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RESEARCH

Solving the puzzle of neanderthal occupations: a reassessment of temporal indicators of occupation duration

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Abstract

The identification of the duration of Neanderthal occupations is a tricky topic by the palimpsest nature of archaeological assemblages. This study explores the challenges associated with distinguishing between long and short-term occupations, using qualitative and quantitative data from relevant archaeological sites in the Late Middle Palaeolithic in Spain and south-eastern France. We highlight the proposed occupation models and their specific characteristics, considering the heterogeneity of archaeological evidence and the limitations of current methodologies. The article offers a reassessment of the topic, critically analysing the current indicators used to determine the duration of Neanderthal occupations. Furthermore, we discuss the complexity in defining the concepts of short and long-term occupation, emphasising the need for a multidisciplinary approach to fully understand the complexity of the practices of the Late Neanderthals.

Keywords Neanderthals · Human behaviour · Late Middle Palaeolithic · Temporal resolution

Introduction

The study of Neanderthal behaviour is one of the main subjects of interest in Palaeolithic archaeological research. The topic continues to gain relevance, playing an important role in the discussion about cultural transformations that characterise the Late Neanderthals and the transition from the Middle to the Upper Palaeolithic. To sustain and further enhance this interest, the wealth of data generated in recent decades significantly contributes to driving exploration and understanding. Moreover, much literature has been published on the Late Neanderthal period (70 – 40 ka) and serves to diminish the distinctions initially stressed between Neanderthals and *Homo sapiens*. The cultural capabilities of Neanderthals represent the starting point for addressing the broader question about Neanderthal behaviour.

The examination of human behaviour is a critical aspect of comprehending the diversity of Middle Palaeolithic archaeological sites. Studying Neanderthal behaviour provides insights into occupational patterns and site functionality. In addition, the analysis of occupational patterns and site functions provides data that help identify mobility patterns, social interactions, and the size of the groups that occupied caves and shelters during the Middle Palaeolithic. The concept of mobility depends on various variables such as the use made of a territory, the availability of resources, the distance covered during each movement, the number of displacements, and the type of occupation (Binford 1980; Cascalheira and Picin 2020; Fernández-Laso et al. 2011; Gómez De Soler et al. 2020; Kelly 1983, 1995; Kuhn et al. 2016; Marín et al. 2019; Mayor et al. 2022; Moncel et al. 2019; Picin 2022; Picin and Carbonell 2016; Spagnolo et al. 2019).

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Duration of occupation is intricately linked to both its function and the type of occupation it serves. When identifying site typology, the primary distinction lies in whether the site serves a residential or logistic function. Binford (1980:9) defines a residential site as 'the locus where most processing, manufacturing, and maintenance activities take place'. A residential site constitutes the place where the group resides, and where resources are introduced, processed, and shared. Some authors (e.g., O'Connell, 1987; Rolland 2004) describe the presence of hearths as a characteristic element of residential sites. Indeed, hearths represent the place where domestic activities took place and are essential for keeping predators away. They also provide illumination and offer heat when it is cold (Rosell and Blasco 2019; Vallverdú et al. 2010). Fireplaces also have a crucial social function, as they represent the place where socialisation occurs and knowledge is transmitted. As the hub of social life and resource sharing, hearths give sense to the concept of 'hearth-related areas' in literature (Stevenson 1991; Vaquero and Pastó 2001; Vaquero et al. 2004; Vaquero 2012). Hearth-related areas are the results of a social structure and correspond to the performance of activities around the fire.

Hearth-related accumulations are a common characteristic of Middle Palaeolithic sites; in addition, they are also important to understand the accumulation patterns and the cultural processes involved in the assemblage formation. The activities developed in these areas include processing and food consumption, as well as the production and resharpening tools, among others. Hearths are areas that might have been used to sleep, converse or play. In 1983, Binford provided a model associated with hearth-related assemblages and identified two areas according to the depositional patterns of remains and their dimensions. According to him, remains found near the hearths were probably produced during the development of activities *in situ*, and constitute the 'drop area'. A second zone, known as the 'toss area', was located away from the hearth, where humans accumulated the remains intentionally removed from the activity area. Both areas could be distinguished by the size of the remains: while in the drop area the remains tend to be small, large remains tend to accumulate in the toss zone. Moreover, Binford (1983) describes another type of cleaning activity, referred to as "preventive maintenance." This process involves the accumulation of large refuse in areas specifically designated as trash zones. This practice corresponds to what Schiffer (Bökonyi 1972) called the "primary refuse area," which differs from the "de facto refuse area," that is, the actual location where an activity took place. When the primary (or de facto) refuse is moved away from the activity area, it creates what is called the "secondary refuse area." These behaviours suggest a site organization linked to more enduring occupations, where waste management becomes an integrated part of daily activities.

