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Reconstructing forest history from archaeological data: A case study in the Duero basin assessing the origin of controversial forests and the loss of tree populations of great biogeographical interest

Laura Hernández [a,b,*], Juan M. Rubiales [b], César Morales-Molino [b], Fernando Romero [c], Carlos Sanz [c], Fernando Gómez Manzaneque [b]

[a] *Departamento de Selvicultura y Gestión Forestal Sostenible, CIFOR-INIA, Crta. La Coruña, km 7.5, 28040 Madrid, Spain*
[b] *Departamento de Silvopascicultura, Escuela Técnica Superior de Ingenieros de Montes, Universidad Politécnica de Madrid, Ciudad Universitaria, s/n, 28040 Madrid, Spain*
[c] *Departamento de Prehistoria y Arqueología, Universidad de Valladolid, C/Real de Burgos, s/n, 47011 Valladolid, Spain*

A B S T R A C T

The study of more than 700 charcoals from the Vaccaean settlement of Pintia (Padilla del Duero, Valladolid) provides new local and detailed data about the Iron Age II forest composition in Continental–Mediterranean inland Spain. *Pinus* gr. *sylvestris/nigra* (from which an unexpectedly high number of charcoals were identified), together with Mediterranean pines (also highly represented), *Juniperus* L. and evergreen and deciduous *Quercus*, were the main taxa living in the area, revealing two different marked biogeographical elements in the late-Holocene landscapes of the Duero basin: Mediterranean and Eurosiberian. On one hand, the results shed new light on the assessment of the origin of Mediterranean pinewoods in the area. On the other hand, the charcoal assemblage of Pintia reveals a more important presence of the current Mediterranean highland pines in the lowlands of the Central Iberian Peninsula in the late-Holocene suggesting the existence of interglacial refugia. Finally, this work highlights palaeoecological studies as valuable tools to support decisions on forest management related to conservation and restoration of our natural heritage.

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1. Introduction

Extensive changes in the landscape have been widely documented in the Iberian Peninsula since the times of the Roman invasion, such as the impact of mining activities (Lewis and Jones, 1970), the introduction of plant varieties (e.g., Conedera et al., 2004; Gil et al., 2004) or the intensification of deforestation (Figueiral, 1995, 1996; Carrión et al., 2000, 2009; Rubiales et al., 2007; López-Sáez et al., 2009). In the northern Iberian plateau (inland Spain), where this study was performed, biogeographers have long addressed the interpretation of modern vegetal landscapes (Willkomm, 1896; Huguet del Villar, 1925; Font Quer, 1954; Calonge Cano, 1987; Franco Múgica et al., 2001, 2005; Gil and Torre, 2007), while historians have debated the nature and timing of human-induced changes in the vegetation

cover over time (e.g., Hopfner, 1954; Schulten, 1963; Blanco Abril, 2003). Unfortunately, scientists have not yet come to a consensus regarding any of the proposed scenarios. The information from historical texts is neither regionally nor chronologically complete, especially prior to the Roman invasion. Despite the substantial amount of data on modern vegetation that exists today for southern Europe, no long-term studies on vegetation history are available in the area other than those of a palaeoecological nature. The palynological information for the Duero basin is restricted to a few lake systems and mires that hold Holocene records of past vegetation history (Franco Múgica et al., 2001, 2005). Conversely, the palaeoecological potential of archaeological charcoal remains is almost completely unexplored.

In this context, different hypotheses about the origin of the Mediterranean pinewoods in the area and their role in the long-term vegetation dynamics have been proposed, resulting in an interesting scientific debate among plant biogeographers (Rivas Martínez, 1987; Gil et al., 1990; Costa et al., 1997; López-Sáez et al., 2009). In fact, one of the largest Mediterranean pinewoods (*Pinus pinaster* Ait. and *Pinus pinea* L.) of the Iberian Peninsula has been found to be linked to the Duero basin sand dunes next to the study site analysed in this paper (Calonge Cano, 1987, 1998). Traditional

* Corresponding author at: Departamento de Selvicultura y Gestión Forestal Sostenible, CIFOR-(INIA), Crta. La Coruña, Km 7.5, 28040 Madrid, Spain.
Tel.: +34 91 347 1461.
E-mail addresses: hernandez.laura@inia.es, laurahmateo@yahoo.es
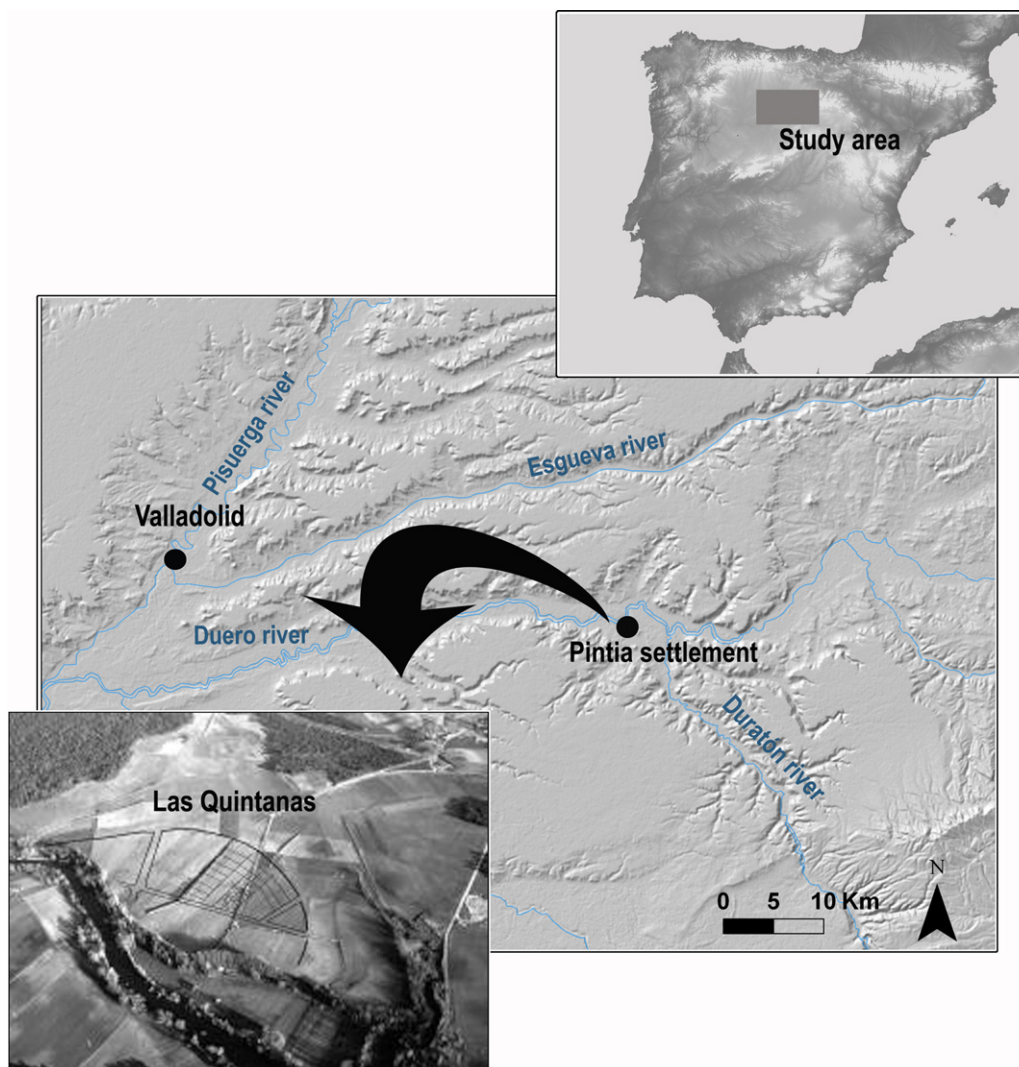(L. Hernández).

