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Lateglacial and Holocene climate and environmental change in the northeastern Mediterranean region: diatom evidence from Lake Dojran (Republic of Macedonia/Greece)

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ABSTRACT

The juncture between the west–east and north–south contrasting Holocene climatic domains across the Mediterranean is complex and poorly understood. Diatom analysis of Lake Dojran (Republic of Macedonia/Greece) provides a new insight into lake levels and trophic status during the Lateglacial and Holocene periods in the northeastern Mediterranean. Following a very shallow or even desiccated state at the core base at ca. 12,500 cal yr BP, indicated by sedimentological and hydro-acoustic data, diatoms indicate lake infilling, from a shallow state with abundant benthos to a plankton-dominated relatively high lake level and eutrophic state thereafter. Diatom-inferred shallowing between ca. 12,400–12,000 cal yr BP and a very low lake level and eutrophic, oligosaline state between ca. 12,000–11,500 cal yr BP provide strong evidence for Younger Dryas aridity. The earliest Holocene (ca. 11,500–10,700 cal yr BP) was characterised by a high lake level, followed by a lake-level reduction and increased trophic level between ca. 10,700–8,500 cal yr BP. The lake was relatively deep and exhibited peak Holocene trophic level between ca. 8,500–3,000 cal yr BP, becoming shallow thereafter. The diatom data provide more robust evidence and strengthen previous lake-level interpretation based on sedimentological and geochemical data during the earliest, mid and late Holocene, and also clarify previous uncertainty in interpretation of Lateglacial and early-Holocene lake-level change. Our results are also important in disentangling regional climate effects from local catchment dynamics during the Holocene, and to this end we exploit extant regional palynological evidence for vegetation change in the highlands and lowlands. The importance of seasonality in driving Holocene climate change is assessed by reference to the summer and winter latitudinal temperature gradient (LTG) model of Davis and Brewer (2009). We suggest that increased precipitation drove the high lake level during the earliest Holocene. The early-Holocene low lake level and relatively high trophic state may result climatically from high seasonality of precipitation and locally from limited, nutrient-rich catchment runoff. We argue that the mid-Holocene relatively deep and eutrophic state was driven mainly by local vegetation succession and associated changes in catchment processes, rather than showing a close relationship to climate change. The late-Holocene shallow state may have been influenced by a temperature-induced increase in evaporative concentration, but was coupled with clear evidence for intensified human impact. This study improves understanding of Lateglacial and Holocene climate change in the northeastern Mediterranean, suggests the important role of the LTG on moisture availability during the Holocene, and clarifies the influence of catchment processes on palaeohydrology.

1. Introduction

The Mediterranean region is a primary global climate response hotspot (Giorgi, 2006) and a hotspot of biodiversity (Myers et al., 2000; Mittermeier et al., 2004). It is a transitional zone climatically influenced both by the mid-latitude westerlies and the Subtropical High pressure (anticyclone) belt, with the North Atlantic

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Oscillation (NAO) modulating winter precipitation and the migration of the Intertropical Convergence Zone (ITCZ) affecting summer drought (Lionello et al., 2006). It stretches longitudinally from the North Atlantic Ocean to continental Eurasia. It has a diversity of landscapes linked to spatial and altitudinal variation in climatic factors.

Palaeoenvironmental analysis offers potential to improve understanding of Mediterranean climate change, but the clear definition of regional contrasts is still elusive. An early review of lake-level reconstruction proposed an east–west contrast during the Holocene (Harrison and Digerfeldt, 1993). More recently, Roberts et al. (2008, 2011a) confirmed this, defining a marked contrast during the Holocene to the east and west of a line running through the Balkans, southern Italy and Tunisia, based on stable isotope data and model output; on a centennial-decadal timescale, the complexity of regional patterns was also demonstrated in an east–west contrast between the northern Iberian Peninsula and central Turkey (Roberts et al., 2012). In contrast, Magny et al. (2013) proposed a north–south divide around ca. 40°N during the Holocene in the central Mediterranean from carbonate-based lake-level reconstruction. Peyron et al. (2013) supported this from pollen-based quantitative reconstruction of summer precipitation, and also proposed a similar pattern in the Aegean Sea. This is coherent with a north–south contrast in fire activity in the western Mediterranean (Vannière et al., 2011).

