

Ancient pine forest on inland dunes in the Spanish northern meseta

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Abstract

We present a new stratigraphic (pollen and nonpollen microfossils and charcoal particle) sequence with five AMS dates, covering about the last 9000 yr, of a core collected from the Spanish northern meseta, one of the territories of the Iberian Peninsula for which little paleobotanical information is available. The results support the hypothesis of the permanence of the pine forests, in more or less pure masses or large timber stands, during the Holocene in some Iberian continental zones. The typical substitution in postglacial dynamics of heliophyllous species, such as pines or Cupressaceae, by broadleaf trees did not occur in this inland region. Presumably, factors linked to the substrate, in this case very deep sand dunes covering vast areas, may have contributed to the scarce local competitiveness of the broadleaf trees, which would account for the hegemony of pines in this region. Based on the dynamics of aquatic plants and nonpollen microfossils, an initial phase previous to 7500 ¹⁴C yr B.P. of high levels in the lake can be identified by high percentages of hydrophytes. A progressive increase in helophytes and the gradual infilling of the lake over the last 5000 yr appear to indicate a phase of aridification similar to those established for the western Mediterranean. Study of charcoal particles, more abundant in the last 2500 yr, has given rise to certain hypotheses regarding the incidence of recurring fires of a local or regional nature.

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Introduction

There is very little available information on the dynamics of Holocene vegetation in territories like the Iberian mesetas for two fundamental reasons: (1) these areas are currently subjected to a high degree of human disturbance, with little remaining of the natural vegetation and (2) the lack of paleopollen deposits in these mesetas (Martínez Atienza, 1999) has hindered study of the history of the vegetation.

Relative to the first point, the interpretation of the pine forests occupying this region has traditionally been controversial due to the fact that management of the pine forests has impeded an elucidation of their naturalness. Secular exploitation, for resin tapping and production of pine kernels, has given them an artificial appearance. Reforestation has often been employed in order to extend the area of the forests, and the masses have become homogenous through selective logging. Doubts regarding the naturalness of these pine forests became widespread among botanists when, in Spain, they assumed the evolutive ideas of Clements (1939) regarding the climax. Landscapes began to be interpreted in terms of dynamics related to the theory of ecological succession and more importance was gradually given to the models of potential vegetation.

Willkomm (1852) interpreted the large open spaces of the inland peninsula as natural treeless steppes, although

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he described the large forests of *Pinus pinea* to the south of the river Duero from Valladolid to the Central System (Willkomm, 1896). Reyes Prosper (1915), in his treatise on the steppes, also defended Willkomm's naturalist interpretation. Huguet del Villar (1925), however, disagreed, linking them to the decisive degradation of the inland Holm oak forests. Along these same lines, he considered the frequent remains of existing Holm oaks in the area to be indicators of the native vegetation. Font Quer (1954), however, disagreed with this interpretation, opting for the autochthonous nature of the two pines characteristic of the vegetation of the large sand dune fields of Old Castille. His arguments are based on the preference of these species for sandy, deep substrates, in the case of the Stone pine, and slightly acidic ones for the Cluster pine. Ceballos (1938) developed a regression model of Spanish forest vegetation that attributed to the pines a secondary role in the dynamics. This model was subsequently well developed under the auspices of the school of phytosociology and inspired the outline of series of vegetation proposed by Rivas Martínez (1987) that does not recognize any Mediterranean pine forest as potential vegetation for this territory.

With regard to the second aforementioned aspect, although the mountains surrounding the northern meseta have been well studied, there are hardly any pollen deposits in the lowlands. Noteworthy among these are Calatañazor (Menéndez Amor, 1975) and Quintana Redonda (García

Antón et al., 1995) far to the east, at the foot of the Iberian System, and in the center of the meseta, the most recent one, Espinosa de Cerrato (Franco Múgica et al., 2001), the first high-resolution long sequence with seven dates covering the whole Holocene.

The sequence we present here is uniquely situated in the center-south of the northern meseta, in a region known as Tierra de Pinares (due to the historic importance of its forest formations), dominated by *Pinus pinaster* and *P. pinea*. The interest of a pollen analysis in this area, apart from adding to the little information available on this vast territory, lies in settling an old controversy in relation to whether or not the character of these pines is natural.

Study area

Localization and geologic framework

The El Carrizal lake is located close to the village of Cuéllar (Segovia province), at an altitude of 860 m (geographical coordinates 4°08'49.1"W, 41°19'12.1"N UTM 30 N 404000, 4575000), in the region known as Tierra de Pinares (Fig. 1). Tierra de Pinares takes up part of the provinces of Segovia, Valladolid, and Ávila, in the southern strip of the northern meseta. It stretches as far as the northern piedmont of the Guadarrama mountains

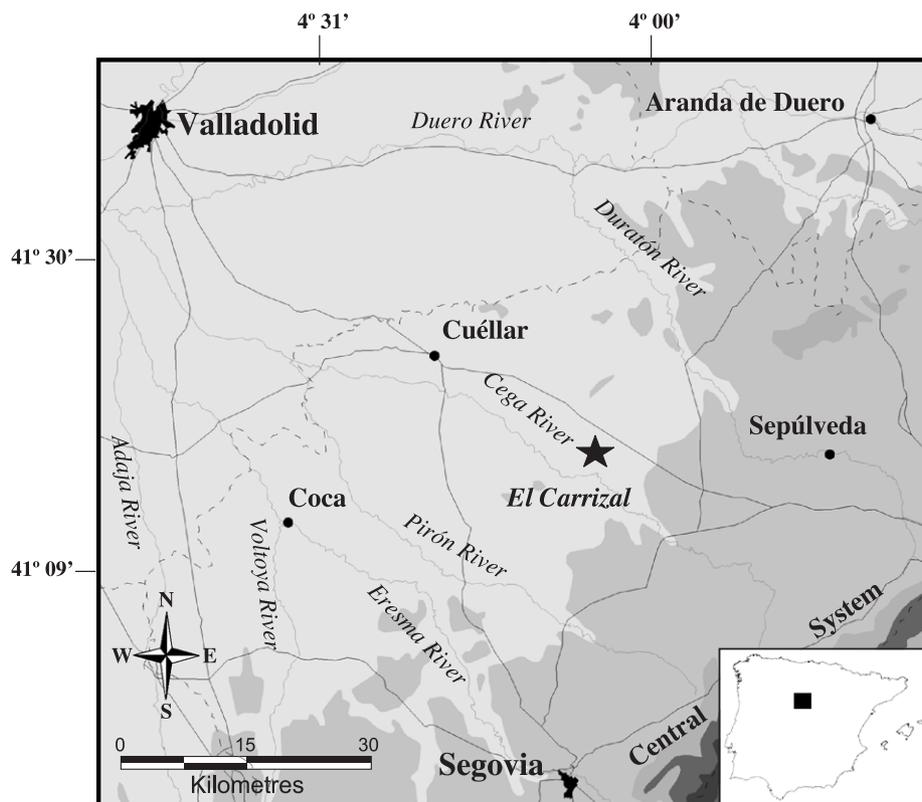


Figure 1. Location map of El Carrizal lake site. The altitude in graded grey ranges from 800 to 1600 m asl with 200-m intervals.

