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2000 years of pastoralism and fire shaping high-altitude vegetation of Sierra de Gredos in central Spain

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ABSTRACT

The palynological record of Puerto de Serranillos provides insights into the late Holocene vegetation history of Sierra de Gredos in the Central Mountain System of the Iberian Peninsula. Overgrazing around the timberline has occurred at least throughout the past two millennia, related to the human management of the landscape. Before the 12th century AD, *Pinus sylvestris* forests were dominant with a diversity of accompanying trees and understorey. The current landscape of the Gredos Range is clearly anthropogenic, and includes a combination of forest patches, pastures, dense shrubby formations and prostrate junipers, overall generated during the transition between the 17th and 18th centuries AD, when continued human activity in the mountain pine forests, using fire and intensifying grazing practices, caused a progressive deforestation, and the expansion of the current fire-prone scrub.

1. Introduction

The palynological discrimination of cultural landscapes is a challenging task in high-elevation mountain systems because agricultural pollen indicators are usually absent, and humans may have modified local vegetation without leaving clear traces in the pollen record (Carrión, 2003; Walsh and Richer, 2006). In the Mediterranean region of Spain, the combination of pollen and non-pollen microfossils together with measurements of charcoal particles have shed light onto the influence of human activities on vegetation changes during the Holocene. Successful cases of study come from the Segura Mountains (Carrión et al., 2001; Carrión, 2002), Sierra de Gádor (Carrión et al., 2003) and Sierra de Baza (Carrión et al., 2007) in the Betic cordillera north of Sierra Nevada, and Iberian System at Montes Universales (Stevenson, 2000). It is here shown that overgrazing and burning were historical contingent–and interactive (Kerby et al., 2007)–factors shaping mountain landscapes over millennia.

There is a lack of similar studies in central Spain, notwithstanding the geographic amplitude of mountains and the documentation of extensive pastoral activities since prehistoric times (Klein, 1990). Here we provide a new palynological record from Sierra de Gredos in the Central Mountain System (Ávila) with the aim of describing the late Holocene vegetation history, and weighting the anthropogenic component of the present-day vegetation.

The Gredos cordillera is a complex social space which, according to historical sources, would have been intensively used by the human population and organized according to a difficult and precarious equilibrium between man and nature (Troitiño, 1987; López-Sáez and López-García, 1994). The natural vs. anthropic character of vegetation types in the Sierra de Gredos has been a traditional topic of controversy between plant ecologists, phytosociologists and palaeobotanists. Ruiz-Pérez and Valero-Sáez (1990) contend that, floristically, the high-altitude Gredos grasslands are shaped by recent human activities, while Escudero and Sánchez-Mata (1996) point to a climatic control, largely the influence of Atlantic rainfall, although not discarding human activities may have led to a recent expansion at the expense of forest cover. Based on pollen data, Franco-Múgica et al. (1997) postulate that the situation with Gredos might be equivalent to the rest of the Central Ranges where clearance of timberline pine woodlands seem to have resulted in the spread of montane grasslands and shrublands. Historiographical analyses seem to support this viewpoint (Gil-Sánchez, 1991; Pardo and Gil-Sánchez, 1997) which parallels the situation in other Mediterranean areas (Blondel, 2006; Riera, 2006; Kaniewski et al., 2008).

Sierra de Gredos could be definitively a suitable system to address this issue because transhumant movements appear to have occurred since Prehistory (Cabo-Alonso, 1991; Klein, 1996; Sánchez-Moreno, 1998), particularly significantly in the Ávila province, where the first written document referring to transhumants appeared only in AD 1135 (Ser-Quijano, 2000). It must be stressed that this information is absent from the general medieval historical sources (Casado, 1991; Barrios-García, 2000). Transhumance is a complex phenomenon and

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includes a diversity of spatio-temporal components related to economy and land occupation (Antón, 1992; Gómez-Pantoja, 1995; Vega-Toscano et al., 1998; Gerbet, 2002).

2. Physical setting

Central Ranges of Iberia run east–west and comprise Sierras de Ayllón, Guadarrama, Paramera, Gredos, Peña de Francia and Gata (Fig. 1). Sierra de Gredos's highest summit is the Almanzor (2592 m a.s.l.) and is mainly in the Ávila province. The lithology is mainly siliceous, although granite, slate and gneiss are also present (Troitiño, 2000). The tectonic constitution, a tilted horst, with a fault orientated towards the south, imposes a clear asymmetry in both the northern and southern faces (Parrillas and Palacios, 1995). Mean annual temperatures oscillate between 0 and 2 °C during the coldest month, and 20–22 °C during the hottest month, averaging 10 °C. The total annual rainfall is c. 1400 mm, falling within the humid ombrotype (Sánchez-Mata, 1989; Ninyerola et al., 2005). Phytogeographically, Gredos lies in the western Mediterranean subregion, Carpetan–Leonese subprovince, and embraces the Guadarramean, Bejaran–Gredensean, and Salmanticensean sectors (Rivas-Martínez et al., 2002). The Sierra is an important pool of Mediterranean endemics and Quaternary relict trees (Blanco, 1989; López-Sáez and López-García, 1994; López-Sáez et al., 1996; Franco-Múgica et al., 1997; Vargas, 2003; Alcalde et al., 2006).

The study site is a relatively extensive mire (c. 24,000 m^2) located at 1700 m a.s.l. in the Puerto de Serranillos (40°18′26″N, 4°56′03″W) on the southern slopes of the mountain, along a pass near the Eliza River headwalls (Fig. 1). This area is flat and goes through quite an extended annual period of snowing favouring peat accumulation of up to 120 cm-thick overlying granitic bedrock. Flat areas of the Gredos altitudes are the result of postglacial modelling including erosive land removals (Marcos and Palacios, 1995; Troitiño, 2000). Peats accumulate on a few of these flatted areas where streams meet and faults intersect providing waterlogged environments (Parrillas and Palacios, 1995).

Local vegetation is a grassland with patches of *Juniperus communis* ssp. *alpina* and *Cytisus oromediterraneus*, above a *Pinus sylvestris* timberline belt. The mire vegetation is formed of a mosaic of oligotrophic bog communities (*Caricetum carpetanae*) dominated by *Carex carpetana*, *C. demissa*, *C. echinata*, *Parnassia palustris*, *Sphagnum*, *Drosera rotundifolia* and *Viola juressi* (Sánchez-Mata, 1989; Escudero and Sánchez-Mata, 1996). The Sierra de Gredos vegetation belts include a mosaic of open pastures, shrublands, wooded pastures and pine stands (Rodríguez-Rojo and Sánchez-Mata, 2004).

