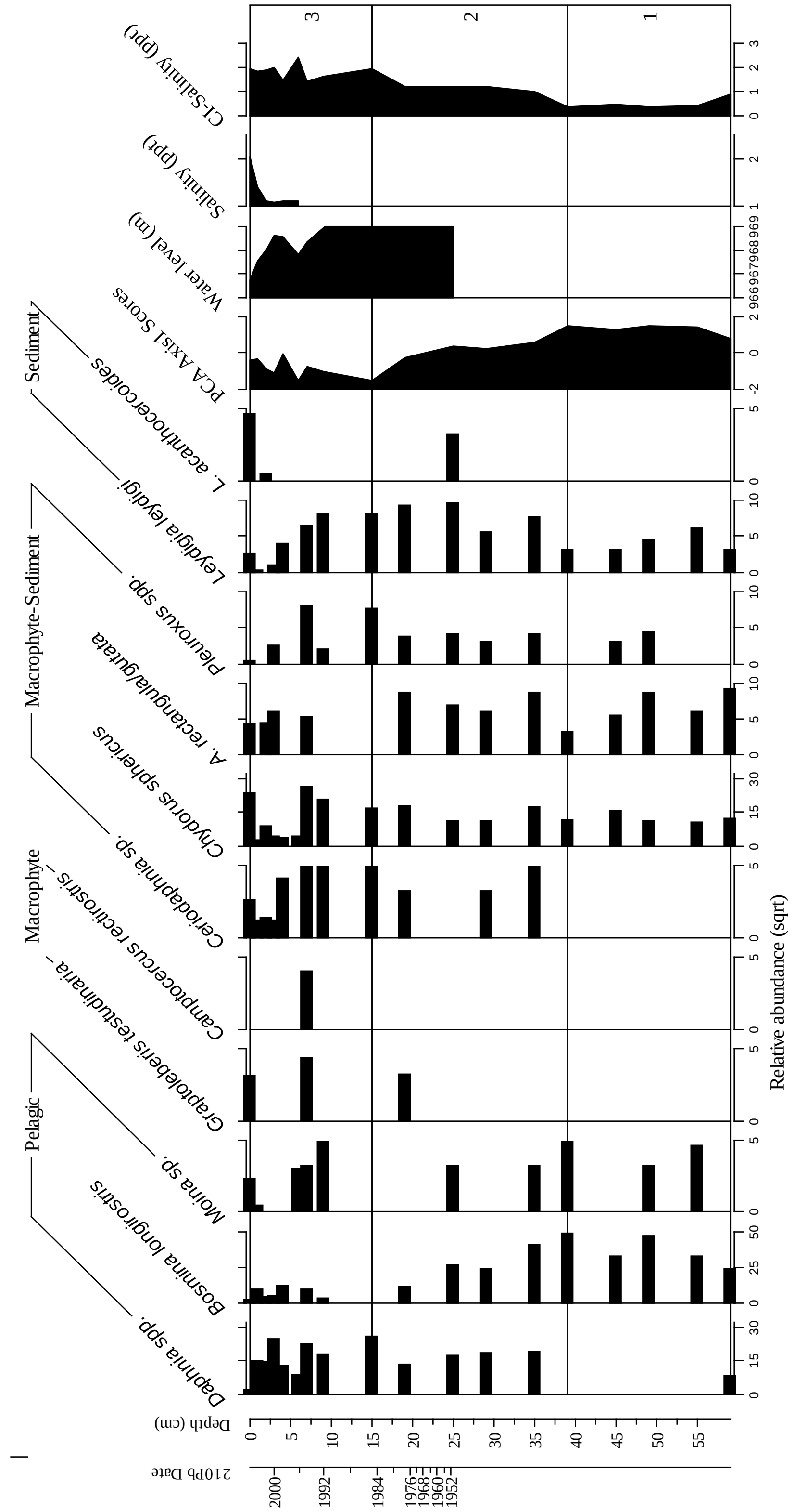

Figure 4.11. Cladoceran biostratigraphy of Lake Eymir.

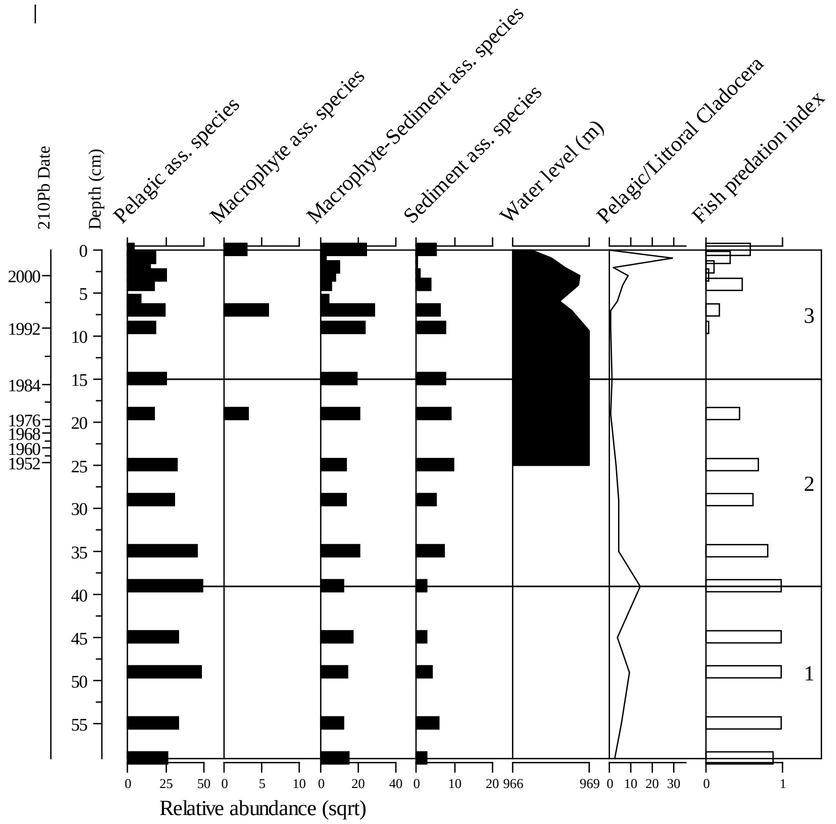

Figure 4.12. Cladoceran habitat groups of Lake Eymir. Habitat groups calculated as the sum of relative square root abundance of each taxon. A fish predation index value 1 indicates high predation.

4.3.3. Ordination

Ordination by DCA based on calibration set data resulted gradient length of 1.95 S.D., the first and second DCA ordination axes explained 65 % of the cumulative variation of the data. Thus, linear method, RDA was employed to qualitatively estimate the historical changes in environmental variables.

Lake Mogan

When plotting Lake Mogan core sample scores from RDA ordination by using cladoceran abundance data from each depth with environmental variables from calibration set, a clear differenciation between the zones was observed. The distribution of the Lake Mogan core samples relative to the environmental vectors in the RDA ordination indicated a shift towards salinization and eutrophication (Figure 4.13). Furthermore, in zone 1, PVI and water clarity seemed to have retained overall relatively high levels with a decreasing trend towards present day.

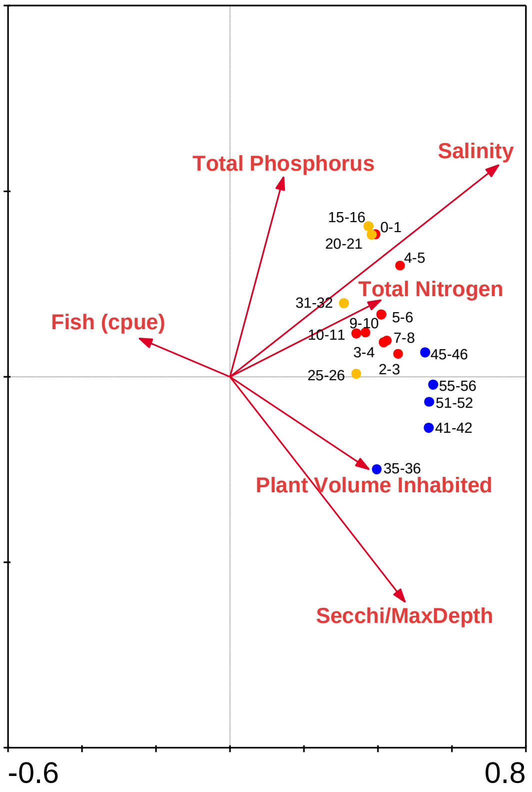

Figure 4.13. RDA plot with sedimentary Cladocera sub-fossils of Lake Mogan. Blue dots represent the zone 1, orange dots represent the zone 2 and red dots represent the zone 3.

Lake Eymir

As in Lake Mogan, the distribution of the Lake Eymir core samples relative to the environmental vectors in the RDA ordination indicated a shift towards salinization and eutrophication (Figure 4.14). In addition, fish$_{(cpue)}$ shaped lake ecosystem relatively high levels with a decreasing trend towards present day. Moreover, pre- biomanipulation years which corresponded the core depths of 1-2 and 4-5 cm showed high fish$_{(cpue)}$ abundance.

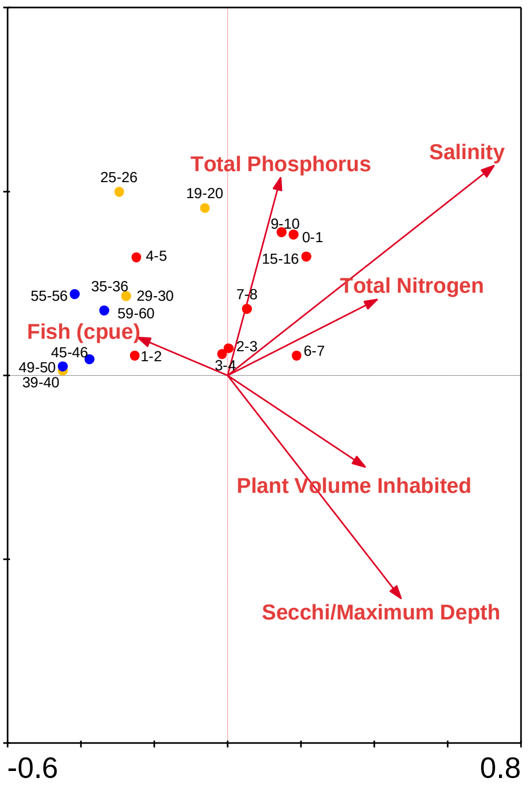

Figure 4.14. RDA plot with sediment core samples of Lake Eymir. Blue dots represent zone 1, orange dots represent zone 2 and red dots represent zone 3.

4.3.4. Cladoceran Inferred Salinity (CI-Salinity) Model Application

Weighted averaging (WA) and weighted averaging partial least squares (WA-PLS) regression models were applied to calibration data set of 44 lakes. However, according to low coefficients of determination (r^2), high root mean square error (RMSE), high root mean square error of prediction (RMSEP) and >5 % reduction in the prediction error, four outlier high saline lakes (Erikli, Gebekirse, Barutçu and Baldımaz) were removed from the models (Table 4.3). WA and WA-PLS models were run again by using 40 lakes. According to high r^2 (0.63), low RMSE and RMSEP (0.26 and 0.36, respectively) and high % (6.43 %) change in the prediction error, WA-PLS model using 40 lakes was chosen as final model for salinity inference (Table 4.3). Observed salinity, estimated salinity, residuals and WAPLS scores can be found in Appendix C. The transfer function equation is the inverse function of the regression below:

$$y=0.738x+0.111 \text{ (where y is observed salinity; x is estimated salinity)}$$

Table 4.3. Salinity inference models based on 25 cladoceran taxa with 44 lakes and 40 lakes.

Number of Lakes	Model	RMSE	r^2	RMSEP	%Change	t-test
44	WA-PLS	0.75	0.66	1.13	2.38	0.39
44	WA	1.04	0.37	1.13		
40	WA-PLS	**0.26**	0.63	0.36	**6.43**	0.21
40	WA	0.32	0.44	0.38		

Lake Mogan

The improved transfer function developed from the 40 lakes dataset was applied to a short core from Lake Mogan. CI-Salinity shows similar increase along the core and was characterised by three zones (Figure 4.8). In zone 1, the average CI-Salinity was 0.7 ‰ and the low salinity tolerant *C.rectirostris* (0.22 ‰), *Pleuroxus* sp. (0.35 ‰) and *Alonella exigua* (0.37 ‰) were only identified in this zone (Table 3.2; Figure 4.8). Zone 2 was characterized by an increase of CI-Salinity. The average value increased to 1.3 ‰. High salinity tolerant macrophyte-sediment associated *C.sphaericus* (1.2 ‰) and *A.rectangula/gutata* (1.4 ‰) and sediment associated *L.leydigi* (1.1 ‰) and *L.acanthocercoides* (1.4 ‰) were found abundantly (Table 3.2; Figure 4.8). In constrast, the abundance of *B.longirostris* decreased gradually from the onset of zone 2 towards zone 3. From 10 cm to the top of the sediment sequence, zone 1, the inferred salinity continued to increase from 1.2 ‰ to 2.2 ‰ with increased abundances of high salinity tolerant species such as, *C.sphaericus, A.rectangula/gutata, L.leydigi* and *L.acanthocercoides* (Figure 4.8).