(Central System) in a territory with few elevation differences, between altitudes of 700 and 900 m, and takes in an area of around 7500 km². The area is delimited to the west by the river Adaja and to the east by the river Duratón, and above all occupies the basins of the rivers Voltoya, Eresma, Pirón, and Cega.

Geologically, the El Carrizal lake is situated on sediments that fill in the depression of the Duero river in its southern section. The nature of these sediments is sandy, and their thickness varies in depth from 2 or 3 m to over 50. Beneath the stratum of sands lies the contact between the Paleozoic base rock and the Guadarrama mountains and the Tertiary loams and limestones in the southern part of the depression. This is why in the Cuéllar region (where the thickness of the sandy stratum greatly decreases), small areas of scattered rocky outcrops appear that are of a different nature from the point of view of their chemical composition (acidic or carbonated); as we will see, all of this plays an important role in the definition of the natural vegetation of the area.

The intense accumulation of sands in this sector to the north of the Guadarrama mountains is the consequence of several factors. Traditionally, deposits of eolic origin were considered to be generated by alteration of the Guadarrama granites (Hernández Pacheco, 1923), but the outcropping of Cretaceous nuclei in several places to the south of the province of Segovia probably constitutes the main source of the stratum of sands in this part of Segovia. These Cretaceous deposits are topped by compact Senonian

limestones, but at lower stratigraphic levels there are thick layers of sands from the Albian age. When the compact levels of the upper limestones are broken down by erosion, the sands are released and begin to drift throughout the region, transported by the waters from the regional drainage system (Calonge Cano, 1987; Serrano Cañadas and Calonge Cano, 2001). These processes can therefore be of ancient chronological origin, given that the morphogenesis related to the Cretaceous outcrops occurs throughout the whole Neogene. In the long period of time that subsequently transpired, the space currently occupied by the river Duero underwent big changes, from an endorheic depression to a system draining toward the Atlantic. Throughout this whole period, the sands were mobilized, first accumulating and then being transported by the winds and waters. It is at present in the valleys where these sands reach their maximum thicknesses and are then gradually displaced toward the north by the southern tributaries of the river Duero (primarily the Cega and the Eresma). This river serves as an active drainage system, whereas their Albian source is still active in the Cretaceous outcrops situated further to the south. This is probably the reason for the scarcity of sandy substrates in the Duero basin to the north of the river.

Some of the sand formations previously constituted mobile dune systems, but today the area of pine forests throughout the whole region stabilizes the sandy fraction susceptible to being carried off by the winds.

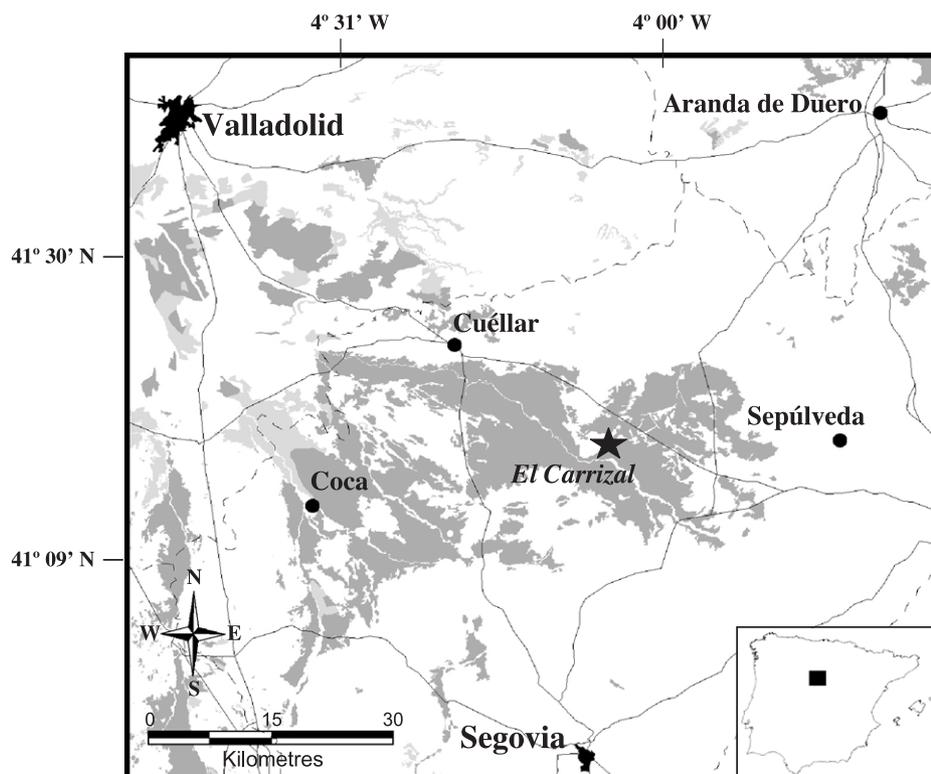


Figure 2. Modern distribution of the forest formations dominated by *Pinus* in the Tierra de Pinares region. Light grey represents *P. pinea* and dark grey shows *P. pinaster*.

Table 1
El Carrizal lake: radiocarbon dates

Laboratory number	Depth (cm)	Radiocarbon date (^{14}C yr B.P.)	Calibrated age 2σ (calendar yr B.P.)
GrA-18606	39–40	1605 \pm 45	1388–1573
GrA-18607	94–96	4000 \pm 50	4346–4576
Beta-146009	150–153	8560 \pm 50	9471–9602
GrA-18608	180–184	8610 \pm 60	9487–9749
GrA-23078	220–224	8670 \pm 50	9534–9777

All samples are standard AMS on bulk sediment. Calibrations were carried out following CALIB 4.4 (Stuiver et al., 1998).

El Carrizal lake is located in a section of watershed relatively close to the river Cega that flows at a much lower topographic elevation (Fig. 1). This situation is quite infrequent in lake systems and is due to the immaturity of the regional hydrographic network, which has not become sufficiently imbedded to drain the nearby lakes suspended at higher elevations (Calonge Cano, 1986, 1989).

El Carrizal is a persistent, natural lake, originated by the exit of long distance or regional subterranean flows. It is presently affected by the exploitation of the aquifer, the direct extraction of water by pumping and turf extraction with machinery to be sold as horticultural peat. The lake morphometry shows that the maximum surface is 11 ha, the largest perimeter is around 2 km, top width 0.24 km, maximum depth 1.5 m, and uppermost length of the flooding area is about 1 km. Currently, there are only waters in the eastern part of the basin.

