Landscape dynamics and fire activity since 6740 cal yr BP in the Cantabrian region (La Molina peat bog, Puente Viesgo, Spain)

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Abstract

A lack of paleobotanic studies with adequate resolution and multiproxy approaches has limited proper discussion of vegetation dynamics in Cantabria and of the role of fires in the configuration of the plant landscape during the Holocene in the northwest part of the Iberian peninsula. The pollen diagram of La Molina peat bog in Puente Viesgo (43°15′38″ N–3°58′37″ W; ETRS89), located at 484 m.a.s.l., and the study of its sedimentary charcoals allowed the acquisition of a continuous and thorough fire sequence for the last 6.700 cal yr BP and an understanding of its relationship to the forest. The results show the importance of human influence on the incidence and characteristics of fire activity during the different phases studied: the Neolithic, Bronze Age, Iron Age, Roman period, and Middle Ages. A synergy seems to exist between dry climate periods (especially during Bond events 3 and 4) and a greater presence of biomass. As the Holocene advances, vegetation coverage clearly tends to decrease. This study provides key elements for understanding the role of fire activity in the forest dynamics of deciduous and evergreen *Quercus*, *Corylus*, *Pinus*, *Fagus*, and *Alnus* and demonstrates the strongly artificialized character of the present landscape.

Keywords: Fire; Sedimentary charcoal; Pollen; Cantabria; Holocene; Iberian peninsula

1 Introduction

In recent years, environmental history geographers have shown the importance of a joint consideration of natural dynamics and human influence when interpreting landscape changes during the Holocene (Battarbe et al., 2004). As a result, paleoecology studies have given way to multiproxy studies as we attempt to clearly discern the human and natural signs that remain from those changes.

Researchers have synthesized the changing plant landscape of the Iberian peninsula during the Holocene based on pollen (Allen et al., 1996; Ramil-Rego et al., 1998a,b; Riera, 2006; Pérez-Obiol et al., 2011; Carrión, 2012) and other indicators (García-Amorena et al., 2008). Their findings reveal the unequal distribution of information and lack of multiproxy studies in some regions.

In Cantabria, the reconstruction of the historical vegetation dynamics in this region during the Holocene has produced some synthesis (Ezquerra, 2005). The research was based on sedimentary records preserved in various peat bogs (Fig. 1): Puertos de Riofrío (Florschütz and Menéndez, 1962; Menéndez and Florschütz, 1963), Cueto de la Avellanosa (Mariscal, 1983); Sertal (Mariscal, 1986); Estacas de Trueba (Mariscal, 1987, 1989); Alsa (Mariscal, 1993); Los Tornos (Peñalba, 1989; 1994; Muñoz-Sobrino et al., 2005); and Culazón (González-Pellejero et al., 2014). Nonetheless, most of the pollen sequences – mainly compiled by Carrión (2012) – are from the interior of caves and sheltered spaces (Peña-Chocarro et al., 2005a, 2005b; Baena et al., 2005).

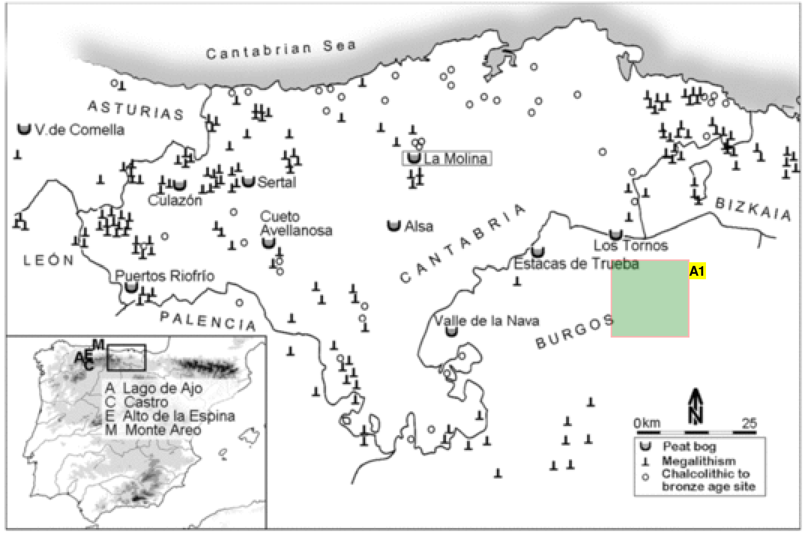

Fig. 1 Megaliths, Chalcolithic to Bronze Age remains and locations of peat bogs cited in the text.

Source: drawn by the authors from Solórzano-Telechea et al. (1999) and other sources.

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From a paleoclimatic and paleobiogeographic perspective, we must also consider several Asturian locations with a certain proximity to the region: Lago de Ajo (Allen et al., 1996) in Somiedo; Comella hollow (Ruiz-Zapata et al., 2002) in the Picos de Europa (Cangas de Onís); and the peat bogs at Alto de la Espina (Concejo de Salas) (López-Merino, 2009) and at Monte Areo (Carreño) (López-Merino et al., 2010). A study of Enol Lake by Moreno et al. (2011) revealed significant environmental fluctuations covering the last 13,500 years, which they identified by a multiproxy analysis combining sedimentological and geochemical techniques, diatom and ostracod species assemblages, and palynological analyses. Superimposed on relatively stable landscape conditions (e.g. maintenance of well-established forests), the typical environmental variability of the southern European region is observed at this site.

Farther away but no less important, El Castro in Villaseca de Laciana (León) (Jalut et al., 2010), La Nava (Burgos) (Menéndez-Amor, 1968), and the synthesis developed for the mountains in the northeast of the Iberian peninsula (Muñoz-Sobrino, 2001) can all serve as a point of reference for the Holocene vegetation. Archeological analysis has made available large quantities of information about the Basque Country, recently incorporated by Hernández-Beloqui et al. (2015) (Sould be linked) into a synthesis in the south-west of the Pyrenees, the east of the Cantabrian Mountains and the upper Ebro valley with information about the Late Holocene. Finally, the maps published by Rivas-Martínez (1987) and Sainz-Ollero et al. (2010) are essential to understanding the current distribution of vegetation.

All of these paleobotanical data have explained the history of the landscape in the north and northwest of the Iberian peninsula. The discussion has centered on determining whether the presence or absence of certain arboreal taxa were attributable to the climate conditions and/or to human activities at different points in the Late-glacial or Holocene periods. In this sense, phylogeographic studies are contributing new information that encourages the debate. The present article focuses on five points:

a) Lack of pine forests

According to Maldonado (1994), the disappearance of the pine forests had different causes depending on their location. In zones of the Cantabrian mountain range with an Atlantic influence and in the northwestern part of the peninsula, the cause is the installation of a temperate oceanic climate at the beginning of the Holocene. Rubiales et al. (2008) related this to an early and sudden decline in pine forests in the northern slopes of the Cantabrian range, which would have favored deciduous taxa over coniferous species because of the temperate and humid climate. In some interior valleys and the southern slope of the range, where the climate quickly acquires more continental characteristics, pines maintained a certain domain not only in these initial phases but also throughout much of the Holocene. Some clear examples exist in Puertos de Riofrío (Menéndez-Amor and Florschütz, 1963) and Lago de Ajo (Allen et al., 1996). In the latter case, their disappearance was related to intense human activity, a deforestation that mainly occurred about 1000 years ago, as observed in the interior southern slopes (drier and more continental) of León, beginning in the localities of Villaseca and La Mata (Jalut et al., 2010). The natural pine forests were replaced by heath formations.

b) Origin of the holm oaks

From the analysis of cpDNA of sclerophyllous Quercus, López de Heredia (2006) finds a distinct group in Cantabria formed by a single genetic population, which would strengthen the idea that the current holm oak forest constituted a refuge during the glaciation. This population does not seem to have expanded, as Costa et al. (2005) state that its current relevance in the landscape has been enhanced by the regression of other forests and Ramil-Rego et al. (1998a,b) indicate that the low proportion of *Quercus ilex* type pollen in the different diagrams of this area suggest that sclerophyllous arboreal formations maintained a scattered presence in the landscape, both in the Late-glacial Interstadial and throughout the Holocene.

c) Hazelnut as a species of zonal communities

At present, the capacity of this species to colonize altered spaces has been described, highlighting its serial or phased replacement function in Cantabria and other mountainous zones of the Iberian peninsula. On the other hand, numerous authors have emphasized that the hazelnut could have generated nonriparian monospecific formations or played a clearly dominant role in other areas with a stable or permanent character, normally in Eurosiberian environments, since the onset of the Holocene, independently of any human activity (Costa et al., 2005; García-Antón et al., 2006).

d) Source of the beech

Genetic studies provide different findings depending on the molecular markers used. This leads to considering beech colonization as the result of the expansion of ancient refuges located in the Cantabrian range (Magri et al., 2006; Muñoz-Sobrino et al., 2009; Uzquiano, 1992) or as the migration from the eastern and central regions of Europe (Peñalba, 1994; Rodríguez-Guitán, 2004). Many authors have described the relationship between human action and the development of *Fagus* (López-Merino et al., 2008). Jalut et al. (2010) suggest that the *Fagus* occurrences might be the consequence of very strong human impact. Small-scale clearances of high woodlands might in some cases have been followed by rapid tree recolonization, a situation in which the competitive capacity of beech would again give it an advantage over other species (Muñoz-Sobrino et al., 2009).

e) Past role of fire activity

In recent years, fire has had an effect on the landscape of the Northern Hemisphere that contrasts with the beginning of the Holocene and has been linked to the availability of biomass and to climate episodes (Power et al., 2008; Carcaillet et al., 2012; Feurdean et al., 2012). The arrival of the Neolithic and later cultural stages (until the Middle Ages) shows how fire activity has been a great ally in opening forested space and maintaining open landscapes after the arboreal vegetation disappeared (Bal et al., 2011; Cunill et al., 2012; Feurdean et al., 2012; Gil-Romera et al., 2014). Gil-Romera et al. (2010) have also reconstructed a sequence of vegetation dynamics and fire changes across southeastern Iberia, improving our understanding of the long-term post-fire vegetation response and the fire–climate–vegetation relationship.

In the Cantabrian zone, no paleoecological studies have specifically incorporated fire signs, independent of pollen signs, as has been done in the present study. This approach has been successful in the Pyrenees, where sedimentary charcoals contribute information on fire events over time (Carcaillet, 1998; Tinner et al., 2005; Miras et al., 2007; Bal et al., 2011). In these settings, the pine and other conifers have provided the fuel for fire activity. In Cantabria, fires now primarily burn scrublands (for example, gorse) (Carracedo, 2015). The combustible species available in Cantabria in the past are unknown. Sequence analysis at La Molina should help to solve this question. Nonetheless, the impossibility of detecting fires that did not affect woody plants and the possible role of *Ulex*, a markedly flammable taxon that is very abundant in the region but not well detected in the pollen diagrams, adds complexity to this task.