Monitoring the lake water salinity was started on 1997 and between 1997 and 2004 the average salinity was measured as 1.2 ‰. After 2004, measured salinity started to increase gradually and almost doubled its value in 2008 reaching 2.5 ‰ (Figure 4.8). Moreover, Altınbilek (1995) and Akbulut (1998) measured conductivity in 1993, 1994 and 1995 as 1.78, 2.06, 2.3 µS/cm, respectively. CI-Salinity pointed out similar values as measured salinity and it can be examined in zone 1 (Figure 4.8). Pearson correlation analysis gave significant ($p=0.02$) relationship between measured salinity and inferred salinity. Furthermore, water level measurements were negatively significantly correlated both with CI-Salinity ($p=0.01$) and measured salinity ($p=0.005$).

Lake Eymir

The improved transfer function developed from the 40 lakes dataset was applied to a short core from Lake Eymir. Cladoceran inferred salinity (CI-Salinity) shows some variation as in Lake Mogan along the core and was characterised by three stages (Figure 4.11). From the bottom of the core to 40 cm, lake salinity was less than 1 ‰. After 40 cm, there was an increase in inferred salinity. The salinity increase was synchronized with the abundance decrease of low salinity tolerant *B.longirostris* (0.37 ‰) and *Moina* sp. (0.57 ‰) and also the abundance increase of high salinity tolerant *Leydigia leydigi* (1.1 ‰) in zone 2 (Table 3.2; Figure 4.11). The increase of inferred salinity continues to its monitored present day value (~2 ‰) in zone 3.

The salinity measurements were started in 1997 and between 1997 and 2004 average salinity was 1.1 ‰. After 2004 salinity started to increased and in 2008 it reached 1.9 ‰. However CI-Salinity indicates that salinity was higher and average inferred salinity was 1.8 ‰ in past decade. There was an insignificant correlation between CI-Salinity and measured salinity ($p=0.6$). Moreover, water level measurements were significantly correlated with measured salinity ($p=0.008$) whereas not correlated with CI-Salinity ($p=0.9$).

4.4. Discussion

The well-documented long term monitoring programmes in Lakes Mogan and Eymir created an opportunity to compare monitoring and paleolimnological records. Such a comparison revealed that the concentration of sub-fossil Cladocera in the sediment reflected the previous abundance of Cladocera in the lakes. Comparison of variables from the monitoring years and the reconstructed salinities indicated that the sediment record reflected the known lake salinity history fairly well, with a good linear correlation. In general, the sub-fossil cladoceran record captured salinity changes known from the monitoring programme. Such finding showed that the lake ecosystem fluctuations could be tracked beyond the pre-monitoring years by using paleolimnological methods.

In Lake Mogan, according to monitoring results, water level changes triggered salinization and eutrophication, controlling the cladoceran community. The zones identified from sub-fossil cladocera reflected the known salinization history of Lake Mogan. For instance, Tanyolaç and Karabatak (1974) measured Lake Mogan salinity as 1.4 ‰ in 1971, with a great accuracy, same as our inferred salinity of 1.45 ‰ in 1971.

Zone 1 (ca. 1860-1930) was dominated by taxa typically associated with macrophyte and sediment-macrophyte and also the pelagic/littoral cladocera ratio was very low. This assemblage suggested low water level conditions and thus, high salinity values expected. Whereas the average CI-Salinity in zone 1 was the lowest along the core and the low salinity tolerant *C. rectirostris* (0.22 ‰), *Pleuroxus* sp. (0.35 ‰) and *A. exigua* (0.37 ‰) were only identified in this zone. Bos et al. (1999) also initiated similar salinity tolerant values for these taxa such as, *C. rectirostris* (0.23 ‰) and *Pleuroxus* sp. (0.26 ‰). Moreover, *A. exigua* was identified in low saline (0.08-0.23 ‰) streams by the Lake Köyceğiz (Mis et al., 2011). Despite low water level conditions with high macrophyte coverage in the lake, the highest abundance of these low salinity tolerant taxa in zone 1 resulted low salinity inference. Furthermore, low water level can boost fish predation and allow submerged plant grow and expand (Bucak et al., 2012; Tavşanoğlu, 2012). In this zone, the absence of large-bodied *Daphnia* sp. and *Simocephalus* sp. can be explained by size-selective predation (Brooks and Dodson, 1965). Moreover, RDA ordination also elucidated that this zone could be indicated by high PVI. Furthermore, between 55-35 cm Levi (2009) showed high abundance of short growing plant macrofossils such as, Characeae oospores, *Najas marina* seed fragments and *Potamogeton* sp. leaf tips, suggesting low water level conditions. Furthermore, the pelagic/littoral ratio change can be a result of anoxic water column above the sediment and this could misinterpret the water level inference.

Zone 2 (ca. 1930-1990) was characterized by slight increase of CI-Salinity. The average value increased from 0.7 ‰ to 1.3 ‰. High salinity tolerant macrophyte-sediment associated *C. sphaericus* (1.2 ‰) and *A. rectangula/gutata* (1.4 ‰) and sediment associated *L. leydigi* (1.1 ‰) and *L. acanthocercoides* (1.4 ‰) were found abundantly on the other hand the low tolerant species from zone 1 were disappeared. Generally, cladoceran species richness decreases with increasing salinity (Frey, 1993; Bos et al., 1999; Boronat et al., 2001, Brucet et al., 2009) because many cladoceran taxa are not well adapted to high salinity conditions (Aladin, 1991). Previous studies showed that *L. acanthocercoides, A. rectangula* and *C. sphaericus* were found in salinities of 3.5 ‰, 33 ‰ and 59 ‰, respectively (Löffler, 1961; Hammer, 1986; Aladin, 1991; Wolfram et al., 1999; Ustaoğlu et al., 2012). Therefore, these stenohaline species have become very abundant in zone 3 (1998-2008) since the onset of first LWL period in 2001 and consequent salinity increase observed by both *in situ* measurements and inferences. Furthermore, moderate salinity tolerant taxa *Daphnia* spp., *Moina* sp. and *Simocephalus* sp. became also abundant in zone 3. Even though, in our research *Simocephalus* sp. and *Daphnia* spp. salinity tolerance were 0.69 ‰ and 0.62 ‰, respectively. Ustaoğlu et al. (2012) found *Simocephalus* sp. and *Daphnia* sp. in brackish lakes with salinities up to 10 ‰. Moreover, Williams et al. (1990) collected *Moina* sp. from lakes with salinities up to 4.2 ‰. Around 1960 in zone 2, pelagic/littoral cladoceran ratio started to decline towards present day, suggesting water level decrease. The instrumental measurement of water level since 1970 supports this. Moreover, the first and second LWL periods can be identified in pelagic/littoral ratio at 5 cm and between 2.5 cm to top of the sediment core. In both zones water level decline increased salinity and eutrophication as also shown in RDA ordination plot.

In Lake Eymir, according to monitoring results, water level changes triggered salinization and eutrophication as in Lake Mogan. However, the cladoceran community not only controls by salinity and eutrophication but also by biomanipulation affords in Lake Eymir. Zone 1 was dominated by low salinity tolerant pelagic taxa *B. longirostris* (0.37 ‰) and *Moina* sp. (0.57 ‰); macrophyte and sediment associated stenohaline taxa *C sphaericus,* and *A.rectangula/gutata* and low salinity tolerant *Pleuroxus* spp. (0.35 ‰) and benthic species *L.leydigi* (1.10 ‰) while macrophyte associated taxa were absent. Having high abundance of low salinity tolerant taxa, this zone can be characterized by low saline waters. However, *B.longirostris* was very dominant taxa in Danish brackish lakes with 7-16 ‰ salinity range (Jeppesen et al., 1994). Moreover, this low salinity values corresponded with high water level indicator, the high pelagic/littoral cladoceran ratio, in this zone. Furthermore, at the bottom of the core a large-sized pelagic cladocera *Daphnia* spp. was identified however it was disappeared until zone 2 (39-15 cm). This could be an evidence for an increase in fish predation, as indicated by a size efficiency hypothesis (Brooks and Dodson, 1965). In addition, RDA ordination suggested fish dominance in zone 1. This was also captured by the predation pressure index.

After 40 cm at the onset of zone 2, there was an increase in inferred salinity to average 1.3 ‰. The salinity increase was synchronized with the decrease in abundance of low salinity tolerant *B. longirostris* (0.37 ‰) and *Moina* sp. (0.57 ‰) and also the increase in abundance of high salinity tolerant *L. leydigi* (1.1 ‰). Moreover, pelagic/littoral cladoceran ratio showed a decline towards zone 3, reflecting water level decrease and thus, salinization. In zone 2 when the abundances of *B. longirostris* decreased at the same time the abundances of *Daphnia* spp. increased and reached its maximum value at 15th cm (around 1985) of the core. There was also a decline in predation pressure index parallel to *Daphnia* increase. The highest peak of *Daphnia* might have been the result of fish kills during 1970s due to increased eutrophication through over 25 years raw sewage effluents to the Lake Eymir starting from 1970 (Altınbilek, 1995; Beklioğlu et al., 2003). Also nutrient increase in 19-20 and 15-16 cm (ca. 1970 to 1980s) can be seen in RDA ordination. Furthermore, cladoceran species number was declined and only five taxa were identified at this time period.

Zone 3 was characterized by the continuous inferred salinity increase towards present day. There was a CI-Salinity peak at 6-7 cm which is around 1997, corresponding water level drop to 967.8 m above sea level. Then water level increased with decreasing CI-Salinity and nutrient concentration as seen in RDA ordination. The first biomanipulation was performed during this high water level period in 1998-1999. During this period lake was in eutrophic condition and dominated by cyprinid fish via stirring up the sediment causing turbidity (Meijer et al. 1999; Beklioğlu et al. 2003). Moreover, the decrease of sub-fossil *Daphnia* spp. abundance reflected the predation pressure by cyprinids at 6-7 and 4-5 cm of the core. Furthermore, small sized sub-fossil *Ceriodaphnia* sp. dominance for the period was in well accordance with the monitoring data (Tavşanoğlu, 2012). After approximately 50 % of cyprinid fish removal, at 2-3 cm of the core large sized *Daphnia* spp. became abundant and clear water condition was returned as reported by Beklioğlu et al. (2003). Also, CI-Salinity continued to increase in this period as a result of increased abundance of stenohaline taxa *A.rectangula/gutata.* Moreover, *Daphnia magna* was able to tolerate 1.2 ‰ salinity concentrations in Lake Eymir (Tavşanoğlu, 2012). According to RDA plot, fish abundance started to increase at 1-2 cm which corresponds to start of the second biomanipulation period in 2006. Water level continued to drop at around with increasing CI-Salinity and measured salinity. Furthermore, at the top of the core which was the year 2008, the lowest water level was observed and the lake was eutrophicated through in lake sediment TP release since all inflows were dried out (Özen et al., 2010). RDA plot indicated the eutrophication as TP increase in 0-1 cm of the core. *C.sphaericus, A.rectangula/gutata* and *L.acanthocercoides* were the most abundant species at the top of the core and according to Brodersen et al. (1998), those species had high TP optima.

Water level fluctuations affect both lakes changing water salinity and nutrient concentrations with water clarity. From past to present overall salinity increase as a result of water level decrease was observed in both lakes. Furthermore, water level decline changes trophic structure of the lakes via eutrophication and increase top-down effect. Yağbasan et al. (2012) used IPCC A2 and B1 emission scenarios and indicated that long-term changes in precipitation and temperature can cause significant declines in Eymir and Mogan lake levels and drying out of the both lakes in dry seasons. In the future, the impact of climate change on lake levels can be regulated by sustainable management strategies.

CHAPTER 5

INFERRING PAST SALINITY TURKISH SHALLOW LAKES LOCATED ALONG LATITUDINAL GRADIENT BY COMMUNITY CHANGE OF SUB-FOSSIL CLADOCERA

5.1. Introduction

Paleolimnological studies allow infering of past environmental changes, achieved by analyses of plant and animal remains (Frey, 1986, 1988; Korhola and Rautio, 2001). Palaeolimnology can provide insight into natural and anthropogenic impacts on lakes and their surrondings extending from annual, decadal to millennia. Chemical, physical, and biological parameters of lake sediment can supply a substantial amount of information on past lake ecosystems (Birks and Birks, 1980; Smol, 1990; Smol et xal., 1991, 1994)

Cladoceran taxa are informative and extensively used invertebrates in paleolimnological and paleoclimatological studies, because they are abundant in freshwater lakes, their skeletal pieces, namely called carapace, preserve well and are identifiable and they respond quickly to environmental changes (Frey 1986; Korhola and Rautio 2001; Luoto et al., 2008). Cladocera are dominant among zooplankton and are the only group which are well preserved in sediment.Therefore, fossil cladoceran analysis allows contribute to reconstruction of lake history (Szeroczynska, 2002).

Being arthropods, upon death their skeletal body parts are rapidly disarticulated into components such as, head shields, carapace, post-abdomen, post-abdominal claws and mandibles via biological activity. The remains of pelagic, plant and benthic associated cladocerans can be used to assess both quantitatively and qualitatively trophic structure, plant composition, fish population, climatic change, eutrophication, salinity and water-level fluctuation, (Jeppesen et al., 1996; Hofmann, 1998; Lotter et al., 1998; Bos et al., 1999; Jeppesen et al., 2003; Johansson et al., 2005; Amsinck et al., 2005a; Korhola et al., 2005; Luoto et al., 2008; Nevalainen and Luoto, 2010). For instance, Jeppesen et al. (1996) created the first quantitative reconstruction model using the relationship between cladoceran remains and planktivorous fish that allowed to reconstruct past planktivorous fish density and trophic structure. Moreover, Jeppesen et al. (2003) showed that size and abundance of ephippia of some planktonic cladoceran species are related to fish abundance and can therefore be used as indicators for planktivorous fish stocks. Another example could be a quantitative method which was developed to relate cladocera composition to total phophorus by Brodersen et al. (1998). They established a reconstruction model to infer TP by weighted average regression and calibration techniques. A study by Bos et al. (1999) recovered cladoceran and anostracan remains from the surficial sediments of 33 lakes in the Interior Plateau of British Columbia to infer past salinity as well as lake depth. This study provided information on the optima and tolerance of individual Cladoceran species to lake water salinity and showed the potential that these organisms have for paleoenvironmental and paleoclimatic research. Moreover, Amsinck et al. (2003) used cladocerans salinity sensitivity to infer past trophic structure with special interest on macrophyte abundance and fish predation of two shallow brackish lakes. Also, Amsinck et al. (2005a) showed that the sub-fossil zooplankton composition from surface sediment of 36 coastal brackish lakes was significantly related to planktivorous fish density, salinity and total phosphorus and established weighted averaging models for the reconstruction of these parameters.

