TRANSHUMANCE AND LONG-TERM DEFORESTATION IN THE SUBALPINE BELT OF THE CENTRAL SPANISH PYRENEES: AN INTERDISCIPLINARY APPROACH

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Abstract

A key problem in explaining the mountain landscapes of the Mediterranean region is the relationship between the development of transhumance (seasonal movement of livestock over long distances) and deforestation of the subalpine and upper montane belts at 1350 to 2200 meters above sea level (m a.s.l.). We examined this relationship in the Central Southern Pyrenees using information from multiple proxies — archaeology, pollen analysis, lacustrine sedimentation patterns, historical documents, and geomorphology. Although there is evidence of forest clearing since the Neolithic, and we can infer the presence of shepherds and livestock in mountain areas based on

archaeological sites and pollen analysis in some lacustrine records, there is no strong evidence for transhumance between the Ebro Depression and the Pyrenees during the Prehistory. Instead, we found evidence of transterminance (seasonal movement of livestock over short distances) during this time. Growth of human populations and the establishment of large-scale markets favored longer livestock movements during the Roman period, although we only have indirect information on this for other areas of the Iberian Peninsula and the Mediterranean region. A few documents indicate the occurrence of transhumance during the Early Middle Ages, whereas all other proxies indicate a general expansion of livestock and transhumance during the 12th and 13th centuries. This coincides with the Christian conquest of the Central Ebro Depression by the Aragon Kingdom, the organization of large wool markets in Western Europe, and the exemptions conferred by the kings of Aragon to herders in the city of Saragossa. This led to rapid deforestation, in that forests were rapidly logged or burned to expand the summer grasslands. During this period, written documents indicate many conflicts between people in the villages and valleys for control of summer grasslands, pollen analyses show a rapid decline of arboreal pollen, and geomorphology studies indicate greatly increased sedimentation rates following deforestation, suggesting intense erosion. Transhumance has declined since the end of the 18th century, and particularly throughout the 20th century, and this has led to tree re-colonization of less accessible and marginal areas. The hydrological and geomorphological consequences of these recent events are important topics for future studies.

Keywords: Mountain belts, Subalpine environment, Livestock management, Multi-proxy approach, Landscape changes, Spanish Pyrenees.

1. Introduction

Mountain areas are mainly defined by their altitude and slope gradients and by the presence of distinct altitudinal geoecological belts (Troll, 1972, 1973; García-Ruiz et al., 2015). Alexander von Humboldt first described these geoecological belts at Mount Teide in the Canary Islands and in South America during the early 1800's (Wulf, 2016). With the exception of mountains in the Arctic and Antarctic, a mountain must have at least two altitudinal belts to be considered an authentic mountain (Byers et al., 2013). Mountains thus have several altitudinal belts of vegetation, such as montane, subalpine, and alpine.

Since Neolithic times, land management of mountains has been based on the knowledge of (i) the diverse opportunities that altitudinal belts provide for obtaining a range of resources; (ii) the topographic and topoclimatic variability of the slopes according to insolation, gradient, redistribution of soil fertility, and water circulation (García Ruiz and Lasanta, 2018); and (iii) complementarity of distinct altitudinal belts for optimizing grazing management and livestock cycles (Puigdefábregas and Fillat, 1986; Rodríguez Pascual, 2010; Fernández-Giménez and Fillat, 2012; Oteros-Rozas et al., 2013).

For centuries, one of the most characteristic features of mountains of the temperate zone was transhumance — the seasonal movement of livestock (mainly sheep and goats, occasionally also cows and horses) to high elevations during summer and low elevations during winter (Berezowski, 1971). This represented a holistic interpretation of vegetation complementarity between grasslands and scrublands in the lowlands (usually grazed from October to May) and the upper montane, subalpine, and alpine belts (which reach maximum grassland productivity from late spring to late summer) (Ruiz and Ruiz, 1985; Puigdefábregas and Fillat, 1986). Transhumance usually implies a long movement of livestock, in some cases hundreds of kilometers, along routes that link highlands with areas far outside the mountains. Stockbreeders from the mountains and the lowlands have traditionally practiced transhumance (Puigdefábregas and Balcells, 1966; Costello and Svensson, 2018). The term "transterminance", or "valley transhumance" (Fernández Mier et al., 2013), refers to local livestock movements within a mountain, in which there is no exploitation of grasslands outside the mountain. In this case, livestock remains in the valley bottom around villages and hamlets during the cold season and moves about 10 to 25 km to the high mountain region during summer, so that all management occurs within the same mountain (Fernández Mier and Tente, 2018; Fernández Lozano and Cabero Diéguez, 2017). Antolín et al. (2018) noted there is confusion in use of the terms "transhumance" and "transterminance" because the literature does not provide clear definitions and because there are multiple interpretations of transhumance (Costello and Svensson, 2018). In any case, Antolín et al. (2018) propose that "transhumance" should be used restrictively to refer to long-distance movements of herds. In both transhumance and transterminance, the subalpine belt is a key resource for the movement of large livestock herds. These movements of thousands of sheep, goats, cows, and horses have

occurred in the Pyrenees for hundreds of years, and they still occur, although at a declining level (O'Flanagan et al., 2011).

Transhumance and transterminance were the reason for the enlargement of the area occupied by subalpine grasslands, due to an imbalance in the extent of winter and summer grasslands (Fig. 1). The subalpine and montane belts were forested since the beginning of the Holocene (González-Sampériz et al., 2017), although they have undergone progressive deforestation historically. Most of the Pyrenean subalpine and upper montane belts are currently covered with grasslands, isolated trees, and forest patches, with evidence of the extensive previous occupation by conifers (*Pinus uncinata, Abies alba*, *P. sylvestris*) and deciduous trees (*Fagus sylvatica*) (Montserrat, 1971, 1988). These human-induced deforested areas, used as grazing areas from May to October, are the object of this study.

The upper limit of the subalpine and montane belt is at approximately 2200 meters above sea level (m a.s.l.), where more extreme climatic conditions indicate a transition to the alpine belt. The lower limit is highly variable, depending on topographic accessibility for grazing, and the pressures of local shepherds. Usually, the lower limit of the summer grasslands is at approximately 1600 m a.s.l. (Montserrat, 1971, 1988), although it can be as low as 1500 m a.s.l., and in exceptional cases at 1300 m a.s.l., coinciding with the bottoms of U-shaped valleys. For this reason we use the term "subalpine grasslands" or "subalpine belt" for areas that also include parts of the upper- and mid-montane belts that were deforested for summer grazing. This radical change in plant cover has had major hydrological and geomorphological consequences, including changes in snowmelt processes and overland flow (Puigdefábregas and Alvera, 1986; Lana-Renault et al., 2011; López-Moreno et al., 2012), and activation of certain geomorphic processes, particularly shallow landslides (García-Ruiz and Puigdefábregas, 1982; García-Ruiz et al., 2010), soil erosion, creeping, rilling, and solifluction (Höllermann, 1985).

Historically, trees were harvested from some mountain areas for use as commercial timber, or production of resin and charcoal (Bielza de Ory et al., 1986; Palet et al., 2010; Tomás-Faci and Laliena, 2016), although most authors attribute deforestation to the increasing need for summer grasslands, which dates back to Neolithic times in some cases. In fact, the presence of megalithic monuments, which are particularly numerous in the mid-montane and subalpine belts, are evidence of early seasonal livestock movements (Blondel, 2006; Rojo Guerra et al., 2013; Montes et al.,

2016a; Tornero et al., 2016). Similarly, research suggests that remnants of charcoal fragments in subalpine soils and in lacustrine sediments are due to manmade fires designed to open up the forest during the Neolithic and the Bronze Ages (Connor et al., 2019). These activities occurred in the Pyrenees (Bal et al., 2011; Gassiot et al., 2014), other ranges of the Iberian Peninsula such as the Urbión Massif in the Iberian Range (García-Ruiz et al., 2016), and in the Cantabrian Mountains (Carracedo et al., 2017; Pérez-Díaz et al., 2018). However, other researchers emphasized that these fires could have had mainly a natural origin, and that deforestation had minor effect prior to the Middle Ages (González-Sampériz et al., 2019).

In spite of the importance of landscape changes in the subalpine belt, some crucial questions remain. First, we do not know exactly how deforestation progressed, nor the most critical times of deforestation, because it is extremely difficult to reconstruct the landscape and extent of deforestation in prehistoric times. A second question is the origin of transhumance. At present, information on the origin of transhumance seems to be fragmentary, based on historical documents, and published in national or regional historical journals and books that are mostly inaccessible to environmentalists, despite the extreme importance of transhumance as a global factor that changes landscapes.

Studies of changes in plant cover and its relationship with transhumance are important to specialists in multiple fields, including geographers, geologists, paleoenvironmentalists, pre-historians, and historians. Unfortunately, over-specialization of researchers may cause them to overlook useful information from similar or related fields. Environmental studies currently use an interdisciplinary approach, and consider information from a variety of sciences, in the belief that science mainly advances at the frontiers between disciplines. For this reason, a multidisciplinary group of scientists collaborated in the present study to provide a global perspective about the evolution of deforestation and the advance of grasslands in the subalpine belt, and the relationship of these processes with the origin and development of livestock management and transhumant movements.

We reviewed publications that examined different historical periods (ancient, medieval, modern, and contemporary) and from different disciplines (geology, ecology, and geography). Many of these publications used proxy measurements (pollen analysis; micro-charcoal content and sedimentology from paleolakes, lakes and peat bogs; geomorphological mapping; charcoal dating from soils affected by shallow landslides;

data from archaeological sites) and historical documents. Our diverse backgrounds allowed us to synthesize this complex and varied information to examine the relationship between livestock management — particularly the development of transhumance — and deforestation of the subalpine belt.

2. Study area

The study area is the Central Spanish Pyrenees, in the region between the Veral Valley (to the west) and the Noguera Ribagorzana Valley (to the east), and between the French border (to the north) and the contact between the Pre-Pyrenees and the Central Ebro Depression (to the south). The subalpine belt (1600-2200 m) within this region is the main focus (Fig. 2). To simplify the terminology, we use the term "Central Pyrenees" (or "Aragon Pyrenees") for the study area; "Eastern Pyrenees" for land east of the Noguera Ribagorzana Valley (or "Catalonia Pyrenees"); and "Western Pyrenees" for land west of the Ansó Valley (or "Navarre Pyrenees").

Broadly speaking, the subalpine belt spreads over a large variety of geological environments including Paleozoic quartzite, limestone and shale outcrops, and Mesozoic/Cenozoic limestone, sandstone and flysch. Nevertheless, subalpine grasslands are particularly located in slopes of relatively gentle or moderate gradient and are almost excluded from rocky, steep outcrops. Glacial U-shaped valleys, tills, deep-seated landslides and old erosion surfaces with deep soils have generally been the best valued areas for summer grazing.

The Mediterranean and Atlantic regions influence the climate of this region, with increasing continentality and Mediterranean influence east of the Gállego Valley. After removal of elevation effects (0.55ºC per 100 m a.s.l.; Navarro et al., 2018), average annual temperature follows two gradients, one increasing from west to east and the other increasing from north to south; precipitation clearly decreases from north to south (in parallel with altitude), and ranges from 700 to 800 mm at 800 m a.s.l. to approximately 2000 mm at 2000 m a.s.l., and slightly less above 2000 m a.s.l. (Del Barrio et al., 1990). Snowfalls are common from November to May or even June, with remarkable snow accumulation above 1650 m a.s.l., and rapid snowmelt during April, May, and June (López-Moreno and García-Ruiz, 2004). Five elevational belts distinguish the Central-Western Pyrenees (Montserrat, 1988; Benito Alonso, 2018). The basal or hilly belt, also called the meso-Mediterranean belt (800 to 1000 m a.s.l.), is dominated by cultivated fields, *Quercus* gr. *faginea* forests, and sub-Mediterranean

shrubs. The montane (or supra-Mediterranean) belt (up to 1650 m a.s.l.) is dominated by abandoned fields on south-facing slopes, extensive *Pinus sylvestris* forests in north- and south-facing slopes, and *Fagus sylvatica* forest in north-facing (particularly concave) slopes. The subalpine (or oro-Mediterranean) belt (up to 2200 m a.s.l.) was originally covered with *Pinus uncinata* forests, but is now almost completely deforested and consists of extensive grasslands. The alpine (or cryo-Mediterranean) belt (2200 to 2900 m a.s.l.) has grasslands alternating with large rocky areas. The nival belt has prevailing rock outcrops and scree accumulations. Notably, the lower limit of the subalpine belt roughly coincides with the location of the 0ºC winter isotherm, which is approximately the lower limit of the permanent cold season snow cover (Del Barrio et al., 1990).

3. Changes in the subalpine belt of the Pyrenees in relation with livestock management

3.1. Livestock management and landscape transformation during prehistory

Knowledge of the presence of humans and landscape changes in Mediterranean mountains has increased rapidly during recent decades (Palet et al., 2010), mainly studies in archaeology, palynology, and paleolimnology. In particular, studies of the Pyrenees have examined the Eastern region (Riera et al., 2004; Pèlachs et al., 2007; Ejarque et al., 2010; Bal et al., 2011; Cunill et al., 2012; Catalán et al., 2013; Gassiot et al., 2014; Orengo et al., 2014; Palet et al., 2014; Garcés-Pastor et al., 2017), the Central region (Montserrat, 1992; González-Sampériz et al., 2006, 2017; Morellón et al., 2009; Pérez-Sanz et al., 2013; Leunda et al., 2017, 2019), and the northern face (Galop, 1998, 2016; Aubert et al., 2004; Rius et al., 2012; Le Couédic et al., 2016; Rendu et al., 2016).

Archaeological evidence demonstrated that some pastoral activity was present in the subalpine and mid-montane belts since the early Neolithic (ArchaeoGLOBE Project, 2019). In the Eastern Pyrenees, archaeologists have identified and dated shelters, shepherd huts, enclosures, ovens, charcoal kilns, and megalithic monuments in the Andorran valleys (Palet et al., 2014), even above 2000 m a.s.l. Miras et al. (2010) found evidence of human impact in this region from 5300 to 4900 cal BCE, and of a previous occupation at 5544 ± 69 cal BCE, in which the percentage of pine pollen declined. There was also increased human presence from 4350 to 3500 cal BCE (Orengo et al., 2014), based on the presence of coprophilous fungal spores and ruderal species, suggesting forest clearance related to grazing activity. At 3500 cal BCE, Ejarque et al. (2010) reported a decline in the elevation of the upper forest limit (timberline) in the

same valleys. Notably, forest clearing only occurred in small areas, most likely because of the small sizes of the sheep and goat herds, and open forest areas for grazing alternated with woodland recovery (Ejarque et al., 2010). In the Central Pyrenees, archaeologists have clearly confirmed early human activity in sites such as the Pardina ravine (Ordesa and Monte Perdido National Park; Laborda et al. 2017), based on excavation of several rock shelters with archaeological remnants corresponding to the late Neolithic and Chalcolithic eras or earlier. Some studies suggested that grazing and deforestation during the Neolithic and Bronze Age affected the mid-montane belt and the upper forest limit at its contact with the alpine belt. For example, Palet et al. (2010) found two huts and a livestock enclosure located at 2500 m a.s.l. dated at 2400 to 2160 cal BCE. In the French Pyrenees, Galop et al. (1998) noted early altitudinal declines of the upper forest limit at approximately 2900 BCE (4850 BP). Parallel studies in the Central Pyrenees at the archaeological sites of Els Trocs in the Isábena valley (Rojo Guerra et al, 2014, 2018) and Coro Trasito in the Cinca valley (Clemente et al., 2014, 2016; Obea Gómez, 2014) indicated the presence of intermediate or transitional grazing areas at approximately 1500 m a.s.l., between the valley bottoms (700 to 900 m a.s.l.) and the highest grassland areas. These intermediate areas would be mostly grazed during May, June, and October, in parallel with seasonal livestock movements.