Despite hearths being an excellent indicator of residential function, they can occasionally appear in non-residential contexts, such as kill-butchery sites (Binford 1978a; Yellen 1977). Thus, other aspects should be considered to differentiate activity areas related to hearths, such as the intensity and depth of the sediment altered by the fire. In this line, micromorphology studies provide crucial information about hearth characteristics and aspects that define the timing of the settlements (Aldeias et al. 2016; Leierer et al. 2019, 2020; Machado and Pérez 2016; Pérez et al. 2017; Stevenson 1991; Vallverdú et al. 2010).

Beyond the residential sites, we can distinguish other non-residential sites, known as 'logistical sites' or 'locations' (Binford 1980, 1982). These sites are dedicated solely to extractive tasks or food procurement processes. In the locations, the activities have a transient nature that includes short-term occupations (Cascalheira and Picin 2020). Hunting camps fall within this category, serving as locations where, following the hunt, prey is selectively processed (Moclán et al. 2021, 2023; Costamagno et al. 2006; Griggo et al. 2011; Rendu et al. 2011). The selection of portions is influenced by factors such as proximity to residential sites and the number of individuals involved and composing the group (O'Connell et al. 1992, Hawkes et al. 2001; Marín et al. 2017). As a result, less valuable anatomical parts, a limited number of lithic items, and occasionally a hearth is left behind, along with evidence of constrained processing activities (Moclán et al. 2021, 2023; Costamagno et al. 2011).

In non-residential sites, quarry sites are also included, which are locations where lithic resources were extracted and initially worked. They are characterised by the exclusive presence of lithic remains at the initial stages of the reduction sequence (Turq 2013).

Inextricably connected to the site typology and the variability within each assemblage are factors such as the length of occupation and the size of the group. There is limited knowledge to calculate group size, and it is normally based on indirect approaches such as ethnography. The number of archaeological remains, size of the occupied area, spatial behaviour, or presence of footprints are potential archaeological indicators of group size, as well as genetic data (Duveau et al. 2019; Gaudzinski et al. 2023; Fabre et al. 2009). That being said, reconstructing the duration of Neanderthal occupations is a rather complex topic. Currently, two recognized occupational models are distinguished: long-term and short-term occupations. Identifying duration of occupations poses a challenging task, given that nearly all archaeological assemblages are palimpsests (Bailey 2007; Lucas 2005). For this reason, long-term occupations are difficult todiagnose. To address the multiple variables involved in determining the duration of an occupation, studies conducted in the field of ethnoarchaeology on modern

hunter-gatherers (Binford 1981; Galanidou 2000) are used as reference. These studies provide general insights into the characteristics of long-term and short-term campsites, with long-term sites typically occupied for several weeks or months, and short-term residential sites used for only a few days or hours (Carbonell 2012). While these ethnographic studies do not serve as direct indicators of occupation duration in archaeological contexts, they offer useful frameworks for understanding what might be expected in terms of site use and occupation length.

In this context, Burke (2006) claims that trying to completely correlate site typologies to archaeological context is unrealistic. The most important problem is related to a lack of temporal correspondence. In contexts where the variability of each assemblage is shaped not solely by the factor of time but also by the behaviour associated with each occupational event, it becomes essential to account for the distinction between the scale of events and the scale of structures (Brooks 1982; Vaquero 2008, 2012). The temporal scope of ethnoarchaeological evidence markedly differs from that of the majority of archaeological assemblages (Harding 2005; Sewell 1996; Giddens 1979; Binford 1981, 1986). The latter ones reflect the period in which they formed, evolving over hundreds or thousands of years during which many natural and cultural processes contribute (Bailey 2007). Moreover, archaeological assemblages are the sum of an unknown number of decisions taken in different moments and to deal with different situations. Frequently, an entire assemblage is attributed to a uniform set of behaviours, under the assumption that identical constraints have influenced all occupational events. This is a groundless assumption as there may have been significant differences concerning circumstances and constraints affecting those events. It will always be difficult, if not impossible, to explain the reasons behind certain behaviours since they are circumstantial, and therefore not always understandable and reproducible in the same way. However, despite the challenges discussed above, it is important to note that there are also numerous ethnographic examples of occupations that fall between these two extremes, such as those lasting a few weeks, which are crucial for understanding the variability in occupation duration.