Fig. 1. Maps showing the location of the archaeological site of Pintia established in the Duero River banks (Valladolid, inland Spain). Below the aerial photo shows an on-site sketch of the archaeological area called "Las Quintanas" from which the charcoal assemblage came.

human use of some pinewood resources, like wood, resin and pine kernels, has probably influenced some geographers who have questioned the naturalness of the Mediterranean pine stands in the area (Hopfner, 1954; Bennassar, 1967; Navarro and Valle, 1987). Furthermore, the potential vegetation map based on phytosociological models indicates that these pine extensions would be occupied by Holm oak (*Quercus ilex* L.) instead of pines (Rivas Martínez, 2007). As a result, the presence of the *Pinus* species is not mentioned in the vegetation inventories in environmental technical works, and these pine stands are treated as merely exotic plantations. Consequently, one of the most important pine stands of the Iberian Peninsula is commonly relegated to an anthropogenic, secondary role. On the contrary, palaeoecological studies (García Antón et al., 1995; Costa et al., 1997; Franco Múgica et al., 2001, 2005), historical compilations (Gil, 1991) and other biogeographical and genetic works (Font Quer, 1954; Calonge Cano and Santos, 2006; Bucci et al., 2007) suggest completely different interpretations considering that these Mediterranean pinewoods are not only indigenous in the area but, more importantly, were stable throughout the Holocene.

This study provides detailed new information that fills a geographical gap in the central part of the Iberian plateau by applying on-site vegetation data from the analysis of a wood charcoal assemblage dating from the Iron Age II at the archaeological site of Pintia (Padilla del Duero, Central Spain). The combination of pre-vious works with the anthracological information should help reconstruct the forest landscape history of this zone during the late-Holocene. Moreover, this work presents knowledge of long-term ecological information as a useful tool to support forest management strategies. Forest history and ecology should be primary considerations in future decisions concerning forests.

2. Materials and methods

2.1. Study area

2.1.1. Environmental setting

The archaeological site of Pintia (41°36′24″N, 4°6′48″W, 775 m a.s.l.) is located close to the village of Padilla del Duero (Valladolid province) in the Spanish northern plateau (Fig. 1). This Vaccaean settlement was strategically sited in an area where different landforms offered protection, forest resources and land suitable for cultivation. Thus, the site was surrounded by a complex landscape where river buffers, sandy environments, swampy areas and limestone plateaus coexisted.

The most distinctive feature in this region is the sedimentary inland plains of the Duero Basin, which is bound by limestone plateaus 900 m high and the incised valleys created by fluvial erosion in the north and northeast. The sediments that fill the basin

are sandy (mostly siliceous), but other tertiary loams and limestones can also be found. Interesting aeolian sand dunes that can be more than 10 m deep and whose origins date back to the quaternary (Díez-Herrero et al., 2002) can be found to the west and south of the study site.

The climate in this area of inland Spain is Continental–Mediterranean, with hard winters and approximately three months of summer drought. The mean annual temperature and rainfall are 11.9 °C and 420 mm (S.I.G.A., http://sig.marm.es/siga/), respectively. The human activity that developed during the last millennia (mostly cereal cultivation and vineyards) left scattered remains of the original forests in the vicinity of the archaeological site. As a consequence, dispersed or fragmented stands of evergreen Holm-oak woods (*Q. ilex* L. subsp. *ballota* Samp. (Desf.)) together with *Juniperus communis* L. or *Juniperus oxycedrus* L. can now be found in the area. *Juniperus thurifera* L. also grow in the limestone plateaus. In sites with moister soils and/or in the northern-oriented slopes, a small representation of deciduous forest (dominated by *Quercus faginea* Lam.) is detected. Deforestation was particularly intense in the fertile river banks, where riparian elements such as *Alnus glutinosa* (L.) Gaertn., *Ulmus minor* Mill., *Fraxinus angustifolia* Vahl., *Salix alba* L., *Salix eleagnos* Scop., *Salix triandra* L. and *Tamarix* spp. with helophytes like *Phragmites australis* (Cav.) Steudel are currently rare. The high prevalence of pinewoods composed by *P. pinaster* and *P. pinea* linked to sandy soils has given the name of "Tierra de Pinares" ("Land of Pinewoods") to the area lying to the southwest of Pintia. These forests have been subject to intensive and traditional forest exploitation since the mid-19th century. The wood, the kernel, and especially the resin, were sources of income for the inhabitants of the area until the mid-20th century, when these products ceased to be profitable (García Fernández, 2004).