Zooplankton species composition varies greatly with salinity (Bos et al., 1996). Many cladocerans show a unimodal response over a gradient of salinity because they have poor ability to osmoregulate (Frey, 1993). Among the Cladocera more than 40 species live in saline/brackish water, eight species inhabit in oceans and five species live in highly mineralised continental waters (Aladin, 1991).

Paleolimnology can be a great asset in Turkey since long term lake monitoring programmes are very scarce. In Turkey, paleolimnology studies have been focusing mostly on the climatic changes in Late Quaternary period. Beug (1967) studied postglacial vegetatinoal history of Northern Turkey by retrieving a sediment core from Lake Yeniçağa and Lake Abant, Bolu in 1957. This research was followed by Woldring et al. (1986), a detailed vegetational history study of northern and northwestern

Turkey. After 1990's English researchers collected sediment cores from Lakes Gölhisar, Burdur; Süleymanhacı and Pınarbaşı and Konya plain to study the Late-Holocene environmental change in Southern Turkey (Roberts et al., 1997, Eastwood and Pearce, 1998, Reed et al., 1999, Eastwood et al., 1999a, Eastwood et al., 1999b, Roberts et al., 1999, Jones et al., 2002). Kashima (2003) studied climatic changes during the Late Quaternary using three sediment cores from closed and semi-arid lacustrine basins in the central Anatolia, based on diatom assemblages of sediments from 38 lakes and rivers and living and fossil diatoms for quantitative reconstruction of water salinity for Turkey. Jones et al. (2005) sampled varved sediment of Nar Lake, and studied oxygen isotope records for comparing oxygen isotope record from the lake sediment with instrumental records of temperature, precipitation, wind speed, relative humidity and calculated values of evaporation. They showed that the isotope record followed the same trends in the temperature and evaporation records. Furthermore, England et al. (2008) coupled stable isotope, pollen and charcoal from Nar Lake sediment core in order to investigate land use in Cappadocia region. They indicated that Cappadocia has been a predominantly open landscape throughout the last two millennia. They also found the first significant cultural landscape transformation occurrence during the Bronze Age. Woodbridge and Roberts (2010) used the same laminated sediments to investigate the link between modern and fossil diatom assemblages. Thereafter, Woodbridge and Roberts (2011) compared sedimentary diatom record with stable isotope and pollen record from the same core over last 1720 years and they investigated that Nar lake water was much more saline and the climate of central Anatolia was significantly more arid during the decades prior to AD 540. Recently, Reed et al. (2012) developed conductivity transfer functions using diatoms and ostracods from Turkish lake training sets using weighted averaging techniques to confirm the potential for diatoms and ostracods to strengthen palaeoclimate inferences by quantitative multi-proxy reconstruction. Results of paired diatom-ostracod analysis indicated that the most important ecological threshold occurs at a conductivity boundary of ~3 mScm^{-1}.

The current study is an first attempt to use a Cladocera-based transfer function for infering salinity based on a training set of 44 Turkish shallow lakes. The aim of this study is to reconstruct the past (100-150 years) changes in salinity using sub-fossil cladocera to test the hypothesis that the lakes with wetter conditions having low salinities whereas the lakes with drier conditions having high salinities through time as a result of different temperature, evaporation and precipitation regimes. For this purpose recostruction of the past salinity conditions was carried out for lakes Hamam, Yeniçağa, Gölhisar and Gölcük.

5.2. Methodology

5.2.1. Study Sites

Hamam (41°49´N, 27°57´E) and Yeniçağa (45°15´N, 41°81´E) lakes were considered highly precipitated and low evaporated lakes whereas Gölhisar (37°06´N, 29°36´E) and Gölcük (38°18´N, 28°01´E) lakes were considered high evaporated lakes because of their latitudinal gradient along Turkey (Figure 5.1, Table 5.1, Appendix A). Because of the high altitude geographical characteristic of Anatolian Plateau, only Lake Hamam considered in low altitude lake as it is situated by the Black Sea coast, the rest of the lakes are high altitude lakes (Table 5.1).

Figure 5.1. Location of the study lakes.

Table 5.1. Environmental and biological variables from the sampled lakes.

Lake	Altitude (m)	Size (ha)	Precipitation (mm)	Evaporation (mm)	Average Temperature	pH	TP(µg L^{-1})	TN(µg L^{-1})	Alkalinity (meq L^{-1})	Salinity (‰)	Chlorophyll-*a* (µg L^{-1})	Secchi Disc Depth (cm)	PVI (%)	Fish (cpue)
Hamam	5	20	700	33.1	21.2	8.98	40.1	328.3	0.5	0.06	16.3	50	7	40
Yeniçağa	988	400	537	24.4	25.7	9.10	266.2	731.4	1.9	0.16	7.7	90	7.5	149
Gölhisar	930	400	523	37.7	25.8	9.16	67.3	775.1	7.4	0.31	12.7	50	15	44
Gölcük	1050	75	560	47.7	24.6	9.64	326	2028.4	1.4	0.12	14.5	25	0	49

Lake Hamam (41°5'N, 27°6'E, elevation 5 m) is small (20 ha) and shallow (max. 1.9 m) lake located in İğneada-Kırklareli province (Figure 5.1). The lake water had low alkaline (0.50 meq L^{-1}), low saline (0.06 ‰) and having a pH of 8.98 when sampling carried out in August 2006 (Table 4.1). The lake was considered in clear water state having 40.06 µg L^{-1} TP, 328.3 µg L^{-1} TN, 16.30 µg L^{-1} Chlorophyll-*a* and 50 cm Secchi disc depth (Table 5.1).

Lake Yeniçağa (45°1'N, 41°8'E; elevation 988 m) is relatively large (400 ha) and shallow (max. 4.4 m) lake located in Bolu province (Figure 5.1). The lake water had low alkaline (1.90 meq L^{-1}), low saline (0.16 ‰) and having a pH of 9.10when sampling carried out in August 2007 (Table 4.1).The lake was considered eutrophic having 266.2 µg L^{-1} TP, 731.4 µg L^{-1} TN, 7.68 µg L^{-1} Chlorophyll-*a* and contrary to these values high (90 cm) Secchi disc transparency (Table 5.1).

Lake Gölhisar (37°8′N, 29°36′E; elevation 930 m) is 400 ha lake and shallow (1.6 m) lake located in Burdur province in the south of Turkey (Figure 5.1). The lake's hydrological catchment is ~88 km^2. Average annual precipitation for Gölhisar is 560 mm, of which 50 % falls during the winter and 12 % during the summer (Eastwood et al., 1999). The lake water was alkaline (7.40 meq L^{-1}), oligosaline (0.31 ‰) and having a pH of 9.16 when sampling carried out in August 2007. The lake was considered eutrophic having 67.2 µg L^{-1} TP, 775 µg L^{-1} TN, 12.7 µg L^{-1} Chlorophyll-*a* and 50 cm Secchi disc depth.

Lake Gölcük (38°18'N, 28°01'E; elevation 1050 m) is a small (75 ha) shallow (2.5 m) lake located in Manisa province (Figure 5.1). The lake was considered the more eutrophic than the rest of the lakes, having 326 µg L^{-1} TP, 2028 µg L^{-1} TN, 14.54 µg L^{-1} Chlorophyll-*a* and very low light transparency (25 cm Secchi disc depth).

5.2.2. Field sampling

Sediment cores (~ 50 cm-long) by using KC Denmark Kajak-type coring equipment were collected from all four lakes at the deepest point (Figure 5.1). Snap shot sampling was employed for the contemporary data as explained from Chapter 2 in 2006 for Lake Hamam and in 2007 for Yeniçağa, Gölhisar and Gölcük.

5.2.3. Laboratory analysis

For Cladoceran taxonomical analysis, the same methodology explained in Chapter 2 was used.

5.2.4. Data analyses

For all the cores, Detrended Correspondance Analysis (DCA) and Principal Component Analysis (PCA) were performed to identify the changes in the cladoceran records along the cores. PCA was used if the first axis gradient length in DCA ordination was < 2 standard deviations (ter Braak and Prentice, 1988). Ordinations were carried out using the vegan package (version 2.0-1) in R program (The R Foundation for Statistical Computing Version 2.12.2).

Weighted averaging partial least squares (WA-PLS) regression models were applied to calibration data set of 40 lakes which explained from the previous chapter to infer past salinity changes using the program C2 (Juggins, 2003).

The physical, chemical, biological and sedimentary data were taken from Beklioğlu et al., (in prep.) and TÜBİTAK Project no: 110Y125. Thus, the same data excluding sub-fossil Cladocera will be used in the several PhD thesis who have carried out their thesis at METU, Biology Department (Şeyda Erdoğan, Gizem Bezirci, Eti Ester Levi) and was used in completed PhD thesis (Ü. Nihan Tavşanoğlu and ArdaÖzen).

5.2.5. Dating

For dating recent sediments (past 150 years), ^{137}Cs and ^{210}Pb radioactive isotopes are commonly used (Appleby, 2001). With a half life of 22.3 years, ^{210}Pb is ideal for establishing depth-time scales over the past century (Smol, 2008). Core chronology was calculated by measuring the constant rate of ^{210}Pb supply (CRS). Analyses were operated by Flett Research, Canada (www.flettresearch.ca) and Gamma Dating Center, Institute of Geography, University of Copenhagen. The samples have been analysed for the activity of ^{210}Pb, ^{226}Ra and ^{137}Cs via gammaspectrometry. The measurements were carried out on a Canberra low-background Germanium well-detector. ^{210}Pb was measured viaits gamma-peak at 46,5 keV.

5.3. Results

5.3.1. ^{210}Pb Dating of the cores from the study lakes

According to constant rate of ^{210}Pb supply (CRS) analysis, sedimentation rates were calculated for Lakes Hamam, Yeniçağa, Gölcük and Gölhisar as 0.22, 0.93, 0.19, 0.5 cm year^{-1}, respectively.The deepest point of the core that the last ^{210}Pb signal collected was at 27.5 cm for Lake Hamam, 66 cm for Lake Yeniçağa, 60 cm for Lake Gölcük, and 26 cm for Lake Gölhisar. Therefore, the dates at that point was calculated as 1886, 1939, 1942, 1942 according to CRS model, respectively. (Figures 5.2, 5.3, 5.4, 5.5). For Lake Haman, after 27.5 cm, the rest of the dating along the core were extrapolated calculating the activity on the basis of the regression line (Figure 5.2).

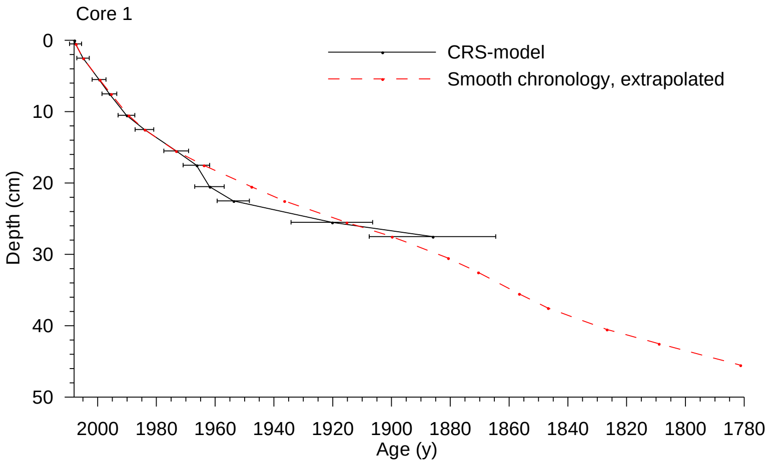

Figure 5.2. ^{210}Pb signal retrieved from Lake Hamam short core and dating with CRS model and interpolation along the core. Analysis were run at Gamma Dating Center, Institute of Geography, University of Copenhagen.

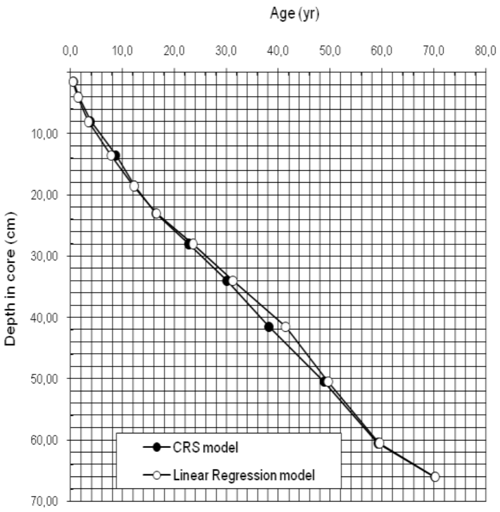

Figure 5.3. ^{210}Pb signal retrieved from Lake Yeniçağashort core and dating with CRS model and linear regression model along the core. Analysis were run by Flett Research, Canada.

