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Holocene hydrological changes in south-western Mediterranean as recorded by lake-level fluctuations at Lago Preola, a coastal lake in southern Sicily, Italy

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ABSTRACT

This paper presents a high-resolution lake-level record for the Holocene at Lago Preola (Sicily, southern Italy) based on a specific sedimentological approach, with a chronology derived from AMS radiocarbon dates. It gives evidence of three major successive palaeohydrological periods, with (1) a pronounced dryness during the early Holocene until ca 10300 cal BP, (2) a highstand from ca 10300 to 4500 cal BP, and (3) a marked lowstand from 4500 cal BP to present. Large amplitude lake-level fluctuations characterise two transition phases at ca 10300–9000 and 6400–4500 cal BP. Period 2 was interrupted between 8300 and 7000 cal BP by a dry phase that was punctuated to ca 7300 cal BP by the deposition of a tephra from neighbouring Pantelleria Island. Comparisons of the Preola record with other palaeohydrological records along north–south and west–east transects in the Mediterranean show contrasting patterns of hydrological changes: north (south) of around 40°N latitude, the records highlight a mid-Holocene period characterised by lake-level minima (maxima). Humid mid-Holocene conditions over the Mediterranean south of 40°N were probably linked to a strong weakening of the Hadley cell circulation and of monsoon winds. We suggest that the maximum of humidity in the Mediterranean during the mid-Holocene was characterised by humid winters to the north of 40°N and humid summers to the south. On a multi-centennial scale, the high-resolution palaeohydrological reconstructions in the central Mediterranean area reveal a strong climate reversal around 4500–4000 cal BP, with contrasting changes in the hydrological cycle. In addition to seasonal and inter-hemispherical changes related to orbital forcing, this major oscillation might be related to non-linear responses of the climatic system to the gradual decrease in summer insolation at northern latitudes. Another major climate oscillation around 7500–7000 cal BP may have resulted from the combined effects of (1) a strong rate of change in insolation, and (2) variations in solar activity. Finally, comparisons of the Preola lake-level record with Sicilian pollen records suggest a strong influence of moisture availability on vegetation development in Sicily. Very dry early Holocene conditions probably prevented the expansion of coastal evergreen forests, while decreasing moisture availability since the onset of the late Holocene may have exacerbated effects of intensive land-use.

1. Introduction

Understanding conditions behind hydrological changes is crucial for the Mediterranean area, particularly in the face of present-day global warming. Regional sets of palaeoclimatic and palaeoenvironmental data may provide key contributions to this understanding. As pointed out by Reed et al. (2001), Holocene lake-level data offer independent palaeohydrological data to help refine pollen-inferred studies. Detailed, systematic studies aimed specifically at lake-level reconstructions are still scarce in the Mediterranean area. In addition, they often suffer from insufficient dating and temporal resolution. In a compilation based on litho- and biostratigraphic data from literature, Harrison and Digerfeldt (1993) have outlined Holocene patterns of lake-level changes for the Mediterranean region. They distinguished a western Mediterranean

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pattern characterised by conditions significantly wetter than today's remaining throughout the early to mid-Holocene, with an abrupt transition to drier conditions after ca 5700 cal BP. Conversely, for the eastern Mediterranean they suggested relatively arid conditions during the early Holocene, moister conditions for the mid-Holocene, and a gradual transition to drier conditions after ca 5700 cal BP. More recently, a thorough review by Tzedakis (2007) has pointed out the increasingly complex climatic scenarios invoked by authors, and attempted to reconcile conflicting interpretations. He specifically questioned the notion of an accentuated summer rain regime in the northern Mediterranean borderlands during the boreal insolation maximum. On the basis of lake isotope records, Roberts et al. (2008) suggest a possible NW/SE contrast in Mediterranean climate history during the Holocene. On the other hand, using mainly pollen data, Jalut et al. (2009) concluded that, in the circum-Mediterranean region, the Holocene can be divided into three periods: a humid early Holocene (11500–7000 cal BP), a transition phase (7000–5500 cal BP), and a dry late Holocene (5500 cal BP-present), which was characterised by drier conditions.

Recent research including oxygen-isotope analysis and climate modelling (see synthesis in Roberts et al., 2011a) emphasises the spatio-temporal complexity of Mediterranean paleo-environmental dynamics (e.g. Bar-Matthews and Ayalon, 2011; Brayshaw et al., 2011; Giraudi et al., 2011; Kuzucuoglu et al., 2011; Mercuri et al., 2011; Roberts et al., 2011b; Sadori et al., 2011). Multiproxy evidence from several sites suggests a wet period 6000–3000 cal. BP in the Western Mediterranean, while in the Eastern Mediterranean precipitation declined already after 6000 cal. BP (Roberts et al., 2011a). Latitudinal differences contributed to paleo-environmental complexity, suggesting a north–south partition around 40°N with almost inverse Mediterranean fire-activity patterns during the Holocene (Vannière et al., 2011). Such latitudinal differences seem in agreement with a spatial tri-partition of western Europe (including Scandinavia and the Mediterranean) as inferred from a comparison of palaeohydrological records: during the Holocene, mid-European latitudes between ca 50° and 43°N were characterised by wetter conditions, while drier climatic conditions prevailed in northern and southern Europe during cold events such as around 8200 cal. BP (Magny et al., 2003). Moreover, long-term seasonal effects emerged (e.g. Finsinger et al., 2010; Peyron et al., 2011), which may reconcile seeming contradictions among the different proxies.

