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Deliverable D3.B: Manuscript on time series analyses from the Mediterranean region (METU)

Lead beneficiary: METU, AU
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Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Executive summary

This deliverable investigates the impacts of changes in hydrology and nutrients on ecosystem structure and function of Mediterranean shallow lakes by using long term monitoring data of two lakes (Lakes Mogan and Eymir) and paleolimnological records of six lakes from Turkey. The first two papers are on Lakes Eymir and Mogan, which are two inter-connected lakes in Central Anatolia situated in a cold dry steppe climate. Both papers used 20 years of monitoring data. **Manuscript 1** focused on annual and seasonal water and nutrient (TP, SRP, DIN, TN) budgets of the two lakes and highlighted the impacts of water balance on eutrophication of Mediterranean shallow lakes. It was published in *Science for the Total Environment* in April 2016. **Manuscript 2** focused on understanding the impacts of nutrient concentrations and hydrological conditions (e.g. water level fluctuation and hydraulic retention time) on lake restoration efforts, which included sewage effluent diversion and biomanipulation in a relatively deep and shallow Mediterranean lake. This paper is out online in February 2017 in the open access journal *Water*. The third and fourth manuscirpts provide long-term paleoecological data to infere the impact of past environmental changes using a paleolimnological approach with single or multiple proxies. In **Manuscript 3**, the Cladocera sub-fossils community assemblage was used to explain ecological changes that took place in three Anatolian lakes (Lakes Eymir, Mogan and Gölhisar), which are located in Mediterranean climatic zones. Sub-fossil cladoceran remains provide a good indicator of key environmental changes including water level, eutrophication and salinization. This manuscript has been published in *Hydrobiologia* in November 2015. **Manuscript 4** used multi-proxy data of Cladocera, Diatom, pigment, plant macrofossil as well as XRF-determined minerals to trace the impacts of lake-level changes on benthic-pelagic primary and secondary productions over the last 50-100 years in three Turkish shallow lakes. It was published in *Palaeogeography, Palaeoclimatology, Palaeoecology* in March 2016.

Paper 1: Impact of alternating wet and dry periods on long-term seasonal phosphorus and nitrogen budgets of two shallow Mediterranean lakes

Published in Science of the Total Environment in April 2016 with DOI: 10.1016/j.scitotenv.2016.04.028

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Abstract: The water balance, with large seasonal and annual water level fluctuations, has a critical influence on the nitrogen and phosphorus dynamics of shallow lakes in the semi-arid climate zone. We constructed seasonal water and nutrient budgets for two connected shallow lakes, Lakes Mogan and Eymir, located in Central Anatolia, Turkey. The study period covered 20 years with alternations between dry and wet years as well as restoration efforts including sewage effluent diversion and biomanipulations in Lake Eymir. Both lakes experienced a 1–2 m water level drop during a drought period and a subsequent increase during the wet period, with seasonal water level fluctuations of 0.60 to 0.70 m. During wet years with high water levels, small seasonal differences were observed with a nutrient peak in spring caused by external loading and nutrient loss via retention during summer. During years with low water levels, nutrient concentrations increased due to internal and external loading, exacerbated by evaporative water loss. In Lake Eymir, a shift to eutrophic conditions with turbid water occurred under low water level conditions and consequent internal loading of P from the sediment, causing high nutrient concentrations in summer. Our results indicate a threat of lakes drying out in the semi-arid climate zone if evaporation increases and precipitation decreases as anticipated from the global climate change predictions. In addition, our results show the influence of the water balance on the eutrophication of shallow lakes in the Mediterranean climate zone and highlight the ultimate consequences for lake management.

Keywords: water level fluctuation, climate change, seasonality, eutrophication, arid region

Paper 2: Restoration of eutrophic lakes with fluctuating water levels: A 20 year monitoring study of 2 inter-connected lakes

