



Eastern Mediterranean hydroclimate over the late glacial and Holocene, reconstructed from the sediments of Nar lake, central Turkey, using stable isotopes and carbonate mineralogy

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ABSTRACT

There is a lack of high-resolution records of hydroclimate variability in the Eastern Mediterranean from the late glacial and early Holocene. More knowledge of the speed of climate shifts and the degree to which they were synchronous with changes in the North Atlantic or elsewhere is required to understand better the controls on Eastern Mediterranean climate. Using endogenic carbonate from a sediment sequence from Nar Gölü, a maar lake in central Turkey, dated by varve counting and uranium-thorium methods, we present high-resolution (~25 years) oxygen ($\delta^{18}\text{O}$) and carbon isotope records, supported by carbonate mineralogy data, spanning the late glacial and Holocene. $\delta^{18}\text{O}_{\text{carbonate}}$ at Nar Gölü has been shown previously to be a strong proxy for regional water balance. After a dry period (i.e. evaporation far exceeding precipitation) in the Younger Dryas, the data show a transition into the relatively wetter early Holocene. In the early Holocene there are two drier periods that appear to peak at ~9.3 ka and ~8.2 ka, coincident with cooling 'events' seen in North Atlantic records. After this, and as seen in other records from the Eastern Mediterranean, there is a millennial-scale drying trend through the Mid Holocene Transition. The relatively dry late Holocene is punctuated by centennial-scale drought intervals, at the times of 4.2 ka 'event' and Late Bronze Age societal 'collapse'. Overall, we show that central Turkey is drier when the North Atlantic is cooler, throughout this record and at multiple timescales, thought to be due to a weakening of the westerly storm track resulting from reduced cyclogenesis in the North Atlantic. However, some features, such as the Mid Holocene Transition and the fact the early Holocene dry episodes at Nar Gölü are of a longer duration than the more discrete 'events' seen in North Atlantic records, imply there are additional controls on Eastern Mediterranean hydroclimate.

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1. Introduction

Water in the Eastern Mediterranean is a key and politically sensitive resource (Issar and Adar, 2010) with rain-fed agriculture impossible across much of the region and regional climate models suggesting conditions will become even drier through this century

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(Kitoh et al., 2008). An improved understanding of hydroclimate over long timescales, >100 years, can help identify the potential drivers of climate in the region under different boundary conditions, assisting in the long-term sustainable management of water resources. This link between people and their hydro-environment has been important for millennia, potentially influencing the rise and fall of civilisations (e.g. Issar and Zohar, 2007; Rosen, 2007).

Current knowledge of regional palaeoclimatology suggests a dry, cool period in the Eastern Mediterranean from ~12,900–11,700 years BP at the time of the Younger Dryas (Bar-Matthews et al.,

1999; Wick et al., 2003; Jones et al., 2007; Castañeda et al., 2010; Kotthoff et al., 2011), followed by a wetter early Holocene marked by increased precipitation (Bar-Matthews et al., 1999; Jones et al., 2007; Verheyden et al., 2008; Ocakoğlu et al., 2013). There followed a significant shift in hydroclimate in the mid Holocene to a drier late Holocene: the so-called Mid Holocene Transition (review of lake isotope data; Roberts et al., 2008, 2011).

In the early Holocene in the North Atlantic region, two key centennial-scale cooling episodes, at ~9300 years BP and ~8200 years BP, are well documented (e.g. von Grafenstein et al., 1999; Rasmussen et al., 2006). These are expressed in many other northern hemisphere regions as cool and/or dry periods, for example at the time of the 9.3 ka 'event' in China (Dykoski et al., 2005) and Oman (Fleitmann et al., 2003, 2007) and at the time of the 8.2 ka 'event' in Turkey (Turner et al., 2008; Göktürk et al., 2011), Israel (Bar-Matthews et al., 2003; Almogi-Labin et al., 2009), China (Dykoski et al., 2005) and Oman (Fleitmann et al., 2003, 2007).

