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Tracking the hydro-climatic signal from lake to sediment: A field study from central Turkey

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SUMMARY

Palaeo-hydrological interpretations of lake sediment proxies can benefit from a robust understanding of the modern lake environment. In this study, we use Nar Gölü, a non-outlet, monomictic maar lake in central Turkey, as a field site for a natural experiment using observations and measurements over a 17-year monitoring period (1997–2014). We compare lake water and sediment trap data to isotopic, chemical and biotic proxies preserved in its varved sediments. Nar Gölü underwent a 3 m lake-level fall between 2000 and 2010. $\delta^{18}O_{lakewater}$ is correlated with this lake-level fall, responding to the change in water balance. Endogenic carbonate is shown to precipitate in isotopic equilibrium with lake water and there is a strong relationship between $\delta^{18}O_{lakewater}$ and $\delta^{18}O_{carbonate}$, which suggests the water balance signal is accurately recorded in the sediment isotope record. Over the same period, sedimentary diatom assemblages also responded, and conductivity inferred from diatoms showed a rise. Shifts in carbonate mineralogy and elemental chemistry in the sediment record through this decade were also recorded. Intra-annual changes in $\delta^{18}O_{lakewater}$ and lake water chemistry are used to demonstrate the seasonal variability of the system and the influence this may have on the interpretation of $\delta^{18}O_{carbonate}$. We use these relationships to help interpret the sedimentary record of changing lake hydrology over the last 1725 years. Nar Gölü has provided an opportunity to test critically the chain of connection from present to past, and its sedimentary record offers an archive of decadal- to centennial-scale hydro-climatic change.

1. Introduction

In order to use lake sediments to reconstruct past climate change reliably, it is vital to understand the modern hydrology of the study site (e.g. Hollander and McKenzie, 1991; Leng et al., 1999; Saros, 2009) and to be able to track this signal to the sediments. Lake systems respond to hydro-climatic variations via a number of linked parameters, including lake volume, salinity concentrations and the oxygen isotope ($\delta^{18}O$) composition of waters. Non-outlet lakes respond particularly dynamically to changes in water balance (Leng and Marshall, 2004 and references therein); with increased evaporation, water volume decreases, salts become concentrated and $\delta^{18}O_{lakewater}$ becomes more positive, and vice versa, although parameters may be subject to hysteretic effects (Langbein, 1961) as well as other factors such as saline groundwater inflows.

Limnological parameters such as water balance are registered by proxies preserved in lake sediments, which in turn permit the reconstruction of lake hydrology for pre-instrumental time periods (Fritz, 2008 and references therein). Past water level fluctuations can be reconstructed via dated lake marginal depositional facies, such as shoreline terraces and carbonate platforms (Magny, 2006), and by changes in the species assemblages and life forms of diatoms and other biological indicators (e.g. Barker et al.,

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1994). Salinity inferred from biological indicators, such as diatom and ostracod assemblages, is sometimes quantified as variability in electrical conductivity (EC) based on transfer function techniques using a modern training set (e.g. Fritz et al., 2010; Reed et al., 2012). Past salinity levels can also be reconstructed semi-quantitatively from elemental chemistry ratios such as Ca/Sr and Mg/Ca (Ito, 2001). In many lakes, the form of carbonate precipitated from lake waters shifts from low-Mg calcite in dilute lake waters to high-Mg calcite or aragonite in more saline lake waters (Kelts and Hsü, 1978) and the Ca/Sr ratio can decrease if there is a shift from calcite to aragonite precipitation (Tesoriero and Pankow, 1996). Stable isotopes can also be used as a palaeo-hydrological proxy: lake water $\delta^{18}O$ is recorded in carbonates that precipitate in lake water; $\delta^{18}O_{carbonate}$ is also modified by temperature and potentially by disequilibrium or diagenetic effects (Leng and Marshall, 2004 and references therein).

Limnological sampling, monitoring and observation can provide fundamental insights into all of the processes described above, and therefore strengthen the interpretation of lake sediment records. Monitoring of lake levels leads to an understanding of the sensitivity of a given lake to hydrological and/or climatic change. Recording biological response to measured climate or hydrological change improves the interpretation of downcore species changes. Monitoring data may be especially important when using stable isotopes as a hydro-climatic proxy because it is not possible to apply modern analogue or transfer function techniques, substituting time with space, to these records due to their dependence on multiple climatic and site-specific non-climatic variables (Tian et al., 2011). Monitoring allows the establishment of the key drivers of $\delta^{18}O_{lakewater}$ in the lake being studied and a better understanding of how the signal is transferred to carbonates in the sediment record. Such a monitoring approach can provide a basis for judging which proxies provide the most reliable register of environmental changes (such as hydro-climate) and why different proxies can show different trends in the palaeo-limnological record, although the possibility that present lake states are not good analogues for the past should also be considered.

