sustainability

Supplementary S1. Geographic and temporal sketch of the Pyrenees

The Pyrenees Mountains are aligned ca. 42-43º north latitude, and the border between France and Spain traces their axis along a distance of nearly 450 km from the Bay of Biscay on the Atlantic Ocean to the Cap de Creus peninsula on the Mediterranean Sea. The western Pyrenees bend west at the Bay of Biscay, pass through a low saddle then continue as the Cantabrian Mountain Range that span the northern edge of the Iberian Peninsula (Figure S1.1). The Pyrenees Mountains have a triangular cross-section with a maximum elevation ca. 3400 m asl at their approximate mid-point, while the eastern and western extremes are near sea level.

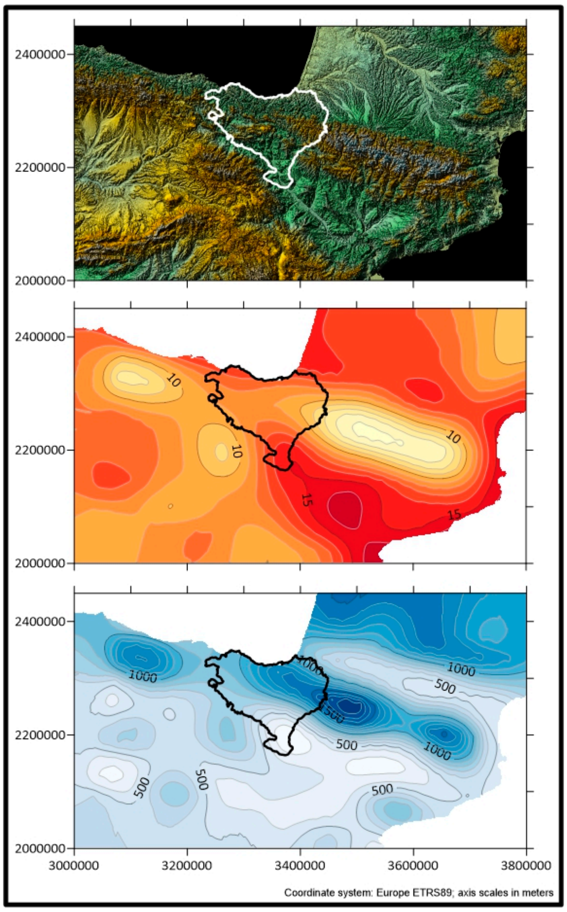

Figure S1.1: Relief, average temperature and average precipitation across the Pyrenees Mountains and surrounding area (Coordinate system: Europe ETRS89; scale in meters).

The Pyrenees Mountain range is highly sensitive to climatic and anthropogenic change with two aspects that make it both a barrier and a bridge across time in Europe. The western Pyrenees where the Soule Valley is located are centrally placed vis-à-vis three European glacial refugia to which biota including humans retreated during glacial advances then re-colonized the surrounding areas once conditions improved [1-4]. The western extent of the Würm glaciation in the Pyrenees Mountains impacted the upper reaches of the Soule Valley, bounded on the west by Pic d'Orhy (2017 m asl) and on the east by Pic d'Anie (2507 m asl). There were cirque glaciers on the peaks and plateau glaciers on the flanks [5,6], while the glacial equilibrium line was ca. 1400 m asl on the north slope and ca. 2000 m asl on the south slope. The ice depth was between 400 and 900 m and valley glaciers descended on the north slope into the Pau and Ossau valleys to ca. 400 m asl.

The western Pyrenees were weakly glaciated by comparison to the Central Pyrenees because of their lower elevations and the influence of Atlantic airmasses (Figure S1.2). The Soule Valley is centrally placed vis-à-vis three European glacial refugia to which biota including humans retreated during glacial advances then re-colonized the surrounding areas once conditions improved [1-4]. However, the archaeology of the western Pyrenees from the terminal Pleistocene through the early Holocene is fragmentary and while the number of archaeological sites reported in the mountains is small, recent literature suggests the bias may simply be a lack of systematic research [7,8].

Our periodization draws on several current sources including the work of the Integrating Ice Core, Marine and Terrestrial Records (INTIMATE) working group [9-11]. Numerical dating for the north slope (^{14}C, ^{10}Be) combined with geomorphic evidence indicating that the glaciers retreated to the upper reaches of the western Pyrenees by 30000-34000 cal BP, well in advance of the Last Glacial Maximum dated elsewhere ca. 21000 cal BP [6,8,12]. The early retreat of the glaciers in the western Pyrenees is attested at a series of stratified archaeological sites near Arundy in the lower Ossau Valley where occupation levels range between 20203 and 14285 cal BP [8,13]. This indicates that the piedmont zones up to an elevation of ca. 500 m asl were clear of glacial ice by ca. 20000 cal BP. The Arundy site complex helps resolve the chronology of glacial retreat for the north slope while also suggesting that the interpretation of the western Pyrenees as an 'uninhabitable desert' during the Last Glacial Maximum most likely results from an absence of systematic research. Recently reported stratified cave sites in the Soule Valley help confirm the early glacial retreat and add support to the idea that more systematic archaeological research is needed to address the habitability question. The site of Harregi at 211 m asl contains Last Glacial Maximum levels that date between 17431-16312 cal BP. (An older level ca. 30000 cal BP was also reported, but it has problems in stratigraphy and dating.) The site of Etxeberri at 440 m asl dates to between 16920-15865 cal BP [14].

