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

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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 ^{210}Pb and ^{137}Cs dated cores. Dating of the cores were robust, with the exception of uncertainties in Lake Marmara littoral core due to low unsupported ^{210}Pb 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.

1. Introduction

The hydrology and ecosystem dynamics of shallow Mediterranean lakes respond to the natural cycle of seasonal dry and wet periods of variable annual and inter-annual periodicity and intensity. Along with intense seasonality and climatic change, long term anthropogenic impacts of irrigation, damming, soil erosion and groundwater drawdown have greatly affected lake water levels and their continued variability in the Mediterranean region (Coops et al., 2003).

Lake ecosystems respond to water-level change, as their inter-linked habitats adjust to dynamic environmental parameters. Prediction of future ecological patterns and trajectories of change due to lake water-level change is therefore difficult, but can be assisted by assessment of recent palaeoecological and sediment evidence from lakes with documented water-level records. Individual lakes will respond to water-level changes in a unique way, depending on their basin morphometry, climate, duration and magnitude of change and resilience of ecological communities, but some general processes can be identified. Water-level fluctuations expand and contract spatial patterns of sedimentation and determine edaphic–hydrological conditions that control the zonation of littoral vegetation (Harrison and Digerfeldt, 1993). A

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significant rise in lake level causes transgressive overlap of fine-grained muds (low energy, deep water) on top of shoreline sediments (high energy, shallow water), expanding the area for aquatic and marginal plants. Conversely, a regressive fall in lake level will reduce the areal extent of littoral habitats and may generate a hiatus in deposition due to erosion of previously deposited high lake-level fine mud. This simple model is of course complicated by basin morphology; i.e. a fall in level, revealing a wide shallow margin that may increase littoral habitats. Reduced water depth may also cause a greater proportion of catchment-derived matter to be transported towards the centre of the lake basin. Equally, a fall in water depth can extend the photic zone to the bottom of shallow, turbid lakes, increasing the potential area of aquatic plant growth and organic sedimentation. Periods of water-level stability allow development of marginal wetland peats, carbonate benches and chemical precipitates depending on water chemistry (Jones and Jordan, 2013).

Indirect effects of water-level change on biological communities include changing nutrient availability, turbidity (water clarity) and fish predation (Jeppesen et al., 2015). Reduced water levels in shallow lakes can cause a decrease or increase in water clarity depending on the morphometry and amplitude of water-level reduction (e.g. proportion of sediment exposed to the resuspension), thus, either negatively or positively affecting aquatic macrophyte and benthic/epiphytic diatom growth (Jones and Jordan, 2013). Furthermore, increased water levels reduce light penetration to the lake bottom, having a negative impact on the growth of light-demanding species. The direction of water-level change can have dual effect on fish, zooplankton and phytoplankton numbers. Where macrophytes expand, small planktivorous fish can take refuge in macrophyte beds, especially in warmer climates (Meerhoff et al., 2007), causing an increase in small-bodied zooplankters (e.g. rotifers and small cladocerans) and in phytoplankton due to the enhanced fish predation on large-bodied zooplankton (Amsinck et al., 2005). Conversely, very low water levels can induce fish kills (Nõges et al., 2007), expectedly resulting in higher abundance of large-bodied zooplankters (e.g. *Daphnia* spp.) and lower phytoplankton biomass (Iglesias et al., 2011).

Lake ecosystems in Turkey are subject to annually variable water volumes, depths and salinities due to the Mediterranean climate of extreme summer heat with high evaporation and variable autumn/winter precipitation (Beklioğlu et al., 2006; İyigün et al., 2013). As in many other parts of the world where arid to semi-arid climates predominate, lake catchments in Turkey have been heavily modified by human activities, especially in the last century due to agricultural and population demands on water usage.

Climate change projections indicate that catchments in arid and semi-arid Mediterranean regions are likely to show an approximate decrease of 25–30% in precipitation and enhanced evaporation accompanied by an even stronger reduction in runoff by the end of the 21st century (Giorgi and Lionello, 2008). This would magnify seasonal and multiannual water-level amplitudes and enhance hydrological stresses and thus cause prolonged hydraulic drought periods.