A further issue is related to the temporal resolution of archaeological assemblage that depends on the difficulty of differentiating single occupations from palimpsests (Vaquero 2008, 2012; Vermeersch 2001). The term palimpsest is widely used in archaeology and in many other disciplines (Bailey 2007; Lucas 2005). In common usage, a palimpsest refers to a superimposition of different activities, whose material traces are partially destroyed or reworked. This process can lead to the complete erasure of information or the partial preservation, accumulation, and transformation of subsequent activities (Bailey 2007; Binford 1981). The geological criteria used to define archaeological deposits -through the identification of stratigraphic sequences- contribute to the creation of an illusory contemporaneity within each level, since all the remains found in the same archaeological unit are included in the same assemblage. Assuming that the remains found in the same stratigraphic unit are the result of a single occupation, and consequently, the activities contained in it are contemporary and carried out by the same human group, would promote distorted reconstructions (Romagnoli et al. 2018). Nevertheless, it is possible to identify situations characterized by particular sedimentological conditions, for example, due to catastrophic events (Marciani et al. 2016), or cases where the sedimentation rate was significantly faster than the cyclicity of human occupations (Bridgland 2000; Antoine et al.2007; Schick 1987). Dissecting processes, particularly concerning occupations, is essential. Delving into human behaviour and assessing the timing of human occupations is crucial (Bargalló et al. 2016, 2020; Fraile-Márquez et al. 2022; Gabucio et al. 2018, 2023; Machado and Pérez 2016). In the majority of Palaeolithic sites, archaeological horizons are characterised by recurring and diachronic occupations. Despite all the aspects mentioned before, and other factors that will be analysed later, some elements have been identified to determine the duration of Late Neanderthal occupations. Some of these features are the volume of archaeological remains, knapping sequence, cores percentage, butchering activities, the degree of carnivore damages, taxonomic diversity, variety of procurement methods, number and characteristics of hearts, spatial distribution, long-connection refit, the extent of the occupied surface, and the evidence of maintenance and cleaning of the work areas, relevant to site management practices, such as the reuse of specific areas and the removal of remains from previous activities (Carbonell 2012; Bargalló et al. 2020; Gabucio et al. 2016; Leierer et al. 2019; Vaquero 1999; Vaquero and Pastó 2001; Vallverdú et al. 2010; Nadel et al. 2004; Fisher and Strickand 1991; Sossa-Rios et al. 2022). The presence of structured activity zones, and possible intentional deposits (caches) of resources or tools, provide valuable data on the long duration of occupations (e.g., Vaquero 1999; Vaquero and Pastó 2001; Vallverdú et al. 2010; Nadel et al. 2004; Fisher and Strickand 1991; Brooks 1982; Yellen 1977; Kuhn 1995; Spagnolo et al. 2020b). However, these aspects have not beendiscussed in this study. Moreover, based on these elements, temporal indicators of occupation duration have been outlined to distinguish and identify short and long-term occupations at the end of the Middle Palaeolithic. Occasionally, a third model, known as the 'brief stopping place', is employed to describe situations where natural or carnivore accumulations featuring limited human activities, with burnt bones being rare or absent, and retouchers being scarce or absent (Daujeard and Moncel 2010; Daujeard et al. 2012a, 2014; Marín et al. 2020; Moncel et al. 2002, 2015; Richard et al. 2021).

According to some researchers (Carbonell 2012; Bargalló et al. 2020; Gabucio et al. 2016; Leierer et al. 2019) short-term occupations are usually assumed when we find few archaeological remains in a reduced settlement area, as well as low taxonomic diversity. In addition, short refit connection, a high percentage of retouched imported tools (not produced in the settlement), and high carnivore activity on the faunal assemblages might indicate short-term occupations, since leftover bones after human consumption would still be fresh and more appealing to carnivores (e.g., Rosell and Blasco et al. 2009; Rosell et al. 2017; Pinto-Llona et al. 2023; Yravedra et al. 2011, 2014; Linares-Matás et al. 2021; Daujeard et al. 2012a). On the contrary, long-term occupations generally involve a high density of archaeological remains in a large settlement area, high taxonomic diversity, low levels of carnivore activity, long refit connection and local raw material acquisition taking place near the site (Carbonell 2012; Bargalló et al. 2020; Gabucio et al. 2016; Leierer et al. 2019).