At present, fires, which occur in winter, are mostly provoked (Carracedo, 2015), and require meteorological conditions that make available dry combustible material and permit fire propagation; these include persistent winter anticyclones or Föhn-type situations, called the “south wind” in the study region (Carracedo et al., 2009). No studies to date have shown whether this has always been the case, and it is difficult to develop a theory based on the main climate trends during the Holocene, which reflect the variations in solar radiation from the Earth's orbit around the sun (Milankovitch, 1920). This information is very useful in explaining the major changes during the mid-Holocene (Pèlachs et al., 2011; Pérez-Obiol et al., 2011), but is not sufficient to interpret the climate conditions that affected fire activity (temperature, precipitation, humidity, winds, electrical storms, etc.) and the associated biological factors (biomass, plant species, etc.) with much shorter timescales.

Bond et al. (1997) contributed very interesting work based on North Atlantic deep-sea sediment cores, establishing quasi-periodic (c. 1500 years) climate fluctuations during the Holocene. They related ice-rafted debris (IRD) to the slowdown of the Atlantic thermohaline circulation (THC) and, later (Bond et al., 2001), to variation in solar radiation, as the IRD fluctuations were coherent with the production rates of cosmogenic nuclides of ^{14}C and ^{10}Be. Therefore, Bond cycles suggest that solar radiation must have had a marked influence on Holocene climate variation in all regions influenced by changes in Atlantic Ocean circulation (Battarbee et al., 2004; Magny, 2004; Baker et al., 2005). Although most Bond events do not have a clear climate signal (Burjachs and Expósito, 2014), some correspond to periods of cooling and others are coincident with aridification in certain regions. It can be hypothesized that IRD cycles in the Cantabrian range could be a useful proxy for revealing climate fluctuations at sub-Milankovich timescales with atmospheric circulation patterns that could have increased fire activity.

1.1 Historical context

Human presence in the Cantabrian region is well documented throughout the Upper Pleistocene, with the primary evidence being Paleolithic parietal art distributed across about a hundred caves included in UNESCO's list of World Heritage sites (Gobierno de Cantabria et al., 2008), which has given rise to great quantities of scientific literature in the field of prehistoric archeology (Straus, 2005). Nonetheless, the recent Prehistory has been less studied and, paradoxically, is less well known, although the transition from hunter-gatherer societies to the first agrarian cultures is the object of growing academic interest and is now well documented and chronologically defined (Bailey and Spikins, 2008).

The process of neolithization of the northwest Iberian peninsula occurred relatively late in the European context (Peña-Chocarro et al., 2005a; Fano et al., 2015); evidence of agriculture begins to appear in 4300 cal yr BCE (6250 cal yr BP) (Straus and González Morales, 2003). Some of the most representative evidence of this period, such as the megaliths or schematic art, offers abundant testimony showing the intensity and breadth of the phenomenon throughout the region; it even survived during two subsequent millennia in more developed cultural contexts (Díaz-Casado, 1993). The Chalcolithic (c. 3000–2200 cal yr BCE) (4950–4150 cal yr BP) and Bronze Age (c. 2200–725 cal yr BCE) (4150–2675 cal yr BP), which left scant traces that are difficult to contextualize and date (Ontañón, 1995, Armendáriz and Arias, 2007), should not reflect very deep cultural changes because the nearly nonexistent deposits of copper, tin, and gold limited the development of metallurgy and favored the maintenance of earlier ways of life (Blas-Cortina and Fernández-Manzano, 1992). Nonetheless, and based on the indices of human presence, the Bronze Age is usually considered a period of demographic growth and occupation of new spaces by human groups (Fig. 1).

Iron manufacture appeared about 2700 cal yr BP and, in contrast to bronze metallurgy, developed very rapidly because of the region's extraordinary abundance of iron deposits and easy access to them. Mentioned by Pliny the Elder and active until the last third of the 20th~~th~~ century, the mines of Peña Cabarga were the object of intense exploitation (Mantecón-Callejo, 2003). Work must have begun at about the same time in Castro Urdiales and Reocín-Mercadal, where the presence of galena and calamine also permitted the mining of lead, silver, and probably zinc (Torres-Martínez, 2011).

The peat bog of La Molina is situated in a strategic place for the study of environmental history of the recent Prehistory and of the effects of the activity of successive human groups. In the immediate surroundings, we find important archeological sites that cover all of the ages mentioned: Upper Pleistocene-Paleolithic in the caves of Monte Castillo (El Castillo, Las Monedas, La Pasiega, Las Chimeneas) and in Hornos de la Peña; Neolithic to Bronze Age in the caves of El Castillo and Las Monedas and in the six burial mounds distributed throughout the areas of La Peña del Ramo and La Sierra de Quintana (Teira, 1994); Iron Age and Cantabro-Roman Age in the mines of Mercadal; and remains of settlements and military camps in Las Sierras de Tejas-Dobra or the Pas-Besaya water-divide.

1.2 Study setting

La Molina peat bog (43°15′38″ N–3°58′37″ W; ETRS89) is situated at 484 m.a.s.l. in Puente Viesgo (Cantabria) at 20 km from the Cantabrian coast. It occupies a concave topography on the north side of La Cuera (Pas-Besaya water-divide) produced by a gravitational landslide of very large dimensions (approx. 1600 × 1750 m), during which an undetermined volume of sandstone and valanginian quartzites were displaced in favor of dips in the strata over a berriasian substrate of shales and sandstone. This landslide remains active and has been dated as the “recent Holocene” (Portero-García, 2009) although the date we obtained at the base of the peat bog, 18 840 cal yr BP, could indicate a somewhat earlier timeframe.

The climate is oceanic (type Cfb as defined by the Köppen climate classification), with mild temperatures (annual mean: 13 °C), scant thermal amplitude, and abundant precipitation (1400 mm/year) that is relatively well distributed throughout the year. This yields a favorable water balance and maintains a humid environment.

All these factors and the steep slopes of the area surrounding the peat bog determine the predominance of poorly developed soils, mainly dystric regosols and leptosols (CITIMAC, 2003–2005), acidic and unproductive, with a vegetation potential dominated by oligotrophic *Quercus robur*. In nearby locations at higher altitude we also found beech (*Fagus sylvatica*) and, in the valleys, mixed oaks with an entourage of thermohygrophilous species. At present, however, most of the surface appears to be occupied by pastures, maintained by periodic burns, and eucalyptus (*Eucalyptus globulus*) and pine stands (*Pinus radiata* and *Pinus sylvestris*) that have been developed during the last century to satisfy industry demands (Fig. 2).

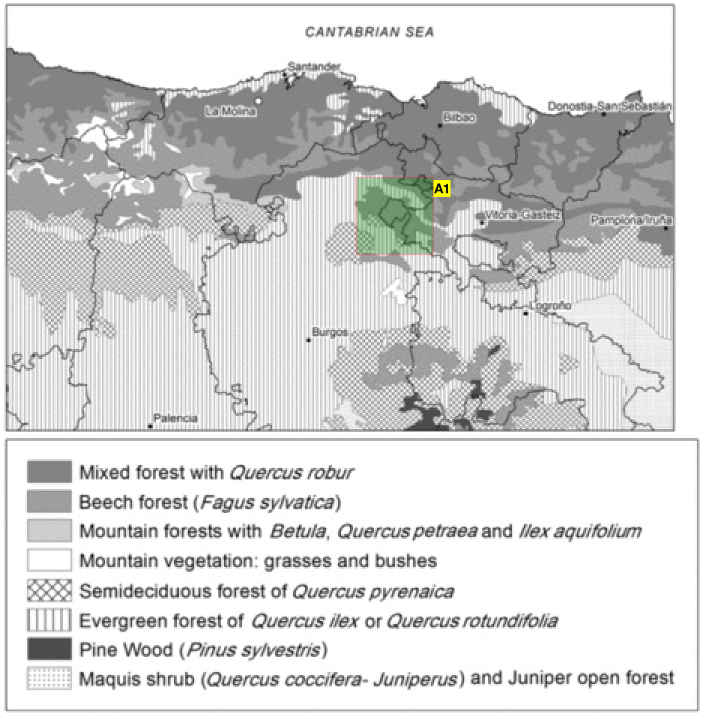

Fig. 2 Map of potential landscapes.

Source: redrawn and simplified by the authors from Sainz Ollero et al. (2010).

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La Molina is currently dominated by minerotrophic fens, although some patches of incipient ombrotrophic bogs are also present. Groundwater pH is strongly acidic in bogs (3.5–3.6) and in fens (3.9–5.0). The plant layer is dominated by *Molinia caerulea*, *Rhynchospora alba*, *Erica tetralix*, *Drosera rotundifolia*, *Eriophorum angustifolium*, whereas peat moss (genus *Sphagnum*) is ubiquitous on the moss layer. *Sphagnum fallax*, *Sphagnum~~.~~ cuspidatum*, and *Sphagnum~~.~~ denticulatum* are the most common on fens, while *Sphagnum rubellum* make up the moss layer on bogs. This vegetation is a good example of Cantabrian acidic fens and bogs from sea level to 800 m (Fernández-Prieto et al., 1987).

2 Materials and methods

2.1 Sampling

Fieldwork at La Molina peat bog was carried out during 2013. Three surface samples of sediment (MOL-1, MOL-2, and MOL-5) were collected manually by driving a 3-m~~eter~~ PVC tube, 110 mm in diameter, into the peat bog. Using a mechanical sampler with a diameter of 50 mm and a percussion hammer, two more samples (MOL-3 and MOL-4) were collected from a maximum depth of 4.67 m ~~meters~~.

Sample MOL-2 was selected for the present analysis because the continuous recovery of 2.60 m ~~meters~~ of sediment guaranteed good temporal resolution and ensured the absence of any possible contamination due to changes in maneuver. Therefore, the sample was cut below the centimeter into 302 samples that were used for the analysis of pollen, sedimentary charcoal, and organic matter.

2.2 Chronology

Five samples of peat were selected for ^{14}C AMS dating (Beta Analytic Inc.). A smooth spline age-depth model was constructed using the classical age-depth modeling software Clam (Blaauw, 2010) with the R statistical software package (R Core Team, 2015). The ^{14}C ages were calibrated using the INTCAL13 calibration database (Reimer et al., 2013). Once the pollen diagram was completed, the most recent part of the chronological model was corrected using documentation of the introduction of forest species such as *Pinus* and *Eucalyptus* in the study area.

2.3 Palynology

Pollen analysis was done every two cm. The sediment samples were prepared according to standard chemical procedures, including treatment with 10% HCl, 10% KOH, 70% HF to remove the carbonates and silica, followed by glycerol mounting and mineral separation in heavy liquid (density 2.0).

Pollen was identified under a light microscope using reference collections and standard determination keys (e.g., Moore et al., 1991) and photo atlases (e.g., Reille, 1992; 1998). Results are expressed in relative percentages, excluding algae, spores, and hydro- and hygrophyte plants from the pollen sum. The pollen diagram was constructed using TILIA and TILIAGRAPH (Grimm, 1991) and does not show pollen types with low percentage values. CONISS (CONstrained Incremental Sum of Square cluster analysis) was used to delineate pollen zones (Grimm, 1987).

