Laura Obea Gómez*, Ermengol Gassiot Ballbè*, Raquel Piqué Huerta*, Maria Martín Seijó*, Oriol López Bultó*

* Department de Prehistòria, Universitat Autònoma de Barcelona.

KEEPING THE FIRE ALIVE: A REGIONAL AND DIACHRONIC STUDY OF FIREWOOD COLLECTION IN THE SOUTH CENTRAL PYRENEES

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Abstract: A research developed over the last 25 years in different high mountain areas of the Pyrenees has confirmed continuous human occupation of these areas over time. Of the various economic activities carried out in these areas, livestock farming is particularly notable. Thanks to extensive excavations, the daily activities that sustained and promoted the well-being of the area's inhabitants are increasingly well documented. Notably, the collection and use of fuel for households sheds light on the relationships that societies established with their environment. In this diachronic, regional-scope study, we have unified all available anthracological records for dwelling sites in the southern Central Pyrenees dating from the 9th millennium BCE in a single database. A total of 34 taxa have been identified, although only a few were probably used as the main fuel. Changes and continuities detected over time are related to both the altitude of the site and the historical dynamics of land use in the area.

Keywords: anthracology, Central Pyrenees, firewood, maintenance activities, landscape management.

1. Introduction and objectives

Until the early 2000s, archaeological research on the southern slopes of the Pyrenean range was discontinuous and focused primarily on medieval occupation in valley bottoms. From 2000 onwards, several research groups began to investigate higher-altitude zones, documenting a wide range of human activities through time (Clemente Conte et al., 2020; Colominas Barberà et al., 2022; Gassiot Ballbè, 2016; Orengo et al., 2014; Palet Martínez et al., 2017; Rendu, 2003). The implementation of extensive radiocarbon dating programmes has since made it possible to define broad

patterns of upland occupation, demonstrating that mountain environments were not marginal to past societies.

Evidence from identified structures indicates that livestock herding was the predominant economic activity across the different altitudinal zones of the Pyrenees. The presence of hut clusters, enclosures of varying sizes, and facilities for counting and milking animals further suggests that pastoral practices varied through time (Garcia Casas, 2018; Garcia Casas & Gassiot Ballbè, 2022; Orengo Romeu, 2010; Rendu, 2003). At the same time, the identification of hunting camps, mining sites, ovens, and charcoal kilns highlights the exploitation of mountain environments for hunting and for the extraction and processing of resources such as iron, pitch, and wood.

Recent excavations have also begun to reveal everyday or maintenance activities, which are fundamental to group subsistence and well-being (González Marcén & Picazo Gurina, 2005). These encompass food preparation and consumption, spatial organisation and cleaning, and the production and maintenance of fire, as documented through anthracological remains (Dufraisse, 2012; Martín Seijo, 2013; Picornell Gelabert, 2012; Piqué i Huerta, 1999). The present study focuses on this latter activity – specifically, the procurement and use of fuelwood – given the abundance and ubiquity of charcoal remains in the archaeological record.

Anthracological research in the Pyrenees has developed unevenly, closely mirroring the trajectory of archaeological investigation in the region. The earliest analyses, conducted in the late 1980s and early 1990s, derive from excavations in Andorra (Heinz & Vernet, 1995; Llovera Massana, 1986; Llovera Massana et al., 1997). Since the 1990s, archaeobotanical studies have become a regular component of fieldwork in Andorra, including preventive archaeology (Alonso et al., 2010; Piqué i Huerta, 2021; Piqué, 2015). Elsewhere in the mountain range, however, research has often prioritised the restoration of heritage elements – mainly of medieval and early modern date – delaying the systematic integration of anthracological analyses until the development of high-altitude research projects (Gassiot Ballbè, 2016; Palet et al., 2014; Palet Martínez et al., 2017). These projects marked a turning point, leading to dedicated anthracological studies and highlighting their interpretative potential at both site (Celma, 2009; Obea Gómez et al., 2021) and regional scales (Euba Rementeria, 2009).

Although still fragmentary, the recovery and analysis of archaeobotanical remains have expanded significantly in recent decades, substantially increasing the available dataset (Obea Gómez, 2024), even if some reports remain unpublished (López Bultó, 2021; Martín Seijo, 2005; Piqué i Huerta, 2011).

With the aim of undertaking a regional and diachronic analysis, we compiled available anthracological data from the Iberian side of the Central Pyrenees and standardised them within a single database. This approach enables the comparison and correlation of different records. The main research questions address taxonomic representation, source biotopes, and the variables influencing assemblage composition. Ultimately, the objective is to better understand the relationships between human societies and their environments from the Mesolithic to the Early Middle Ages.

This paper also presents the database and makes it available to the research community, with the expectation that it will be expanded and refined as research progresses

in the Pyrenees. At present, it includes a selection of contexts that meet the project's geographical, chronological, and analytical criteria.

2. Materials and methods

The dataset primarily comprises domestic contexts identified through excavation or survey and supported by radiocarbon dating (**tab. 1**). Priority was given to assemblages derived from everyday fuel use. Consequently, contexts associated with charcoal production – such as iron-smelting furnaces and charcoal kilns – were excluded, despite their prominence in previous studies from the axial Pyrenees (Augé et al., 2012; Celma, 2009; Euba Rementeria, 2009; Pèlachs Mañosa, 2004). Funerary contexts were also excluded (Llovera Massana, 1986).

To ensure comparability, the dataset was organised chronologically, treating each occupation phase at a given site as the minimum analytical unit. This approach accommodates differences in the resolution of published data while simplifying certain aspects explored in previous studies, particularly intra-site variability between stratigraphic units (Piqué i Huerta, 2021; Piqué i Huerta et al., 2015) and specialised analyses such as wood anatomical anomalies (Celma, 2008). Future iterations of the database aim to incorporate this level of detail.

For each occupation phase, three main categories of data were recorded: geographical variables (including UTM coordinates, altitude, slope orientation, and estimated catchment area), archaeological data (radiocarbon dates, cultural attribution, and type of intervention), and anthracological variables (fragment counts by taxon, taxonomic richness, and diversity indices).

To explore fuel procurement strategies, a potential wood-supply catchment area was estimated for each site using a travel-time threshold. This catchment represents the area that could plausibly be accessed for wood collection and transport under a cost-distance model based on topography. The procedure involved: (1) preparing a topographic base using the Copernicus DEM (30 m resolution); (2) modelling travel time as a function of slope using Tobler's (1993) hiking function, with slopes >67° treated as impassable and water bodies assigned higher movement costs; and (3) defining a maximum travel time of 60 minutes, based on ethnoarchaeological and palaeoecological studies of mobility in agro-pastoral societies (e.g. Davidson & Bailey, 1984; Vita-Finzi et al., 1970; Dufraisse et al., 2007; Henry et al., 2018; Picornell Gelabert, 2018, 2020; Piqué et al., 2016). The model was implemented as a return-to-site cost surface, reflecting the transport of fuelwood back to settlements.