3. Methods

A Russian core sampler was used to obtain a 120 cm core (Table 1) from the deepest area of the mire basin. The core was collected in January of 2002 and protected in plastic guttering, sealed in polythene tubing, and placed in cold storage (4 °C) prior to laboratory subsampling at c. 3 cm intervals. Thirty-four samples of 1 cm^3 were analysed. Macrofossils were not discerned throughout the core. All samples were treated according to the Faegri and Iversen (1989) method although acetolysis was not carried out to allow the identification of any contamination by modern pollen (Franco-Múgica et al., 1997, 1998). One *Lycopodium* tablet was added to each sample to allow the calculation of pollen concentrations (Stockmarr, 1971), and these values were divided by deposition time (yr cm^{-1}) to calculate pollen accumulation rate (PAR; grains cm^{-2} yr^{-1}). Small aliquots of the residues were mounted in glycerine, sealed with Histolaque and all recognizable pollen and spores were counted under a light microscope using a 400× magnification, until a pollen amount of at least 500 units was reached. Pollen and spore taxonomy follows Valdés et al. (1987), Faegri and Iversen (1989), Moore et al. (1991) and Reille (1992). *Pinus pinaster* was palynologically identified according Arobba (1979) and Carrión et al. (2000). Non-pollen

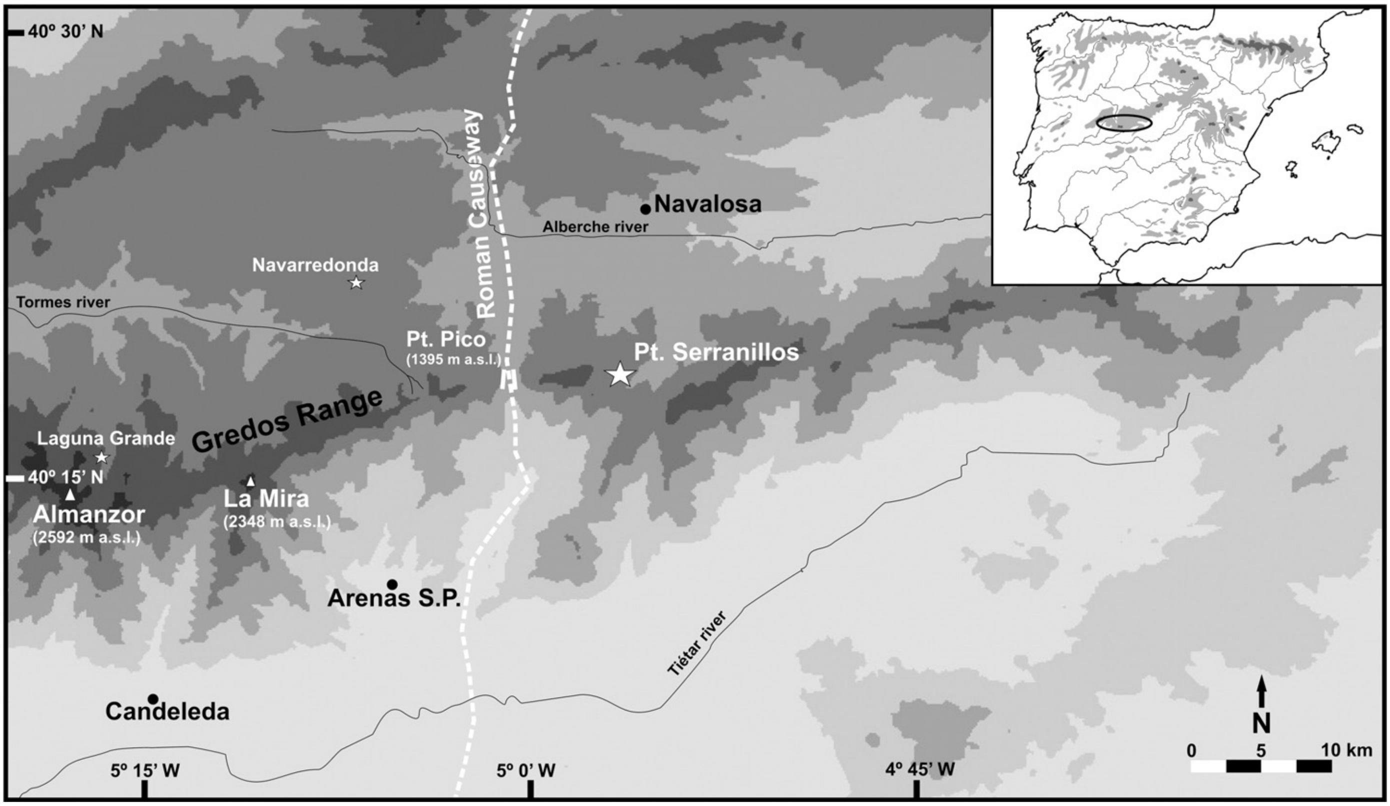

Fig. 1. Location of the study site in Puerto de Serranillos and other palaeoecological sites from the Gredos Range in Central Spain.

Table 1
Lithology of the peat section at Puerto de Serranillos.

Depth (cm)	Characteristics
0–19	Dark brown, decomposed *Sphagnum*: Tb(S)2
19–22	Dark brown, humified peat, gravels >1 cm: Sh3 Gg(maj)3
22–38	Dark brown, humified peat: Sh2
38–42	Light brown, humified peat, sands >0,5 cm: Sh1 Gg(min)2
42–49	Light brown, humified peat: Sh1
49–70	Light brown, humified peat, gravels >1 cm: Sh1 Gg(maj)1
70–90	Dark brown, humified peat: Sh3
90–95	Dark brown, humified peat, gravels >1 cm: Sh2 Gg(maj)1
95–100	Light brown, humified peat: Sh1
100–105	Light brown, humified peat, gravels >1 cm: Sh1 Gg(maj)1
105–120	Dark brown, humified peat: Sh3

palynomorphs (NPPs) were mainly identified according to van Geel et al. (1989, 2003), van Geel (2001), Carrión and Navarro (2002), and van Geel and Aptroot (2006). Palynological identifications and counting was aided by the reference collection of the Laboratory of Archaeobiology at the CSIC, Madrid.

