DOI 10.13131/UNIPI/3FEM-PB67

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ABSOLUTE CHRONOLOGY OF HUMAN OCCUPATIONS IN THE HIGH MOUNTAIN ENVIRONMENTS OF THE SOUTHERN CENTRAL PYRENEES: RADIOCARBON DATES FROM THE AIGÜESTORTES AREA

DATASET: DOI 10.13131/UNIPI/Y9ZQ-JD80

Abstract: After 20 years of archaeological surveys and excavations, the Aigüestortes i Estany de Sant Maurici National Park is one of the high mountain areas with the most extensive archaeological record in the Pyrenees. This work presents a database of 124 radiocarbon dates that allow a total of 380 documented sites to be placed in chronological sequence. Along with the data, some analyses are proposed to evaluate trends in the expansion and contraction of the number of documented contexts throughout the Holocene. A brief analysis of the temporal variation of the different types of contexts is also provided.

Keywords: Radiocarbon dating, mountain archaeology, Pyrenees, Holocene.

1. Introduction

Until just over a quarter of a century ago, high-mountain areas remained largely overlooked by archaeological research, with only a handful of isolated discoveries drawing attention to them. Their rugged terrain and harsh climate made them appear, to archaeologists throughout much of the twentieth century, unpromising settings for past human occupation. Such occupation was assumed to have occurred only under particular circumstances, either as a temporary refuge during times of conflict or for sporadic, highly specialised activities.

Over the last three decades, however, this picture has begun to change across many mountain regions of central and southern Europe. Numerous research projects have revealed extensive archaeological records, consisting largely of open-air architectural remains but also including cave occupations, rock-art sites, open-air artefact scatters, megalithic structures, burial mounds, and more (for the Pyrenees, for example, Clemente et al., 2020; Garcia Casas, 2018; Gassiot, 2016; Gragson et al., 2015; Le Couédic, 2010; Montes et al., 2019; Palet et al., 2019; Rendu, 2003; Rendu et al., 2016).

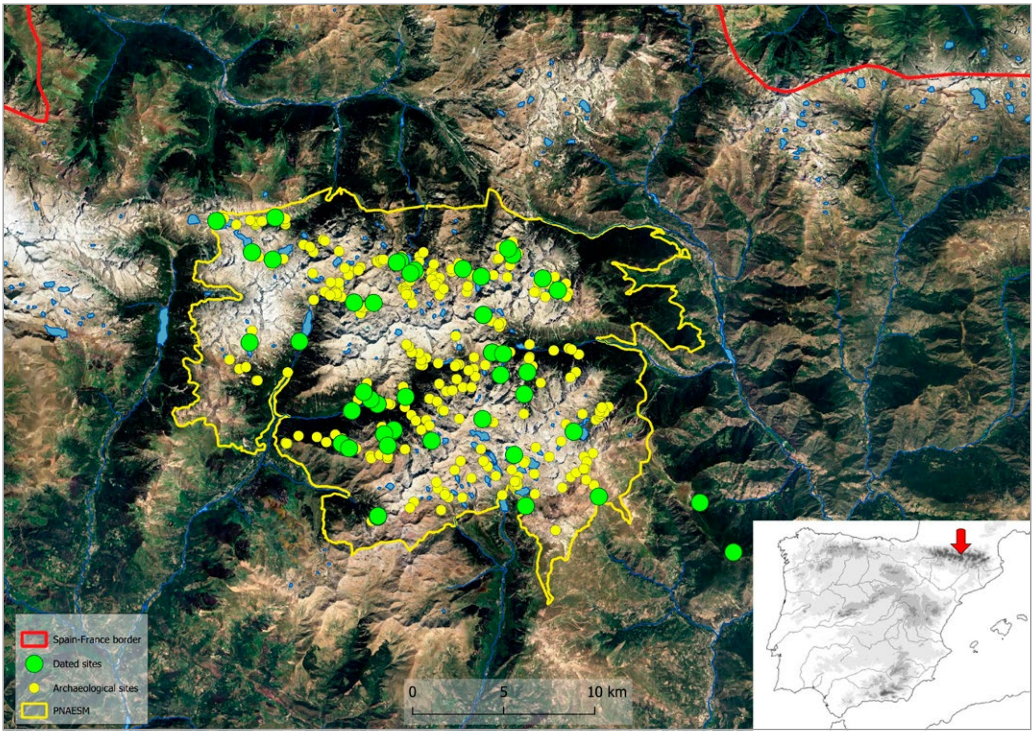

fig. 1. Map showing sites documented in the PNAESM. Sites with radiocarbon dating are highlighted.

Consequently, a previously unknown archaeological heritage has come to light – relatively extensive and diverse even at very high altitudes, which in the mountains of the European Mediterranean arc can exceed 2,500 m.

The Aigüestortes and Estany de Sant Maurici National Park (PNAESM) offers a clear example of this phenomenon. Located in the northwest of Catalonia, it covers nearly 40,000 hectares on the eastern edge of the Aneto – Maladeta granite batholith in the central Pyrenees, at the headwaters of the Noguera Ribagorçana, Noguera Pallaresa, and Garona rivers. The first two drain into the Mediterranean, while the third flows toward the Atlantic. This is one of the most rugged sectors of the mountain range, with peaks rising to 3,000 m and valley floors lying above 1,500 m, their morphology strongly shaped by glacial processes.

In 2004, the High Mountain Archaeology Group (GAAM) began conducting archaeological surface surveys in the PNAESM, an activity that continued over the following years (Gassiot et al., 2014, 2016). As a result, a large number of archaeological remains have been documented to date, grouped into a total of 378 distinct sites according to various criteria that allow us to hypothesize their chronological and functional coherence (Garcia & Gassiot 2022; Gassiot 2016) (**fig. 1**). Their typology is diverse (**fig. 2**). Most of the sites contain architectural elements visible on the surface, displaying a variety of forms: isolated huts or enclosures, clusters of one or more huts combined with one or more enclosures, large groups of interconnected enclosures

fig. 2. Examples of sites located in the PNAESM. a) Abric de Les Obagues de Ratera, b) Garguilhs de Jos, c) Port de Rus, d) Conjunt del Planell Gran.

forming a kind of nucleated settlement, small rock shelters, cattle steps, and so on. In general, these types of remains – representing 66.3% of the sites – are associated with herd management and are classified as livestock-related architecture. Other types of remains complement this assemblage, such as small caves and rock shelters (21.4%), stone circles (2.7%), charcoal kilns (2.9%), and a variety of additional elements (6.9%), including occasional pottery finds, rock engravings, and surface lithic scatters.