From the foregoing, the southern Balkans is a key location for understanding Mediterranean climate change, being located at the juncture of the proposed boundaries between west–east and north–south contrasting climate and hydrological domains. The southern Balkans is particularly complex, and patterns and mechanisms of climate and environmental change are still poorly understood. The complexity of palaeoenvironments is indicated, for example, by discrepancies in vegetation reconstruction between adjacent sites such as Lake Ioannina (northwestern Greece) and Nisi Fen (northern Greece) (Lawson et al., 2004, 2005), and between Lake Gramousti at low altitude and Rezina Marsh at high altitude in northwestern Greece (Willis, 1992a).

Here, we build on previous multi-proxy palaeoclimate research in investigating the Lateglacial and Holocene record of Lake Dojran (Macedonia/Greece), by using diatom analysis as a strong proxy for lake levels and trophic status to strengthen interpretation based on sedimentological and geochemical data from the same core (Francke et al., 2013). In interpretation of Holocene limnological change in terms of palaeoclimate shifts *versus* the influence of local catchment dynamics, we exploit extant regional palynological data for vegetation change, comprising late-Holocene pollen data from a separate littoral Dojran sequence (Athanasiadis et al., 2000) and chronologically-robust Holocene pollen data from the highlands and lowlands in the southern Balkans (Kotthoff et al., 2008a; Tonkov et al., 2008, 2013). Adopting a novel approach, the importance of seasonality in driving Holocene climate change is assessed by reference to the summer and winter latitudinal temperature gradient (LTG) model (Davis and Brewer, 2009), which incorporates variation in the Subtropical High pressure and Arctic Oscillation (AO). For clarity, this is expanded upon in Section 2. We also compare with proxy data from the northeastern Mediterranean (the Balkans, Italy and Anatolia) (Fig. 1).

2. Review of Holocene climatic forcing

2.1. Summer climate mode and the Subtropical High pressure

The character and influence of the Holocene summer insolation maximum across the Mediterranean is a topic for vigorous ongoing debate (Tzedakis, 2007). In a major review, Tzedakis (2007) argued that the enhanced African monsoon did not extend to the

Fig. 1. Map of the northeastern Mediterranean showing the locations of the study site (*red*), relevant palynological records with robust chronologies (*purple*) and other palaeoenvironmental records (*black*) referred to in this paper. 1. Lake Dojran (this paper; Athanasiadis et al., 2000; Francke et al., 2013), 2. Lake Trilistnika (Tonkov et al., 2008), 3. Lake Ribno (Tonkov et al., 2013), 4. SL152 (Kotthoff et al., 2008a, 2008b, 2011; Dormoy et al., 2009), 5. Tenaghi Philippon (Müller et al., 2011), 6. Lake Ohrid (Wagner et al., 2009; Leng et al., 2010), 7. Lake Prespa (Aufgebauer et al., 2012; Panagiotopoulos et al., 2013; Leng et al., 2013; Cvetkoska et al., 2014), 8. Lake Maliq (Bordon et al., 2009), 9. Nisi Fen (Lawson et al., 2005), 10. Rezina Marsh (Willis, 1992a, 1992b), 11. Lake Gramousti (Willis, 1992a), 12. Lake Ioannina (Frogley et al., 2001; Lawson et al., 2004; Wilson et al., 2008; Jones et al., 2013), 13. Lake Xinias (Digerfeldt et al., 2007), 14. Lake Stymphalia (Heymann et al., 2013), 15. Lake Frassino (Baroni et al., 2006), 16. Lake Accesa (Drescher-Schneider et al., 2007; Peyron et al., 2011), 17. Valle di Castiglione (Di Rita et al., 2013), 18. Lake Albano (Guilizzoni et al., 2002), 19. Lago Grande di Monticchio (Allen et al., 2002), 20. MD90-917 (Combourieu-Nebout et al., 2013), 21. Lake Pergusa (Sadori and Narcisi, 2001; Sadori et al., 2008; Magny et al., 2012), 22. Lake Preola (Magny et al., 2011), 23. MD04-2797 (Desprat et al., 2013), 24. Lake Iznik (Roeser et al., 2012), 25. Lake Gölhisar (Eastwood et al., 2007), 26. Eski Acıgöl (Roberts et al., 2001; Turner et al., 2008), 27. Lake Van (Wick et al., 2003; Litt et al., 2009). The dashed-line rectangle shows the range of Fig. 2. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)