3. Results

The database encompasses 77 occupations spanning from the 9th millennium BCE to the 13th-14th centuries CE, identified across 39 archaeological sites situated between the Enveig mountain and the Goriz valley, at elevations ranging from 893 to 2,514 m a.s.l. (**fig. 1**). This long temporal sequence provides a robust basis for

Site	Code	Altitud (m asl)	Type of intervention	Ph.	Year of intervention	Analyst
Granja Parramon	Peramea	893,41	Preventive excavation	1	1999	Martin inèdit
Camp Vermell	CVJ	930,87	Preventive excavation	3	2007	Alonso et al 2010
Balma Margineda	B. Marg	948,30	Partial extensive excavation	3	1979-1991	Heinz 1990 Heinz i Vernet in Guilaine i Martzluff 1995
Escola Meritxell	EMA	986,82	Preventive excavation	1	2009	Piqué inèdit
Roureda de la Margineda	RMA	994,51	Extensive excavation	2	2007 i 2013	Obea 2024
Castellot de Bolvir	BEC	1.135,37	Extensive excavation	3	2006-currently	Obea 2024
Tossal de Baltarga	BTB	1.161,31	Extensive excavation	2	2011-2023	Obea 2024
Roc d'Enclar	REA	1.171,58	Extensive excavation	1	1979-1993	Llovera et al 1997
Camp del Colomer	CCJ	1.294,67	Partial extensive excavation	1	2009-2011	Piqué 2016 Piqué in Fortó i Vidal 2021
M22	M22	1.335,43	Survey pit (big)	1	2010	Piqué inèdit
Coro Trasito	CT	1.561,22	Survey pit (big)	4	2013	Obea 2024
Despoblat de Santa Creu de Llagunes	SCLl	1.606,13	Extensive excavation	1	1993-1997	Obea 2024
Cova del Sardo	VB-014	1.788,47	Extensive excavation	5	2006-2008	Obea et al. 2021 Obea 2024
Pletiu deth Pòrt de Caldes II	NA-026	2217,41	Survey pit (small)	1	2010	Obea 2024
Dolmen de la Font dels Coms	LL-007	1.849,08	Extensive excavation	1	2003-2004	Celma 2009
Orri d'en Corbill 83	Corbill 83	1.919,65	Extensive excavation	1	1992-1994	Davasse in Rendu 2003
Orri d'en Corbill 82	Corbill 82	1.939,77	Extensive excavation	4	1992-1994	Davasse in Rendu 2003
Orri d'en Corbill 85.1	Corbill 85.1	1.950,90	Extensive excavation	1	1992-1994	Davasse in Rendu 2003
Bony del Graller	VB-001A	1.982,96	Survey pit (small)	1	2011	Obea 2024
El Goleró	Goleró	2.023,32	Survey pit (small)	4	2004-2006	Euba 2009
Pradell	Pradell	2.025,00	Survey pit (small)	1	2004-2006	Euba 2009
FL-031_C1	FL-031	2.113,29	Survey pit (small)	1	2016	Obea 2024
Despoblat de la Cova	VB-017sup	2.134,80	Survey pit (big)	1	2012	Obea 2024
FL-009	FL-009	2.160,44	Survey pit (big)	3	2016	Obea 2024
Costa de la Coma 2	LCO14	2.212,32	Survey pit (big)	3	2014	Obea 2024
Despoblat de Casesnoves	VB-019	2.216,31	Survey pit (big)	1	2011	Obea 2024
Maurà 22	Maurà 22	2.231,59	Extensive excavation	1	1992-1994	Davasse in Rendu 2003
Pleta d'Erdo	VB-085	2.259,51	Survey pit (small)	1	2011	Obea 2024
Conjunt de l'Estany Gran Primer	AND_OR_001	2.270,36	Survey pit (small)	1	2016	Obea 2024
Orris de Setut III	O. Setut III	2.300,43	Survey pit (big)	2	2004-2006	Euba 2009
Abric de les Obagues de Ratera	ESP-018	2.304,47	Extensive excavation	7	2015-2017	Obea 2024
Basses de Setut III	B. Setut III	2.311,93	Survey pit (big)	1	2004-2006	Euba 2009
Serrat de la Padrilla	Padrilla	2.315,56	Extensive excavation	2	1992-1994	Davasse in Rendu 2003
FL-008 Abric	FL-008	2.338,38	Survey pit (small)	1	2016	Obea 2024
Lac Tort de Rius	NA-090	2.361,38	Survey pit (small)	1	2012	Obea 2024
Abric del Lac Major de Saboredo II	AA-067	2.365,94	Survey pit (small)	2	2010	Obea 2024
Tuc deth Lac Redon	NA-084	2.424,74	Survey pit (small)	1	2010	Obea 2024
Abric de l'Estany de la Coveta I	ESP-008	2.454,13	Extensive excavation	2	2008	Mireia Celma in Obea et al 2021
Pleta de les Bacives	P. Bacives	2.514,36	Survey pit (big)	4	2004-2006	Euba 2009

tab. 1. Sites included in the database, ordered by altitude. The table specifies the type of intervention conducted, the number of occupations recorded at each site, the years of intervention, and the authors of the anthracological studies.