Climate

The region's climate is Continental–Mediterranean with four drought months from June to September. Mean annual temperature and rainfall data from the meteorological station at Cuéllar (Segovia) are 11.2°C and 610 mm, respectively. Mean minimum temperature of the coldest month is -2.2°C

and the mean maximum of the warmest month is 30.5°C. Wind intensity is about 15 km/h, with a predominant S–NE direction. According to Rivas Martínez's Bioclimatic Systematics, these parameters place the site within the dry, supramediterranean belt (Rivas Martínez et al., 2002). Furthermore, according to the Phytoclimatic Atlas of Spain (Allué Andrade, 1990), the climate is continental nemoromediterranean and particularly cold in winter (type VI(IV)₁).

The vegetation landscape of Tierra de Pinares

The vegetation landscape of the region known as Tierra de Pinares is true to its name. It is dominated by conifer formations mainly comprising Cluster pines (*P. pinaster*) and Stone pines (*P. pinea*) (Fig. 2). On the banks of the river Cega, the Spanish Black pine (*P. nigra*) and even the Scots pine (*P. sylvestris*) can be found, these species apparently being relictic. All these formations of conifers are set on the sandy substrates that, forming part of inland dune systems, make the region unique. Among these, occupying the Tertiary outcrops of a carbonate nature, are Holm oak forests (*Quercus ilex* subspecies *ballota*) or Gall oak forests (*Quercus faginea* subspecies *faginea*) that give rise to a mosaic-like landscape. In some places, on the damper sand dunes, scattered stands of *Quercus pyrenaica* can also be found.

In general, the deciduous trees occupy the hills and Tertiary residual reliefs, with or without a cover of Messinian, whereas the pines grow in the Plio-Quaternary sandy cover. This is often more frequent at the bottoms of the valleys, which mainly respond to the fluvial transport of the sands; this is why a branched-out landscape of pine forests is generated along the course of the rivers, these converging toward the Duero (Fig. 2).

Rivas Martínez (1987) included the area corresponding to Tierra de Pinares in the supra-mesomediterranean,

Table 2
El Carrizal lake: core lithostratigraphy

Unit	Depth (cm)	Color	Troels-Smith (1955) notation	Description
1	0–20	Dark brown	Ld ⁰ 2Dh2	Nonhumified coarse limus and herbaceous detritus
2	20–23	Light brown	Ld ³ 2Dh2	Humified limus and herbaceous detritus
3	23–28	Dark brown	Ld ⁰ 2Dh2	Nonhumified coarse limus and herbaceous detritus
4	28–33	Light brown	Ld ³ 2Dh2	Humified limus and herbaceous detritus
5	33–58	Dark brown	Ld ⁰ 2Dh2	Nonhumified coarse limus and herbaceous detritus
6	58–84	Light brown	Ld ³ 2Dh2	Humified limus and herbaceous detritus
7	84–120	Brown	Ld ² 2Dh2	Moderately humified limus and herbaceous detritus
8	120–134	Dark brown	Ld ⁰ 2Dh2	Nonhumified coarse limus and herbaceous detritus
9	134–139	Fawn	Ld ¹ 2Dh2	Moderately humified limus and herbaceous detritus
10	139–154	Dark brown	Ld ⁰ 2Dh2	Nonhumified coarse limus and herbaceous detritus
11	154–166	Fawn	Ld ¹ 2Dh2	Moderately humified limus and herbaceous detritus
12	166–180	Greyish	Ld3As1	Limus detritus and clay
13	180–200	Fawn	Ld3As1Gmin+ test mol	Limus detritus with clay, fine sand, and mollusc shells
14	200–240	Fawn	Ld3As1Gmaj+	Limus detritus with clay and coarse sand
15	240–340	Greenish	As3Ld1	Clay

Notations follow Troels-Smith (1955).

El Carrizal, Segovia (Spain), 860 m

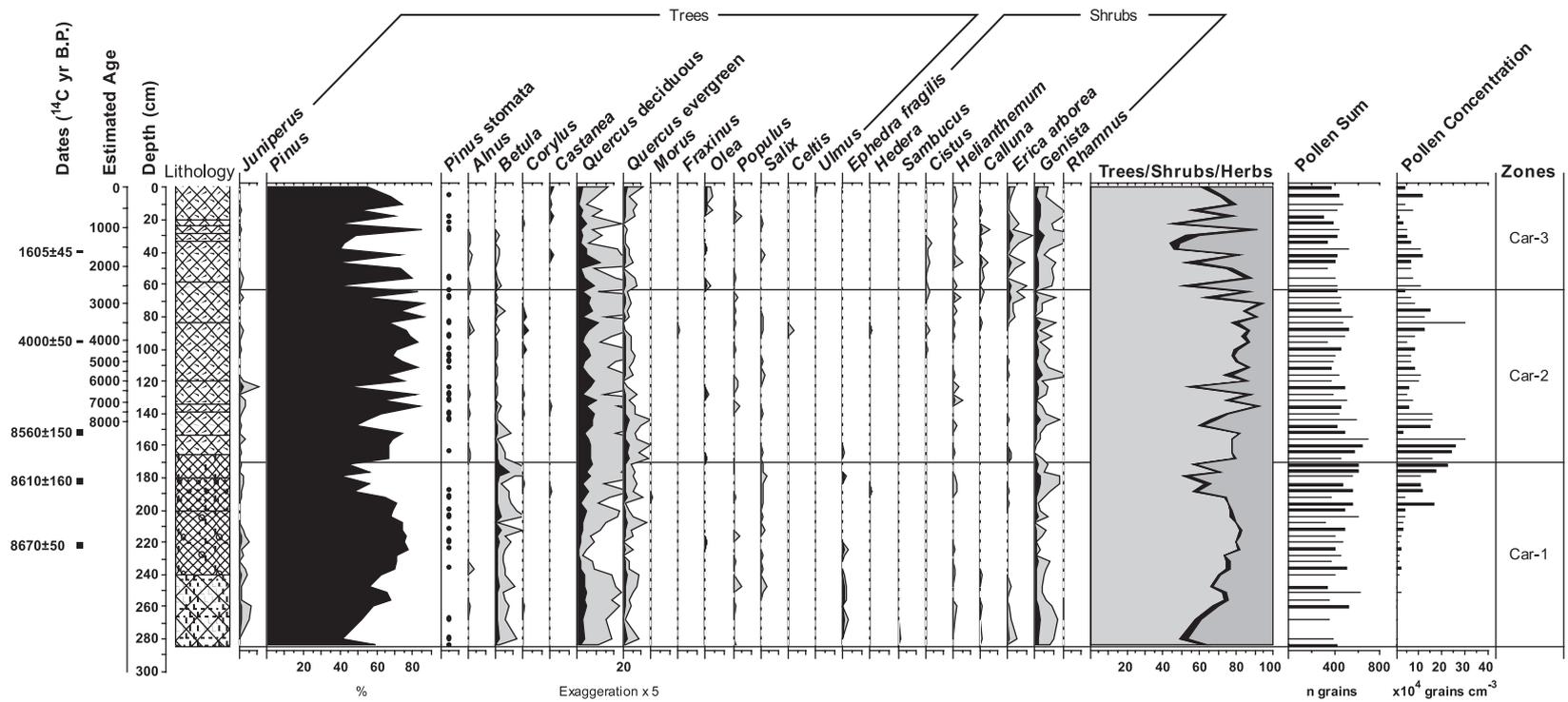


Figure 3. Percentage pollen diagram of El Carrizal lake: trees and shrubs.