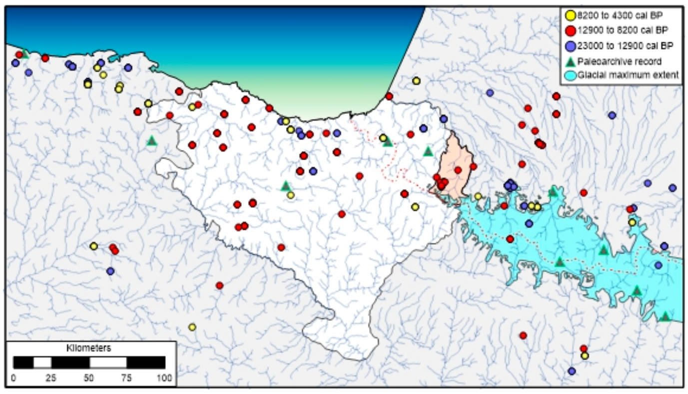

Figure S1.2: Distribution of key paleoarchives for the western Pyrenees-Cantabrian mountain belt and dated archaeological sites by major periods from the LGM through the Middle Holocene. Our distribution of archaeological sites subsets a European compilation for the Pleistocene [15] and supplements it with recent findings for the Holocene [13,16,17].

There are currently no known archaeological sites in the Soule Valley between ca.14700 cal BP and 9700 cal BP although hunter-gatherer populations residing in the low and mid-elevation zones including the upper Ebro Basin most likely used the uplands intermittently depending on weather conditions. The colder, drier conditions of the Middle Holocene (8200 to 4200 cal BP) are correlated with increasing evidence for human activities across the western Pyrenees to ca. 1000 m between ca. 6500-5300 cal BP. The process is marked by a decrease in pines and birch and an increase in ash, grasses, and cereal-type pollen, as well as an increase in nitrophilous and anthropozoogenous taxa indicating the presence of livestock [16,18,19]. Archaeological evidence for the first Neolithic groups in Iberia appears on the coast of Catalonia between 7650 and 7600 cal BP [20]. Neolithic markers including pollen, charred seeds and domestic animal bones appear at the site of Peña Larga ca. 7500 cal BP in the extreme southern reach of Euskal Herria [7,17].

These markers appear soon after in the Pyrenees foothills below 280 m asl in open-air village sites such as Aizpea (7425-7170 cal BP) and Marizulio (7483-7172 cal BP), while cereal pollen has been recovered from numerous archaeological sites across the Cantabrian Range dated between 7000 and 5800 cal BP [21]. A domestic cattle bone was recovered at the cave site of Arenaza from a layer dated 7157-6407 cal BP. Highland colluvial sedimentary records in Soule indicate an increase in fires and sedimentation rates ca. 6000-5000 cal BP attributable to late Neolithic conversion of forests to pastures [22], and evidence of human-triggered erosion in the sediment records from secondary valleys in the upper Ebro Basin ca. 6500 cal BP [17]. The trend nevertheless reverses across the region ca. 5200-4000 cal BP. There is an increase in deciduous tree pollen suggesting forest recovery, and the near disappearance of nitrophilous pollen and anthropozoogenous taxa, cultivated plants and CHAR as indicated by the archives at Arbarrain bog [16].

Southern Europe during the late Holocene (4200 BP to ca. AD 1950) is characterized by an aridity trend that is more pronounced in the Mediterranean than in the Atlantic region [17,23-25]. The expansion of beech in the western Pyrenees during this period peaks ca. 2900 ca BP and is assumed to be causally linked to increased anthropic pressures [16,26-29]. Cereal pollen and herbaceous taxa typical of pastures, as well as the ascospores of coprophilous fungi indicative of livestock are present in high levels from regional palynological records [i.e., Sotombo, Arbarrain and Zalama 16,27] as well from cores obtained above 1000 m asl within or close to the Soule Valley [i.e., Artxilondo, Occabe 30,31]. There is also evidence for intense iron metallurgy ca. 2000 cal BP [i.e. Quinto Real 32].

Landscape transformation in Soule intensified again ca. 800 cal BP in conjunction with the expansion of the secular and religious nobilities in Spain and France [7,33]. Mountain spaces were a key asset during the High Middle Ages, and the peasantry articulated humans and landscapes from valleys to mountains. The intensification of livestock activity is evidenced by the formation of 'aldeas' (hamlets/towns) in the valleys and 'majadas' (livestock pens and associated features) in the mountains. Aldeas become relatively dense in the western Pyrenees by the 8th century [7,33,34]. The majada de Arrubi in the Sierra de Aralar is occupied from the 6/7th century and by the 8th/9th century there were at least half a dozen additional majadas in the area. Pastoral intensification is further evidenced in zooarchaeological remains [35,36].

Recent research suggests the intensification of pastoral activities may go back to Antiquity in the western Pyrenees. In Argarbi (Gipuzkoa) two cabins were identified at >800 m asl with a late-Roman chronology, which have been interpreted as seasonal livestock cabins [37]. Comparable sites of an equivalent age have been found on the north slope [38]. The close proximity of major ecotonal differences has made the western Pyrenees and the Soule Valley useful and desirable for satisfying diverse human land needs across the Holocene.

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