2.1.2. Archaeological site and chronology

In its origins (Iron Age II), the Pintia site was settled on both banks of the Duero River. The settlement, considered one of the first cities on the Iberian Peninsula (Álvarez-Sanchís, 2005), covers 125 ha and consists of three differentiated parts: the fortified village called "Las Quintanas", where the studied charcoals come from, the "Carralaceña" artisan neighbourhood and the "Las Ruedas" necropolis (Sanz Mínguez and Romero Carnicero, 2007). The chronology was established by relative dating based on the typology of the historical elements found in the sediments of the different layers and the radiocarbon dating of several elements, which consistently yielded two late-Holocene dates of 2640 ± 30 BP (2745–2770 cal BP) and 2470 ± 30 (2470–2700 cal BP) 1 sigma calibration with the INTCAL09 dataset (Reimer et al., 2009).

The archaeological macro-remains recovered in the area of "Las Quintanas" cover five centuries of the settlement's history. The oldest levels (5th–3rd centuries BC) belong to the Celtiberian (Vaccaean) ages, and the most modern level studied in this work coincides with a period of Roman rule over the Iberian Peninsula (1st century BC and 1st century AD). An intermediate stage called the Sertorian stage (1st and 2nd centuries BC) characterised by Roman civil wars on the Iberian Peninsula was also taken into account in the archaeological work.

2.2. Anthracological analysis

The present study is based on the analysis of 768 charcoal fragments that were manually collected by an archaeological team from the Valladolid University during the Pintia excavation work from 1998 to 2006.

The remains were found either scattered or in clusters throughout the three different archaeological layers of "Las Quintanas"

Table 1

Absolute frequencies of the charcoal fragments identified from the different archaeological layers of Pintia. Taxa are ordered according to their abundance. The most abundant taxa in the charcoal assemblage are shown in bold.

Taxa	No. fragments
Pinus pinaster Ait.	176
Quercus subgen. *Sclerophyllodris* O. Schwarz (*Quercus ilex* L. type) = evergreen *Quercus* type	127
Quercus subgen. *Quercus* Oested = deciduous *Quercus* type (*Quercus faginea* Lam. and *Quercus pyrenaica* Wild. type)	121
Juniperus spp.	120
Pinus gr. *sylvestris/nigra*	117
Pinus gr. *pinaster/pinea*	32
Ilex aquifolium L.	15
Castanea sativa Miller	13
Fraxinus spp.	10
Pinus pinea L.	9
Maloideae	3
Corylus avellana L.	1
Indeterminable	24
Total	768

(Vaccaean, Sertorian and Roman stages) but most of the analysed charcoals came from the oldest layers of the settlement (Vaccaean stage). The origins of the charcoals were domestic fireplaces, ditches, post-holes, pits and burnt tools. Because of the sampling method (manual collection), the size of the analysed charcoal fragments from "Las Quintanas" was relatively large in size. The sample included fragments ranging from 2 cm to more than 10 cm long.

In general, the good preservation of the charcoals facilitated the identification of some taxa to the species level. In other cases, a poor state of preservation due to different taphonomic processes (vitrification, high fragmentation or insect and fungal degradation) made the distinctive anatomical features difficult to observe.

In the laboratory, the fracture of the charcoals along the three anatomical planes (transverse, longitudinal and tangential) necessary for fragment identification was performed manually. Then, the three observation sections were analysed under reflected light microscopy. Taxonomic identification was achieved by using atlases of wood anatomy (e.g., Jacquiot, 1955; Schweingruber, 1990; García Esteban et al., 2003) and comparing the charred fragments with wood reference collections. In other cases, biogeographical information was considered when the anatomical identification of the charcoal was not conclusive.

3. Results

The microscopic analysis showed similar typologies in most of the charcoals, providing evidence of the presence of twelve woody taxa in the area (Table 1). Some microscopic features taken in consideration in the anatomical identification of charcoal fragments are shown in Fig. 2.