El Carrizal, Segovia (Spain), 860 m

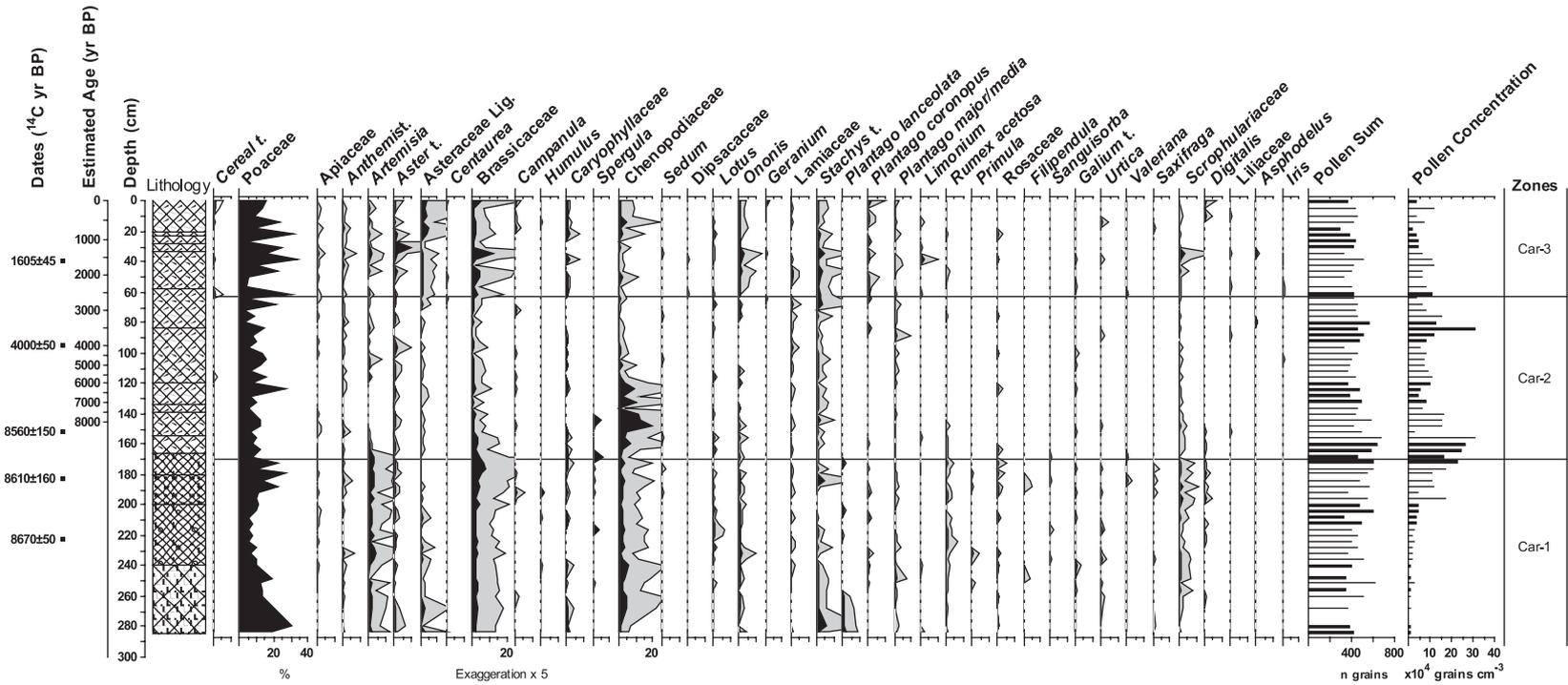
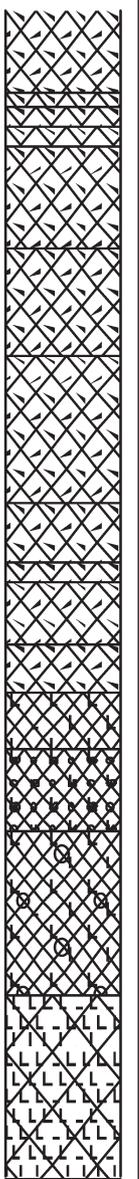
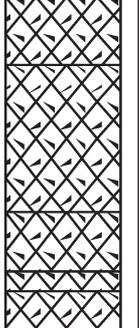
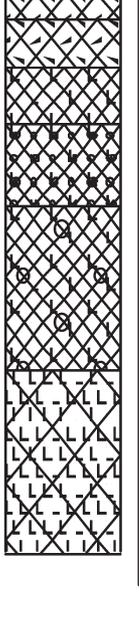


Figure 4. Percentage pollen diagram of El Carrizal lake: herbs.

siliceous, and continental series of the Holm oak (*Junipero oxycedri-Querceto rotundifoliae sigmetum*). On the riverbanks and lakeshores appear ash forests and alder forests belonging to the edaphophyllous riparian geo-series. On the loamy hills, the potential vegetation is related to the supramediterranean basophilous series of the Holm oak (*Junipero Thuriferae-Querceto rotundifoliae sigmetum*). The loamy slopes of these hills were repopulated with Aleppo pine (*Pinus halepensis*) around 50 yr ago.