These sites are distributed across all areas surveyed within the PNAESM, and their overall density shows little variation. Taken as a whole, the sites display a broad altitudinal range, from 1,496 to 2,882 meters above sea level. Even so, their second and third quartiles are concentrated between 2,172 and 2,380 meters. Another characteristic of their spatial distribution is that most are located close to water sources (65.3% are within 200 m) and are predominantly situated in grassland areas. Broadly speaking, contexts associated with human habitation and livestock stabling exhibit similar spatial patterns, which in some parameters contrast with those of other site types (Gassiot 2016, 2026).

At this initial level of analysis, however, surface data present a temporally aggregated picture, insofar as chronology is not yet considered. Nevertheless, small stratigraphic test pits at selected sites have made it possible to establish, through AMS dating, preliminary stratigraphic sequences and the chronology of at least some occupations.

In addition, 10 archaeological excavations have been conducted at 9 sites to obtain more detailed information. In all cases, these interventions involved identifying stratigraphic deposits during sediment removal and recording the positions of archaeological materials (Gassiot, 2011; Gassiot & Jiménez, 2008; Gassiot et al. 2015, 2021; Obea et al., 2014). Following GAAM's methodological guidelines, priority was given to sheltered sites where there were preliminary indications of prehistoric occupations. All such cases correspond to rock-shelter contexts: Abric de l'Estany de la Coveta I, Cova del Sardo, Abric de les Obagues de Ratera, and Portarró, all of which, as will be shown, preserve long occupational sequences. Excavations were also undertaken in several open-air dwelling areas, generally associated with built features such as enclosures: Tallada Llarga, Vidals de Dalt, Conjunt del Planell Gran, and Despoblat de la Cova.

This paper presents the results obtained through these absolute dating methods. The analysis considers several aspects: first, the overall depth of the temporal sequence, which illustrates the continuity of human occupation processes in this high mountain area of the Pyrenees, second, the temporal variability observed in the radiocarbon results and its historical significance, and finally, the temporal variability of different elements within the archaeological record.

2. Methods and materials

2.1. The series of absolute dates from archaeological sites in the PNAESM

A total of 119 absolute dates were obtained from 43 archaeological sites in the PNAESM. Most derive from rock shelters (22) and open-air architectural remains (19). The remaining two correspond to combustion structures interpreted as iron ore processing furnaces (Gassiot 2016). To increase the number of dates of this type and thereby improve the basis for inference, two additional sites with similar structures have been incorporated: the furnaces at Piflorit (LL-003) and those located above the Dolmen de la Font dels Coms (LL-007) tumulus (Gassiot et al., 2006). Both lie at the head of the Baiasca valley, 9 and 6 km respectively from the southwestern boundary of the PNAESM. With these additions, the full series of absolute dates for the PNAESM and its immediate surroundings comprises 124 dates from 45 different sites (**tab. 1**).

The dated samples come from three types of intervention: profile cleanings, test pits, and open area excavations (**tab. 2**). The first two were carried out during archaeological surveys to document the characteristics of the sedimentary sequence, recover materials that might assist interpretation, and, where possible, obtain datable samples. Profile cleanings were conducted on rare occasions, when an archaeological context displayed a pathway cut. This approach was chosen to minimise impact on undisturbed contexts. It involved removing a 10-cm layer along a section of the cut and documenting the resulting profile, from which samples were taken. In all cases, these samples came from contexts interpreted as kiln combustion residues from furnaces.

Test pits were also carried out during surface surveys as part of the documentation of some sites. In some cases, the primary aim was to confirm the archaeological nature of some rock shelters that had no visible archaeological elements on the surface. Once this question had been resolved, in all cases they sought to resolve the issues mentioned in the previous paragraph. These consisted of very small-scale excavations with the aim, once again, of limiting their impact. They generally covered an area of 50×50 cm, which in some cases, due to the presence of blocks during their execution, was

Site type	number of dates	number of sites dated
Furnace	7	4
Open air (architecture)	35	19
Rock shelter / cave	82	22

tab. 1. Summary of the provenance of dated samples (type of site).

Excavation type	number of dates	number of sites dated
Open area	73	9
Profile cleaning	3	3
Test pit	48	36

tab. 2. Summary of the provenance of dated samples (type of intervention).

Sample material	number of dates	number of sites dated
Charcoal (charred wood)	120	44
Seed (charred)	4	2

tab. 3. Summary of the type of material of the dated samples.

extended to 1 m 2 (Gassiot et al. 2023). The sediment was excavated in arbitrary 10 cm thick layers which, where possible, were adapted to the perceptible changes in the sediment. However, in high mountain contexts, the sedimentation ratio is generally very low and, above the geological strata, changes are hardly perceptible. The archaeological materials were recorded both in plan and in depth, and the profiles were documented. In all cases, the samples selected for dating were contextualized in the stratigraphy. A total of 36 of the 43 sites dated were dated using this type of intervention. However, three of them were also dated later through open area excavations.

About 60% of the dates come from open area excavations carried out at nine sites. These excavations encompassed all shelters and built structures at the respective locations. At two of them – Cova del Sardo and Portarró – excavation areas were extended beyond the shelters, covering more than 40 m². At three sites of this group, only a single sample was dated; in two cases, these were enclosures with a single identified occupation level, while the excavation at the other site remains incomplete. At the opposite extreme, three sites have produced long dating sequences: Cova del Sardo (12 dates), Abric de les Obagues de Ratera (17), and Portarró (27 dates: 13 from the Abric (Shelter) 1 and 14 from Abric (Shelter) 2). Owing to their characteristics, the open area excavations allowed a much more robust characterisation of spatial and stratigraphic contexts, which were central criteria in sample selection.

Most dated materials were charcoal (**tab. 3**), and therefore long-lived samples. This is due to two factors: first, the acidity of granite-derived soils prevents the preservation of fauna with adequate collagen for dating; and second, very few seeds or nutshells were recovered in situ. To mitigate this limitation, samples with few growth rings were prioritised, wood taxonomy was documented, and in recent years the number of growth rings in each analysed fragment has been systematically counted.

At the same time, both during excavation and in the subsequent selection of samples for dating, great care was taken to document each sample's contextual origin. In addition to recording the stratigraphic unit and precise position, a clear distinction was drawn between charcoal derived from occupations of the site (shelter, enclosure, etc.) and charcoal associated with construction elements (**tab. 4**). The former were

Context_type	number of dates	number of sites dated
Bioturbation	1	1
Construction (wall or roof)	9	6
Furnace	6	4
Hearth	51	24
Occupation level	56	22
Unclear	1	1

tab. 4. Summary of the classification of the context of provenance of the dated samples.

assigned to three categories which, in general, correspond to events close to the abandonment of the context:

- Occupation level, when recovered from sediment with traces of human activity that cannot be linked to a specific structure.
- Hearth, when they come from a combustion area or structure or from a deposit clearly resulting from its cleaning.
- Furnace, when they come from the use surface of a structure identified as a furnace or its associated refuse.