Palynological analyses of glaciolacustrine deposits are less conclusive. For instance, Montserrat (1992) dated charcoal in the Tramacastilla Lake (Upper Gállego Valley) to 4000 cal BP, although recovery of the forest was rapid, indicating little human impact. In the Basa de la Mora Lake (Cinqueta Valley; Pérez-Sanz et al., 2013), the landscape was densely forested, as well as the area around the El Portalet peat bog (Upper Gállego Valley), at least until 5000 cal BP (González-Sampériz, 2006). A similar situation can be inferred at a regional scale from the Marboré Lake record (Leunda et al., 2017). Nevertheless, fire activity increased at ca. 3700 cal BP, indicating a reinforcement of human activities and forest clearing (Leunda et al., 2020).

In any case, most studies considered the changes in plant cover to have been limited, in that there were only small forest clearings that changed location due to recolonization and creation of new clearings. The impact progressively increased during the Bronze Age and the beginning of the Iron Age (Galop, 1998, 2016; Le Couédic et al., 2016; Rendu et al., 2016), as in the Swiss Alps (Colombaroli et al., 2010).

What was the significance of seasonal livestock grazing in the subalpine belt? It is difficult to provide a definitive answer. Some researchers have repeatedly used the

term “transhumance” (Higgs, 1976; Blondel, 2006; Rojo Guerra et al., 2013; Tornero et al., 2016), but others have consistently rejected this term (Chapman, 1979). Davidson (1980) suggested that the presence of Neolithic and Bronze Age lithic manufacturing along the transhumant pathways must be interpreted with caution. Fairén Jiménez et al. (2006) prefer the use of “transterminance” (short-distance displacements from a valley bottom to a subalpine grassland), and reject the occurrence of long-distance livestock movements because this would require regulations among different territories.

It is generally accepted that deforestation is intimately linked to transhumance and transterminance, although large wild herbivores would have been able to partially open the forest during the Holocene (Vera, 2000; Montserrat-Martí and Gómez-García, 2019). The main problem is that most information on primitive livestock cycles and deforestation is indirect and fragmentary, making it difficult to infer the details of livestock management during the Neolithic and the Bronze and Iron ages. We know that shepherds with their herds of sheep and goats were present in the subalpine belt of the Pyrenees during summer. The large number of dolmens and stone circles is evidence of the seasonal importance of the subalpine belt for these local shepherds, as they show an interest in demonstrating to others ownership of the space (e.g. Domínguez and Calvo, 1990; Andrés Rupérez, 2000; Fernández Mier et al., 2013, for the Cantabrian Mountains), because people do not typically bury their dead in a strange territory. Some authors conclude that the presence of these structures supports the presence of large seasonal livestock movements (Rojo Guerra et al., 2013; Tornero et al., 2016) from the lowlands to the highlands — the initiation of transhumance.

To identify the origins of transhumance, it is essential to know the reasons why people would want to develop this system. Transhumance is a difficult and strenuous activity that requires significant personal and familial sacrifices, exposes individuals to many dangers, and can only occur under certain conditions. Besides, we must consider that because the movement of large herds affects many people it must be profitable. For this reason transhumance is only possible when there is: (i) a period of population growth and relative prosperity that allows establishment of increasingly important regional and national markets; and (ii) political stability and the substitution of territorial fragmentation by more complex forms of organization with a supra-regional political regulation that ensures the movement of shepherds and livestock, or a network of alliances that is continually renewed (Galán Domingo and Ruiz Gálvez, 2001; Fairén Jiménez et al., 2006). Instead, transterminance, short-distance livestock movements

between the valley bottom and subalpine belt of the same mountain, was common. This is supported by the presence of megalithic monuments and limited deforestation in the subalpine belt. Nevertheless, it is possible there were some occasional long-distance movements of herds prior to the Roman period in other parts of the Iberian Peninsula, as suggested by the presence of cinnabar in the bones of domestic animals in the Iberian Range (Logeman et al., 1995; Gómez-Pantoja, 2001, 2011), some hundreds of kilometres away of the Alcudia Valley (Southern Spain), where mercury mines were present.

Nevertheless, there is a remaining unsolved geomorphic problem that is most likely related to deforestation. Some slopes in the subalpine belt are affected by intense rilling and gullying, with a dense network of parallel incisions that, in their lower stretches, are up to 3 m deep in the flysch. Such extreme degradation of this relatively hard bedrock must have occurred over a long time in a deforested environment. Were these slopes deforested during the Neolithic and Bronze Age? This is a pending question suggesting that some slopes would have been deforested early, experienced strong erosion and faced difficulties for forest recovery (Fig. 3A).

As suggested by archaeological structures in the subalpine belt and evidence of agriculture in the valley bottoms, farmers would migrate in late spring with their small herds to the intermediate-altitude grasslands. They then moved in summer to the highest grasslands, close to the timberline, and activities there caused a progressive, although initially limited, decline of the upper forest limit. In October, the herds returned to the valley bottoms, and they grazed in the surroundings of small hamlets. The absence of regional or national markets and cities, and the absence of a consistent political organization exclude the possibility of transhumant herds coming from more than 100 km.

3.2. Evidence of livestock management during the Roman period (2nd century AC to 5th century CE) and the Early Middle Ages (5th to 9/10th centuries)

Little is known about the occurrence of seasonal livestock movements during the Roman period, although some indirect evidence suggests an increasing importance of grazing along with a general increase of human activities (Diarte-Blasco, 2018). In general, the Roman conquest of *Hispania* led to significant changes in the social, cultural, and economic life of the Iberian Peninsula (Santos Yanguas and Cruz Andreotti, 2012). This coincided with the “Warm Roman Period”, from 250 BCE to 450

CE (Desprat et al., 2003), which also increased land productivity. The Roman occupation was associated with increased deforestation due to military activities and the need for fuel and materials for building and transport (Hughes, 1994; Aranbarri et al., 2014) and with intensive cultivation, particularly in the lowlands.

The mountain areas were also affected by mining, charcoal production, logging, and hunting (Palet et al., 2010; López-Sáez et al., 2014). According to Gómez-Pantoja (2001), sheep herds were the main livelihood for people living in the interior of the Iberian Peninsula. Nevertheless, it is difficult to establish the consequences of this extensive grazing and its dependence on long-distance seasonal displacements in search of the best grasslands. Unfortunately, most archaeological remnants (e.g., huts, watering places, stalls) have disappeared because they were only transitory structures or because they were only scarcely studied, except in the Eastern Pyrenees (Ejarque et al., 2010; Bal et al., 2011; Catalán et al., 2013; Gassiot et al., 2014; Palet et al., 2014), in the Pardina Ravine of the Central Pyrenees (Laborda et al., 2017), and in the Cantabrian Mountains (González-Álvarez et al., 2016, 2018; González-Álvarez, 2019). Another complication is that the Latin terminology is often confusing. For example, the *pastio agrestis* of Varron (*r.r.* 3, 2, 13) could be a type of transhumance or livestock displacement, although we cannot currently determine the distance and the travel time associated with this terminology. This was not unusual in other Mediterranean regions. For example, in the Italian Peninsula, Varron (*r.r.* 2 *praef*.) reported that large sheep and mare herds moved between Sabina and Apulia. Gómez-Pantoja (2001) noted that transhumant livestock was economically profitable in the Italian Peninsula, and concluded that this practice also developed in Roman *Hispania*, given the adequate climate conditions and the many ancient literary references to the excellence of Hispanic livestock (fast horses, large herds of beef cattle, large pigs in Lusitania and other mountainous areas, and many sheep herds). In the closest *Gallia*, Pliny (*NH* 21, 57) reported that the *campi lapidei* of *Arelate* (currently Arlès), a grassland area of ca. 600 km^2 at the foot of the Alpilles massif, accommodated thousands of sheep every year.

Studies of the Iberian Peninsula provide no definitive information on the occurrence of transhumance between the lowlands and highlands, although some indirect evidence suggests there was seasonal movement of livestock to optimize the use of grasslands. Gómez-Pantoja (2016) stresses that there is no reliable written evidence of transhumance before late antiquity, although there is indirect evidence of

livestock movements from the 1st and 2nd centuries CE based on inscriptions indicating strategic points for livestock movements. These inscriptions include points for counting of sheep going from the northern Iberian ranges to the winter grasslands of the Guadiana River, and mention of the regulation of grasslands. Besides, we must consider that Romanization entailed control of this territory and the organization of a complex administration supported by a powerful army. This meant the construction of a dense network of roads, increased security, and particularly the opportunity for increased relationships among distinct territories that previously were controlled by different authorities (Galán Domingo and Ruiz Gálvez, 2001). It is obvious that the existence of rules, norms, and laws, the writing of documents with permissions, and confirmation of property favored the spatial integration of land for the first time in *Hispania*. Besides, the foundation and growth of cities and the opening of larger markets provided opportunities for rural development (Alfaro Giner, 2001).

The flourishing of livestock during the Roman Period was confirmed at many sites. For instance, in the Aralar Sierra (Navarre), located between the western Pyrenees and the Cantabrian Mountains, Mujika-Alustiza et al. (2011) documented many materials of Roman origin. These authors proposed two possible livestock management systems: seasonal local movements with short journeys, and long-distance transhumant movements. This second system was documented in other parts of the Roman Empire (Gabba and Pasquinucci, 1979), such as the transhumance of large sheep herds used for wool production (Leveau, 2016) since the 2nd century BCE (García Martín, 2001; Gómez-Pantoja, 2001b). Nevertheless, even if the environmental conditions of the Iberian Peninsula could accommodate long-distance transhumance, Gómez-Pantoja (2001) confirmed that its occurrence is not easily documented because of the historical opacity of grazing activities, and the absence or rarity of vestiges.

In the Eastern Pyrenees, the Madriu, Perafita, and Claror valleys (Andorra), have evidence of increased pastoral activity from the middle of the 1st century to the middle of the 5th century CE at approximately 2200 m a.s.l. The greater livestock pressure on these subalpine and alpine grasslands is based on pollen analyses, which indicate a loss of forest and a greater floristic diversity (Ejarque et al., 2010). The presence of pines drastically declined, particularly during the 4th century CE (Palet et al., 2007). However, the need for more summer grasslands to feed the increasing number of livestock was not the only cause of deforestation and enlargement of subalpine grasslands; resin extraction, charcoal production, and metallurgic activities were also

responsible. Ejarque et al. (2010) and Palet et al. (2010) identified a kiln used for resin extraction dated at about the 2nd century CE, and found many kilns at 2200 to 2350 m a.s.l. Catalán et al. (2013) reported an increase of archaeological sites in the National Park of Aigües Tortes and Sant Maurici during the Iberian-Roman period and the Roman Imperial Period (1st–4th/5th centuries), with evidence of livestock enclosures and exploitation of iron minerals. This practice would clearly reduce the extent and density of natural forests, making them more easily grazed henceforth. All of this information indicates there were significant enlargements of cleared areas during the Roman period, although most of the deforestation occurred in the upper subalpine belt (Ejarque et al., 2010) and the valley bottoms for agricultural purposes, in a similar way than in the Cantabrian Mountains (Fernández Mier and Tente, 2019).

On the French side of the Pyrenees, remnants of permanent structures in the subalpine belt, with evidence of Roman hand-made pottery, are very common in Aquitania (Southern France) and *Hispania Tarraconensis* (Northern and Middle Spain). The route between Bordeaux (*Burdigala*) and Saragossa (*Caesaraugusta*) could have had a remarkable influence in the development of some transhumance pathways, particularly in the Aspe and Ossau valleys. This is supported by the establishment of the city of *Beneharnum* (now Lescar) at the northern piedmont of the Pyrenees, which is related to agropastoral activities in the Entre-deux-Gaves area, including transhumance from the Landes of Gascony (now Aquitaine) to the summer grasslands in the Pyrenees (Callegarin et al., 2005; Réchin, 2008).

Summarizing, there are many indications suggesting transhumance during late protohistory or the Roman Period. These include: (i) the establishment of new forms of territorial administration and more complex political organization, developments that provided more security and facilitated interregional relationships; (ii) the increasing importance of cities, population growth, and the corresponding consolidation of local and regional markets; (iii) the progressive clearing of the forest in mountain areas, because of grazing, mining, metallurgy, and charcoal production; and (iv) indirect evidence from inscriptions and Roman writers that indicate livestock movements in distinct areas of the Iberian Peninsula and other similar areas in the Mediterranean region.

Based on our limited knowledge of seasonal livestock movements during the Roman period, it seems almost certain that some transhumance between the semi-arid lowland areas and the subalpine belt of the mountains occurred during the Imperial

Roman Period, although we do not know its extent or significance. This, together with other activities, would explain the progressive, though limited, deforestation of mountainous areas at this time.

After the fall of the Roman Empire, the *Lex Visigothorum* (Law of the Visigoths) confirms the importance of large-scale livestock production. This law regulated free livestock movements (Butzer, 1988), and is a compilation of Roman Law and an up-date of the *Lex Agraria Epigraphica* (Agrarian Epigraphic Law) from the year 111 BCE (Gómez-Pantoja, 2011, 2016). A document dated at 551 CE from the Visigothic Monastery of San Martín de Asán (at the current Monastery of San Victorián, Cinca Valley, Central Pyrenees, according to archaeological vestiges), reports interest in having properties at the summer pastures of the Pyrenees, in the area of Sobrarbe, and in the dryland areas of the Central Ebro Depression, close to Caesaraugusta (Saragossa) and Ilerda (Lérida) (Fita, 1906; Fortacín, 1983; Tomás-Faci and Martín-Iglesias, 2017). This is likely the first known document to indicate the complementarity of highlands and lowlands, and suggests the occurrence of seasonal livestock movements. Although the Arab conquest of the Iberian Peninsula at the beginning of the 8th century CE disrupted relationships between the Ebro Valley and the Pyrenees (the former dominated by the Arabs until the 11th and 12th centuries CE, and the latter by the Christians), there is evidence of continuing communication among the elites of both territories (Butzer, 1988). Thus, we cannot rule out that some movements of people and livestock could have survived the fragmentation of this territory. For instance, in the year 1023 CE the Muslim King Mundir of Saragossa allowed the Monastery of Sant Sadurni of Tavèrnoles (in the County of Urgell, Eastern Pyrenees) to access the Low Ribagorza, in the Central Ebro Depression, most likely for grazing during winter (Baraut, 1994-1995).