To reconstruct local fire history at Puerto de Serranillos, macroscopic charcoal was identified and counted from subsamples of 1 cm^3 at every c. 3 cm depth by sediment sieving. The samples were soaked in a 3% sodium metaphosphate solution (72 h) to deflocculate any particles, and then washed through a 125 µm mesh sieve. Macrocharcoal was identified a 40× magnification according Rhodes (1998). Particles >125 µm diameter are not transported far from their source and thus provide information on local fire history (e.g. Whitlock and Larsen, 2001). Microscopic charcoal (<125 µm) were identified and counted at a magnification of 400× on the same slides used for pollen analysis (Tinner and Hu, 2003; Finsinger and Tinner, 2005). Charcoal accumulation rates (CHARs) were calculated by sedimentation rate (cm yr^{-1}) and are expressed in particles cm^{-2} yr^{-1}.

4. Chronology

The radiocarbon chronology is based on one AMS ^{14}C age (The Ångström Laboratory, Uppsala Universitet, Sweden) and three conventional ^{14}C ages (Geochronology Laboratory, CSIC, Madrid, Spain) on bulk organic sediment (Table 2). These dates were used to build an age–depth model by linear interpolation (Fig. 2) taking into account the maximum probability intervals at 2 sigma ranges, which is considered to be a robust statistical value (Telford et al., 2004). Calibrated dates (2σ) were calculated using CALIB v.5.0.2. program (http://calib.qub.ac.uk/calib/). Except where radiocarbon dates are given, all ages quoted in the text are in calibrated yrs BC/AD.

5. Palaeoecological results

The pollen, spore and NPP occurrences are presented as a percentage diagram (Fig. 3). The total pollen sum was considered by excluding pteridophytes, sedges and other angiosperm types typical of local mire vegetation ("aquatics") and non-pollen palynomorphs (NPPs). Local pollen assemblage zones (LPAZ) were constructed on the basis of agglomerative cluster analysis of incremental sum of squares (CONISS) with square root transformed percentage data including all identified palynomorphs (Grimm, 1987). The diagrams were plotted using TILIA and TILIA-GRAPH v. 2.0.b.5 softwares (Grimm, 1991). Fig. 4 shows CHARs, PAR, pollen concentration and deposition times related to selected pollen and NPP percentage curves. The pollen sequence was divided into eight zones (Figs. 3 and 4) and provides insight into the vegetation history of the high-altitude areas of Sierra de Gredos from c. 15 BC to the present day.

Table 2
Chronology of the pollen sequence of Puerto de Serranillos.

Laboratory code	Depth	Sample	^{14}C age (yrs. BP)	Calibrated ages (probabilities at 2σ range)	Calendar age
CSIC-1767	37–42 cm	Peat, bulk	522 ± 27	AD 1326–1343 (8.7%) AD 1394–1441 (91.3%)	AD 1415
CSIC-1768	80–85 cm	Peat, bulk	1664 ± 35	AD 257–301 (10.6%) AD 316–438(84.6%) AD 488–530 (4.8%)	AD 382
Ua-21490	90–92 cm	Peat, bulk	1895 ± 45	AD 21–233(100%)	AD 111
CSIC-1938	100–105 cm	Peat, bulk	1938 ± 35	37–28 BC (1.4%) 24–10 BC (2.5%) 2 BC–AD 131 (96.2%)	AD 62

The dates were calibrated using CALIB v. 5.0.2 (Stuiver et al., 1998) with the INTCAL04 curve (Reimer et al., 2004).

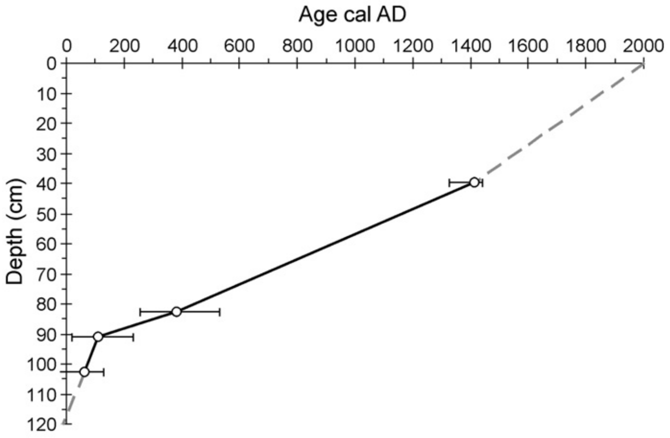

Fig. 2. Age–depth model for Puerto de Serranillos. Lines connecting each plotted point are interpolated sediment-accumulation rates.

5.1. Zone Ser-1 (depth 120–108.5 cm)

Pinus sylvestris/nigra percentages are high (>60%), indicating a montane pine forest in the vicinity. *Pinus pinaster* (5–7%), *Quercus pyrenaica* (4–6%), *Erica arborea* (4–7%) and Poaceae (6–7%) show continuous occurrences, while *Alnus*, *Betula*, *Quercus suber*, *Cistus ladanifer* and *Cytisus/Genista* pollen types are low (<3%). Anthropogenic types (*Aster*, Cardueae, Cichorioideae) were also present at low amounts, while pastoral indicators like Chenopodiaceae/Amaranthaceae, *Urtica dioica* type, and the coprophilous fungus *Sordaria*, account for less than 1%. The combination of Cyperaceae, *Parnassia palustris*, Ranunculaceae and the microfossil 107 (larval mandible of Coleoptera–Carabidae) suggest the existence of oligo- to mesotrophic conditions in the peat deposit. PAR oscillates between c. 2–4 × 10^3 grain cm^{-2} yr^{-1} and charcoal accumulation rates are in their lowest values.

5.2. Zone Ser-2 (depth 108.5–91 cm)

Pinus sylvestris/nigra exceeds 55% while *Quercus pyrenaica* (2–4%) decreases. *Alnus*, *Betula*, *Erica arborea*, *Pinus pinaster* and *Quercus suber* remained constant, whereas *Olea europaea* pollen (<1%) occurs for the first time in the sequence. *Cistus ladanifer* and *Cytisus/Genista* are absent. *Pinus sylvestris/nigra* shows a decreasing pattern (69–57%) at 100–95 cm coinciding with the appearance of *Olea europaea*. The herbaceous component is dominated by grass pollen (8–19%). *Aster*, Cardueae and Cichorioideae occur in very low amounts (<3%), as *Sordaria* and the NPP type 107. A progressive enrichment in PAR (c. 6–19 × 10^3 grain cm^{-2} yr^{-1}) is observed.