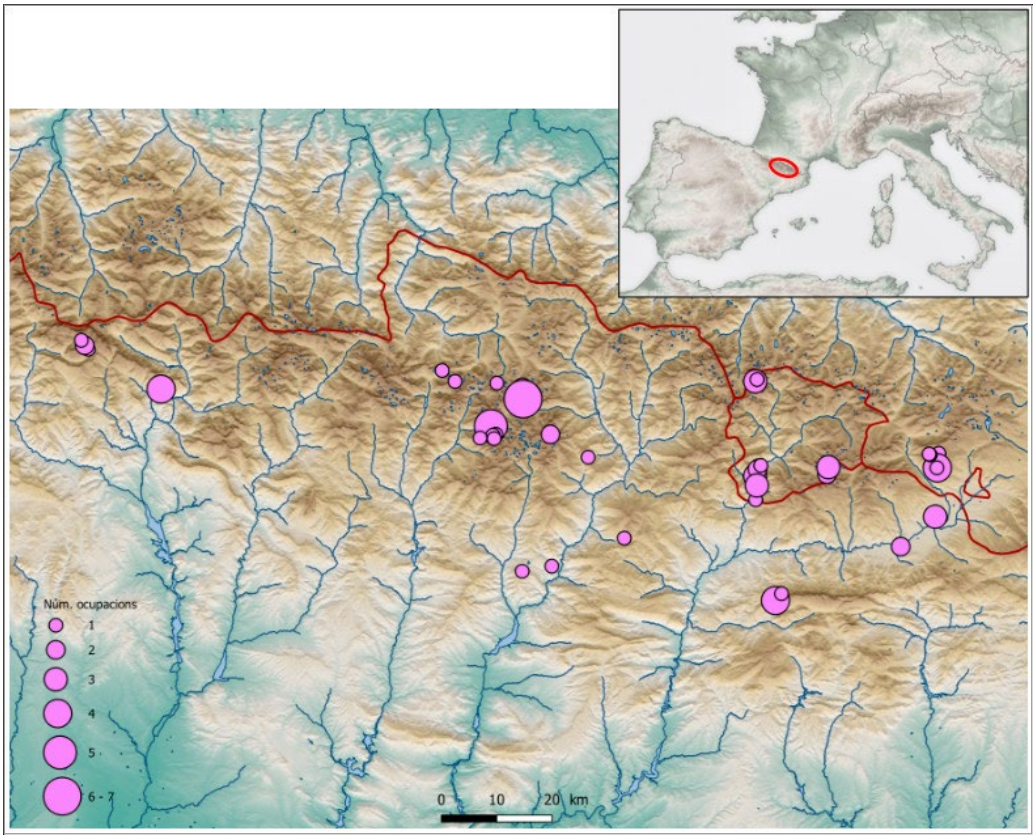

fig. 1. Map showing the location of each site. Circle size indicates the number of phases identified at each site. Areas with the highest site density correspond to regions where systematic field survey projects have been conducted.

	Phase		Chronology
1	Mesolithic	Meso	8600 – 5600 cal BCE
2	Neolithic I	Neo I	5600 – 3500 cal BCE
3	Neolithic II	Neo II	3500 – 2350 cal BCE
4	Bronze-Iron I	Bro-Iron I	2350 – 500 cal BCE
5	Iron II	Iron II	500 - 200/100 cal BCE
6	Roman domain	Rom	100 cal BCE - 250 cal CE
7	Late antiquity	Late ant.	250 – 800 cal CE
8	High Middle Age	HMA	800 – 1300 cal CE

tab. 2. Historical periods used to group the settlements, together with their corresponding chronological ranges. The labels used in the graphs are also indicated.

diachronic analysis. To facilitate historical contextualization, the occupations have been grouped into eight chronological phases (**tab. 2**).

Of the total occupations, 34 derive from stratigraphic surveys, while 43 originate from preventive and extensive excavations. The settlements include permanent sites, likely occupied year-round by part of the community; seasonal settlements, used during specific periods (primarily the warmer months); and short-term sites, occupied for durations ranging from a few days to several weeks.

Settlement areas vary in size, from 5,353.56 m² at Castellot de Bolvir to 1,306.75 m² at Despoblat de Casanoves. Generally, larger settlements are located in wide valleys or high-altitude zones with gentle topography, whereas sites in more rugged terrain tend to exhibit smaller areas of influence. Nonetheless, most catchment areas, regardless of size, span altitudinal ranges between 900 and 1,300 m. Exceptions (500-800 m) correspond to settlements in low-lying expanses and the Pleta de les Bacives site, situated at the highest altitude.

A total of 13,191 charcoal fragments were analysed, of which 12,820 (97.19%) were taxonomically identified. Sample sizes per occupation vary from a single fragment to 1,025 fragments. 34 taxa, representing at least 34 tree and shrub species characteristic of mid- and high-mountain environments, were identified. Mountain pine (*Pinus* tp. *sylvestris*) dominates the assemblage (65.55%), followed by deciduous *Quercus* (9.70%). The remaining taxa occur in significantly lower proportions, suggesting a more selective or context-dependent use. These include juniper (*Juniperus* sp.), yew (*Taxus baccata*), evergreen *Quercus*, silver fir (*Abies alba*), boxwood (*Buxus sempervirens*), Maloideae (Rosaceae/Maloideae), poplar/willow (*Populus* sp./*Salix* sp.), hazel (*Corylus avellana*), birch (*Betula* sp.), ash (*Fraxinus* sp.), beech (*Fagus* sp.), maple (*Acer* sp.), walnut (*Juglans regia*), and Fabaceae/Leguminosae.

4. Discussion

4.1 Spatial and chronological distribution

The spatial distribution of occupation records remains uneven, largely reflecting differences in research intensity (**fig. 2**). Areas subject to systematic survey like the Enveig mountain, the Madriu-Perafita-Claror valley (MPC), and the PNAESM (e.g., Gassiot Ballbè, 2016; Gassiot Ballbè et al., 2016; Orengo Romeu, 2010; Rendu, 2003) display higher densities of recorded sites, while less-studied regions remain under-represented. Despite these biases, the dataset provides sufficiently broad geographical coverage, with current gaps likely to be addressed through future research.

Chronological differences in occupation counts per phase (**fig. 2**) reflect both the history of research and broader settlement dynamics. For example, during the Late Bronze Age (phase Bronze-Iron I), settlement appears concentrated in valley bottoms, coinciding with the abandonment of higher-altitude sites (Oller Guzmán et al., 2018).

Given the prominence of stratigraphic survey contexts in this study (34 out of 77 occupations), their representativeness for regional analysis was assessed. Although such samples present certain limitations, they may be considered suitable for regional and diachronic analyses provided that at least 50 fragments per phase are analysed (see Euba Rementeria, 2009). While variation in sample size may influence the number of taxa identified, altitude also emerges as a key factor, as the richest assemblages tend to correspond to lower-altitude contexts (**fig. 3**).

Across the dataset, taxonomic richness is influenced by multiple factors, among which altitude emerges as particularly significant (**fig. 4b**). Higher-altitude occupations tend to show lower richness and diversity, while sample size exerts a weaker but still