Accepted to be published in Water

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Abstract: Eutrophication continues to be the most important problem preventing a favourable environmental state and detrimentally impacting the ecosystem services of lakes. The current study describes the results of analyses undertaken of 20 years of monitoring data from two interconnected Anatolian lakes, Lakes Mogan and Eymir, receiving sewage effluents and undergoing restoration. The first step of restoration in both lakes was sewage effluent diversion. Additionally, in hypertrophic Lake Eymir, biomanipulation was conducted, involving removal of benthi-planktivorous fish and prohibition of pike fishing. The monitoring period included water level (WL) fluctuations as being low/high (L/H), enabling elucidation of the effects of hydrological changes on lake restoration. In shallower Lake Mogan, macrophyte abundance increased after the sewage diversion in periods with low water levels even at turbid water. In relatively deep Lake Eymir, the first biomanipulation led to a clear water state with abundant macrophyte coverage. However, shortly after biomanipulation, the water clarity deteoriated and it coincided with LWL periods during which nutrient concentrations increased. A second biomanipulation was conducted, mostly during HWL period, resulting in a major decrease in nutrient concentrations and clearer water, but without an expansion of macrophytes. We conclude that repetitive fish removal may induce recovery but its success may be confounded by high availability of nutrients and adverse hydrological conditions.

Keywords: benthivorous fish; biomanipulation; clear water; climate change; drought; flushing; sewage effluent diversion; Mediterranean

Paper 3: Inferring past environmental changes in three Turkish lakes from sub-fossil Cladocera

Published in Hydrobiologia in September 2016 with DOI: 10.1007/s10750-015-2581-x

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Abstract: Cladocerans are increasingly used in palaeolimnological studies as their community composition is sensitive to both anthropogenic and natural forces in lakes. We present the results of a palaeolimnological investigation of three Turkish shallow lakes located in cold dry steppe and semi-dry Mediterranean climatic regions. The aim was to elucidate historical changes in environmental conditions by analyzing sub-fossil cladocerans in 210Pb-dated sediment cores. Sub-fossil cladoceran remains from the surface sediment of 40 Turkish lakes were analysed to examine the environmental factors that most correlated with variation in the cladoceran assemblage. Redundancy analysis showed that salinity, macrophyte abundance, fish density, depth and total phosphorus were the most correlated with change in cladoceran assemblage composition with eigenvalues for the first and the second axes being k1 = 0.312 and k2 = 0.061, respectively. Sedimentary cladoceran assemblages from three cores were placed passively within the framework of the surface sediment ordination. The results reveal a prevalent impact of salinity, fish abundance and water level changes from the past to present. Thus, using cladoceran-based inferences, we traced key environmental changes related to variation in climate change, restoration and water level regulation over the last century.

Keywords: fish abundance, macrophyte, salinity, water level change, eutrophication, palaeolimnology, irrigation

Paper 4: Multi-proxy palaeoecological responses to water-level fluctuations in three shallow Turkish lakes

Published in Palaeogeography, Palaeoclimatology, Palaeoecology in March 2016 with DOI: 10.1016/j.palaeo.2016.02.052

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Abstract: Natural or human-induced water-level fluctuations influence the structure and function of shallow lakes, especially in semi-arid to arid climate regions. In order to reliably interpret the effect of water-level changes from sedimentary remains in the absence of historical data, it is crucial to understand the variation in sedimentary proxies in relation to water level measurements. Here, we took advantage of existing water surface elevation data on three large shallow lakes in Turkey to elucidate the impact of lake-level changes on benthic-pelagic primary production over the last 50–100 years. Sub-fossil cladocerans, diatoms, plant remains and pigments were investigated as biological variables; X-ray fluorescence (XRF) and loss on ignition (LOI) analyses were conducted as geochemical-physical variables on a set of 210Pb and 137Cs dated cores. Dating of the cores were robust, with the exception of uncertainties in Lake Marmara littoral core due to low unsupported 210Pb activities and high counting errors. Results indicated that Lake Marmara was dominated by benthic species throughout the sediment record, while Lakes Beyşehir and Uluabat shifted from a littoral-dominated system to one with increased pelagic species abundance. In all cores there was a stronger response to longer-term (decadal) and pronounced water-level changes than to short-term (annual-biennial) and subtle changes. It was also noted that degree of alteration in proxies differed between lakes, through time and among pelagic-littoral areas, likely emphasising differences in depositional environments and/or resolution of sampling and effects of other stressors such as eutrophication. Our results highlight lake-specific changes

associated with water-level fluctuations, difficulties of conducting studies at required resolution in lakes with rather mixed sediment records and complexity of palaeolimnological studies covering recent periods where multiple drivers are in force. They further emphasise the need to include instrumental records when interpreting effects of recent water-level changes from sediment core data in large shallow lakes.

Keywords: diatom sub-fossil, plant macrofossil, cladocera sub-fossil, pigment, sediment geochemistry, mediterranean