The basin maintains a permanent water level in which the following plant communities develop, from greater to lesser depths: (1) communities of nympheids, aquatic plants with floating leaves, and flowers above the surface, in stagnant, deep waters with *Potamogeton natans*, *Polygonum amphibium*, and *Nymphaea alba*; (2) aquatic communities in stagnanat, shallower waters with *Potamogeton crispus*, *Potamogeton trichoides*, *Myriophyllum alterniflorum*, *Ranunculus aquatilis*, *Ranunculus penicillatus*, *Ceratophyl-*

Table 3
Pollen and nonpollen microfossil zone description along with the lithostratigraphic column

Lithology	POLLEN ZONES (TERRESTRIAL VEGETATION)	AQUATICS AND OTHER MICROFOSSILS ZONES
	<p>Marked oscillations in pines, much more abrupt than in the previous zone (jagged profile). Continuous presence of <i>Castanea</i> and <i>Olea</i>. Asteraceae, Brassicaceae, Lamiaceae or Fabaceae are the most notable herbaceous components apart from Poaceae and shrubs as Ericaceae and <i>Genista</i>.</p>	<p>Increase in helophytes (<i>Typha</i>, Cyperaceae, <i>Equisetum</i>). Infilling of much of the lake. Microfossils from shallow, temperate, warm, stagnant waters, such as the filamentous green algae <i>Zygnema</i> and <i>Spirogyra</i></p>
	<p>Oscillations in the percentages of pines. Decline in pines coinciding with the greater representation of deciduous <i>Quercus</i>. More or less continuous presence of <i>Corylus</i> and <i>Alnus</i>. <i>Betula</i> is less represented. <i>Artemisia</i> and Brassicaceae become less abundant, although Chenopodiaceae are represented by as much as 15% in the lower half of the zone.</p>	<p>Transition from deep to shallower waters with an increase in helophytic species on the shores of the lake. Abundance of microfossil type 128 associated with eu-mesotrophic open waters.</p>
	<p>Pine forests with no important oscillations. Birches and <i>Ephedra</i> more abundant than in the following two zones. Accompanied by <i>Quercus</i>, above all of the deciduous type, as well as riparian trees such as <i>Populus</i> and <i>Salix</i>. <i>Artemisia</i>, Brassicaceae and Chenopodiaceae, together with Poaceae constitute the main herbaceous components.</p>	<p>Dominance of hydrophytic species typical of deep waters, with floating leaves, of the genera <i>Nymphaea</i>, <i>Potamogeton</i>, <i>Polygonum</i> or <i>Lemma</i>.</p>

lum demersum, *Apium inundatum*; (3) reed swamps on the shores of lakes that had been flooded over long periods of time, dominated by *Phragmites australis*, *Scirpus lacustris*, *Typha latifolia*; (4) decumbent grasses in stagnant and shallow water margins with *Glyceria fluitans*, *Equisetum palustre*, *Eleocharis palustris*, *Juncus subnodulosus*, *Mentha aquatica*, *Mentha arvensis*, *Veronica anagallis-aquatica*; and (5) sedge beds with *Molinia caerulea*, *Baldellia ranunculoides*, *Carum verticillatum*, and several species of *Carex*.

Methods

The site was cored in the center of the basin using a Russian corer, and 3.40 m of sediment was retrieved. Core sections were stored in plastic drainpipes, wrapped in aluminum foil, and kept at 4°C until subsampling. We selected subsamples of 0.5-cm thickness at 4-cm intervals. Each sample was treated for pollen analysis following Faegri and Iversen (1989). Pollen extraction for minerogenic nature sediments (200- to 340-cm depth) followed the standard procedure described in Munsterman and Kerstholt (1996), in which the heavy liquid, sodium polytungstate at 2.0 g cm⁻³ density, was used to separate the pollen grains by density. *Lycopodium* tablets were added at the beginning of the treatment to estimate pollen concentrations (Stockmarr, 1973). Total pollen sum was always around or above 400 grains. Spores and pollen of aquatic plants were excluded from this sum.

Pollen diagrams were plotted using the programs TILIA 2.0 and TILIAGRAPH 2.0 (Grimm, 1992). The zonation was based on an agglomerative zonation method (CONISS).

Identification of nonpollen microfossils follows Van Geel et al. (1986, 1989), and Carrión and Van Geel (1999).

Simultaneous to the pollen analysis, we counted the number of charcoal particles bigger than 10 µm. Upon calculation of the concentration of charcoal particles, we based the total area of charcoal using the equation described by Tinner et al. (1998) and Tinner and Hu (2003).

Lithostratigraphic units were described following Troels-Smith (1955). Six radiocarbon dates were obtained by standard AMS methods on bulk sediment. Dates were calibrated to calendar years with the program CALIB 4.4 (Stuiver et al., 1998). All dates given in the text are calibrated (Table 1).

Results

Dating and chronology

The sequence covers approximately the last 9000 years.

The sedimentation rate throughout the sequence was quite variable. Especially noteworthy were the high values at the bottom of the sequence, between 284 and 150 cm

(ca. 8800–8500 ¹⁴C yr B.P.), which reach 0.66 cm yr⁻¹, each centimeter of sediment therefore representing 1.5 yr. To the contrary, between depths of 150 and 94 cm (ca. 8500–4000 ¹⁴C yr B.P.), the sedimentation rate was very low (0.012 cm yr⁻¹) and the deposition time was therefore around 80 yr cm⁻¹. In the upper part, from 94 to 0 cm (since 4000 ¹⁴C yr B.P.), the sedimentation rate rises again to approximately 0.024 cm yr⁻¹ and the deposition time to 42 yr cm⁻¹.

Lithostratigraphy

A total of 15 lithostratigraphic units were differentiated in the sequence. Table 2 presents the detailed information of each of these units: depth interval, color, notations following Troels-Smith (1955), and a brief description of the sediment.

There are two clearly different intervals within the record. Between 0 and 166 cm, three distinct lithostratigraphic units with organic matter alternate. On the contrary, between 340 and 166 cm, the sediment changes into exclusively inorganic, being constituted of limus detritus, sand, and clay.

Pollen analysis

The results of the pollen analysis are reflected in the diagrams of Figures 3–5. Of the 340-cm depth of the profile, the lower 50 cm contained no pollen content. There is a noteworthy presence of pine forests throughout most of the Holocene. In the core segment that contained pollen, the lowest percentage of *Pinus* compared to all pollen is 40% and the highest around 90%. Besides the high pine percentages, the local presence of this taxon is inferred from the pine stomata record (Fig. 3).

Pollen zonation reflects the variation in the frequency of pine and other accompanying trees (*Quercus*, *Betula*), bushes (Ericaceae, *Genista*), or herbaceous plants. Table 3 summarizes the main events in the three pollen zones established for the terrestrial vegetation. Car-1 (284–170 cm) reflects pine forests with *Quercus*, basically deciduous oaks, and as a peculiar fact, *Betula* and *Ephedra* are present together with high frequencies of *Artemisia*, Chenopodiaceae, and Brassicaceae. In Car-2 (170–63 cm), significant oscillations on the pine curve can be observed. *Quercus*, *Corylus*, and *Alnus* show a greater presence in this zone but *Betula*, *Artemisia*, and Brassicaceae curves sharply decline. Car-3 (63–0 cm) is characterized again by important oscillations in the pine curve (between 40% and 80%). However, these are more frequent and more abrupt than in Car-2. It is also significant in Car-3, the continuous presence of *Castanea* and *Olea*, and an increase of *Erica*, *Genista*, Poaceae, Asteraceae, Brassicaceae, and Lamiaceae.