The Late Middle Palaeolithic, also comprising MIS 3 (70 – 40 ka), is a period that has provided new qualitative and quantitative data for exploring the topic of long- and short-term human occupations from a multidisciplinary perspective. Being aware that the definition of short and long is not clear, it is challenging to identify the duration of an occupation, considering all the aspects that characterise an archaeological assemblage (e.g., the sedimentation rate or the palimpsest effect). The proposed analysis examines the faunal and lithic temporal indicators commonly used in the scientific context to estimate the duration of Neanderthal cave occupations. This reflection is based on an evaluation of the results obtained from these temporal indicators across various archaeological levels from different sites in Spain and south-eastern France, selected for their contemporaneity, their association with previously published multidisciplinary studies, and their clearly defined occupational durations. By comparing the relevant data for each temporal indicator, we assess their applicability. The selection of faunal and lithic temporal indicators, as well as the preference for certain indicators over others, was guided by the availability of consistent data across all the archaeological levels analysed. We prioritized temporal indicators for which data were uniformly available for all levels. It is important to highlight that, as acknowledged in the literature, these temporal indicators are not, as Bargalló et al. (2020) report, "an infallible procedure". Furthermore, while cultural variables remain poorly defined and each site exhibits unique characteristics, our analysis seeks to determine whether these indicators recur consistently across different contexts and, if so, whether they can be considered broadly reliable and applicable, specifically evaluating their recurrence and applicability at the selected sites. Through this approach, we aim to assess how various temporal indicators relate to broader interpretations of the duration of Neanderthal's occupations and critically evaluate their reliability.

Occupational features

The sites considered for this review (Fig. 1) have undergone a comprehensive examination through bibliographic analysis and taking into account a multidisciplinary perspective. For each site, this study considers the majority of aspects recognized so far as indicative of the duration of Neanderthal occupations (Table 1).

The descriptions conducted for this study aim to highlight the actual applicability of these indicators in determining occupational duration. Initially, we have examined features relative to zooarchaeological and taphonomic aspects, followed by those associated with lithic studies. In addition to detailing the chosen characteristics, this study delves into those considered non-applicable elements, exploring possible explanations for their lack of functionality. Ultimately, our aim is to improve the usability of the characteristics that prove functional for subsequent integrations.

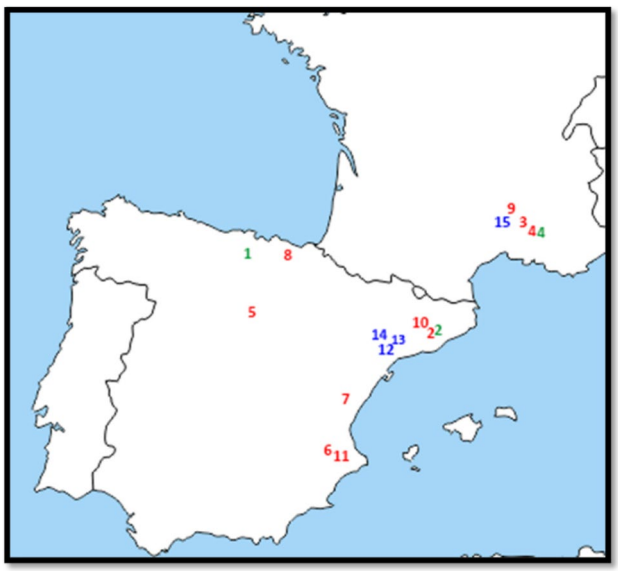

Fig. 1 Location of review sites in Spain and south-eastern France. Long-term occupation in green; Brief stopping place in blue, and Short-term occupation in red. 1: Prado Vargas N4; 2green: Abric Romaní Ja, Jb, M, Ob; 3: Saint Marcel; 4red: Abri du Maras 4; 4green: Abri du Maras 5; 2red: Abric Romaní L, H, I, K, Oa; 5: Navalmaíllo F and D; 6: El Salt X; 7: Quebrada Cave IV; 8: Amalda VII; 9: Grotte du Figuier; 10: Teixoneres Cave III; 11: Abric del Pastor IV; 12: Cova del Gegant; 13: Cova del Rinoceront; 14: Cova del Coll Verdaguer; 15: Abri des Pêcheurs

Table 1 Characteristics utilized to discern occupation duration within the current indicators (Bargalló et al. 2020; Carbonell 2002, 2012; Vaquero and Pastó 2001; Vaquero et al. 2007, Vaquero 2012; Vaquero et al. 2019; Leierer et al. 2019; Cascalheira and Picin 2020; Moclán et al. 2021, 2023; Mallol et al. 2013; Mellars 1996; Marín et al. 2020; Moncel and Rivals 2011).