2.4 Sedimentary charcoals

For the same core samples, at each centimeter the number of charcoals larger than 150 µm (Carcaillet et al., 2001) was estimated in order to determine fire events. Even though this dimension does not allow a taxonomic determination level for each fragment, it is possible to establish the relative magnitude of these events, assuming that phases with and without fires can be detected and, in the latter case, to identify the periods of particular intensity (Vannière, 2001).

The nature of peat bogs made it necessary to adjust the Carcaillet protocol (Carcaillet et al., 2001, 2007). Therefore, weight was used instead of volume in order to minimize the effect produced by differences in density in the interior of the peat bog. We used potassium hydroxide (KOH) as the deflocculating solution and to remove organic content, and a bleaching solution of sodium hypochlorite (NaClH) at 15% concentration (Finsinger et al., 2014). All of the samples were heated to 70 °C for 90 min and sieved over a 150 mm mesh when cooled. The number of macroscopic charcoal particles in each sample was estimated under a stereomicroscope at 40 magnification. The area was measured using an ocular grid with 100 squares, each 0.0625 mm^2 (Carcaillet et al., 2001). Fragments were classified in size classes, which increased exponentially. Charcoal counts were combined and divided by sample weight and sedimentation rate to calculate the charcoal accumulation rate (mm^2/g/yr). All charcoals larger than 0.250 mm^2 were graphed, along with the number of charcoal particles per sample, in order to more clearly indicate local fire events (Whitlock and Larsen, 2001; Finsinger et al., 2014).

2.5 Organic matter

Loss on ignition (LOI) analysis was carried out, modifying the standard procedures to achieve combustion at 550 °C for 4 h.

2.6 Titanium (Ti) and Aluminum (Al) analysis

Metals analysis was carried out on 100 samples. After molding, 0.25 g of each sample were digested in a microwave oven (CEM, Mars model) with a solution of HNO3, HCL and HF, along with parallel blank digestion. The remaining dissolutions were colorless and clear, and were analyzed using an inductively coupled plasma mass spectrometer (ICP-MS, Agilent, model 7500 ce).

3 Results

3.1 Chronological model

Basal MOL-4 dating allowed us to estimate a date of 18 840 cal yr BP; however, the present article presents only the first 6740 cal yr BP for MOL-2 (Table 1). Due to major differences in the sedimentation rates, a smooth-spline age-depth model was used, as described in the Methods section and shown in Fig. 3.

Table 1 Radiocarbon data for the sediment cores of La Molina peat bog (MOL-2).

Laboratory code	Sample depth (cm)	Material dated	$^{13}C/^{12}C$ (‰)	Conventional radiocarbon age	Age used for chronological model [cal yr BP]
Documental data	14	*Pinus*/*Eucalyptus* plantations			0 (1950 AD)
Beta- 371859	40	Peat	−27.5	650 ± 30	580
Beta-385973	68	Peat	−27.3	3340 ± 30	3575
Beta- 371860	113	Peat	−25.9	3480 ± 30	3800
Beta-371861	186	Peat	−26.6	4130 ± 30	4760

Beta-360118	260	Peat	−27.7	5910 ± 30	6740

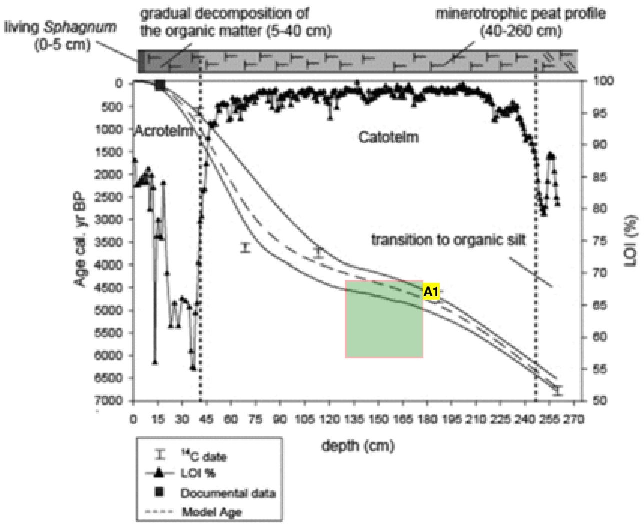

Fig. 3 Loss on Ignition (LOI), dates, depth-age model and sedimentary description.

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3.2 Sedimentology and organic matter

The main lithology of the first 2.60 m of La Molina is peat, and therefore organic material always constituted more than 55% of the sample. Stratigraphically, three levels can be distinguished (Fig. 3): (a) Acrotelm, from the top to a depth of 40 cm. In the first 5 cm the live *Sphagnum* gave way to slow decomposition with high hydration and an absence of mineralized peat; between 55% and 87% was organic material. (b) Catotelm, from 40 cm to 250 cm. Stratigraphy showed a high percentage of organic material (as low as 78% but almost always above 95%) and a progressive mineralization of the peat. (c) From 250 to 260 cm, the sample was characterized by a slight decrease in organic content and an increase in lime. This seems to indicate a transition of the peat bog to another organic phase (organic silts).

3.3 Pollen

The pollen diagrams from La Molina peat bog permitted us to reconstruct the vegetation changes in the studied zone over the last 6740 cal yr BP (Fig. 4). The diagram is divided into five pollen assemblage zones (PAZ). The following description refers to La Molina (MOL-2) followed by the identified zones (MOL-2/1, 2, 3, etc.), to emphasize the main characteristics of the diagram.

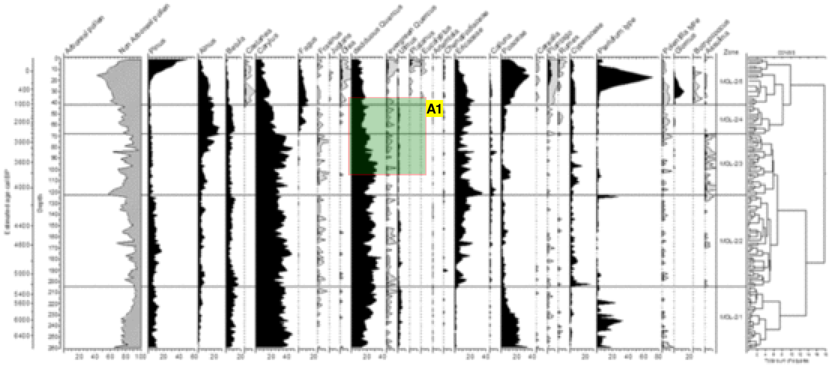

Fig. 4 Pollen diagram of La Molina.

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At the base of the diagram (MOL-2/1) between 6720 and 5250 cal yr BP, during the Neolithic, the values of the fern *Pteridium* stand out, together with the values of Poaceae. The percentages of arboreal pollen (AP) were characterized by a rising trend. In the landscape, *Corylus* and deciduous *Quercus* stand out in an environment of local openings. Percentages of *Pinus* and evergreen *Quercus* were low. The values for Cerealia were minimal.

Between 5250 and 4100 cal yr BP (MOL-2/2), the agricultural pressure began to decrease (disappearance of cereal signs) but during this period the curves of Ericaceae, deciduous *Quercus*, and *Corylus* appear and the increased evidence of Cyperaceae stands out. In general, AP percentages at this depth showed a slight decreasing trend and there was a decline in AP concentration that maintained low values.

Beginning in 4100 cal yr BP and lasting until 2650 cal yr BP, corresponding to the Bronze Age (MOL-2/3), the diagram shows some peaks of Ericaceae, the consolidation of *Calluna*, and some significant Poaceae peaks (c. 3800 cal yr BP). The AP curve shows a slightly increasing trend, despite major fluctuations in the values caused by various perturbations. This zone was characterized by the continuous presence of *Assulina*, indicative of a peat bog that was drier and increased in inverse proportions to *Alnus*, which had a large increase at the end of the zone. Low *Pinus* values (8%–10%) decreased by half (4%) and became residual.

After 2650 cal yr BP and until 1050 cal yr BP (MOL-2/4), the human pressure increased greatly, as indicated by the marked fall in AP, provoked in part by the strong decrease in *Corylus* at the beginning of the zone (c. 2650–2200 cal yr BP), which corresponds to the Iron Age. This phase coincided with the maximum values of *Alnus*, which declined after that point, and with high values of Poaceae and *Plantago*. In addition, this zone is characterized by the continuous *Fagus* curve that was consolidated in the landscape.

During the last 1050 cal yr BP (MOL-2/5), the fundamental characteristic is the great artificialization of the landscape. An open landscape was detected, with maximum values for Poaceae along with Cerealia and *Plantago*. The maximum for *Glomus*, indicating erosion, and *Pteridium aquilinum*, together with the appearance of *Castanea*, *Platanus*, *Eucalyptus*, and pine plantations, marked the last years of a highly transformed landscape in the last two centuries. The open forest landscape with few trees was clearly drawn by the abrupt fall in AP and in the marked trend of decline in *Alnus*, *Corylus*, *Fagus*, and Ericaceae. What stands out is that *Corylus* had never had such low percentage values in the previous 6740 years.

3.4 Sedimentary charcoal

The sieving method is used to reconstruct local fire frequency and to identify fire events (Whitlock and Larsen, 2001); therefore, charcoal accumulation rates (CHAR) served to identify a low frequency of fires over the past 3500 cal yr BP and a higher frequency with many charcoal peaks between 6740 and 3500 cal yr BP, a period in which a greater number of fire events of local origin were identified. The strong local component of these fires is evident because of the size (<0.250 mm^2) and number of particles present, which was unaffected by mass movements or abrupt sedimentary deposits, as indicated by Ti and Al data (Fig. 6). Therefore, the interpretation of the fires was based on the pollen zones and the types of landscape described; five situations were identified that are related to fuel availability (plant biomass) and climate phase (Figs. 5 and 6).

