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Mid and Late Holocene Forest Fires and Deforestation in the Subalpine Belt of the Iberian Range, Northern Spain

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Abstract: The conversion of subalpine forests into grasslands for pastoral use is a well-known phenomenon, although for most mountain areas the timing of deforestation has not been determined. The presence of charcoal fragments in soil profiles affected by shallow landsliding enabled us to date the occurrence of fires and the periods of conversion of subalpine forest into grasslands in the Urbión Mountains, Iberian Range, Spain. We found that the treeline in the highest parts of the northwestern massifs of the Iberian Range (the Urbión, Demanda, Neila, and Cebollera massifs) is currently between 1500 and 1600 m a.s.l., probably because of pastoral use of the subalpine belt, whereas in the past it would have reached almost the highest divides (at approximately 2100–2200 m a.s.l.). The radiocarbon dates obtained indicate that the transformation of the subalpine belt occurred during the Late Neolithic, Chalcolithic, Bronze Age, Iron Age, and Middle Ages. Forest clearing was probably moderate during fires prior to the Middle Ages, as the small size of the sheep herds and the local character of the markets only required small clearings, and therefore more limited fires. Thus, it is likely that the forest recovered burnt areas in a few decades; this suggests that the management of the forest and grasslands following a slash-and-burn system. During the Middle and Modern Ages deforestation and grassland expansion affected most of the subalpine belt and coincided with the increasing prevalence of transhumance, as occurred in other mountains in the Iberian Peninsula (particularly the Pyrenees). Although the occurrence of shallow landslides following deforestation between the Neolithic and the Roman Period cannot be ruled out, the most extensive shallow landsliding processes would have occurred from the Middle Ages until recent times.

Keywords: Forest fires; Holocene; Subalpine grasslands; Shallow landslides; Landscape changes; Iberian Range

Introduction

Mountain areas have altitudinal belts that are defined by their biota and anthropogenic management characteristics, typically associated with the optimization of the use of natural resources (i.e. grasslands, timber, agricultural fields) (García-Ruiz et al. 2015). Each altitudinal belt occupies a specific place in the management system, which is organized according to population density, culture, market options, and environmental characteristics. Commonly, there is a low altitude montane belt, where husbandry activities prevail, a mid montane belt, where logging alternates with agricultural fields (occasionally under shifting agriculture), a high montane belt dominated by logging, and a subalpine belt used for livestock during the summer (García-Ruiz and Lasanta 1990). At higher altitudes the alpine belt is only used for hunting or recreational activities, and sometimes mining. The way and intensity with which such belts are managed have direct consequences for geomorphic processes, soil redistribution, and runoff generation (García-Ruiz et al. 2015). There have been relatively few reports on landscape evolution and soil erosion in the subalpine belt of the European mountains. However, an increasing number of studies have examined lacustrine and peatbog sediments, thus contributing to the identification of the main steps in forest clearing and the transformation of subalpine belts into grasslands. Of particular relevance are those of Montserrat (1992), Galop and Jalut (1994), Miras et al. (2007, 2010), Ninot et al. (2008), Bal et al. (2011), and Pérez-Sanz et al. (2013) in the Central Pyrenees; and Tinner et al. (1999, 2003), Schmidt et al. (2002), Blarquez et al. (2010), Colombaroli et al. (2010, 2013), Guiguet-Covex et al. (2011), Roepke and Krause (2013), and Walsh et al. (2014) in the Alps. These studies have all considered the important role of human activities, in most cases since at least the mid Holocene, in changing the structure and composition of forests in the subalpine belt, and in the use of large grassland areas to feed transhumant livestock in summer (e.g. García-Ruiz and Valero-Garcés 1998; Guiguet-Covex et al. 2011). Although some studies have continued to emphasize the role of climate in such changes, particularly through its influence as a cause of wildfires (Daniau et al. 2012; Marlon et al. 2013; Gil-Romera et al. 2014), it is widely acknowledged that since the mid Holocene the impact of human-induced fires, especially through slash-and-burn practices, may have been greater than large climate-induced fire events (Colombaroli et al. 2010; Bal et al. 2011).

The current subalpine landscape in the mountains of the Iberian Peninsula is characterized by extensive grasslands, alternating with patches of shrub (*Calluna vulgaris* and *Erica cinerea* on acid soils, and *Juniperus communis* on alkaline soils) and open forests of *Pinus sylvestris* and *P. uncinata*, the latter occurring at the upper boundary of the subalpine belt in the northern mountains. This landscape is a consequence of the interactions between climate and grazing activities, which have progressively reduced the number of trees and the altitude of the treeline, and the almost complete loss of krummholz areas. Changes in the altitude of the upper forest limit have been highly variable as a result of past management systems (García-Ruiz et al. 1990). The consequences of an altitudinal reduction in the treeline and deforestation can be an altitudinal reduction in solifluction processes (Höllermann1985), the triggering of shallow landslides (García-Ruiz et al. 2010), and the occurrence of a variety of erosion processes, including gullying and extensive development of gelifluction terracettes (García-Ruiz and Puigdefábregas 1982). Snow accumulation and snowmelt are also directly influenced by the conversion of forests into grasslands (Alvera and Puigdefábregas 1985; López-Moreno and García-Ruiz 2004; Lana-Renault et al. 2011). Geomorphological and hydrological changes because of past land cover disturbances demonstrate the fragility of the subalpine belt, and have conditioned forest re-establishment following the recent decline in livestock numbers and grazing activities. This is a major environmental issue in the short term, because climate change is affecting snow accumulation and the timing of snowmelt (e.g. López-Moreno and García-Ruiz 2004; Stewart 2009; Hantel et al. 2012; Marty and Meister 2012; Sharma et al. 2013), and is indirectly driving forest re-establishment in the subalpine belt.