Feature	Long-term occupation	Short-term occupation
Taxonomic diversity	High	Low
Hunting spectrum	Specialized	Varied
Anthropogenic modifications	High	Medium-high
Carcass transport	Whole carcass/ the best pieces	Different transport strategy
Butchery	Differences related to prey size	Intensive and generalised butchery
Carnivore modifications	Low	High/Medium-high
Raw material	Local	Non-local
Knapping method	*Levallois*	Discoid
Chaîne opératoire	Complete/Mostly complete	Fragmented
Retouched tool	Low	Moderate
Number Remains	High	Low
Raw material diversity	High	Low
Number of cores	High	Low

Zooarchaeological and taphonomic characteristics

Determining the duration of an occupation, whether it occurred continuously with semi-permanent camps or intermittently with short-term regular hunting camps, can indeed be challenging. However, some faunal criteria provide insights into understanding subsistence strategies (Díez and Rosell, 1998), behaviour, and estimating the duration of occupations. Zooarchaeology and taphonomy are disciplines aimed at understanding the intricate relationships between ancient humans and animals. They shed light on the tactics employed by Pleistocene hunter-gatherers in acquiring and managing faunal resources. Aspects such as the representation of different faunal species, their transport to the base camp, and traces of human or carnivore activity on bones (and the relationship between their percentages) provide valuable data for determining the synchronicity or diachrony of activities at an archaeological site. In a multidisciplinary approach, this data helps illuminate the ways of life of human communities during the Late Pleistocene and their evolution over time.

Taxonomic diversity

Among the elements used for identifying the duration of occupations, taxonomic diversity emerges as a highly significant factor (Bargalló et al. 2020; Carbonell, 2002, 2012; Vaquero and Pastó 2001; Vaquero et al. 2007, 2019; Vaquero 2012; Leierer et al. 2019; Cascalheira and Picin 2020; Moclán et al. 2021, 2023; Mallol et al. 2013; Mellars 1996; Marín et al. 2020; Moncel and Rivals 2011). High taxonomic diversity is considered a diagnostic factor for long-term occupations. Conversely, low taxonomic diversity is regarded as a discerning factor for short-term occupations (Table 1).

Among the reviewed archaeological levels identified as short-term and repeated occupations just a few of the analysed assemblages align with the indicators of occupation duration. Only levels L (51.8 ± 1.4) and K of Abric Romaní (50.6 ± 2.0) present what can be considered a low taxonomic diversity, with three taxa represented (Rosell and Blasco 2019). On the contrary, other assemblages identified as short-term occupations show a high taxonomic diversity (Fig. 2). Among those, Navalmaíllo levels F and D (77 and 71 ka) and Teixoneres Cave unit III (> 51–43 ka BP) exhibit 21 and 17 taxa, respectively (Arrianza et al. 2017; Márquez et al. 2016; Moclán et al. 2018, 2020, 2021, 2023; Rosell et al. 2010, 2017). Regarding long-term occupations, the presence of assemblages with a reduced number of taxa stands out. One example is the level M at Abric Romaní (54.5 ka) where, despite being interpreted as a long-term occupation, the taxonomic diversity is represented by seven species (Fernández-Laso et al. 2010; Marín et al. 2017, 2020; Gabucio et al. 2018). This value seems notably restricted when contrasted with the 16 species recovered at the Prado Vargas site level N4 (54.7 to 39.8 ka BP) which is also recognized as a long-term occupation (Alonso-García et al. 2020; de la Fuente Juez et al. 2020, 2023; Navazo Ruiz et al. 2021; Santamaria et al. 2021; Vallejo et al. 2017).

In the context of taxonomic diversity, carnivores also play an important role. Their impact is noteworthy, as discerned at Cova del Gegant (~ 94–52 ka). This cave, identified as a 'brief stopping place' exhibits no signs of human habitation; rather, it has solely witnessed the activity of carnivores (Daura et al. 2022; Sanz et al. 2017). However, a considerable taxonomic diversity is observed, with 17 taxa documented. This suggests that predators had a wide range of prey available, and they introduced them into the cave.

From what is highlighted, it seems that both long-term and short-term occupations can exhibit high taxonomic diversity.