Late Holocene records (e.g. Jones et al., 2006) and present day climate (e.g. Cullen and deMenocal, 2000; Harding et al., 2009) show clear links between the Eastern Mediterranean and both the North Atlantic and the Indian Summer Monsoon. However, there is a lack of records from the region with the required temporal resolution to allow for a thorough investigation of centennial-scale climate change, and hence teleconnections to other regions, beyond the late Holocene. To address this gap, we present a new, high-resolution (~25 years) oxygen ($\delta^{18}\text{O}$) and carbon ($\delta^{13}\text{C}$) isotope record, with carbonate mineralogy data, from Nar Gölü (Gölü = lake in Turkish) in central Turkey through the late glacial and Holocene. This allows us to investigate the rapidity of climate shifts and centennial-scale change throughout the whole Holocene and late glacial in a way that was not possible with the previous, lower resolution records.

2. Site description

Nar Gölü (38°20'24"N, 34°27'23"E; 1363 m.a.s.l.; Fig. 1) is a non-outlet, brackish maar lake, 0.7 km² in area and >20 m deep, in the Cappadocia region of central Turkey (see Dean et al., in press, for detailed catchment map). Modern $\delta^{18}\text{O}_{\text{lake water}}$ values plot off the meteoric water line (average for July surface samples from the centre of the lake 2001–2012 was −1.3‰), suggesting high rates of evaporation (Jones et al., 2005; Dean et al., in press). The crater geology is dominated by basalt and ignimbrite (Gevrek and Kazancı, 2000), reducing the possibility for detrital carbonate

contamination (cf. Leng et al., 2010). The climate of the region is continental Mediterranean (Kutiel and Türkeş, 2005). Annual precipitation at Niğde, 45 km from Nar Gölü, averaged 339 mm between 1935 and 2010. July, August and September receive only 6% of the total precipitation, while April and May are the wettest months (27% of the total). The hottest months are July and August, when temperatures average +23 °C, while from December to February temperatures average +0.7 °C (meteorological data given in Dean et al., 2013).

Stable isotope (Jones et al., 2006; Dean et al., 2013), pollen (England et al., 2008) and diatom (Woodbridge and Roberts, 2011) studies have previously been carried out on a 1720 year core sequence (NAR01/02) from the lake. The distinctive carbonate-organic couplets in the sediment have been shown to be annual (varves) and $\delta^{18}\text{O}_{\text{carbonate}}$ has been shown to provide a means of reconstructing water balance (Jones et al., 2005; Dean et al., in press).

3. Methods

3.1. Field work and chronology

Three parallel cores from the deepest part of Nar Gölü were retrieved using a UWITEC hammer-piston coring system, from the Laboratoire Environnement, Dynamiques et Territoires de la Montagne (EDYTEM), Université Savoie Mont Blanc, in July 2010. The three core sequences were matched visually at tie-points where turbidites or distinctive sedimentological patterns could be clearly correlated, which led to the compilation of a 21.7 m master sequence (NAR10).

Where possible, chronologies for the sequence were established by varve counting. Counts were made independently by two people and recounted until agreement (to within five varve years) was reached. However, as the core sequence was not varved throughout, additional age estimates were needed. Radiocarbon dating had previously been undertaken on bulk organic and carbonate samples known to be ~500 years old (dated by varve counting), but these gave apparent radiocarbon ages of 14,320 and 23,450 years BP respectively, indicating a substantial old carbon reservoir linked to volcanic out-gassing (Jones, 2004). Pollen and charcoal could not be extracted in sufficient quantities for radiocarbon dating of these components, and there were no terrestrial macrofossils found in the cores.

Uranium–thorium (U–Th) dating was carried out on two aragonite and four calcite dominated horizons (Dean, 2014). The



Fig. 1. Location of Nar Gölü in central Turkey, and the lake, ice and cave sites from which key isotope records referred to in this study have been produced.

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