Charcoal related to construction was grouped under the category "Construction (wall or roof)" and corresponds to fragments of beams or posts that had collapsed onto occupation levels or filled post-holes. Stratigraphically, these remains predate the associated occupations. Finally, in a few specific instances, some samples were attributed to possible bioturbation or to an unclear context after careful evaluation of both their results and their stratigraphic position.

2.2 Analysis of absolute dating of archaeological sites in the PNAESM

This article presents a brief analysis of the chronology of the sites and contexts dated in the PNAESM, together with two additional sites from the adjacent Baiasca Valley. For this purpose, the *rcarbon* package for R 4.5 has been used (Crema & Bevan, 2021). All dates were calibrated with the IntCal20 curve (Reimer et al. 2020), from which individual calibration plots for each date, as well as a multiplot, were produced.

To obtain an overall synthesis of the chronological sequence of the PNAESM, a Summed Probability Distribution (SPD) of the radiocarbon dates was generated as a parameter for assessing temporal variation in the intensity of human presence (Crema & Bevan, 2021). The "spd" function of *rcarbon* was used for this calculation. Although the resulting SPD provides an easily visualised representation of the temporal sequencing of the summed probabilities, it does incorporate biases arising from uneven sampling by period, site type, and other factors. To mitigate this limitation, we applied "binning" (Timpson et al. 2014), which consists of calculating the summed probability distribution of all dates associated with a given group – in our case, a phase of the same site – and dividing it by the number of dates contributing to it. This approach controls for differences in sampling intensity and ensures that each site phase contributes equally to the final SPD. In this study, bins were set at 50 years.

Several SPDs were generated. First, an SPD was produced using all radiocarbon dates from the PNAESM, with a 200-year rolling average curve overlaid. Additional

SPDs were derived according to the characteristics of the context of provenance of the sample. Each sample was assigned, in a highly synthetic manner, to one or more descriptive categories with the following characteristics:

- **Rock shelter**: occupations occurring in shelters where no substantial associated constructions are documented. This category also includes shelters where the interior was enclosed with palisades or small stone plinths. Shelters with more substantial stone enclosure walls were excluded.
- **Rock shelter + architecture**: occupations in shelters associated with external constructions (e.g., fences) or where stone enclosure walls are documented.
- Single habitation structure: samples linked to the occupation of a single enclosure, including both stone-built constructions and structures made of perishable materials such as wood, whether documented or inferred through excavation.
- **Small/intermediate settlement**: groups of several structures, typically one or more enclosures associated with one or more huts. When the habitation area is a shelter, samples are assigned to the second category above.
- **Grouped settlement**: groups of more than eight enclosures and huts attached to one another, a well-defined type of site in the PNAESM (Garcia and Gassiot 2022; Gassiot 2016).
- **Furnace**: apparently metallurgical furnaces and associated waste accumulations.

These parameters should be considered with caution, especially in cases where samples were obtained from test pits conducted during surface surveys. Advances in research in the coming years will undoubtedly refine and complement this classification.

To complete the SPD, Composite Kernel Density Estimates (CKDE) have also been calculated. CKDEs provide a smooth curve of the temporal distribution of a set of calibrated dates, combining probabilistic information with bias reduction (Ramsey, 2017, Menéndez-Quirós et al., 2023). To reduce short-term variability and focus on broader trends, a bandwidth of 200 years and 100 simulations (nSim = 100) were used. For comparison, an additional calculation with a bandwidth of 50 years was performed, which is more sensitive to short-term fluctuations.

Various simulations were also conducted using the modelTest function in *rcarbon* (Crema & Bevan, 2021). This function performs a Monte Carlo test to compare a theoretical or adjusted statistical model with an observed SPD – in this case, the PNAESM dataset. Different theoretical models (uniform, linear growth, exponential, and adjusted logistic) were compared against a 95% critical envelope derived from simulations. For the first three models, the defaults provided by *rcarbon* were used. For the logistic model, the smoothed SPD was used as a reference, defining the inflection point (xmid), the slope (scale), and the asymptote (Asym), following the approach of Crema and Bevan (2025).

The overall significance and local deviations of the observed SPD are determined by comparison with this envelope, highlighting periods of relative intensification or underrepresentation of human presence. While these theoretical models should be interpreted cautiously, they allow identification of possible phases of increased or decreased human activity in the area. In all cases, an nSim of 100 and a running mean (runm) of 100 were applied to reduce statistical noise caused by low sample numbers in some periods.

Finally, the modelTest function also allows statistical comparison between the observed and expected growth rates of the fitted model. This is done by comparing the sum of probabilities for each focal year with that of a preceding year – 50 years earlier by default – yielding an annual rate of change over the interval. Variations that are extreme relative to the theoretical models are flagged as anomalies and highlighted in the resulting graph.

3. The radiocarbon dates of the PNAESM: results and analysis

3.1 A chronological sequence covering the entire Holocene

The information from the set of 124 radiocarbon dates from the PNAESM and the head of the Baiasca Valley is provided in Table 14C_PNAESM in the supplementary material. The file 0_Readme_ENG details the metadata of the all the dataset.

Overall, the radiocarbon dataset reflects a long sequence of occupation in the current PNAESM, which should be noted is a high mountain area. The earliest occupations date to approximately 8700-7600 cal BC, specifically in the oldest levels of the Dolmen de la Font dels Coms (LL-007) and the Abric de Les Obagues de Ratera (ESP-018). The earliest date comes from a post hole located about 20 cm below the base of the mound of a dolmen at 1843 m a.s.l, associated with a fragment of carved flint. This context was documented only partially in a trench designed to analyze the internal structure of the mound and is therefore somewhat ambiguous. The second earliest date comes from a small piece of charcoal recovered from a hearth constructed