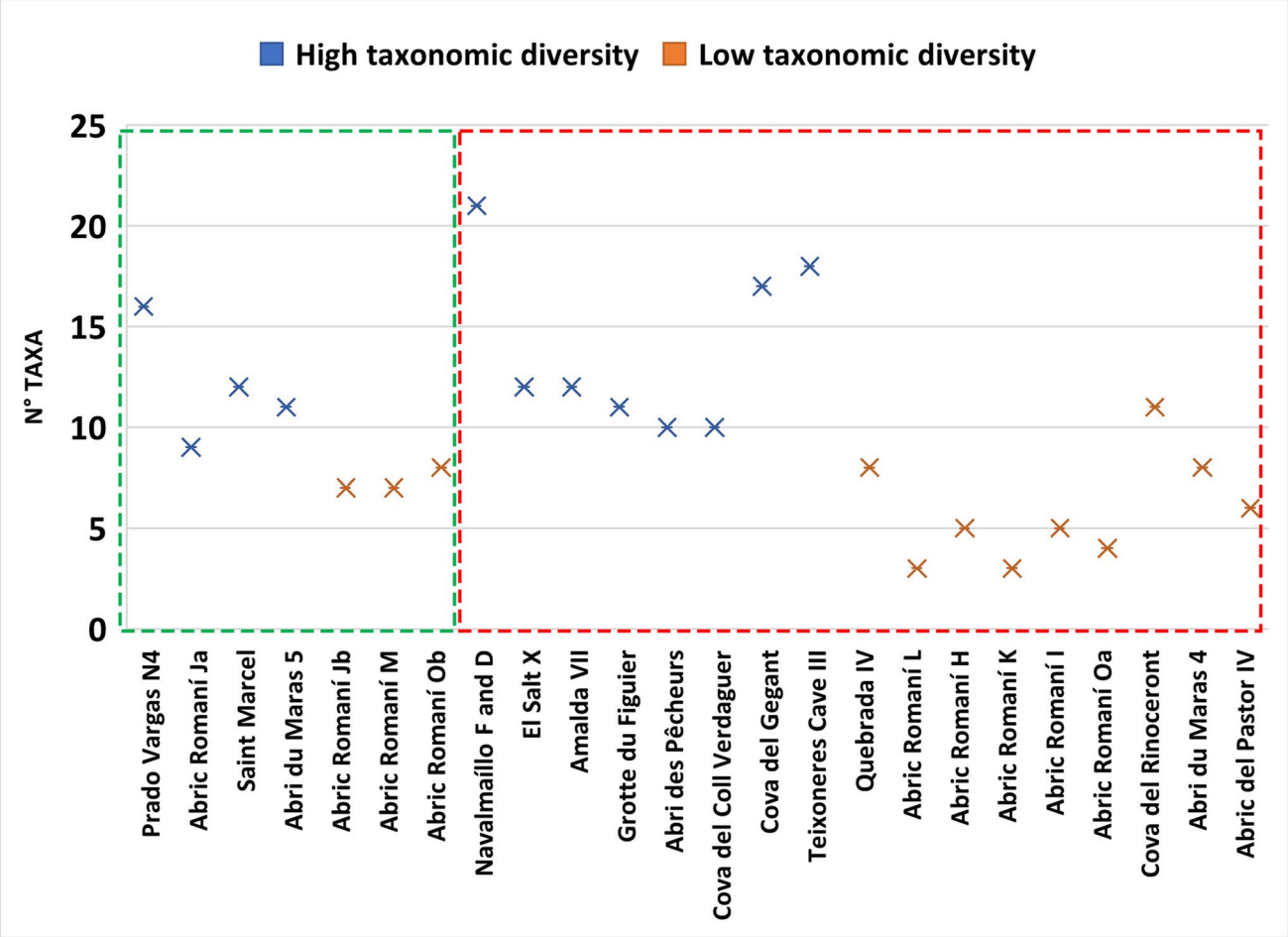

Fig. 2 Taxonomic diversity comparison among previously identified sites, classified as long (in green rectangle) and short-term occupations (in red rectangle). See Supplementary information to look for the additional references used for each archaeological context

Hunting spectrum

Hunting spectrum, or the assessment of the array of animals hunted by human groups, represent another key variable employed in examining the duration of Late Neanderthal occupations. The hunting spectrum differs from taxonomic diversity, which refers to the variety of species found in a faunal assemblage, regardless of whether they were hunted or used by humans. The hunting spectrum, on the other hand, refers to the range of animals hunted by human groups at the site.

In this context, there is a general assumption that short-term occupations are characterised by a varied hunting spectrum, whereas long-term occupations exhibit a specialised hunting spectrum (Table 1) (e.g., Daujeard and Moncel 2010; Marín et al. 2020). In the taxonomic records of the reviewed short-term occupation assemblages dating to the end of the Middle Palaeolithic, a consistent observation emerges: one or more species consistently outnumber others. The only case where there seems to be a varied hunting spectrum is of Amalda I cave level VII, dated between 44.5 and 42.6 ka uncal BP (Sánchez-Romero et al. 2020; Yravedra 2010) (Fig. 3).

Regarding long-term occupations, the majority of study cases explored exhibit a total of three or four taxa (Fig. 3), not a single species as Burke's definition (2000) would suggest. Exclusively, level M of Abric Romaní (52.2 ka) and Saint Marcel (around 42 ka) show a prevalence of red deer, even if Saint Marcel, has also been defined as a selective hunting of red deer place (Richard et al. 2021; Daujeard et al. 2012a, 2014; Daujeard and Moncel 2010; Moncel et al. 2010, 2015; Lateur et al. 2023).