3.3. The Late Middle Ages (10th to 15th centuries): A key period for deforestation and transhumance

There are methodological difficulties in using written documents of the Middle Ages to study transhumance at that time because of the drastic changes in the characteristics of documentation between the 13th and the 14th centuries. This is because of the emergence of public notaries, the introduction and growth in the use of paper, and the beginning of administrative documentation during this period (Pascua Echegaray, 2012; Menant, 2015). Thus, apparent changes in deforestation,

transhumance, and other factors could simply be due to changes in the way information was recorded and transferred. In general, documents prior 1300 CE provide information on the rights of land-use, the appropriation of territory or tax exemptions in grazing areas, above all in the case of monasteries or other ecclesiastical institutions, and to a lesser extent aristocratic people and town councils. These documents were preserved to record the rights of land use and management (Cursente, 2016).

Information on the use of pastoral resources is scarce before the 12th century suggesting that these resources had a limited importance (Tomás-Faci, 2016). Interestingly, during the Early Middle Ages, socially prominent people of the Central Pyrenees had constant disputes regarding the control of agricultural resources (as inferred from monastic cartularies, from San Juan de la Peña to Alaón) (Ubieto, 1962-63; Corral, 1984). Since the second half of the 12th century, documents regarding the property and the use of the subalpine belt became more common (Pallaruelo, 1993). This is clear evidence of the increasing importance of livestock and transhumance between the highlands and lowlands. In fact, we can assume that if the competence for the property of a resource increases, an increasing use of such resource occurs. Most documents on this topic refer to ecclesiastic institutions, although the oligarchy of the city of Saragossa also succeeded in the fight for summer pastoral resources (see below). Utrilla et al. (2005) stressed the importance of Christian monasteries as major livestock owners and the existence of royal concessions granting herders the right to graze in summer grasslands. These authors thus confirm the occurrence of transhumance in the 10th century. Other document of the 12th century indicate that King Pedro I exempted the Monastery of San Juan de la Peña from paying taxes for its sheep herds at any place in the Kingdom of Aragon, where they used to graze during winter and summer (Utrilla et al., 2005).

The control of the subalpine belt had a major impact on the functional organization of the Pyrenean valleys during the 12th and the 13th centuries (Pascua Echegaray, 2012). Utrilla et al. (2005) emphasized the revaluation of summer grasslands in Pyrenean valleys after the end of the 12th century, and the interest of the great monasteries in obtaining royal exemptions that provided them free circulation and grazing rights in the whole Kingdom of Aragon. In the Ésera Valley, the most important and disputed area during the Early Middle Ages was the agricultural plain of Castejón de Sos, and subsequently the headwaters of the valley, where the Benasque locality controlled most of the summer grasslands. A similar process occurred in the Castanesa

Valley, where the Castanesa locality, previously irrelevant, became one of the main settlements in Ribagorza County because of its summer pastoral resources (Tomás-Faci, 2016).

In the Central Pyrenees, some valleys lost control of their mountains to others due to political circumstances. The best example is the Ansó Valley, which was favoured by King Jaime I to obtain control of the grasslands and forests in the headwaters of the neighboring Echo, Aragüés, and Aísa valleys, and thereby reinforce its border with Navarre and France (Tomás-Faci and Laliena, 2016). At the end of the Middle Ages, the competence for the subalpine pastoral resources increased extraordinarily (Martín de las Pueblas and Hidalgo, 1999). Conflicts between Ansó and Echo for control of the headwaters of the Aragon Subordán Valley led to many casualties, until there was a definitive resolution during the 15th century, which led to the shared use of some of these disputed areas (Tomás-Faci and Laliena, 2016). In other cases, the increasing numbers of livestock led to land use changes; for example, vineyards dominated the plain of Castejón de Sos during the 11th century, but meadows dominated after the 14th century (Tomás-Faci, 2016).

Changes in the subalpine grasslands coincided with the southward advance of Christian kingdoms and the decline of Muslims domains, which led to occupation of the semi-arid lands of the Central Ebro Depression and made grazing in large steppes and open forests possible. The city of Saragossa had a notable role from the beginning of the 12th century. In 1118, King Alfonso I conquered Saragossa, the main city (then and now) in the Ebro Depression, and designated it as the capital of the Kingdom of Aragon. With the purpose of attracting a new Christian population, he conferred to all the stockbreeders who were established in Saragossa the right of "universal grazing", allowing them to graze any place in the Kingdom of Aragon. In 1218, King Jaime I reinforced this privilege with the creation of the (still existing) *Casa de Ganaderos* (House of Stockbreeders), an institution devoted to the defence of Saragossa's stockbreeders against the interests of other stockbreeders and municipalities in other parts of the Kingdom of Aragon. This institution had the right to punish people who caused harm to livestock or shepherds from Saragossa (Serrano Martínez, 1997). There were several important consequences of these actions. First, the number of large herds greatly increased in Saragossa (most of them from southern France, Navarre, the Basque Country, and the Aragon Pyrenees), stockbreeding became the main economic activity, and many related artisanal activities also developed (Serrano Martínez, 1997).

Second, many conflicts arose between Saragossa's stockbreeders and the local shepherds, particularly in the Western region of the Central Pyrenees (including the Ansó, Echo, Aragüés, Aísa, Canfranc, Gállego and Broto valleys), because of the increasing grazing pressures on the subalpine grasslands during summer (Canellas, 1988; Fernández Otal, 1993). These conflicts were slowly resolved during the mid-14th century, particularly in the Ansó Valley (Tomás-Faci and Laliena, 2016). Most of transhumance movements connected the Ebro Valley with the Pyrenees and the Iberian Range. In addition, there were other transhumant circuits that linked Aragon to other neighbouring kingdoms (i.e. towards the Mediterranean coast and the south of Castile: Pascua Echegaray, 2012). Political boundaries did not block cross-border transhumance, although they were determinant in their geographical shaping. It is also noteworthy that the organization of stockbreeding and transhumance was quite different in the kingdoms of Aragon and Castile: in the former it was controlled by urban and rural owners grouped in local associations (the most important, the *Casa de Ganaderos*, from Saragossa), whereas the latter developed a unique centralized institution, the Mesta, which rather represented the interests of large owners (Pascua Echegaray, 2012). In any case, both kingdoms established rules for the preservation of transhumant routes called *Cañadas Reales*.

These large-scale changes in the Pyrenean economy during the Middle Ages were intimately linked to social and economic changes in Western Europe (Bourin et al., 2011). First, there was rapid population growth since the beginning of the 11th century, so that the number of inhabitants by about 1300 was greater than at any other time before the 18th century (Sesma and Laliena, 2004). This population growth was accompanied by an increase in overall production and productivity, because of the increasing economic specialization and the development of efficient commercial networks (Britnell, 1996; Sesma and Laliena, 2009). Besides, there was a spectacular growth of the wool market in Europe, particularly in Catalonia, Genoa, and Venice, throughout the 13th century (Munro, 2001; Sesma and Laliena, 2013). In the Kingdom of Aragon, economic specialization was achieved in the production of raw materials such as saffron, olive oil, and especially wool (Sesma, 2013), leading to a "golden period" for transhumance in the Pyrenees and the Iberian Peninsula (Diago Hernando, 2002). Of course, the Aragon monarchy also benefited from these dramatic economic transformations and the related development of transhumance. Thus, at the middle of

the 13th century, King Jaime I created a uniform system for the payment of taxes by stockbreeders as they moved to and from the Pyrenees (Moret and Tomás-Faci, 2014).

Studies of lacustrine sediments indicated that humans have had a major impact in the lower slopes of the Central Pyrenees (Riera et al., 2004; Morellón et al., 2011) since the 8th century. This impact included the increasing cultivation of cereals, grapes (for wine), olive trees, and hemp. However, evidence from the subalpine belt indicates that large changes in plant cover and hydrology occurred beginning in the 12th century (González-Sampériz et al., 2017, 2019). One of the best studied sites is the Basa de la Mora Lake (1900 m a.s.l.), in the headwaters of the Cinqueta Valley. Pollen sequences indicate the presence of a forested landscape during the late Holocene, suggesting limited human impact, but an abrupt decline in the percentage of pine pollen beginning in about 950 CE (Pérez Sanz et al., 2011, 2013). The pollen series at Marboré Lake (2600 m a.s.l.), in the Upper Cinca Valley, indicates a decline in the percentage of arboreal pollen during the last 1300 years, with a remarkable increase of non-arboreal pollen (Leunda et al., 2017), even though this lake is very far from arboreal pollen sources.

Montserrat (1992) studied Tramacastilla Lake (1670 m a.s.l.), in the Upper Gállego Valley and found a layer with abundant charcoal remnants that was associated with critical changes in plant cover that was dated to approximately 1000 years BP. This indicates a general deforestation of pines and beech trees, and an increase of grasslands. This author attributed the rapid deforestation to the need for more summer grasslands as the conquest of the lowlands of the Ebro Depression advanced. Charcoal data from the Basa de la Mora and Marboré sequences from 1250 years BP, and especially during the last 300 years, indicated increasing fire activity during recent centuries (Leunda et al., 2020). In fact, it is impossible to explain the rapid expansion and consolidation of transhumance without a widespread deforestation of the subalpine and upper montane belts, and their transformation into large open landscapes dominated by grasslands.

This deforestation manifested as an abrupt increase in the sedimentation of Tramacastilla Lake, due to activation of geomorphological processes, mainly shallow landslides (Fig. 3B), rilling, and gullying (Del Barrio and Puigdefábregas, 1987; García-Ruiz et al., 2010), and an increase in sediment grain size, clear evidence of enhanced overland flow. The problems created by excessive logging (used to enlarge summer grasslands and for timber harvesting) obligated some municipalities to approve by-laws that regulated forest exploitation, particularly in Ansó, at least since the 17th century

and probably before (Tomás-Faci and Laliena, 2016) and Bielsa (Bielza de Ory et al., 1986).

Other researchers also found evidence of a major period of deforestation in the subalpine belt of the Pyrenees. Thus, Cunill et al. (2012) attributed the greater number of fires in the Upper Noguera Ribagorzana Valley during the Middle Ages to the increase of transhumant livestock. In Burg Lake (1821 m a.s.l.), between the Noguera Ribagorzana and Noguera Pallaresa valleys, the subalpine belt became an open landscape, with a strong decline of *Pinus* since 1450 cal BP (Bal et al., 2011). Reviews of landscape evolution in the Eastern Pyrenees also indicated an expansion of grasslands in the subalpine belt of the Catalonia Pyrenees (Pèlachs et al., 2007; Palet et al., 2014), in accordance with the development of transhumance during the 11th and 12th centuries (Roigé Ventura et al., 1993). The species of the original forests, dominated by *Pinus sylvestris* and particularly *P. uncinata*, were rapidly relegated to rocky, steep areas, where they were subjected to long periods of snow cover, low temperatures, snow and rock avalanches, and thin soils. In general, the current timberline is at approximately 500 to 600 m below the natural treeline, i.e. about 1600 m a.s.l., and even lower in some exceptional cases such as the headwaters of the Ansó and Echo valleys (see also Ninot et al., 2008, and Cunill et al., 2012, for the Catalonia Pyrenees). Similar changes also occurred in the French Pyrenees (Galop, 1998; Mazier et al., 2009; Rendu et al., 2016), the Iberian Range in the northern Iberian Peninsula, especially in Urbión Sierra (García de Celis, 2008; García-Ruiz et al., 2016), and in other European mountains (Giguet-Covex et al., 2011; Roepke and Krause, 2013; Dietre et al., 2014).

All available information points out to an exceptionally rapid development of transhumance during the Late Middle Ages. Although there are some examples of long-distance livestock movements during the Early Middle Ages, the long distance movement of herds was definitively established during the 12th and 13th centuries, as in other Iberian mountains, e.g. the Gredos Sierra in the Central Range (López-Sáez et al., 2014, 2018) and the western Cantabrian Mountains (Fernández Mier et al., 2013; Fernández Mier and Tente, 2018).

Summarizing, the enlargement of summer grasslands to feed the transhumant herds was only possible by a systematic deforestation of the subalpine belt of the Pyrenees. This changed the mountain landscape at the expense of the forests above 1600 m a.s.l. Summer grasslands became the most important natural resource for the

high Pyrenean villages, and were the cause for many human conflicts (Tomás-Faci and Laliena, 2016). Most forests were logged or burnt and transformed into large grasslands, starting a period of increased erosion and geomorphic destabilization of the slopes, as deduced from lacustrine sedimentation (Montserrat, 1992; Pérez-Sanz, 2011, 2013). This led to some authors determining this period as the beginning of the Anthropocene era in the Pyrenees during the 12th and 13th centuries (González-Sampériz et al., 2019).

3.4. Modern (16th to the end of 18th centuries) and Contemporary (since the beginning of the 19th century) ages: Consolidation and crisis of transhumance

From the 14th century to the beginning of the second half of the 20th century, there were no large landscape changes in the subalpine belt of the Central Pyrenees. Transhumance was a sustainable and successful system until the 18th or 19th centuries, in that it allowed an increasing number of animals to travel between the Pyrenees and the Central Ebro Depression. New deforestation events cannot be ruled out in the less accessible areas because mountain communities wanted to increase their incomes by renting summer grasslands. For instance, Pérez Sanz et al. (2011) recorded changes in the pollen sequence of the Basa de la Mora Lake, with a decline in the percentage of arboreal pollen during the 17th and 18th centuries. Similarly, the Marboré sequence shows an intense decline of *Pinus* and an increase of fire activity since the end of the 18th century, and especially during the 19th century (Leunda et al., 2020). Also, logging at the end of the 19th century altered the headwaters of the Ijuez River, coinciding with a great population increase, and resulting in the development of large debris flows and a braided fluvial channel that was partially the consequence of deforestation in the subalpine belt (Sanjuán et al., 2016). Unfortunately, sedimentary records from paleolakes at high altitudes in the Pyrenees are scarce and provide limited details of the changes in vegetation of the subalpine belt after the Middle Ages. In any case, the potential capacity of summer grasslands in some Pyrenean valleys record extremely high values in the last centuries: for instance, 152,399 sheep in the Ansó Valley, 80,925 in the Echo Valley, 115,869 in the Gállego Valley, and 54,380 in the Benasque Valley (O'Flanagan et al., 2011).