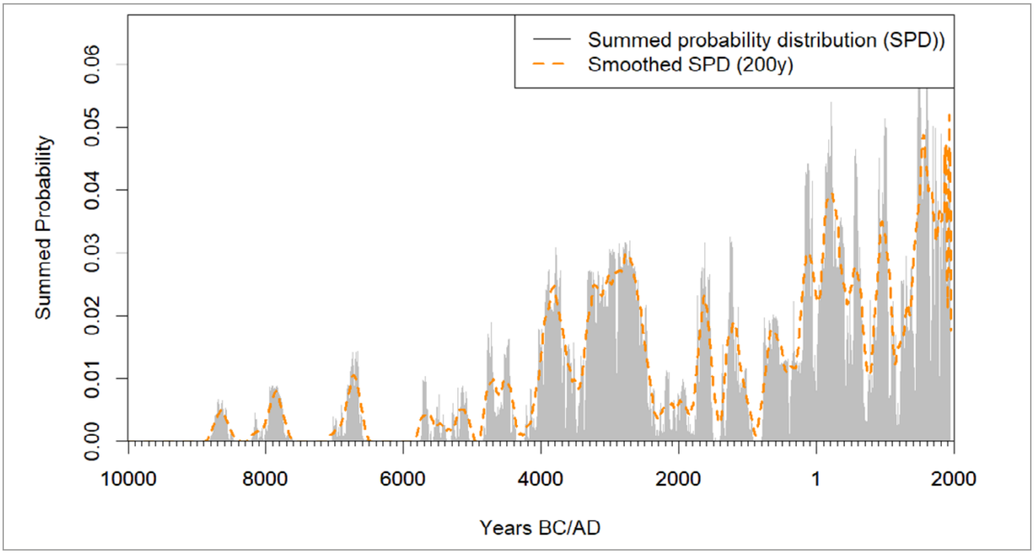

fig. 3. Graphical representation of the Summed Probability Distribution (SPD) of the PNAESM radiocarbon dates (in gray) and of the smoothed SPD, with a window of 200 years.

Number of dates	Num sites
1	31
2	7
3	1
4	2
18	1
22	1
28	1

tab. 5. Summary of the number of sites by quantity of dates.

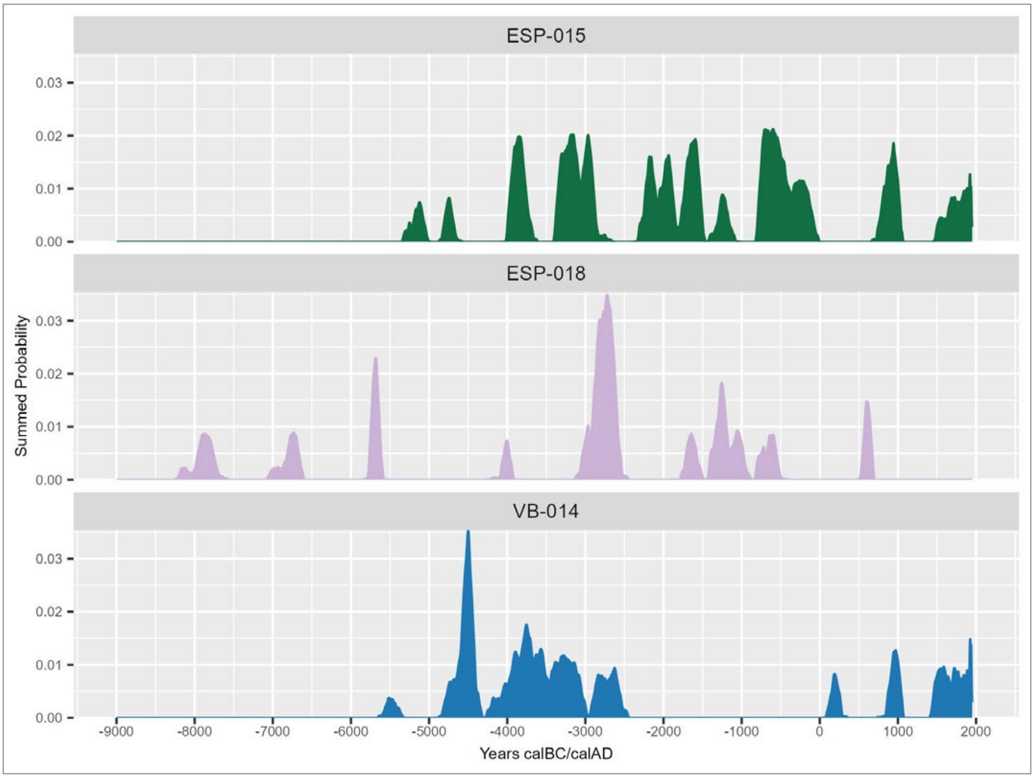

fig. 4. Graphical representation of the Summed Probability Distributions (SPD) of Portarró site (ESP-015), Abric de Les Obagues de Ratera (ESP-018) and Cova del Sardo (VB-014).

with a series of embedded clasts at the base of the stratigraphic sequence inside the shelter. The site lies in a very rocky valley with a NW-SE orientation at an altitude of 2312 m. This date is followed by other results also belonging to the early Holocene.

From this initial period onwards, human presence in the area shows a degree of continuity, particularly from the early Neolithic (c. 5500 cal BC), with various fluctuations in intensity (**fig. 3**). This aspect will be discussed in more detail later.

Most sites have only a single radiocarbon date (**tab. 5**). In contrast, three of the extensively excavated sites present substantial series of 18 or more dates. These are, in order, Cova del Sardo (VB-014), Abric de les Obagues de Ratera (ESP-018), and Portarró (ESP-105). While these figures clearly reflect the effort invested in dating the archaeological contexts identified, they also indicate the recurrence of occupation phases at some of the documented sites.

Diachronicity in high mountain settlements is a pattern increasingly documented as research in these areas accumulates empirical data (Carbonell, 2024; Gassiot et al., 2016; Montes et al., 2019; Rendu et al., 2016). It is frequently observed at sites with architecture, where sequences of remodeling and stratigraphic overlap occur, along with a certain chronological variability among constructions situated close to one another. In the PNAESM, this diachrony is particularly evident in most of the rock shelters documented during surface surveys, through test pits and, especially, in open-area excavations. In this respect, the occupation sequences of the three sites mentioned above are paradigmatic (**fig. 4**). All of them exhibit overlapping occupations that begin at the start of the Neolithic, or even earlier, and continue through various prehistoric and historical phases. This situation is unusual in the recent prehistory of northeastern Iberia: at two of the sites, there is continuity of occupation throughout almost the entire Neolithic period. Moreover, this recurrence of phases has been identified mainly in extensive excavations, underscoring the limitations of small test pits in capturing complex occupation sequences in some cases.

3.2 Changes in the intensity of occupation?

Establishing a direct correlation between the number of radiocarbon dates and a given intensity of occupation of a territory is a complex task in which multiple variables must be considered (Carleton, 2021; Crema & Bevan, 2021; Freeman et al., 2018; Menéndez-Quirós, 2023). First, there is the process of obtaining and selecting the samples that have been dated; that is, the way in which the record itself has been generated. In the case of the PNAESM, certain aspects of this process can be controlled. One derives from the fact that the entire archaeological record has been generated over a relatively short period of about 25 years and by the same research team, the GAAM. Although fieldwork techniques and strategies have evolved over time, there is a certain unity in the overall record, and its primary aspects are well understood.

However, two other factors involved in the creation of this record are likely to introduce asymmetries between periods. The first is the uneven visibility of sites, which affects their detectability during survey work and can lead to the underrepresentation of certain typologies and chronologies. The second is linked to the research interests of the GAAM, which have favoured cave or rockshelter contexts for extensive excavations aimed primarily at documenting prehistoric contexts. This results directly in a high number of dates from a few sites and for specific periods of prehistory.