During a field study of geomorphic processes related to the transformation of subalpine forests into grasslands in the northwestern massifs of the Iberian Range, we found various charcoal fragments in the soil profiles of shallow landslide scars. This provided the opportunity to date the occurrence of paleo-fires and to clarify the main features of evolution of the landscape.

This report is the first concerning the occurrence of prehistoric and historic forest fires in the subalpine and upper montane belts of the Iberian Range, in the northern Iberian Peninsula. Its findings contribute to interpretation of the evolution of the landscape in a grassland area traditionally characterized by intensive summer grazing by many thousands of sheep. We also reviewed regional palaeoenvironmental studies, and provide information on the characteristics of the subalpine areas transformed into grasslands, and the main geomorphological impacts of this process.

1 Study Area

The Urbión massif is one of the highest mountain areas of the Iberian Range, in the northeastern sector of the Iberian Peninsula (Figure 1). The massif (maximum peak height 2228 m) is mainly composed of Upper Jurassic and Lower Cretaceous small quartz conglomerate, and red mudstone and limestone that were deposited in a large delta. The alpine tectonics folded and faulted these materials, resulting in a monoclinal relief with the abrupt front facing north. The front was affected by Pleistocene glaciation, with the development of cirques, U-shaped valleys (up to 6–7 km in length), and moraine-dammed lacustrine deposits and tills. The lowest tills in the Urbión Valley are located at 1270 m a.s.l. (García-Ruiz et al. 1998).

Climate data are only available from observatories located on the southern face of the massif, at approximately 1100–1150 m a.s.l. These have recorded a temperature increase in the last 60 years; thus, the mean annual temperature at Vinuesa was 7.7ºC for the period 1957–1965, and 9.6ºC for the period 1990–2001. In general, the mean annual temperature has increased by 1.1ºC, and particularly in winter (average 1.3ºC) (García de Celis et al. 2008). A dendroclimate study in the neighboring Cebollera Range confirmed that temperature increased significantly during the 20th century (Camarero Martínez and Gutiérrez Merino 2008). Mean annual precipitation exceeds 900 mm above 1000 m a.s.l., and is probably 1500–1600 mm in the main divide, as estimated by Arnáez Vadillo (1987) for the neighboring Demanda Range. Precipitation has declined slightly since the mid-20th century, particularly between November and March (García de Celis et al. 2008).

Plant cover is dominated by extensive *P. sylvestris* forests on the south-facing slope, whereas the northern face has a complex mosaic of *P. sylvestris* and *Fagus sylvatica* forests, grasslands and shrubs with heathers of *C. vulgaris* and *E. cinerea*, and *Vaccinium myrtillus* and *J. communis*, even on soils developed on limestone substratum. The area has been used in summer for transhumant sheep herds, with two notable periods of intense activity: the 15th century, and the period between the end of the 17th and the end of the 18th centuries, coinciding with an international increase in wool demand (Diago Hernando 2002). A crisis occurred in the transhumance system at the beginning of the 19th century, resulting in local populations increasing the cultivated area (Moreno Fernández 1994). In 1792 the main two villages (Viniegra de Abajo and Viniegra de Arriba) accounted for 17,169 (262 per km^2) and 19,100 (497 per km^2) sheep, respectively (Moreno Fernández 1996). At present the number of sheep is only 840 and 2690 in total, respectively. The increase in temperature and the decline in grazing activities explain the recent increase in the altitude of the treeline; on the south-facing slope of the Urbión Range in 1956 it was located at 1866 m, but it was at 1900 m in 2006 (García de Celis et al. 2008).

2 Methods

The Ormazal Valley (total area 2449 ha), which is upstream of Viniegra de Arriba, was selected for sampling and detailed study. The valley has a small glacial cirque in the headwater area, karstic activity on the limestone outcrops, relatively gentle slopes (in general, < 30%), wide divides, and large areas covered with subalpine grasslands intensively disturbed by shallow landslides. The valley ranges in altitude from 1240 m to 1887 m a.s.l.

A map showing the location of the active scars of shallow landslides was developed using the 2006 orthophoto available from the National Geographic Institute of Spain. Data on the topographical features of the scars (altitude, aspect, and gradient) were recorded.

Aerial photos from 1956, the 2006 orthophoto, and a GIS were used to develop the corresponding vegetation maps. The resolution of digitized maps was 18 × 18 m per pixel.

A field campaign in summer 2014, and analysis of aerial photos and orthophotos enabled the shallow landslide scars in the Ormazal Valley to be identified, and their distribution determined in relation to plant cover and altitude.