5.3. Zone Ser-3 (depth 91–70)

Pollen zone Ser-3 shows high percentages of *Pinus sylvestris/nigra* (>60%), but in the bottom (87 cm) and top (72 cm) parts, this type falls to 55% and 45%, respectively, while *Betula* and *Juniperus* peak

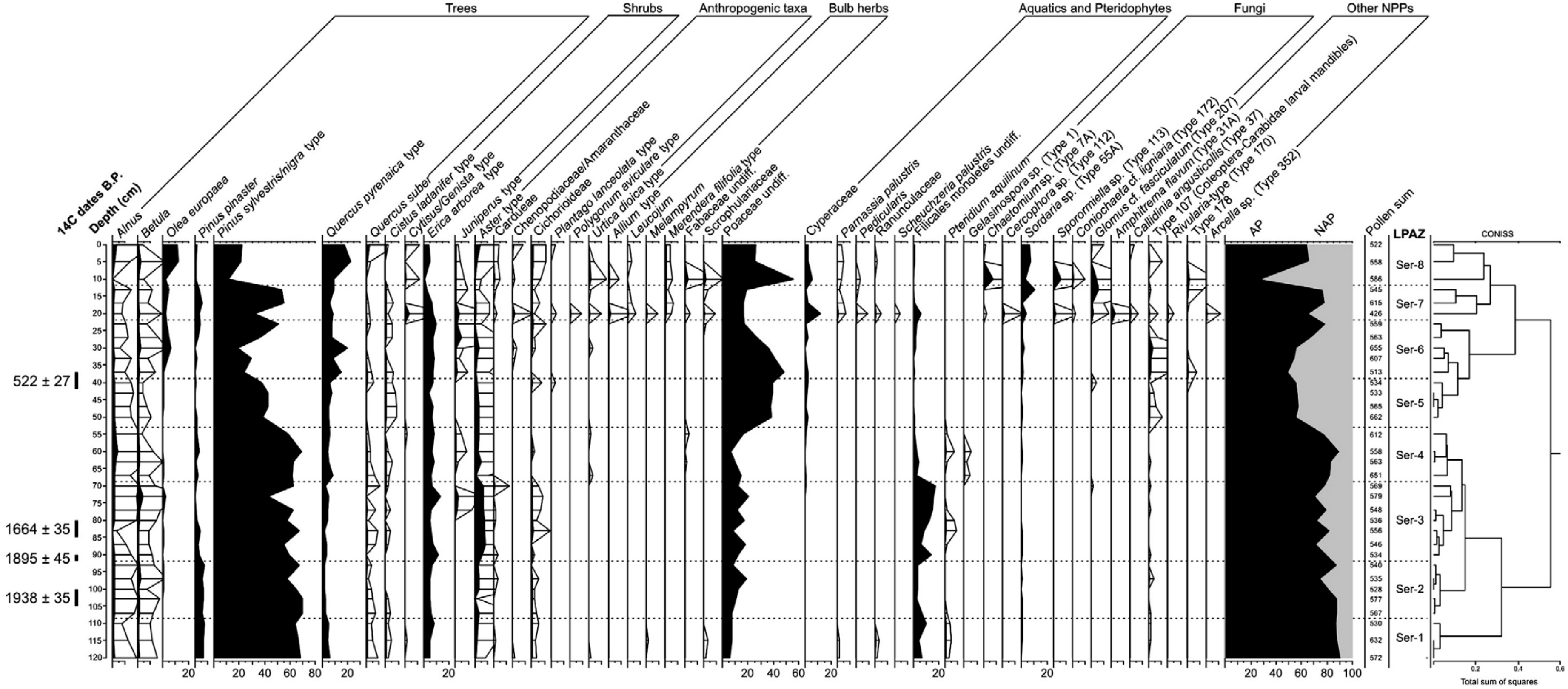

Fig. 3. Percentage pollen diagram for selected trees, shrubs, herbs and NPPs of Puerto de Serranillos (exaggeration curves are ×10).

