

Late holocene environments in Las Tablas de Daimiel (south central Iberian peninsula, Spain)

Abstract The use of a high resolution pollen record in combination with geochemical data from sediments composed mainly of layers of charophytes alternating with layers of vegetal remains plus some detrital beds permits the reconstruction of the environmental evolution of the last 3000 years in an inland wetland of the Mediterranean domain, thus introducing a new climatic dataset for the Late Holocene. Hydrological fluctuations, reflected in the relationship between emerged and aquatic vegetation and inorganic and organic C and N changes, can be related to aridity or humid phases, while relations among arboreal taxa (*Quercus* and *Pinus*) and *Artemisia* are used as temperature indicators. Five climatic periods have been identified: a Subatlantic Cold Period (<150 B.C.), cold and arid; the Roman Warm Period (150 B.C.–A.D. 270), warmer and wetter; the Dark Ages (A.D. 270–A.D. 950), colder and drier; the Medieval Warm Period (A.D. 950–A.D. 1400), warmer and wetter; and the Little Ice Age (>A.D. 1400) indicated by a cooling and drying trend. Despite the lack of any direct evidence of human action, there are some episodes related to deforestation during the Reconquista (Middle Ages) that mask the real climatic signal.

Keywords Pollen · Late Holocene · Environmental changes · Mediterranean area

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Introduction

There has been an increasing interest in Late Holocene climate variability during recent years that is reflected, for example, in the IPCC (2001) report. This states “There is emerging evidence for significant, rapid (timescales of several decades or more), regional temperature changes during the last 10,000 years. However, the evidence does not indicate that any such events were global in scale” (Folland et al. 2001); this includes periods like the “Little Ice Age” or the “Medieval Warm Period” (IPCC 2001, pp 133–136). However there is still debate about the procedures used to reach those conclusions and their validity (Soon and Baliunas 2003; Soon et al. 2003; McIntyre and McKittrick 2003, 2005). Apart from the numerical procedures used for data analysis, there is one key fact that affects the truly “global” validity of the global palaeoclimatic reconstructions: “there are still only a small number of long, well-dated, high-resolution proxy records” (Briffa and Osborn 1999). This is true in two main senses, the spatial coverage is very heterogeneous and the number of proxies used in studies of global climate change is low.

The Iberian Peninsula is unique as it is located at the intersection between the Mediterranean and the Atlantic, Europe and Africa and is consequently affected by all of them. Because of its geodynamic position, its tectonic evolution is very complex and this is reflected in a very variable topography. As a result the variability of environments and records is very high. Despite this, research has centred on similar environments to those of north and central Europe (peat bogs, high altitude lakes, deep lakes) while multi-proxy study of many of the unusual systems existing in the Iberian Peninsula (saline lakes, temperate middle and low altitude biogenic lakes, etc.) did not begin until recently.

For example, Martínez-Cortizas et al. (1999), using variations in Hg in a peat bog in NW Spain found evidence of some important climate changes during the last 4000 years. Valero-Garcés et al. (1999, 2000) identified variations in saline lake levels in NE Spain related to the end of the Medieval Warm Period. Luque and Julià (2002) attributed

most of the variations found in the sediments for the last 1000 years from the Lake Sanabria (NW Spain) to human activity, but were able to identify the Little Ice Age. Desprat et al. (2003) recognised the classical climate episodes for recent times (First Cold Period of the Subatlantic, Roman Warm Period, Dark Ages, Medieval Warm Period, Little Ice Age, Recent Warming) in the pollen record of the last 3000 years from the Ría de Vigo (NW Spain). More recently, Riera et al. (2004) carried out a study very similar to that presented in this paper. They used a multiproxy approach to reconstruct the last 2000 years of lake level variations in the Estanya lakes (NE Spain), differentiating between the human record and the climate record, and also clearly identifying the Medieval Warm Period and the Little Ice Age. González-Alvarez et al. (2005), in a multiproxy study of the last 3000 years on the Galician continental shelf (NW Spain), identified two periods of contrasting environmental conditions. They found that during the Subboreal/Subatlantic transition (2850 cal B.P.) conditions were stormy in comparison to those during the following Subatlantic and they identified an upwelling related to the cooling of oceanic waters at around A.D. 1420, probably linked to the colder temperatures of the Little Ice Age.

Despite the incomplete record from the Iberian Peninsula, there is considerable evidence of climate oscillations during the last 3000 years. These records show slight differences but this could be due to environmental factors as well as the complexity of the vegetation dynamics. Against this background the present paper describes a high-resolution study developed in a relatively continuous record from inland Spain and in particular tries to analyse the response of the vegetation to such changes with the help of the geochemical record.

