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

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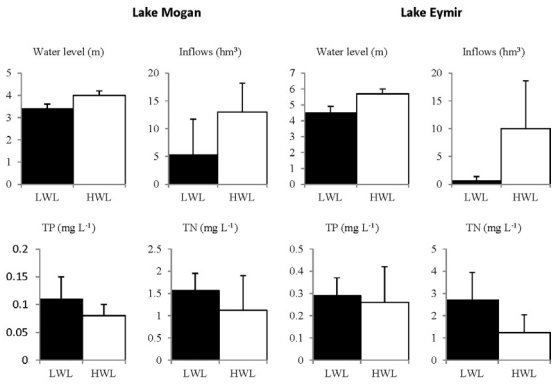
HIGHLIGHTS

- Seasonal and annual variability of the hydrology of semi-arid shallow lakes is high.
- We built 20-year water and nutrient budgets of two lakes during dry and wet periods.
- Changes in inflow and water level have an impact on the lake nutrient dynamics.
- During wet years nutrients are influenced by inflow volume and concentration.
- Internal loading was important during dry years in the absence of external loading.

GRAPHICAL ABSTRACT



LWL = low water level years; HWL = high water level years

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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

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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.

1. Introduction

Shallow lakes in semi-arid and arid climate regions, including the Mediterranean, are subjected to large water level fluctuations (WLF), both on a seasonal and an annual scale (Beklioğlu et al., 2007). On a seasonal scale, precipitation is limited to winter and spring, while high evaporation in summer causes substantial water loss from freshwater bodies (Naselli-Flores and Barone, 2005; Önol and Unal, 2014). Year-to-year variation in precipitation is typically high in the Mediterranean climate zone, causing alternations between dry periods with low hydraulic loading, high residence times and low water levels and wet periods with high inflows, increased flushing and high water levels (Mariotti and Dell'Aquila, 2012).

WLF have major effects on the ecological functioning of shallow lakes, including changes in nutrient processing and nutrient retention (Jeppesen et al., 2015). Nutrient concentrations in lakes are predominantly determined by the external nutrient loading (Saunders and Kalff, 2001), but in years with reduced external loading, concentrations can remain high due to internal loading by resuspension or release of nutrients stored in the top layer of the sediment (Søndergaard et al., 2003). Lake nutrient concentrations are also influenced by retention or loss of nutrients present in the water column through a combination of sedimentation processes, assimilation by organisms and loss to the atmosphere (denitrification) (Correl, 1998; Wetzel, 2001).

Retention and internal loading are influenced by water depth and hydraulic residence time. The empirical model of Vollenweider (1976) proposed lower lake nutrient concentrations with increasing hydraulic retention time at otherwise similar external loading. By contrast, Özen et al. (2010) found higher nutrient concentrations during periods with long residence times and low water levels in two Mediterranean lakes, which they attributed to higher internal loading and higher concentrations caused by evaporative water loss.

Climate change will have major implications for the water and nutrient balances of lakes (Jeppesen et al., 2011). The Mediterranean climate zone is predicted to be particularly severely affected by climate change in the near future (Giorgi, 2006). Precipitation is expected to decrease and evaporation to increase over this century (Erol and Randhir, 2012). Önol and Unal (2014) have predicted a 3–4 °C increase in temperature for the Central Anatolian region in Turkey by 2071–2100, while the annual precipitation is projected to decrease (−10%) despite enhanced precipitation in autumn. Fewer days with rainfall will occur and the frequency of extreme events will increase. All these predicted changes in climate have the potential to significantly affect the water and nutrient balances of shallow lakes. Therefore, it is important to study the relationship between the water balance and the nutrient dynamics of shallow lakes.

Nutrient budgets have been calculated for a series of temperate lakes (e.g. Garnier et al., 1999; Schernewski, 2003; Nõges, 2005; French and Petticrew, 2007) and for some lakes in other climate zones (Romero et al., 2002; Romo et al., 2005; Cook et al., 2010; Özen et al., 2010; James et al., 2011). Özen et al. (2010) studied the nutrient budgets of Lakes Mogan and Eymir between 1993 and 2007. We built on this study and added 6 more years of data to further investigate the effect of high hydraulic loading after prolonged drought conditions on the shallow lakes in the semi-arid climate zone. In addition, we used a seasonal approach and constructed seasonal water and nutrient budgets for both lakes and all years to investigate the impact of periods with low and high water levels on seasonality. We further included both inorganic and total phosphorus and nitrogen in the nutrient budgets and used time series regression analysis to study the influence of water level and external and internal loading on the nutrient concentrations in the lakes. This allowed us to study in more detail how changes in hydraulic loading, water level and hydraulic residence time influenced the nutrient concentrations under low and high water level conditions. Such knowledge might contribute to the understanding of how climate change affects lake eutrophication and the consequences hereof for lake restoration and management. The aim of our research was (1) to further analyse the impacts of low and high water level periods on the nutrient concentrations of shallow, semi-arid lakes based on an extended set of data from the two lakes studied by Özen et al. (2010) and (2) to explore how the seasonality of lake nutrient concentrations changes between low and high water level periods.

2. Material and methods

2.1. Study area

The study area comprised two shallow interconnected lakes, Lakes Mogan and Eymir, situated 20 km south of Ankara at an altitude of 970 m on the Anatolian plateau in Central Turkey (Fig. 1). The local climate is characterised by arid cold steppe conditions (Peel et al., 2007) with hot summers, cold winters and most rainfall (including snow) in winter and spring. The average annual temperature is 12.0 °C and average temperatures have been slowly increasing in recent decades, from 11.2 °C in 1980 to 13.2 °C in 2013. Average yearly total rainfall is 408 mm, alternating between dry periods with precipitation below 350 mm and wet years with precipitation above 500 mm (Turkish Meteorological Office). Average yearly pan evaporation is 1200 mm. Pan evaporation was positively correlated with mean temperatures (0.88***) and due to increases in temperature, yearly pan evaporation has been increasing from 1125 mm in 1985 to 1275 mm in 2012 (Turkish Meteorology Office).

Upstream Lake Mogan (39° 47′N 32° 47′E) has a surface area of 5.6–8 km^2, depending on water level, and an average depth of 2.4 m. The catchment area covers 940 km^2. The lake has several, mainly seasonal,

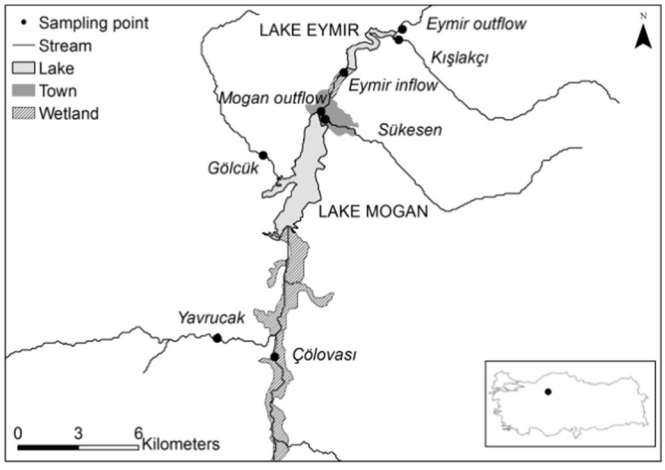

Fig. 1. The study area comprising the Lakes Mogan and Eymir catchment in the Central Anatolia region of Turkey, showing both lakes, the sampling stations on the major in- and outflows, the location of Gölbaşı town and the wetland areas.