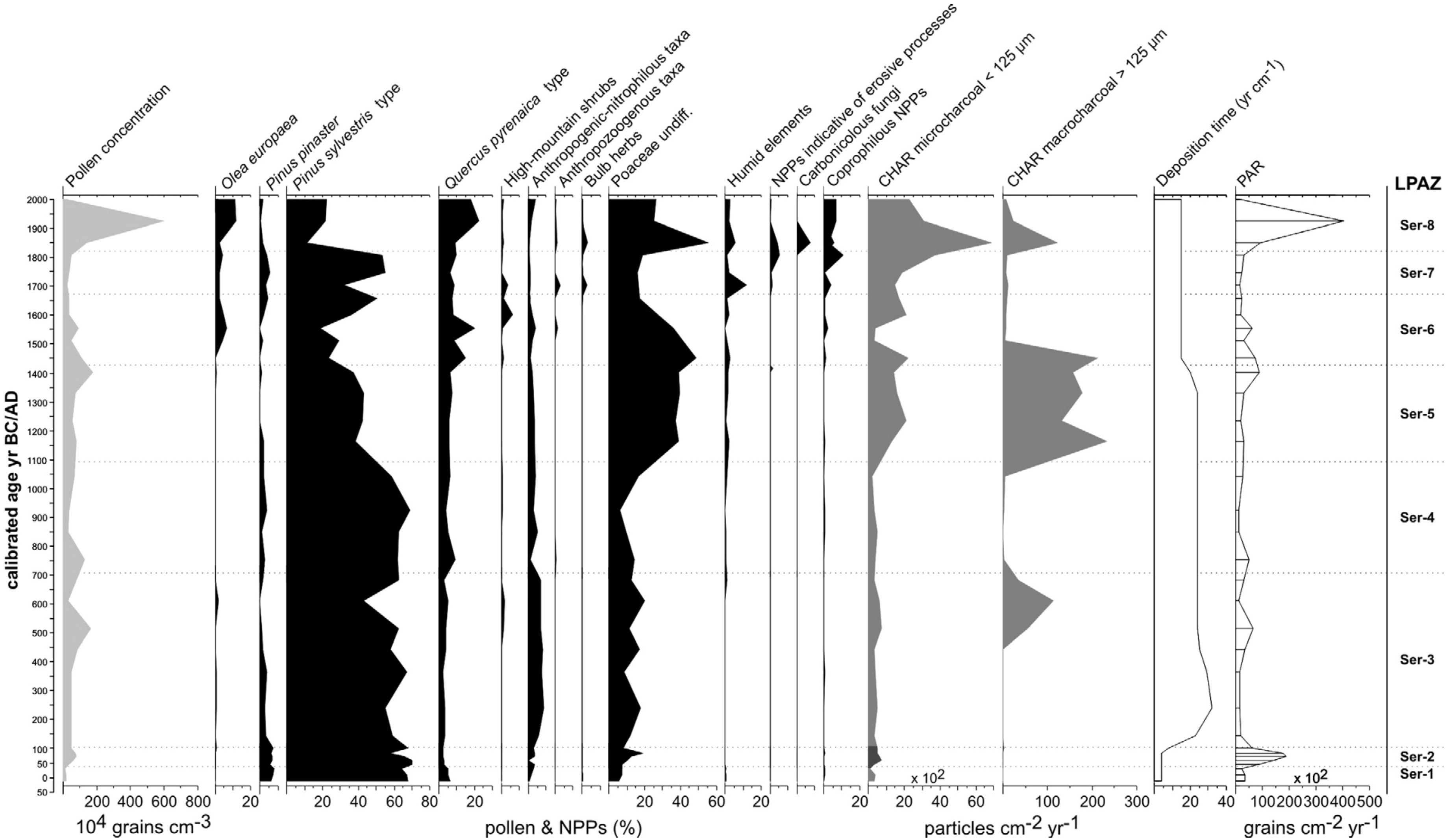

Fig. 4. Charcoal accumulation rates (CHAR), pollen accumulation rate (PAR), deposition time, pollen concentration, and selected pollen and NPP percentage diagram from the Puerto de Serranillos palynological record plotted against age (cal BC/AD). "High-mountain shrubs" include *Cytisus/Genista* type and *Juniperus* type. "Anthropogenic-nitrophilous taxa" include *Aster* type, Cardueae, *Cerealia*-type, Cichorioideae, *Rumex acetosa* type and *R. acetosella* type. "Anthropozoogenous taxa" include Chenopodiaceae/Amaranthaceae, *Plantago lanceolata* type, *Polygonum aviculare* type and *Urtica dioica* type. "Bulb herbs" include *Allium* type, *Anemone*, *Leucojum*, *Erodium*, Liliaceae undiff., Scrophulariaceae, *Melampyrum* and *Merendera filifolia* type. "NPPs indicative of erosive processes" include *Glomus* cf. *fasciculatum* and *Pseudoschizaea circula*. "Coprophilous NPPs" include *Sordaria* sp., *Sporormiella* sp., *Cercophora* sp. and *Riccia*. These ecological affinities largely follow the interpretations by Behre (1981), García-Sancho (1986), Sánchez-Mata (1989), Gil-García et al. (1993), Escudero and Sánchez-Mata (1996), López-Sáez et al. (1998), Carrión and Navarro (2002), Rodríguez-Rojo and Sánchez-Mata (2004).

about 5%. Deciduous *Quercus* slightly increase (2–6%), as did other broadleaved trees such as *Alnus*, *Betula* and *Quercus suber*. *Pinus pinaster* shows a decreasing tendency, more pronounced at the end of Ser-3 (72 cm, <1%). *Olea europaea*, *Cistus ladanifer* and *Erica arborea* maintain a continuous and significant presence throughout. This zone is also characterized by increased percentages of *Aster* (6–9%), Cichorioideae, monolete spores (>10%) and *Pteridium aquilinum*; *Sordaria* is present (91–82 cm) with very low percentages. PAR remains relatively stable (c. $1.3–6.7\times10^3$ grain cm^{-2} yr^{-1}). The CHAR (>125 µm) is high (113 particles cm^{-2} yr^{-1}) at the top of Ser-3, suggesting an enhanced local fire event.

5.4. Zone Ser-4 (depth 70–53 cm)

Pinus sylvestris/nigra is at its maximum in this pollen zone (70%). Other components increase such as *Pinus pinaster*, *Alnus* and *Quercus pyrenaica* (7–10%) while other arboreal taxa (*Betula*, *Quercus suber*) decrease, and *Olea europaea* disappears. *Cistus ladanifer* and *Juniperus* decline, and *Cytisus/Genista* occurs in the uppermost pollen spectra above 60 cm depth. Among the herbs, only Poaceae, *Aster*, Cardueae, Cichorioideae, Fabaceae and *Urtica dioica* show significant values, as well as Cyperaceae (1–2%) among the hygrophilic taxa. A decrease of monolete spores occurs (c. 2%). Coprophilous fungi are represented by *Sordaria* (<1%). The joint occurrence, in low percentages, of *Gelasinospora* and Type 107 may well be indicative of oligo- to mesotrophic conditions in the mire. PAR remains still relatively stable (c. $1.3–5.3\times10^3$ grain cm^{-2} yr^{-1}) and both micro and macrocharcoal particles are present in low concentrations.

5.5. Zone Ser-5 (depth 53–37 cm)

In this zone, significant oscillations and decreasing levels of *Pinus sylvestris/nigra* (25–42%) are noticed, reaching a minimum of 25% at 42–38 cm associated with the presence of sands and quartz microcrystals larger than 0.5 cm, and chlamydospores of *Glomus* cf. *fasciculatum*. *Pinus pinaster* and *Olea europaea* disappear, while *Cistus ladanifer* increases to above 1%, and Poaceae increases from 25% to 50%. Other arboreal taxa include *Alnus*, *Betula*, *Quercus pyrenaica* (c. 5–7%) and *Q. suber*. Among the herbs, only Poaceae show high values (27–48%). Cyperaceae attains higher values (1–2%), and *Sordaria* c. 1%. Other NPPs include the types 107 and 178 which combination suggests the existence of a semi-permanent body of shallow water rich in nutrients. A progressive enrichment, between CHARs maxima [$13–21\times10^2$ (<125 µm) and 132–233 (>125 µm) particles cm^{-2} yr^{-1}], in PAR (c. $2–9\times10^3$ grain cm^{-2} yr^{-1}), is observed.