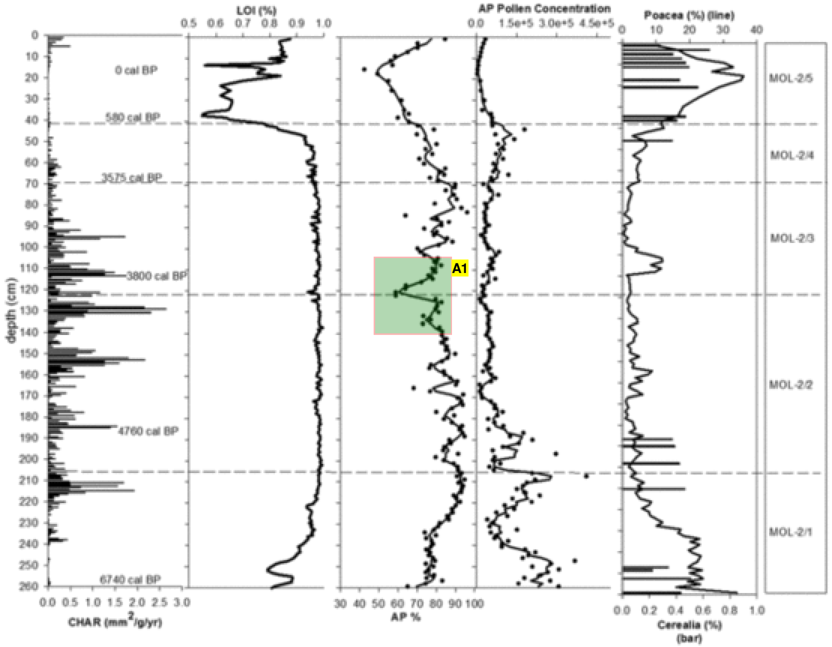

Fig. 5 Charcoal accumulation rate (CHAR), LOI and vegetation analysis from La Molina (MOL-2). The AP% and AP pollen concentration values are shown as scattered and 3-point moving average.

Annotations:

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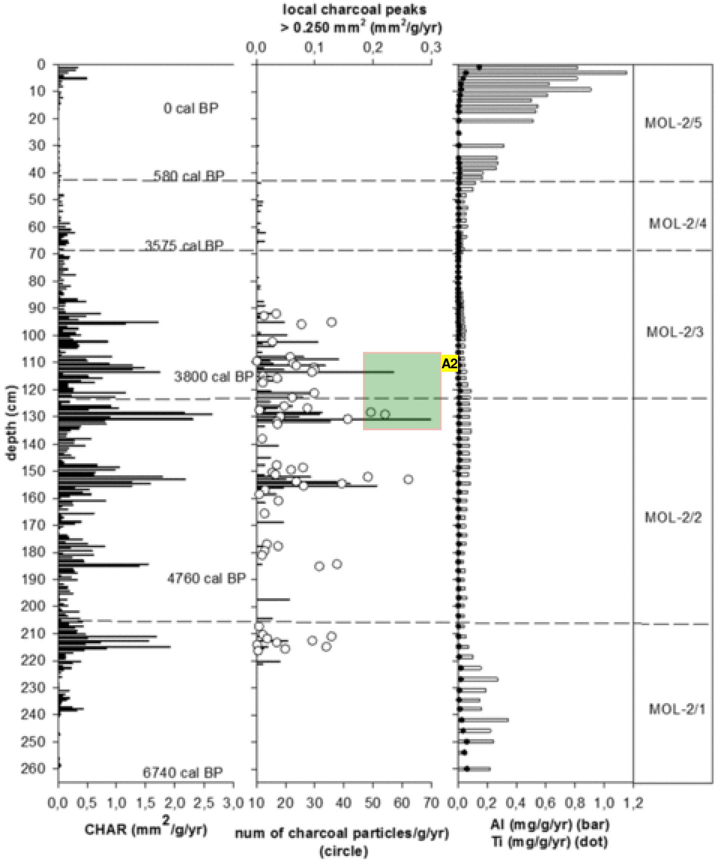

Fig. 6 Charcoal accumulation rate (CHAR), local charcoal peaks (charcoal particles > 0.250 mm^2) and Titanium (Ti) and Aluminum (Al) influx indicating erosion phenomena from La Molina (MOL-2).

Significant fire events occurred between c. 5500 and 5300 cal yr BP (MOL-2/1), with a progressive increase in fire activity that accompanied the decline in Poaceae and increase in pollen concentration (biomass); this coincided with Bond Event 4 and the increase in the IRD index (cold and dry). The high values of Cerealia and Poaceae coincided with a lack of fire activity.

Increased frequency of fires was accompanied by some local charcoal peaks that occurred at about 4850, 4430, and 4170 cal yr BP (MOL-2/2). This phase of fire events coincided with the progressive decline in AP percentages and AP pollen concentration and with the Bond Event 3 climate episode, with a higher magnitude than in Bond 4, according to the IRD index values.

The first part of the Bronze Age (MOL-2/3) coincided with two significant fire events (c. 3970 and 3640 cal yr BP). At this point, AP percentage values showed abrupt changes and there were low values for AP concentration, coinciding with peaks of Poaceae and an absence of Cerealia. In addition, this was the first time that the fire events coincided with low values on the IRD index in La Molina. After these events, low CHAR values appeared at the same time as Bond Event 2 occurred.

Beginning in 2650 cal yr BP (MOL-2/4), some fires occurred at the base of the zone, although low values persisted, reflecting a major change compared to previous zones, and coincided with the abrupt decline in AP% and a slight recovery of AP pollen concentration. The increase in Poaceae and the presence of Cerealia at the end of the zone again coincided with a lack of fire activity.

In the final part of the sequence, coinciding with the most recent centuries (MOL-2/5), there were almost no fires involving woody plants and the maximum values observed were Poaceae and Cerealia. Fluctuations in the IRD index cannot be compared with undetected fires fueled by herbaceous species.

4 Discussion

4.1 Forests and the absence of pines at La Molina

From the pollen diagram (Fig. 4), we can deduce that La Molina has never had large pine forests during the Holocene. This observation is confirmed in other pollen diagrams (reaching only 15% *Pinus* sp.) of the Iberian Atlantic coast (García-Amorena et al., 2008; Moreno et al., 2011) and fits with the absence of macroremains of pine in the caves. Peña-Chocarro et al. (2005a) identified several wood charcoal remains in different Neolithic levels in El Mirón cave, Cantabria, but *Pinus* does not appear. Therefore, the *Pinus* pollen found in the pollen diagram of La Molina must have a distant origin, given the low percentages that were found. Judging from recent vegetation studies and the dominant winds from the southwest (Rasilla-Álvarez, 1999), where primary pine forests do exist, we must look in that direction for the origin of the pine pollens that reach the study area.

Does this mean that pines were never a major presence in La Molina during the Holocene? Two considerations must be taken into account. First, there was a very large presence of pines in the Upper Pleistocene, Late Glacial, and early Holocene. The basal C^{14} dating at La Molina (18 840 cal yr BP) should allow us to address this question in the near future. For now, we can affirm that the paleobotanic deposits of these periods with macroremains and montane pine pollens are very numerous in the mountain range. Baena et al. (2005) reported a certain degree of homogeneity in their analysis of pollen from the Upper Pleistocene found in caves, in terms of the composition of vegetation, mainly *Pinus* and *Juniperus*. In anthracological analysis, *Pinus* also dominated the entire excavated sequence. Some authors affirm that a montane forest zone formed in the northeast *Pinus sylvestris* during the early and mid-Holocene and *Quercus* woodlands were present throughout the lowlands, with woodlands of *Betula* at higher elevation probably forming the tree line in the Cantabrian Mountains (Allen et al., 1996; Aedo et al., 1991), an idea that could correspond to the arrival of the Oceanic climate at the beginning of the Holocene and would fit with the major presence of deciduous *Quercus* in the studied sequence. The available pollen data for this area concur with these findings, showing that deciduous *Quercus* species expanded at the beginning of the Holocene. The presence of wood belonging to *Quercus robur* and *Q. petraea* at almost all the study sites shows that these species grew on the Cantabrian coast during the Holocene (García-Amorena et al., 2008). According to Hewitt (1999), the oak survived in refuge areas to the north of the Cantabrian Mountain chain during the last glaciation.

Second, in zones where oak groves and pines overlap, the latter would probably be displaced in times of fire occurrence. The presence of regenerating species such as some types of *Quercus* suggests an advantage for this genus and is very important in fashioning the landscape. In peat bogs near the present study area, Mariscal (1983, 1993) identified a decline in *Pinus* pollen at about 4000 BP in data from El Cueto de la Avellanosa and in the peat bog at Alsa, simultaneous with correlated increases in Ericaceae, Cyperaceae, and Poaceae; according to the author, this shows a clear human impact. At the time this occurred in the pollen diagram at La Molina, the percentage of *Pinus* fell to about half. Rubiales et al. (2008) suggest that fire-resilient communities and re-sprouters would have been favored over *P. sylvestris*, which is much more sensitive to human disturbance. According to Muñoz-Sobrino (2001), the protagonists in the most humid zones of the Cantabrian range, where *Pinus* is less important, are *Corylus* and *Quercus*. Deforestation, burnings, and grazing led to heathland dominated by Ericaceae, *Calluna*, Cistaceae, and Fabaceae. Fires strongly affected the Cantabrian pinewoods (*Pinus sylvestris*), which could not re-sprout (Sevilla, 1997). In fact, the arboreal masses that surround the northern subplateau have low levels of interpopulation diversity, which explains a recent (postglacial) fragmentation of those masses (Robledo-Arnucio et al., 2005). In this way the mitochondrial marker survey reveals a single haplotype restricted to the Pyrenees and the Cantabrian mountains (Cheddadi et al., 2006).

The presence of pine pollen in the upper portion of the diagram is due to recent plantations. Historical sources show that there were no significant masses of pinewoods in this region in the mid-19th century (Madoz, 1984; García-Martino, 1862).

4.2 Holm oak forests, an ancient relict

There are very low *Quercus ilex*-type pollen percentages in La Molina throughout the sequence, which would indicate a residual presence in accordance with a small distribution area. At present, Mediterranean-type evergreen oak forests of *Quercus ilex* are scattered in rocky elevations of limestone all along the coast, as well as in mountain limestone canyons as relict forests that include many Tertiary relict species, such as *Laurus nobilis* (Costa et al., 2005). The insignificance of these forests during the Holocene is reinforced if we consider that *Quercus ilex*-type suggests an efficient upward wind dispersal, which warns against a straightforward interpretation of its presence in the pollen diagrams (Cañellas-Boltà et al., 2009). The pollen data obtained indicate that the holm oak groves constitute an older relict from a small distribution area and suggest that human disturbance has not favored this species during the Holocene, although the population has increased recently.

4.3 Stable formations of hazelnut and alder

The large quantity of *Corylus* pollen in our diagram and in the diagrams from the Cantabrian range is an important point. Our data agree with those of Mariscal (1983) in the pollen diagram for El Cueto de la Avellanosa, which shows extensive hazelnut covering mountainsides, valley floors, and protected zones. Lara et al. (2005) also claim that hazelnut is not a strictly riparian formation because it extends to the mountainsides in regions without water stress. Hazelnut only needs to take advantage of regular edaphic and atmospheric humidity such as that which can occur in La Molina. The Enol Lake pollen sequence (Moreno et al., 2011) reflects a rapid and intense development of mesophilous forests beginning at the onset of the Holocene, probably due to the proximity to refuge areas during glacial conditions. This evidence in the pollen diagrams partially contradicts González-Pellejero et al. (2014), who attributed the presence of *Corylus* and *Betula* in a nearby core sample to a certain capacity of the species to colonize altered spaces. Even if it is true that this dynamic exists today, we cannot extrapolate it to the past and it seems more likely that there were stable and mature populations in the area of La Molina.