Secondly, there are variables specific to the societies that generated the archaeological evidence currently being recorded. The concentration or dispersion of settlement patterns, for instance, can produce a greater or lesser number of potentially documentable and datable contexts without necessarily implying a larger or smaller demographic contingent. The same applies to mobility. A community that spends only a short time in one location before moving to a neighbouring valley can generate the same "archaeological noise," in terms of the number of settlements, as two communities more permanently established in those same valleys. In short, interpreting

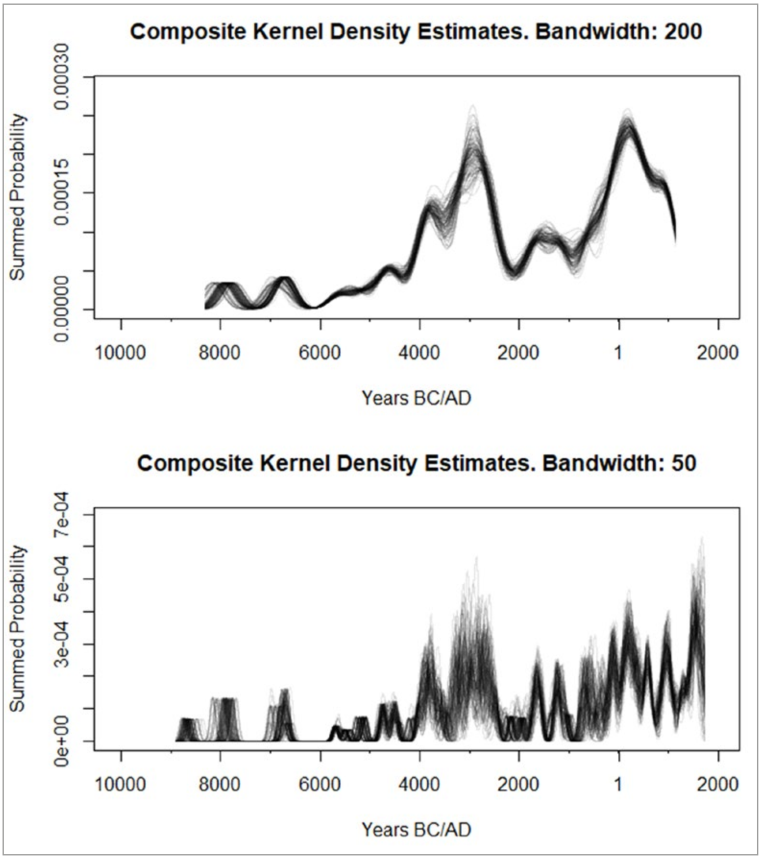

fig. 5. Composite Kernel Density Estimates of Radiocarbon Dates (CKDE) of the PNAESM, with Kernel bandwidths of 200 and 50 years.

the demographic significance of a given number of radiocarbon dates is a complex task that requires detailed analysis.

Finally, although the calibration of a radiocarbon date defines a probability range in which each year receives a corresponding value, the date of death of the analysed tissue refers to a specific and discrete event within that interval. In other words, an overlap between the bounds of two calibration intervals does not necessarily imply synchrony or temporal continuity between the two samples, which may in fact be separated by decades or even centuries.

With all these considerations in mind, we nevertheless propose a review of the dating sequence in the PNAESM with the aim of assessing the temporal recurrence of the results and suggesting some possible interpretations. To do this, we use the graphical representation of the Composite Kernel Density Estimates (CKDE) and, in parallel, the Summed Probability Distribution (SPD). It is important to remember that we are working with a series of 124 radiocarbon dates from a limited geographical area. Although this can be considered a sufficiently large dataset given the scale of the study area, it also spans an extensive period of just over 10,000 years – equivalent to roughly one date every 80 years on average. Moreover, the temporal distribution of the results is far from homogeneous, which further reduces the statistical significance of the least represented periods.

The graphical representation of the Composite Kernel Density Estimates (CKDE) reveals two major peaks (**fig. 5**). The first covers the second half of the Neolithic and aligns with the high number of contexts dated to this period, both within individual sites and across different sites. The second corresponds to an increase in sites during the Roman period, especially in Late Antiquity and up until the collapse of the Visigothic kingdom. It is worth noting that the 200-year bandwidth (bw), which is of moderate amplitude, preserves general trends while smoothing out random or short-term fluctuations and limiting extreme values (a version using a bw = 50 can also be consulted). In any case, the pattern seems to reflect dynamics that have been archaeologically documented for years: an increase in archaeological sites and layers from approximately 3300 cal BC to 2500/2300 cal BC, followed by another rise during the Late Roman Empire and Late Antiquity.

The Summed Probability Distribution (SPD) (**fig. 4**) yields a compatible scenario, although with greater sensitivity to short-term variability. In its earliest section, it reflects the scarce data currently available for the early Holocene, without defining a continuous time span. A gap is also evident between 6500 and 5900/5800 cal BC, in which the 8.2 ka BP event (around 6250 cal BC) would fall. Given the limited dataset, it is difficult to determine to what extent these gaps – especially the latter – stem from sampling issues or from genuine historical dynamics.

During the Middle Holocene, the number of dates increases, with three relative maxima in the cumulative probability distribution. The first defines an initial period between approximately 5700 and 4400 cal BC (Gassiot et al., 2021; Salvador, 2024) and broadly corresponds to the Early Neolithic in the northeast of the Iberian Peninsula (Oms et al., 2018; Palomo et al., 2022). It should be noted that all dates for this period come from only three sites with open-area excavations. The second begins around 4300/4200 cal BC and continues – after a relative minimum around 3500/3400 cal BC – into the third period, which ends relatively abruptly in the last third of the third millennium cal BC. Broadly speaking, these two periods correspond to the Middle Neolithic and the Late Neolithic/Chalcolithic in the region (Gassiot et al., 2017; Oms et al., 2016; Salvador, 2024). While all dates for the Middle Neolithic derive from the same three sites, those of the third period come from a much wider range of sites – seven in total, three of which are documented only through test pits.

Throughout the Recent Holocene, the SPD also shows several oscillations, with three or four more or less defined periods. In this case, there is a notable increase in the number of sites providing datable contexts. The first period spans the second millennium BC and largely corresponds to the Bronze Age phases at Abric de les Obagues de Ratera (ESP-018) and Portarró (ESP-015), supplemented by two additional results from VB-017sup and AA-043. Following a minimum around 1000 cal BC, the second period extends through the Iron Age and the whole of Antiquity, up to the decline in dates also documented elsewhere in the Pyrenees during the 8th century AD (Rendu, 2021). Finally, the last period covers much of the Middle Ages to the present. Within this interval, one may intuit a decline in the curve coinciding with the late medieval crisis, prior to the marked increase observed in recent centuries.