It is well known that transhumance progressively expanded in this region until the end of the 18th century, when the greatest numbers of transhumant sheep were recorded (Le Flem, 1972). Many large churches in the main villages of the Pyrenees were built during the 16th century (Tomás-Faci and Laliena, 2016), in the same places

where small Romanic churches were built centuries earlier, confirming this was a period of prosperity and population growth that affected the whole Kingdom of Aragon and the rest of the Iberian Peninsula. This period of widespread transhumance extended until the end of the 18th century, when many large stockbreeders collapsed and the number of sheep declined (Diago Hernando, 2002). Consequently, the pressure of livestock on the subalpine grasslands was strong enough until the beginning of the 19th century to maintain the high quality of the summer pastures and prevent the re-colonization of trees. The transition between the 18th and the 19th centuries is also when Saragossa's *Casa de Ganaderos* experienced a marked decline in its power and when pressure on summer grasslands started to decline (Serrano Martínez, 1997). The causes of the decline of transhumance and the numbers of large stockbreeders were the progressive decline of profits from livestock farming, a decline of wool prices, and the abrupt decline of Spanish wool exports during the first third of the 19th century, all of which were exacerbated by the Napoleonic wars in Spain (García Sanz, 1978). Besides, the price for renting the winter grasslands in the lowlands increased in parallel with the increased price of cereals, and this encouraged the cultivation of these grasslands (Pinilla Navarro, 1996; Collantes, 2003; O'Flanagan et al., 2011).

The collapse of the transhumance system — the transhumance crisis — had remarkable effects on the Pyrenean landscape, as in other mountains of the Iberian Peninsula, such as the Iberian Range in La Rioja (Moreno Fernández, 1996). The transhumance crisis occurred during a period of significant demographic pressure and the decline of textile craftsmanship, thus obligating people to transform many marginal lands into cultivated fields. In some cases, marginal shifting agriculture was used, and this had dramatic adverse consequences on soil conservation (Lasanta et al., 2006) in the montane belt. This was similar to the process described by Gómez Urdáñez and Moreno Fernández (1997) for the Iberian Range.

We do not know how the transhumance crisis affected the subalpine belt of the Pyrenees in the 19th century. One of the most common types of cultivated fields in the Pyrenees are the *panares*, bench-terraced fields created in the upper limits of cultivated areas (1550 to 1700 m a.s.l.), often in contact with subalpine grasslands. Farmers mainly grew rye in the *panares,* which were mostly located in lateral moraines. Because of the high elevation, they grew rye in a 13-month cycle, with sowing in August and harvesting in September of the next year. Daumas (1976) suggested that *panares* date from the 19th century, because it was necessary to increase cereal production to feed the

local population and to compensate the declining of the transhumance. However, some documents indicate the presence of *panares* at some sites of the Gistaín Valley since at least the 16th century (Fernández Piñar, 2019), with an increase during the last decades of the 19th century and the beginning of the 20th century. Surprisingly, we have no information on the consequences of the Little Ice Age (14th to 19th centuries) on summer grazing (Bal et al., 2011).

Following the transhumance crisis, there was a depopulation of this region during the 20th century, a general decline in the number of sheep and goats that was not compensated by an increase in cattle, and a recent and obvious expansion of forest at higher elevations, also favoured by global warming (Camarero et al., 2015; García-Ruiz et al., 2015). The human population declined by approximately two-thirds in the main livestock villages in the Central Pyrenees during the last 150 years. This, together with the ageing of stockbreeders, led to the collapse of transhumance from the Pyrenees to the Central Ebro Depression during the 1960s-1980s. A small flourishing has been noted in the last decades, thanks to European and Spanish subsidies and to changes in the livestock management, including the use of cattle trucks for livestock displacements (O'Flanagan et al., 2011). In any case, the transhumance crisis is major evidence of a social disruption that affected traditional agropastoral activity (García-Ruiz et al., 2015). As indicated above, the current upper forest limit is at approximately 1600 to 1700 m a.s.l., and even lower in the Ansó and Echo valleys. For centuries, the establishment of new trees and shrubs was prevented because of the strong livestock pressure, particularly horses and goats; sheep herds maintained the quality of the grasslands in the slopes, and cattle grazed in the valley bottoms and peat bogs (Montserrat, 1964, 2009), helping to stabilize the new landscape and impeding forest recovery. The abrupt declines in the numbers of sheep, goats, and horses and the spectacular expansion of cattle herds (Lasanta-Martínez et al., 2005) transformed the summer grasslands, with under-grazing of the slopes and overgrazing of the flat areas, thus causing changes in the floristic composition of this region (Montserrat, 2009). The major consequence is the rapid colonization by trees and shrubs at high elevations (Gartzia et al., 2014; García-Ruiz et al., 2015; Nadal-Romero et al., 2018) (Fig. 3 C). Global warming has contributed to these changes, particularly in the timberline (Camarero et al., 2015). This phenomenon was also reported in the Eastern Pyrenees (Batllori and Gutiérrez, 2008), the northern sierras of the Iberian Range (Sanjuán et al., 2018), and other European ranges (e.g. Caviezel et al., 2014). Tree colonization is reducing the overall area of

grasslands and is dividing them into smaller areas (Pueyo and Beguería, 2007; García-Ruiz et al., 2015). No doubt this process will have remarkable consequences from a geomorphological and hydrological point of view, because forest consume more water than grasslands, and canopy interception of rain will reduce the quantity of raingfall that reaches the soil (Lorens and Domingo, 2007). The presence of forests instead of grasslands in the subalpine belt will also alter snow accumulation and melting, the consequences of which are currently under study (López-Moreno and Latron, 2008; Sanmiguel-Vallelado et al., 2020).

4. Concluding remarks

We have reviewed the evolution of deforestation in the subalpine belt of the Pyrenees and its relationship with the development of livestock management, particularly transhumance, a system in which livestock rely upon grasslands in the mountains and the lowlands during different seasons. Transhumance, as well as transterminance (or valley transhumance), had a major impact on the landscape and social and economic organization in the Pyrenees and many other Mediterranean mountains. This explains the necessity for the progressive enlargement of grasslands needed for summer grazing, in contrast to grasslands and shrublands in the lowlands of the Ebro Depression, which have greater productivity between autumn and spring. Figure 4 summarizes the main features of each historical period and their relationships with the evolution of transhumance and consequent deforestation. It provides a holistic perspective of changes that have accompanied the development of transhumance, and allow us to underline the most relevant conclusions of this study:

(i) The time when deforestation occurred in the subalpine belt is critical for understanding changes in plant cover in the Pyrenees and the multiple environmental effects of human activities. It is also critical for linking landscape changes with seasonal livestock movements, a key factor affecting biodiversity.

(ii) Changes in the landscape of the Pyrenean subalpine belt are the result of a long history of interactions between livestock management and deforestation related with market development, population growth and political issues.

(iii) The Neolithic/Chalcolithic period (7000-3700 BP) showed the seasonal presence of shepherds, according to the existence of a high number of megalithic monuments and structures from that period related with livestock management. The main consequences were the first forest clearings since around 4000 BP, the increase in

the occurrence of forest fires and temporal soil erosion. This period was characterized by short seasonal livestock movements.

(iv) During the Bronce Age/Iron Age (3700-2200 BP) there was a light livestock pressure increase and the moderate clearing of the forest continued.

(v) The Roman Period (2nd century AC to 5th century CE) brought a new territorial administration and complex political organization, together with population growth and the establishment and consolidation of regional markets. This constituted an adequate framework for the beginning of transhumant movements. Deforestation of the subalpine belt progressed.

(vi) During the Early Middle Ages (5th to 9/10th centuries) the first written evidence of transhumance between the highlands (the subalpine belt of the Pyrenees) and the lowlands (the Central Ebro Depression) appeared. They explain new, although limited, forest openings and slight increases in erosion and sedimentation rates.

(vii) The Late Middle Ages (10th to 15th centuries) represented abrupt political, demographic and economic changes leading to a general establishment of transhumance and the generalization of deforestation in the subalpine belt of the Pyrenees. Presence of microcharcoal is abundant in lacustrine sediments. There is evidence of an abrupt increase in erosion and sedimentation rates, with a large variety of geomorphic processes. Large sheep herds are developed in both the Pyrenees and the Central Ebro Depression.

(viii) Changes in plant cover and the hydrogeomorphological consequences during the Late Middle Ages were so intense that they initiated the Anthropocene era in the Pyrenees during the 12th and 13th centuries, when general changes occurred in landscape configuration, rainfall partitioning, soil erosion, landsliding, overland flow, fluvial dynamics, and the spatial distribution of fauna and flora. In high mountain areas, this was a major geoecological change, much more intense than any since the Neolithic and the Bronze Ages.

(ix) During the Modern Period (16th to the end of 18th centuries) a remarkable population growth occurred, together with the consolidation of the international wool markets. Deforestation of the subalpine belt concluded, including the less accessible areas. The recurrent use of fire resulted in the maximum presence of microcharcoal in lacustrine sediments. High erosion and sedimentation rates in the subalpine belt and the establishment of braided rivers indicate clear signs of intense geomorphic activity.

(x) The Contemporary Period (since the beginning of the 19th century) saw the highest demographic pressure in the Pyrenees at mid-19th century and a strong and rapid decline in population afterwards. Transhumant systems experienced a strong crisis, with a rapid decline in the number of sheep. A progressive number of cattle occurred since 1970. Partial abandonment of livestock grazing occurred in the subalpine belt, which promoted forest expansion on former pasture lands. Declining erosion and sediment yield resulted in incision of the fluvial channels.

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References

Alfaro Giner, C., 2001. Vías pecuarias y romanización en la Peninsula Ibérica. In: J.L. Gómez-Pantoja (Ed.), Los rebaños de Gerión. Pastores y trashumantes en Iberia antigua y medieval, Casa de Velázquez, Madrid, pp. 215-231.

Andrés Rupérez, M.T., 2000. El espacio funerario dolménico: abandono y clausura. Saldvie 1, 59-76.

Antolín, F. Navarrete, V., Saña, M., Viñerta, A., Gassiot, E. (2018). Herders in the mountains and farmers in the plains? A comparative evaluation of the archaeobiological record from Neolithic sites in the eastern Iberian Pyrenees and the southern lower lands. Quaternary International 484, 75-93. Doi: 10.1016/j.quaint.2017.05.056.

Aranbarri, J., González-Sampériz, P., Valero-Garcés, B., Moreno, A., Gil-Romera, G., Sevilla-Callejo, M., García-Prieto, E., Di Rita, F., Mata, M.P., Morellón, M., Magri, D., Rodríguez-Lázaro, J., Carrión, J.S., 2014. Rapid climatic changes and resilient vegetation during the Lateglacial and Holocene in a continental region of

south-western Europe. Global and Planetary Change 114, 50–65. Doi: 10.1016/j.gloplacha.2014.01.003.

ArchaeoGLOBE Project, 2019. Archaeological assessment reveals Earth's early transformations through land use. Science 365, 897-902.

Aubert, S., Belet, J.M., Bouchette, A., Otto, T., Dedoubat, J.J., Fontugne, M., Jalut, G., 2004. Dynamique tardiglaciaire et holocène de la végétation à l'étage montagnard dans les Pyrénées centrales. Comptes Rendus Biologies 327, 381-388. Doi: 10.1016/j.crvi.2004.02.001.

Bal, M.C., Pèlachs, A., Pérez-Obiol, R., Julia, R., Cunill, R., 2011. Fire history and human activities during the last 3300 cal yr BP in Spain's Central Pyrenees. The case of the Estany de Bourg. Palaeogeography, Palaeoclimatology, Palaeoecology 300, 179-190. Doi: 10.1016/j.palaeo.2010.12.023.

Baraut, C., 1994-95. Diplomatari del monestir de Sant Sadurní de Tavèrnoles (segles IX-XIII. Urgellia 12, 7-414.

Batllori, E., Gutiérrez, E., 2008. Regional tree line dynamics in response to global change in the Pyrenees. Journal of Ecology 96, 1275-1288. Doi: 10.1111/j.1365-2745.2008.01429.x.

Benito Alonso, J.L., 2018. Mapa de vegetación actual, a escala 1:10.000, del Parque Nacional de Ordesa y Monte Perdido y su zona periférica de protección. Organismo Autónomo Parques Nacionales, Madrid, 447 pp.

Berezowski, S., 1971. Tipologie des migrations pastorals en Europe et methods de leurs etudes. L'Aménagement de la Montagne 87, 165-174.

Bielza de Ory, V., Corral Lafuente, J.R., Escolano Utrilla, S., Laliena Corbera, C., Sesma Muñoz, A., Ubieto Arteta, A., 1986. Estudio histórico-geográfico del valle de Bielsa (Huesca). Instituto de Estudios Altoaragoneses, Huesca, 224 pp.

Blondel, J., 2006. The "design" of Mediterranean landscapes: A millennial story of humans during the historic period. Human Ecology 34, 713-729. Doi: 10.1007/s10745-006-9030-4.

Bourin, M., Carocci, S., Menant, F., To, L., 2011. Les campagnes de la Méditerranée occidentale autoru de 1300: tensions destructrices, tensions novatrices. Annales, Histoire, Sciences Sociales 3, 663-704. Doi: 10.1017/S0395264900011082.

Britnell, R., 1996. The commercialisation of English society, 1000-1500. Mancherter University Press, Manchester / New York, 281 pp.

Butzer, K.W., 1988. Cattle and sheep from old to new Spain. Historical antecedents. Annals of the Association of American Geographers 78 (1), 29-56. Doi: 10.1111/j.1467-8306.1988.tb00190.x.

Byers, A.C., Price, L.W., Price, M.F., 2013. An introduction to mountains. In: M.F. Price, A.C. Byers, D.A. Friend, T. Kohler, L.W. Price (Eds.), Mountain Geography. Physical and human dimensions. University of California Press, Berkeley, pp. 1-10.

Callegarin, L., Darles , C., Rechin, F. 2005. La villa de l'Arribèra deus Gleisiars à Lalonquette (Pyrénées-Atlantiques). L' Archéologue 78, 15-18.

Camarero, J.J., García-Ruiz, J.M., Sangüesa-Barreda, G., Galván, J.D., Alla, A.Q., Sanjua, Y., Beguería, S., Gutiérrez, E., 2015. Recent and intense dynamics in a formerly static Pyrenean treeline. Arctic, Antarctic, and Alpine Research 47 (4), 773-783. Doi: 10.1657/AAAR0015-001.

Canellas, A., 1988. Diplomatura medieval de la Casa de Ganaderos de Zaragoza. Real Sociedad Económica de Amigos del País, Zaragoza, 533 pp.

Carracedo, V., Cunill, R., García-Codrón, J.C., Pèlachs, A., Pérez-Obiol, R., Soriano, J.M., 2017. History of fires and vegetation since the Neolithic in the Cantabrian Mountains (Spain). Land Degradation & Development 29 (7), 2060-2072. Doi: 10.1002/ldr.2891.

Catalán, J., Pèlachs, A., Gassiot, E., Antolín, F., Ballesteros, A., Batalla, M., Burjachs, F., Buchaca, T., Camarero, L., Clemente, I., Clop, X., García, D., Giralt, S., Jordana LLuch, L., Madella, M., Mazzuco, N., Mur, E., Ninyerola, M., Obea, L., Oltra, J., Pérez-Obiol, R., Piqué, R., Pla-Rabés, S., Rivera Rondón, C., Rodríguez, J.M., Rodríguez, D., Sáez, A., Soriano, J.M., 2013. Interacción entre clima y ocupación humana en la configuración del paisaje vegetal del Parque Nacional de Aigües Tortes I Estany de Sant Maurici a lo largo de los últimos 15.000 años. In: L. Ramírez, B. Assensio (Eds.), Proyectos de investigación en parques nacionales: 2009-2012. Organismo Autónomo Parques Nacionales, Madrid, pp. 71-92.

