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Rapid climatic changes and resilient vegetation during the Lateglacial and Holocene in a continental region of south-western Europe

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ABSTRACT

Palynological, sedimentological and geochemical analyses performed on the Villarquemado paleolake sequence (987 m a.s.l, 40°30′N; 1°18′W) reveal the vegetation dynamics and climate variability in continental Iberia over the last 13,500 cal yr BP. The Lateglacial and early Holocene periods are characterized by arid conditions with a stable landscape dominated by pinewoods and steppe until ca. 7780 cal yr BP, despite sedimentological evidence for large paleohydrological fluctuations in the paleolake. The most humid phase occurred between ca. 7780 and 5000 cal yr BP and was characterized by the maximum spread of mesophytes (e.g., *Betula*, *Corylus*, *Quercus faginea* type), the expansion of a mixed Mediterranean oak woodland with evergreen *Quercus* as dominant forest communities and more frequent higher lake level periods. The return of a dense pinewood synchronous with the depletion of mesophytes characterizes the mid-late Holocene transition (ca. 5000 cal yr BP) most likely as a consequence of an increasing aridity that coincides with the reappearance of a shallow, carbonate wetland environment. The paleohydrological and vegetation evolution shows similarities with other continental Mediterranean areas of Iberia and demonstrates a marked resilience of terrestrial vegetation and gradual responses to millennial-scale climate fluctuations. Human impact is negligible until the Ibero-Roman period (ca. 2500 cal yr BP) when a major deforestation occurred in the nearby pine forest. The last 1500 years are characterized by increasing landscape management, mainly associated with grazing practices shaping the current landscape.

1. Introduction

The progressive increase in the number of well-dated, high-resolution Holocene climate records in both marine and continental areas (Hoek et al., 2008; Lowe et al., 2008) has demonstrated the existence of complex millennial-scale oscillations and rapid climate changes in response to both extraterrestrial forcings (e.g., orbital parameters, insolation) and internal mechanisms (e.g., changes in deep-ocean circulation, internal climate system variability) (Bond et al., 1997; Alley et al., 2003; Mayewski et al., 2004; Denton and Broecker, 2008; Wanner et al., 2008; Renssen et al., 2009). In particular, the western Mediterranean Basin, strategically located under the incursion of North-Atlantic storm tracks and the influence of a high pressure system in summer-months, is a fundamental region to understand the climate evolution and the vegetation response to abrupt changes and perturbations originated at high (Fletcher and Sánchez Goñi, 2008) and lower latitudes (Peyron et al., 2011). Indeed, several marine cores from the western Iberian margin demonstrate the impact of short-lived Holocene climatic events (e.g., Preboreal Oscillation, 8200 cal yr BP event, 4200 cal yr BP aridity crisis) on vegetation firstly identified in North Atlantic cores (Alley et al., 1997; Björck et al., 1997; Rasmussen et al., 2007) and then recorded in the Iberian Peninsula as dry spells and probably cool conditions (Cacho et al., 2001; Frigola et al., 2007; Combourieu Nebout et al., 2009; Fletcher et al., 2010). Iberian sedimentary sequences have reported similar Holocene oscillations, clearly documented by prominent peaks of xerophytes in pollen records (Muñoz Sobrino et al., 2005; González-Sampériz et al., 2006; Fletcher et al., 2007; Moreno et al., 2011; Pérez-Sánz et al., 2013), by abrupt drops in lake water-levels (Carrión, 2002; González-Sampériz et al., 2008; Martín-Puertas et al.,

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2008; Morellón et al., 2009), and complex patterns of human adaptations (González-Sampériz et al., 2009; Cortés-Sánchez et al., 2012).

Regarding ecosystem responses to climate change, recent reviews have highlighted the unidirectional response of the Iberian phytodiversity throughout the late Quaternary (Carrión et al., 2010a; González-Sampériz et al., 2010), where regional ecological dissimilarities, enhanced by particular orographic and edaphic features, have prevented the unraveling of common climatic patterns. Ecosystem inertia to Lateglacial and Holocene climate changes has been a clear example of the mentioned unidirectional trend (e.g., Carrión and van Geel, 1999; Franco-Múgica et al., 2001, 2005; García-Antón et al., 2011; Morales-Molino et al., 2012), being long-term pinewood resilience the main distinctive aspect of wide areas of continental Iberia (Rubiales et al., 2010, and references therein).

Despite the number of Lateglacial and Holocene paleoenvironmental sequences in the Iberian Peninsula have increased during the last decades (Carrión et al., 2010a and references therein), the continental lowlands of Iberia have hardly been investigated, leaving a paleobiogeographical gap between inner continental mountains and coastal areas. Climatically located near the Ebro Basin, the Iberian Range borders the northernmost area of truly semi-arid climate in Europe, whose patchy and fragile steppe-like vegetation is strongly conditioned by an arid climate regime and edaphic constraints (Vicente-Serrano et al., 2012; Pueyo et al., 2013). Permanent lakes are absent in the region and therefore, most of the regional paleorecords have been obtained from large ephemeral or hypersaline lakes (Valero-Garcés et al., 2000a,b, 2004; Davis and Stevenson, 2007; Luzón et al., 2007; González-Sampériz et al., 2008; Sancho et al., 2011; Gutiérrez et al., 2013), where recurrent hiatuses and complex geochemical processes often hamper chronological control and pollen preservation, preventing continuous high-resolution environmental reconstructions (González-Sampériz et al., 2008). Further southwest from the Ebro Basin, studies providing detailed climatic oscillations are available. These are derived mainly from lake level fluctuations and paleoflood frequency records, although they cover relatively short timescales spanning only the last three millennia (Moreno et al., 2008; Romero-Viana et al., 2011; López-Blanco et al., 2012; Barreiro-Lostres et al., 2013). Additional paleoenvironmental information, somewhat fragmentary and influenced by local peculiarities, is provided by geomorphological (Valero-Garcés et al., 2008; Constante et al., 2011) and archaeological studies (González-Sampériz et al., 2009; Aura et al., 2011; Utrilla et al., 2012).