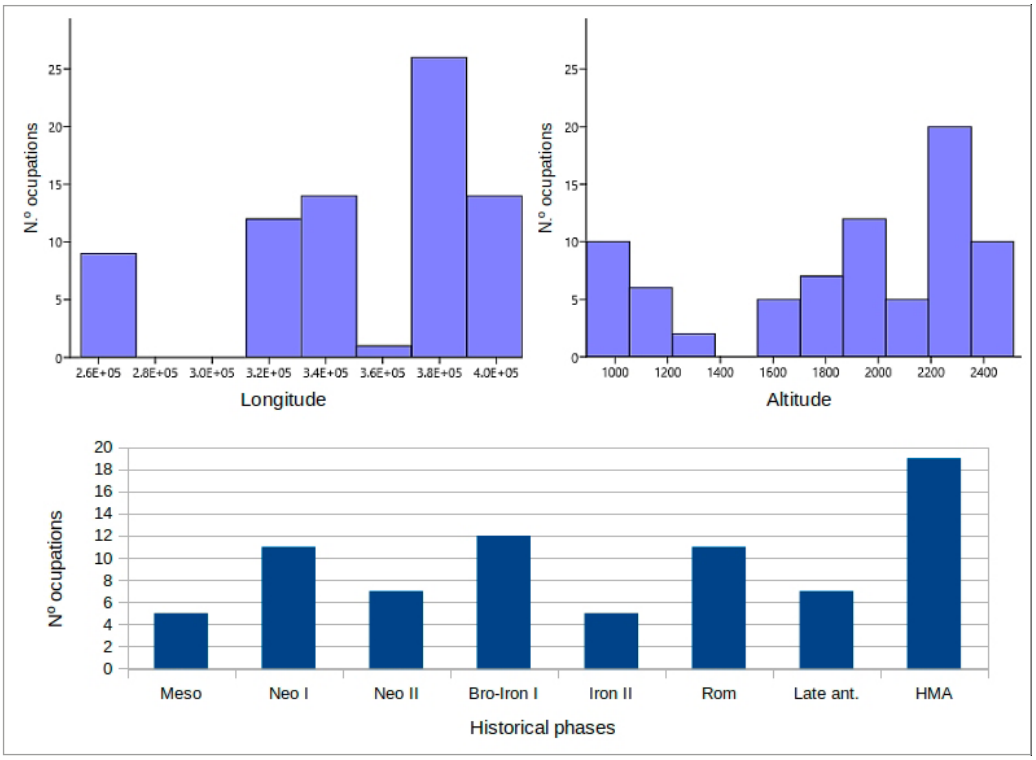

fig. 2. Histograms showing the longitudinal, altitudinal (top), and chronological (bottom) distribution of all occupations. Gaps correspond to areas that have been little or not studied. Longitudinal gaps match those shown in Figure 1. Altitudinal gaps reflect the lower limit of survey work, which was conducted mainly in subalpine environments with sparse tree cover. Three groups are identified and subsequently used to structure the diachronic analysis of firewood use presented in **fig. 6**.

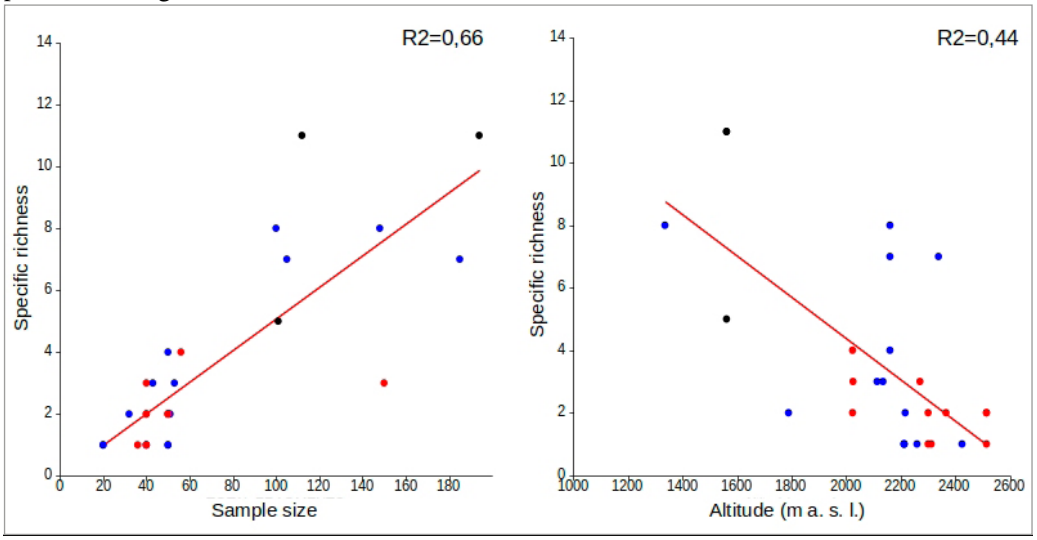

fig.3. Correlation between sample size and number of taxa identified (left), and between taxonomic richness and altitude (right), based on samples recovered from survey pits. The R^2 value corresponds to the coefficient of determination; higher values indicate stronger correlations. In both graphs, the R2 value shows a moderate correlation.