Study site

The study area is located in the La Mancha Plain, within the South-central Iberian Peninsula (Fig. 1). The La Mancha Plain corresponds to an E-W morphostructural depression in which Cainozoic terrestrial deposits overlie the Paleozoic (to the W) and Mesozoic basement. Unlike other Tertiary basins in the Iberian Peninsula, this depression has smaller dimensions and a younger sedimentary filling.

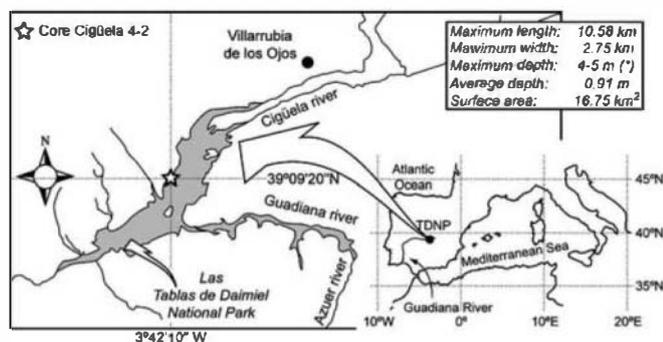


Fig. 1 Location of Las Tablas de Daimiel National Park and the core Cigüela 4-2. TDNP: Las Tablas de Daimiel National Park

The potential vegetation in the La Mancha Plain is typically Mediterranean, made up of *Quercus rotundifolia* (evergreen oak) forest together with *Arbutus unedo*, *Phillyrea angustifolia*, *Rhamnus alaternus*, *Pistacia terebinthus* and *Rosa canina*. At present, the vegetation consists of evergreen oak forests (*Quercus rotundifolia*), cleared and used as “dehesas” (forests of evergreen oak with tree-cover lower than 40% and with cleared spaces used for cultivation or pastures), together with extensive cultivation zones (Peinado-Lorca and Rivas-Martínez 1987).

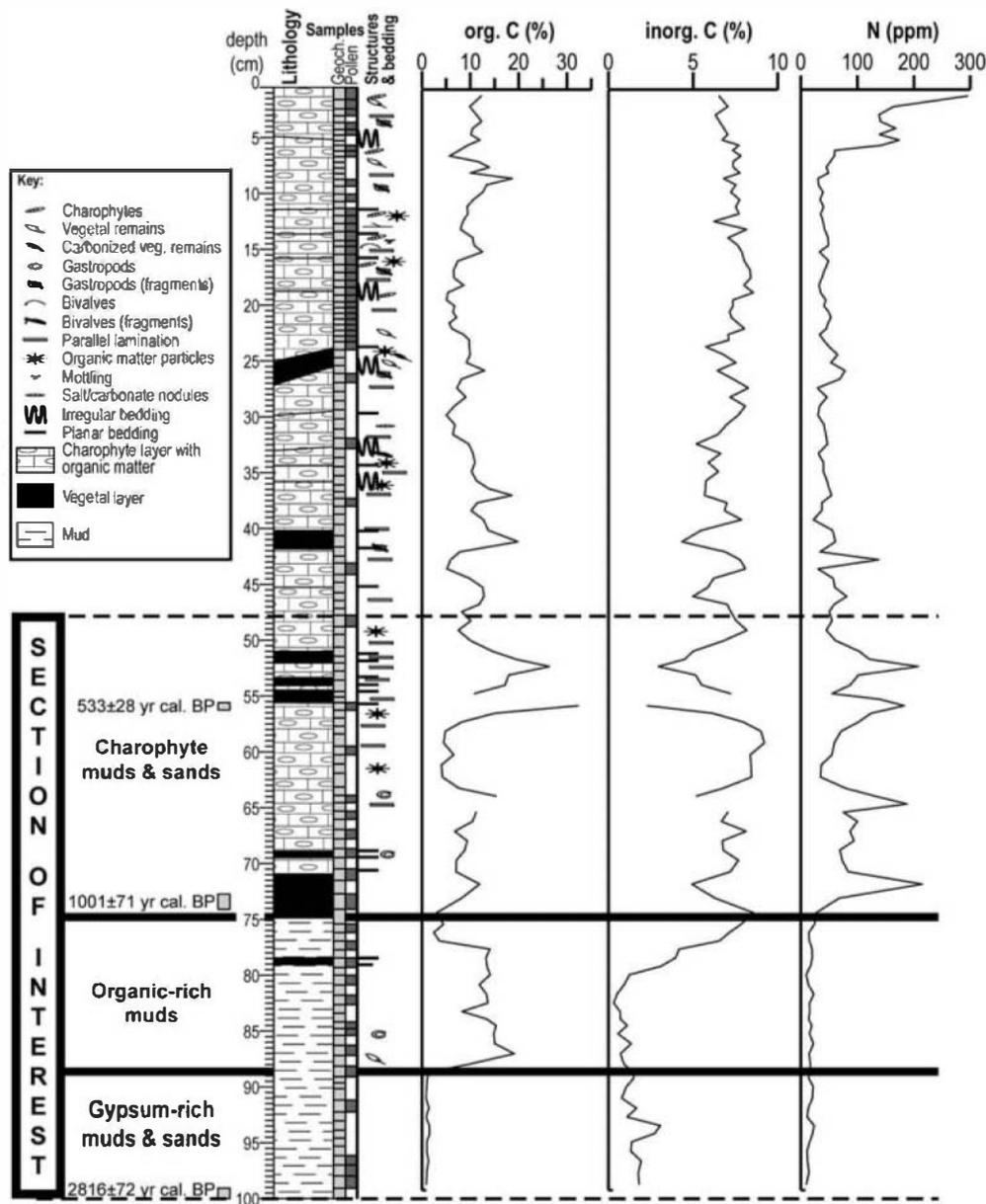
The Las Tablas de Daimiel National Park is a fluvial wetland or open lake linked to the Gígüela and Guadiana rivers, located at 605 m a.s.l. in central Spain (Fig. 1). The present-day system is fed by sulphated waters from the Gígüela River, but since 1983 the Guadiana River has supplied carbonated surface and groundwaters. The climate is temperate Mediterranean with dry and hot summers and cold winters. Hydrologically, the system is controlled by high seasonal rainfall. In a typical year, the wetland is flooded for seven months, being almost dry for the rest of the year.