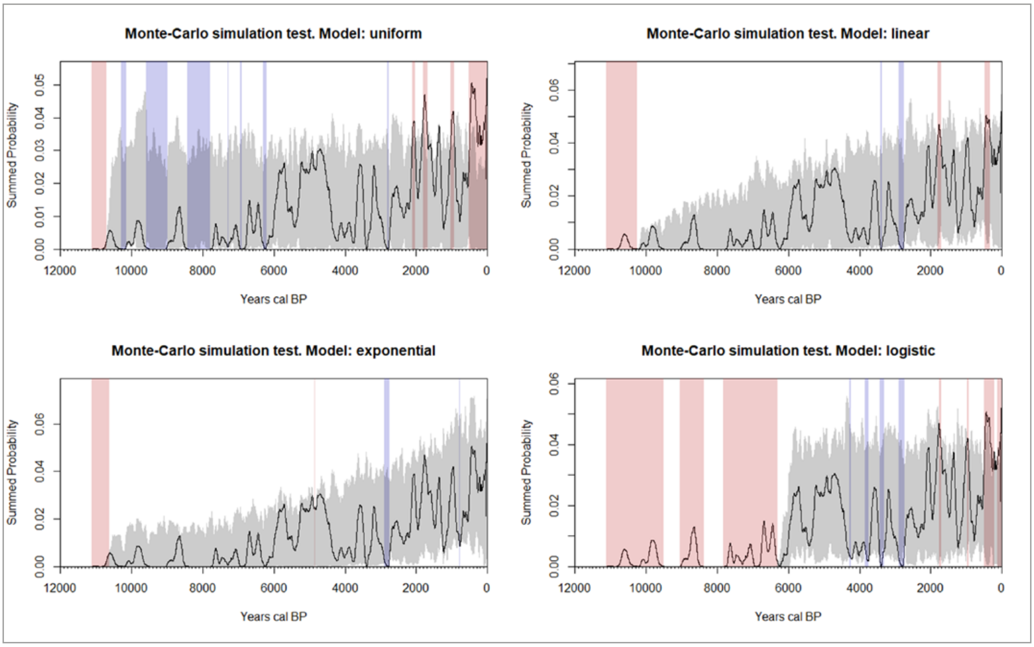

fig. 6. Comparison of the PNAESM's SPD with several theoretical demographic growth models: uniform, linear, exponential, and fitted logistic. In red, positive anomalies and in blue, negative ones.

As mentioned, interpreting the CKDE and SPD curves in terms of historical processes and settlement dynamics is inherently difficult. Setting aside, for a moment, the potential impact of the factors discussed above, comparing the shape of the SPD with theoretical simulations can be informative. **Fig. 6** presents the graphical output of the *rcarbon* modelTest for various possible scenarios. The discrepancies between the results are substantial, underscoring the need to critically evaluate the theoretical reference model. The validity of each model must be assessed in relation to different hypotheses about historical dynamics, which may themselves vary across periods. In any case, this issue lies beyond the scope of the present work. However, when not tied to a demographic inference, this comparison may be useful can be a valid tool if we use it exclusively to detect continuities and discontinuities in the sequence of calibrated radiocarbon dates.

The uniform model scenario can be ruled out a priori, as it assumes a constant population over the last 10,000 years. In the linear growth model, the positive anomalies in the SPD are mainly concentrated in historical periods (in all cases, the initial positive anomaly must be dismissed as an effect of the boundary). Again, translated into population terms, this scenario – based on a stable growth ratio – also appears implausible.

The exponential growth model shows a brief positive anomaly during the early Neolithic and somewhat a longer negative anomaly during the post-Neolithic/Chalcolithic gap. However, using this type of growth model without considering an upper limit – such as that imposed by the carrying capacity of the environment under particular production strategies – seems inappropriate. Finally, comparing the SPD with

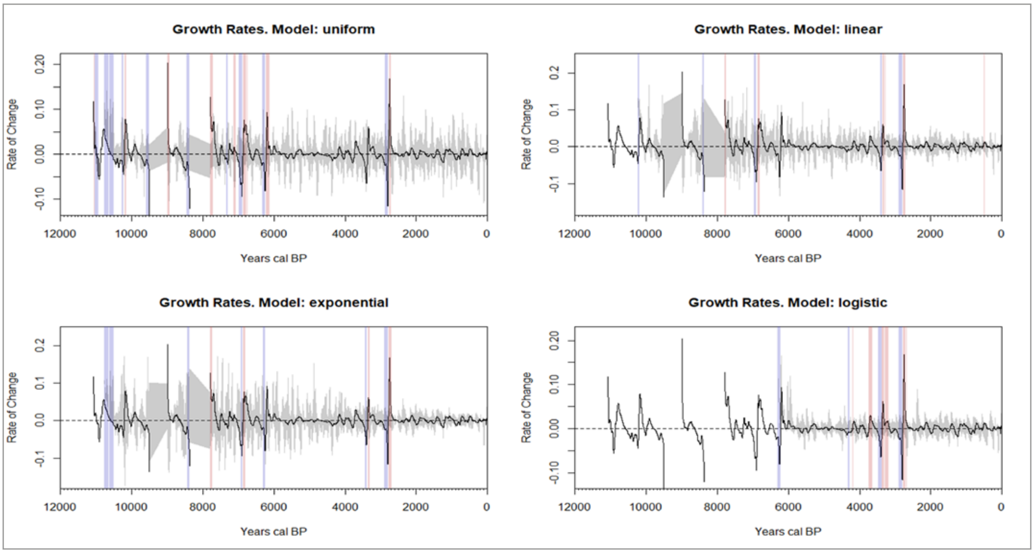

fig. 7. Representation of the deviations of the SPD's growth rates from the PNAESM in relation to the 4 theoretical demographic growth models. In red are the positive anomalies and in blue the negative ones.

an adjusted logistic growth model highlights an extended period of positive anomaly that coincides with the first block of Neolithic dates, followed by shorter periods during the Late Empire, the Early Middle Ages, and the Modern Era. It should be noted that such models assume an initial phase of progressively accelerating growth, followed by a decline in growth after a turning point.

Observation of the growth rates provides a much more homogeneous picture (**fig.** 7). If we disregard the first section of the sequence, where the number of results is very low, we observe positive and negative deviations in growth rates (marked here by red and blue bands). These fluctuations are quite similar across the different models, particularly within the 4000-0 calBP interval. Except in the logistic model, certain recurrences can also be observed in the first half of the Neolithic. These may reflect an increase in human activity in the PNAESM territory during the initial centuries of the introduction of livestock herding, which appears to have been sustained over time.