As a contribution to the reconstruction of Holocene hydro-climatic conditions in the central Mediterranean, we first present a high-resolution lake-level record established at Lago Preola, a small lake in southern Sicily, using a specific sedimentological approach and summary pollen analysis. On the basis of a comparison with other palaeohydrological records recently reconstructed in the Mediterranean area and in west–central Europe, we then examine the palaeoclimatic significance of our results in regard to regional patterns of hydrological changes, seasonality, forcing factors and vegetation.

2. Site and methods

2.1. Study area

Lago Preola (37°37 N, 12°38 E, 4 m a.s.l., ca 33 ha) lies in south-western Sicily (Fig. 1), ca 2 km east of the Mediterranean Sea. Maximal water depth was 2 m in June 2008 during coring, but before the lake basin was transformed into a vegetated swamp after a sequence of dry years prior to 2004. It is of karstic origin and topographically closed with no major inlet or outlet, which makes the lake ideal for Holocene lake-level reconstructions. A calcareous ridge up to ca 30 m high separates the lake from the Mediterranean Sea. The catchment area of the lake covers ca 17 km^2 (Fig. 1) and is dominated by limestone and Pleistocene calcarenites. It is characterised by gentle slopes and relatively flat plateaus culminating at ca 70 m a.s.l. The climate of the area is Mediterranean with marked seasonal variations in precipitation. Mean annual precipitation reaches 505 mm at nearby Trapani/Mazara del Vallo, summer precipitation (June–August) 26 mm, and winter precipitation (December–January) 177 mm (AD 1961–1990 average; World Climate, 2008). Mean annual temperature is 17.6 °C, with 25.2 °C for August, and 11.7 °C for January. Preola is part of a nature reserve including the swamp Pantano Murana and the three small karstic depressions of Gorghi Tondi, i.e. the ponds Gorgo Alto, Gorgo Medio, and Gorgo Basso. Pollen and charcoal investigations have been carried out recently at Gorgo Basso to reconstruct Holocene vegetation and fire dynamics (Tinner et al., 2009).

2.2. Coring and dating

Two cores were taken in June 2008 with a modified Streif-Livingstone piston corer 4.8 cm in diameter (Lang, 1994) (Fig. 1). Core LPA was extracted in the littoral zone and core LPBC in the deeper part of the lake. The coring was stopped due to high friction in the sandy and clayey sediment at the base. Similarities observed in the sediment profiles allow lithostratigraphic correlations between the cores LPA and LPBC. The chronology is based on AMS radiocarbon dates (Table 1). Radiocarbon ages were calibrated using Calib 6 (Stuiver et al., 1998; Reimer et al., 2004). In addition to radiocarbon ages, pollen analyses carried out on core LPBC offer the support of correlations with the pollen-stratigraphy of Gorgo Basso, which was radiocarbon-dated from terrestrial plant macrofossils only (Tinner et al., 2009). The age-depth models were made using general addictive models (GAM, Heegaard et al., 2005) that take into account the 2s errors of the calibrated ^{14}C dates as well as the sampling depths of the dated material.

2.3. Tephra analyses

Core LPBC includes a mm-thick tephra layer at level 730 cm. Energy-dispersive spectrometry (EDS) analyses of glass shards and glasses from micro-pumice fragments were performed at the Dipartimento di Scienze della Terra (University of Pisa), with an EDAX-DX micro-analyser mounted on a Philips SEM 515 (operating conditions: 20 kV acceleration voltage, 100 s live time counting, 200–500 nm beam diameter, 2100–2400 shots per second, ZAF correction). The ZAF correction procedure does not include natural or synthetic standards for reference, and requires analysis normalisation at a given value (which is chosen at 100%). Analytical precision is 0.5% for abundances higher than 15 wt%, 1% for abundances around 5 wt%, 5% for abundances of 1 wt% and less than 20% for abundances close to the detection limit (around 0.5 wt%). Accuracy and analytical comparison have been extensively discussed elsewhere (Caron et al., 2010; Sulpizio et al., 2010; Vogel et al., 2010).

2.4. Sedimentological analyses

The lake-level fluctuations were reconstructed using a specific technique described in detail and validated elsewhere (Magny, 1992, 1998, 2004, 2006) and based on a sedimentological approach combining several markers as follows.

- Lithology: fine carbonate lake-marl is deposited in lake water, whereas peat and anmoor reflect marshland conditions. Sand accumulation corresponds to runoff (blunt shining quartz grains) or wind-transport (round-frosted quartz grains).
- Macroscopic components of lake-marl: it has been shown that, in carbonate lakes, the coarser fractions (larger than 0.2 mm) of