In this paper we present palynological and lithological data from the core Cigüela 4-2 located in Las Tablas de Daimiel National Park (Fig. 1). Four other pollen sequences obtained from this area have been investigated previously. The first of these is Daimiel II, covering about the last 3200 years (3190 ± 70 B.P.; 1628–1305 B.C.) although information is limited by the low quantity of pollen grains in almost all samples (Menéndez-Amor and Florschütz 1968) and the absence of pollen from several sections. The second, Castillo de Calatrava, covers only about the last 6300 B.P. (6240 ± 190 B.P.; 5536–4727 B.C.; García-Antón et al. 1986). The third, core CC-17, provides palaeoclimatic information since Late-glacial/Holocene transition (Dorado-Valiño et al. 1999, 2002) and the fourth, core TD, corresponds to the Last Glacial Cycle (Valdeolmillos et al. 2003).

Material and methods

During December 2002, a coring campaign was carried out in the Las Tablas National Park yielding 40 cores taken from 15 coring sites. Five master points were selected and in each one two “dry” rotation cores (9 cm in diameter) were drilled and two manual PVC cores (11 cm in diameter, 1 m in length) were made to recover the uppermost part. As result we obtained a composite core for visual study and sampling (one of which is core Cigüela 4-2, Fig. 1). Once in the laboratory, the cores were opened, photographed and the stratigraphy recorded. With these data and the scanned photographs, a detailed stratigraphical section (scale 1:1) was prepared for use during sampling. Sampling was performed with a guillotine of our own design adapted to the shape of our cores. Samples were taken contiguously with an average thickness of 0.7 cm, each sample being split for the different analyses. After sampling a new stratigraphical section (Fig. 2) was constructed with lineally corrected

Fig. 2 Core Cigiuela 4-2. Facies, vegetation-related geochemical parameters and dated samples



depths and sample thicknesses (correcting for the mechanical compaction produced by coring).

Samples for geochemistry were sent to ALS Chemex laboratories in Vancouver (Canada) where they were analysed for total carbon content (measured with a Leco[®] SC-444DR carbon and sulphur analyser), inorganic carbon (measured by CO₂ coulometry with an UIC[®] CM140 Total Inorganic Carbon Analyzer) and organic carbon (calculated as the difference between total and inorganic C). N was determined as extractable N (NH₄, using a Technicon Autoanalyser[®], and NO₃, colorimetrically using the CTA method) at ALS Environ Labs (Vancouver, Canada).