Soil samples (15) selected from the landslide scars were sieved to isolate micro-charcoal for radiocarbon analysis to determine a chronological framework. A total of 8 accelerator mass spectrometry (AMS) radiocarbon dates were obtained from various profiles in the study area; these were calibrated using Calib v. 7.02 (Stuiver and Reimer 1993) using the latest calibration datasets (Reimer et al. 2013).

3 Results

3.1 Plant cover characteristics

Figure 2a and Table 1 show the 1956 vegetation cover map and data, respectively. Grasslands (34%) and shrub communities (31.9%) were the most extensive types of vegetation cover, with the former dominating in the eastern sector of the valley and the latter in the western and southern sectors. Most of the shrub areas were probably occupied by grasslands in previous decades (perhaps for centuries), when the transhumance system was at its height. Open forests dominated by *P. sylvestris* occupied small patches in the western and southern sectors of the valley (9.8%). Dense forests composed mainly of *F. sylvatica* covered only 1.8% of the area, and were exclusively located in the northernmost sector of the valley. Eroded areas occupied 18.4% of the study area, and seem to be spatially related to grasslands, forming small patches having irregular borders. A small area (0.7%) in the northwest of the valley was still cultivated, and was surrounded by abandoned fields (2.9%). In total, the grasslands, shrubs, and eroded areas represented 84% of the study area in 1956. This can be assumed to be the minimum area occupied by grasslands at the time of maximum livestock pressure.

Figure 2b shows the plant cover map for 2006, and the proportion occupied by each vegetation class is shown in Table 1. These demonstrate that a remarkable decline had occurred in the areas of grassland (25.4%) and shrubs (23.9%) since 1956 and that there had been an increase in the dense forest area (16.3%). Dense forest of *P. sylvestris* was particularly evident in the southernmost part of the valley, and in small patches of the western sector, whereas there had been a moderate increase in the area of dense deciduous forests in the northern sector. Also noteworthy are the decline in open forest area (8%) and the presence of two areas afforested with *P. sylvestris* (4%). The eroded areas were similar in extent (17.8%), and the cultivated areas had disappeared and been replaced by abandoned fields.

3.2 Fire history records

As noted above, eight charcoal fragments from soil profiles in shallow landslide scars were dated. Figure 3 shows the location of the charcoal fragments, and Table 2 provides data for each fragment and the altitude at which it was collected. The fragments represent the occurrence of local or more general fires of natural or human-induced origin. A wide variety of ages were established among the fragments.

(i) The oldest recorded fires corresponded to the Late Neolithic (5630 cal yr BP) and the Chalcolithic (4911, 4858, and 3962 cal yr BP).

(ii) Some fire remains corresponded to the Bronze Age (3162 cal yr BP).

(iii) Two charcoal remains indicated fires that occurred during the Iron Age (2234 and 2034 cal yr BP).

(iv) Only one charcoal fragment could be associated with the Middle Ages (1116 cal yr BP).

No relationship was found between the dates established for fire occurrence and topographic variables. In fact, fragments having highly contrasting dates were found in the same area of the valley at similar altitudes. Consequently, deforestation was not found to be associated with altitude or topographic aspect. The altitudinal range of the charcoal samples was 1738–1859 m a.s.l.

3.3 Spatial distribution of shallow landslides

Figure 4 shows the location of shallow landslides in the Ormazal Valley, based on the orthophoto for the year 2006. The landslides were characterized by a semicircular crown or scar of highly variable width (5–25 m) (Figure 5). Bedrock and abundant detached rock fragments were visible in the area directly affected by landsliding, and gelifluction terracettes had develop in the remnants of the soil. In most cases the landslide plane coincided with the contact between the C soil horizon and the bedrock (i.e. between 40 and 60 cm depth). The soil depth varied as a function of topography; 80–90 cm deep on concave slopes; 40–60 cm on straight slopes; and approximately 35–40 cm on convex slopes.

A total of 270 landslide scars were identified in the Ormazal Valley (10.7 scars km^{-2}). Most of the scars occurred in the highest areas, almost always above 1500 m a.s.l., and particularly between 1600 and 1950 m (185 landslide scars, 68% of the total) in the subalpine belt. The presence of shallow landslides was particularly related to grasslands (58%) and eroded hillslopes having small patches of remaining soil (28%). Shrub cover areas contained 10% of the scars, whereas few (2%) were present in forest areas, including natural forests and afforested areas. The density of landslides was 22.8 per km^2in grassland areas, 17 per km^2 in the eroded areas, 4 per km^2 in shrub areas and 1 per km^2 in forest areas. It is noteworthy that the landslide scars tended to have an aggregated spatial distribution (Figure 6).