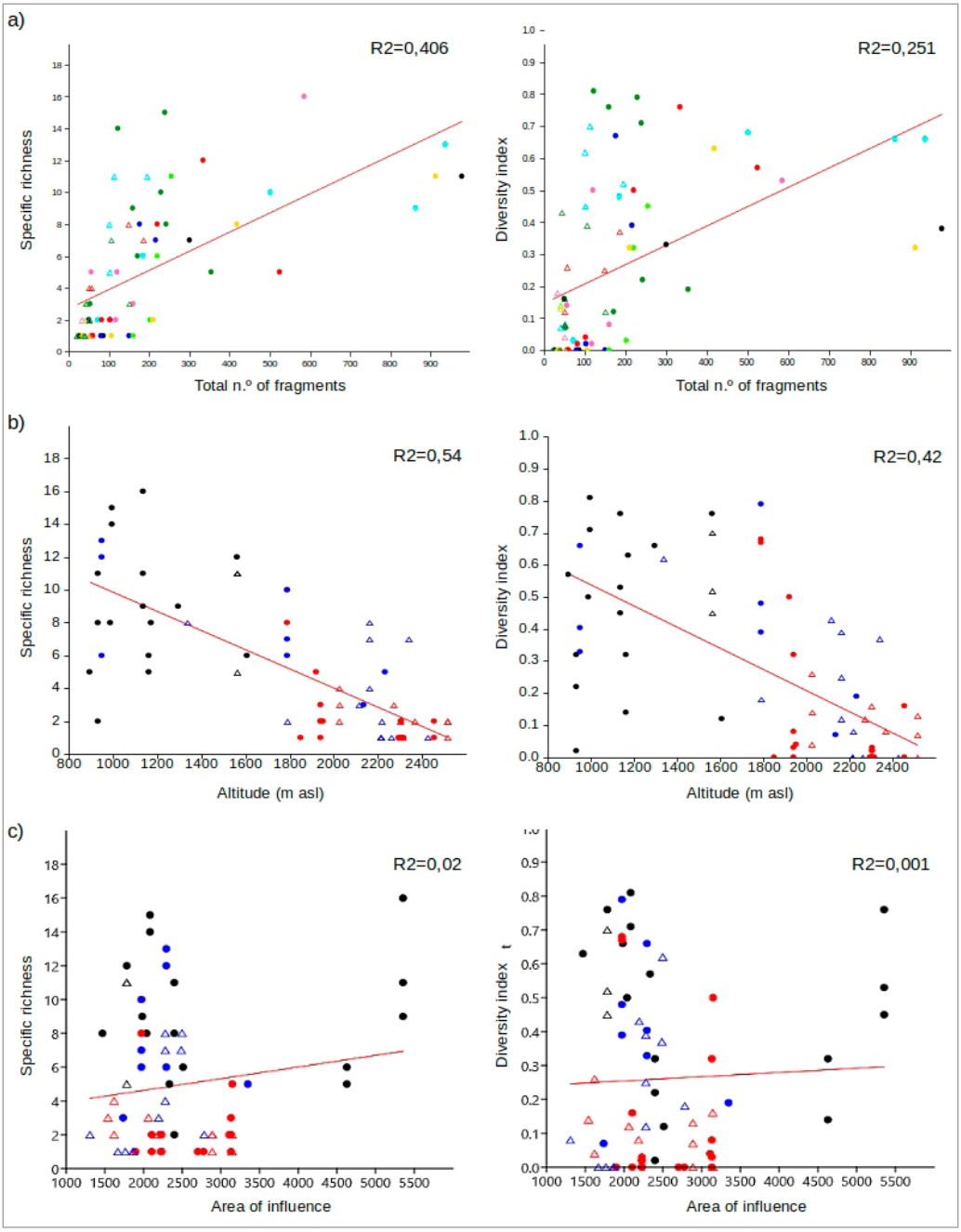

fig.4. Correlation graphs exploring variables potentially influencing specific richness (left) and the diversity index (right): (a) sample size; (b) altitude of the occupation; and (c) size of the catchment area. The R^2 value corresponds to the coefficient of determination; higher values indicate stronger correlations. Overall, R^2 values indicate weak to moderate correlations, with altitude showing the strongest relationship.

noticeable effect (**fig. 4a**). Deviations from these trends suggest additional influences, including resource availability and selective procurement practices. Catchment area size, however, shows no clear correlation with richness (**fig. 4c**), indicating that further GIS-based exploration is warranted.

4.2 Plant formations and wood used

The 34 identified taxa represent at least 34 tree and shrub species currently distributed between 600 and 2,700 m a.s.l. Most belong to supra-Mediterranean and montane plant formations, corresponding today to oak forest climax communities with a boxwood understory (Buxo sempervirentis-Quercetum pubescentis) (Ninot et al., 2017). In more arid or seasonal areas, meso-Mediterranean taxa such as holm oak (*Quercus* sp. evergreen) appear, reaching altitudes up to 1,600 m a.s.l. Conversely, temperate taxa like yew (*Taxus baccata*), beech (*Fagus sylvatica*), and silver fir (*Abies alba*) occur in more humid zones.

Subalpine species associated with black pine (*Pinus uncinata*) forests and rhododendron undergrowth (*Rhododendron ferrugineum*) are found in acidic soils with persistent snow cover Rhododendro ferruginei-Pinetum uncinatae, whereas limestone or irregularly snow-covered areas feature black pine undergrowth dominated by juniper (*Juniperus communis* ssp. *nana*), bearberry (*Arctostaphylos uva-ursi*), and Pyrenean broom (*Cytisus oromediterraneus*) (Arctostaphylo uva-ursi-Pinetum uncinatae) (Folch i Guillén, 1986; Ninot et al., 2017; Vigo i Bonada, 2008).

Only 10 taxa exceed 1% of the total assemblage (**fig. 5**), indicating recurrent use of a limited set of locally available woody species. *Pinus* tp. *sylvestris* occurs in all occupations (65.54%). Deciduous oak and Maloideae are next most frequent, with high proportions in specific occupations. Juniper, silver fir, boxwood, evergreen oak, and poplar/willow show similar patterns. Hazel, maple, birch, ash, and prunoids occur in 15-26% of occupations, suggesting their repeated exploitation as fuel (Piqué i Huerta, 1999; Vila Moreiras, 2018).

On this basis, the identified taxa can be classified into three groups: (1) abundant and recurrent (2) scarce but recurrent, and (3) scarce and infrequent. The first group is interpreted as representing primary fuel, the second as complementary fuel, and the third as sporadic fuel. However, in the latter case, it is not always possible to confirm intentional use as firewood, as their presence may also derive from the disposal of by-products from other activities, such as woodworking or the burning of woody residues resulting from the use of trees and shrubs as fodder (Delhon et al., 2008; Martín Seijo, 2013).

4.3 Changes and continuities in wood use

The anthracological diagrams based on taxonomic percentages enable a diachronic analysis of fuel use (**fig. 6**). Given the influence of altitude on the composition of anthracological assemblages, separate diagrams were constructed for each of the altitudinal zones defined in **fig. 2**. A primary observation is the contrasting behaviour between occupations located above 2000 m a.s.l. and those situated at lower altitudes. In the former, mountain pine remains the dominant taxon throughout all phases,