The flora indicating aquatic vegetation is well represented throughout the diagram (Fig. 5). Table 3 summarizes the main events in the three zones recognized taking

El Carrizal, Segovia (Spain), 860 m

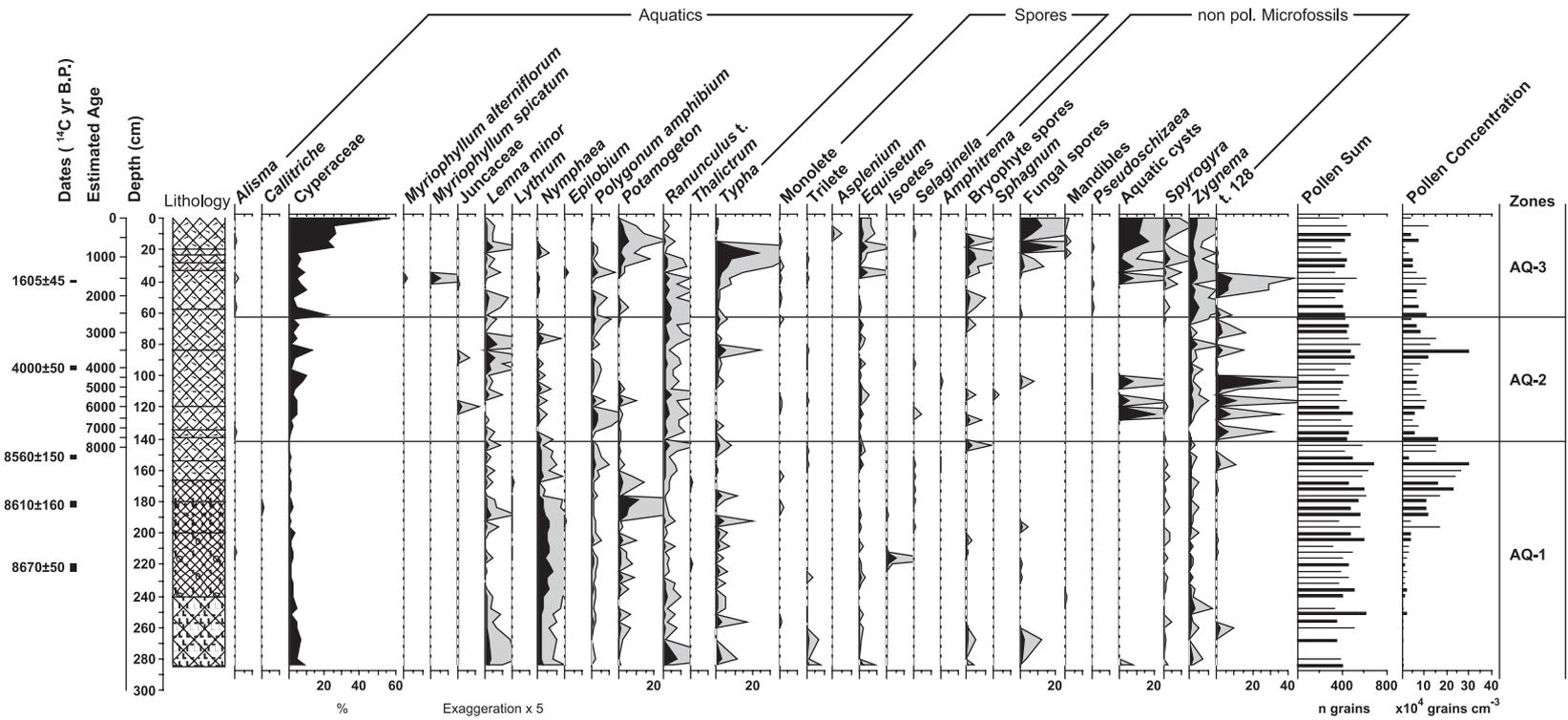


Figure 5. Percentage pollen diagram of El Carrizal lake: aquatics, spores, and nonpollen microfossils.

into account the aquatic vegetation and some nonpollen microfossils.

We observed a progressive enrichment, toward the upper zone, in helophytes such as *Typha* and Cyperaceae that must be related to the progressive infilling of the lake over time. We differentiated between two main groups: (1) floating hydrophytes, rooted vegetation with floating or submerged leaves, between 2 and 0.5 m deep, with the inclusion of *Nymphaea*, *Potamogeton*, *Polygonum*, or *Myriophyllum*; and (2) amphibious hydrophytes or helophytes, vegetation only submerged at its base, most of its vegetative apparatus being aerial, including *Typha* and sedges as *Scirpus* and *Carex*, among others. Many of the Poaceae found probably correspond to pollen from *Phragmites*, *Molinia*, and other genera, which, in spite of belonging to this amphibious hydrophyte group, cannot be separated from the rest of the terrestrial Poaceae.

Between 285 and 141 cm, there is a predominance of floating hydrophytes over helophytes such as *Nymphaea*, *Potamogeton*, *Polygonum*, or *Lemna*. From 141 to 63 cm, there is a progressive increase in helophytes, mainly Cyperaceae. Some of the floating hydrophytic taxa present in the former interval, such as *Lemna* or *Polygonum*, keep their percentage curves. It is noteworthy the presence and increase of the microfossil type 128. Finally, the last 63 cm shows a sharp increase in helophytes (Cyperaceae and *Typha*). In this period, the sporadic presence of *Pseudoschizaea* was observed.

Charcoal analysis

Figure 6 shows the results of the charcoal analysis, in which three main phases can be identified. At the bottom, from the base to 128 cm, the total area of charcoal is negligible. Between 128 and 60 cm, the charcoal surface increases slightly, with mean values of around 4 mm² cm⁻³, with a marked peak at 112 cm reaching an area of 22.3 mm² cm⁻³. In the upper 60 cm, the charcoal area increases considerably, with values clearly oscillating from 8 to 20 mm² cm⁻³.

A positive correlation with $r = 0.72$ was found between the oscillations in the *Pinus* curve and the charcoal area curve in the upper 60 cm and a negative correlation ($r = -0.8$) for the Poaceae curve.