There are logistical and financial barriers to collecting modern data and samples over multiple years and different seasons for a length of time suitable to ensure robust proxy interpretation, especially in remote regions. However, in this study, we have been able to collect a substantial number of samples from Nar Gölü (göl = lake in Turkish), a small, hydrologically sensitive maar lake in central Turkey, over a period of 17 years (1997–2014). Although our monitoring and observational data are far from complete, they do allow an assessment to be made of both seasonal variations and multi-year trends. If lake sediments are sufficiently well resolved in time, it is possible to trace changes measured from lake waters collected from certain years to the sediments that correspond to that year. Nar Gölü is particularly useful for such an exercise because the sediment record is annually laminated (varved). We have therefore been able to correlate, with high precision, monitoring and instrumental climate data to palaeo-limnological information from the sediment cores over the same period.

The study lake was subject to a progressive water level decrease between 2000 and 2010. We examine how this change in lake water balance was registered by different hydro-chemical and biological parameters over time, and how they were subsequently incorporated in the contemporaneous lake sediment record. Some neo-limnological data from Nar Gölü have been previously published: Jones et al. (2005) compared modelled and measured $\delta^{18}O$ results (using water isotope data from 1999 to 2002) and Woodbridge and Roberts (2010) examined diatom assemblage data (with contemporary samples taken 2002–2007). Here we present new water isotope and chemistry data to extend the record up to 2014 and new sediment isotope and diatom assemblage data to bring the record up to 2010. With this longer time series of monitoring data, we build on these previous studies and aim to: (1) establish the general physical, isotopic and geochemical characteristics of the lake, (2) scrutinise intra-annual trends in lake water chemistry and $\delta^{18}O_{lakewater}$ to understand the seasonal variability of the system, (3) compare inter-annual variability in lake water chemistry and $\delta^{18}O_{lakewater}$ to physical and climate variables in order to test the drivers of the record, and (4) compare these data to isotopic, biological and geochemical proxies from the sediment record. The analysis of modern limnology and the tracking of signals from the lake water to sediments from the last decade allow us to assess critically individual palaeo-limnological proxies at Nar Gölü, ultimately to better interpret the long-term sediment record of Holocene hydro-climatic change (e.g. Jones et al., 2006; Woodbridge and Roberts, 2011; Yiğitbaşıoğlu et al., in press).

2. Site description

Nar Gölü (38°20′24″N, 34°27′23″E; 1363 m.a.s.l.) is a small (~0.7 km^2) but relatively deep (>20 m) maar lake in Cappadocia, central Turkey (Fig. 1). It is oligosaline, alkaline and predominately groundwater-fed, with a residence time of 8–11 years (Jones et al., 2005; Woodbridge and Roberts, 2010). The crater geology is predominately basalt and ignimbrite (Gevrek and Kazancı, 2000). Nar Gölü lacks any surface outflow. At its southern edge there are a series of small inflowing ephemeral stream channels forming an alluvial fan, and the bathymetric map (Fig. 1) shows that this extends into the lake as a fan-delta.

The climate of the region is continental Mediterranean (Kutiel and Türkeş, 2005) with annual precipitation at Niğde, 45 km from Nar Gölü and 1208 m.a.s.l., averaging 339 mm from 1935 to 2010. Mean monthly temperatures 1935–2010 varied from an average of +23 °C in July and August to +0.7 °C from December to February (see Dean et al., 2013 for more detailed regional climate data).

Although the lake watershed contains no permanent dwellings and only a few agricultural fields, Nar Gölü has not entirely escaped human impact. Firstly, groundwater pumping for irrigation in the valley below the lake is likely to have steepened the hydraulic gradient in recent decades, possibly increasing groundwater outflows from the lake. Secondly, in 1990 the Turkish Geological Survey (MTA) drilled boreholes near to the lake to reach artesian geothermal groundwaters (Akbaşlı, 1992). Oral testimony indicates that one of these drill holes significantly disturbed lake hydrology and ecology (potentially including a breakdown in lake stratification and a decrease in the population of aquatic macrophytes), probably for several years, for which there is some evidence in lake sediment cores. Consequently, and given the lake residence time, we restrict our analysis of changing lake conditions to the period since 1997.

3. Materials and methods

3.1. Fieldwork

Water samples were collected from the lake during 22 field visits between 1997 and 2014. When conditions permitted, depth profiles were taken from the deepest part of the lake through the water column using a Van Dorn bottle (Van Dorn, 1956) or a Glew corer (Glew et al., 2001) with temperature, pH and EC measured at the time on a Myron® meter. Maximum lake depths were estimated using a Garmin Fish Finder® and a weighted tape and checked against water level stage readings at the lake edge when possible. Bathymetry was measured using a Boomer system coupled with a high precision GPS, based on 53 transect lines north–south and east–west (Smith, 2010), in order to identify a suitable