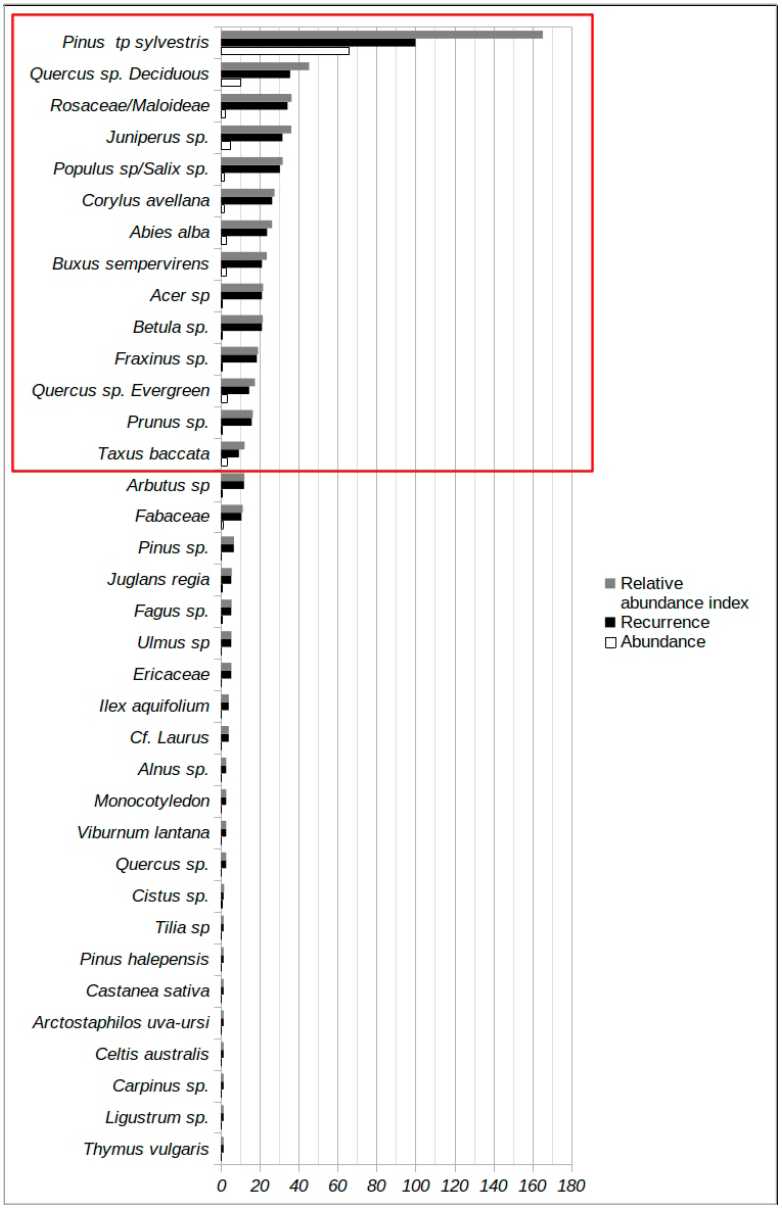

fig. 5. Graph showing the abundance and recurrence of identified taxa. The relative abundance index is calculated by summing the percentages of both variables. This index integrates abundance and recurrence to assess the economic importance of taxa: those within the box are classified as primary and/or supplementary fuels, whereas those outside are considered sporadic or incidental.

whereas in the altimontane and montane zones, temporal shifts in fuel selection are evident. The most significant changes occur at the end of the Mesolithic (7th-6th millennium cal BCE), at the onset of the Second Iron Age (c. 800 cal BCE), and at the beginning of the High Middle Ages (9th-10th centuries cal CE).

During the Mesolithic, conifers likely predominated due to environmental availability. Deciduous taxa such as oak and hazel expanded during the Middle Holocene, peaking in the 7th-6th millennium cal BCE (Garcés-Pastor et al., 2017; Miras et al., 2007; Pérez-Obiol et al., 2012; Pla & Catalan, 2005). Opportunistic use of deadwood

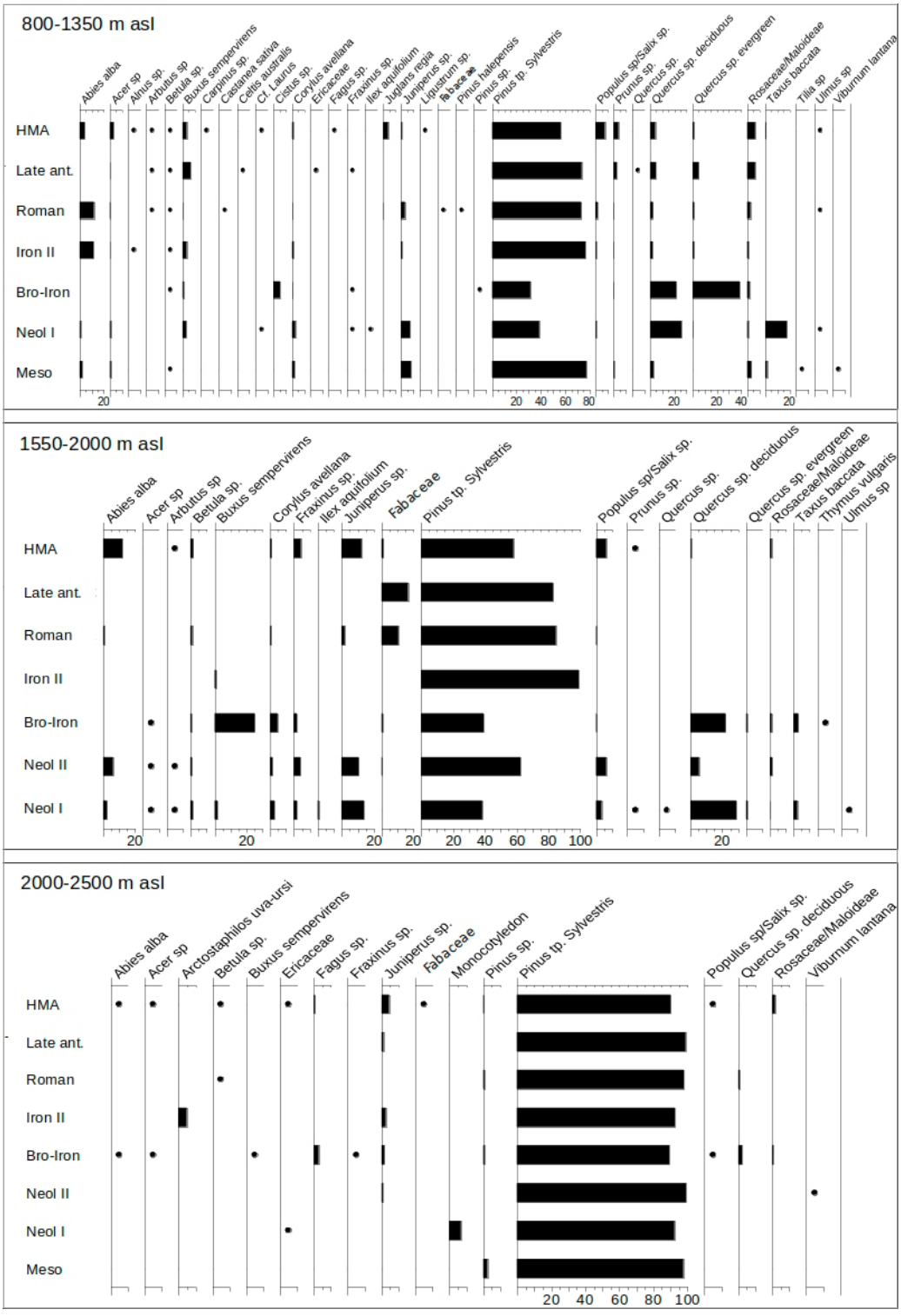

fig. 6. Anthracological diagrams showing taxa percentages for each historical phase. Taxa represented by less than 5% are recorded only by presence (dot). As altitude is considered a relevant variable influencing taxonomic composition, and may affect diachronic interpretation, the groups defined in the altitudinal histogram (**fig. 2**) have been taken into account.

may also explain the high pine proportions, as pine is prone to natural pruning (Alcolea, 2017; Allué, 2002).

From the 6th-5th millennium cal BCE to the 1st millennium cal BCE (Neolithic I, Neolithic II, Bronze-Iron phases), mountain pine decreases at sites below 2,000 m a.s.l., replaced by supra-Mediterranean and montane taxa (oak, boxwood, yew, fir, hazel, riparian species) and, at lower elevations, holm oak. Presence of birch, Fabaceae, and juniper suggests fuel collection in open or degraded forests, locally confined, as reflected in pollen records only from the 2nd millennium cal BCE (Catalan et al., 2013; Cunill Artigas, 2010; Ejarque et al., 2010; Galop, 1998; Pèlachs Mañosa, 2004; Rendu, 2003; Revelles et al., 2022; Rodríguez Antón et al., 2016).