Anthropic modifications

The percentage of anthropogenic bone surface modifications (BSM) is another parameter that provides information about the duration and the type of occupation (residential, seasonal or transient) (Daujeard et al. 2012a; Daujeard and Moncel 2010).

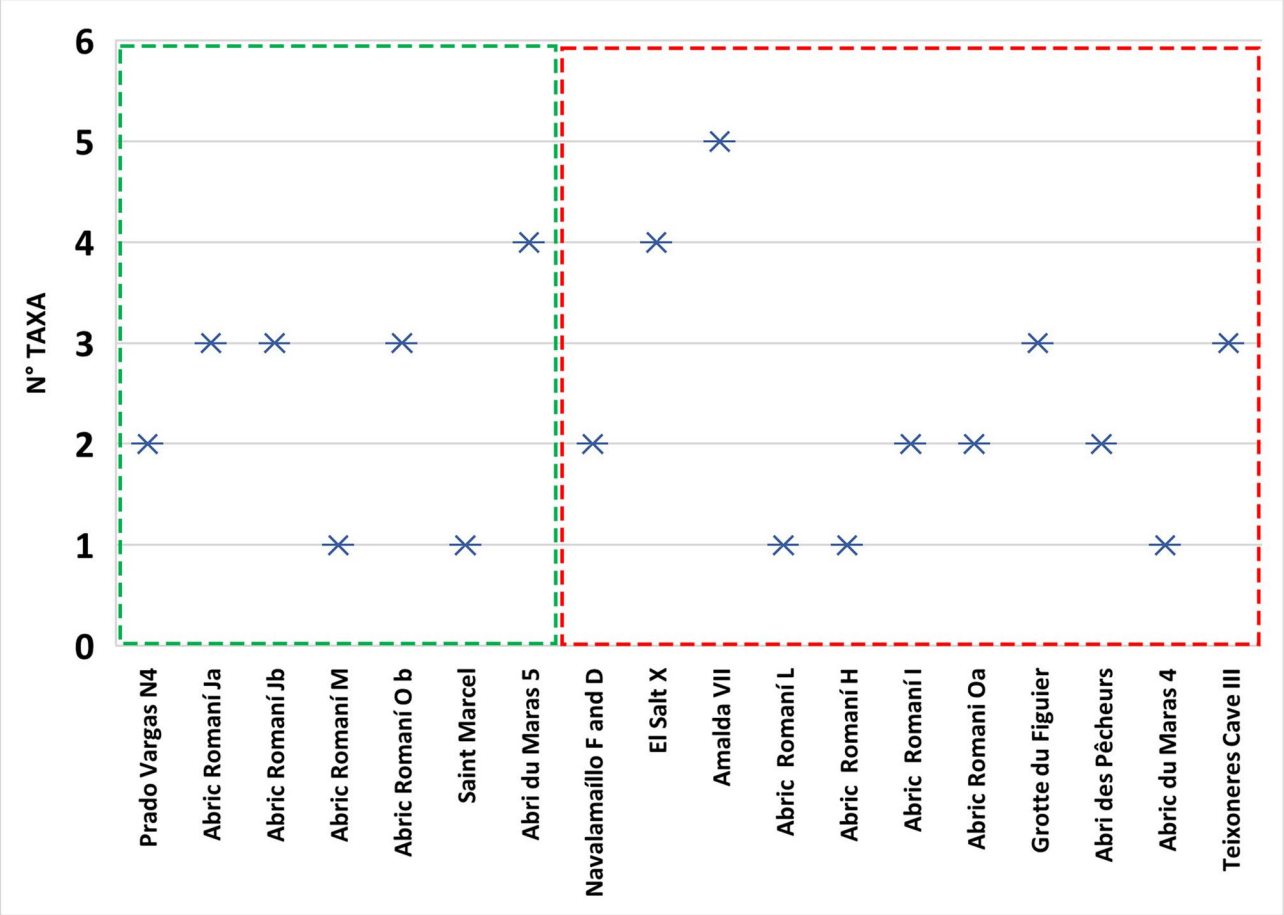

Fig. 3 Differentiation of the Hunting spectrum among reviewed sites; long-term occupations in the green rectangle, short-term occupations in the red one. Some assemblages were excluded due to incomplete data. See Supplementary information to look for the additional references used for each archaeological context

Human BSM encompasses all alterations associated with human activities (cut marks and all products resulting from bone percussion). According to the indicators identified to determine the duration of occupations, long-term occupations tend to show a high value of anthropogenic modifications related to the prolonged human presence at the site (Table 1). Conversely, for sites with short human presence, the traces related to human activity decrease. In addition, in most cases, the absence of humans is a higher prevalence of carnivores, leading to corresponding damages.