Caviezel, C., Hunziker, M., Schaffner, M., Kuhn, N.J., 2014. Soil-vegetation interaction on slopes with bush encroachment in the central Alps – adapting slope stability measurements to shifting process domains. Earth Surface Processes and Landforms 39, 509-521. Doi: 10.1002/esp.3513.

Chapman, B., 1979. Transhumance and megalithic tombs in Iberia. Antiquity 53, 150-151. Doi: 10.1017/S0003598X00109214.

Clemente, I., Gassiot Ballbé, Rey Lanaspa, J., Antolín, F., Obea, L., Viñerta, A., Saña I Seguí, M., 2016. Cueva de Coro Trasito (Tella-Sin, Huesca): Un asentamiento pastoral en el Pirineo central con ocupaciones del Neolítico antiguo y del Bronce reciente. I Congreso de Arqueología y Patrimonio Aragonés, pp. 71-79.

Clemente, I., Gassiot, E., Rey, J., Mazzucco, N., Obea, L., 2014. "Cort o Trasito" –Coro Trasito– o corral de tránsito: una cueva pastoral del Neolítico antiguo en el corazón de Sobrarbe. In: I. Clemente, E. Gassiot, J. Rey (Eds.), Sobrarbe antes de Sobrarbe. Pinceladas de historia de los Pirineos. Centro de Estudios de Sobrarbe, Huesca, pp. 11-32.

Colombaroli, D., Henne, P.D., Kaltenrieder, P., Gobet, E., Tinner, W., 2010. Species responses to fire, climate and human impact at tree line in the Alps evidenced by palaeo-environmental records and a dynamic simulation model. Journal of Ecology 98, 1346-1357. Doi: 10.1111/j.1365-2745.2010.01723.x.

Connor, S.E., Vannière, B., Colombaroli, D., Anderson, R.S., Carrión, J.S., Ejarque, A., Gil-Romera, G., González-Sampériz, P., Hoefer, D., Morales-Molino, C., Revelles, J., Schneider, H., van der Knaap, W.O., van Leeuwen, J.F.N., Woodbridge, J., 2019. Humans take control of fire-driven diversity changes in Mediterranean Iberia's vegetation during the mid-late Holocene. Holocene 29 (5), 886-901. Doi: 10.1177/0959683619826652.

Corral, J.L., 1984. Cartulario de Alaón (Huesca). Anubar, Zaragoza, 332 pp.

Costello, E., Svensson, E., 2018. Transhumant pastoralism in historical landscapes. In: E. Costello, E. Svensson (Eds.), Historical archaeologies of transhumance in Europe. Toutledge, Oxon, pp. 1-13. Doi: 10.4324/9781351213394-1.

Cunill, R., Soriano, J.M., Bal, M.C., Pèlachs, A., Pérez-Obiol, R., 2012. Holocene treeline changes on the south slope of the Pyrenees: a pedoanthracological analysis. Vegetation History and Archaeobotany 21, 373-384. Doi: 10.1007/s00334-011-0342-y.

Cursente, B., 2016. Communautés, montagne et écriture. L'exemple de Sainte Colome (XiVe-XVIIIe siècle). In: C. Rendu, C. Calastrenc, M. Le Couédic, A. Berdoy (Eds.), Estives d'Ossau. 7000 ans de pastoralisme dans les Pyrenées. Éditions Le Pas d'Oiseaux, pp. 255-269.

Daumas, M., 1976. La vie rurale dans le Haut Aragon Oriental. Institutos de Estudios Oscenses y de Geografía Aplicada, Madrid, 774 pp.

Davidson, I., 1980. Transhumance, Spain and ethnoarchaeology. Antiquity 54, 144-147. Doi: 10.1017/S0003598X00103035.

Del Barrio, G., Puigdefábregas, J., 1987. Mass wasting features above the timberline in the Central Pyrenees and their topographic controls. Pirineos 130, 29-51. Doi: 10.2307/3673602.

Del Barrio, G., Creus, J., Puigdefábregas, J., 1990. Thermal seasonality of the high mountain belts of the Pyrenees. Mountain Research and Development 10 (3), 227-233. Doi: 10.2307/3673602.

Desprat, S., Sánchez Goñi, M.F., Loutre, M.F., 2003. Revealing climatic variability of the last three millennia in northwestern Iberia using pollen influx data. Earth and Planetary Science Letters 213, 63-78. Doi: 10.1016/S0012-821X(03)00292-9.

Diarte-Blasco, P., 2018. Late Antique and Early Medieval Hispania: Landscapes without strategy? Oxbow Books, Oxford. Doi: 10.2307/j.ctvh1dkqh.

Diago Hernando, M., 2002. Mesta y trashumancia en Castilla (siglos XIII a XIX). Arco Libros, Madrid, 95 pp.

Dietre, B., Walser, C., Lambers, K., Reimaier, T., Hajdas, I., Haas, J.N., 2014. Palaeoecological evidence for Mesolithic to Medieval climatic change and anthropogenic impact on the Alpine flora and vegetation of the Silvretta Massif (Switzerland/Austria). Quaternary International 353, 3-16. Doi: 10.1016/j.quaint.05.001.

Domínguez, A., Calvo, M.J., 1990. La arquitectura megalítica. Instituto de Estudios Altoaragoneses, Huesca, 32 pp.

Dumontier, P., Courtaud, P., Armand, D., Convertini, F., Ferrier, C., 2016. Entre montagne et piedmont, temoignages agropastoraux du Néolithique à l'âge du Fer. In: C. Rendu, C. Calastrenc, M. Le Couédic, A. Berdoy (Eds.), Estives d'Ossau. 7000 ans de pastoralisme dans les Pyrénées. Éditions Le Pas d'Oiseau, pp. 175-203.

Ejarque, A., Miras, Y., Riera, S., Palet, J.M., Orengo, H.A., 2010. Testing micro-regional variability in the Holocene shaping of high mountain cultural landscapes: a palaeoenvironmental case-study in the eastern Pyrenees. Journal of Archaeological Science 37, 1468-1479. Doi: 10.1016/j.jas.2010.01.007.

Fairén Jiménez, S., Cruz Berrocal, M., López-Romero González de la Aleja, E., Walid Sbeinati, S., 2006. Las vías pecuarias como elementos arquerológicos. In: I. Grau Mira (Ed.), La aplicación de los SIG en la arqueología del paisaje. Universidad de Alicante, Alicante, pp. 55-68.

Fernández-Giménez, M.E., Fillat Estaque, F., 2012. Pyrenean pastoralists' ecological knowledge: documentation and application to natural resource management and adaptation. Human Ecology 40 (2), 287-300. Doi: 10.1007/s10745-012-9463-x.

Fernández Lozano, J., Cabero Diéguez, V., 2017. Aproximación a un modelo de trasterminancia vertical para el borde suroccidental de la provincia de León en la Antigüedad. Sautuola 22, 405-416.

Fernández Mier, M., Quirós Castillo, J.A., 2015. El aprovechamiento de los espacios comunales en el noroeste de la Península Ibérica entre el periodo romano y el medieval. Il capitale culturale 12, 695-723.

Fernández Mier, M., Tente, C., 2018. Transhumant herding systems in Iberia. In: E. Costello, E. Svensson (Eds.), Historical archaeologies of transhumance across Europe, Taylor & Francis, London, pp. 219-232.

Fernández Mier, M., López Gómez, P., González Álvarez, D., 2013. Prácticas ganaderas en la Cordillera Cantábrica. Aproximación multidisciplinar al estudio de las áreas de pasto en la Edad Media. Debates de Arqueología Medieval 3, 167-219.

Fernández Otal, J.A., 1993. La Casa de Ganaderos de Zaragoza. Derecho y trashumancia a finales del siglo XX. Institución Fernando El Católico, Zaragoza, 314 pp.

Fernández Piñar, C., 2019. Origen, localización y evolución de los panares en el municipio de Gistaín. Historia Agraria 78, 67-97. Doi: 10.26882/histagrar.ot8eo3f.

Fita, F., 1906. Patrología visigótica. Elpidio, Pompeyano, Vicente y Gabino, Obispos de Huesca en el siglo VI. Boletín de la Real Academia de la Historia 49, 137–169.

Fortacín, J., 1983. La donación del diácono Vicente al monasterio de Asán y su posterior testamento como obispo de Huesca en el siglo VI. Precisiones críticas para la fijación del texto. Cuadernos de Historia Jerónimo Zurita 47-48, 59–64.

Gabba E., Pasquinucci M., 1979. Strutture agrarie e allevamento transumante nell'Italia romana (III-I secolo a C), Pisa, Giardini.

Galán Domingo, E., Ruiz Gálvez, M., 2001. Rutas ganaderas, trasterminancia y caminos antiguos. El caso del Occidente peninsular entre el Calcolítico y la Edad de Hierro. In: J.L. Gómez-Pantoja (Ed.), Los rebaños de Gerión. Pastores y trashumantes en Iberia antigua y medieval, Casa de Velázquez, Madrid, pp.

Galop, D., 1998. La foret, l'homme et le troupeau dans les Pyrénées. 6000 and d'histoire de l'environnement entre Garonne et Méditérranée. Geode, Toulouse, 285 pp.

Galop, D., 2016. Évolutions paleo-environmentales en vallée d'Ossau, du Néolithique à l'epoque contemporaine. In: C. Rendu, C. Calastrenc, M. Le Couédic, A. Berdoy (Eds.), Estives d'Ossau. 7000 ans de pastoralisme dans les Pyrénées. Éditions Le Pas d'Oiseau, pp. 161-173.

Garcés-Pastor, S., Cañellas-Boltà, N., Pèlachs, A., Soriano, J.-M., Pérez-Obiol, R., Pérez-Haase, A., Calero, M.A., Andreu, O., Escolà, N., Vegas-Vilarrúbia, T., 2017. Environmental history and vegetation dynamics in response to climate variations and human pressure during the Holocene in Bassa Nera, Central Pyrenees. Palaeogeography, Palaeoclimatology, Palaeoecology 479, 48–60. Doi: 10.1016/j.palaeo.2017.04.016.

García de Celis, A., Arroyo Pérez, P., Gandía Fernández, A., 2008. Cambios recientes del límite superior del bosque en Urbión: gestión forestal, ganadería y clima. Zubía Monográfico 20, 97-118.

García Martín, P., 2001. La principal sustancia destos reynos. De la trashumancia premesteña en la Península Ibérica. In: J.L. Gómez-Pantoja (Ed.), Los rebaños de Gerión. Pastores y trashumantes en Iberia antigua y medieval, Casa de Velázquez, Madrid, pp. 1-19.

García-Ruiz, J.M., Puigdefábregas, J., 1982. Formas de erosión en el flysch eoceno surpirenaico. Cuadernos de Investigación Geográfica 8, 85-130. Doi: 10.18172/cig.897.

García-Ruiz, J.M., Lasanta, T., 2018. El Pirineo aragonés como paisaje cultural. Pirineos 137, e038. Doi: 10.3989/pirineos.2018.173005.

García-Ruiz, J.M., Beguería, S., Alatorre, L.C., Puigdefábregas, J., 2010. Land cover changes and shallow landsliding in the Flysch Sector of the Spanish Pyrenees. Geomorphology 124, 250-259. Doi: 10.1016/2010.03.016.

García-Ruiz, J.M., López-Moreno, J.I., Lasanta, T., Vicente-Serrano, S.M., González-Sampériz, P., Valero-Garcés, B.L., Sanjuán, Y., Beguería, S., Nadal-Romero, E., Lana-Renault, N., Gómez-Villar, A., 2015. Los efectos geoecológicos del cambio global en el Pirineo Central español: Una revisión a distintas escalas espaciales y temporales. Pirineos 170, e012. Doi: 10.3989/Pirineos.2015.170005.

García-Ruiz, J.M., Sanjuán, Y., Gil-Romera, G., González-Sampériz, P., Beguería, S., Arnáez, J., Coba-Pérez, P., Gómez-Villar, A., Álvarez-Martínez, J., Lana-Renault, N., Pérez-Cardiel, E., López de Calle, C., 2016. Mid and Late Holocene forest fires and deforestation in the subalpine belt of the Iberian Range, Northern Spain.

Journal of Mountain Science 13 (19), 1760-1772. Doi: 10.1007/s11629-015-3763-8.

García Sanz, A., 1978. La agonía de la Mesta y el hundimiento de las exportaciones laneras: un capítulo de la crisis económica del Antiguo Régimen en España. Agricultura y Sociedad 6, 283-356.

Gartzia, M., Alados, C.L., Pérez-Cabello, F., 2014. Assessment of the effects of biophysical and anthropogenic factors of woody plant encroachment in dense and sparse mountain grasslands based on remote sensing data. Progress in Physical Geography 38 (2), 201-217. Doi: 10.1177/0309133314524429.

Gassiot, E., Rodríguez Antón, D., Pèlachs, A., Pérez Obiol, R., Julià, R., Bal-Serin, M.C., Mazzuco, N., 2014. La alta montaña durante la Prehistoria: 10 años de investigación en el Pirineo catalán occidental. Trabajos de Prehistoria 71 (2), 261-281. Doi: 10.3989/tp.2014.12134.

Gómez-Pantoja, J., 2001. *Pastio agrestis*. Pastoreo y trashumancia en Hispania romana. In: J.L. Gómez-Pantoja (Ed.), Los rebaños de Gerión. Pastores y trashumantes en Iberia antigua y medieval, Casa de Velázquez, Madrid, pp. 177-213.

Gómez-Pantoja, J.L. 2016. Algunos indicios de pastoralismo en Hispania romana. Mélanges de l'École Française de Rome – Antiquité (on line), 128 (2). Doi: 10.4000/mefra.3521.

Gómez Urdáñez, J.L., Moreno Fernández, J.R., 1997. El problema agrario en las sierras de La Rioja: de la propiedad a la subsistencia (siglos XVIII y XIX). Agricultura y Sociedad 82, 79-113.

González-Álvarez, D., 2019. The need to understand the cultural biographies of alpine and subalpine landscapes during later Prehistory: upland archaeology in the Cantabrian Mountains. Cuadernos de Investigación Geográfica 45 (1), 143-165. Doi: 10.18172/cig.3824.

González-Álvarez, D., Fernández-Mier, M., López-Gómez, P., 2016. An archaeological approach to the brañas: summer farms in the pastures of the Cantabrian Mountains (northern Spain). In: J.R. Collis, M. Pearce, F. Nicolis (Eds.), Summer farms. Seasonal exploitation of the uplands from Prehistory to the present. Equinox Publishing, Sheffield, pp. 203-219.

González-Álvarez, D., Martín-Suárez, C., Farci, C., López-Gómez, P., López-Sáez, J.A., Martínez-Barrio, C., Martinón-Torres, M., Menéndez-Blanco, A., Moreno-García, M., Núñez de la Fuente, S., Peña-Chocarro, L., Pérez-Jordá, G., Rodríguez-

Hernández, J., Tejerizo-García, C., Fernández-Mier, M., 2018. (El Castru, Vigaña, Belmonte de Miranda, Asturias): un pequeño poblado fortificado de las montañas occidentales cantábricas durante la Edad del Hierro. Munibe. Antropologia-Arkeologia 69, 211-237. Doi: 10.21630/maa.2018.69.14.

