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Holocene treeline history of a high-mountain landscape inferred from soil charcoal: The case of Sierra de Gredos (Iberian Central System, SW Europe)

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ABSTRACT

Unravelling the precise Holocene altitudinal fluctuation of the highland vegetation communities (>1800 m asl) in the Gredos Range (Central System, Spain) is challenging owing to the complexity of the long-term human-environmental interactions in the area. Aiming at improving the knowledge of these highland dynamics, a pedoanthracological analysis was conducted on six soil profiles located on the northern slope of the central sector of the Gredos Range, following an altitudinal transect between 2200 and 1700 m asl in the *Las Pozas* valley. The soil charcoal analysis revealed the long-term stability of the Leguminosae shrublands, which have dominated the landscape over 1800 m asl since the Early Holocene. The highest ancient timberline was stimated to be at approximately 1700 m asl in this valley, from the Early Holocene until the beginning of the Late Holocene. This ancient forest contained *Pinus* gr. *sylvestris*, with significant numbers of deciduous *Quercus*. However, scattered individuals or small groves of pioneer deciduous taxa (*Betula* sp., *Populus* sp., *Salix* sp., Maloideae and *Prunus* sp.) were found to have thrived over the timberline during the Early and Middle Holocene, especially between 1900 and 2000 m asl. The highest treeline was marked by *Betula* at 2100 m asl. Elevated values of charcoal concentration reflect the intense fire regime of the area. The pattern of fire events accumulation periods that can be inferred from the 23 dated charcoal samples is consistent with previous data, which supports an increase in fire frequency around 2000 cal yr BP, during the first reported period of significant human influence.

1. Introduction

The cultural landscape of the Gredos Range (Central System, Spain) provides an excellent opportunity to gain an insight into the significant, diversified challenges in the study of long-term human-environment interactions in the highlands (Consejería de Fomento y Medio Ambiente, 2003). On the one hand, the Gredos highlands are considered an essential part of the natural value of the area. They are located at the core of the Gredos Regional Park, providing support to local socio-economic activities, such as tourism and extensive grazing (Troitiño, 1998). On the other hand, the present-day state of the highlands cannot be understood without a long-term landscape perspective, in which both, the Holocene environmental changes and the long-term human interference are taken into account. The landscape concept includes a dynamic perspective (Girel, 2006), which in the case of the Gredos highlands, is especially important, as shown through the controversial interpretations of the current mountain vegetation, which included hypotheses about a recent anthropogenic origin of pinewoods (Rivas-Martínez, 1987; Rivas-Martínez et al., 1987; Luceño and Vargas, 1991) and grasslands (Ruiz-Pérez and Valero-Sáez, 1990), before a definitive acceptance of the naturalness of pinewoods, based on palaeoecological studies (e.g., Franco-Múgica et al., 1997; Martínez García and Costa, 2001; Génova et al., 2009).

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The last decades of palaeoecological study on the Gredos landscape has revealed two important facts: i) the major role played by mountain pinewoods for millennia (Middle and Late Holocene), with an anthropogenic demise occurring in the last two millennia only, and ii) the evidence of the local presence of mountain pinewoods at 1100–1840 m asl in a large area of the Gredos Range (Franco-Múgica, 1995; Rubiales et al., 2007; López-Merino et al., 2009; López-Sáez et al., 2014; Rubiales and Génova, 2015). On a macro-regional scale, the nearest homologous mountain pinewood belt is located in the neighbouring eastern range of the Central System, in the Guadarrama Mountains, as the nearest western ranges (Béjar and Francia Ranges) cannot provide suitable pinewoods because of their lower altitudes and stronger oceanicity. Currently, the *Pinus sylvestris* L. forests reach 2100 m asl at Guadarrama and they were also dominant during most of the Holocene (Franco-Múgica et al., 1998; López-Sáez et al., 2014). The West-East oceanicity gradient and the differences in the historical land-use in both areas are the main factors explaining the difference between these timberlines (Rubiales et al., 2010). Nevertheless, the Holocene evolution of the Gredos treeline and timberline is difficult to specify because of the scarcity of relict pinewoods in the area and the near total absence of palaeobotanical macroremains over 1800 m asl. Several pollen records from high altitudes reconstruct broad scale landscape dynamics (e.g. Franco-Múgica, 1995; Ruiz-Zapata et al., 1996; López-Merino et al., 2009), as unequivocal evidence regarding the local presence of pinewoods but timberline altitude cannot be inferred. *Pinus* pollen percentages between 20% and 40% do not guarantee the local presence of *Pinus*, according to modern pollen assemblages (Andrade et al., 1994). Only values over 60% could be indicative of the local occurrence of *P. sylvestris* woods according to modern pollen rain samples (Gómez González, 2007; López-Sáez et al., 2013), while low ratios of *Pinus* pollen could be produced by local stands during dry cold periods (Birks and Birks, 2000; Hicks, 2006). Furthermore, the Leguminosae shrublands expected to replace the mountain pinewoods along with grasslands are very difficult to identify due to their limited pollen production (Franco-Múgica, 1995).