4 Discussion and Conclusions

Extensive deforestation, aimed at creating new pastures for summer transhumant livestock, occurred in the ancient past at altitudes exceeding 1500 m a.s.l. in the northwest Iberian Range, affecting the subalpine belt and upper sectors of the montane belts. Forest clearing began in Neolithic times, and persisted until the present because of the grazing system, although the number of sheep flocks that reach the upper part of the mountains has clearly declined in recent decades. The golden period of transhumance probably occurred during the 15th century, and between the end of the 17th and the end of the 18th centuries (Diago Hernando 2002). The recent decline in the size of the total sheep flock has changed the landscape stability, with a marked trend of transformation of grasslands into shrubs, and ultimately into dense forests (Sobrón García 1987). The importance of transhumant livestock can be deduced from the fact that more than 80% of the study area comprised grasslands, shrubs, or eroded areas during the 1950s. We hypothesize that the eroded areas were covered by deep soils in the past, and they were eroded following deforestation, based on the activity of shallow landslides in the areas covered by grasslands. This process was similar to those observed in the Pyrenees (García-Ruiz et al. 2015) and the Alps (Roepke and Krause 2013).

The oldest charcoal fragments were obtained from soils affected by landsliding. Fires occurred during Late Neolithic times (5630 cal yr BP) and the Chalcolithic (5000–4000 cal yr BP), and also during the Bronze and Iron ages and the Middle Ages, indicating that fire activity has been a constant since the Neolithic, and suggesting ancient landscape disturbance for grazing purposes. Human-induced fires probably affected small areas, particularly during the Neolithic, Chalcolithic and Bronze ages, as small flocks managed for limited local markets would have required only small extensions of pasture area. Nevertheless, extensive uncontrolled fires would also have occurred. Studies of archaeological sites in mountains of northern Spain have shown that specialization in livestock exploitation has occurred since at least 5300 cal BC (e.g. Els Trocs Cave, Central Pyrenees; Rojo Guerra et al. 2013). The main consequence of this fire activity was a reduction in the altitude of the timberline, which would have been at approximately 2100 m a.s.l. but at present forms an uneven boundary at 1600–1850 m a.s.l. A similar evolution occurred in the Pyrenees, where the potential timberline would be located between 2300 and 2400 m a.s.l. (Ninot et al. 2008), in contrast to its present location at 1650–1800 m.

Various reports on the evolution of Holocene paleoenvironments have noted that human disturbance of the landscape dates to the Neolithic, as deduced by the presence of human indicators in pollen lacustrine sequences, as well as the occurrence of archaeological sites coinciding with changes in land cover (Carrión et al. 2007; Colombaroli et al. 2008; Gil-Romera et al. 2010). Nevertheless, some of these changes have occurred in parallel with climate fluctuations (Marlon et al. 2013), such that it is not easy to discriminate between anthropogenic and climatic forcings in explaining landscape evolution (Marlon et al. 2009; Pérez-Sanz et al. 2013). This problem is exacerbated in high mountain areas, where the impact of human activities since the Neolithic has been reduced to clearing of small forest patches and the grazing of small flocks in summer. Unfortunately, there is almost no information for this study area on landscape changes from lacustrine sequences, or archaeological evidence prior to the Roman Period. Analysis of the base of the lacustrine deposit in a sedimentary sequence from Nava Lake (Cebollera Range, near the Urbión Mountains) showed that the plant cover was dominated by grasslands related to local forest fires, as suggested by the presence of abundant large charcoal fragments (Gil García et al. 1996), although no radiocarbon dates were available. The peatbog of Hoyos de Iregua (1780 m a.s.l.), also in the Cebollera Range, shows a trend of forest decline since 5060 ± 90 yr BP, indicating the occurrence of forest clearings in the immediate area of the bog (Gil García et al. 2002; López de Calle and Tudanca 2014). Nine dolmens have been excavated in the Cebollera Range, and a similar number has been identified. These have been dated between 6000 and 3500 cal yr BP, the period covering the Neolithic and the transition to the Chalcolithic (López de Calle and Pérez Arrondo 1995; López de Calle and Tudanca 2014). Unfortunately, all the sites involved are located below 1400 m a.s.l. (Barrios Gil 2005) and are quite far from the subalpine belt. However, they confirm the occurrence of the first agro-pastoral societies in the area (López de Calle et al. 2001), which probably used the subalpine belt during summer for their small sheep flocks, including landscape clearing through selective fires. This is consistent with the oldest fires (ca. 5600 years BP) recorded in the present study. Landscape changes would have continued during the Bronze and Iron ages, and probably during the Roman Period. This would have been at a relatively low intensity, probably with forest clearing alternating with forest re-colonization in distinct areas, as suggested by the different ages of the charcoal fragments.

The Middle and Modern Ages probably represent a change in the characteristics of landscape transformation, with intensification of sheep transhumance and the entry of Iberian Peninsula wool production into international markets. The northern massifs of the Iberian Range (the Neila, Urbión, Demanda, and Cebollera massifs) were particularly affected by these processes, which resulted in the grazing of thousands of sheep, and generalized deforestation (Diago Hernando 2002). A study of sedimentary sequences from four lakes in the Urbión Range (Gómez-Lobo 1993), which provides information on the period since 15510 ± 90 BP, reported no evidence for human influence prior to 560 BP, although a decline in arboreal pollen was detected after ca.