Climatic changes – specifically increased aridity and reduced continentality – combined with a degree of anthropogenic intensification, may have influenced forest succession dynamics, favouring the expansion of boxwood and secondary pine forests in the supra-Mediterranean and montane belts (Allué et al., 2013; Mas & Allué Martí, 2020; Piqué et al., 2018, 2022). From the 5th century BCE onwards, this may have facilitated the dominance of *Pinus* tp. *sylvestris* as fuel across altitudinal zones. However, below 2000 m a.s.l., particularly in the 1550-2000 m band, its frequency begins to decline from the Roman/Late Antique periods onwards, with a more pronounced decrease during the High Middle Ages. This trend is accompanied by a marked reduction in oak, particularly between 1550 and 2000 m a.s.l., reflecting the expansion of secondary pine forests as a primary fuel source. Although similar oak replacement dynamics have been documented elsewhere in the north-eastern Iberian Peninsula (Allué et al., 2017), suggesting a broader regional trend, caution is warranted, as local variability is evident in sites such as Cova Colomera, where fuel use remains relatively stable over time (Mas et al., 2022).

During the High Middle Ages (9th-14th centuries CE), the decline of *Pinus* tp. *sylvestris* becomes more pronounced below 2000 m a.s.l., particularly in the 1550-2000 m band (and also between 800-1350 m), whereas higher-altitude occupations remain largely pine-dominated. Concurrently, taxa such as *Populus* sp./*Salix* sp., prunoids, Maloideae, walnut, and maple increase in frequency between 800 and 1350 m a.s.l., while *Populus* sp./*Salix* sp., ash, juniper, and silver fir become more prominent between 1550 and 2000 m a.s.l. These taxa, previously considered complementary or sporadic fuels, gain importance alongside cultivated species.

At the same time, pollen records indicate a significant reduction in arboreal cover and an increase in indicators of livestock and agricultural activity (Catalan et al., 2013; Ejarque et al., 2010; Galop, 1998; Garcés-Pastor et al., 2017; González-Sampériz et al., 2017; Leunda et al., 2017; Miras et al., 2007; Pèlachs Mañosa et al., 2007, 2010; Pérez-Obiol et al., 2012; Rull et al., 2021). These patterns may reflect changes in fuel procurement strategies driven by increased pressure on forest resources, leading to the exploitation of previously underused environments – such as riparian zones – and the incorporation of by-products from arboricultural practices, as well as a potential expansion of wood catchment areas (Vila Moreiras & Piqué Huerta, 2012).

In contrast, above 2,000 m a.s.l., *Pinus* tp. *sylvestris* remains dominant, with slight increases in juniper and Maloideae. Pastoral intensification likely shifted upper forest limits, expanding rhododendron and juniper heaths (Folch i Guillén, 1986; Ninot et

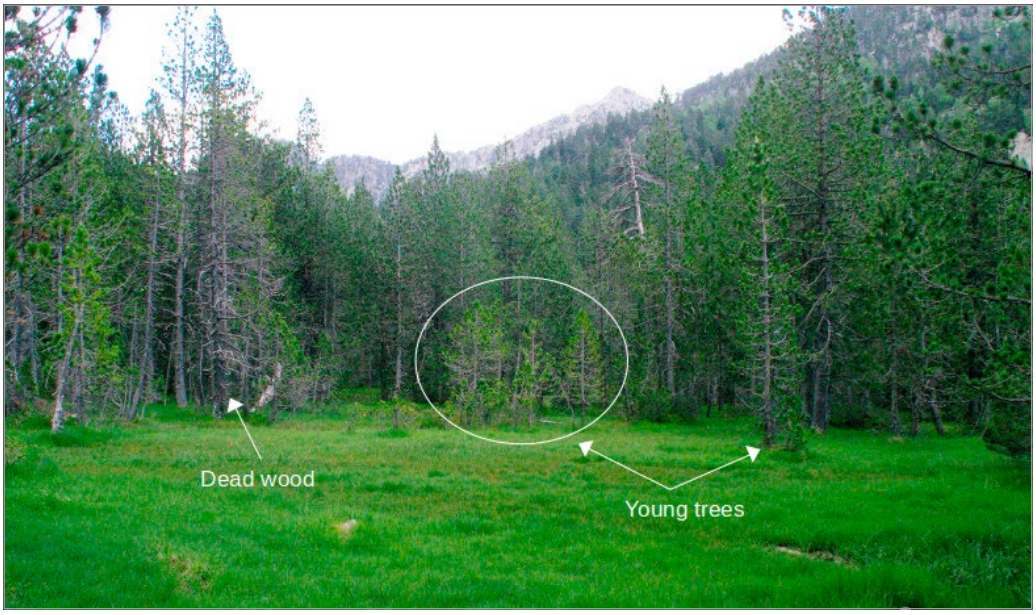

fig. 7. Image of a subalpine forest clearing illustrating vegetation dynamics. Reduced livestock activity allows young pines to colonise open areas, while older trees display lower dead branches. Continued grazing by some herds limits the growth of characteristic subalpine understory shrubs, such as rhododendron and juniper.

al., 2017) while restricting pine to steeper terrain. Maintenance of pine stands near pastures may have ensured firewood supply until the 9th-10th centuries CE (Cunill Artigas, 2010; Rendu, 2003), after which increased exploitation likely necessitated greater mobility and intensified use of complementary fuels like juniper, rhododendron, and Pyrenean broom.

Firewood for domestic use was most likely gathered from areas actively managed by human groups, while spaces perceived as natural may have remained largely undisturbed throughout much of the period (Martín Seijo, 2013; Picornell Gelabert, 2018). This interpretation finds support in the early and consistent presence of pioneer taxa characteristic of secondary forests within the anthracological sequences. The recurrent identification of birch and juniper in the earliest phases, the divergent trajectories observed between oak and the boxwood-Maloideae assemblage, and the marked expansion of pine between 800 and 2000 m a.s.l. from the Iron Age II onwards all point in this direction.