González-Sampériz, P., Valero-Garcés, A., Moreno, A., Jalut, G., García-Ruiz, J.M., Martí-Bono, C., Delgado-Huertas, A., Navas, A., Otto, T., Dedoubat, J.J., 2006. Climate variability in the Spanish Pyrenees during the last 30,000 yr revealed by the El Portalet sequence. Quaternary Research 66, 38-52. Doi: 10.1016/j.yqres.2006.02.004.

González-Sampériz, P., Aranbarri, A., Pérez-Sanz, A., Gil-Romera, G., Moreno, A., Leunda, M., Sevilla-Callejo, M., Corella, J.P., Morellón, M., Oliva, B., Valero-Garcés, B., 2017. Environmental and climate change since the Last Glacial Maximum: A view from the lake records. Catena 149, 668-689. Doi: 10.1016/j.catena.2016.07.041.

González-Sampériz, P., Montes, L., Aranbarri, J., Leunda, M., Domingo, R., Laborda, R., Sanjuán, Y., Gil-Romera, G., Lasanta, T., García-Ruiz, J.M., 2019. Escenarios, tempo e indicadores paleoambientales para la identificación del Antropoceno en el paisaje vegetal del Pirineo Central (NE Iberia). Cuadernos de Investigación Geográfica 45 (1), 167-193. http://doi.org/10.18172/cig.3691.

Guiguet-Covex, C., Arnaud, F., Poulenard, J., Disnar, J.R., Delhon, C., Francus, P., David, F., Enters, D., Rey, P.J., Delannoy, J.J., 2011. Changes in erosion patterns during the Holocene in a currently treeless subalpine catchment inferred from lake sediment geochemistry (Lake Anterne, 2063 m a.s.l., NW French Alps): The role of climate and human activities. The Holocene 21 (4), 651-665. Doi: 10.1177/0959683610391320.

Higgs, E.S., 1976. The history of European agriculture: the uplands. Philosophical Transactions of the Royal Society, London B 275, 159-173. Doi: 10.1098/rstb.1976.0078.

Höllermann, P., 1985. The periglacial belt of mid-latitude mountains from a geoecological point of view. Erdkunde 39, 259-270. Doi: 10.3112/erdkunde.1985.04.02.

Hughes, D. (1994) Forestry and forest economy in the Mediterranean region in the time of the Roman Empire in the light of historical sources. In B. Frenzel (Ed.)

Evaluation of Land Surfaces Cleared from Forests in the Mediterranean Region During the Time of the Roman Empire, 1-14. Stuttgart, Gustav Fischer Verlag.

Laborda, R., Villalba-Mouco, V., Lanau, P., Gisbert, M., Sebastián, M., Domingo, R., Montes, L., 2017. El Puerto bajo de Góriz (Parque Nacional de Ordesa y Monte Perdido). Ocupación y explotación de un paisaje de alta montaña desde la prehistoria hasta el siglo XX. Bolskan 26, 9-30.

Lana-Renault, N., Alvera, B., García-Ruiz, J.M., 2011. Runoff and sediment transport during the snowmelt period in a Mediterranean high mountain catchment. Arctic, Antarctic and Alpine Research 43 (L2), 213-222. Doi: 10.1657/1938.4246-43.2.213.

Lasanta, T., Beguería, S., García-Ruiz, J.M., 2006. Geomorphic and hydrological effects of traditional shifting agriculture in a Mediterranean mountain area, Central Spanish Pyrenees. Mountain Research and Development 26 (2), 146-152. Doi: 10.1659/0276-4741(2006)26[146:GAHEOT]2.0.CO;2.

Lasanta-Martínez, T., Vicente-Serrano, S.M. & Cuadrat-Prats, J.M., 2005. Mountain Mediterranean landscape evolution caused by the abandonment of traditional primary activities: a study of the Spanish Central Pyrenees. Applied Geography 25, 47-65. Doi: 10.1016/j.apgeog.2004.11.001.

Le Couédic, M., Calastrenc, C., Rendu, C., 2016. À la recherché de la chronologie. In: C. Rendu, C. Calastrenc, M. Le Couédic, A. Berdoy (Eds.), Estives d'Ossau. 7000 ans de pastoralisme dans les Pyrénées. Éditions Le Pas d'Oiseau, pp. 85-113.

Le Flem, J.P., 1972. Las cuentas de la Mesta, 1510-1709. Moneda y Crédito 121, 23-104.

Leunda, M., González-Sampériz, P., Gil-Romera, G., Aranbarri, J., Moreno, A., Oliva-Urcia, B., Valero-Garcés, B., 2017. The Late-Glacial and Holocene Marboré Lake sequence (2612 m a.s.l., Central Pyrenees, Spain): Testing high altitude sites sensitivity to millennial scale vegetation and climate variability. Global and Planetary Change 157, 214-231. Doi: 10.1016/j.gloplacha.2017.08.008.

Leunda, M., González-Sampériz, P., Gil-Romera, G., Bartolomé, M., Belmonte, A., Gómez, D., Kaltenrieder, P., Rubiales, JM., Schwörer, C., Tinner, W., Morales-Molino, C., Sancho, C., 2019. Ice cave reveals environmental forcing of long-term Pyrenean treeline dynamics. Journal of Ecology 107, 814-828. Doi: 10.1111/1365-2745.13077.

Leunda M., Gil-Romera, G., Daniau, A.L., Benito, B., González-Sampériz, P., (2020). Holocene fire-vegetation dynamics in the Central Pyrenees (Spain). Catena 188, 104411. Doi: 10.1016/ catena.2019.104411.

Leveau, P., 2016. Approches de la transhumance en Gaule à l'époque romaine. In: C. Rendu, C. Calastrenc, M. Le Couédic, A. Berdoy (Eds.), Estives d'Ossau. 7000 ans de pastoralisme dans les Pyrénées. Éditions Le Pas d'Oiseau, pp. 205-221.

Llorens, P., Domingo, F., 2007. Rainfall partitioning by vegetation under Mediterranean conditions. A review of studies in Europe. Journal of Hydrology 335, 37-54. Doi: 10.1016/j.hydrol.2006.10.032.

Logemann, E., Kalbrenner, G., Schüle, W., Krützfeldt, B., 1995. Contenido de mercurio en huesos de animales domésticos y trashumancia. Actas del I Congreso Peninsular de Arqueología, Trabalhos de Antropologia e Etnologia 35 (2), 457-471.

López-Moreno, J.I., García-Ruiz, J.M., 2004. Influence of snow accumulation and snowmelt on streamflow in the central Spanish Pyrenees. Hydrological Sciences Journal 49 (5), 787-802. Doi: 10.1623/hysj.49.5.787.55135.

López-Moreno, J.I., Latron, J., 2008. Influence of forest canopy on snow distribution in a temperate mountain range. Hydrological processes 22 (1), 117-126. Doi: 10.1002/hyp.6572.

López-Moreno, J.I., Pomeroy, J.W., Revuelto, J., Vicente-Serrano, S.M., 2012. Response of snow processes to climate change: spatial variability in a small basin in the Spanish Pyrenees. Hydrological Processes 27 (18), 2637-2650. Doi: 10.1002/hyp.9408.

López-Sáez, J.A., Abel-Schaad, D.A., Pérez-Díaz, S., Blanco-González, A., Alba-Sánchez, F., Dorado, M., Ruiz-Zapata, B., Gil-García, M. J., Gómez-González, C. and Franco-Mugica, F. (2014) Vegetation history and human impact in the Spanish Central System over the last 9000 years. Quaternary International 353, 98-122. Doi: 10.1016/j.quaint.2013.06.034.

López-Sáez, J.A., Blanco-González, A., Abel-Schaad, D., Robles-López, S., Luelmo-Lautenschlaeger, R., Pérez-Díaz, S., Alba-Sánchez, F., 2018. Transhumance dynamics in the Gredos Range (central Spain) during the last two millennia. Environmental and socio political vectors of change. In: E. Costello, E. Svensson (Eds.), Historical archaeologies of transhumance across Europe. Routledge, Oxon, pp. 233-244. Doi: 10.4324/9781351213394-16.

Martín de las Pueblas, J., Hidalgo, M.A., 1999. El Lucero de Benasque. Edición y studio lingüístico. Ayuntamiento de Benasque, Zaragoza, 253 pp.

Mazier, F., Galop, D., Gaillard, M.J., Rendu, C., Cugny, C., Legaz, A., Peyron, O., Buttler, A., 2009. Multidisciplinary approach to reconstructing local pastoral activities: An example from the Pyrenean mountains (Pays Basque). The Holocene 19 (2), 171-188. Doi: 10.1177/0959683608098956.

Menant, F., 2015. Las transformaciones de la escritura documental entre los siglos XII y XIII. Edad Media, Revista de Historia 16, 33-53.

Miras, Y., Ejarque, H.A., Orengo, S., Riera, J.M., Palet, J.M., Poiraud, A., 2010. Prehistoric impact on landscape and vegetation at high altitudes: an integrated palaeoecological and archaeological approach in the eastern Pyrenees (Perafita valley, Andorra). Plant Biosystems 144 (4), 946-961. Doi: 10.1080/11263504.2010.491980.

Montes, L., Domingo, R., Sebastián, M., Lanau, P., 2016a. ¿Construyendo un paisaje? Megalitos, arte esquemático y cabañeras en el Pirineo Central. Arpi 4, 248-263.

Montes, L., Bea, M., Domingo, R., Sánchez, P., Alcolea, M., Sebastián, M., 2016b. La gestión prehistórica de un territorio en la montaña Prepirenaica: Tierra Bucho (Huesca, España). Munibe Antropologia-Arkeologia 67, 349–362. Doi: 10.21630/maa.2016.67.mis07.

Montserrat, J., 1992. Evolución glaciar y postglaciar del clima y la vegetación en la vertiente sur del Pirineo: Estudio palinológico. Monografías del Instituto Pirenaico de Ecología, Zaragoza, 147 pp.

Montserrat-Martí, G., Gómez-García, D., 2019. Variación de los dominios forestal y herbáceo en el paisaje vegetal de la Península Ibérica en los últimos 20.000 años. Importancia del efecto de los grandes herbívoros sobre la vegetación. Cuadernos de Investigación Geográfica 45 (1), 87-121. Doi: 10.18172.cig.3659.

Montserrat, P., 1964. Ecología del pasto. Publicaciones del Centro Pirenaico de Biología Experimental 1 (5), 1-22.

Montserrat, P., 1971. La Jacetania y la vida vegetal. Publicaciones de la Caja de Ahorros y Monte de Piedad de Zaragoza, Aragón y Rioja, Zaragoza, 108 pp.

Montserrat, P., 1988. Flora. In: Enciclopedia temática de Aragón 6, Ediciones Moncayo, Zaragoza, 323 pp.

Montserrat, P., 2009. La cultura que hace al paisaje. Fertilidad de la Tierra, Estella, 237 pp.

Morellón, M., Valero-Garcés, B., Vegas-Villarrúbia, T., González-Sampériz, P., Romero, Ó., Delgado-Huertas, A., Mata, P., Moreno, A., Rico, M., Corella, J.P., 2009. Lateglacial and Holocene palaeohydrology in the western Mediterranean region: The Lake Estanya record (NE Spain). Quaternary Science Reviews 28, 2582-2599. Doi: 10.1016/j.quascirev.2009.05.014.

Moreno Fernández, J.R., 1996. La ganadería trashumante en La Rioja 1752-1865. Una revision bibliográfica y cuantitativa. Berceo 20, 277-303. Doi: 10.18172/brocar.1767.

Moret Oliver, M.T., Tomás-Faci, G., 2014. El pleito del guiaje ganadero de Ribagorza (1316-1319). Edición y estudio histórico lingüístico. Institución Fernando El Católico, Zaragoza, 173 pp.

Mujika Alustiza J.A., Agirre García J., Edeso Fito J.M., Lopetegi Galarraga A., Pérez Díaz S., Ruiz Alonso M., Tarriño Vinagre A., Yusta Arnal I., 2013. La continuidad de la actividad pastoril durante la época romana en la zona de Argarbi (Sierra de Aralar, Gipuzkoa). Kobie, Serie Paleoantropologia 32, 217-258.

Munro, J., 2001. The 'New Institutional Economics' and the changing fortunes of fairs in Medieval and Early Modern Europe: The textile trades, warfare, and transaction costs. Vierteljahrschrift für Sozial- und Wirtschaftsgeschichte 88, 1-47.

Nadal-Romero, E., Otal-Otín, I., Lasanta, T., Sánchez-Navarrete, P., Errea, P., Cammeraat, E., 2018. Woody encroachment and soil carbon stocks in subalpine areas in the Central Spanish Pyrenees. Science of the Total Environment 636, 727-736. Doi: 10.1016/j.scitotenv.2018.04.324.

Ninot, J.M., Batllori, E., Carrillo, E., Carreras, J., Ferré, A., Gutiérrez, E., 2008. Timberline structure and limited tree recruitment in the Catalan Pyrenees. Plant Ecology & Diversity 1 (1), 47-57. Doi: 10.1080/17550870802260764.

O'Flanagan, P., Lasanta, T., Errea, M.P., 2011. Restoration of sheep transhumance in the Ebro Valley, Aragon, Spain. The Geographical Review 101 (4), 556-575. Doi: 10.1111/j.1931-0846.2011.00117.x.

Obea Gómez, L., 2014. El paisaje en el Neolítico: un estudio preliminar de los restos antracológicos de Coro Trasito (Tella). In: I. Clemente Conte, E. Gassiot Ballbé, J. Rey Lanaspa (Eds.), Sobrarbe antes de Sobrarbe. Pinceladas de historia de los Pirineos. Centro de Estudios de Sobrarbe, Aínsa, pp. 43-54.

Orengo, H.A., Palet, J.M., Ejarque, Y., Miras, S., Riera, S., 2014. Shifting occupation dynamics in the Madriu-Perafita-Claror valleys (Andorra) from the early Neolithic

to the Chalcolithic: the onset of high mountain cultural landscapes. Quaternary International 353, 140-152. Doi: 10.1016/j.quaint.2014.01.035.

Oteros-Rozas, E., Ontillera-Sánchez, R., Sanosa, P., Gómez-Baggethun, E., Reyes-García, V., González, J.A., 2013. Traditional ecological knowledge among transhumant pastoralists in Mediterranean Spain. Ecology and Society 18 (3), 33. Doi: 10.5751/ES-05597-180333.

Palet, J.M., Ejarque, A., Miras, Y., Riera, S., Euba, I., Orengo, H.A. 2007. Formes d'ocupació d'alta muntanya a la vall de la Vansa (Serra del Cadí - Alt Urgell) i a la vall del Madriu-Perafita-Claror (Andorra): estudi diacrònic de paisatges culturals pirinencs. Tribuna d'Arqueologia 2006, 229-253.