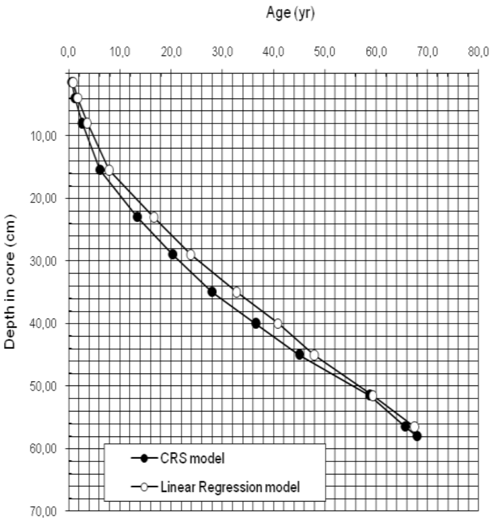

Figure 5.4. ^{210}Pb signal retrieved from Lake Gölcükshort core and dating with CRS model and linear regression model along the core. Analysis were run by Flett Research, Canada.

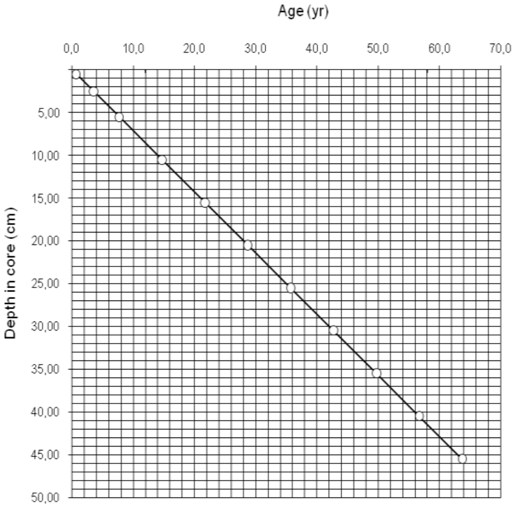

Figure 5.5. ^{210}Pb signal retrieved from Lake Gölhisarshort core and dating with linear regression model along the core. Analysis were run by Flett Research, Canada.

5.3.2 Sub-fossil cladocera and salinity change through time in the study lakes

Lake Hamam

A total of 15 cladoceran taxa were recorded by chitinous and ephippial remains along the sediment core (Figure 5.6). *Bosmina longirostris* was the most abundant taxa along the core on the other hand *Daphnia* spp. was the least abundant taxa and it was only found in the past decade. PCA was used since the first axis gradient length in DCA ordination was 1.8 standard deviations. According to PCA Axis 1 scores three zones were identified. In the first zone, the cladoceran assemblage was relatively stable and composed of mixture of benthic and pelagic species. However, from 1900s to present time the abundance of sedimentary taxa had decreased and pelagic species had increased. Also in the same period macrophyte associated taxa *Acroperus harpei* abundance increased. In the second zone, there was a shift in community composition with decline in sedimentary and macrophyte associated taxa, *Ceriodaphnia* sp., *C. sphaericus. A. quadrangularis. A. rectangula/gutata. Pleuroxus* spp., *Disparalona rostrata.* and *Alonella excisa* and an increase in pelagic taxa *B. longirostris* and *Moina* sp. (Figure 5.6). The third zone consisting early 1800s were characterized by low number of cladocera species and the highest salinity values at the bottom of the core.

Cladoceran inferred salinity showed slightly low variation since 1780. In the zones 2 and 3, there were two distinct salinity peaks by the presence of only *Bosmina longirostris. Moina* sp., *Acroperus harpei* and *Leydigia leydigi.* Zone 1 was characterized by low and uniform salinity except the present day which was charcaterized by the lowest value. Zone 1 included more taxa than zones 2 and 3. Parallel to species number increase their habitat diversity changed such as the more macrophyte and sediment associated species abundance increased in zone 1. Furthermore, top of the core showed high species number and species abundance.

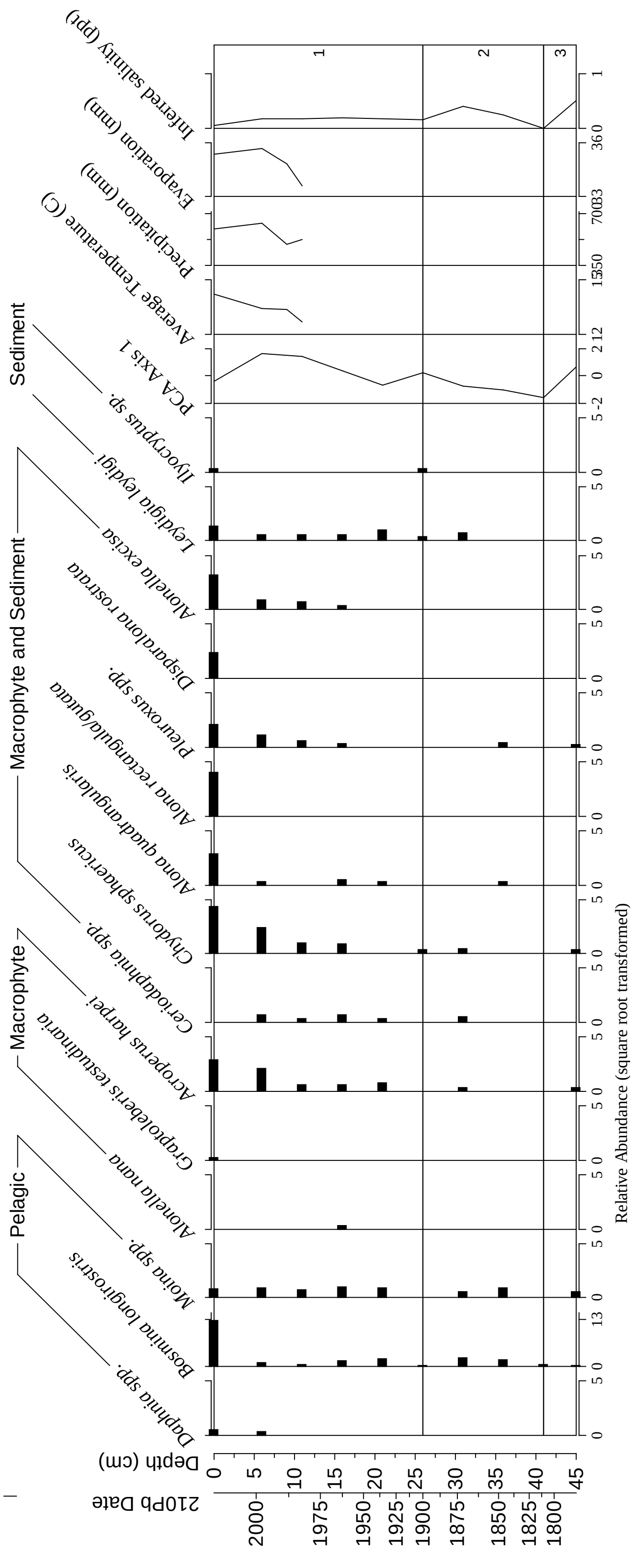

Figure 5.6. A Cladoceran stratigraphy for Lake Hamam and Cladoceran-inferred log salinity change along the core. Notice the difference in scale for relative abundance. especially for *Bosmina longirostris*.

Lake Yeniçağa

A total of 20 cladoceran taxa were recorded by chitinous and ephippial remains along the 65 cm sediment core of Lake Yeniçağ (Figure 5.7). PCA was used since the first axis gradient length in DCA ordination was 1.6 standard deviations. According to PCA Axis 1 scores Lake Yeniçağa sequence can be divided into four zones. Through the bottom of the core which represented 1936 ^{210}Pb date to late 1940s was named Zone 4. The assemblage was very diverse and relatively stable and the salinity inference showed low values (Figure 5.7). This zone was dominated by the abundant taxa *Bosmina longirostris* and relatively high abundant taxa *Chydorus sphaericus* and *Camptocercus rectirostris*. Moreover zone 4 can be identified by the high species richness of macrophyte and sediment associated taxa. Also macrophyte associated taxa *Sida crystallina* and *Eurycercus lamellatus* were only found in this zone along the core stratigraphy. Zone 3 from late 1940s to mid 1970s can be characterized by the gradually disappearence of macrophyte associated taxa and they were replaced by pelagic taxa. There was an increase of salinity (Figure 5.7). In addition. macrophyte - sediment associated taxa such as *Disparalona rostrata, Alona quadrangularis, Alonella exisa* and *Alonella exigua* gradually disappeared in the zone 3. The zone 2 started from mid 1970s through early 2000s. It was characterized by disappearance of macrophyte associated taxa. The most abundant taxa were pelagic species including *Daphnia* spp., *Bosmina longirostris* and sedimentary species *Leydigia leydigi.* Salinity increased towards present day and reached its maximum value in this zone. Lastly, the zone 1 represented the last decade, there were changes in assemblage composition and the species richness, which increased towards the present day (Figure 5.7). *Daphnia* spp. fell sharply and the abundance of *Bosmina longirostris* increased towards present day. Macrophyte associated species *Alonella nana, Graptoleberis testudinaria* and *Acroperus harpei* reappeared and for the first time *Simocephalus* spp. appeared. Macrophyte and sediment associated taxa *Chydorus sphaericus, Ceriodaphnia* spp., *Alona quadrangularis, Alona rectangula/gutata, Leydigia leydigi* and *Leydigia acanthocercoides* became more abundant in this zone. It was also identified as decreased salinity to the present day value.

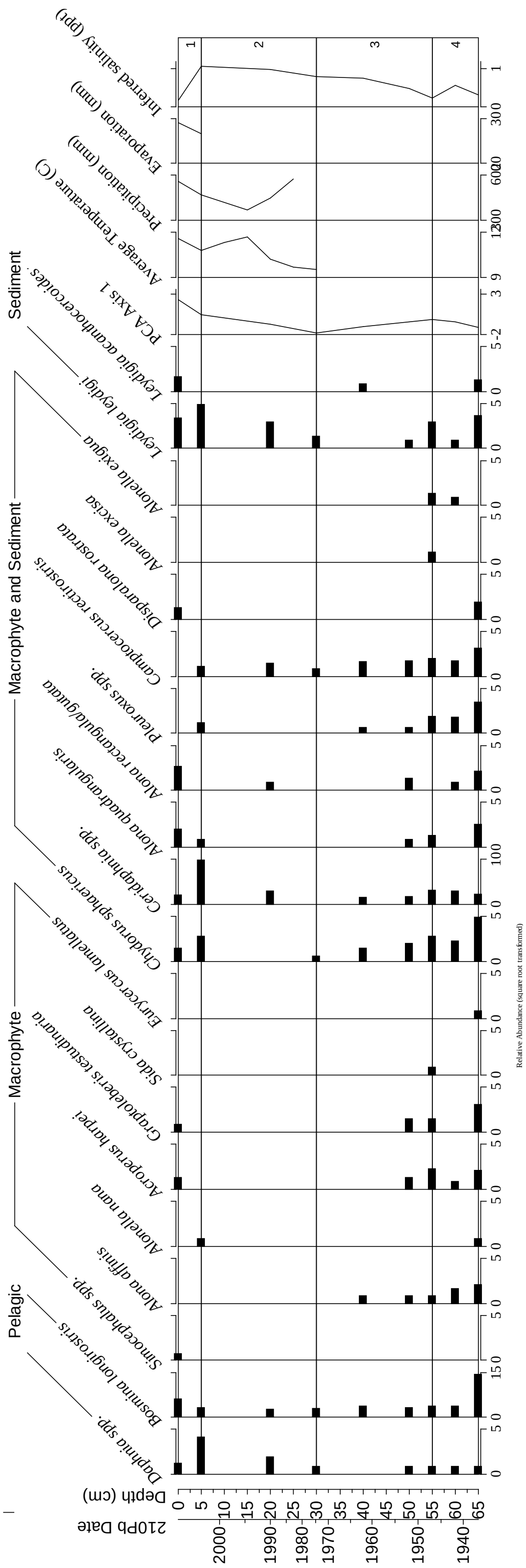

Figure 5.7. A Cladoceran stratigraphy for Lake Yeniçağa and Cladoceran-inferred salinity change along the core. Notice the difference in scale for relative abundance. especially for *B. longirostris* and *Ceriodaphnia* spp.

Lake Gölcük

A total of 14 cladoceran taxa were recorded by chitinous and ephippial remains along the sediment core of Lake Gölcük (Figure 5.8). PCA was used since the first axis gradient length in DCA ordination was 0.9 standard deviations. Lake Gölcük sequence can be divided into two zones according to PCA Axis 1 scores although; the cladoceran stratigraphy did not show significant changes. Along the core *Ceriodaphnia* spp., *B. longirostris* and *C. sphaericus* were the most abundant taxa and found every depth of the core. In zone two, there were an increase in pelagic community and decrease in relative abundance of the macrophte and sediment associated community towards present day. However, during the most of Zone 1 *Daphnia* spp., was presenta as well as *A. harpei* and *L. acanthocercoides.* Cladoceran inferred salinity was high along the Zone 2 with highest peak around late 1990s and the Zone 1 showed a decline of salinity towards present day (Figure 5.8).