5.6. Zone Ser-6 (depth 37–22 cm)

Percentages of several tree taxa increased, including *Quercus pyrenaica* (maxima 20%), *Pinus pinaster* (c. 1–11%) and *Olea europaea* (c. 1–6%), while *Pinus sylvestris/nigra* increased (20–50%). Other arboreal pollen percentages decrease (*Alnus*, *Quercus suber*). Among the shrubs, only *Cistus ladanifer* (<1%), *Erica arborea* (c. 10%) and *Juniperus* (0–6%) show significant values. Poaceae diminishes from 49% to 19% and *Sordaria* sp. reaches a maximum (3%). *Aster* and Cichorioideae remained low. Indicators of grazing such as Chenopodiaceae/Amaranthaceae and *Urtica dioica* are present while *Plantago lanceolata* type disappears. PAR oscillates between c. $2–7\times10^3$ grain cm^{-2} yr^{-1}. Two maxima in microcharcoal influx (22 and 21×10^2 particles cm^{-2} yr^{-1}) and one maximum in macrocharcoal influx (213 particles cm^{-2} yr^{-1}) are noticed.

5.7. Zone Ser-7 (depth 22–12 cm)

The occurrence and relative percentages of herbaceous pollen types such as *Allium*, Cardueae, Chenopodiaceae/Amaranthaceae, Fabaceae, *Leucojum*, *Melampyrum*, *Merendera filifolia*, *Plantago lanceolata*, *Polygonum aviculare*, Scrophulariaceae and *Urtica dioica*, increase. *Pinus sylvestris/nigra* increase to 58%. *Alnus*, *Betula*, *Cytisus/Genista*, *Olea*, *Pinus pinaster*, *Quercus pyrenaica* and *Q. suber* are also recorded. Coprophilous fungi are now represented by *Sordaria* (maximum 12%), *Cercophora* (5%) and *Sporormiella* (7%), while *Glomus* cf. *fasciculatum* reached a maximum (8%), as well as carbonicolous ascospores of *Chaetomium* (9%). This zone is associated with the colonisation by aquatics and pteridophytes (Cyperaceae, *Parnassia palustris*, *Pedicularis*, Ranunculaceae, *Scheuchzeria palustris* and Filicales monoletes undiff.) suggestive of water tables, higher that in the former zones. Other NPPs recorded include *Amphitrema flavum, Callidinia angusticollis*, *Coniochaeta* cf. *lignaria*, Types 107 and 178, *Rivularia* and *Arcella*. Microcharcoal influx increases (15 to 37×10^2 particles cm^{-2} yr^{-1}) and PAR diminishes.

5.8. Zone Ser-8 (depth 12–0 cm)

This zone is characterized by synchronous increases of *Pinus sylvestris/nigra* (c. 10–20%), *Quercus pyrenaica* (maximum 22% at 5 cm) and *Q. suber*. *Olea europaea* slightly increases reaching 12%, while *Pinus pinaster* decreases. Shrub taxa percentages (*Cistus ladanifer*, *Erica arborea*, *Juniperus*) experience a decreasing tendency while *Cytisus/Genista* continue to be relatively abundant. Anthropic types such as *Aster*, Cardueae, Chenopodiaceae/Amaranthaceae, Cichorioideae, *Plantago lanceolata* and *Urtica dioica* continue to be present. Poaceae surpasses 50% at c. AD 1852 (10 cm) decreasing to c. 25%. Several among the geophytes mentioned in zone Ser-7, disappear (*Allium*, Fabaceae) while other maintain its amounts (*Leucojum*, *Merendera filifolia* type). Aquatic elements such as Cyperaceae, *Pedicularis* or Ranunculaceae decrease, while other such as *Scheuchzeria palustris* disappear suggesting water tables lower that in the former zone. Although there is not great variation in the NPP assemblages, coprophilous and carbonicolous fungi decrease, as does *Glomus*. The charcoal record envisages a picture of decreasing fire incidence from the maximum values at the base of Ser-8 to the end of this zone: 69 to 23×10^2 (microcharcoal) and 123 to 7 (macrocharcoal) particles cm^{-2} yr^{-1}. PAR is in its highest values (c. 41×10^3 grain cm^{-2} yr^{-1}).

6. Discussion

The palynological sequence of Puerto de Serranillos allows us to reconstruct the environmental history of Sierra de Gredos during the last c. 2000 yrs (Figs. 3 and 4). Previous studies on the Holocene of Gredos are mainly focused on palaeoclimatic and palaeogeographical aspects (López-Sáez and López-García, 1994; López-Sáez et al., 1996; Franco-Múgica et al., 1997), and most of the palynological work lacks chronological control (Toro et al., 1992, 1993; Andrade et al., 1996; Ruiz-Zapata et al., 1996; López-Sáez et al., 1996, 1997; Dorado-Valiño et al., 2001). Due to the absence of antecedents with paleo-fire record in Sierra de Gredos, a comparison of the present sequence is only possible with the Navarredonda and Laguna Grande records (Toro et al., 1992, 1993; Franco-Múgica et al., 1997) (Fig. 1).

6.1. Environmental and cultural changes in the Gredos Range in a regional context

Between c. 15 BC and the 5th century AD (zones Ser-1, Ser-2, first half of Ser-3; Figs. 3 and 4) the uppermost forest belt of Sierra de Gredos was characterized by pine woodlands (probably *Pinus sylvestris* with patches of *P. nigra*). This parallels Navarredonda (Franco-Múgica et al., 1997), where a dense pine forest (>80%) is documented until the 5th century AD (zone NR-Ia; 1770 ± 80 BP). The supra and mesomediterranean belts may have been abundant in oak species such as *Quercus pyrenaica*, and locally cork oaks (*Quercus* *suber*), and pine groves of *Pinus pinaster* on granitic outcrops (Gil-Sánchez et al., 1990; Gil-Sánchez, 1991). In this phase, the landscape appears scarcely altered by human activities: the values of anthropogenic pollen indicators are not significant and the charcoal record suggests that fire activity was low. During this time, Sierra de Gredos was only an access route for Romans, indeed a marginal territory (Troitiño, 1987), and the area was poorly populated due to its inhospitable character for the development of urban centres and large-scale Roman estates (Mariné, 1995).