Palet, J.M., Orengo, H., Ejarque, A., Euba, I., Miras, Y., Riera, S., 2010. Formas de paisaje de montaña y ocupación del territorio en los Pirineos orientales en época romana: estudios pluridisciplinares en el valle del Madriu-Perafita, Claror (Andorra) y en la Sierra del Cadí (Cataluña). Bollettino da Archeologia On Line, Volume Speciale A/A8/5, 67-79.

Palet, J.M., García, A., Orengo, H.A., Riera, S., Miras, Y., Juliá, R., 2014. Ocupación y explotación de espacios altimontanos pirenaicos en la Antigüedad: Visiones desde la arqueología del paisaje. In: P.L. Dall'Aglio, C. Franceschelli, L. Maganzani (Eds.), Atti del IX Convegno Internazionali di Studi Veleiati, Ante Quem, Bologna, pp. 455-470.

Pallaruelo, S., 1993. Pirineo aragonés. Cuadernos de la Trashumancia número 6, ICONA, Madrid, 75 pp.

Pascua Echegaray, E., 2012. Señores del paisaje. Ganadería y recursos naturales en Aragón, siglos XIII-XVII. Publicacions de la Universitat de València, Valencia, 327 pp.

Pèlachs, A., Soriano López, J.M., Esteban I Amat, A., Nadal Teresa, J., 2007. Holocene environmental history and human impact in the Pyrenees. Contributions to Science 3, 421-429. Doi: 10.2436/20.7010.01.19.

Pérez-Díaz, S., López-Sáez, J.A., Núñez de la Fuente, S., Ruiz-Alonso, M., 2018. Early farmers, megalithic builders and the shaping of the cultural landscapes during the Holocene in Northern Iberian mountains. A palaeoenvironmental perspective. Journal of Archaeological Science 18, 463-474. Doi: 10.1016/j.jasrep.2018.01.043.

Pérez Sanz, A., González-Sampériz, P., Valero-Garcés, B., Moreno, A., Morellón, M., Sancho, C., Belmonte, A., Gil-Romera, G., Sevilla, M., Navas, A., 2011. Clima y

actividades humanas en la dinámica de la vegetación durante los últimos 2000 años en el Pirineo Central. El registro palinológico de la Basa de la Mora (Macizo de Cotiella). Zubía 23, 17-38.

Pérez-Sanz, A., González-Sampériz, P., Moreno, A., Valero-Garcés, B., Gil-Romera, G., Rieradevall, M., Tarrats, P., Lasheras-Álvarez, L., Morellón, M., Belmonte, A., Sancho, C., Sevilla-Callejo, M., Navas, A., 2013. Holocene climate variability, vegetation dynamics and fire regime in the central Pyrenees: The Basa de la Mora sequence (NE Spain). Quaternary Science Reviews 73, 149-169. Doi: 10.1016/j.quascirev.2013.05.010.

Pinilla Navarro, V., 1995. Entre la inercia y el cambio: El sector agrario aragonés 1850-1935. Ministerio de Agricultura, Pesca y Alimentación, Madrid.

Pueyo, Y., Beguería, S., 2007. Modelling the rate of secondary succession after farmland abandonment in a Mediterranean mountain area. Landscape and Urban Planning 83 (4), 245–254. Doi: 10.1016/j.landurbplan.2007.04.008.

Puigdefábregas, J., Balcells, E., 1966. Resumen sobre el régimen de explotación ovina trashumante en el Alto Aragón, especialmente en el valle de Ansó. Publ. Centr. Pir. Biol. Exp. 1 (6), 1-18.

Puigdefábregas, J., Alvera, B., 1986. Particulate and dissolved matter in snowmelt runoff from small watersheds. Zeitschrift für Geomorphologie Suppl. Bd. 58, 69-80.

Puigdefábregas, J., Fillat, F., 1986. Ecological adaptation of traditional land uses in the Spanish Pyrenees. Mountain Research and Development 6 (1), 63-72. Doi: 10.2307/3673341.

Réchin F. 2000. Établissements pastoraux du piémont occidental des Pyrénées, in Organisation des espaces antiques: entre nature et histoire, sous la direction du G. Fabre. Pau, Université de Pau, pp. 13-50.

Rendu, C., Calastrenc, C., Le Couédic, M., 2016. Quatre cartes pour une synthèse. In: C. Rendu, C. Calastrenc, M. Le Couédic, A. Berdoy (Eds.), Estives d'Ossau. 7000 ans de pastoralisme dans les Pyrénées. Éditions Le Pas d'Oiseau, pp. 143-157.

Riera, S., Wansard, G., Julià, R., 2004. 2000year environmental history of a karstic lake in the Mediterranean pre-pyrenees: the Estanya lakes (Spain). Catena 55, 293-324. Doi: 10.1016/S0341-8162(03)00107-3.

Rius, D., Vannière, B., Galop, D., 2012. Holocene history of fire, vegetation and land use from the central Pyrenees (France). Quaternary Research 77, 54-64. Doi: 10.1016/j.yqres.2011.09.009.

Rodríguez Pascual, M., 2010. La trashumancia en la Cordillera Cantábrica: Equilibrio entre producción y conservación del medio natural. Anales de la Real Academia de Ciencias Veterinarias 18, 35-54.

Roepke, A., Krause, R., 2013. High montane-subalpine soils in the Montafon Valley (Austria, Northern Alps) and their link to land-use, fire and settlement history. Quaternary International 308-309, 178-189. Doi: 10.1016/j.quaint.2013.01.022.

Roigé Ventura, X., Contreras, J., Cots, P., Font, J., Gómez, M.P., Parès, P.M., Peret, M., Ros, I., Such, X., 1993. Pirineo Catalán. Cuadernos de la Trashumancia, 13. ICONA, Madrid.

Rojo Guerra, M.A., Peña Chocarro, L., Royo Guillén, J.I., Tejedor Rodríguez, C., García Martínez de Lagrán, I., Arcusa Magallón, H., Garrido Pena, R., Moreno García, M., Mazzuco, N., Gibaja Bao, J.F., Ortega, D., Kromer, B., Alt, K.W., 2013. Pastores trashumantes del Neolítico Antiguo en un entorno de alta montaña: secuencia crono-cultural de la cova de Els Trocs (San Feliu de Veri, Huesca). Boletín del Seminario de Estudios de Arte y Arqueología 79: 9-55.

Rojo Guerra, M., Arcusa Magallón, H., Peña Chocarro, L.,Royo Guillén, J.I., Tejedor Rodríguez, C., García Martínez de Lagrán, I., Garrido Pena, R., Moreno García, M., Pimenta, C., Mazzuco, N., Gibaja Bao, J.F., Pérez Jorá, G., Jiménez Jiménez, I., Iriarte, E., Alt, K.W., 2014. Los primeros pastores trashumantes en la Alta Ribagorza. In: I. Clemente Conte, E. Gassiot Ballbe, J. Rey Lanaspa (Eds.), Sobrarbe antes de Sobrarbe. Pinceladas de historia de los Pirineos. Centro de Estudios de Sobrarbe, Aínsa, pp. 127-151.

Rojo-Guerra, M., García-Martínez de Lagrán, I., González-Sampériz, P., 2018. El Pirineo Central y Occidental en los inicios del Neolítico. In: G. Remolins Zamora, J.F. Grijalba Bao (Eds.), Les Valls d'Andorra Durant el Neolithic: un encreuament de camins al centre dels Pirineus. Museu d'Arqueologia de Catalunya, Barcelona, pp. 17-35.

Ruiz, M., Ruiz, J.P., 1986. Ecological history of transhumance in Spain. Biological Conservation 37 (1), 73-86. Doi: 10.1016/0006-3207(86)90035-2.

Sanjuán, Y., Gómez-Villar, A., Nadal-Romero, E., Álvarez-Martínez, J., Arn´aaez, J., Serrano-Muela, M.P., Rubiales, J.M., González-Sampériz, P., García-Ruiz, J.M.,

2016. Linking land cover changes in the sub-alpine and montane belts to changes in a torrential river. Land Degradation and Development 27, 179-189. Doi: 10.1002/ldr.2294.

Sanjuán, Y., Arnáez, J., Beguería, S., Lana-Renault, N., Lasanta, T., Gómez-Villar, A., Álvarez-Martínez, J., Coba-Pérez, P., García-Ruiz, J.M., 2018. Woody plant encroachment following grazing abandonament in the subalpine belt: a case study in northern Spain. Regional Environmental Change 18, 1103-1115. Doi: 10.1007/s10113-017-1245-y.

Sanmiguel-Vallelado, A., López-Moreno, J.I., Morán-Tejeda, E., Alonso-González, E., Navarro-Serrano, F.M., Rico, I., Camarero, J.J., 2020. The variable effects of forest canopy on snow processes in a valley of the central Spanish Pyrenees. Hydrological Processes. Doi: 10.1002/hyp.13721.

Santos Yanguas, J. and Cruz Andreotti, G. eds. (2012) Romanización, fronteras y etnias en la Roma antigua: el caso hispano. Vitoria, Universidad del País Vasco.

Serrano Martínez, A., 1997. La Casa de Ganaderos de Zaragoza. In: La Casa de Ganaderos de Zaragoza: Ocho siglos en la Historia de Aragón. Justicia de Aragón y Fundación "Casa de Ganaderos", Zaragoza, pp. 9-23.

Sesma, J.A. (2013). Revolución comercial y cambio social. Aragón y el mundo mediterráneo. Prensas de la Universidad de Zaragoza, Zaragoza, 416 pp.

Sesma, J.A., Laliena, C., 2004. Introducción. La población de Aragón en la Edad Media (siflos XIII-XV). Estudios de demografía histórica. Universidad de Zaragoza, Zaragoza, pp. 9-19.

Sesma, J.A., Laliena, C., 2009. Crecimiento económico y formación de los mercados en Aragón en la Edad Media (1200-1350). Grupo CEMA, Zaragoza, 426 pp.

Tomás-Faci, G., Laliena, J., 2016. Ansó. Historia de un valle pirenaico. Editorial Pirineo, 411 pp.

Tomás-Faci, G., Martín Iglesias, J.C., 2017. Cuatro documentos inéditos del monasterio visigodo de San Martín de Asán (522-586). Mittellateinisches jahrbuch Internationale Zeitschrift für Mediavistik 52, 261-286.

Tornero, C., Aguilera, M., Ferrio, J.P., Arcusa, H., Moreno-García, M., García-Reig, S., Rojo-Guerra, M., 2016. Vertical sheep mobility along the altitudinal gradient through stable isotope analyses in tooth molar bioapatite, meteoric water and pastures: a reference from the Ebro valley to the central Pyrenees. Quaternary International 484, 94-106. Doi: 10.1016/j.quaint.2016.11.042.

Troll, C., 1972. Geoecology of the world-wide differentiation of high mountain ecosystems. In: C. Troll (Ed.), Geoecology of the high mountain regions of Eurasia. Franz Steiner, Wiesbaden, pp. 1-13.

Troll, C., 1973. High mountain belts between the polar caps and the equator: Their definition and lower limit. Arctic and Alpine Research 5 (3), 19-28.

Ubieto, A., 1962-1963. Cartulario de San Juan de la Peña. Anubar, Valencia, 2 vols.

Utrilla, J.F., Laliena, C., Navarro, G., 2005. Los recursos naturales y su transformación en los Pirineos aragoneses durante la Edad Media. In: Les ressources naturelles des Pyrénées du Moyen Age à l'époque moderne. Actes du Congrès International RESOPYR-1, Presses Universitaires de Perpignan, pp. 19-48.

Vera, F.W.M., 2000. Grazing ecology and forest history. CABI Publishing, Oxon. Doi: 10.1079/9780851994420.0000.

Wulf, A., 2016. La invención de la naturaleza. El nuevo mundo de Alexander von Humboldt. Taurus, Madrid, 578 pp.

FIGURE CAPTIONS

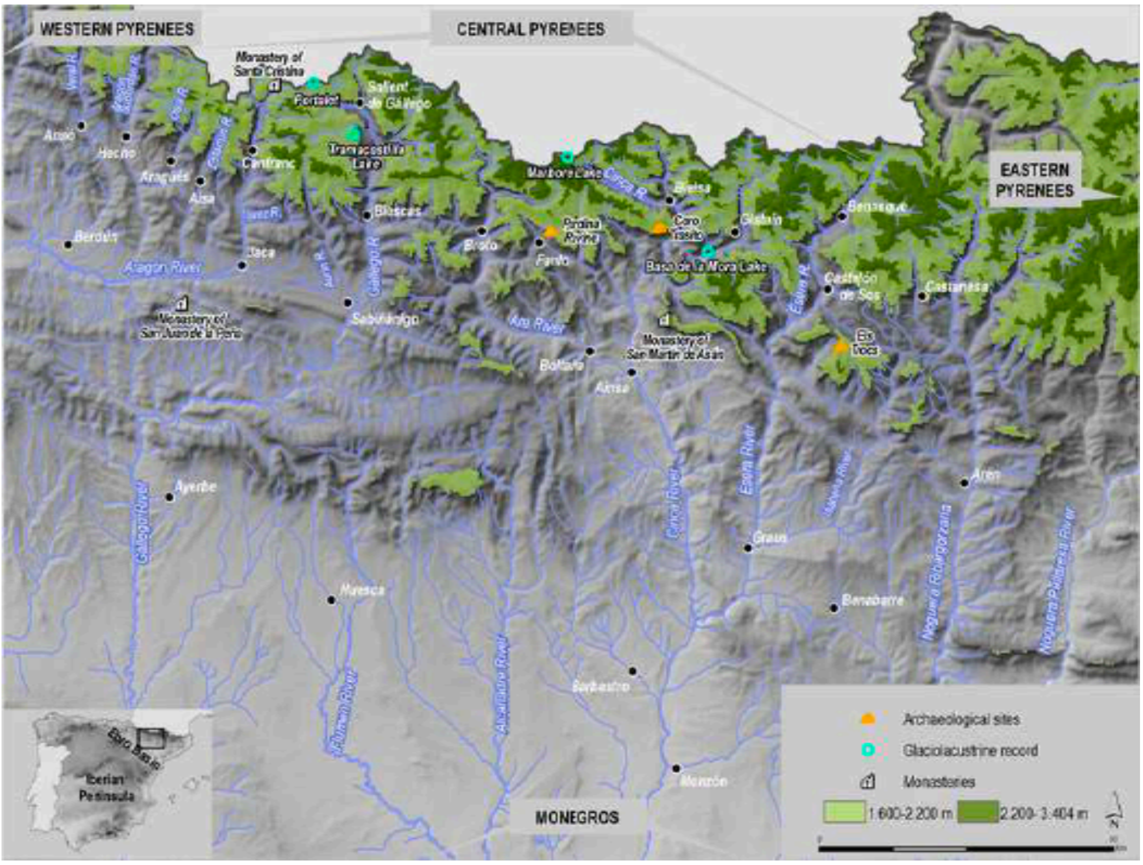
Figure 1. The subalpine belt in the Acherito Valley, a tributary of the Aragón Subordán River, as an example of the current landscape after centuries of livestock management. The bottoms and hillslopes of glacial U-shaped valleys have been the preferred landscapes for summer grazing because of accessibility, topoclimatic variability and biodiversity for the distinct types of livestock. The subalpine belt of the Pyrenees and other Mediterranean mountains was deforested to enlarge the area of summer grasslands and thereby balance the winter resources (lowlands) and summer resources (highlands).