4500 yr BP. In the neighboring Cebollera Range, a study of the Ciega Lake also dated the beginning of forest degradation at ca. 560 ± 80 yr BP, coinciding with the remarkable presence of ruderal taxa and the substitution of pine for deciduous forests (Gil García et al. 1995). In the Grande Lake (Neila Range, immediately westward of the Urbión Mountains), Vegas (2007) found three main periods of higher water levels: 6000–5500; 4100–3500; and 750–650 cal yr BP. The high water levels during the two former periods had a climatic origin. The latter period was characterized by a decline in the area of forest, which was attributed to more intense human activity in the high mountain areas. Therefore, there is general agreement that extensive transformation of the landscape of the subalpine belt of the Iberian Range has occurred since the Middle Ages. Nevertheless, forest loss probably intensified during the 18th and 19th centuries, coinciding with the crisis of the transhumance system, the decline of textile industries, and the increase in population density (Gómez Urdáñez 1986). This forced the local stock breeders to expand their flocks, which required the use of local resources. Similarly, in some Pyrenean valleys the forests were replaced by cultivated fields and subalpine grasslands, resulting in changes in geomorphic processes and fluvial channel dynamics (Gómez-Villar et al. 2014; Sanjuán et al. 2014). A diversity of information on the beginning of human activities in the northern massifs of the Iberian Range suggests that fires were small and localized, and were associated with slash-and-burn systems. The use of fire as a tool to manage forest clearing did not commence until the Middle Ages, concurrent with access to larger markets.

Studies of other Spanish mountain areas confirm the importance of human activity in changing the spatial organization of forests and grasslands in subalpine areas during the Mid and Late Holocene (Morales-Molino et al. 2011; Berrocal et al. 2014). Pérez-Díaz et al. (2014) reported the emergence of anthropogenic palynomorphs during the Early Neolithic (5500–4500 cal yr BC) in the western Pyrenees. Rull et al. (2011) showed that human activity was the main driver of Holocene land cover changes in the southern Pyrenees during the last two millennia. Thus, study of a peatbog at 2180 m a.s.l. in the Madriu Valley (Andorra) indicated that moderate forest clearing and grazing activities occurred between 8400 and 7800 cal BP, and between 7000 and 6300 cal BP, with the presence of ruderals and pollen providing evidence of woodland clearance. However, the most important threshold of intensified human activity occurred during the Early Bronze Age, at approximately 4100–3600 cal BP. A second threshold occurred between 2050 and 1800 cal BP (during the Iron Age and the Roman Period), and a third threshold corresponded to the 16th–18th centuries (during one of the golden periods of the transhumance system) (Miras et al. 2007). Some of these thresholds were also detected in the Perafita Valley (also in Andorra) associated with intense grazing activity during the Mid and Late Neolithic, and the Early and Late Bronze ages (Miras et al. 2010). In the Andorra valleys the finding of small huts dating to the Early Neolithic confirmed the seasonal use of high mountain areas, probably for both hunting and grazing (Orengo et al. 2014). This period was followed by forest recovery and subsequent landscape transformation, as deduced from archaeological data and clear evidence of forest clearing related to occasional fires. Orengo et al. (2014) noted that after 3500 cal BP “some areas remained deforested until today”.

Human-induced fires were also been detected at 1821 m a.s.l. in Bourg Lake (Central Pyrenees), where clear relationships have been found between fire frequency and anthropogenic pollen indicators (Bal et al. 2011), particularly during the transition from the Bronze Age to the Iron Age (when the recovery of forest was rapid), and during the Roman Period. Since the Roman Period, “fires were used to maintain already open spaces” (Bal et al. 2011). Evidence of early landscape transformation was found in the Upper Noguera Pallaresa Valley, where intensification of human activity during the Bronze and Iron ages and the Roman Period were deduced from the presence of numerous charcoal fragments, particularly during the Middle Ages, when a decline in the altitude of the treeline was detected (Cunill et al. 2012). A sedimentary sequence from Basa de la Mora Lake (1914 m a.s.l.) revealed a decrease in the total arboreal pollen between 4500 and 3900 cal BP (Pérez-Sanz et al. 2013), coinciding with the first deforestation detected in Tramacastilla Lake by Montserrat (1992). Analysis of the Basa de la Mora Lake sequence suggests that anthropogenic pressure was negligible until ca. 1700 yr BP, when fire dynamics intensified (Lasheras-Álvarez et al. 2013), and particularly since 1150 yr BP, with clear evidence of forest management during the Medieval Climate Anomaly (900–1300 AD).