With respect to *Alnus*, it has now been related to river banks with a superficial water level, to swampy areas, and very humid soil mountainsides, frequently forming alder woods. In the peat bog studied here, swampy alder woods are relatively common today. In the past, a major colonization occurred over the past 3500 cal yr BP, which would indicate a change in climate, geomorphology, or human management of the territory; this change would favor their increase in the immediate surroundings, as high percentage values of these taxa are associated with the immediate presence of alder forests (Huntley and Birks, 1983). Something similar occurs in the Enol Lake area where, after 4650 cal yr BP, a small decrease in the arboreal percentages can be seen. In contrast, the percentages increased for other taxa, including *Alnus*. Therefore, a change in the hydric distribution of the peat bog would be noted, decreasing the *Sphagnum* zones and increasing small, much more superficial, rivulets of water, facilitating colonization of its margins by *Alnus*.

4.4 Provenance of beech

Fagus appears in the zone around 2800 cal yr BP (quite similar to the dates proposed by Mariscal in 1983 and 1986), and most of the reported percentages exceed 5%. Huntley and Birks (1983) indicate that >5% may imply the regional presence of beech-dominated woodland. However, according to Cañellas-Boltà et al. (2009), the case of *Fagus* is noteworthy because when the tree is present at lower levels its pollen percentages reach maximum values at 800 m higher. According to Muñoz-Sobrino et al. (2009), this forest expansion at the end of the mid-Holocene in the Cantabrian seems initially to have been due to a warmer climate and a consequent decline of the hyperoceanic conditions on mid-altitude hilltops. This synchrony with *Alnus* colonization supports the idea that climate could be the spark that sets off this situation, which perfectly complements the human and geomorphology causes already discussed.

Muñoz-Sobrino et al. (2009) indicate that *Fagus* expanded in the Cantabrian mountains after 4000 cal yr BP, but a first stage of increased beech pollen existed around the 8.2 event and subsequently retreated during the mid-Holocene. The authors say that the pollen records for *Fagus* in northwest Iberia during this period suggest that it survived in moister and warmer areas (near the coast or at inner mid-altitude locations), where it was embedded in mixed deciduous or deciduous/coniferous forest, and from which it gradually began to expand as a result of climate improvement during the early and mid-Holocene. The presence of beech is demonstrated by macrofossils during the last glacial maximum and the Late-glacial period in the Cantabrian range (Uzquiano, 1992). *Fagus* and other mesophytes appear in Enol Lake (Moreno et al., 2011), at the Younger Dryas and during the beginning of the Holocene, pointing to the presence of refuge areas in the region. In several diagrams from the northern Iberian peninsula (Ramil-Rego et al., 1998a,b), an interesting feature of the *Fagus* curves in some of the pollen diagrams is their intermittent character and the discontinuity of the presence of beech pollen grains, which occurs in other diagrams from the rest of Europe but was not clearly evidenced in this pollen diagram of La Molina.

In the Villaviciosa estuary (Asturias, North Spain), García-Antón et al. (2006) argue that the spread of beech has been detected, albeit discreetly, since around 3000 years ago in this deposit and was probably favored by human activities; they reveal evidence of its presence in at least 7000 cal yr BP. This evidence also corroborates the hypothesis of the nearby presence of refuge areas in the region.

In the Iberian range, *Fagus* forests are represented by at least a relict population going back to the Upper Pleistocene. The first Fagus occurrence is documented in the Laguna Grande before 20 526–20 000 cal yr BP (Ruiz-Zapata et al., 2002). From c. 8000–5600 cal yr BP, *Fagus* began to be abundant in Sierra de Cebollera (Hoyos de Iregua, Nieva, and La Chopera) and the expansion phase began in c. 4500 cal yr BP in many parts of the northwestern Iberian range. However, it was not until c. 3000–2000 cal yr BP when *Fagus* became widespread in most of the sites, reaching higher percentages (López-Merino et al., 2008). According to Jalut et al. (2010), beech was possibly present early on but its spread was late and limited. At La Mata (Province of Leon, further southwest), sporadic occurrences have been observed from around 11 000 cal yr BP.

This idea is also supported by genetic studies (Magri et al., 2006) that suggest the existence of small isolated populations before beech forests were abundant in these areas. The nuclear markers very effectively distinguished different populations in Spain and France, whose long-term persistence is confirmed by the macrofossil and pollen records. A differentiated isozyme group is found in the Cantabrian Mountains and is clearly separated from the other groups.

On the other hand, some authors (Peñalba, 1994) suggest the arrival of the recent *Fagus* populations from Eastern Europe during the *Fagus* migration. Recent *Fagus* inventories in this area (Rodríguez-Guitán, 2004) suggest that the expansion of beech in western Iberia still may be in progress, which could agree with Magri et al. (2006), who used chloroplast microsatellites that reveal the presence of a single haplotype widespread in Europe (including all populations of the Iberian Peninsula), a typical Italian haplotype, and some divergent haplotypes in the southern part of the Balkan Peninsula. The finding of a unique chloroplast haplotype in these populations suggests that they are remnants of a very important pre-Holocene diffusion of beech extending at least from the Cantabrian Mountains to the eastern Alps. In addition, isozyme data reveal the presence of an isozyme group in the Cantabrian range that can be traced back to Slovenia–Istria and possibly southern Bohemia–southern Moravia. That group spread from these regions and reached central and northern Europe, extending from northwest France to the eastern Carpathians. The authors indicate that this result is likely due to a lack of resolution.

Given that *Fagus* behaves like a eurioic species with broad ecological valence in the center of its distribution area (Costa et al., 2005), if a refuge existed nearby its presence would have been detected in the pollen diagram of La Molina. In that pollen diagram, *Fagus* reaches its maximum at around c. 1000 cal yr BP when arboreal pollen percentages are decreasing. This episode is evidenced in most of the sequences of the Iberian Peninsula and could be explained within the framework of anthropic action. In this sense, fire could have helped to create the conditions necessary for *Fagus* expansion. In the western Cantabrian range, Muñoz-Sobrino et al. (2009) report a major increase in beech around 1500 cal yr BP, while total tree pollen percentages fell and heathland began to expand. Given that the decline affected both relatively thermophilous taxa and cold-tolerant genera, the apparently contradictory expansion of *Fagus* may have been facilitated by human activity.

According to López-Merino et al. (2008), the development of *Fagus* in the Iberian range (Sierra de Neila, Sierra de Urbión, and Sierra de la Demanda) since c. 5900–4200 cal yr BP has been supported by a moderate human impact. For instance, grazing has created openings, which favored the establishment of *Fagus*. In areas where anthropic pressure has been stronger, *Fagus* forests declined.

Jalut et al. (2010) suggest that the *Fagus* occurrences might be the consequence of a very strong human impact. Small-scale clearances of high woodlands might in some cases have been followed by rapid tree recolonization, a situation in which the competitive capacity of beech would again give it an advantage over other species (Muñoz-Sobrino et al., 2009). According to González-Pellejero et al. (2014), the progression of *Fagus* only occurs if repeated burnings disappear, a fact not clearly evidenced in our sequence, where Fagus appears when fire intensity decreases but does not disappear. This makes the recent spread in La Molina difficult to understand. We cannot discard the hypothesis that large fires accompanied by major processes of human occupation do not favor *Fagus*, but moderate fires and oak grove openings do.

4.5 Fire, human activity, and climate

There is no doubt that fire is now mostly associated with human intervention and with adequate knowledge of favorable meteorological conditions (Carracedo, 2015; Carracedo et al., 2009). Was this the case throughout the Holocene? Some studies have shown that climate could have influenced fires that occurred at the beginning of the Holocene, leading to the burning of deciduous growth (Gil-Romera et al., 2014), but how might climate have affected processes of human occupation and intervention based on the use of fire, which beyond any doubt occurred in Cantabria? In previous studies, we have shown the importance of Bond cycles and the climate influence in the processes of human adaptation to living in high mountain areas (Pèlachs et al., 2011). Recently, Burjachs and Expósito (2014) highlighted the coincidence of many charcoal peaks and Bond events and suggested this could mean fires are more conditioned by the climate than by anthropogenic impact. In southeastern Iberia, Gil-Romera et al. (2010) state that the presence of human activity since the Neolithic would have enhanced the effects of the mid-late Holocene arid pulses, increasing fire activity. While it is true that fires are now provoked, independent of the favorability of climate conditions, in the past the Bond cycles, especially Bond 3 and 4, had a certain relationship with high levels of fire events.

Of course, the sedimentary charcoals we work with correspond to the burning of woody species. This means we do not know whether an open landscape, such as the one at the beginning of the 6740 cal yr BP sequence and again starting during the Bronze Age, was associated with a decrease in fire events because there were no sedimentary charcoals or because some of them were from *Ulex*, a plant whose stem has a very small woody zone. The presence of some anthropic indicators could represent an absence of woody plants, although fires that burned herbaceous plants continued to occur, as they do now. This process could perfectly well have occurred all through the past three millennia with a greater presence of maintenance fires in the system. Some maintenance fires also could have occurred during the Neolithic, and the climate changes that explain the Bond cycle of about 5500 cal yr BP ago could have had a wider radius of activity (Feurdean et al., 2012). Most Bond events do not have a clear climate signal. Some correspond to periods of cooling; others coincide with dry phases in some regions. If we combine biomass (which means combustible material) with meteorological conditions that favor a dry environment, the fire potential is greater, as observed at La Molina (Fig. 7).

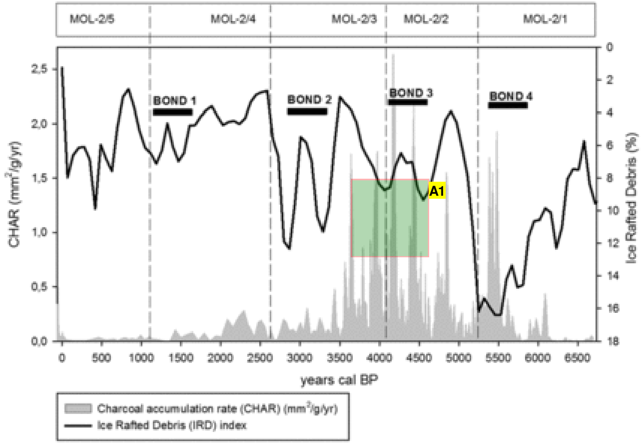

Fig. 7 Comparison of CHAR and Ice Rafted Debris (IRD) index. IRD (%): Stack of MC52-V29191 + MC21-GGC22 (Bond et al., 2001). To indicate warm conditions upwards, the plotted scales of the IRD records have been inverted. Note that the *x*-axis is plotted on calibrated ages.