With regard to vegetation composition in this zone, the results show very similar richness in terms of the quantity of genera to what is currently present. In fact, the most representative genera of the sample, *Pinus* and *Quercus*, are the main genera present in the current inland Iberian vegetation landscapes. However, two different floristic elements can be detected: (i) Mediterranean taxa like evergreen *Quercus* and conifers like *P. pinaster*, *P. pinea* and *Juniperus* spp. and (ii) microthermal/hygrophilous taxa like *Pinus* gr. *sylvestris/nigra*, *Ilex aquifolium* and *Corylus avellana*, most of which are currently absent closer to the archaeological site. The deciduous oaks would indicate a transition between the two previous groups and may be taken as an indicator of a sub-Mediterranean element.
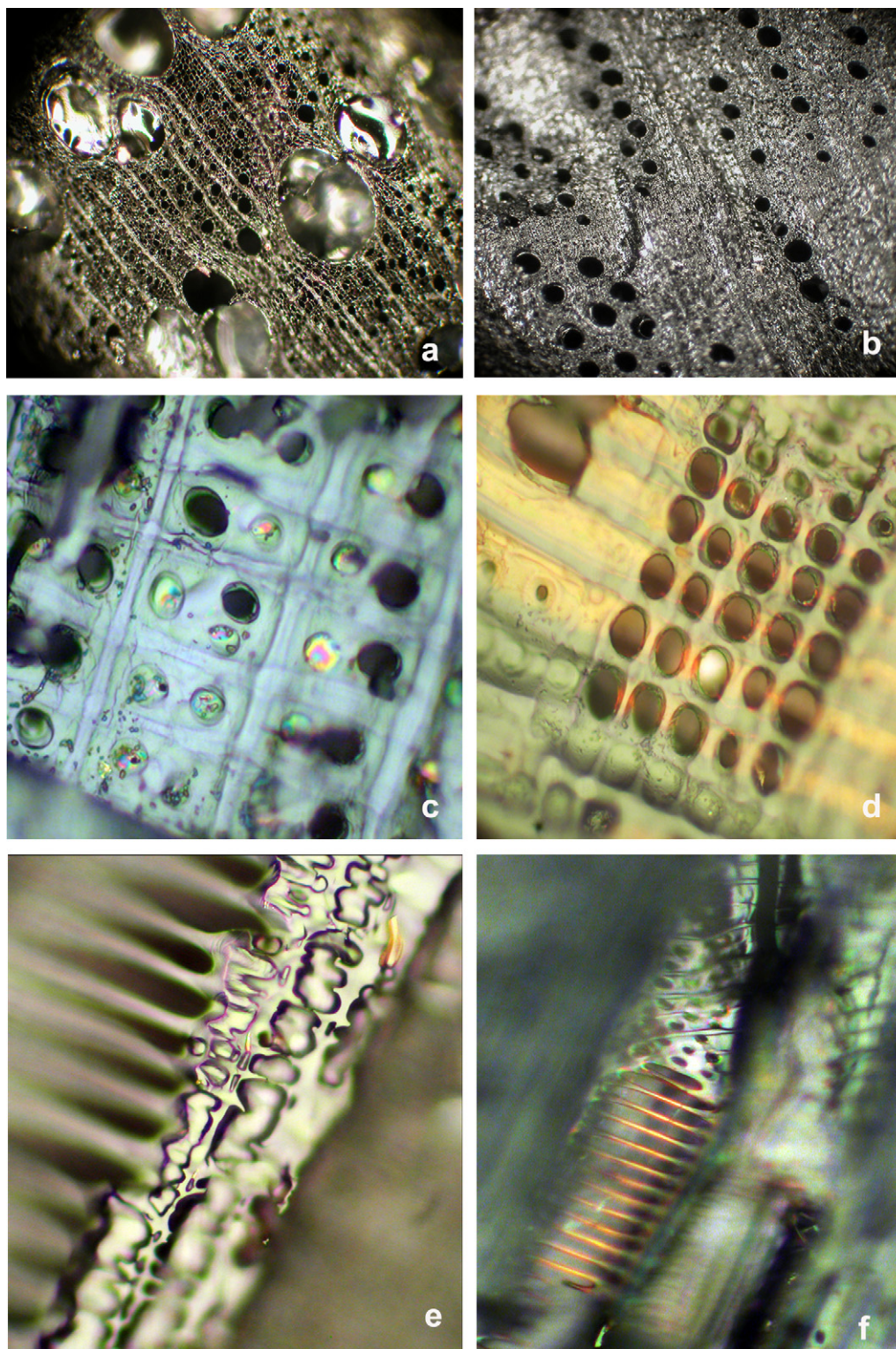
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Fig. 2. Microscopic view of the charcoal fragments of some of the identified taxa collected within the archaeological remains: (a) large solitary and grouped vessels in ring porous (transverse section, *Quercus* subgen. *Quercus* Oested); (b) diffuse-porous wood with solitary vessels in radial bands (transverse section, *Quercus* subgen. *Sclerophyllodris* O. Schwarz); (c) small pinoid (oval) pits occurring in the cross-fields (radial section, *Pinus* gr. *pinaster/pinea*); (d) large pinoid (fenestriform) type pits in the cross fields (radial section, *Pinus* gr. *sylvestris/nigra*); (e) walls of the highly dentate radial tracheids (radial section, *Pinus pinaster* Ait.); (f) vessel with scalariform perforations (radial section, *Ilex aquifolium* L.).

4. Discussion

4.1. Ecological and biogeographical interpretation of some results

Due to the poor preservation of some of the carbonised material and the problematic differentiation of the wood of some species, some uncertainties in the identification of the charcoals occurred. In these cases, ecological and biogeographical information was useful to help interpret the findings. This was the case for the identification of the pines corresponding to section *Sylvestris* (i.e., *P. sylvestris* L., *P. nigra* Arn. and *Pinus uncinata* Mill), as some authors

consider that the specimens of this group cannot be identified to the species level based in wood anatomy (for examples, see Schweingruber, 1990; Carcaillet and Vernet, 2001; Figueiral and Carcaillet, 2005). The current habitat of *P. uncinata* in high mountain environments above 1600 m restricts its distribution area almost completely to the Pyrenees and thus allows us to discard this species in the context of the present study. The ecological characteristics of the study area focused our diagnosis on the other two species (*P. sylvestris* and *P. nigra*). Some of the anatomical features used by xilologists to differentiate these species are not conclusive (i.e., location of the resin ducts in the cross-section, dentation of the walls of the ray tracheids (Jacquiot, 1955; Peraza, 1964)). Because of this, the name *Pinus* gr. *sylvestris/nigra* was used. Another problem arose when trying to differentiate between the group comprising *P. pinaster*, *P. pinea*, *Pinus halepensis* and the *Pinus canariensis* species. Due to the ecology and present distributions of the last two species (*P. canariensis* is extinct today in the Iberian Peninsula, whereas *P. halepensis* occurs in the eastern part of Spain), neither taxon was considered in this identification process. In order to differentiate between the other two Mediterranean pines, most authors (Jacquiot, 1955; Peraza, 1964; García Esteban and Guindeo Casasús, 1989; Schweingruber, 1990; Figueiral, 1995; de Palacios de Palacios, 1997) agree on the use of the dentation of the ray tracheids (usually smooth in *P. pinea* and highly dentate in *P. pinaster*). When the poor preservation of the charred remains did not allow the use of this distinction, the sample was identified as *Pinus* gr. *pinaster/pinea*. In the case of the identification of the evergreen *Quercus*, the classification was focused on three species: (i) Cork oak (*Quercus suber* L.), which grows primarily in south-western Iberia on siliceous soils and in a temperate climate; (ii) Kermes oak (*Quercus coccifera* L.), which belongs to the subgenus *Sclerophyllodris* and is a typical element of maquis and coppice forests in the coastal area; (iii) Holm oak (*Q. ilex* subsp. *ballota*), which is adapted to Continental–Mediterranean environments characterised by severe drought and high summer temperatures. Therefore the charcoals identified as evergreen *Quercus* might correspond to *Q. ilex* subsp. *ballota*. Regarding the identification of deciduous *Quercus*, two marcescent species commonly occur in inland Spain, namely *Quercus pyrenaica* and *Quercus faginea*. However, as *Q. pyrenaica* acts as a calcifuge, the soil conditions in the available niches near Pintia point to *Q. faginea* as the most suitable oak species growing in the vicinity of the study site. *Juniperus* species could not be distinguished to species level based on their wood anatomy (Schweingruber, 1990), although considering the ecology of the genus and its current presence in the study area, three species must be considered. Spanish juniper (*J. thurifera*) is well adapted to Continental climates and its forests are widely distributed across inland and eastern Iberia, but the presence of other juniper trees, such as the common juniper (*J. communis*) or the Spanish cedar (*J. oxycedrus*), in the surrounding forests cannot be ruled out.