In a review of fire activity in the Mediterranean basin, Vannière et al. (2011) noted that charcoal records during the Mid Holocene “Thermal Maximum” (approximately 7500–4000 cal yr BP) suggest an increase in fire, and that “human influence on regional fire activity became increasingly important after c. 4000–3000 cal. BP”. Walsh et al. (2014) detected four stages of landscape change in the French Alps (the Mesolithic, the Chalcolithic/Bronze Age, the Iron Age and Roman Period, and the post-Medieval period), including forest clearance close to the treeline for hunting, and progressive intervention in the subalpine belt to establish the transhumant system. Roepke and Krause (2013) detected four phases of human activity in the French Alps, including the Early to Middle Bronze Age, the Late Iron Age, the Early Middle Ages and the High Middle Ages. Guiguet-Covex et al. (2011) confirmed that the extensive grasslands in European alpine landscapes are the consequence of increasing grazing pressure from 5500 cal yr BP, and particularly since the mid Bronze Age, as demonstrated by a large number of studies in Austria and Switzerland. Colombaroli et al. (2013) arrived at the same conclusions for the central Swiss Alps (Mont d'Orge Lake), and noted that the first forest clearances involved slash-and-burn practices that affected small patches, contributing "to the establishment of a more diversified and fragmented landscape"; this suggests a natural feedback for the occurrence of more small localized fires. A study of sedimentary sequences from four Swiss lakes also detected distinct phases of forest clearance and intensified land use, particularly during the Bronze Age, the Late Iron Age, the Roman Period and the early Middle Ages (Tinner et al. 2003). A high resolution multiproxy study (Dietre et al. 2014) of a 177 cm-long radiocarbon dated peat-bog in the Silvretta Massif (Switzerland/Austria) confirmed that "the exploitation of alpine landscape resources (cultivation of cereals in the valley) and livestock grazing (in the subalpine and alpine areas) has therefore a long tradition going back at least for 6200 years". In southern Switzerland the occurrence of charcoal peaks was preceded by changes in pollen record, indicating human activity (Tinner et al. 1999). Reconstruction of fire variability at 2343 m a.s.l. in the Gouillé Rion, Swiss Alps, demonstrated the combined effects of climate variability and human activity. This showed that moderate fires occurred during the first half of the Holocene, but a clear increase occurred during the Chalcolithic and the Bronze Age, when the altitude of the timberline declined by several hundred meters (Colombaroli et al. 2010). Open areas were also found to have been present at high altitudes during the Bronze Age, which is a sign of human-induced subalpine grassland development. Many studies have reported that the timberline was in general located more than 300 m above its current position (Dietre et al. 2014).

As in other European mountains, forest loss to enlarge the area of subalpine grasslands in the Urbión Mountains favored pastoral activity and the development of transhumant systems. This contributed to the establishment of societies having complex organization and the capacity to use distinct altitudinal belts in different seasons (Anglada et al. 1980; García-Ruiz and Lasanta 1990; García-Ruiz et al. 2015).

Nevertheless, the substitution of forests by subalpine grasslands had a high environmental cost, resulting in severe erosion caused by gullying and shallow landsliding because of changes in land cover and soil properties (Zavala et al. 2014; García-Ruiz 2015). The location of most of the shallow landslide scars in the subalpine grasslands, and their almost total absence within the forest, confirm that deforestation caused the loss of soil cohesion because of an increase in pore water pressure during periods of intense rainfall or snowmelt (Van Asch et al. 1999). We do not know how often shallow landslides recurred in the study area. However, in similar soils in the Pyrenees, rainstorms corresponding to a return period of more than 25 years have triggered landslides (García-Ruiz et al. 2010) particularly when the preceding soil moisture content was high. This is a very significant problem for soil conservation, because large areas appear to have lost most of their soil (17.8% of the total area), reducing soil productivity and the sustainability of the system. It is worth determining when generalized shallow landsliding began, but we have insufficient information to address this issue. Shallow landslides probably began with the first forest clearing following Neolithic times, as occurred in the Alps (Guiguet-Covex et al. 2011). We hypothesize that the most dramatic soil erosion impact of deforestation occurred after the Middle Ages, when this process affected a large proportion of the study area. It is also likely that the climatic conditions of the 16th–19th centuries (when the snowpack was deeper) enhanced the occurrence of shallow landslides, as suggested for the Central Pyrenees (García-Ruiz et al. 2010). A sedimentological study of Tramacastilla Lake, in the Spanish Pyrenees (Montserrat, 1992), corroborated the occurrence of moderate soil erosion processes during small deforestation events at ca. 4000 cal yr BP, and dramatic soil erosion activity following generalized fires in the subalpine belt since the Middle Ages.