Developing adaptive management plans in order to protect lake environments and their ecosystem services is therefore a necessity. However, to develop suitable adaptive strategies, it is essential to investigate the response of lakes and resilience of ecological communities to past water-level fluctuations as a key to understanding current and future conditions. Multi-proxy palaeolimnological techniques can contribute to such an understanding, especially where there is no long-term biological monitoring data. To elucidate this further, a range of palaeolimnological techniques was employed on dated sediment cores from three lakes (Lakes Beyşehir, Marmara and Uluabat) for which long-term instrumental water-level monitoring records (50–100 years) were available. This paper addresses three key questions:

1) Do recent sedimentary (biological/non-biological) records accurately reflect known water level changes?
2) Do measured proxies respond in synchrony to known water level changes?
3) If relationships between proxy data and known water-level changes are complex or poorly-correlated, what factors might account for this?

2. Materials and methods

2.1. Study sites

The three study lakes are located in the mid-western part of Turkey (Table 1, Fig. 1). According to Köppen-Geiger Climate classification Lake Beyşehir is located in the Warm-summer Mediterranean climatic zone (Csb), while Lakes Marmara and Uluabat are located in Hot-Summer Mediterranean zone (Csa). The instrumental water-level data from these lakes were compiled by the General Directorate of State Hydraulic Works (DSI) and the General Directorate of Electrical Power Resources (EIE) of Turkey (here onwards DSI-EIE Database). The three lakes have been classified as important bird areas (IBA) since 2004 (BirdLife International, 2015). Moreover Lake Beyşehir is one of the most important plant areas (IPA) in Turkey (PlantLife International, 2015) and since 1991 it has been classified as a 1st degree Natural Site protection area (a site protection status defined by the Turkish Ministry of Culture) (Nas et al., 2009), while Lake Uluabat has been listed as a Ramsar site since 1998 (Salihoğlu and Karaer, 2004).

2.1.1. Lake Marmara

At the beginning of the 20th century, Lake Marmara was endorheic, saline and around 50% smaller than at present (Girgin, 2000). Inflow (17 $hm^3\ yr^{-1}$) to the lake was originally derived from temporary streams and fault-generated springs (Altınayar et al., 1994). The water level and area of the lake increased in the early-mid 20th century, after converting the lake to a reservoir for irrigation purposes between 1932 and 1953 (Girgin, 2000). The construction of the first canal network south of the lake, which is used to divert the surplus lake water to the Gediz River, was completed in 1945. In the north a diversion canal and a regulator were built to divert river water to the lake (completed in 1952), and in the south another regulator was constructed to control the outflow from the first drainage canal and to ensure a lake level of 79 m.a.s.l (completed in 1953). Another canal on the eastern side carrying the water from a dam to the lake was completed in 1955. An impoundment was also made in the eastern part (finished in 1963) to prevent flooding (Girgin, 2000). Maximum water storage capacity was reached around 1960, with a level of 79.2 m.a.s.l and area of 6800 ha (Arı and Derinöz, 2011). Prior to the early-mid 20th century, the lake level was measured as ca. 73–74 m.a.s.l (Girgin, 2000). Downstream irrigation demands are probably the most significant control on water loss from the lake (Altınayar et al., 1994).

Turkish State Meteorological Service data (available at http://mgm.gov.tr/) indicated that the months with higher precipitation had been between November and March for the 1980–2012 period. Pronounced intra-annual, spring/summer low water-level periods and inter-annual water-level fluctuations have subsequently been recorded (Beklioğlu et al., 2006; DSI-EIE Database).

During very shallow periods, previously flooded areas of the lake and surrounding wetlands have been cultivated (Arı and Derinöz, 2011). Agricultural data retrieved from the Turkish Statistical Institute (TÜİK) (available at http://tuik.gov.tr) shows that between 1995 and 2012 there has not been a significant change in the area of cultivated land around the lake. Conversely, the area of artificial land use, such as continuous urban areas and industrial units, increased from 1995 to 2006 (available at http://aris.ormansu.gov.tr/csa/). In addition, increased nutrient inputs due to population growth and agricultural intensification has led to hypertrophic conditions in the lake, especially in the last 20 years (Arı and Derinöz, 2011; Gülersoy, 2013). A study conducted in Gediz River Basin showed that the mean annual total