3.3 Temporal variability of different types of sites

Beyond the number of dates and the cumulative probability curves (SPD), it is also useful to analyze the temporal range of different types of archaeological contexts or occupations. In this regard, we have also derived SPDs for the different types of occupation, following the classification presented in the previous section (**fig. 8**). Their graphical representation offers an intuitive approximation of the spatial distribution of the various types of remains documented, based on the probability distributions of their radiocarbon dates. The oldest date in the entire sequence, obtained from a possible post hole beneath the burial mound of the Dolmen de la Font dels Coms, has been excluded due to uncertainties concerning the interpretation of the context.

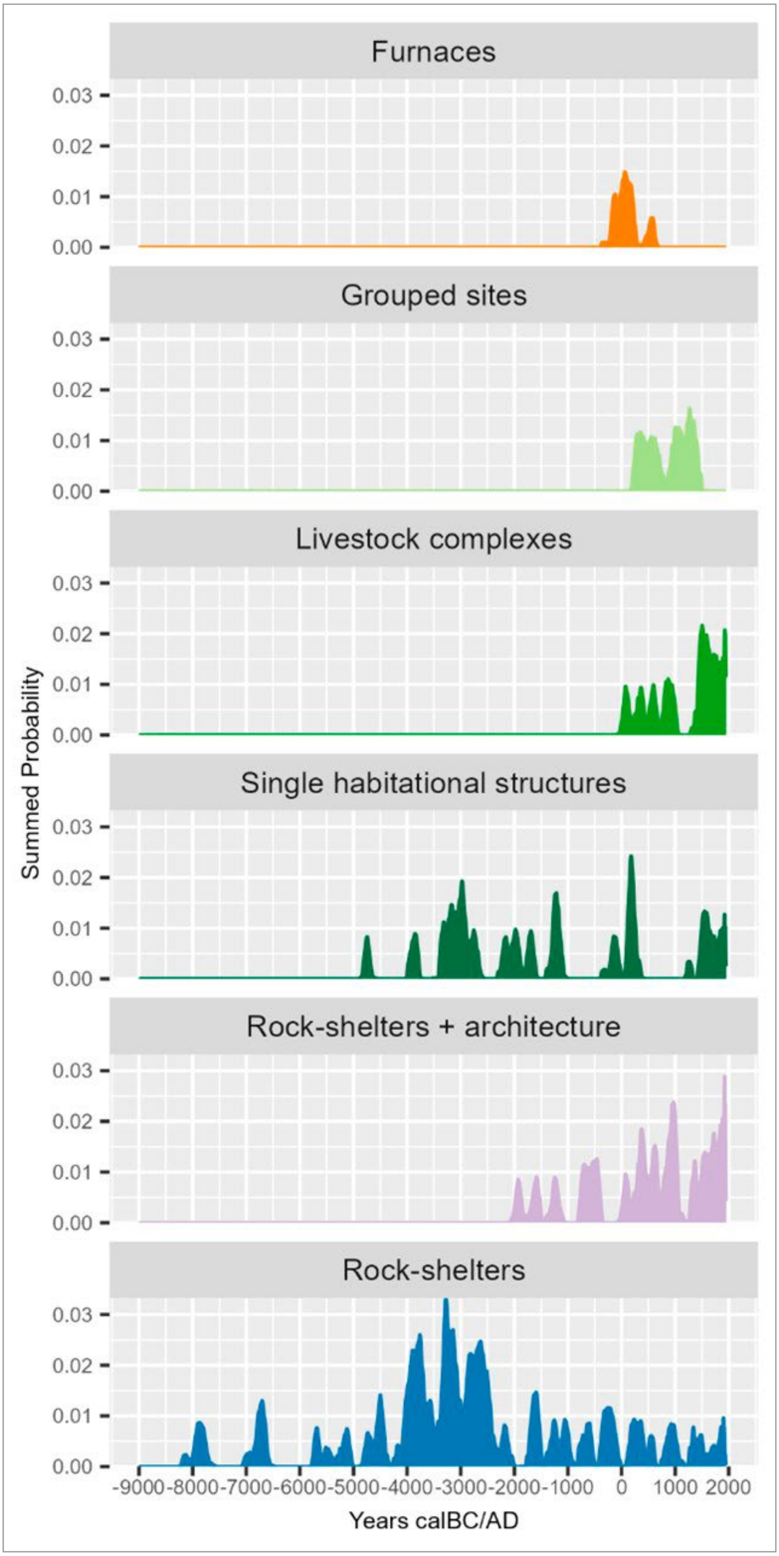

fig. 8. Graphical representation of the SPD of the different types of occupation.

Type of occupation	Number of dates
Rock shelter	54
Rock shelter + architecture	27
Single habitation structure	21
Small/intermediate settlement	13
Grouped settlement	15
Furnace	5

tab. 6. Number of radiocarbon dates for each type of occupation.

The number of radiocarbon dates per class varies, and the underrepresentation of some types of occupation (**tab. 6**) must be considered, as these are, to a certain extent, the most temporally restricted.

The graphs show that the occupation of rock shelters spans the full chronological sequence recorded in the PNAESM. They also place sites with stone architecture – both those identified on the surface during surveys and those documented through excavation – within more recent phases. Thus, rock shelters with associated architecture generally show occupation beginning in the historical period. The few cases with earlier chronologies correspond to two specific situations. In the first, small structures enclosing the space – typically stone wall bases complemented by above-ground wooden elements – were documented during excavation. In the second, the rock shelters are directly associated with external architectural structures such as enclosures, isolated walls, or possible terraces. In these cases, the association between radiocarbon dates and the architectural elements is imprecise since test pits inside the shelters typically document multiple overlapping occupations.

The dates from livestock-related complexes, whose architectural forms correspond closely to patterns known from historical and ethnographic sources, all fall within the last 2,000 years. In fact, they show greater concentration and continuity between the Late Middle Ages and the contemporary period. This second group corresponds to architecturally more homogeneous complexes (Garcia and Gassiot 2022). The grouped complexes present an even more clearly defined chronological range, from the Late Roman Empire to the Late Middle Ages. The cumulative probability of their dates also shows a decline in the 8th century.

The single habitational structures present the second widest temporal range after the rock shelters. This derives from the identification, in the open-area excavations at the Portarró site (ESP-015), of several constructions located outside one of the shelters. Once again, these consist of stone foundations supporting wooden superstructures, and have been included within this category. With several occupation phases, their dates fall within the second half of the Neolithic and the Bronze Age. Similarly, the structure documented at the Coma de Espós site (TC-026) has yielded comparable results. These dates are consistent with those obtained from excavations at Haille de Pout, in the Tremouse cirque, on the northern slope of the mountain range (Perrin et al., 2018; Saint-Sever, et al. 2028). Comparable constructions – isolated enclosures with stone bases and wooden closures – have also been documented in Protohistory and Roman times, and even as late as the 16th century. Smaller huts with traces of corbelled (false dome) roofing have likewise been dated to this period.