Annotations:

A1. a better quality image has been attached

Climate, together with the human factor, explains how mountain areas were exploited as occasional small settlements (Arias-Cabal, 1990) increased in number and importance with the domestication that marks the transition to the Neolithic period. The transformation of economic systems is accelerated from 7000 years ago, when contacts with other human groups introduced agriculture and livestock. The opening of spaces for grazing and agriculture is characterized by episodes of "cultural" fires. Forest clearance has taken place since the Neolithic expansion of agriculture and livestock. The cultivation of Cerealia and Fabaceae, the use of fire, the stone industry, mining, and logging all progressively led to the demise of the area's forests over the last 6000 years (Martínez-Cortizas et al., 2005). The presence of free-threshing wheat at El Mirón cave opens up an interesting subject for debate, as naked wheats have been absent from the early Neolithic archeobotanical record of the coastal Cantabrian region (Peña-Chocarro et al., 2015b) until now. In the Monte Areo mire in Asturias, northern Spain, the first evidence of human transformations of the landscape dates back to 7300 cal yr BP and seems to have been related to pastoral practices (López-Merino et al., 2010). The first appearance of Cereal-type pollen at 6735-6495 cal yr BP shows that the spread of agriculture on the Atlantic coast (northern Iberia) was a relatively rapid process. The base of the sequence from La Molina, until older results are obtained, would confirm these initial findings. For the Atlantic regions, the dates are more recent than those of the Mediterranean part of the Iberian Peninsula (Pérez-Obiol et al., 2011). Based on the available data, the arrival of agriculture in the Atlantic coastal zone may have occurred almost a millennium later than on the eastern and southern Mediterranean coasts. Further southwest, the first anthropogenic indicators are recorded around 7600–7700 cal yr BP with increasing percentages of Ericaceae and *Calluna*, as well as a regular presence of *Plantago* and Chenopodiaceae and occurrences of Cerealia (Jalut et al., 2010).

In our case, despite the clear appearance of the Ericaceae and *Calluna* pollen curve since 5250 cal yr BP at La Molina, Cerealia disappears in the sequence and does not become continuous until the most recent centuries. This has been related to local aspects of the peat bog because there is no regional explanation that would explain its absence. As other authors have pointed out, farming activities and their influence in the configuration of the environment become more important during the Bronze and Iron Age and much stronger and more evident beginning in the Roman period. The seeds found in archeological sites in the Basque country (Zapata, 1997) suggest a relatively developed system, with diversification of crops, since the Bronze Age. This information coincides in part with the hypothesis proposed by Hernández-Beloqui et al. (2015) (Sould be linked). They suggest that the anthropization of the landscape was constant throughout the Late Holocene, and no clear differences existed between the different periods, particularly between the Iron Age and the Romanization. Finally, we cannot neglect to point out the importance of arboreal plantations in the most recent century. Pinewoods, *Platanus*, *Eucalyptus*, etc., constitute a clearly cultural group of species that very recently have achieved their maximum values.

5 Conclusions

The present study of La Molina peat bog in Puente Viesgo, Cantabria, identified the main vectors affecting Cantabrian vegetation dynamics, demonstrating the fundamental role of fire activity in the configuration of the plant landscape in the last 6740 cal yr BP. Beginning in the Neolithic period, burns with a clear human influence could be detected that had benefited from two key characteristics of the Holocene:

1) Climate phases coinciding with Bond cycles 3 and 4 that likely contributed to increased recurrence of synoptic situations favoring fire activity.

2) Periods of abundant biomass in which highly productive vegetation predominated and there was a notable capacity for recovery and regrowth.

The combination of human influence, climate, and type of vegetation determined the plant landscape as some species adapted to fire activity better than others. This is the case of the Cantabrian oak groves that burned regularly because their high primary productivity and biomass ensured the availability of combustible material. It appears that human intervention took advantage of certain climatic phases such as Bond 4, during the Neolithic, to increase fire activity. Therefore, fire and climate are two of the major vectors of change in the mid-Holocene, which has been characterized by a change in forest density accompanied by a significant increase in Ericaceae, typical of secondary succession phases. The regenerative capacity of *Quercus* has meant that fire favors its succession, and therefore, despite the disturbances, it has been able to reach a maximum during Bond 3. After this episode, and due to human management, the oak groves and other deciduous vegetation would burn again during the Metal Ages. This process also would have had to affect some distant zones, probably higher areas, as shown by a 50% decrease in *Pinus* during this phase (c. 3800 cal yr BP).

In general, despite the regenerative capacity of taxa such as *Quercus* or *Corylus*, fire activity helped to decrease arboreal coverage and density as the Holocene advanced, which has tended to form more varied mosaics with forest, scrub, and pasture. The relevant fire events ended during the Bronze Age (c. 3500 cal yr BP).

The current distribution of *Corylus* is a direct result of the disturbance that occurred between about 2800 and 2600 cal yr BP. This also coincided with the veritable eruption of beech in the landscape, so that this species appeared in a landscape that had been greatly disturbed, with lower fire activity, which could have encouraged the colonization. From current data, it is difficult to determine provenance, although the low value obtained before the arrival of beech indicates that if there were Cantabrian refuges they were very small. Our current knowledge suggests that the appearance of beech in the landscape might coincide with the colonization processes that originated in refuge zones located in the northwest Iberian range. In this context of high-intensity human modification, the increased presence of *Alnus* (c. 3500 cal yr BP) appears to indicate that the peat bog would have a different hydric distribution, increasing small flows of surface water that would allow the colonization of *Alnus* on their banks. This process might have been the result of climate, human influence, or local geomorphological processes.

One of the only cases in which fire does not seem to have had any influence is the distribution of holm oak groves. *Quercus* evergreens constitute an ancient relict, with a small distribution area, suggesting that neither human disturbance nor climate changes have favored this species during the Holocene, if we exempt the anthropic action of the past two centuries.

The configuration of the current landscape goes back to the Middle Ages, when cereals and Poaceae had a large presence in many of the ancient forest spaces and the percentage of the main arboreal species experienced great declines, with major erosion processes that would modify the peat bog. In this sense, the *Corylus* values stand out; they are at their lowest percentage of the landscape in the past 6740 cal yr BP.

Therefore, the scant importance of sedimentary charcoal values since the Early Middle Ages can only be attributed to the fact that most fire activity was the product of efforts to maintain already open spaces. In order to find a similar disturbance in terms of fire activity and anthropic indicators, we must look back to the first human impact identified in the pollen diagram. This corresponds to the beginning of the sequence (c. 6200–6740 cal yr BP), when there is almost no evidence of fire activity in woody plants, and Poaceae and Cerealia occupy large surface areas.

In La Molina, there has never been a landscape like the present one in the past 6000 years. With the artificialization of the past century, previously unknown processes have appeared, such as increased holm oak populations. The current landscape also includes the plantations and management of *Platanus*, *Eucalyptus Juglans* and *Castanea*. *Pinus* does not appear to have replaced other forests, judging by the low level of forest recovery in the zone prior to these plantations.

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References

Aedo C., Diego C., García-Codron J.C. and Moreno G., El bosque en Cantabria, 1991, Universidad de Cantabria; Santander.

Arias-Cabal P., Adaptaciones al medio natural de las sociedades humanas de la región Cantábrica durante el Boreal y el Atlántico, In: Cearreta A. and Ugarte F.M., (Eds.), *The Late Quaternary in the Western Pyrenean Region, Servicio de Publicaciones* 1990, Universidad del País Vasco; Álava, 269–283.

Armendáriz Gutiérrez A. and Arias Cabal P., El desarrollo de las sociedades complejas. Cantabria durante los milenios III y II a.c., In: Cortina Suárez, (Ed), *Historia de Cantabria* **vol. 3**, 2007, Santander; Cantabria, 57–64.

Baena J., Carrión E., Ruiz-Zapata M.B., Sesé C., Yravedra J., Jordá J., Bárez S., Uzquiano P., Velázquez R. and Manzano E., Paleoecología y comportamiento humano durante el Pleistoceno superior en la comarca de La Liébana: la secuencia de la cueva de El Esquilleu (Occidente de Cantabria, España), In: Montes R. and Lasheras J.A., (Eds.), *Neandertales cantábricos, estado de la cuestión. Monografías Museo de Altamira 20, Santander,* 2005, 461–487.

Bailey G. and Spikins P., Mesolithic Europe, 2008, Cambridge University Press; Cambridge.

Baker P.A., Fritz S.C., Garland J. and Ekdahl E., Holocene hydrologic variation at Lake Titicaca, Bolivia/Peru, and its relationship to North Atlantic climate variation, *J. Quat. Sci.* **20** (7–8), 2005, 655–662.

Bal M.-C., Pèlachs A., Pérez-Obiol R., Julià R. and Cunill R., Fire history and human activities during the last 3300 cal yr BP in Spain's Central Pyrenees: the case of the Estany de Burg, *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **300**, 2011, 179–190.

Battarbee R.W., Gasse F. and Stickley C.E., Past Climate Variability through Europe and Africa, 2004, Springer; New York.

Blaauw M., Methods and code for 'classical' age-modelling of radiocarbon sequences, *Quat. Geochronol.* **5**, 2010, 512–518.

Blas-Cortina M.A. de and Fernández-Manzano J., Asturias y Cantabria en el primer milenio a.c., *Complutum* 1992, 399–416.

Bond G., Showers W., Cheseby M., Lotti R., Almasi P., deMenocal P., Priore P., Cullen H., Hajdas I. and Bonani G., A pervasive millennial-scale cycle in North Atlantic Holocene and glacial climates, *Science* **278** (5341), 1997, 1257–1266.

Bond G., Kromer B., Beer J., Muscheler R., Evans M.N., Showers W., Hoffmann S., Lotti-Bond R., Hajdas I. and Bonani G., Persistent solar influence on North Atlantic climate during the Holocene, *Science* **294**, 2001, 2130.

Burjachs F. and Expósito I., Charcoal and Pollen Analysis: Examples of Holocene Fire Dynamics in Mediterranean Iberian Peninsula, 2014, Catena http://dx.doi.org/10.1016/j.catena.2014.10.006.

Cañellas-Boltà N., Rull V., Vigo J. and Mercadé A., Modern pollen vegetation relationships along an altitudinal transect in the central Pyrenees (southwestern Europe), *Holocene* **19** (8), 2009, 1185–1200.

~~Cantabria~~Gobierno de Cantabria, Gobierno del Principado de Asturias (Sould be reordered) ~~Gobierno de~~, ~~Asturias~~ ~~Gobierno del Principado de~~ and ~~Vasco~~ ~~Gobierno~~Gobierno Vasco (This sentence must end with a "period"), Palaeolithic Cave Art of Northern Spain. Proposal of Extension to the Inscription of Properties in the UNESCO List of World Heritage, 2008, Santander http://whc.unesco.org/en/list/310/documents/.

Carcaillet C., A spatially precise study of Holocene fire history, climate and human impact within the Maurienne valley, North French Alps, *J. Ecol.* **86**, 1998, 384–396.

Carcaillet C., Bouvier M., Fréchette B., Larouche A.C. and Richard P.J.H., Comparison of pollen-slide and sieving methods in lacustrine charcoal analysis for local and regional fire history, *Holocene* **11**, 2001, 467–476.