AMS ¹⁴C dating of samples was done at the GADAM Centre (Gliwice, Poland) and ²³⁹Pu, ²⁴⁰Pu and ²¹⁰Po at the Centro de Investigaciones Medioambientales (CIEMAT, Madrid, Spain). Bulk samples were used as there was no evidence of contamination and all the C sources were

biological (vegetal remains and bio-induced carbonates). The selection of samples was determined by their stratigraphical position and lack of evidence of contamination. The AMS dates were calibrated with CALIB v.4.4.2 (Stuiver and Reimer 1993; Stuiver et al. 2003) using the calibration datasets cited in Table 1. Additionally, the ²¹⁰Po and ²³⁹, ²⁴⁰Pu profiles confirmed that there was no evidence of mixing of sediment or of hiatuses in the uppermost 20 cm, as was also indicated from visual inspection of the cores. An age-depth model was constructed from these data and was tested against known (documentary) events recognisable in the sediments. From this a final recalibrated model was obtained. A good indication of the quality of the material was the fact that only minor adjustments were made to the age-depth model and these were probably related to the linear nature of the thickness correction method that does not allow for lack of homogeneity in the lithology.

Table 1 Radiocarbon data. Calibration was performed with CALIB v.4.4.2 (Stuiver and Reimer 1993; Stuiver et al. 2003) using calibration data from Stuiver and Braziunas (1993), Stuiver et al. (1998a, b) and McCormac et al. (2002)

Lab. code	Sample	Depth (m)	¹⁴ C age (yr B.P.)	cal ages, 2σ (cal B.P.)	probability distribution
GdA-308	4-2-79	0.56	521 ± 37	A.D. 1321-1351 (599-629)	0.169
				A.D. 1389-1445 (505-561)	0.831
GdA-309	4-2-101	0.73	1098 ± 39	A.D. 784-787 (1163-1166)	0.003
				A.D. 833-836 (1114-1117)	0.003
				A.D. 877-1020 (930-1073)	0.994
GdA-306	4-2-132	0.99	2699 ± 53	972-957 B.C. (2906-2921)	0.028
				939-795 B.C. (2744-2888)	0.972

Data analyses were performed using R statistical software (R Development Core Team 2005).

Samples were prepared for pollen analysis using standard palynological methods (Faegri et al. 1989; Moore et al. 1991). A total terrestrial pollen sum (>250) was used in calculating percentages. The pollen percentages for each taxon are based on the main pollen sum that excludes aquatic plants and pteridophyte spores because of their over-representation in these deposits. Spores and aquatic pollen percentages were obtained from the total sum (pollen + spores). Pollen data are presented as the relative pollen frequency of each taxon in the pollen diagram (Fig. 3) prepared using the TILIA[®] and TILIA-GRAPH[®] (© Eric C. Grimm) computer programs. The representation of all taxa in the pollen diagram has been exaggerated (shading) twice. Local pollen assemblage zones in the sense of Reille (1990) were recognised on the basis of changes in the representation of at least two ecologically significant taxa (Watts 1973; Reille 1990).

Vegetation indexes were also constructed as they give guidance on the environmental variables (Fig. 4). Thus, the arboreal vs. non-arboreal pollen (AP/NAP) is used as a key for moisture. The ratio of evergreen *Quercus* to the sum of *Pinus* and *Artemisia* is considered indicative of the temperature. Finally, the ratio of hydrophytes to hygrophylles reflects the extent of the open area of the water body (the area not occupied by aquatic-emergent vegetation).

Three main facies were identified by visual inspection of the cores (Fig. 2): (1) gypsum-rich siliciclastic muds and sands, changing at 88.5 cm (corrected depth) to (2) organic muds, and from 74.5 cm upwards, (3) alternation of Charophyte layers with organic matter laminae (of vegetal origin). The Principal Component Analysis of geochemical and mineralogical data confirmed this division by coincidence of the main PCs with sample visual facies (Santisteban et al. 2004a). These analyses show the strong link between vegetation and C (organic C is de-

rived from terrestrial and aquatic vegetation while inorganic C is derived from Charophyceae oospores and stems; Santisteban et al. 2004b). Also N, more abundant in purely aquatic vegetation, is an indicative element of aquatic productivity (Fig. 2). Thus, the relation between inorganic and organic C gives an indication of the relationship between the aquatic macroalgae and the remaining vegetation while the N/organic C ratio gives clues about the ratio of aquatic to emerged vegetation.