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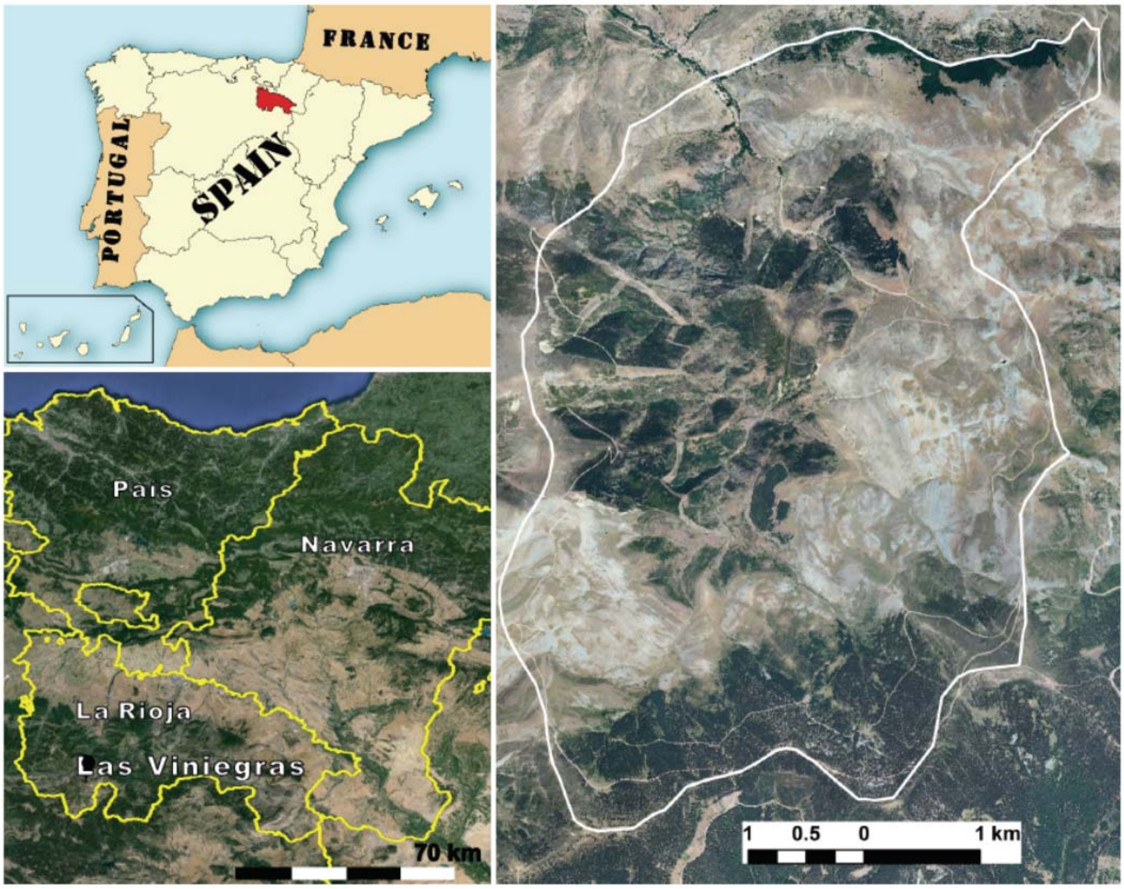

Figure 1 The location of the study area at distinct scales within the Iberian Peninsula, Southwestern Europe. Coordinates of the center of the study area are 42° 3' 58.68'' N, 2° 49' 33.4'' W.

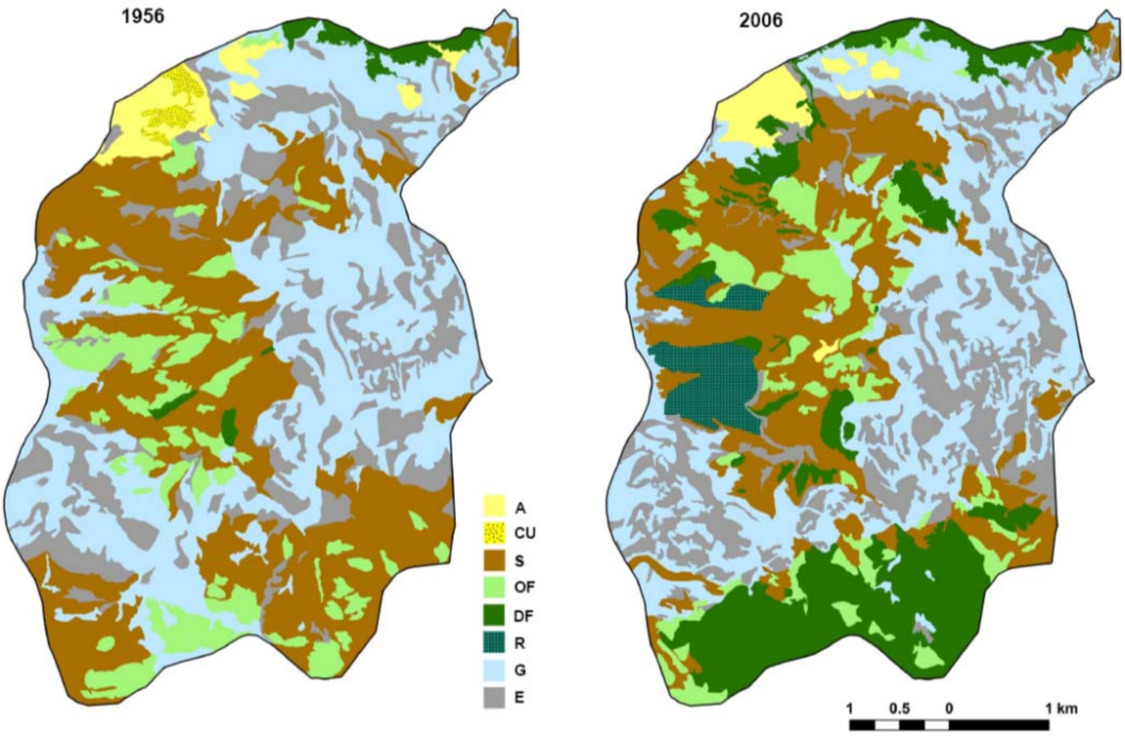

Figure 2 Land cover maps of the study area in 1956(a) and 2006(b). A: Abandoned fields; CU: cultivated fields; S: Shrublands; OF: Open forest; DF: Dense forest; G: Grasslands; E: Eroded areas; R: Afforested areas.