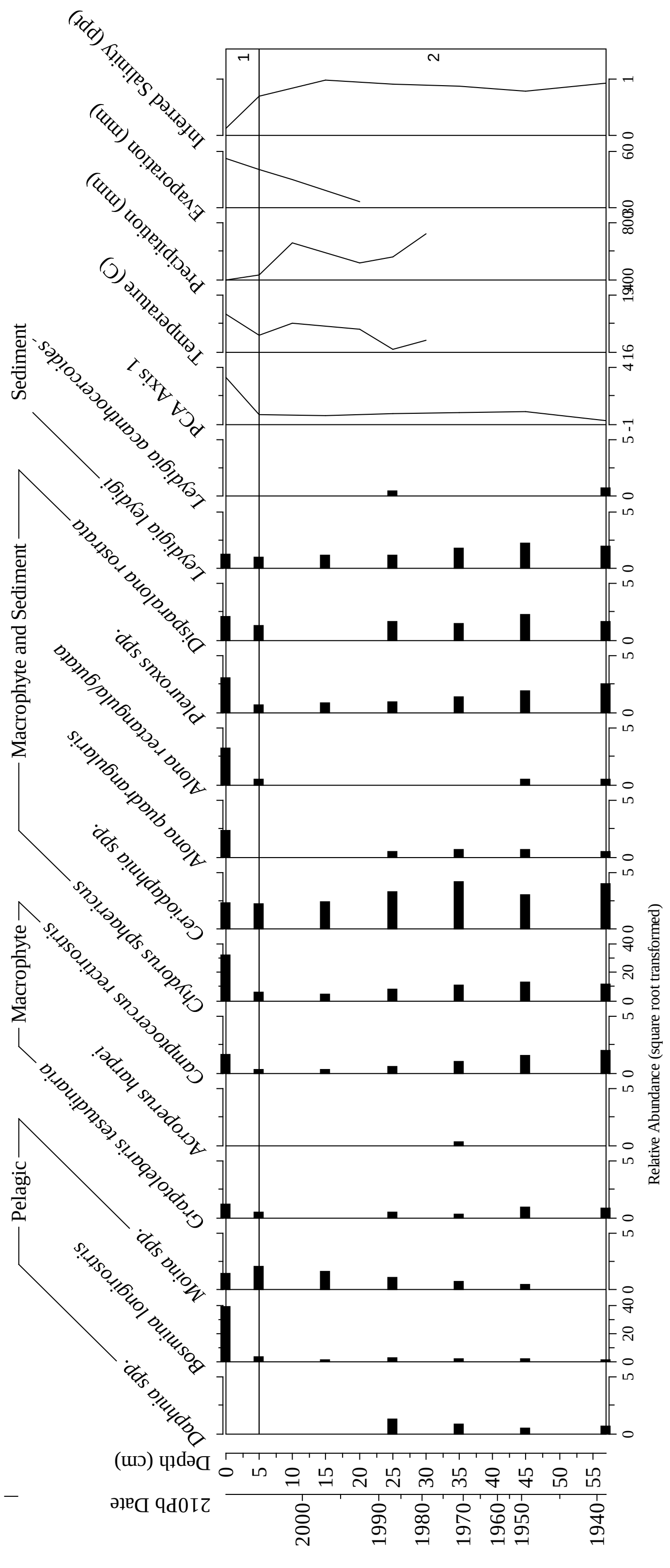

Figure 5.8. A Cladoceran stratigraphy for Lake Gölcük and Cladoceran-inferred salinity change along the core. Notice the different scale in *Bosmina longirostris* and *Chydorus sphaericus*.

Lake Gölhisar

A total of 14 cladoceran taxa were recorded by chitinous and ephippial remains along the sediment core (Figure 5.9). *B. longirostris* showed the highest abundance along the core. The relative abundace of *A. rectangula/gutata, C. sphaericus* and *L. leydigi* were the other abundant taxa. PCA was used since the first axis gradient length in DCA ordination was 0.5 standard deviations. According to PCA Axis 1 scores three different zones were identified. The zone 3 was identified from the bottom of the core to early 1960s. Macrophyte associated *C. rectirostris* was only found in this zone along the core. The lowest values of inferred salinity were calculated in Zone 3 and this zone could be characterized by its high precipitation values. Zone 2 represents early 1960s to mid 1990s. This zone can be characterized by high relative abundance. Precipitation declined towards present day consequently the caldoceran based inferred salinity increased. Pelagic taxa *Daphnia* spp. was only found in this zone. Zone 1 covers the dates from mid 1990s to present day. In this zone pelagic species *Bosmina longirostris* and *Moina* sp. decreased in abundance towards present day and *Alonella exigua* reappeared. This zone can also be characterized by decreasing precipitation with increasing temperature and evaporation. However, inferred salinity did not show increasing response.

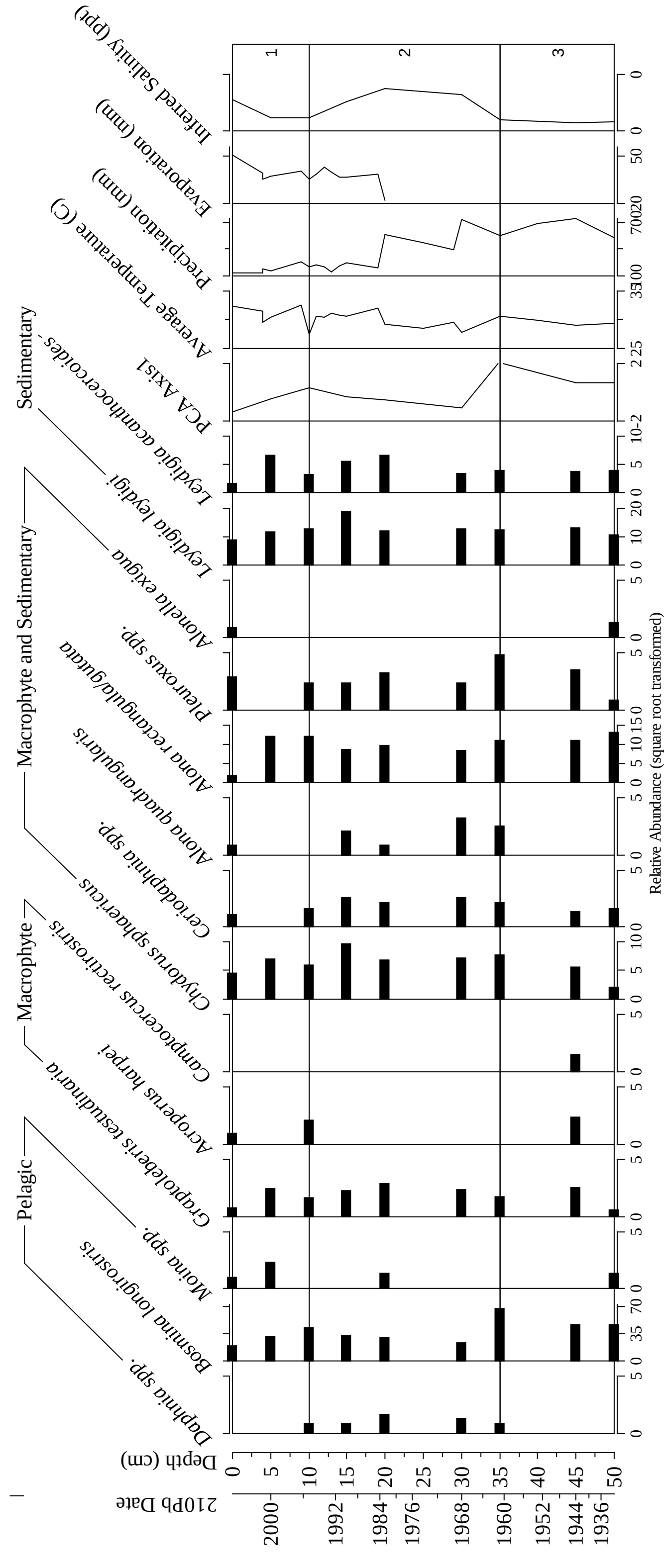

Figure 5.9. Cladoceran stratigraphy for Lake Gölhisar and Cladocera-inferred salinity. Notice the different scale in *B. Longirostris,.C. Sphaericus, A.rectangula/gutata, L.Leydigi* and *L.acanthocercoides.*

5.4. Discussion

Cladoceran species composition varies greatly throughout the cores that was used for inferring the changes in lake water salinity through time. There were more species richness in Lake Yeniçağa (20 taxa) compared to other lakes (Gölcük: 14; Gölhisar: 14, Hamam: 15). Salinity decreased from past to present in all lakes except Gölhisar. The analyses showed that in all four lakes cladoceran community structure changed in response to their salinity tolerances. Species richness decreased when salinity increased in Lakes Yeniçağa, Hamam and Gölhisar in contrast species richness was relatively high in Lake Gölcük in high salinity periods.

Since ca. 1940, salinity has been increasing in Lakes Yeniçağa, Gölcük and Gölhisar. However, in Lake Yeniçağa and Lake Gölcük salinity decreased in last decade while in Lake Gölhisar salinity increase continued. Although in Bolu region the average yearly precipitation was approx. 540 mm and evaporation 24.4 mm, according to Ministry of Food, Agriculture and Livestock in Yeniçağa district irrigated farming caused intense water use for agriculture, starting 1940s. In Gölhisar region the average yearly precipitation was approx. 520 mm and evaporation was 37.7 mm. In addition to this high evaporation, past 15 years seven dams (Yapraklı Dam, etc.) and ponds have been established in the area for irrigation purposes (DSI, 2000). Furthermore, in the area unknown amount of illegal irrigation wells decrease the ground water table. Having high evaporation and low water inflow to the Lake Gölhisar, the increase in the salinity was inevitable.

The relatively slow salinity changes and low salinity values in Lake Gölcük is probably the result of high precipitation in the area. Lake Gölcük is situated below the Bozdağ mountain ranges (1350 m) with elevation of 1050 m. According to Ceylan (1996) yearly average precipitation for Bozdağ is 1362 mm. Inspite of high precipitation intense agricultural activities in the lowland areas especially water removal from the lake in summer result the slight increase of salinity through time (Ceylan. 1996).

In the early periods, zones 2 and 3 (ca. 1800-1900) Lake Hamam had the highest salinity and the cladoceran community mainly consisted of *Bosmina longirostris, Chydorus sphaericus, Alona quadrangularis, Pleuroxus* spp., *Leydigia leydigi, Acroperus harpei, Moina* sp. and *Ceriodaphnia* spp. According to salinity tolerances calculated in Chapter 3, *B.longirostris, A. quadrangularis,* and *Pleuroxus* spp. were low salinity tolerant species. However, Ustaoğlu et al (2012) identified *B.longirostris,* and *Pleuroxus* spp. in lakes with salinities up to 33 ‰. Later in Zone 1, species richness increased with increasing abundance of the taxa from zones 2 and 3 and new appearance of *Daphnia* spp., *Graptoleberis testudinaria, Alonella nana, Alona rectanugla/gutata, Disparalona rostrata, Alonella excisa,* and *Ilyocryptus* sp. In general cladoceran species richness declines with increasing salinity (Frey, 1993, Bos et al., 1999) since many cladoceran species cannot tolerate high salinity (Aladin, 1991). Jeppesen et al. (1994) found that *Daphnia* spp. completely disappeared in Danish brackish lakes when the salinity reached 2 ‰ whereas other cladocerans except *B. longirostris* disappeared when the salinity reached 7.2 ‰. Also in the brackish Lake Glombak, the cladoceran community composition changed with a major influence of salinity and mainly consisted of *Ceriodaphnia* spp., *C. sphaericus, A. rectangula,* and *B. longirostris* (Amsinck et al., 2003)

In Yeniçağa, the influence of salinity indicated by the change of cladoceran community composition. The low salinity period, the zone 4, included, 19 different taxa from all four habitats in contrast the highest salinity period, the zone 2, captured 7 different taxa from macrophyte-sediment and sediment habitat. The relative abundance of each cladocera decreased from early 1940 through ca. 2000. After ca. 1960, macrophyte and also macrophyte and sediment associated species declined with increasing salinity. Amsinck et al. (2005b) reported decline in macrophyte abundance with increasing salinity in Lake Flade, Denmark. Also, it was shown that salinity increase has been associated with eutrophic conditions through deficiency in water budget that up-concentrate nutrients, thus led to the low macrophyte abundance due to turbid conditions (Beklioğlu and Tan, 2008; Özen et al., 2010; Tavşanoğlu, 2012). Then in zone 1, with the decline of salinity, macrophyte-sediment associated and low salinity tolerance species, *A. nana, A. harpei, G. testudinaria, A. quadrangularis, S. crystallina* and *D. rostrata* reappeared. Similarly, the absence of low salinity tolerant *A. quadrangularis* in Lake Ruokolampi during brackish-water transgressions of the Littorina Sea was reported (Sarmaja-Korjonen and Hyvarinen 2002). The most common stenohaline species *B. longirostris* and *C. sphaericus* were abundant along the core and they were not affected from salinity increase. Deasley et al. (2012) showed that *Chydorus brevilabris*, *A. circumfimbriata*, and *Bosmina* were abundant both before and after the saline intrusion, and continued to survive and reproduce even after the lake switched rapidly from a freshwater to a brackish system in an Arctic Lake, Canada.

In Lake Gölcük, the cladoceran stratigraphy did not show much changes along the core. The relative abundance of the most common species *B. longirostris, C. sphaericus,* and low salinity tolerant taxa *A. quadrangularis, A. rectangula/gutata, Pleuroxus* spp., and *D. rostrata* increased with decreasing salinity in Zone 1. Green et al. (2005) indicated the species richness and abundance of cladocera were higher when salinity had its lowest values in brackish lakes in Eastern Spain.