Thereafter, since the 5th century AD until c. AD 700 (second half of Ser-3; Figs. 3 and 4), the beginning of the Visigoth (Germanic people) domination appears related to a sudden decrease of the percentages of *Pinus sylvestris* and *P. pinaster*, in parallel to increase of birch, *Erica arborea*, *Juniperus* and Poaceae. This opening of the pine forest may have been a consequence of intensifying fire regimes of local origin (Whitlock and Larsen, 2001), anthropogenically induced, since the first important macrocharcoal peak (c. AD 610) coincides with the minimum value of *Pinus sylvestris*/*nigra* and by some degree of anthropogenic modification of the Sierra, when anthropogenic and nitrophilous taxa such as *Aster*, Cichorioideae or Cardueae were present (García-Sancho, 1986; Dorado-Valiño and Ruiz-Zapata, 1994). Similar trends are documented in the pollen record of Navarredonda (Franco-Múgica et al., 1997). The presence of coprophilous NPPs continues low, as seen under the Romans. Given the few pollen records in this part of the Gredos mountains, any attempt to analyse short-range livestock movements (transtermitance) between the Roman and the Visigothic periods would be based on scarce evidence, though the few records available do prove their existence (Sánchez-Moreno, 1998; Ser-Quijano, 2000).

Interestingly, since the 8th century to the 10th century AD, during the Islamic period (zone Ser-4; Figs. 3 and 4), a progressive rise of the *Pinus sylvestris* forests took place and the land used reached a minimum in the Gredos Range. *Pinus pinaster* and *Quercus pyrenaica* expand, while there is a retreat of junipers, anthropogenic-nitrophilous and anthropozoogenous species. The macro- and microcharcoal concentration are both very low and oligo-mesotrophic conditions prevailed. The Gredos Range, at this time, acted as a natural barrier between the southern Islamic kingdoms and the northern Christian ones (Troitiño, 1987; Manzano, 1991), as a 'no-man's land' (Barrios-García, 2000), which could be the reason for the absence of pollen indications of transtermitance processes across the Puerto de Serranillos. In the Navarredonda pollen record (Franco-Múgica et al., 1997), at this time (transition between zones NR-Ia and NR-IIa; 1090 ± 70 BP) pine pollen percentages increase (>60%).

Around the 10th century AD, the Christian repopulation of the province of Ávila began (Martín, 2000). In the first centuries, historical sites were created in the plains and valley bottoms, but from the 12th century AD the repopulation of higher locations of the Gredos Range commenced (Mariné, 1995). This process is depicted in the pollen diagrams (top of zone Ser-4 and zone Ser-5; Figs. 3 and 4), where the amounts of *Pinus sylvestris* type pollen decrease progressively as the Christian Reconquest advanced (60–50% in the 11th century AD to <45% during the 12-first half of 15th centuries AD), reaching a minimum of 25% at c. AD 1400–1430 (42–38 cm) associated with the presence of sands and quartz microcrystals larger than 0.5 cm (Table 1), and the presence of chlamydospores of *Glomus* cf. *fasciculatum*, suggestive of changes in sedimentation dynamics (van Geel et al., 1989; López-Sáez et al., 2000; Argant et al., 2006; Ruiz-Zapata et al., 2006).

It is only since the 12th–13th centuries AD, when strong local fire events took place, as shown by maxima values of macrocharcoal influx (Whitlock and Larsen, 2001), and pasture grasslands increased. Pastoral practices have been documented to be extensive during the Christian period (10th–15th centuries AD) in the Gredos Range, especially with the appearance of the 'Concejo de La Mesta' around AD 1273, a medieval organization controlling the migration of livestock (Klein, 1990). These favoured intense human activities on the environment which gave way to a reduction of the forest cover accompanied by clearings after cutting and firing woodlands. The latter originated a considerable reduction of the pinewoods in Gredos. In Navarredonda, and also about AD 1000, deforestation became more prevalent due to increasing anthropogenic pressure in the Gredos Range (Franco-Múgica et al., 1997). These data are in agreement with a sudden, rapid and irreversible deforestation of mountain pine forests in the whole of the Iberian Central System around AD 1000 (Vázquez-Gómez and Ruiz-Zapata, 1992; Gil-García et al., 1993; van der Knaap and van Leeuwen, 1994, 1995; Ruiz-Zapata et al., 1996, 2006, 2007; Franco-Múgica et al., 1998).

As soon as 'La Mesta' disintegrated in AD 1836, the transhumant passes through the Gredos Range became more diverse, and the Puerto del Pico was no longer the only pass for migrating livestock, but other secondary routes were now permitted, like Puerto de Serranillos (Klein, 1990, 1996). The farming nature of these areas is easily observed in the pollen diagrams (zones Ser-6, Ser-7 and Ser-8; Figs. 3 and 4) based on the increase of nitrophilous and other anthropogenic taxa, as well as coprophilous NPP indicators. This is particularly noticeable in Ser-7 and Ser-8, where peaks in local pollen type indicators of heavy grazing such as Chenopodiaceae/Amaranthaceae, *Plantago lanceolata* type and *Polygonum aviculare* type, together with *Sordaria*, *Cercophora* and *Sporormiella*, suggest nearby pastures (Behre, 1981; Sjögren, 2006; López-Sáez and López-Merino, 2007; Sjögren and Lamentowicz, 2008). Geophytes occurring for the first time in Ser-7, are probably indicative of a greater incidence of fire events after c. AD 1675. The surrounding forest areas were definitively grazed and rather open (indicated by *Melampyrum*, carbonicolous fungi and CHARs maxima).

The vegetation history of the last centuries (c. AD 1492–present) shows changes consistent with human land-use and human-induced landscapes, such as the replacement of high-mountain grassland communities dominated by Poaceae by shrub patches of pyrophilous species as *Juniperus communis* ssp. *alpina* (*Juniperus* type) and *Cytisus oromediterraneus* (*Cytisus*/*Genista* type). The vegetation of the Mediterranean ecosystems is known to regenerate quickly after fire using different regeneration mechanisms (Buhk et al., 2006). In the study area, and depending on agricultural and pastoral activities, the common broom *Cytisus oromediterraneus* can quickly cover wide spaces after grazing withdrawal and fire events and prevents colonization by pines over some periods (Fernández-Santos et al., 2004). Therefore, the first years after the abandonment of pasture are highly favourable for pine colonization, but can be followed by a less favourable period due to the presence of a dense shrubby vegetation (Prévosto et al., 2003), because *Cytisus oromediterraneus* populations showed both germination and vegetative post-fire regeneration (Fernández-Santos et al., 2004). In fact, mountain shrubby communities of the Gredos Range, dominated by species of Leguminosae (gen. *Adenocarpus*, *Cytisus*, *Echinospartum*, *Genista*), have higher resilience to fire than mountain pines (Fernández-Santos and Gómez-Gutiérrez, 1994; Fernández-Santos et al., 2004). These events can be seen in the Ser-7 and Ser-8 zones of the pollen diagram where the development of dense shrubby populations of *Cytisus*/*Genista* type and prostrate junipers (*Juniperus* type), in response to recurrent regional and local (macrocharcoal influx maximum at c. AD 1852) anthropic fire processes for the generation of pasture areas, would have prevented the regeneration of the pinewoods. Similar trends have been observed in the Laguna Grande pollen record (Toro et al., 1992, 1993).