Fire frequency is often mentioned as a key disturbance element in understanding the past as well as the present Iberian Central System landscape dynamics (Moreno et al., 2011; Connor et al., 2012; López-Sáez et al., 2014). Across the Gredos Range, the strong influence of fire as a landscape shaper has been identified in recent years (Viedma et al., 2006), as well as during the last two millennia (Franco-Múgica et al., 1997; López-Merino et al., 2009; López-Sáez et al., 2016a, 2016b).

These last-mentioned palaeoecological works suggest the importance of the human use of fire, especially since the Middle Ages, often linked with grazing activities in the highlands. In order to improve the knowledge of local fire occurrence in this area new palaeo-fire data is needed due to the historical complexity in the human and micro-topography interactions in the area (e.g., mandatory mountain passes during some periods). However, little information is available on fires older than 2000 years (Franco-Múgica, 1995).

Therefore, the main aim of this study was to find key elements to improve the spatial and temporal interpretation of the Holocene landscape dynamics in the Gredos highlands. Special focus has been paid to reconstruct, i) the altitude reached by the treeline and the timberline, ii) the role played by the Leguminosae shrublands, and iii) the chronology of fire events.

To achieve this objective, a pedoanthracological altitudinal transect (1700–2200 m asl) from the northern slope of the central sector of the Gredos Range was studied. The soil charcoal analysis was complemented with twenty-three radiocarbon dates of charcoal macroremains.

2. Study area

2.1. Geographical context

The Central System is a SW-NE oriented mountain range located in the central part of the Iberian Peninsula that divides the Spanish plateau into two parts. At the centre of this chain, the Gredos Range is located between the major elevations of the Guadarrama and the Ayllón Ranges to the east, and the lower altitudes of the Gata-Peña de Francia Range and the Serra da Estrela to the west. The Gredos Range reaches its highest altitude at the Almanzor peak (2592 m asl), the highest summit of the entire Central System. The Gredos Range is approximately 150 km long and 50 km wide, making it the largest mountainous region in central Spain (Fig. 1).

This range has a subcontinental Mediterranean climate, characterised by a long (three month) summer drought (Font Tullot, 1983). Due to the climatic influence of the humid south-western winds, the annual precipitation is 1000–2000 mm at the highest altitudes along the southern slopes, while it is 500 mm in the northern lowlands. The annual average temperature of the entire range is lower than 12 °C, while it is lower than 8 °C in highlands over 1500 m asl (Font Tullot, 1983; Ninyerola et al., 2005). Summer storms are also experienced in the area (Morla and García García, 2009).

The siliceous substrates of the Gredos Range—mainly granites and gneisses—come from a Paleozoic continental basement that achieved a horst-graben structure during the Alpine orogeny. Quaternary glacial and periglacial events were also significant in the current configuration of the highlands (Pedraza, 1994).

Within this regional context, the present work is more precisely focussed on the northern slope of the central sector of the Gredos Range (Central Massif of Gredos or High Gredos). It is mainly delimited by the polygon marked by the Puerto del Pico pass (East), the Tormes valley (North), the Tornavacas pass (West) and the summit line (South). The central sector of Gredos is a granitic horst containing the highest peaks of the range, including the Almanzor. The northern slope of this sector exhibits a high concentration of glacial and periglacial traces. Glacial lakes, moraines and ancient glacial cirques continue to exist, despite the Holocene fluvial dynamics, while some cryoturbation and solifluxion phenomena currently occur in this area. Rocky substrates and granitic walls are often found, mainly due to Pleistocene glacial erosion and the recent fluvial net is mainly oriented in the South-North direction, towards the Tormes River. This open landscape, dominated by a mosaic of shrublands and grasslands, emphasises the presence of the imposing granitic peaks and rocky elements.

2.2. Vegetation in the Gredos Range

The Gredos Range has diverse flora. The presence of some Eurosiberian elements in the main Mediterranean floristic matrix of Gredos has been highlighted, along with the high level of endemicity (Luceño and Vargas, 1991; Sainz Ollero and Moreno Saiz, 2002; Andrade Olalla and González-Jonte, 2007). A paradigmatic example is *Echinospartum barnadessii* (Graells) Rothm., which is one of the dominant taxa in the high-altitude shrublands. In contrast, the warm, wet southern valleys provide refuge for small stands of the thermo-hydrophilous relict taxon, *Prunus lusitanica* L.

In short, the present-day vegetation can be divided across four altitudinal belts. The mesomediterranean belt (400–1000 m asl) is dominated by evergreen *Quercus* (*Quercus ilex* subsp. *ballota* (Desf.) Samp. and *Quercus suber* L.) and/or *Pinus pinea* L. forests. The supramediterranean belt (900–1500 m asl) is characterised by deciduous *Quercus* (*Quercus pyrenaica* Willd.) and *Pinus pinaster* Aiton forests, although scattered individual stands of *Q. pyrenaica* can

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