There is also a risk of using single variable inference models for modelling change in lake physical, chemical and biological structures when there are other important co-variables as stated in Davidson et al. (2011). Moreover, environmental changes in a region possibly more as a result of indirect impacts, such as changes in trophic state and habitat availability related to climatic change rather than as a direct result of salinity change (Kattel et al., 2008). The anthropogenic activities around lakes can significantly changed the natural environment through deforestation, irrigation and agriculture. All of these processes, directly or indirectly, can trigger an increase in the lake's trophic structure. For example, the dominance of salinity tolerant *C. sphaericus* along all cores may also indicate relatively eutrophic conditions during that period (Galbarczyk-Gasiorowska et al., 2009).

In order to test our hypothesis, a multiproxy study together with diatoms and plant macrophytes could give more reliable inferences about lake ecosystems (Birks and Birks. 2006). Also for application of a transfer function requires certain criteria to be met as stated in Chapter 1. Sites in the calibration data-set need to be distributed across a wide eco-climatic gradient and the study sites should be free from human disturbance as well as long-range atmospheric deposition (Birks and Juggins, 2012). In addition, the aquatic organisms studied in the calibration data-set should be well distributed and indirectly sensitive to climate change (Birks, 1995) and the lake which is used for past environment reconstruction should contain biota that are well represented in the calibration data-set and that are sensitive to climate change (Birks. 1995). In our calibration data set, 26 taxa were identified and among them almost half of the cladoceran species were found in the cores. Thus, extreme caution is needed in interpreting cladocera inference results because many factors other than salinity appear to have driven the community dynamics such as, water level changes, fish predation, etc.

In conclusion, up to now, the first sub-fossil Cladocera calibration data set for Turkey was produced based on 40 Turkish shallow lakes and for the first time in Turkey cladoceran based transfer function was developed for salinity. According to the predicted salinity in high evaporated lakes drought and unbalanced hydrological changes and in high precipitated lakes regional rainfall regime can cause salinity change. Apart from these, anthropogenic impacts are important shaping cladoceran community structure and whole lake ecosystem.

CHAPTER 6

CONCLUSIONS

The objectives of this thesis were to analyze the reliability of contemporary and sub-fossil Cladocera relationship with environmental factors shaping the cladoceran community; to determine the relationship between the distribution of sedimentary cladoceran species and environmental variables; to delineate the effects of climate change from the recent past (100-150 years) to the present using sub-fossil Cladocera, chemical and physical proxies by constructing salinity transfer functions and to hindcast the reliability of salinity transfer functions using long-term monitoring data from two interconnected shallow lakes.

The following main conclusions summarize the findings in this thesis:

1. Comparing the contemporary and sub-fossil data, we found a good correlation in the cladoceran community response to the changing environment between the contemporary community and the assemblages from surface sediment. As a result, a calibration set including sub-fossil cladoceran assemblages against modern environmental variables in order to reconstruct past salinity change could applicable.

2. There has been no study so far carried out on sub-fossil Cladocera from Turkish lakes. For the first time, 44 shallow Turkish lakes were thoroughly studied for the lake environmental variables and sub-fossil Cladocera in order to investigate the key environmental factor that was related with climate change structuring cladoceran community composition. Our results indicated that Cladocera assemblages preserved in lake sediments were reliable and sensitive indicators of lake salinity. Cladoceran sub-fossils can be a useful tool in the paleolimnological reconstruction of salinity in shallow lakes, which may help interpret past changes in climate. Thus, a sub-fossil cladoceran-salinity calibration set for Turkey was generated.

3. The current study was also a first attempt to use a Cladoceran transfer function for infering salinity based on a training set of 44 Turkish shallow lakes. The aim of this study was to reconstruct the past (100-150 years) changes in salinity using sub-fossil cladocera to test the hypothesis that northern latitude lakes with wetter conditions having low salinities whereas southern lakes with drier condition having high salinities through time as a result of different temperature, evaporation and precipitation regimes. For this purpose recostruction of the past salinity conditions was carried out for two lakes, Hamam and Yeniçağa from the north, and two lakes, Gölhisar and Gölcük from the south of Turkey. In conclusion, the predicted salinity change from past to present suggested that in highly evaporated lakes drought and unbalanced hydrological changes whereas in highly precipitated lakes climate can cause salinity change. Apart from these, anthropogenic impacts were important shaping cladoceran community structure and whole lake ecosystem.

4. Validation of paleolimnological results was rarely tested. This thesis revealed the results of long-term monitoring and paleolimnological investigation of two interconnected shallow lakes. Hindcasting of variables from the monitoring years and the reconstructed salinities indicated that the sediment record reflected the known lake salinity history fairly well, with a good linear correlation. Such finding showed that the lake ecosystem fluctuations could be tracked beyond the pre-monitoring years by using sub-fossil Cladocera.

This study has confirmed that sub-fossil Cladocera was a valuable tool as biological indicator for historical salinity change and a marker for the long-term monitoring of lakes. For the first time, the lake environmental variables and sub-fossil cladoceran species composition from the surface sediments of Turkish shallow lakes were studied and salinity transfer functions were developed in order to elucidate past salinity change. Since monitoring programmes are scarce in Turkey, paleolimnological analyses would give great benefit. Especially for the management purposes, the known data about previous biological and chemical conditions of a lake could help to define reasonable restoration goals.

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APPENDIX A

Geographical information about the lakes that were sampled for thesis.

Lake	**Province**	**Latitute (N)**	**Longitute (E)**	**GPS Projection**	**UTM**	**Elevation (m)**	**Area (ha)**	**Max. Depth (cm)**
Hamam-İğneada	Kırklareli	41 49,400	27 57,936	Lat/Long	35T	5	20	190
Poyrazlar	Adapazarı	40 50 32,8	30 28 12,3	Lat/Long	36T	36	60	470
Abant	Bolu	40 36,454	31 16,917	Lat/Long	36T	1328	128	1740
Büyük-Yedigöller	Bolu	40 56,633	31 44,764	Lat/Long	36T	784	2,4	1550
Derin-Yedigöller	Bolu	40 56,579	31 44,990	Lat/Long	36T	987	1,5	970
Nazlı-Yedigöller	Bolu	40 56 20,2	31 44 32,0	Lat/Long	36T	987	1,6	540
İnce-Yedigöller	Bolu	40 56 22,6	31 44 27,1	Lat/Long	36T	987	0,1	100
Serin-Yedigöller	Bolu	40 56 45,3	31 44 50,6	Lat/Long	36T	987	0,17	150
Pedina-İğneada	Kırklareli	46 31 58,5	57 76 71,0	UTM	35T	20	10	90
Eymir	Ankara	39 49 37,1	32 49 57,7	Lat/Long	36S	971	125	350
Mogan	Ankara	39 46 08,7	32 47 27,16	Lat/Long	36S	975	635	300
Taşkısığı	Sakarya	40 52 25,9	30 24 02,8	Lat/Long	36T	33	90	340
Küçük Akgöl	Sakarya	40 52 42,8	30 25 55,4	Lat/Long	36T	22	20	95
Büyük Akgöl	Sakarya	45 46 76,5	29 51 77	UTM	36T	10	190	370
Çubuk	Bolu	40 28 51,9	30 50 05,3	Lat/Long	36T	1058	20	560
Gölcük_Bolu	Bolu	45 01 50,8	38 38 82	UTM	36S	1380	4,5	520
Yeniçağa	Bolu	45 15 55,0	41 81 61	UTM	36T	990	400	440
Gölhisar	Burdur	37 06 50	29 36 22,6	Lat/Long	35S	949	400	160
Saka	İğneada	41 48 10,0	27 59 36,3	Lat/Long	35T	1	5	250
Gebekirse	İzmir	37 59 07,2	27 18 15,5	Lat/Long	35S	0	75	540
Barutçu	İzmir	37 59 29,9	27 19 08,0	Lat/Long	35S	0	75	250
Karagöl_İ	İzmir	38 33 28,7	27 13 05,1	Lat/Long	35S	813	2	470
Gölcük_Ö	Ödemiş	38 18 38,5	28 01 42,7	Lat/Long	35S	1049	75	370
Emre	Afyon	39 06 29,7	30 26 16,2	Lat/Long	36S	1154	25	430
Gök Göl	Konya	39,01052	32,83822	Lat/Long	36S	977	50	110
Karagöl_D	Denizli	37,73513	29,49533	Lat/Long	35S	1244	20	410
Gölcük_S	Kütahya	39,16903	29,08391	Lat/Long	35S	1300	70	340
Yayla	Buldan	38 03,118	28 46,350	Lat/Long	35S	1300	70	200
Saklı	Denizli	37 46,644	29 23,865	Lat/Long	35S	959	0,75	750
Baldımaz	Muğla	36 41,725	28 50,063	Lat/Long	35S	4	10	100
Gıcı	Samsun	41 34 59	36 04 03	Lat/Long	37T	0	146	140
Tatlı	Samsun	41 34 15	36 03 58	Lat/Long	37T	0	93	125
Kocagöl	Bolu	40 50 36	32 26 51	Lat/Long	36T	1232	13	320
Gerede	Bolu	40 47 49,3	32 10 00,9	Lat/Long	36T	1292	4	680
Keçi	Bolu	40 50 00,1	32 26 19,7	Lat/Long	36T	1216	11	610
Karagöl_Beypazarı	Ankara	40 21 21	31 55 34	Lat/Long	36T	1423	9	650
Uyuz	Konya	39 14 26	32 55 34,3	Lat/Long	36S	1191	15	150
Balikli	Aksaray	38 23 51,3	34 21 55,1	Lat/Long	36S	1173	6	430
Kaya	Aksaray	38 24 05,2	34 22 34,5	Lat/Long	36S	1182	7	340,00
Eğri	Kayseri	38 15,362	35 12,183	Lat/Long	36S	1071	1	160,00
Sarp	Kayseri	38 15,706	35 12,606	Lat/Long	36S	1074	5	170,00
Kaz	Tokat	40 16,672	36 09,414	Lat/Long	37T	535	3	120,00
Seyfe Göleti	Kırşehir	39 11,666	34 20,257	Lat/Long	36S	1120	10	210,00

APPENDIX B

Sub-fossil Cladocera presence/absence data from 44 Turkish shallow lakes.

Lake	Daph	Cerio	Simo	Bosm	Chyd	A.quad	A.rect
Hamam	+			+	+	+	
Poyrazlar		+		+	+		
Abant		+		+	+	+	+
Büyük Akgöl	+	+		+	+	+	
Derin		+		+	+	+	
Nazlı		+		+	+		
İnce				+	+	+	+
Serin				+	+		
Pedina				+	+		
Eymir	+	+		+	+		
Mogan	+	+	+	+	+	+	+
Taşkısığı	+			+	+	+	+
Küçük Akgöl	+	+		+	+		
Büyük Akgöl		+		+	+	+	+
Çubuk		+		+	+		
Gölcük_Bolu	+	+		+	+	+	
Yeniçağa	+	+	+	+	+	+	
Gölhisar		+		+	+	+	
Saka			+	+	+	+	+
Gebekirse				+			+
Barutçu				+	+		+
Karagöl_İzmir	+	+		+	+		
Gölcük_Ödemiş		+		+	+	+	
Emre	+	+		+	+		+
GökGöl		+	+		+		
Karagol_Denizli		+			+	+	
Gölcük_Simav	+	+		+	+		
Yayla		+	+		+	+	
Saklı	+	+			+		
Baldımaz		+					
Gıcı	+	+	+	+	+	+	+
Tatlı		+		+	+	+	+
Kocagöl		+		+	+		
Gerede	+			+	+		+
Keçi		+		+	+	+	
Kalp							
Karagöl_Beypazar	+	+		+	+	+	
Uyuz		+			+		+
Balıklı	+	+		+	+		+
Kaya	+			+	+	+	+
Eğri	+	+	+	+	+		
Sarp	+	+		+	+		
Kaz	+	+		+	+		
Seyfe	+	+		+	+	+	

Appendix B (continued)

Lake	A.gut	A.recgut	A.affin	P.trunc	Ptrigunci	Pleu sp	Pladunc
Hamam		+		+	+	+	
Poyrazlar		+	+				
Abant		+	+	+			
Büyük Akgöl					+		
Derin		+					
Nazlı							
İnce	+	+					
Serin	+						
Pedina	+			+			
Eymir		+				+	
Mogan							
Taşkısığı							
Küçük Akgöl		+	+			+	
Büyük Akgöl		+	+				
Çubuk		+			+		
Gölcük_Bolu		+	+		+		+
Yeniçağa		+					
Gölhisar		+				+	
Saka							
Gebekirse							
Barutçu							
Karagöl_İzmir						+v	+
Gölcük_Ödemiş		+			+		
Emre		+	+				
GökGöl		+				+	
Karagol_Denizli		+				+	
Gölcük_Simav		+					
Yayla	+	+					
Saklı	+	+				+	
Baldımaz		+					
Gıcı	+	+				+	+
Tatlı		+				+	+
Kocagöl		+	+			+	
Gerede	+	+			+	+	
Keçi		+				+	+
Kalp						+	
Karagöl_Beypazar		+		+		+	
Uyuz	+	+					
Balıklı	+	+				+	+
Kaya	+	+				+	
Eğri		+				+	
Sarp		+	+			+	
Kaz		+				+	
Seyfe		+				+	

Appendix B (continued)