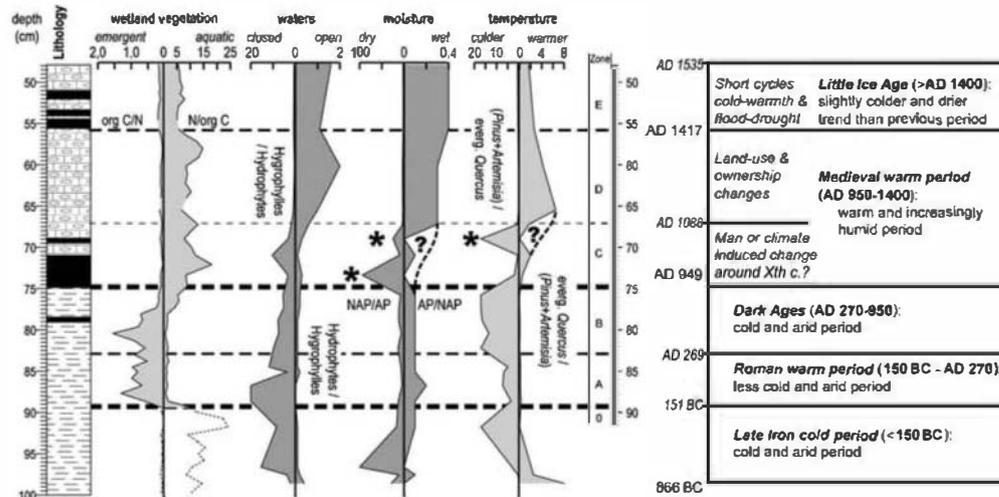
Results

The pollen record can be split in six zones representing different stages of the vegetal cover in the Las Tablas de Daimiel during late Holocene times (Fig. 3).

Zone 0 (100–89.5 cm) shows a landscape dominated by grasslands. The taxa best represented are Asteraceae (liguliflorae and tubuliflorae) and Poaceae followed by *Artemisia*, Brassicaceae, Chenopodiaceae-Amaranthaceae, *Saxifraga* and *Rumex*. The next group, Shrubs, is dominated by an association of *Calluna*, *Juniperus*, *Pistacia* and Rosaceae, replaced by Ericaceae towards the top. Trees are represented by *Pinus*, which is scarce, and minor quantities of evergreen *Quercus*, which replaces *Ulmus*. Aquatic taxa are characterised by the relative abundance of *Typha* monada and Cyperaceae together with the presence of *Potamogeton*, *Typha* tetraeda and spores. Sediments are represented by gypsum-rich muds with very low contents of inorganic and organic C and N.

Zone A (89.5–83 cm) shows an increase in arboreal taxa, mainly *Pinus* and some evergreen *Quercus* followed by *Ulmus* and the presence of Oleaceae. Shrubs are represented by Ericaceae and Cistaceae; there is a minor event that shows a temporary replacement of Cistaceae by *Juniperus*, *Calluna* and *Pistacia*. Grassland communities are still dominated by Asteraceae (tubuliflorae and liguliflorae)

Fig. 4 Vegetation and geochemical indexes related to environmental variables (*: out-of-sequence values; ? : anomalous data, possible human interference) and climatic periods



and Poaceae, but there is an evident upwards trend in Chenopodiaceae-Amaranthaceae together with Poaceae. Aquatic taxa show the major changes. This zone opens with a noticeable increase in *Typha monada* together with Cyperaceae and towards the top this association grows with the incorporation of Ranunculaceae, *Polygonum* and *Potamogeton* and the spore content increases. This zone marks the base of the organic-rich muds, which is characterised by a sudden increase in organic C, a decrease in gypsum, and low inorganic C and N content.

Zone B (83–75 cm) shows a reduction in arboreal pollen, mainly recorded in the drop of evergreen *Quercus*. *Pinus* is still the main taxon and there is a presence of *Tilia* and *Alnus*. Shrubs increase slightly; their main association is Ericaceae and Cistaceae together with *Juniperus* (to the bottom) and *Pistacia* and Rosaceae (towards the top). Herbs are still the main group but the composition of the association changes. Asteraceae liguliflorae values fall suddenly and Chenopodiaceae-Amaranthaceae, Poaceae and Asteraceae tubuliflorae increase. *Artemisia* values are still high but fluctuating. The aquatic taxa show the highest values in *Typha monada* and there is an increase in Cyperaceae, while Ranunculaceae, *Polygonum*, *Potamogeton* and spores content increase. This zone covers the upper part of the organic-rich muds, characterised by a progressive increase in Charophyceae (inorganic C) and a slight increase in N.