At the same time, although anthropogenic transformations of the environment are well documented from the 5th millennium cal BCE onwards (Cunill Artigas, 2010; Ejarque et al., 2009; Miras et al., 2010; Rodríguez Antón, 2020), these dynamics remain largely invisible in regional-scale palaeoenvironmental records. This apparent discrepancy suggests that such interventions were spatially limited, operating at a local scale that is difficult to capture through pollen-based reconstructions. In contrast, peaks in macrocharcoal concentrations (Pèlachs et al., 2009; Pérez-Obiol et al., 2012) provide more direct evidence for the use of fire in forest clearance. These openings in

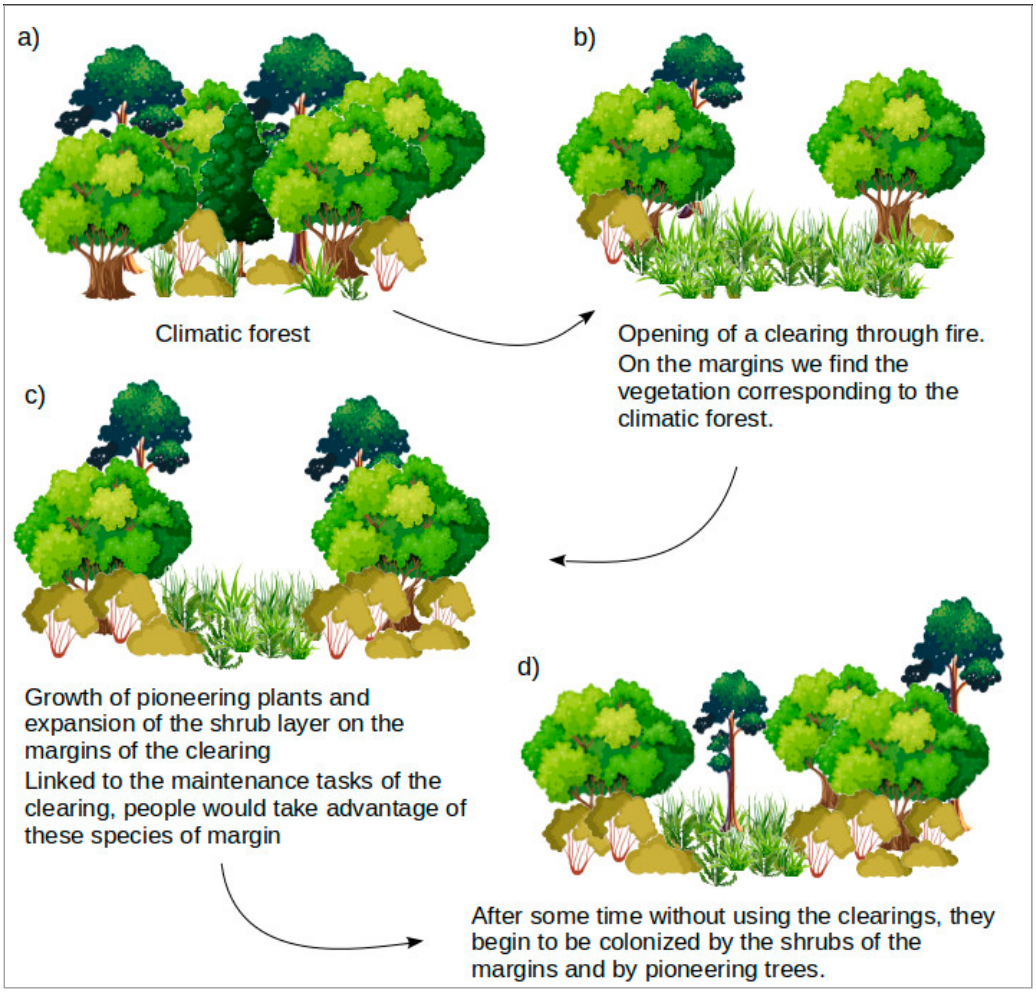

fig. 8. Hypothetical reconstruction of vegetation succession in a clearing created for agricultural and pastoral activities.

the landscape may have been sustained over time through a combination of agricultural and pastoral practices, alongside the selective removal of woody vegetation both along their margins and within their interior during phases of reduced use (**fig.** 7).

Within this framework, if a significant proportion of firewood exploited in mountain settlements originated from these managed open areas, the anthracological record can be read as reflecting a long-term continuity in fuel procurement practices (**fig. 8**). Following the initial creation of a clearing for cultivation or grazing (a), the exploitation of the surrounding climax vegetation would have been immediate (b). As time progressed, the edges of these spaces would have evolved into ecotonal zones, harbouring a mosaic of species associated with different stages of forest regeneration (c). Continued use of these marginal areas would, therefore, generate assemblages combining both pioneer and late-successional taxa. Conversely, periods of abandonment would have allowed the progressive encroachment of later-stage vegetation (d),

eventually requiring renewed clearance – by burning or cutting – if the area were to be re-integrated into productive use. Such cycles of use, abandonment and re-use, unfolding at a micro-regional scale, would leave only a limited imprint on pollen records while remaining clearly legible in anthracological sequences.

5. Conclusion

High-mountain archaeology has become a well-established line of research in the Pyrenees, largely due to the work carried out by several research groups over the past two to three decades. The data generated through these investigations provide valuable insights into the organization of daily life and the range of activities performed at mountain settlements, particularly those related to maintenance practices. Among these, the production and maintenance of fire stand out due to the abundance and visibility of associated remains. Fire was essential for heating, cooking and food processing, craft production, and lighting. Consequently, firewood procurement must therefore be understood as an integral component of everyday practices, often embedded within broader productive activities beyond the settlement.

The integration of anthracological data into a unified database enables a regional analytical perspective and opens new avenues for research. In particular, the application of GIS-based approaches offers strong potential for reconstructing procurement territories and refining our understanding of human-environment interactions.

Drawing on ethnoanthracological frameworks, as well as the application of complementary analytical tools, this study has explored the interpretative potential of charcoal fragment counts by taxon and stratigraphic unit, suggesting that the creation and maintenance of agro-pastoral clearings were major sources of fuelwood, especially in seasonal or short-term occupations. This may also apply to permanent settlements, particularly in cases where pollen records indicate dense forest cover while anthracological assemblages reflect the presence of open-environment taxa. Increased frequencies of heliophilous taxa support this interpretation, indicating managed or anthropogenically modified landscapes.

Future research would benefit from dendrological analyses of charcoal, such as curvature radius measurements, to estimate minimum wood calibre, distinguish between branch and trunk use, and identify exploitation of young trees. This approach is particularly relevant for pine taxa in altimontane and subalpine belts, where they are abundant both as climax and pioneer species. In high-altitude contexts with near-monospecific assemblages, combining growth anomaly studies – such as tree-ring width variation, compression wood, or irregular ring patterns – with geographic and palaeoclimatic data could further clarify shifts in firewood procurement strategies.

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Contribution

Concepts and methodology: Laura Obea, Ermengol Gassiot, Raquel Piqué
Data collection and management: Laura Obea, Raquel Piqué, Maria Martín, Oriol López
Data analysis: Laura Obea, Ermengol Gassiot, Raquel Piqué, Maria Martín, Oriol López
Writing and reviewing the original draft: Laura Obea
Figures: Laura Obea, Ermengol Gassiot
Supervision: Ermengol Gassiot, Raquel Piqué
Project administration: Ermengol Gassiot, Raquel Piqué
Fundings acquisition: Ermengol Gassiot, Raquel Piqué

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