Lake	D.rostra	Alexisa	Alexigu	Alnana	Grapto	Acrop	Lleyd
Hamam	+	+			+	+	+
Poyrazlar	+	+			+	+	+
Abant	+		+	+	+	+	
Büyük Akgöl				+			
Derin							
Nazlı							
İnce							
Serin							
Pedina		+			+	+	
Eymir					+		+
Mogan					+		+
Taşkısığı					+		+
Küçük Akgöl	+				+	+	+
Büyük Akgöl	+	+			+	+	+
Çubuk			+	+	+	+	
Gölcük_Bolu	+			+	+		+
Yeniçağa	+				+	+	+
Gölhisar			+		+	+	+
Saka		+			+	+	
Gebekirse							+
Barutçu						+	+
Karagöl_İzmir							+
Gölcük_Ödemiş	+				+		+
Emre			+		+	+	+
GökGöl							
Karagol_Denizli			+				+
Gölcük_Simav		+	+				+
Yayla		+	+			+	
Saklı		+	+				+
Baldımaz							
Gıcı							+
Tatlı							+
Kocagöl				+			+
Gerede				+	+		+
Keçi				+	+		+
Kalp							
Karagöl_Beypazar			+	+	+	+	
Uyuz							
Balıklı		+	+				+
Kaya		+					+
Eğri			+	+	+	+	
Sarp			+		+		+
Kaz		+			+		
Seyfe		+	+				+

Appendix B (continued)

Lake	Lacanth	Leptod	Kurzia	Eurycer	Ilyocryp	Sida	Campto
Hamam					+		
Poyrazlar	+		+	+	+		
Abant						+	+
Büyük Akgöl							
Derin							
Nazlı							
İnce							
Serin							
Pedina	+						
Eymir	+						
Mogan	+						
Taşkısığı	+	+					
Küçük Akgöl			+		+		
Büyük Akgöl	+						
Çubuk					+		+
Gölcük_Bolu					+		+
Yeniçağa	+						
Gölhisar	+						
Saka		+	+				
Gebekirse	+						
Barutçu	+						
Karagöl_İzmir	+						
Gölcük_Ödemiş							+
Emre				+			
GökGöl	+					+	
Karagol_Denizli	+						
Gölcük_Simav	+				+		
Yayla						+	
Saklı							
Baldımaz							
Gıcı	+						
Tatlı	+						
Kocagöl							
Gerede						+	+
Keçi							+
Kalp							
Karagöl_Beypazar			+				+
Uyuz							
Balıklı	+						
Kaya							
Eğri							
Sarp							
Kaz							
Seyfe	+						

Appendix B (continued)

Lake	**Moina**	**Oxyurella**	**Species abbreviations**
Hamam	+		Daph: *Daphnia* spp.
Poyrazlar			Cerio: *Ceriodaphnia* spp.
Abant			Simo: *Simocephalus* sp.
Büyük Akgöl			Bosm: *Bosmina longirostris*
Derin			Chyd: *Chydorus sphaericus*
Nazlı			A.quad: *Alona quadrangularis*
İnce			A.rect: *Alona rectangula*
Serin			A.gut: *Alona gutata*
Pedina			A.recgut: Alona rectangula/gutata
Eymir	+		A.affin: *Alona affinis*
Mogan			P.trunc: *Pleuroxus truncatus*
Taşkısığı			Ptrigunci: Pleuroxus truncatus/uncinatus
Küçük Akgöl	+		Pleu sp: *Pleuroxus* spp.
Büyük Akgöl	+		Pladunc: *Pleuroxus aduncus*
Çubuk			D.rostra: *Disparalona rostrata*
Gölcük_Bolu			Alexisa: *Alonella excisa*
Yeniçağa			Alexigu: *Alonella exigua*
Gölhisar	+		Alnana: *Alonella nana*
Saka			Grapto: *Graptoleberis testudinaria*
Gebekirse			Acrop: *Acroperus harpei*
Barutçu			Lleyd: *Leydigia leydigi*
Karagöl_İzmir	+		Lacanth: *Leydigia acanthocercoides*
Gölcük_Ödemiş	+		Leptod: *Leptodora kindtii*
Emre			Kurzia: *Kurzia latissima*
GökGöl	+		Eurycer: *Eurycercus lamellatus*
Karagol_Denizli			Ilyocryp: *Ilyocryptus* sp.
Gölcük_Simav			Sida: *Sida crystallina*
Yayla			Campto: *Camptocercus* spp.
Saklı			Moina: *Moina* sp.
Baldımaz			
Gıcı	+	+	
Tatlı		+	
Kocagöl			
Gerede			
Keçi			
Kalp			
Karagöl_Beypazar			
Uyuz			
Balıklı			
Kaya			
Eğri			
Sarp			
Kaz		+	
Seyfe	+		

APPENDIX C

Weighted Averaging Partial Least Square analysis results from C2 software.

Name	Number of Taxa	Observed Salinity	WAPLS Estimates	WAPLS Residuals	WAPLS Scores
Hamam	13	0,06	-0,42	-0,48	0,00
Poyrazlar	14	0,08	-0,05	-0,13	0,01
Abant	14	0,06	-0,07	-0,13	-0,02
Buyuk	7	0,09	0,10	0,01	0,00
Derin	5	0,16	0,12	-0,04	0,00
Nazli	3	0,13	0,08	-0,05	0,00
Ince	4	0,13	-0,11	-0,24	0,00
Serin	3	0,15	0,57	0,42	0,00
Pedina	8	0,18	0,22	0,04	0,00
Eymir	10	1,53	1,36	-0,17	0,00
Mogan	9	2,15	1,39	-0,76	0,00
Taskisigi	9	0,15	0,22	0,07	-0,01
K.Akgol	14	0,14	0,27	0,13	-0,01
B.Akgol	12	0,11	0,03	-0,08	0,00
Cubuk	11	0,06	0,01	-0,05	-0,01
Golcuk_Bolu	14	0,08	0,05	-0,03	0,00
Yenicaga	12	0,16	0,79	0,63	0,01
Golhisar	12	0,31	0,34	0,03	0,00
Saka	10	0,21	0,08	-0,13	0,00
Karagol	8	0,14	0,31	0,17	0,00
Golcuk_Odemis	11	0,12	0,25	0,13	-0,01
Emre	11	0,13	0,27	0,14	0,00
GokGol	8	0,64	0,93	0,29	-0,01
Karagol_Denizli	8	0,43	0,65	0,22	0,00
Gölcük_Simav	10	0,08	0,11	0,03	0,00
Yayla	9	0,09	0,22	0,13	-0,01
Sakli	8	0,50	0,50	0,00	-0,01
Gici	12	0,68	0,77	0,09	0,01
Tatli	9	0,40	0,39	-0,01	0,00
Kocagol	8	0,28	0,18	-0,10	0,00
Gerede	9	0,58	0,35	-0,23	0,00
Keci	10	0,25	0,16	-0,09	0,00
Karagol_Beypazar	13	0,06	0,31	0,25	0,00
Uyuz	3	0,69	0,90	0,21	0,01
Balikli	10	0,31	0,19	-0,12	0,00
Kaya	8	0,32	0,65	0,33	0,00
Egri	11	1,43	0,88	-0,55	0,00
Sarp	10	0,67	1,16	0,50	0,00
Kaz	9	0,34	0,51	0,17	0,00
Seyfe	12	0,18	0,32	0,13	0,00

APPENDIX D

Sub-fossil Cladocera taxa identified from the surface sediment of 44 Turkish shallow lakes and photographs of body parts.that used for identification. All photographs were taken by A. İdil Çakıroğlu.

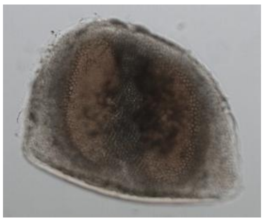
ORDER: CLADOCERA Latreille, 1829

Leptodora kindtii mandibul

Suborder: Haplopoda Sars, 1865
Family: Leptodoridae Lilljeborg, 1861
Genus: *Leptodora* Lilljeborg, 1861
Species: *Leptodora kindtii* (Focke, 1844)
Habitat: Pelagic

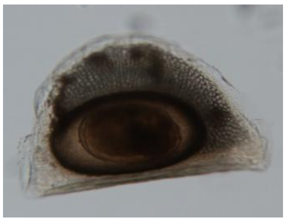
Sida crystallina 3rd exopodite segment

Suborder: Ctenopoda Sars, 1865
Family: Sididae Sars, 1865
Genus: *Sida* Straus, 1820
Species: *Sida crytstallina* (O.F. Müller, 1776)
Habitat: Vegetation



Daphnia spp. ephippia

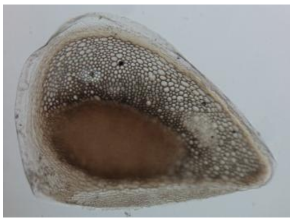
Suborder: Anomopoda Stebbing, 1902
Family: Daphniidae Sars, 1865
Subfamily: Daphniinae Flössner, 2000
Genus: *Daphnia* O.F. Müller, 1785
Species: *Daphnia* spp.
Habitat: Pelagic



Ceriodaphnia spp. ephippia

Suborder: Anomopoda Stebbing, 1902
Family: Daphniidae Sars, 1865
Subfamily: Daphniinae Flössner, 2000
Genus: *Ceriodaphnia* (Dana, 1853)
Species: *Ceriodaphnia* spp.
Habitat: Vegetation and Benthic

Appendix D (continued)

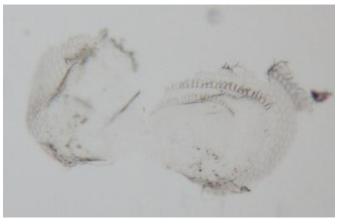


Simocephalus spp. ephippia

Suborder: Anomopoda Stebbing, 1902
Family: Daphniidae Sars, 1865
Subfamily: Daphniinae Flössner, 2000
Genus: *Simocephalus* Schoedler, 1858
Species: *Simocephalus* spp.
Habitat: Vegetation

Bosmina longirostris

Suborder: Anomopoda Stebbing, 1902
Family: Bosminidae Baird, 1845
Genus: *Bosmina*
Species: *Bosmina longirostris* (O.F. Müller, 1785)
Habitat: Pelagic



Ilyocryptus spp. carapace

Suborder: Anomopoda Stebbing, 1902
Family: Macrothricidae Norman & Brady, 1867
Genus: *Ilyocryptus* Sars, 1976
Species: *Ilyocryptus* spp.
Habitat: Benthic

Eurycercus lamellatus post abdomen

Suborder: Anomopoda Stebbing, 1902
Family: Chydoridae Stebbing, 1902
Genus: *Eurycercus* Baird, 1843
Species: *Eurycercus lamellatus* (O.F. Müller, 1785)
Habitat: Vegetation

Camptocercus rectirostris carapace

Suborder: Anomopoda Stebbing, 1902
Family: Chydoridae Stebbing, 1902
Genus: *Camptocercus* Baird, 1843
Species: *Camptocercus rectirostris* Schoedler, 1862
Habitat: Vegetation

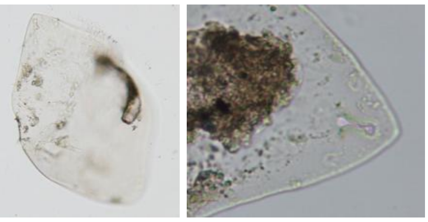
Appendix D (continued)

Acroperus harpei carapace

Suborder: Anomopoda Stebbing, 1902
Family: Chydoridae Stebbing, 1902
Genus: *Acroperus* Baird, 1843
Species: *Acroperus harpae* (Baird, 1835)
Habitat: Vegetation

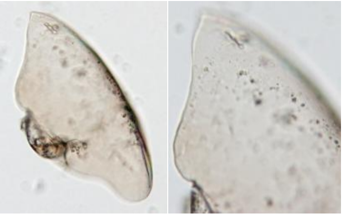
Oxyurella spp. head shield

Suborder: Anomopoda Stebbing, 1902
Family: Chydoridae Stebbing, 1902
Genus: *Oxyurella* Dybowski & Grochowski, 1894
Species: *Oxyurella* spp.
Habitat: Vegetation



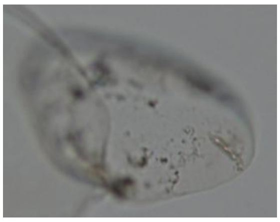
Alona affinis head shield and head pores

Suborder: Anomopoda Stebbing, 1902
Family: Chydoridae Stebbing, 1902
Genus: *Alona* Baird, 1843
Species: *Alona affinis* (Leydig, 1860)
Habitat: Vegetation



Alona quadrangularis head shield and head pores

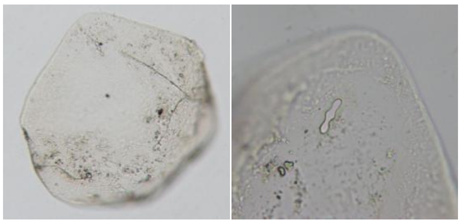
Suborder: Anomopoda Stebbing, 1902
Family: Chydoridae Stebbing, 1902
Genus: *Alona* Baird, 1843
Species: *Alona quadrangularis* (O.F. Müller, 1785)
Habitat: Vegetation



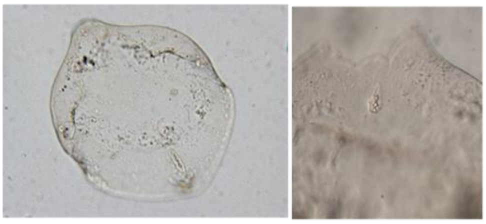
Alona rectangula/gutata head shield

Suborder: Anomopoda Stebbing, 1902
Family: Chydoridae Stebbing, 1902
Genus: *Alona* Baird, 1843
Species: *Alona rectangula/gutata*
Habitat: Vegetation

Appendix D (continued)


Leydigia leydigi head shield and pores

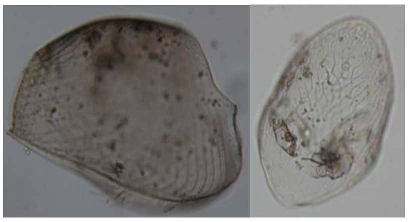
Suborder: Anomopoda Stebbing, 1902
Family: Chydoridae Stebbing, 1902
Genus: *Leydigia* Kurz, 1875
Species: *Leydigia leydigi* (Schoedler, 1858)
Habitat: Benthic