Carcaillet C., Bergman I., Delorme S., Hornberg G. and Zackrisson O., Long-term fire frequency not linked to prehistoric occupations in northern Swedish boreal forest, *Ecology* **88** (2), 2007, 465–477.

Carcaillet C., Hörnberg G. and Zackrisson O., Woody vegetation, fuel and fire track the melting of the Scandinavian ice-sheet before 9500 cal yr BP, *Quat. Res.* **78** (3), 2012, 540–548.

Carracedo V., Incendios forestales y gestión del fuego en Cantabria, (Unpublished PhD)2015, Universidad de Cantabria; Santander, 574.

Carracedo Martín V., Diego Liaño C., García Codron J.C. and Rasilla Álvarez D., Clima e incendios forestales en Cantabria: evolución y tendencias recientes, *Pirineos* **164**, 2009, 33–48.

Carrión-García J.S., (Ed), *Paleoflora y paleovegetación de la Península Ibérica e Islas Baleares: Plioceno-Cuaternario,* 2012, Ministerio de Economía y Competitividad y la Universidad de Murcia; Madrid.

Cheddadi R., Vendramin G.G., Litt T., François L., Kageyama M., Lorentz S., Laurent J.-M., Beaulieu J. L. de, Sadori L., Jost A. and Lunt D., Imprints of glacial refugia in the modern genetic diversity of Pinus sylvestris, *Glob. Ecol. Biogeogr.* **15**, 2006, 271–282.

CITIMAC, Mapa edafológico de Cantabria 1:50000 (hoja 58). Universidad de Cantabria – Dirección General de Desarrollo Rural del Gobierno de Cantabria, 2003–2005, Santander.

Costa M., Morla C. and Sainz-Ollero H., (Eds.), *Los bosques ibéricos: Una interpretación geobotánica,* 2005, Planeta; Barcelona.

Cunill R., Soriano J.M., Bal M.-C., Pèlachs A. and Pérez-Obiol R., Holocene treeline changes on the south slope of the Pyrenees: a pedoanthracological analysis, *Veg. Hist. Archaeobot.* **21** (4–5), 2012, 373–384.

Díaz-Casado Y., El arte rupestre esquemático en Cantabria, 1993, Universidad de Cantabria, Santander.

Ezquerra-Boticario F.J., Influencias antrópicas en la evolución de la vegetación en la montaña cantábrica: del Postglaciar al Neolítico, In: *Actas IV Congreso Forestal Español,* 2005 http://secforestales.org/publicaciones/index.php/congresos/article/view/7102/7025.

Fano M.A., Cubas M. and Wood R., The first farmers in Cantabrian Spain: contribution of numerical chronology to understand an historical process, *Quat. Int.* **364**, 2015, 153–161.

Fernández Prieto J.A., Fernández Ordóñez M.C. and Collado Prieto M.A., Datos sobre la vegetación de las «turberas de esfagnos» galaico-asturianas y orocantábricas, *Lazaroa* **7**, 1987, 443–471.

Feurdean A., Spessa A., Magyari E.K., Willis K.J., Veres D. and Hickler T., Trends in biomass burning in the Carpathian region over the last 15,000 years, *Quat. Sci. Rev.* **45**, 2012, 111–125.

Finsinger W., Kelly R., Fevre J. and Magyari E.K., A guide to screening charcoal peaks in macrocharcoal-area records for fire-episode reconstructions, *Holocene* **24** (8), 2014, 1002–1008.

Florschütz F. and Menéndez-Amor J., Beitrag zur Kenntnis der quartären Vegetationsgeschichte Nordspaniens, *Veröffentlichungen Geobotanisches Inst. Eidg. Tech. Hochsch. Stift. Rübel, Zürich* **37**, 1962, 68–73.

García-Amorena I., Morla C., Rubiales J.M. and Gómez-Manzaneque F., Taxonomic composition of the Holocene forests or the northern coast of Spain, as determined from their macroremains, *Holocene* **18**, 2008, 819–829.

García-Antón M., Gil-Romera G., Pagés J.L. and Alonso-Millán A., The Holocene pollen record in the Villaviciosa Estuary (Asturias, North Spain), *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **237**, 2006, 280–292.

García-Martino F., Bosquejo dasográfico de la provincia de Santander, 1862, Junta General de Estadística; Madrid.

Gil-Romera G., Carrión J.S., Pausas J., Fernández S. and Burjachs F., Holocene fire activity and vegetation response in South-Eastern Iberia, *Quat. Sci. Rev.* **29**, 2010, 1082–1092.

Gil-Romera G., González-Sampériz P., Lasheras-Álvarez L., Sevilla-Callejo M., Moreno A., Valero-Garcés B., López-Merino L., Carrión J.S., Pérez-Sanz A., Aranbarri J. and García-Prieto Fronce E., Biomass-modulated fire dynamics during the Last Glacial–Interglacial Transition at the Central Pyrenees (Spain), *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **402**, 2014, 113–124.

González-Pellejero (The reference : "Gobierno de Cantabria, Gobierno del Principado de Asturias and Gobierno Vasco" should be placed before this reference) R., Allende F., López-Sáez J.A., Frochoso-Sánchez M., Alba-Sánchez F. and Abel-Schaad D., Dinámicas naturales y antrópicas en los paisajes vegetales de los valles internos de Cantabria occidental (Norte de España), *Bol. la Asoc. Geógr. Españoles* **65**, 2014, 139–165.

Grimm E.C., CONISS: AFORTRAN77 program, *Comput. Geosci.* **13**, 1987, 13–35.

Grimm E.C., TILIA and Tilia. Graph, 1991, Illinois State Museum, Springfield.

Hewitt G.M., Post-glacial re-colonization of European biota, *Biol. J. Linn. Soc.* **68** (1–2), 1999, 87–112.

Huntley B. and Birks H.J.B., An Atlas of Past and Present Pollen Maps for Europe: 0–13000 Years Ago, 1983, Cambridge University Press; Cambridge.

Jalut G., Turu-Michels V., Deboubat J.J., Otto T., Ezquerra J., Fontugne M., Belet J.M., Bonnet L., García-de-Celis A., Redondo-Vega J.M., Vidal-Romaní J.R. and Santos L., Paleoenvironmental studies in NW Iberia (Cantabrian range) Vegetation history and synthetic approach of the Last Deglaciation phases in western Mediterranean, *J. Paleo.* **297** (2), 2010, 330–350.

Lara F., Garilletti R. and Calleja J.A., La vegetación de ribera de la mitad norte española. Serie Monografías. Centro de Estudios y Experimentación de Obras Públicas, 2005, Ministerio de Fomento; Madrid.

López de Heredia U., Filogeografía de las especies esclerófilas de Quercus (Q. suber L., Q. ilex L. y Q. coccifera L.) en el Mediterráneo Occidental, 2006, (Unpublished PhD. Universidad Politécnica de Madrid).

López-Merino L., Paleoambiente y antropización en Asturias durante el Holoceno, 2009, (Unpublished PhD, Universidad Autónoma de Madrid).

López-Merino L., López-Sáez J.A., Ruiz-Zapata M.B. and Gil-García M.J., Reconstructing the history of beech (*Fagus sylvatica* L.) in the north-western Iberian Range (Spain): from Late-Glacial refugia to the Holocene anthropic-induced forests, *Rev. Paleobot. Palynol.* **152**, 2008, 58–65.

López-Merino L., Martínez-Cortizas A. and López-Sáez J.A., Early agriculture and palaeoenvironmental history in the North of the Iberian Peninsula: a multi-proxy analysis of the Monte Areo mire (Asturias, Spain), *J. Archaeol. Sci.* **37**, 2010, 1978–1988.

Madoz P., Diccionario geográfico-estadístico-histórico de España y sus provincias de Ultramar, 1845–1850, Madrid. Provincia de Santander (edición facsímil), Ámbito-ESTVDIO, Valladolid, 1984.

Magny M., Holocene climate variability as reflected by mid-European lake-level fluctuations and its probable impact on prehistoric human settlements, *Quat. Int.* **113**, 2004, 65–79.

Magri D., Vendramin G.G., Comps B., Dupanloup I., Geburek T., Gömöry D., Latałowa M., Litt T., Paule L., Roure J.M., Tantau I., van der Knaap W.O., Petit R.J. and de Beaulieu J.-L., A new scenario for the Quaternary history of European beech populations: palaeobotanical evidence and genetic consequences, *New Phytol.* **171**, 2006, 199–221.

Maldonado F.J., Evolución tardiglaciar y holocena de los macizos del Noroeste Peninsular, (Unpublished PhD)1994, Escuela Técnica Superior de Ingenieros de Montes. Universidad Politécnica de Madrid.

Mantecón-Callejo L., Evidencias de minería romana en el arco sur de la Bahía de Santander, In: Fernández-Ibáñez C. and Ruiz-Cobo J., (Eds.), *La Arqueología de la Bahía de Santander,* 2003, Fundación Marcelino Botín, Santander, 651–680.

Mariscal B., Estudio polínico de la turbera del Cueto de la Avellanosa, Polaciones (Cantabria), *Cad. do Lab. Xeolóxico Laxe* **5**, 1983, 205–226.

Mariscal B., Análisis polínico de la turbera del Pico Sertal, de la Sierra de Peña Labra. Reconstrucción de la paleoflora y de la paleoclimatología durante el Holoceno en la zona oriental cantábrica, In: López-Vera F., (Ed), *Quaternary Climate in Western Mediterranean. Proceedings of the Symposium on Climatic Fluctuations during the Quaternary in the Western Mediterranean Region,* 1986, Universidad Autónoma; Madrid, 205–216.

Mariscal B., Estudio Palinológico de la Flora Holocénica de Cantabria. Aspectos Paleoclimáticos, (Unpublished PhD)1987, Universidad Complutense.

Mariscal B., Comparacion palinologica entre una turbera de la cordillera central y unas turberas de la cordillera cantabrica, In: *II European Paleobot. Conference,* 1989, Universidad Complutense; Madrid, 28.

Mariscal B., Variación de la vegetación holocena (4300–280 B.P.) de Cantabria a través del análisis polínico de la turbera del Alsa, *Estud. Geol.* **49**, 1993, 63–68.

Martínez-Cortizas A., Mighall T., Pontevedra Pombal X., Novoa Mufloz J.C., Peteado Varela E. and Pifleiro-Rebolo R., Linking changes in atmospheric dust deposition, vegetation change and human activities in northwest Spain during the last 5300 years, *Holocene* **15**, 2005, 698–706.

Menéndez-Amor J., Estudio esporo-polínico de una turberas en el Valle de la Nava (provincia de Burgos). Boletín de la Real Sociedad Española de Historia Natural, *Sección Geol.* **66**, 1968, 35–39.

Menéndez-Amor J. and Florschütz F., Sur les éléments steppiques dans la végétation quaternaire de l'Espagne, *Bol. la Real Soc. Española Hist. Nat. (Sección Geol.)* **61**, 1963, 121–133.