Although the taxonomic results reflect a low-diversity assemblage, it should be taken into account that most of the taxa identified are trees, while bushes and shrubs are poorly represented. This is due to the manual collection of the macro-remains in the archaeological site.

4.2. The environments of the Duero basin during the Iron Age II as reconstructed from the anthracological record of Pintia

The anthracological assemblage of Pintia confirms the historical presence of most of the tree species that are presently located in the extant stands living close to the study site, but it also shows a more diverse and complex forest landscape than what currently remains. First, the results show the relevance of genuine Mediterranean species in the forests, including *P. pinaster*, *P. pinea*, *Juniperus* and evergreen *Quercus*. In contrast, a great part of the assemblage corresponds to mesic taxa that presently do not grow or are very scarce in this region. The assemblage suggests that this last group, including *Pinus* gr. *sylvestris/nigra*, *Corylus* sp., *Castanea sativa*, *I. aquifolium* and, eventually, deciduous *Quercus*, which is currently characteristic of the Eurosiberian region and of mid- to high-mountain Mediterranean environments, was also locally present. Finally, the charcoal record also shows that other sub-Mediterranean species (i.e., those of intermediate ecological requirements between those of Mediterranean and Eurosiberian affinities), such as *Q. faginea* or juniper trees, probably *J. thurifera*, may also have been dominant in some of the forests growing during that period.

The difficulty to find suitable sites for pollen analysis (lakes, peatbogs) or macrofossil findings in Continental–Mediterranean lowlands of Central Spain, makes that very few previous consistent palaeobotanical works are available in the study area. The Holocene pollen records for the zone under study are restricted to two sites, one of which is an ancient lake in the zone of aeolian sediments of Tierra de Pinares (El Carrizal, Franco Múgica et al., 2005) and the other is situated at mid-altitude plateau of El Cerrato (Espinosa del Cerrato, Franco Múgica et al., 2001). Despite the fact that none of the records correspond exactly to the ecological characteristics of the area from where the charcoal assemblage may have originated, the records support the long-term regional dominance of the Mediterranean species detected in this study. Vegetation types have been very stable since the Lateglacial in the area and, as shown by the microscopic charcoal information, only late-Holocene human disturbances may have had some influence on the species composition at the end of the Holocene. Other anthracological and palaeoenvironmental studies carried out in other archaeological contexts also fit well in this model (e.g., Uzquiano, 1995; Mariscal, 1995; Mariscal et al., 1995; Ruiz Zapata, 1995; Yll, 1995).

Some distinctive anatomical features of the charred remains slightly improved the taxonomical resolution of the woody flora. Concerning pine species, *P. pinaster* and *P. pinea* have been detected in some archaeological units, but a great percentage of charcoal was identified only to the group level (i.e., *Pinus* gr. *pinaster/pinea*, *Pinus* gr. *sylvestris/nigra* and *Juniperus* spp.). Furthermore, some differences were detected in the species composition by comparing macrofossil and palynological records. This mostly affects *Juniperus*, which, after *Pinus* and *Quercus*, is the most represented group in the assemblage, whereas in the pollen records it is consistently but poorly represented. Its local presence was probably more important than previously hypothesised by regional palynological studies, but the human-mediated selection bias (Rubiales et al., 2011) or differences in the geographical and ecological characteristics among the studied sites may also cause this discrepancy.

However, it is worth noting that our anthracological study only recorded woody taxa and, consequently, non-forested landscapes may have alternated with trees over the Duero basin at that period. For example, Pliny and Strabo (as recorded by Wattemberg, 1959) report the existence of cattle and extensive Vaccaean cereal cultivation; conversely, Livy (also recorded in Wattemberg, 1959) describes the existence of important forest stands that the Vaccaean people strategically used to set ambushes for their enemies. As has been previously discussed, the degree of openness or proportion of these open-forested vegetation types remain to be determined on the basis of either the macro- or the microfossil evidence. Furthermore, as the site is located in a presumably active river basin, the geomorphological activity of the river should have constituted a major disturbance agent in the site. The analysis of the sandy deposits of Tierra de Pinares carried out by Bateman and Díez-Herrero (1999) and Díez-Herrero et al. (2002) mostly record fluvial (and aeolian) activity during the early Holocene, but seasonal torrentiality and the existing loose lithology may account for a wider area of influence of riverine areas.