Discussion

As has been previously mentioned, there has been great controversy regarding the history of vegetation in the study area. The debate has been about the potential (or pre-anthropogenic) vegetation of the sandy substrate in the southern sector of the Duero basin (Tierra de Pinares). The only map of potential vegetation existing for the whole of the Iberian peninsula proposes, for the area we are dealing with, the exclusive existence of deciduous forests such as *Q. ilex* subspecies *ballota*, *Q. pyrenaica*, or *Q. faginea* (Rivas

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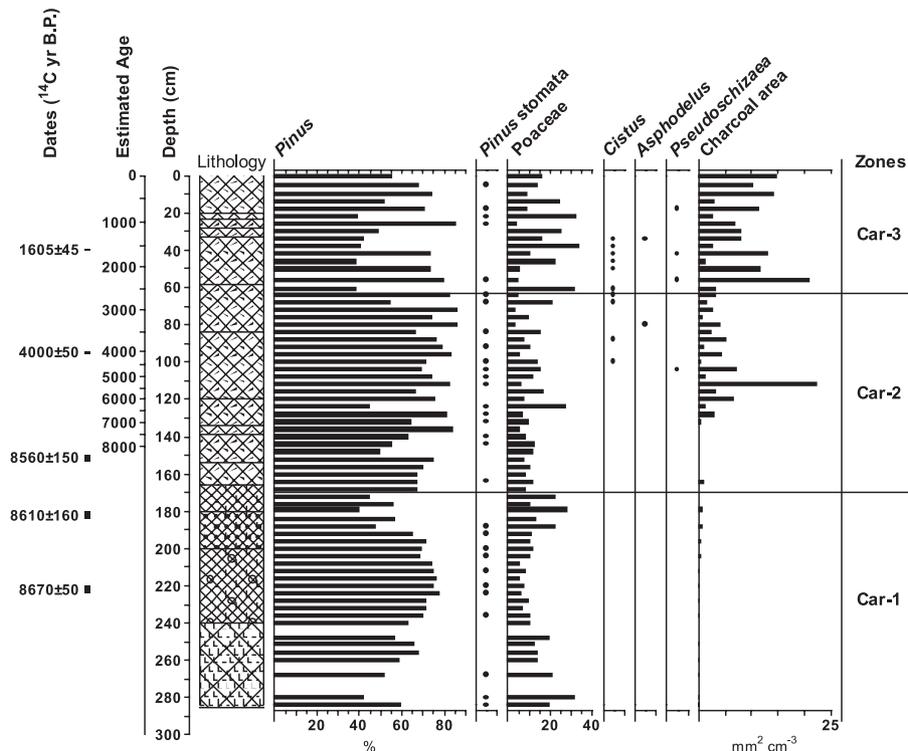


Figure 6. Charcoal percentage related to the *Pinus*, Poaceae, and *Cistus* curves.

Martínez, 1987). According to this interpretation, the origin of the pine forests currently existing in the region appears to be exclusively anthropic. Other authors have defended the spontaneous origin of the aforementioned pine formations (Calonge Cano, 1998; Costa Tenorio et al., 1988; Morla Juaristi, 1996). No paleobotanical data have been brought into play, however, in this intense geo-botanical debate.

Pine forests on dunes

The hegemony of the pine forest landscape has been remarkably constant throughout the last 9000 yr. Although the rise in dominance of deciduous trees over conifers at the end of the late glacial period or in the Holocene was quite generalized in many parts of the Iberian peninsula (Allen et al., 1996; Pérez-Obiol and Julià, 1994; Pons and Reille, 1988), the stability of the pine forest formation throughout the Holocene has been seen in several regions of the inland Duero basin, either in the first half of this period, as in Quintana Redonda, Soria (García Antón et al., 1995), or throughout the whole period in Espinosa de Cerrato, Palencia (Franco Múgica et al., 2001), or in Calatañazor, Soria (Menéndez Amor, 1975). The same resilience of pinewoods from the late glacial period onwards can be observed in other areas of Iberia like the Spanish Levante (Carrión and Van Geel, 1999). This substitution of pine forest by mesophyllous forest indeed occurred in this location although fairly later than in most of the Iberian sites.

The diagram of the El Carrizal lake represents a new case within the Spanish meseta, in which the pine forest predominates throughout the whole Holocene. One peculiarity of this sequence is the maintenance of the forest structure throughout the whole historic period up to the present day. In most of the diagrams reaching the late Holocene, clear signs of deforestation in recent times can frequently be observed. In the case we are dealing with this deforestation cannot be noted although clear signs of anthropogenic impact can be detected in Car-3. Geological characteristics may play a particular role in this respect. Indeed, the sandy substrate is a factor that has sustained the pine forests, as in other nonsandy areas, such as Espinosa de Cerrato: they disappeared in historic times (Franco Múgica et al., 2001). In this sense, it is also interesting to point out that in the area to the north of the river Duero, where sands are scarce, for the reasons given in the section on geology, there are also large areas of pine forest at present. The sandy substrates of these territories are inappropriate for growing crops or planting vegetable patches and have therefore been avoided by the population when establishing settlements. Thus, there is no permanent human occupation of the banks of the river Cega where it flows past these sand dunes in spite of the fact that riverside areas are very attractive places and a priority for human settlement. The only alternative to the exploitation of the pine forest resources (resin, edible pine kernels, timber) has been grapevines, which adapt well to the sands.

Furthermore, historical research in the area has revealed the importance of pine forests in the 13th century and in subsequent times. Repeated documentary references to legislation and commercial operations involving pine trees denote the silvicultural importance of this taxon in the region (Calonge Cano, 2003).

Most of the spontaneous species of the genus *Pinus* on the Iberian peninsula show a capacity to thrive in environments with contrasted climates, which is Mediterranean subcontinental in our case. Also known is the capacity of *Pinus* to occupy sandy substrates (Costa Tenorio et al., 1997; Gil, 1991; Gil et al., 1990; Mirov, 1967; Morla Juaristi, 1993). Both factors, climate and geology, may account for the sustained success of *Pinus* in the Holocene with regard to the competition for space with broadleaved trees, particularly from the genus *Quercus*.

P. pinaster and *P. pinea* are the two species currently occupying the area, the former being by far more abundant. Both can be considered as very good candidates as the main constituents of the Holocene pine forests in the surroundings of El Carrizal lake. These two species are currently abundant in the region to the south of the river Duero (Fig. 2). *P. pinaster* dominates not only around El Carrizal but also in all highest elevation areas close to the Central System mountains. However, *P. pinea*, sporadic in this area, is dominant in the lower, warmer parts of the basin, close to the city of Valladolid (where *P. pinaster* is rare). This circumstance may be due to the greater thermophilia of *P. pinea* (Costa Tenorio et al., 1997) and it is therefore likely and coherent, in the climatic sense, that during the Holocene *P. pinaster* was the most important constituent of the pine forests reflected in the pollen diagram studied. Both of these pines have been of great importance to man, *P. pinaster* for resin extraction and *P. pinea* for its pine kernels. It is therefore very likely that in historic times fluctuations in the markets of both products may have affected the relative proportions of both species in the composition of pine forests, as well as the limits between different types of pine forests.

The charcoal macrofossils corresponding to *P. pinaster*, dating from the end of the Holocene (ca. 1400 ¹⁴C yr B.P.), found a few kilometers from El Carrizal lake (Hontalbilla, Segovia; Alcalde Olivares et al., in press), reinforce the model of dominant pine forests that we present and give consistency to the hypothesis of the main species existing therein, dealt with in the previous paragraph.