Milankovitch M., Théorie Mathématique de phénomenés thermiques produits par la radiation solaire, 1920, Gauthiers-Volars; Paris.

Miras Y., Ejarque A., Riera S., Palet J.M., Orengo H. and Euba I., Dynamique holocène de la végétation et occupation des Pyrénées andorranes depuis le Néolithique ancien, d'après l'analyse pollinique de la tourbière de Bosc dels Estanyons (2180 m, Vall del Madriu, Andorre), *Les. comptes rendus, Série Pale* **6** (4), 2007, 291–300.

Moore P.D., Webb J.A. and Collinson M.E., Pollen Analysis, 1991, Blackwell; Oxford.

Moreno A., Lopez-Merino L., Leira M., Marco-Barba J., Gonzalez-Samperiz P., Valero-Garces B.L., Lopez-Saez J.A., Santos L., Mata P. and Ito E., Revealing the last 13,500 years of environmental history from the multiproxy record of a mountain lake (Lago Enol, northern Iberian Peninsula), *J. Paleolimnol.* **46**, 2011, 327–349.

Muñoz-Sobrino C., Cambio climático y dinámica del paisaje en las montañas del noroeste de la península Ibérica, (Unpublished PhD)2001, Escola Politécnica Superior. Universidade de Santiago de Compostela.

Muñoz-Sobrino C., Ramil-Rego P., Gómez-Orellana L. and Díaz-Varela R.A., Palynological data on major Holocene climatic events in NW Iberia, *Boreas* **34** (3), 2005, 381–400.

Muñoz-Sobrino C., Ramil-Rego P., Gómez-Orellana L., Ferreiro-da-Costa J. and Díaz-Varela R.A., Climatic and human effects on the post-glacial dynamics of *Fagus sylvatica* L. in NW Iberia, *Plant Ecol.* **203**, 2009, 317–340.

Ontañón R., El Neolítico final y el Calcolítico en Cantabria. Cuadernos de Sección, *Prehist. Arqueol.* **6**, 1995, 81–103.

Pèlachs A., Julià R., Pérez-Obiol R., Soriano J.M., Bal M.C., Cunill R. and Catalan J., Potential influence of bond events on mid-Holocene climate and vegetation in southern Pyrenees as assessed from Burg lake LOI and pollen records, *Holocene* **21** (1), 2011, 95–104.

Peña-Chocarro L., Zapata L., Iriarte M.J., González Morales M. and Straus L.G., The oldest agriculture in northern Atlantic Spain: new evidence from El Mirón Cave (Ramales de la Victoria, Cantabria), *J. Archaeol. Sci.* **32** (4), 2005a, 579–587.

Peña-Chocarro L., Zapata L., García-Gazólaz J., González-Morales M., Sesma-Sesma J. and Straus L., The spread of agriculture in northern Iberia: new archaeobotanical data from el Mirón Cave (Cantabria) and the open-air site of Los Cascajos (Navarra), *Veg. Hist. Archaeobot.* **14** (4), 2005b, 268–278.

Peñalba M.C., Dynamique de Végétation Tardiglaciaire et Holocène du Centre-Nord de l'Espagne d'après l'analyse pollinique, (Ph.D. dissertation)1989, Université d'Aix, 165.

Peñalba M.C., The history of the Holocene vegetation in northern Spain from pollen analysis, *J. Ecol.* **82**, 1994, 815–832.

Pérez-Obiol R., Jalut G., Julià R., Pèlachs A., Iriarte M.J., Otto T. and Hernández-Beloqui B., Mid-Holocene vegetation and climatic history of the Iberian Peninsula, *Holocene* **21**, 2011, 75–93.

Portero-García G., Mapa Geomorfológico 1:25000, Hoja 58-II (Puente Viesgo), 2009, Instituto Geológico y Minero de España- Gobierno de Cantabria.

Power M.J.J., Marlon N., Ortiz P.J., Bartlein S.P., Harrison F.E., Mayle A., Ballouche R.H.W., Bradshaw C., Carcaillet C., Cordova S., Mooney P.I., Moreno I.C., Prentice K., Thonicke W., Tinner C., Whitlock Y., Zhang Y. and Zhao A., Changes in fire regimes since the Last Glacial Maximum: an assessment based on a global synthesis and analysis of charcoal data, *Clim. Dyn.* **30**, 2008, 887–907.

R Core Team, R: a Language and Environment for Statistical Computing, 2015, R Foundation for Statistical Computing; Vienna, Austria.

Ramil-Rego P., Muñoz-Sobrino C., Rodríguez-Guitián M. and Gómez-Orellana L., Differences in the vegetation of the North Iberian Peninsula during the last 16,000 years, *Plant Ecol.* **138**, 1998a, 41–62.

Ramil-Rego P., Rodríguez-Guitián M. and Muñoz-Sobrino C., Sclerophyllous vegetation dynamics in the north of the Iberian peninsula during the last 16000 years, *Glob. Ecol. Biogeogr. Lett.* **7**, 1998b, 335–351.

Rasilla-Álvarez D.F., Viento del Sur y efecto Föhn en la Cordillera Cantábrica, 1999, CEDEX, Ministerio de Fomento; Madrid.

Reille M., Pollen et spores d'Europe et d'Afrique du Nord. Marseille. Laboratoire de Botanique Historique et Palynologie, 1992, Université d'Aix-Marseille III; Marseille.

Reille M., Pollen et spores d'Europe et d'Afrique du Nord – Supplément 2. Laboratoire de Botanique Historique et Palynologie, 1998, Université d'Aix-Marseille III; Marseille.

Reimer P.J., Bard E., Bayliss A., Beck J.W., Blackwell P.G., Bronk Ramsey C., Buck C.E., Cheng H., Edwards R.L., Friedrich M., Grootes P.M., Guilderson T.P., Haflidason H., Hajdas I., Hatté C., Heaton T.J., Hoffmann D.L., Hogg A.G., Hughen K.A., Kaiser K.F., Kromer B., Manning S.W., Niu M., Reimer R.W., Richards D.A., Scott E.M., Southon J.R., Staff R.A., Turney C.S.M. and van der Plicht J., IntCal13 and Marine13 radiocarbon age calibration curves 0–50,000 years cal BP, *Radiocarbon* **55** (4), 2013, 1869–1887.

Riera S., Cambios vegetales holocenos en la región mediterránea de la península Ibérica: ensayo de síntesis, *Ecosistemas* 2006, 2006/1.

Rivas-Martínez S., Memoria del mapa de series de vegetación de España 1:400.000, 1987, ICONA. Ministerio de Agricultura, Pesca y Alimentación; Madrid, 268.

Robledo-Arnuncio J.J., Collada C., Alía R. and Gil L., Genetic structure of montane isolates of Pinus sylvestris L. in a Mediterranean refugial area, *J. Biogeogr.* **32** (4), 2005, 595–605.

Rodríguez-Guitán M.A., Aplicación de criterios botánicos para a proposta de modelos de xestión sustentable das masas arborizadas autóctonas do subsector Galaico-Asturiano Septentrional, (Ph.D. Thesis dissertation)2004, Universidade de Santiago de Compostela, Santiago de Compostela.

Rubiales J.M., García-Amorena I., García-Álvarez S. and Gómez-Manzaneque F., The Late Holocene extinction of Pinus sylvestris in the western Cantabrian Range (Spain), *J. Biogeogr.* **35**, 2008, 1840–1850.

Ruiz-Zapata M.B., Gil-García M.J., Dorado M., Valdeolmillos A., Vegas J. and Pérez-González A., Clima y vegetación durante el Tardiglaciar y el Holoceno en la Sierra de Neila (Sistema Ibérico Noroccidental, *Cuaternario Geomorfol.* **16**, 2002, 9–20.

Sainz-Ollero H., Sánchez-de-Dios R. and García-Cervigón-Morales A.I., La cartografía sintética de los paisajes vegetales españoles una asignatura pendiente en geobotánica, *Ecología* **23**, 2010, 249–272.

Sevilla F., Simplificación específica de las comunidades vegetales: el caso del pino silvestre en la cordillera Cantabriana, In: Puertas F. and Redes M., (Eds.), *Actas del I Congreso Forestal Hispano-Luso,* 1997, Departamento de Medio Ambiente, Gobierno de Navarra, 623–628.

Solórzano-Telechea J.A., Vázquez-Álvarez R. and Blanco-Campos B., Atlas histórico de Cantabria, 1999, Gobierno de Cantabria, Santander.

Straus L.G., The Upper Paleolithic of Cantabrian Spain, *Evol. Anthropol.* **14**, 2005, 145–158.

Straus L.G. and González Morales M., El Mirón Cave and the ^{14}C chronology of Cantabrian Spain, *Radiocarbon* **45** (1), 2003, 41–58.

Teira-Mayolini L.C., El megalitismo en Cantabria: aproximación a una realidad arqueológica olvidada, 1994, Universidad de Cantabria, Santander.

The vegetation and climate of northwest Iberian over the last 14000 yr, Allen J.R.M., Huntley B. and Watts W.A., (Eds.), *J. Quat. Sci.* **11** (2), 1996, 125–147.

Tinner W., Conedera M., Ammann B. and Lotter A.F., Fire ecology north and south of the Alps since the last ice age, *Holocene* **15**, 2005, 1214–1226.

Torres-Martínez J.F., El Cantábrico en la Edad del Hierro. Medioambiente, Economía, Territorio y Sociedad, 2011, Real Academia de la Historia; Madrid.

Uzquiano P., Recherches anthracologiques dans le secteur Pyreneo-Cantabrique (Pays Basque, Cantabria et Asturias): environnements et relations homme-mileu au Pleistocene Superior et debut de l'Holocene, (Ph.D. disseration)1992, Université Montpellier II.

Vannière B., Feu, agro-pastoralisme et dynamiques environnementales en France durant l'Holocène, analyse du signal incendie, approches sédimentologiques et études de cas en Berry, Pyrénées et Franche-Comté, 2001, Institut national agronomique; Paris-Grignon.

Whitlock C. and Larsen C., Charcoal as a fire proxy, In: Smol J.P., Birks H.J.B. and Last W.M., (Eds.), *Tracking Environmental Change Using Lake Sediments, Terrestrial, Algal, and Siliceous Indicators* **vol. 3**, 2001, Kluwer Academic Publishers; Dordrecht, The Netherlands, 75–97.

Zapata L., El combustible y la agricultura prehistórica: estudio arqueobotánico de los yacimientos de Arenaza, Kanpanoste Goikoa y Kobaederra, 1997, Isturitz.

Highlights

- There was a synergy between human action and climate regarding fires during Neolithic times.
- During the Bronze Age, decreased forest cover conditioned the fire events.
- A landscape like the present one has never existed before during the last 7000 years.
- The best analog of the recent local landscape is found during Neolithic times.
- Climate change has favored deciduous trees and led to an absence of *Pinus* during the Holocene.

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