4.3. Evidence supporting the occurrence of the Mediterranean pinewoods in the area at Iron Age II

The origin of the extensive Mediterranean pinewoods growing in the Duero basin has long been considered obscure by many of the plant biogeographers who have interpreted these landscapes (see Franco Múgica et al., 2005; Rubiales et al., 2011). Due to the great economic and strategic value of resin and kernels during the 20th century, pines have been intensely managed; they are thus frequently considered as anthropogenic. As a consequence, they are judged by some botanists as being of low interest from the conservation point of view (e.g., Navarro and Valle, 1987; Rivas Martínez, 1987). Although the problem of naturalness is not entirely resolved, both the anthracological data presented in this work at a local scale and previous palynological studies at the regional scale, indicate an early presence of these pines, suggesting that their wood has been widely used by humans at least since the onset of the historic times and that these forests have occurred in the Duero basin throughout the Holocene. Moreover, this late-Holocene record of Pintia fills a palaeobotanical information gap in the central zone of the Duero basin and provides species-level identification of the regional signal of Pinus as detected from pollen archives.

Mediterranean pines (including *P. pinaster* and *P. pinea*) are represented in the anthracological assemblage of Pintia as the most frequent group of taxa. *Pinus* is also the most important pollen type in the palynological records for the Duero basin throughout the Holocene. The site of El Carrizal (Franco Múgica et al., 2005) evidences a long-term persistence of the genus over sandy sediments; the same pattern occurs in the calcareous plains of the northern plateau (Espinosa del Cerrato, Franco Múgica et al., 2001) (Fig. 3), or, during the early Holocene, in Quintana Redonda (García Antón et al., 1995) in the proximity of the Northern Iberian range. The sum of all of these findings strongly agrees with the geobotanical assumptions that the *Pinus* gr. *pinaster*/*pinea* stands were spontaneous and stable in the long term during the Holocene and of primary importance in the vegetal landscapes of the Duero basin (Gil et al., 1990; Costa et al., 1997). The important role of the pinewoods in Duero basin landscapes is also corroborated by the difficult regeneration of *Quercus* in the sandy sediments as this genus can only prosper when bedrock appears on the surface.

Regarding genetic studies of *P. pinaster*, one of the maxima of haplotypic diversity has been found in the northern Iberian plateau (Bucci et al., 2007); therefore, this area is considered as a "hotspot" of intraspecific diversity. However, the interpretations based on molecular markers of the origins of these populations and their putative colonisation pathways have remained controversial, essentially due to the lack of palaeobotanical evidence suggesting the existence of refugia as demonstrated for this species in other areas of Iberia (i.e., Portuguese coast or south-eastern Iberia). A recent study by de-Lucas et al. (2009) tested the hypothesis that the populations from the Duero basin originated from a contact zone between the Atlantic and Mediterranean gene pools of the species. Their results show that these populations cannot have completely originated from the Mediterranean, the Atlantic or a mixture of both gene pools but constitute a different gene pool by themselves. The archaeobotanical evidence from the present work, taken with the existing palaeoecological data, suggests the existence of a long-term origin of the species in the zone, but as no local nor regional Pleistocene fossil evidence exists for the species, it must still be considered as hypothetical. The situation based on the existing genetic data for the stone pine (*P. pinea*) is much different: this pine species is highly depauperate, but one of the four haplotypes identified across its range is exclusively found in central Spain (Vendramin et al., 2008).

Some characteristics of the ecology of the stone pine like the apparent problems with its natural regeneration in the northern Iberian plateau (Calama and Montero, 2007; Barbeito et al., 2008; Pardos et al., 2010) and the low genetically intraspecific diversity of this species, present some difficulties when interpreting its past allocation in the Duero basin. In the rest of the Iberian Peninsula, *P. pinea* usually grows in sandy environments and at lower altitudes (e.g., coastal dunes, Martínez and Montero, 2004) and one would likewise expect to find the species on these substrates in the northern plateau. As a result this tree would be located, as at present, in sandy areas closer to Duero River where the water flow influence would result in a more suitable environmental condition for this species. On the other hand, *P. pinaster*, which is able to tolerate less limiting soils and continentality, may have had a wider distribution. However, in transition zones, both pines may have also developed mixed forest, creating similar landscapes to those that can be appreciated today.

These two species would have remained in inland Spain throughout the Holocene mainly as a result of their ecological adaptations to deep drained sandy sediments, nutrient-poor soils, drought tolerance, marked temperature contrasts and recurrent fires. In fact, in this area, *P. pinaster*, which has a non-serotinous lineage, shows ground fire-adaptions like *P. pinea*, such as a great thickness of bark (Tapias et al., 2004). The understory in the sandy sediments is sparse, and the occurrence of crown fires in these ecosystems is improbable. All these ecological adaptations to the Duero basin environmental conditions make *P. pinaster* and *P. pinea* suitable taxa for consideration in the selection of species in environmental restoration projects in the area.

Although marked oscillations in the *Pinus* pollen curve (Franco Múgica et al., 2005) and decreases in arboreal pollen have been reported since the last 1500 ^{14}C yr BP in the palynological works in the region, accompanied with an increase in the cereal pollen curves (Franco Múgica et al., 2001), Mediterranean pinewoods are still widespread in the area. This pattern does not fit with the generalised trend of other Iberian forests, where the intensification of anthropic disturbances regimes implied the extinction of those arboreal stands. The maintenance and survival of these pinewoods in the lowlands of the Duero basin can be partly explained by the sustainable and traditional exploitation of pine resources carried out by the inhabitants of the central Iberian Peninsula until the mid-20th century. So, even when the anthracological data from Pintia allows us to state that Mediterranean pines (both *P. pinaster* and *P. pinea*) were already present in the surroundings of this archaeological site during the first millennium BC, their long-term dynamics and range variations (transgressions or regressions) and the effects of the anthropogenic influence in these landscapes are difficult to assess and make very difficult to discern what is natural about those stands.

4.4. River buffers as interglacial reservoirs of woody elements: the late-Holocene role of highland pines in the lowlands of the Duero basin

The anthracological record from the Vaccaean village of Pintia indicates the presence of various hygrophilous/microthermal trees and shrubs such as *Pinus* gr. *sylvestris*/*nigra*, *I. aquifolium* and *C. avellana* during the late Holocene near the settlement (Table 1). The regional palynological record from El Carrizal also showed the importance of microthermal taxa in the lowland northern Spanish plateau during the early Holocene. As a consequence of the subsequent climatic amelioration throughout the Holocene, the distribution of these formations was largely reduced in the area, suffering a probable vertical migration to the surrounding mountains.