Zone C (75–67 cm) starts with a sudden drop in content of arboreal and shrub pollen. Trees recover slowly with a clear increase in evergreen *Quercus* accompanied by *Pinus* (which never reaches its previous values), *Tamarix* and minor amounts of Oleaceae. Other arboreal taxa present are *Ulmus*, *Betula* and *Fraxinus*. Shrubs are dominated by Ericaceae together with *Juniperus* and *Pistacia* and minor quantities of Rosaceae, with a very low component of *Calluna* and Cistaceae. Main features of the grassland community are an important rise in Chenopodiaceae-Amaranthaceae and Poaceae and a decrease in Asteraceae (the liguliflorae forms almost disappear), minimum values of *Artemisia*, an abrupt increase in *Plantago*, which shows its maximum values, and an increase in nitrophyllous taxa (*Rumex*, *Sanguisorba minor*, *Urtica*). Of the aquatic

taxa, Cyperaceae reaches its maximum values while *Typha monada* decreases, Ranunculaceae also shows a maximum and is present together with *Polygonum*, *Lemna* and a few Nymphaeaceae; trilete spore values are also the highest. This zone comprises the basal portion of the charophyte mud and sands, which are characterised by high and similar values of inorganic and organic C, plus an increase in the N/organic C ratio (related to an N increase in the sediments) and in the average values of the inorganic/organic C ratio.

Zone D (67–57 cm) records the rapid spread of evergreen *Quercus* along with *Tamarix* and *Alnus* and the practical disappearance of *Pinus*. Ericaceae and *Juniperus* (which reaches its maximum content) dominate the shrubs, followed by *Pistacia* and traces of Cistaceae, while *Calluna* and Rosaceae disappear. The main change in the grassland community is the drop in Asteraceae (tubuliflorae and liguliflorae) and Chenopodiaceae-Amaranthaceae, which almost disappears, and the decrease in Poaceae and *Plantago* along with the increase in *Artemisia*, *Rumex* and Fabaceae, and the presence of Apiaceae, Brassicaceae, Liliaceae, Campanulaceae and *Sanguisorba minor*. The aquatic taxa suffer major changes as there is a sudden reduction in *Typha monada*, *Typha tetra* is absent, Cyperaceae decreases and Ranunculaceae disappears. On the other hand, *Polygonum* rises and monolet spores show an abrupt increase (reaching their maximum values). This section of the charophyte muds and sands is characterised by higher values of the ratio inorganic/organic C, while the N/organic C ratio shows values similar to the previous zone.

Zone E (57–48 cm) reintroduces *Pinus*, along with sparse *Ulmus* and Oleaceae, in the arboreal assemblage that is composed mainly of evergreen *Quercus*, with *Tamarix* and some *Alnus*. Shrubs show a slight decrease in Ericaceae and, more noticeably, in *Juniperus*, while *Pistacia* shows similar values to zone D and Rosaceae reappears. The grassland assemblage is similar to that of zone D. Poaceae decrease and Chenopodiaceae-Amaranthaceae and Asteraceae (liguliflorae disappears) are mere present while *Rumex* is the main taxon. However there are increases in *Artemisia*, *Plantago*, Brassicaceae, Scrophulariaceae and Solanaceae. In the aquatic domain,

Typha monada recovers slightly but *Polygonum* is the more representative taxon together with Cyperaceae. Monolet spores decrease noticeably, but not drastically. This is the uppermost part of the charophyte muds and sand studied in this paper and the main change in the composition of the sediment is the higher and fluctuating values of organic C and N and the decrease in the N/organic C ratio.

Discussion

The sequence starts, Zone 0 (around 2800–2100 cal B.P. or < 150 B.C.), with open landscapes, as it is revealed by the very low content of C and N, dominated by grasslands with sparse trees (*Pinus*) and shrubs (*Calluna*). Halophyte taxa, together with Asteraceae and the low values of the arboreal/non-arboreal pollen (AP/NAP) ratio, reveal arid to semiarid conditions and saline soils (Figs. 3 and 4). Similar features have been interpreted as arid conditions in the pollen record from Castillo de Calatrava (García-Antón et al. 1986) and Daimiel II (Menéndez-Amor and Florschütz 1968), where *Artemisia* and Chenopodiaceae-Amaranthaceae increase simultaneously. This arid phase has also been identified in Tigalmamine (Atlas Range, Morocco) around 2500 to 2000 cal B.P. (Roberts et al. 1994) and in the Ebro Basin (Spain) around 2500 years ago using geomorphological (Gutiérrez-Elorza and Peña-Monné 1998) and other criteria (Davis 1994). It has also been recognised by an arboreal (*Quercus*, *Pinus* and *Salix*) retreat in Huelva (SW Spain) around 2200 B.P. (2220 ± 80 B.P.; 404–54 B.C.) (Menéndez-Amor and Florschütz 1964) and the beginning of aeolian deposits (dunes) and changes in the wind direction both in SW (Borja et al. 1999) and SE (Goy et al. 1998) Spain around 2700 cal B.P.

Despite such arid conditions, groundwaters were near the surface, as revealed by the association *Typha*-Cyperaceae and the nitrophyllous taxa, and there were short wet periods that permitted the development of small ponds colonised by aquatic communities composed of *Potamogeton* and algae.