Based on a multiproxy approach, the well-dated and continuous sedimentary sequence obtained from the Villarquemado paleolake offers the possibility to reconstruct the postglacial paleoenvironmental history of a poorly-studied, ecotonal and continental, Mediterranean area. The main goals of the current study are to:

1) Understand both regional and local vegetation dynamics and hydrological response to the last ca. 13,500 cal yr BP climate variability.
2) Place the Villarquemado vegetation development in regional context through correlation with other well-dated pollen records.
3) Explore the sensitivity of this and other ecotonal regions to detect Holocene abrupt climate changes, especially in areas where pinewoods have been the dominant communities.

2. Regional setting

Villarquemado paleolake (40°30′N; 1°18′W, Fig. 1) is located at about 1000 m a.s.l., in the Jiloca Basin (Iberian Range, NE Spain). This is a 60 km long, 6–10 km wide, N–S half-graben, bounded by NW–SE trending normal faults. The depression belongs to a series of intramontane basins developed in the Iberian Range during the second extensional episode that started in the Upper Pliocene (Simón-Gómez, 1989; Casas-Sainz and De Vicente, 2009). The change from endorheic to exorheic conditions in these depressions occurred during the Neogene and Plio-Quaternary through the capture of the basins by the external drainage network and headwater erosion (Gutiérrez-Elorza and Gracia, 1997). The Jiloca river captured the Daroca half-graben and subsequently the next depression to the south, the Jiloca Depression (Gracia et al., 2003). However the south-central sector of this depression remained an endorheic basin until it was artificially drained in the 18th century, when the maximum flooded area was 11.3 km^2 and the water depth up to 2.8 m (Rubio, 2004).

The current climate of the region is continental Mediterranean, characterized by severe summer droughts, strong seasonal and diurnal temperature oscillations and by relatively low precipitation values (Fig. 2B). The maximum absolute temperature is about 40 °C in summer and the winter minimum can reach −15 °C with frequent freezing days in the region. The mean annual precipitation in the area is about 380 mm (Fig. 2B: Cella station, 1023 m a.s.l.), with large interannual variability and irregular distribution through the year, while higher elevations are influenced by more regular orographic precipitation (Fig. 2C: Griegos station, 1604 m a.s.l.). Regional-scale rainfall dynamics is principally controlled by the westerly winds, associated with cold fronts in spring and high-intensity convective storms in autumn. During the summer, the subtropical Azores anticyclone blocks the moisture from the west and brings warm and dry air masses from the south, being the negative water balance associated to high evapotranspiration values (Fig. 2C).

The Villarquemado paleolake is located in the mesomediterranean bioclimatic belt, with *Quercus ilex* and *Quercus faginea* as principal tree species, along with other Mediterranean xerophytic shrubs (*Rhamnus alaternus*, *Genista scorpius*, *Ephedra fragilis*, *Thymus* spp.) and herbs (*Artemisia assoana*, *A. campestris*, *Atriplex prostata*, *Salicornia ramosissima*) (Fig. 2D). The calcareous soils in the area support *Juniperus phoenicea* and *J. thurifera*. The supramediterranean belt is characterized by *Pinus sylvestris* communities with *Buxus sempervirens* and *Juniperus sabina*. In red sandstones areas, *Pinus pinaster* woodlands, with dense Cistaceae and Ericaceae shrubs, prevail. The hydroseral community is dense, well developed and linked to seasonal water level fluctuations. The dominant species here are *Phragmites australis*, *Juncus acutus*, *J. inflexus*, *J. maritimus* and *Scirpus holoschoenus*; scattered trees of *Salix fragilis* and *S. atrocinerea* with a scrubland of *Crataegus monogyna* and some *Populus canadensis* cultivars. The natural wetland vegetation has been substantially modified by agriculture and grazing (Fig. 2D).

3. Material and methods

A 74 m long sediment core (core VIL-05-1B) was retrieved in 2005 from the deepest area of the Villarquemado wetland, using a truck-mounted drilling system (Moreno et al., 2012a; González-Sampériz et al., 2013). The extracted material was extruded, transported to IPE-CSIC laboratory and stored at 4 °C until required for analysis. The top 61 cm were disturbed due to the coring system and were not considered for analysis. To complete the 0–61 cm gap, a parallel 247 cm long core (core VIL-05-1A) was taken with a modified 5 cm-diameter Livingstone piston corer, a coring system that allows recovering unaltered the uppermost part of the sequence.

Correlation between cores VIL-05-1A and VIL-05-1B was achieved using sedimentary facies, radiocarbon dating and pollen stratigraphy (Fig. 3A). Therefore, the composite sequence of the Villarquemado paleolake was built using the uppermost 40 cm of the shorter core VIL-05-1A and the core VIL-05-1B, excluding the first 61 cm (Fig. 3B).

The cores were longitudinally opened and the sedimentary facies described according to Schnurrenberger et al. (2003). Geochemical data were obtained at 0.5 cm intervals by means of an XRF ITRAX Core scanner at the Large Lakes Observatory (University of Minnesota, USA). Total inorganic carbon (TIC) was analyzed every 2 cm with a LECO SC 144 DR elemental analyzer at the IPE-CSIC laboratory, after the organic matter had been removed. In addition, selected samples were analyzed by X-ray diffraction with a Philips PW1820 diffractometer and relative mineral abundance was determined using peak