At present, there are some relict enclaves closer to the study area (e.g., Cega River) where a number of coexisting Eurosiberian taxa that are much more broadly distributed in the mountains
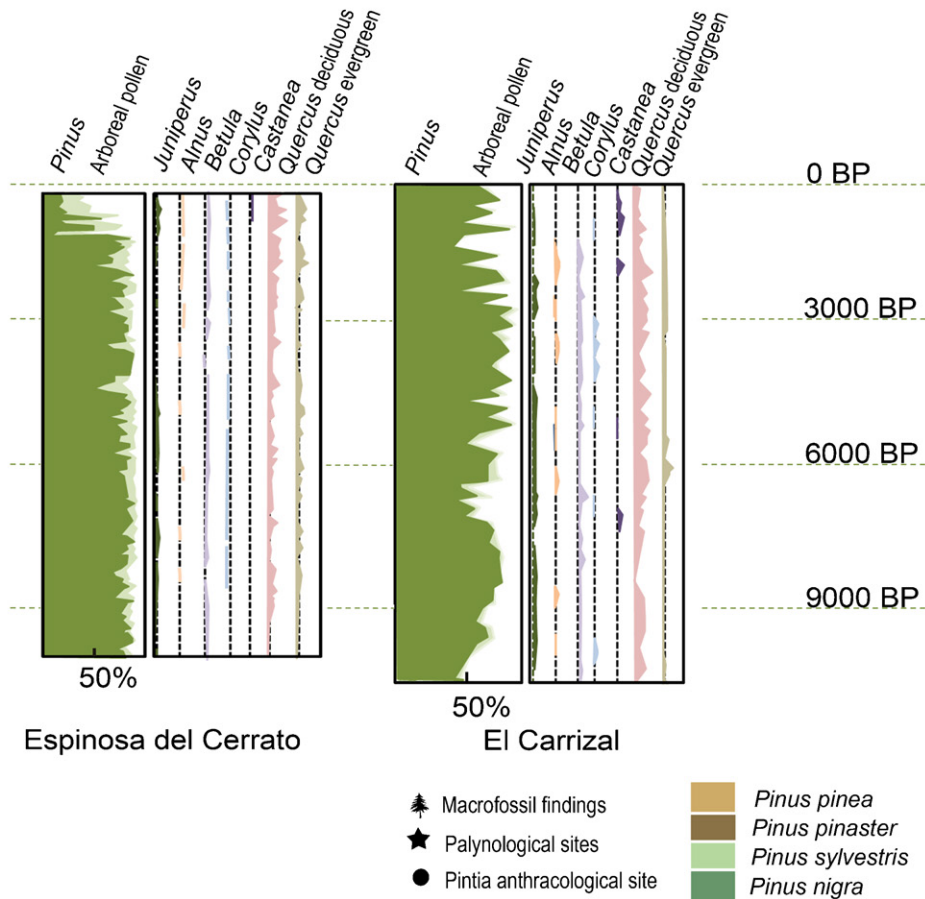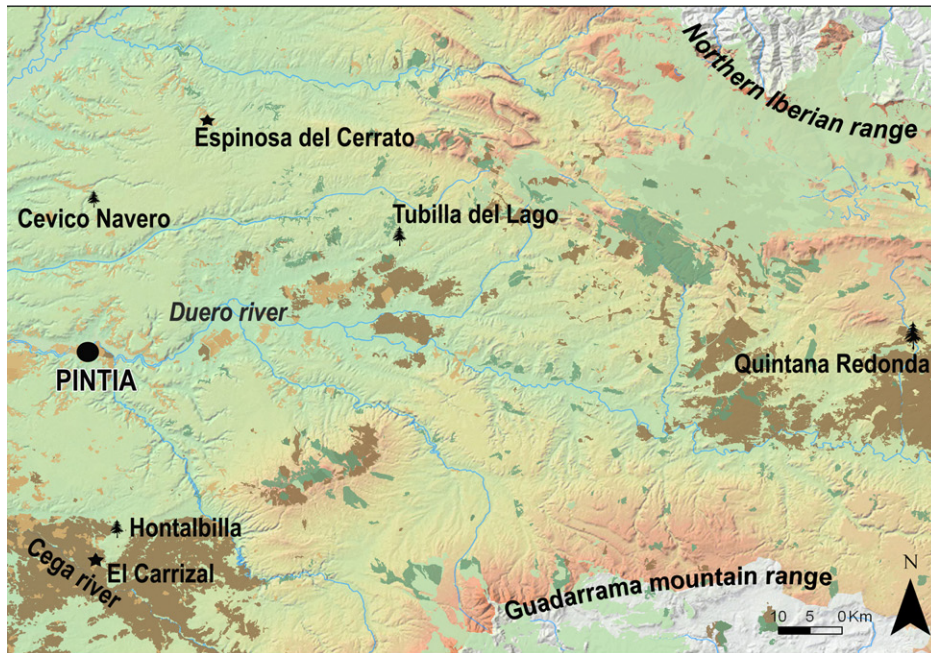
Fig. 3. Map: location of the late-Holocene palaeobotanical Duero basin studies. Palynological works (El Carrizal (Franco Múgica et al., 2001), Espinosa del Cerrato (Franco Múgica et al., 2005)), macrofossils findings (Cevico Navero (Roig et al., 1997), Hontalbilla (Alcalde et al., 2004) and Tubilla del Lago (García-Amorena et al., 2011)). The natural distribution of some pine species which are treated in the discussion as *Pinus pinea*, *P. pinaster*, *P. sylvestris* and *P. nigra*, are also indicated in different colours (García del Barrio et al., 2010). In the bottom, the signal of the pollen types of more relevance in the discussion is shown (gathered from the two pollen records that cover the chronological stage analysed in this paper (Franco Múgica et al., 2001, 2005)).

bordering the Duero basin, such as *P. sylvestris*, *Betula alba* L., *Populus tremula* L., *C. avellana*, *Frangula alnus* Mill. and *Viburnum opulus* L. (Guerra et al., 2006), can be found here within a genuine Mediterranean climate. The persistence of these communities along the Cega River is mainly attributed to the existence of favourable water conditions due to mantle groundwater dis-

Table 2
Pinus macrofossils found in the Duero basin palaeobotanical sites dated from the late-Holocene. Hontalbilla (Alcalde et al., 2004), Cevico Navero (Roig et al., 1997), Tubilla del Lago (García-Amorena et al., 2011) and Pintia (this work).