Despite the low presence of arboreal taxa, the ratio of evergreen *Quercus* to *Pinus* and *Artemisia* seems to indicate a gentle cooling trend and temperatures a little colder than the succeeding episode (Fig. 4).

This event could correspond to the change in solar activity described by van Geel et al. (1999), identified in many places around the world. In Spain it has been identified in the northwest by Desprat et al. (2003) and in the northeast by Gutiérrez-Elorza and Peña Monné (1998). In the Andean region van Geel et al. (2000) recognised it through the analysis of the palaeolimnological, palaeobotanical and glacial records. In raised bogs of England and Ireland, Barber et al. (2003) identified a climatic deterioration around 2700 cal B.P. Also, through analysis of human settlements, colluvial, lake and fluvial deposits, Zolitschka et al. (2003) identified a similar climatic change around the Bronze Age/Iron Age transition.

Recovery of the arboreal taxa in Zone A (2100–1680 cal B.P., 150 B.C.–A.D. 270), the higher diversity of the aquatic assemblage and the decrease in *Calluna* together with the

increase in organic C (local vegetation-derived organic matter), suggest wetter conditions and a rise of the seasonal water table that allowed the development of wet meadows. This is confirmed by the N/org. C ratio, which indicates emerged vegetation as the main source for the organic matter. The AP/NAP ratio suggests an increase in rainfall although arid conditions still remain. The increase in evergreen *Quercus* as opposed to the *Pinus* and *Artemisia* sum (Fig. 4) reveals slightly higher temperatures. This improvement in the climate has been also identified in NW Spain by Desprat et al. (2003), who assigned it to the Roman Warm Period, but these authors extend this phase until A.D. 450. Roos-Barraclough et al. (2004) identified a similar period (B.C. 40–A.D. 350) in peat humification profiles in Switzerland. McDermott (2004) presents the isotopic record of a stalagmite in southern Ireland where he identifies this period. Also Jiang et al. (2005) recognise this period in a similar time slice from reconstruction of the sea surface temperature off Northern Iceland.

At the start of Zone B (1680–1000 cal B.P., A.D. 270–A.D. 950), the rise of the water table allowed the existence of relatively stable water bodies as evidenced by the progressive rise in Charophyceae (inorganic C), aquatic biomass (rising N/organic C ratio) and the increase in Poaceae, Cyperaceae, *Typha*, Ranunculaceae, *Polygonum*, *Potamogeton* and spores (Fig. 3). However the increase in Chenopodiaceae-Amaranthaceae (which reveals the existence of saline soils in the surroundings) together with the almost imperceptible drop of the AP/NAP ratio point to slightly more arid conditions (Fig. 4). The drop in evergreen *Quercus* together with the constant values of *Pinus* and *Artemisia* reveal a climatic deterioration that could be related to slightly lower temperatures assigned by Desprat et al. (2003) to the Dark Ages. Riera et al. (2004) also identified similar conditions, an increase in salinity and more arid conditions, in lakes in NE Spain during their stage *viii* (A.D. 160–820). Roos-Barraclough et al. (2004) also found climatic deterioration centred on A.D. 550 in their Swiss peat humification profiles.

Zone C (1000–860 cal B.P., A.D. 950–1090) data show an important anomaly as arboreal and shrub taxa disappear to the bottom of the zone to recover later and drop again to the top (Figs. 3 and 4). Human influence (Riera et al. 2004) or climatic causes (Desprat et al. 2003) have been invoked to explain similar changes in other areas.

In terms of anthropic influence, the area was entered by Muslims in around the 8th century and was re-conquered by the Christians in late 11th century. The Muslims introduced water mills and herding so clearance for pasture is a possible explanation for the extremely low values of arboreal and shrub pollen, the increase in *Plantago*, Boraginaceae, Brassicaceae and Lamiaceae and the presence of Oleaceae and Solanaceae. Also, the fighting that occurred towards the end of this period can explain the “drop” in arboreal and pasture taxa and the relative increase in shrubs at the top of this zone (Fig. 3).

However, this is the period of maximum diversity in the aquatic environment, coinciding with high values of inorganic C and of the N/organic C ratio (aquatic productivity),

reflecting an increase in water depth (Fig. 4). The increase in riparian taxa (Poaceae, Cyperaceae and *Tamarix*) supports this water level rise and, together with the presence of *Betula* and *Fraxinus* and the decrease in Asteraceae and Chenopodiaceae-Amaranthaceae, implies a gradual shift to wetter conditions. Also, the higher ratio of evergreen *Quercus* to *Pinus* and *Artemisia*, as seen towards the bottom, may reveal a warming trend that would reach its highest point in Zone D (Fig. 4).