In relation to the role played by broadleaved trees, and particularly by *Quercus* species, these must have been scattered among the pines, or, at most, must have formed small groups. This model is well justified given the better adaptation of the pines in general, and in particular of *P. pinaster*, to deep, sandy substrates (Barbéro et al., 1998), in which *Quercus* and other broadleaved trees encounter greater difficulty (Costa Tenorio et al., 1997). If the current vegetation landscape in the region is observed, one will find that it tallies very well with the interpretation we have made

of the paleobotanical information: the *P. pinaster* forests continuously dominate the vegetation landscape of sandy territories. The cluster pine regenerates naturally with great ease as opposed to the difficulties encountered by *Quercus*. The acorns of *Q. ilex* subspecies *ballota*, due to the great potential of their endosperm, germinate well in sands. However, if these are very deep and if after 2 or 3 yr the roots have not reached the underlying rocky level, the individual dies or its growth slows down, producing stunted trees that cannot compete for space with the well-adapted pines. The final reason is the very dry edaphic environment that a deep sandy substrate generates over long periods in a Mediterranean climate.

Within the deciduous taxa, *Betula* was one of the most abundant in the vicinity of the lake between 8800 and 8600 ^{14}C yr B.P. Subsequently, there is a noteworthy decrease in the proportion of its pollen, which appears to be concordant with the role of the birch in the current landscape of the region: very sporadic and sheltered on the slopes of the Cega valley, where insolation is less intense. Similar explanation could be derived for *Corylus* that appears scattered throughout the sequence. Other interesting trees favored by humans, *Castanea* and *Olea*, although with sporadic records, show similar continuous curves during the last ca. 2500 yr.

The local vegetation (Table 3) allows us to learn about lake-level changes and its climatic correlations. On the Iberian peninsula in the first half of the Holocene, high levels have been observed in lakes, whereas in the second half depth shows a tendency diminish (Harrison and Digerfeldt, 1993).

In the base of the core (8800–7500 ^{14}C yr B.P.), there is a predominance of hydrophytes probably linked to an increase in the depth of the lake resulting from an increase in hydric balance. Annual rainfall higher than the present rates by over 100 mm was reconstructed with the use of fossil pollen in the mountains in the center-north of the Iberian peninsula between 9500 and 8000 ^{14}C yr B.P. (Peñalba et al., 1997). Due to the dominance of *Pinus*, no big changes in terrestrial vegetation are observed in the pollen diagram. However, in this more humid phase, a taxon with greater hydric requirements, *Betula*, was more abundant.

The progressive increase in helophytes (7500–2500 ^{14}C yr B.P.) appears to indicate the gradual infilling of the lake. The low levels in the El Carrizal lake observed over the last ca. 5000 yr show a tendency similar to the successive phases of desiccation described for the southeast of Spain in the last ca. 4000 yr (Carrión, 2002; Pantaleón-Cano et al., 2003). Similar phases of aridification have been established for the western Mediterranean (Jalut et al., 2000) and for North Africa (Gasse, 2000; Lamb et al., 1995). After 1600 ^{14}C yr B.P., in spite of the slight increase in hydrophytes, circumstances comparable to present times existed, a partially infilled lake surrounded by helophytic vegetation.

Fires

The results observed in the upper part of the diagram in zones Car-3 and part of Car-2 (Fig. 6), when the intensity and frequency of the fires are greater, may explain big fluctuations in the curves of *Pinus* and Poaceae, although the synchronization with the fires is not particularly accurate. The correlations found between the curves of *Pinus* and Poaceae with the curve of the charcoal area are expected to be, a priori, complementary. However, the *Pinus* and charcoal area curves showed a positive correlation whereas a negative correlation was found between Poaceae curve and the charcoal area curve.

Following a fire in the dominating pine forest, a phase should be observed of dominance of heliophyllous shrubland and herbaceous plants previous to the recovery of the forest cover. There is little increase in shrubland in the diagram, although there is a notable presence of *Cistus*, possibly *C. ladanifer*, a known pyrophyte of markedly Mediterranean character. In addition, the sporadic presence of *Pseudoschizaea* considered to be an indicator of soil erosion (Pantaleón-Cano et al., 1996; Van Konijnenburg-Van Cittert, 1991) probably results from an increase in erosion after fires. Greater resolution between samples will probably be necessary in order to study the postfire dynamics of these formations.

However, a possible explanation for the negative correlation between Poaceae and charcoal might be found in the existence of local fires in the formations of *Phragmites*. We must take into consideration that the pollen of *Phragmites* cannot be distinguished from other Poaceae. The temporary disappearance of *Phragmites* could cause an overrepresentation of the surrounding pine forest, which has been quite unaffected by the fires. It should also be pointed out that the formations of *Phragmites* would have dominated on the lakeshores in this phase in which other helophytes can be seen to have spread (*Typha*, Cyperaceae, etc.) as a consequence of the infilling of part of the basin.

The increase in the number or intensity of the fires in the upper 60 cm may have been favored by warmer, drier climatic conditions, coinciding with a decline in the proportion of *Betula*. These last 2500 yr coincide with a significant increase in pollen grains that can be related to anthropic activity (*Castanea*, *Olea*, Cereal t., *Aster*, Asteraceae t. liguliflorae). An intensification of the fires in the last few millennia has been observed in different parts of the Iberian peninsula and has been related to increases in anthropic pressure and aridity (Carrión, 2002; García Antón et al., 1997; Stevenson, 2000). This phase of more intense fires also tallies with the higher proportion of heliophyllous shrubland and ferns. The historic data available coincide with regard to the intense human activity, at least over the last 1000 yr (Calonge Cano, 2003; Gil, 1991).

Conclusions

Lastly, returning to the geo-botanical debate presented in the Introduction, the palaeobotanical study carried out in El Carrizal lake highlights the antiquity of the pine forests of the region, dating back to at least 9000 yr. The natural origin of the pine forests in this region, as opposed to the anthropic one, has therefore been proved, and this circumstance, as has been pointed out, occurs in other inland parts of the Duero basin. In this case, the resilience of these pinewoods could be related to the sandy nature of the substrates.

The wet and dry spells detected with the use of the aquatic taxa and nonpollen microfossils loosely coincide with similar phenomena in the Mediterranean and in North Africa. An initial phase previous to 7500 ¹⁴C yr. B.P. of high levels in the lake derived by high percentages of hydrophytes can be identified. A progressive increase in helophytes surrounding the lake over the last 5000 yr appears to indicate a phase of low lake levels similar to those desiccation phases established for the western Mediterranean.

The peculiarity of this sequence is the maintenance of the pinewoods up to the present day although moderate signs of anthropogenic disturbance can be detected during the last 2500 yr. The charcoal study shows an intensification of fires from this date onwards. In spite of the predictable fluctuations in forest cover after fires, the pine forests are capable of reacting to disturbances and regain their hegemony in the landscape.

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