Finally, it is worth noting that the iron-roasting furnaces documented in the area are restricted to Antiquity and, predominantly, to the decades around the turn of the era. In all cases, the iron-reduction process must have taken place elsewhere, in contrast with the late antique ironworking installations of Bosc de Virós, in Vallferrera, located slightly farther to the east (Augé et al., 2012).

4. Conclusion

Much of the documentation generated by archaeological research in Europe's high mountain areas has a pronounced spatial dimension. Within a cultural-landscape perspective, surface surveys aim to identify archaeological traces of occupation in environments that, until recently, were considered hostile to sustained human presence. These activities – often described as "non-intrusive archaeology" (Grau 2021) – tend to produce distribution maps and to feed into macro-spatial analyses. In such approaches, the temporal dimension is frequently difficult to disentangle, and broad spatial trends are often reconstructed regardless of chronology. To some extent, the recurrence of occupations in the same locations supports this methodological tendency. However, it also risks obscuring the temporal variability that undoubtedly characterizes human occupation histories in high mountain contexts, as in other environments.

The increasing availability of radiocarbon data for high mountain regions makes it possible to address this limitation. The PNAESM dataset presented here comprises 124 radiocarbon dates from archaeological contexts obtained both through small test pits during surface surveys and open-area excavations at specific sites. These results provide a temporal sequence spanning the entire Holocene. The earliest date, 8798-8537 calBC, comes from 1843 m a.s.l. at Dolmen de la Font dels Coms (LL-007) and attests to human presence in the lower subalpine zone during the Preboreal. Early Holocene activity is further confirmed at Abric de les Obagues de Ratera (ESP-018), with an initial date of 8092-7660 calBC and additional dates of slightly later age. The presence of Holocene hunter-gatherer groups appears consolidated at this site and at Abric de l'Estany de la Coveta I (ESP-008).

From the Neolithic onwards, the various analyses presented indicate an increase in the number of radiocarbon dates, accompanied by higher cumulative probability values. We have already expressed caution regarding a direct translation of these indicators into demographic parameters. Nonetheless, a hypothetical rise in the intensity of human occupation does correspond with the documented increase in sites from the Neolithic onwards, especially from the second half of the 4th millennium BC. It also aligns with paleoecological evidence from sediment cores in and around the PNAESM (Catalan et al., 2013; Garcés-Pastor et al., 2017; Gassiot et al., 2014; Rodríguez González, 2017).

Broadly speaking, these paleoecological data point to anthropogenic impacts on vegetation from the end of the Neolithic – and in some cases earlier – intensifying during the second millennium BC. This evidence consists of an expansion of herbaceous taxa, a decline in forest biomass, and indications of fire activity. The appearance of Cerealia pollen, which persists throughout the later sequence, is also noteworthy.

These anthropogenic signatures show temporal fluctuations, with a downturn around the middle of the first millennium BC and a sharper decline in subsequent centuries, particularly from Late Antiquity and the Early Middle Ages until the 18th century.

A detailed comparison between oscillations in paleoecological records and SPDs a highly interesting topic that will undoubtedly be addressed in the future. This will, however, require increasing the number of radiocarbon dates from archaeological contexts and resolving issues related to sampling strategies and the generation of dates. The current CKDE and SPD curves are derived from two distinct types of samples – those from small test pits and those from archaeological excavations – each with very different informational potential and, consequently, very different explanatory capacities.

The identification of residential enclosures defined by stone wall bases provides a good example. While most dates from such structures fall within historical periods (with one exception from the end of protohistory and two from the Late Neolithic), the excavation of exterior spaces at Shelter 2 of the Portarró site has revealed multiple prehistoric construction phases associated with open-air occupations. Beyond these contrasts in the capacity to identify contexts, small test pits are also limited by the difficulty of establishing secure associations between interior occupations and external architectural features (Gassiot et al., 2023). Similar challenges may arise even in extensive excavations, in cases where occupations inside rock shelters need to be linked to outdoor structures, or where multiple activity areas must be integrated into a coherent sequence. These issues reinforce the need to intensify archaeological work in such contexts and, once initial detection is achieved, to prioritize open-area excavations.

As this process advances, these limitations will gradually diminish. The breakdown by context type already reveals specific and asymmetrical temporal patterns among different classes of sites. Addressing the uncertainties described above will strengthen the emerging picture and help establish more precise chronological ranges for different site types. Consolidating absolute chronologies is essential in this process. Yet obtaining long radiocarbon series remains expensive, both financially and in terms of required labour. This underscores the importance of collaboration across research teams and the open sharing of data. By making the radiocarbon dates from PNAESM archaeological contexts openly accessible, we hope to contribute to the collective effort to advance the archaeology of the European high mountains.

Acknowledgements

Research described in this article has been carried out in the framework of several projects and grants, including numerous contracts awarded by the Aigüestortes i Estany de Sant Maurici National Park (PNAESM), which are detailed in the supplementary material. Data processing and manuscript preparation were carried out within the framework of the research project "Archaeology of pastoralism in high mountains. Human occupation and the shaping of livestock landscapes in the Pyrenean national parks (ArqueoPastoPir)" (ref.: 3150/2024) funded by the Autonomous Agency of National Parks of Spain. The final text has been improved with the contributions of two anonymous reviewers.

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Fundings

This article has been written as part of the research projects *PID2023-148764OB-I00 A – A diversified economy? Occupation and exploitation of the middle and high Pyrenean mountains during the Early Neolithic*, founded by the Agencia Estatal de Investigación and 3150/2024 – *Arqueología del pastoralismo en la alta montaña. Ocupación humana y conformación de paisajes ganaderos en los parques nacionales pirenaicos*, founded by the Organismo Autónomo de Parques Nacionales.
The previous reserch (fieldwork and radiocarbon dating) has been founded also by the next grants:
Grant information: Organismo Autónomo de Parques Nacionales. Spanish Ministry of Environment, Project code: 998/2014
Grant information: Department of Culture, Government of Catalonia, Project code: 2014/100871
Grant information: Department of Culture, Government of Catalonia, Project code: CLT009/18/00032
Grant information: Department of Culture, Government of Catalonia, Project code: CLT17/2022/00112
Grant information: HAR2015-66780-P, Project code: Spanish Ministry of Economy and Competitiveness (MINECO)
Grant information: PID2020-115205GB-I00, Project code: Ministry of Science and Innovation
Grant information: Agencia Estatal de Investigación, Spanish Ministry of Science, Innovation and Universities, Project code: PID2023-148764OB-I00

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