Palaeobotanical sites	*Pinus* gr. *sylvestris*/*nigra*		*Pinus nigra*		*Pinus pinaster*	*Pinus pinea*
Type of macrofossil	Cones	Woods	Cones	Woods	Woods	Woods
Hontalbilla	–	×	–	–	×	–
Cevico Navero	–	–	×	×	–	–
Tubilla del Lago	–	×	×	–	–	–
Pintia	–	×	–		×	×

charges associated with sand and the narrowing of the river valley, which creates a cooler environment than the surrounding area (Guerra et al., 2006).

Pintia is located centrally on the banks of the Duero River. Recently, the channel has undergone pronounced changes caused by the rectification works related to cereal crops, vineyard exploitations and headwater basin regulations. This situation means that the floods have become much less important and that the water level has dropped markedly in comparison to Vaccaean times. During that period, the situation in the Duero basin may have been similar to that of the current Cega River basin, where greater water availability allowed the persistence of Eurosiberian forest in certain areas of the floodplain. Moreover, the human population of Pintia could have contributed significantly to the disappearance of these formations due to the suitability of these woody species for use as construction materials and firewood and the area's proximity to the human settlement (Rubiales et al., 2011).

The abundance of charcoal fragments of *Pinus* gr. *sylvestris*/*nigra* is one of the most notable features of the Pintia assemblage as the two species that may have been present in the immediate environment during that period (*P. sylvestris*, *P. nigra*) are extinct today. *P. sylvestris* has two small relict populations within a few tens of kilometres of the study area fed by high water table enclaves that attenuate the summer drought (Baró and Zorrilla, 1951; Soriano et al., 2002). As suggested previously, in the Pintia environment, this species could have been present in areas of high water availability near the Duero River or shady areas at the foot of the limestone hillslopes. The current relict populations have shown some genetic differentiation with respect to the largest of the surrounding mountains, probably reflecting fragmentation processes and genetic drift since the beginning of the mid-Holocene (Robledo-Arnuncio et al., 2005). Their presence in these environments during the late-Holocene is of particular significance, suggesting that current relict populations located in the lowlands of the Duero basin could have been more significant and less fragmented before the intensification of human impact on the landscape. *P. nigra*, a taxon with sub-Mediterranean character not currently present in the study area, could have undergone a similar process. Indeed, in the northern Iberian plateau, available palaeobotanical information indicates that this species showed a much more extensive distribution in this area throughout the Holocene (Roig et al., 1997; Franco Múgica et al., 2001; Alcalde et al., 2004; García-Amorena et al., 2011), often until the end of the mid- and even late-Holocene (see Table 2 and Fig. 3).

The suggested aridity increase detected in the northern plateau during the second half of the Holocene (Franco Múgica et al., 2001, 2005) could also have adversely affected these two pine species. Conversely, the pollen record shows how these communities were very stable over the Holocene until the intensification of human impact caused their decline (Franco Múgica et al., 2001). Previous studies have indicated that the fires could have played a significant role in triggering these extinctions in other areas of central Spain (Franco Múgica et al., 2001; Rubiales et al., 2007, 2010) as these species have a very limited tolerance to fire and are frequently replaced by resprouter species (Rodrigo et al., 2004).

The anthracological record of Pintia shows how the natural environment close to the human settlement comprised species with mostly Eurosiberian or sub-Mediterranean distributions that are now extinct in the area. This information has to be carefully taken into account when planning future projects aiming to restore the vegetation prior to the intense anthropogenic disturbance of the last two millennia. The persistence of Eurosiberian taxa in the best preserved riparian environments of the Iberian Peninsula (Lara et al., 2004) shows how these sites can behave as "interglacial refuges" (Bennett and Provan, 2008) for some taxa with wider distributions in the lower areas of the Mediterranean region during colder periods. The probable existence of a genuine gene pool in these pine populations reinforces the importance of conservation and management directed toward achieving this goal.

4.5. Conclusions

Archaeological information can be a useful tool to reconstruct forest history and determine future forestry management strategies. This method can confirm the prehistoric presence of some taxa whose natural occurrence in the area has been subject to debate, as has been the case of Mediterranean pines (*P. pinaster*/*P. pinea*) in the Duero basin near Pintia. Furthermore, this work demonstrates the presence of microthermal/hygrophilous vegetation refugia through the interglacial period in inland Spain through historic times. The location of such areas has, until now, been presumably linked to great terrain features such as mountains (Bennett et al., 1991), leading to underestimation of the role that river buffers may have played in the long-term diversity of woody taxa. These relict formations have noticeably decreased in the last millennia, leaving only scattered examples, such as those from the Cega River.

At the present time, European and Spanish regional environmental policies, such as the Habitat Directive or different LIFE projects, promote the restoration of riparian ecosystems and forest cover in an attempt to create functioning ecosystems that are as similar as possible to the original landscapes prior to the substantial anthropogenic disturbances of recent millennia. Palaeoecology is an important source of information to achieve these goals; for example, allowing us to discern which taxa are native, which have been introduced and how the impact of human cultures was in the landscapes (e.g., Willis and Birks, 2006; van Leeuwen et al., 2008; Valsecchi et al., 2010). Pintia's anthracological results highlight the need to conserve the relict Eurosiberian formations, such as the Cega River, as a snapshot of the vegetation landscapes of the recent past near the study area. The results also suggest Mediterranean pinewoods (*P. pinaster* and *P. pinea*) as suitable species for use in regional plans of conservation and restoration of forest cover.

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