***Leydigia acanthocercoides* head shield and pores**

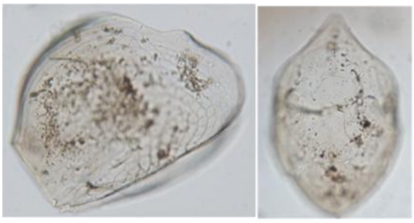
Suborder: Anomopoda Stebbing, 1902
Family: Chydoridae Stebbing, 1902
Genus: *Leydigia* Kurz, 1875
Species: *Leydigia acanthocercoides* (Fischer, 1854)
Habitat: Benthic


Graptoleberis testudinaria carapace

Suborder: Anomopoda Stebbing, 1902
Family: Chydoridae Stebbing, 1902
Genus: *Graptoleberis* Sars, 1862
Species: *Graptoleberis testudinaria* (Fischer, 1848)
Habitat: Vegetation


Alonella excisa carapace and headshield

Suborder: Anomopoda Stebbing, 1902
Family: Chydoridae Stebbing, 1902
Subfamily: Chydorinae Stebbing, 1902
Genus: *Alonella* Sars, 1862
Species: *Alonella excisa* (Fischer, 1854)
Habitat: Vegetation and Benthic

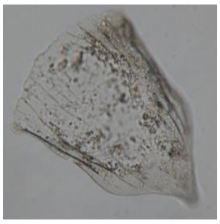

***Alonella exigua* carapace and headshield**

Suborder: Anomopoda Stebbing, 1902
Family: Chydoridae Stebbing, 1902
Subfamily: Chydorinae Stebbing, 1902
Genus: *Alonella* Sars, 1862
Species: *Alonella exigua* (Lilljeborg, 1853)
Habitat: Vegetation and Benthic

Appendix D (continued)

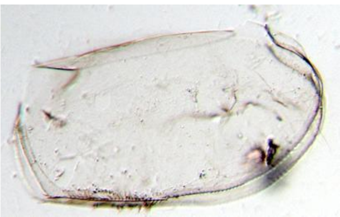
Suborder: Anomopoda Stebbing, 1902
Family: Chydoridae Stebbing, 1902
Subfamily: Chydorinae Stebbing, 1902
Genus: *Alonella* Sars, 1862
Species: *Alonella nana* (Baird, 1843)
Habitat: Vegetation and Benthic

Alonella nana carapace



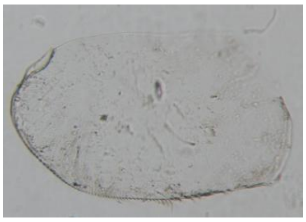
Suborder: Anomopoda Stebbing, 1902
Family: Chydoridae Stebbing, 1902
Subfamily: Chydorinae Stebbing, 1902
Genus: *Disparalona* (Fryer, 1968)
Species: *Disparalona rostrata* (Koch, 1841)
Habitat: Vegetation and Benthic

Disparalona rostrata head shield



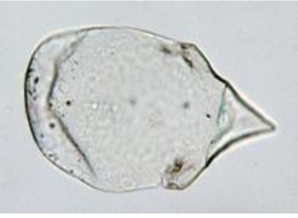
Suborder: Anomopoda Stebbing, 1902
Family: Chydoridae Stebbing, 1902
Subfamily: Chydorinae Stebbing, 1902
Genus: *Pleuroxus* Baird, 1843
Species: *Pleuroxus trigonellus/uncinatus*
Habitat: Vegetation and Benthic

Pleuroxus trigonellus/uncinatus carapace



Suborder: Anomopoda Stebbing, 1902
Family: Chydoridae Stebbing, 1902
Subfamily: Chydorinae Stebbing, 1902
Genus: *Pleuroxus* Baird, 1843
Species: *Pleuroxus aduncus*
Habitat: Vegetation and Benthic

Pleuroxus aduncus carapace



Suborder: Anomopoda Stebbing, 1902
Family: Chydoridae Stebbing, 1902
Subfamily: Chydorinae Stebbing, 1902
Genus: *Chydorus* Leach, 1816
Species: *Chydorus sphaericus* (O.F. Müller, 1785)
Habitat: Vegetation and Benthic

Chydorus sphaericus head shield

CURRICULUM VITAE

PERSONAL INFORMATION

Surname, Name: Çakıroğlu, Ayşe İdil
Nationality: Turkish (TC)
Date and Place of Birth: 24 January 1979, Turkey
Marital Status: Single
Phone / Fax: +90 312 210 51 55 / +90 312 210 79 76
E-mail: ayseidil@gmail.com
Foreign Languages: English

EDUCATION

Degree	Institution	Graduation	C.GPA
Ph.D.	METU Biology Dept.	2013	3.75
M.Sc.	Memorial University of Newfoundland	2005	3.00
B.Sc.	Hacettepe Uni. Biology Dept.	2001	2.41
High School	Ankara Atatürk Lisesi	1995	

ACADEMIC ACTIVITIES

Academic Publications

Tuba Bucak, Ece Saraoğlu, E. Ester Levi, Ü. Nihan Tavşanoğlu, **A. İdil Çakıroğlu**, Erik Jeppesen and Meryem Beklioğlu (2012). The influence of water level on macrophyte growth and trophic interactions in eutrophic Mediterranean shallow lakes: a mesocosm experiment with and without fish. Freshwater Biology, 57, 1631-1642.

Ü. Nihan Tavşanoğlu, **A. İdil Çakıroğlu**, Şeyda Erdoğan, Mariana Meerhoff, Erik Jeppesen, Meryem Beklioğlu (2012). Sediment – not plants – is the preferred refuge for *Daphnia* against fish predation in Mediterranean shallow lakes: an experimental approach. Freshwater Biology, 57, 795-802.

Hiscott R.N., Aksu A.E., Mudie P.J., Marret F., Abrajano T., Kaminski M.A, Evans J., **Çakıroğlu A.İ.**, Yaşar D. "A gradual drowning of the southwestern Black Sea shelf: evidence for a progressive rather than abrupt Holocene reconnection with the eastern Mediterranean Sea through the Marmara Sea Gateway." Quaternary International- 167–168 (2007) 19–34.

Posters and Presentations

Cakiroglu, A.I., Levi, E.E., Tavsanoglu, U.N., Bezirci, G., Davidson, T.A., Jeppesen, E., Beklioglu, M. Sub-fossil Cladocera as indicator of salinity based on surface sediment of 32 Turkish shallow lakes. 12th International Paleolimnology Symposium, 21-25 August 2012, Glasgow, U.K. (Poster Presentation).

Levi, E.E., **Cakiroglu, A.I.**, Bezirci, G., Hansen, L.S., Turner, S., Kernan, M., Jeppesen, E., Beklioğlu, M. Sedimentary Pigments in Turkish shallow lakes: assessing the relation to environmental variables and inferring the change in past phytoplankton communities. 12th International Paleolimnology Symposium, 21-25 August 2012, Glasgow, U.K. (Poster Presentation).

Bezirci, G., **Cakiroğlu, A.I**., Levi, E.E., Bennion, H., Beklioğlu, M. Diatom assemblages as quantitative indicators of past environmental conditions in Turkish shallow lakes. 12th International Paleolimnology Symposium, 21-25 August 2012, Glasgow, U.K. (Poster Presentation).

Ü. Nihan Tavşanoğlu, **A. İdil Çakıroğlu**, Eti E. Levi, Arda Özen, Korhan Özkan, Didem Oğuzkurt,Tuba Bucak, Gizem Bezirci, Erik Jeppesen and Meryem Beklioğlu, Prelimneray Study on Native and Non-native Fish Species Community in Shallow Lakes of Turkey. International workshop for assesing the impats of non-native freshvater fishes in the Mediterranean region. 25-29 October 2010, Muğla (Oral Presentation).

Ayşe İdil Çakıroğlu, Eti Levi, Susanne Lildal Amsinck, Erik Jeppesen, Lisa Doner and Meryem Beklioğlu. Inferring past salinity and eutrophication in latitudinal gradient of turkish shallow lakes using sub-fossil cladocera. 11th International Paleolimnology Symposium, 14-19 December 2009, Guadalajara, Mexico (Oral Presentation).

Meryem Beklioglu, Nihan Tavşanoglu, **A. İdil Çakıroglu**, Arda Özen, Eti Levi, Korhan Özkan, Didem Oguzkurt, Mengü Türk, Tuğba Bucak, Erik Jeppesen. Role of nutrients and climate on functioning of the Turkish shallow lakes. SEFS6, Symposium of European Freshwater Sciences 6, 17-21 August, 2009, Sinaia, Romenia (Oral Presentation).

Meryem Beklioğlu, Nihan Tavşanoglu, **A. İdil Çakıroglu**, Arda Özen, Eti Levi, Korhan Özkan, Didem Oguzkurt, Tuğba Bucak, Erik Jeppesen. Ülkemiz sığ göllerin ekolojik yapısında besin tuzu ve iklimin etkisinin zaman yerine mekan yaklaşımıyla belirlenmesi. IX. Ulusal Ekoloji ve Çevre Kongresi, 7-9 Eylül, 2009, Ürgüp, Nevşehir (Oral Presentation in Turkish).

Beklioğlu, M. ; Özen, A.; **Çakıroğlu, I.** ; Tavşanoğlu, N.; Oğuzkurt, D.; Özkan, K.; Levi, E.; Jeppesen, E., 2008. Role of nutrients and climate on functioning of the Turkish shallow lakes usung space for time substitute approach. In: Abstract book of VI Shallow lakes Conference, November 23-28, Punta DelEste, Uruguay (Oral Presentation).

M. Beklioglu, **A. İdil Çakıroglu**, E. Levi, N. Tavşanoğlu, Arda Özen, E. Jeppesen, Susanne Lildal Amsinck, K. Özkan, Lisa Doner. Past to present and to future: Ecology of Turkish Shallow lakes. International Paleoclimatology Workshop, 20-23 October, 2008, Van, Turkey (Oral Presentation).

Ayşe İdil Çakıroğlu, Eti Levi, Susanne Lildal Amsinck, Erik Jeppesen, Lisa Doner, Meryem Beklioğlu "Determination of the effects of past trophic structure on Turkish shallow lakes based on palaeocology using sub-fossil Cladocera" Ulusal Limmnoloji Sempozyumu, Urla-İzmir, Ağustos 27-29, 2008 (Poster).

Meryem Beklioğlu, **Ayşe İdil Çakıroğlu**, Korhan Özkan, Didem Oğuzkurt, Lisa Doner, Arda Özen, Ceran Şekeryapan, Yetkin Alıcı, Erik Jeppesen "Determination of food web structure by using carbon and nitrogen stable isotopes in deep and shallow lakes" Ulusal Limmnoloji Sempozyumu, Urla-İzmir, Ağustos 27-29, 2008 (Oral Presentation).

Meryem Beklioğlu, Arda Özen, **Ayşe İdil Çakıroğlu**, Didem Oğuzkurt, Korhan Özkan, Nihan Tavşanoğlu, Eti Levi, Mengü Türk "The role of eutrophication and climate change on the ecological structure of Turkish shallow lakes" Ulusal Limmnoloji Sempozyumu, Urla-İzmir, Ağustos 27-29, 2008 (Oral Presentation).

Academic Research Projects

"Determination of Mitigation and Adaptation Strategies by Determining the Role and Factors Affecting the Development of Submerged Macrophytes in the Past, Present and Future Warmer Conditions in Shallow Lakes in the Mediterranean Climatic Region" Funded by: TUBİTAKÇAYDAG 110Y125 Principal Investigator: Prof. Dr. Meryem Beklioğlu

"Adaptive strategies to Mitigate the Impacts of Climate Change on European Freshwater Ecosystems" Funded by: EU- FP7 project no 244121 Project Coordinator: University College of London, Project partner: METU

“The conservation of Turkish shallow lakes by determining the interactions between their ecological structure, climate and anthropogenic use with holistic and sensitive methods and the development of strategies for their restoration.” An Interdisciplinary Project Funded by: TUBITAK-CAYDAG-105Y332 (The Scientific and Technological Research Council of Turkey) Principal Investigator: Assistant Professor Didem OGUZKURT Investigator: Professor Meryem BEKLIOGLU Duration: June, 2006 – June, 2009

“Marmara Sea Gateway Project” Funded by: NSERC (Natural Sciences and Engineering Research Council of Canada) Principal Investigators: Professor Ali E. AKSU and Professor Richard N. HISCOTT

International Conferences, Workshops and Seminars Attended

International

21-24 August 2012	12th International Paleolimnology Symposium Glasgow, U.K.
25-29 October 2010	International workshop for assesing the impats of non-native freshwater fishes in the Mediterranean region. 25-29 October 2010, Muğla
14-19 December 2009	11th International Paleolimnology Symposium Guadalajara, Mexico
24-29 September 2000	13th European SOVE Meeting – Society for Vector Ecology Belek, Turkey

National

07-09 October 2009	IX. National Environment and Ecology Congress, Ürgüp-Nevşehir
13-17 April 2009	62. Geology Kurultai, Ankara, Türkiye
16-18 October 2008	Turkish Earth Sciences Assoc., JMO, TPJD Paleoclimate Workshop Van, Türkiye
27-29 August 2008	III. National Limnology Symposium, Urla
26-29 June 2007	‘Impacts of Global Warming on Freshwater Ecosystems and Society’ Workshop, METU-KKM, Ankara