As a hypothesis, this zone records climatic control of the vegetation plus a low intensity of anthropic action.

In Zone D (860–530 cal B.P., A.D. 1090–1400), the noticeable increase in evergreen *Quercus*, both in percentage and in absolute numbers, together with an increase in pasture and nitrophyllous taxa reveal a more densely vegetated landscape very similar to the present Spanish “dehesas” (Mediterranean forest with *Quercus* and grasslands used for herding; Fig. 3).

However there are also evident changes in the aquatic environment. The drop in emergent vegetation (Cyperaceae, *Typha* and Poaceae), the sudden increase in monolete spores, the low diversity in the aquatic taxa and the high inorganic C (Charophyceae) and N/organic C ratio values reveal the expansion of a very productive aquatic environment with a high nutrient load (Fig. 4) that could lead to frequent eutrophication episodes and algal blooms.

These changes are consistent with the warmer and wetter conditions revealed by the increase in the evergreen *Quercus* to *Pinus* and *Artemisia* and AP/NAP ratios (Fig. 4), similar to those identified as being typically Mediterranean by Dorado et al. (2002). Comparable changes are described by Desprat et al. (2003), Julià et al. (1998) and Riera et al. (2004) in NW, central and NE Spain, and these authors recognise this period as the “Medieval Warm Period” (Lamb 1977). This episode is identified at about a similar date all around the world (China: Chu et al. 2002; Arabia: Fleitmann et al. 2004; Africa: Filippi and Talbot 2005; Iceland: Doner 2003; central Europe: Filippi et al. 1999; New Guinea: Haberle and David 2004; USA: Cabaniss Pederson et al. 2005; Argentina: Mauquoy et al. 2004; etc.) and despite particular features, it is characterised by lower climatic variability than other periods.

After A.D. 1400, Zone E, the landscape was very similar to before, but the progressive rise in *Pinus* and *Artemisia* indicates lower temperatures (Fig. 3), which are also indicated by fewer eutrophication episodes (monolete spores) and higher accumulation rates of organic matter (sudden increase in organic C and decrease of the N/organic C ratio). Despite this the period was still wet (Fig. 4, AP/NAP ratio) and the water table rose. The higher, fluctuating values of organic C (Fig. 3) and the presence of eutrophication episodes indicate frequent alternation of cold and warm periods. These characteristics suggest that this period represents the start of the “Little Ice Age” (Lamb 1977), also identified by Desprat et al. (2003), Julià et al. (1998), Gutiérrez-Elorza and Peña Monné (1998) and Riera et al. (2004) in other records in Spain. This period is consistently found in the sedimentary record and it is characterised by

a higher variability in climatic conditions (Adhikari and Kumon 2001; Barber et al. 2003; Lamb et al. 2003; Valero-Garcés et al. 2003; Cabaniss Pederson et al. 2005; Cohen et al. 2005; Dalton et al. 2005; etc.).

Conclusion

Despite many studies that have pointed to the sun-climate relation (van Geel et al. 1999; Cooper et al. 2000; Dean 2000; Bond et al. 2001; Mauquoy et al. 2002; Labitzke and Matthes 2003; Gimeno et al. 2003; Blaauw et al. 2004; etc.) and the validity of the classical climatic oscillations described for the Late Holocene (Medieval Warm Period, Little Ice Age, etc.) there is a research line that suggests the non-global signature of these periods (IPCC 2001; Jones and Mann 2004).

Looking at Fig. 1 in Mann et al. (1998), the spatial distribution of the proxy series can be seen, allowing for the scarcity of information coming from Mediterranean area. More precisely, in the case of Spain, this information is restricted to two tree-ring series coming from mountain areas.

The best way to solve this controversy would be to increase the number of high-resolution records covering the last millennia and to increase the spatial coverage of these records.

The present paper shows that the record of those Late Holocene climate oscillations identified by other authors in NE and NW Spain can be identified in the Iberian Peninsula interior, and in environments not used until now as high-resolution climatic records.

Despite human impact, which most authors agree adds a signal to the pollen record from A.D. 1000, the use of the pollen record together with geochemical parameters permits the identification of five climatic stages for the last 3000 years. These are a cold and arid phase during the Subatlantic (Late Iron Cold Period, < B.C. 150), a warmer and wetter phase (Roman Warm period, B.C. 150–A.D. 270), a new colder and drier period coinciding with the Dark Ages (A.D. 270–900), the warmer and wetter Medieval Warm Period (A.D. 900–1400), and finally a cooling phase (Little Ice Age, >A.D. 1400).

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