The maximum percentage of *Pinus sylvestris* (ca. 60%), in the middle part of Ser-7 zone (15 cm), can be correlated with the extensive repopulations started before the Law of AD 1877 came into effect (Bauer, 1990). This development promoted the anthropogenic expansion of pinewoods across the whole Iberian Central Range. The substitution of pine (*Pinus sylvestris* type) by oak (*Quercus pyrenaica* type), in the last 10 cm of the sequence, is due possibly to expanding populations of the supramediterranean taxon *Quercus pyrenaica* (López-Sáez et al., 1997; Franco-Múgica et al., 1998) which is favoured because of their ability to persist through disturbance events such as fire (Gracia et al., 2002). The record of the Puerto de Serranillos clearly shows regional olive tree cultivation since c. AD 1450.

6.2. Ancient pine forests in the high Gredos Range

The landscape of the Gredos Range during the last two millenia is therefore dominated by a dense montane pinewood. At lower altitudes, pines would have co-existed with *Quercus pyrenaica* and in smaller quantities by alder, ash, birch, hazel or willow, mainly in small streams on the southern slope of the Gredos Range. Evergreen oak and cork oak would be the characteristic vegetation of the bottom valley with patches of *Pinus pinaster* on granitic outcrops.

Although we did not make any distinction between pollen coming from *Pinus nigra* or *Pinus sylvestris*, we assume that the vast majority of pine pollen in the core was originated from *P. sylvestris*, because it is the only species remaining nowadays in the area surrounding the mire. The continuous dominance of *Pinus sylvestris* type throughout the Late Holocene provides conclusive evidence for the existence of a well developed and extensive natural pine belt in Sierra de Gredos (Morla, 1993; Franco-Múgica et al., 2000). Studies of pollen rain support this view (Andrade et al., 1994; Ruiz-Zapata et al., 2007).

Pinus sylvestris is a widespread species in the Iberian Peninsula with a current area of 183 km^2 and a natural predicted area of 16,786 km^2 (Benito-Garzón et al., 2008). Although, *Pinus sylvestris* forest constitutes an important element in the Eastern Iberian Central Range (Guadarrama Range), forming a continuous band of vegetation between high-supramediterranean and oromediterranean levels, their naturalness in the Western Iberian Range has often been questioned (Rivas-Martínez et al., 1987; Luceño and Vargas, 1991; Sardinero, 2004). However, palaeobotanical evidence suggests that mountain pines grew in both Serra da Estrela and Gredos throughout the Early to Middle Holocene (Toro et al., 1992, 1993; Morla, 1993; van der Knaap and van Leeuwen, 1994, 1995; Franco-Múgica et al., 1997, 2000; López-Sáez et al., 1997).

The pollen records suggest that *Pinus sylvestris* and/or *P. nigra* were usually the dominant trees in the forests around Puerto de Serranillos within Ser-1 and Ser-4 pollen zones, between the c. 15 BC to c. AD 1100 (Fig. 4), because *Pinus sylvestris/nigra* type dominated the pollen spectra with amounts from c. 70 to 55%, thus indicating a forested landscape at least over the oromediterranean belt of the Gredos Range (Toro et al., 1992, 1993; Andrade et al., 1994) favoured by it continental and dry climate. Similar results have been found in the Guadarrama Range (Franco-Múgica et al., 1998; Ruiz-Zapata et al., 2006, 2007) in the Eastern Iberian Central Range. Furthermore, our data agrees with the macrofossil remains records of *Pinus sylvestris* and *P. nigra* in the Gredos Range that prove the existence of a bioclimatic belt where pine trees dominated during the last c. 4600 BC (Alcalde et al., 2006; Rubiales et al., 2007). They are also supported by other palynological and dendrological studies on the Gredos Range (Regato et al., 1992; Toro et al., 1992, 1993; López-Sáez and López-García, 1994; Franco-Múgica et al., 1997, 2000; López-Sáez et al., 1997; Génova, 2000), and are also in accordance with it predicting natural habitat with machine learning models (Benito-Garzón et al., 2006).

Pine abundance was especially great when human activities were low between the Roman and the Islamic periods. There is a strong antagonism between Poaceae and *Pinus sylvestris/nigra* (Figs. 3 and 4), at the same time that there is a clear-cut strong correlation between Poaceae and macrocharcoal accumulation rate, during the Christian period and the Early Modern period (c. AD 1100–1630) and in the Industrial age (after c. AD 1800). These two phases of decline in *Pinus sylvestris/nigra* type pollen percentages are explained by anthropogenic activities when most of pine forest was disrupted by fire to gain new pastures. During the nineteenth century, after the disintegration of 'La Mesta', pine forest deforestation was probably exacerbated by increasing grazing activities (Rubiales et al., 2007).

7. Concluding remarks

In mountainous areas, like Sierra de Gredos, the short growing season and the steep terrain limit the potential for intensive agriculture. Therefore, mountainous territories are developed as cultural landscapes where grazing is the main occupation. In Sierra de Gredos, sheep, goats and cattle need to move from lower to higher pastures in the summer. Some of these movements are localised during the Prehistoric to the Islamic periods (transterminance), while others cover hundreds of kilometers (transhumance) to the highland summer pastures during the Christian period, with the creation of the "Concejo de La Mesta" transhumance system in AD 1273. Grazers, both wild and domesticated, fire and forestry during the Early Modern period and the Industrial age have had a major impact on the composition and structure of the flora in these areas, creating the current pasture woodlands.

The current landscape of the Gredos Range is clearly anthropogenic, and includes dense shrubby formations (*piornal*) of broom (*Cytisus* sp. and other Leguminosae) and prostrate juniper, generated during the transition between the 17th and 18th centuries AD, when continued anthropic activity in the mountain pine forests, using fire and intensifying grazing practices, caused a progressive deforestation, replaced by the current fire-prone scrub. Due to their slow evolution, the traditional farming systems, such as the one attested at Puerto de Serranillos, have created a landscape which can be taken for natural. However, in Gredos, herding and fire have been decisive factors in creating today's heterogenous landscapes and in the general decline of mountain pinewood.

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