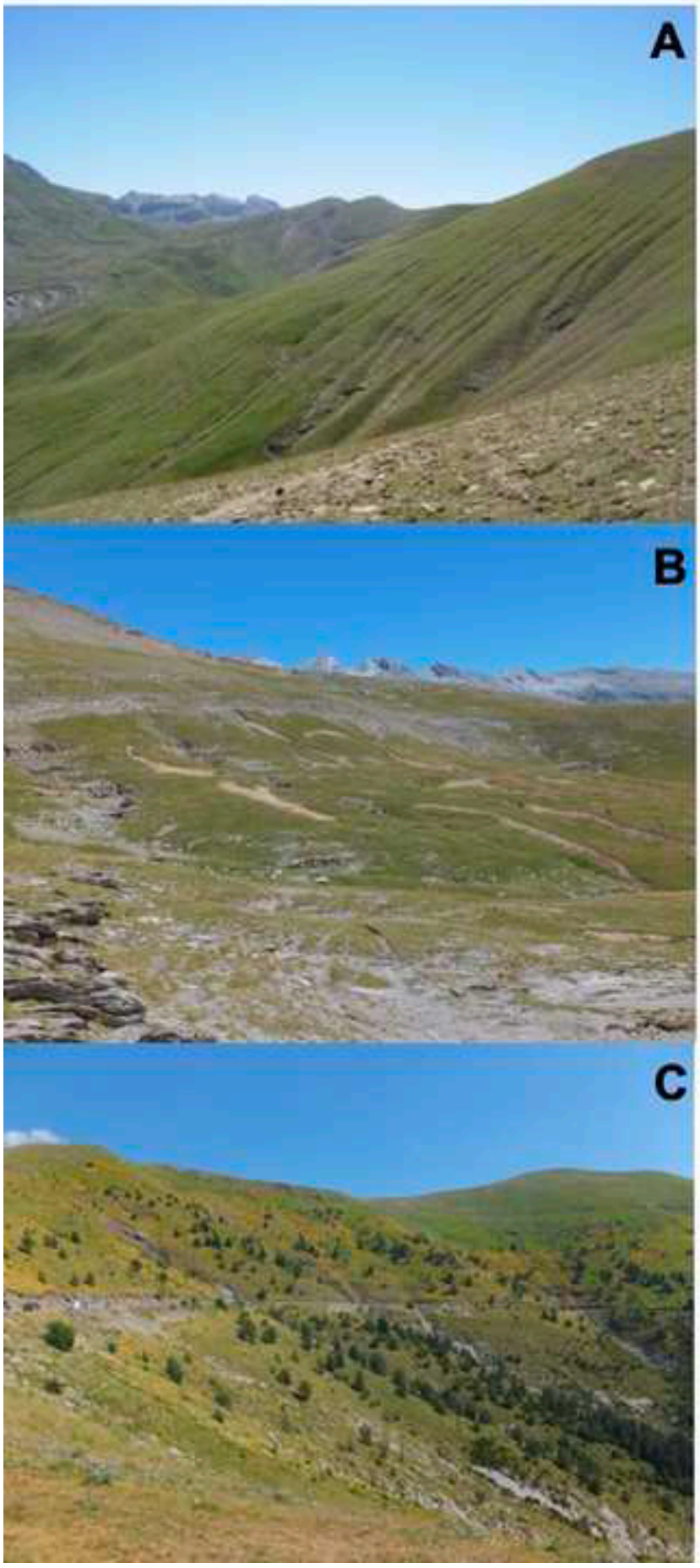
Figure 2. The study area. The location of main rivers and villages is included, as well as the extent of the upper montane and subalpine belts (in light green) and the alpine and nival belts (in dark green). Valleys, settlements, archaeological sites, glaciolacustrine deposits, and monasteries cited in the text are also shown.

Figure 3. A: Parallel rills/gullies in the Agüerri Valley, a tributary of the Aragón Subordán Valley. These erosion landforms suggest the occurrence of local deforestation in steep slopes prior to the Middle Ages, given the deep incision into flysch bedrock, although the exact time of their occurrence is uncertain. B: Shallow landslides in a

deforested area of the Añisclo Valley, close to the Plana Canal Mountain Pass, Ordesa, and Monte Perdido National Park. Deforestation of the subalpine belt led to development of shallow landslides that affected deep soils in slopes with gradients over 15º (García-Ruiz et al., 2010). C: Many summer grasslands were abandoned following depopulation and the transhumance crisis in the Mediterranean mountains. In the Central Pyrenees, the livestock decline led to a rapid recovery of the hillslopes with *Echinospartum horridum* (indicating the recurrent use of fires). At present, young pines (*Pinus sylvestris*) have naturally established as a new forest colonization front.

Figure 4. Summary of changes in forest and livestock management from the Neolithic to the present, with indication of climate features and geomorphic consequences.


WESTERN PYRENEES
CENTRAL PYRENEES
EASTERN PYRENEES
MONEGROS
Monastery of Santa Cristina
Portalet
Sallent de Gállego
Tramacastilla Lake
Marboré Lake
Bielsa
Pardina Ravine
Coro Trasito
Gistaín
Benasque
Basa de la Mora Lake
Castejón de Sos
Castanesa
Els Trocs
Monastery of San Juan de la Peña
Monastery of San Martín de Asán
Ansó
Hecho
Aragüés
Aísa
Canfranc
Biescas
Broto
Fanlo
Berdún
Jaca
Aragón River
Sabiñánigo
Ara River
Boltaña
Aínsa
Ayerbe
Gállego River
Huesca
Flumen River
Alcanadre River
Barbastro
Cinca River
Esera River
Graus
Benabarre
Isábena River
Arén
Noguera Ribagorzana
Noguera Pallaresa River
Monzón
Cinca R.
Esera R.
Gállego R.
Aragón River
Iberian Peninsula
Ebro Basin
Archaeological sites
Glaciolacustrine record
Monasteries
1.600-2.200 m
2.200- 3.404 m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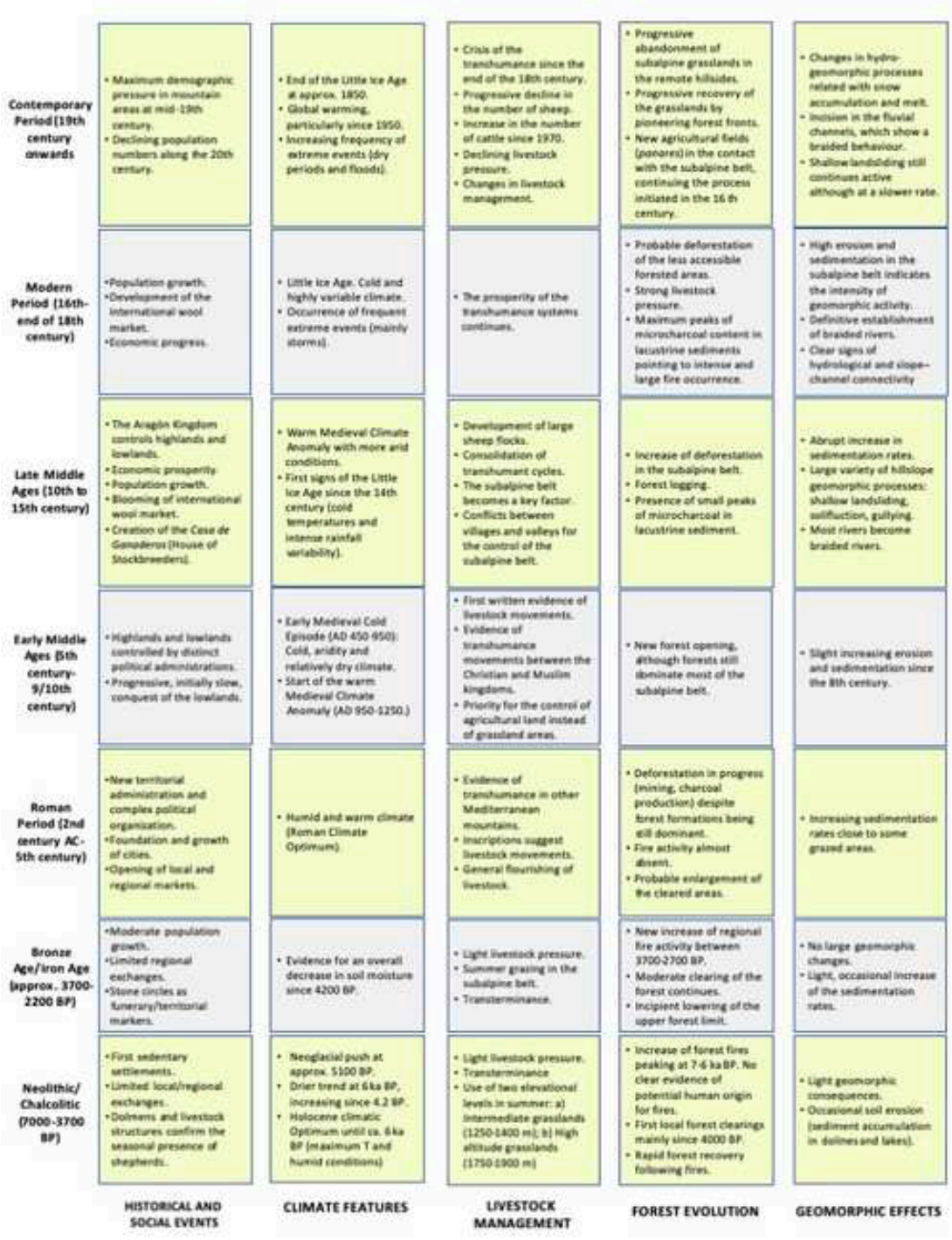
Contemporary Period (19th century onwards)
• Maximum demographic pressure in mountain areas at mid-19th century.
• Declining population numbers along the 20th century.
• End of the Little Ice Age at approx. 1850.
• Global warming, particularly since 1950.
• Increasing frequency of extreme events (dry periods and floods).
• Crisis of the transhumance since the end of the 18th century.
• Progressive decline in the number of sheep.
• Increase in the number of cattle since 1970.
• Declining livestock pressure.
• Changes in livestock management.
• Progressive abandonment of subalpine grasslands in the remote hillsides.
• Progressive recovery of the grasslands by pioneering forest fronts.
• New agricultural fields (panares) in the contact with the subalpine belt, continuing the process initiated in the 16 th century.
• Changes in hydro-geomorphic processes related with snow accumulation and melt.
• Incision in the fluvial channels, which show a braided behaviour.
• Shallow landsliding still continues active although at a slower rate.
Modern Period (16th-end of 18th century)
•Population growth.
•Development of the international wool market.
•Economic progress.
• Little Ice Age. Cold and highly variable climate.
• Occurrence of frequent extreme events (mainly storms).
• The prosperity of the transhumance systems continues.
• Probable deforestation of the less accessible forested areas.
• Strong livestock pressure.
• Maximum peaks of microcharcoal content in lacustrine sediments pointing to intense and large fire occurrence.
• High erosion and sedimentation in the subalpine belt indicates the intensity of geomorphic activity.
• Definitive establishment of braided rivers.
• Clear signs of hydrological and slope–channel connectivity
Late Middle Ages (10th to 15th century)
• The Aragón Kingdom controls highlands and lowlands.
• Economic prosperity
• Population growth.
• Blooming of international wool market.
• Creation of the Casa de Ganaderos (House of Stockbreeders).
• Warm Medieval Climate Anomaly with more arid conditions.
• First signs of the Little Ice Age since the 14th century (cold temperatures and intense rainfall variability).
• Development of large sheep flocks.
• Consolidation of transhumant cycles.
• The subalpine belt becomes a key factor.
• Conflicts between villages and valleys for the control of the subalpine belt.
• Increase of deforestation in the subalpine belt.
• Forest logging.
• Presence of small peaks of microcharcoal in lacustrine sediment.
• Abrupt increase in sedimentation rates.
• Large variety of hillslope geomorphic processes: shallow landsliding, solifluction, gullying.
• Most rivers become braided rivers.
Early Middle Ages (5th century-9/10th century)
• Highlands and lowlands controlled by distinct political administrations.
• Progressive, initially slow, conquest of the lowlands.
• Early Medieval Cold Episode (AD 450-950): Cold, aridity and relatively dry climate.
• Start of the warm Medieval Climate Anomaly (AD 950-1250.)
• First written evidence of livestock movements.
• Evidence of transhumance movements between the Christian and Muslim kingdoms.
• Priority for the control of agricultural land instead of grassland areas.
• New forest opening, although forests still dominate most of the subalpine belt.
• Slight increasing erosion and sedimentation since the 8th century.
Roman Period (2nd century AC-5th century)
•New territorial administration and complex political organization.
•Foundation and growth of cities.
•Opening of local and regional markets.
• Humid and warm climate (Roman Climate Optimum)
• Evidence of transhumance in other Mediterranean mountains.
• Inscriptions suggest livestock movements.
• General flourishing of livestock.
• Deforestation in progress (mining, charcoal production) despite forest formations being still dominant.
• Fire activity almost absent.
• Probable enlargement of the cleared areas.
• Increasing sedimentation rates close to some grazed areas.
Bronze Age/Iron Age (approx. 3700-2200 BP)
•Moderate population growth.
•Limited regional exchanges.
•Stone circles as funerary/territorial markers.
• Evidence for an overall decrease in soil moisture since 4200 BP.
• Light livestock pressure.
• Summer grazing in the subalpine belt.
• Transterminance.
• New increase of regional fire activity between 3700-2700 BP.
• Moderate clearing of the forest continues.
• Incipient lowering of the upper forest limit.
• No large geomorphic changes.
• Light, occasional increase of the sedimentation rates.
Neolithic/ Chalcolitic (7000-3700 BP)
•First sedentary settlements.
•Limited local/regional exchanges.
•Dolmens and livestock structures confirm the seasonal presence of shepherds.
• Neoglacial push at approx. 5100 BP.
• Drier trend at 6 ka BP, increasing since 4.2 BP.
• Holocene climatic Optimum until ca. 6 ka BP (maximum T and humid conditions)
• Light livestock pressure.
• Transterminance
• Use of two elevational levels in summer: a) intermediate grasslands (1250-1400 m); b) High altitude grasslands (1750-1900 m)
• Increase of forest fires peaking at 7-6 ka BP. No clear evidence of potential human origin for fires.
• First local forest clearings mainly since 4000 BP.
• Rapid forest recovery following fires.
• Light geomorphic consequences.
• Occasional soil erosion (sediment accumulation in dolines and lakes).
HISTORICAL AND SOCIAL EVENTS
CLIMATE FEATURES
LIVESTOCK MANAGEMENT
FOREST EVOLUTION
GEOMORPHIC EFFECTS