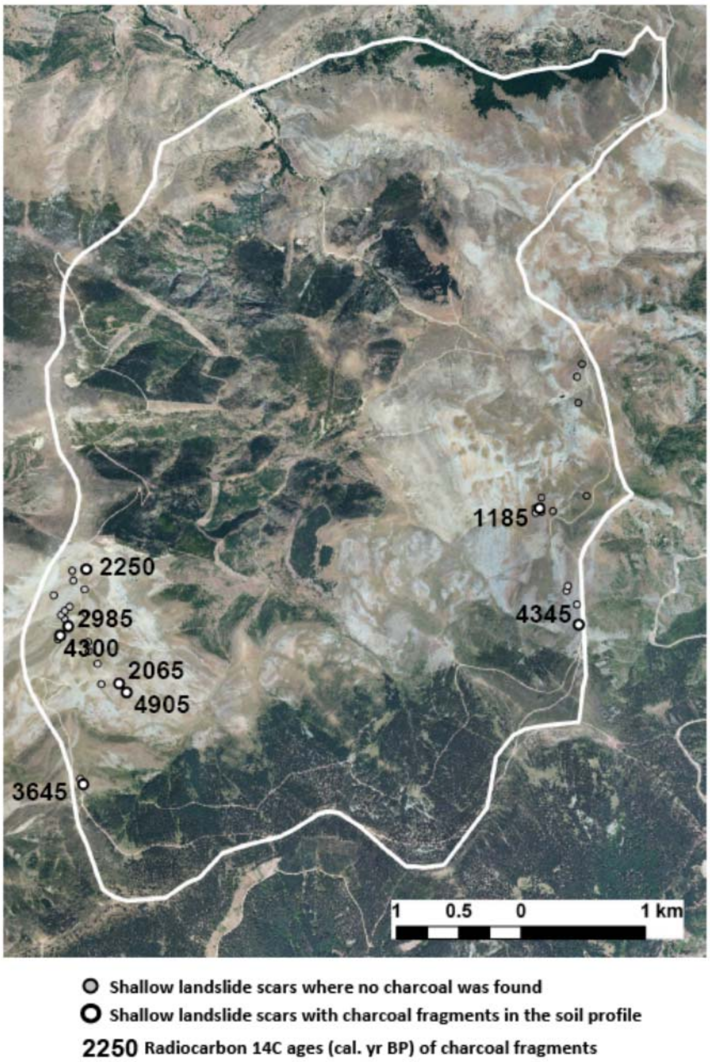

Figure 3 Location of the whole studied profiles in the subalpine belt of the Ormazal Valley, with indication of the soil samples analysed indicating the eight points which provided enough charcoal fragments to date.

Figure 4 Location of the landslide scars in the Ormazal Valley, according to the 2006 ortophoto.


Figure 5 Landslide scars in the subalpine belt of the Ormazal Valley, Urbión Mountains.

Figure 6 Large aggregated landslides in the Ormazal Valley, Urbión Mountains, with the steepest slopes already eroded.

Table 1 Land cover and soil uses in 1956 and 2006

	1956(ha)	%	2006(ha)	%
Abandoned fields	71.28	2.9	59.23	2.4
Cultivated fields	18.31	0.7		
Dense forest	43.22	1.8	397.94	16.3
Open forest	240.47	9.8	196.41	8.0
Grasslands	836.18	34.1	674.24	27.6
Shrublands	780.55	31.9	585.69	23.9
Erodedareas	450.39	18.4	434.84	17.8
Afforestation	8.43	0.4	100.47	4.0
Total	2448.83		2448.83	

Table 2 Chronological data of the charcoal samples shown in Figure 3

Lab code	Sample name	Alt. (m a.s.l.)	$d^{13}C$	Frac.	±	$d^{14}C$	±	^{14}C Age	±	Lower cal range (2sigma)	Upper cal range (2sigma)	Mean cal BP (2sigma)
169725	VIN 14B 8	1742	-25	0.7555	0.0031	-244.5	3.1	2250	35	2154	2272	2234
169726	VIN 18B 11	1794	-25	0.7735	0.0026	-226.5	2.6	2065	30	1966	2119	2034
169727	VIN 23B 3	1848	-25	0.6354	0.0028	-364.6	2.8	3645	35	3871	4014	3962
169728	VIN 25B 4	1755	-25	0.5821	0.0020	-417.9	2.0	4345	30	4848	4973	4911
169729	VIN 29B 9	1859	-25	0.8626	0.0030	-137.4	3.0	1185	30	1051	1182	1116
169730	VIN 19B 5	1847	-25	0.5430	0.0024	-457.0	2.4	4905	40	5589	5663	5630
169731	VIN 2B	1762	-25	0.5855	0.0021	-414.5	2.1	4300	30	4829	4892	4858
169732	VIN 4	1738	-25	0.6895	0.0023	-310.5	2.3	2985	30	3064	3246	3162

Frac.=Fraction modern