To verify this trait, percentages of bones with anthropic traces were calculated, considering the total Number of Remains (NR) in each faunal assemblage. Among the sites identified as long-term occupations, in most of the cases (Fig. 4), the indicator works well. Only Abric Romaní level Jb (50 ka) shows a relatively low percentage of anthropogenic damage (8.6%) (Rosell et al. 2012b), and level Ob of the same site (54.6 ka), whose percentage is not particularly high in relation to the NR (20.7%) (Gabucio et al. 2016).

For short-term occupations, the indicator seems to work correctly, including the brief stopping places. Very short human occupation may justify the high percentage of carnivores and the absence of human activity. Navalmaíllo levels D and F, El Salt X (around 52 ka), Abric Romaní levels L and Oa (around 55 ka) do not seem to fit into the indicator, as they are defined as short-term occupations, but the percentage of anthropogenic modifications is relatively high (Fig. 4) (Moclán et al. 2021; Pérez 2019: Fernández-Laso 2010; Gabucio et al. 2016. See supplementary information for additional references).

Carnivore modifications

Throughout the entire Pleistocene period, humans shared the use of caves and shelters with carnivores (Enloe 2011; Yravedra et al. 2022; Blasco et al. 2019; Rosell et al. 2010; Pinto Llona et al. 2023; Zilio et al. 2021; Shipman and Phillips-Conroy 1977; Brain 1981). Both entities alternated the use of the same spaces but at different times, as cohabitation

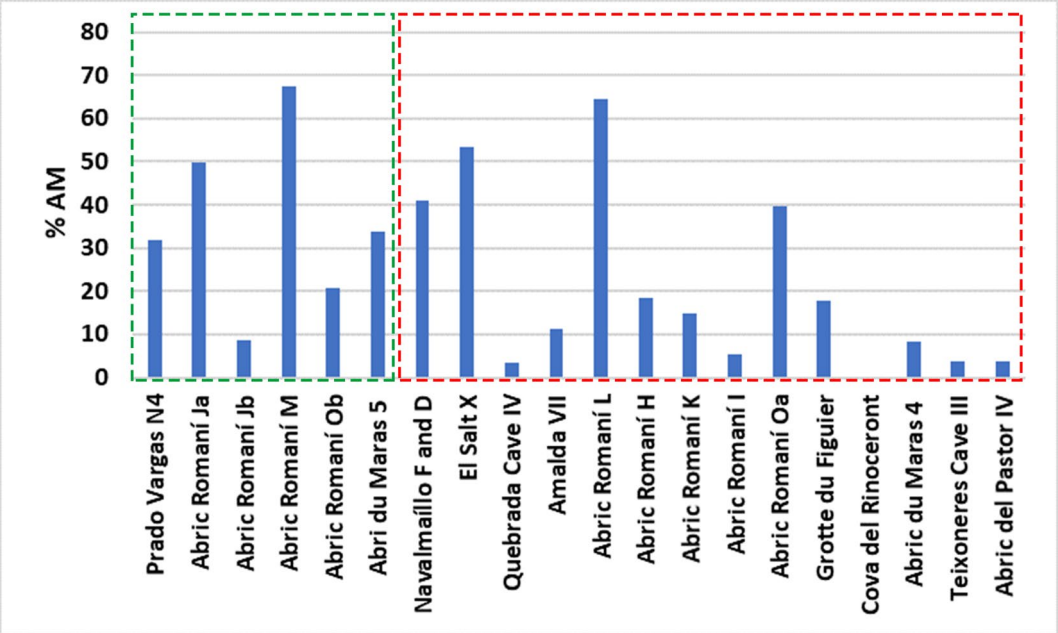

Fig. 4 Percentage of anthropogenic modifications for each site based on their duration. In the green rectangle are the long-term occupations, and in the red one the short-term occupations. Only sites with complete data have been included. See Supplementary information to look for the additional references used for each archaeological context

at the same time was not possible also due to competition for the same prey based on their ethology. Winter seemed to be the preferred season for most bear species, while hyenas and other smaller carnivores could exploit these refuges during their respective breeding seasons (Torres et al. 2007). Villa et al. (2004) documented different types of archaeological sites frequented by both humans and carnivores. These archaeological assemblages show existence of both human and carnivore occupations, albeit during distinct time periods. The presence of human groups is usually easy to detect by identifying lithic artefacts, hearths, and bones showing signs of human modification (Rosell et al. 2017). However, it is important to note that artefacts could have been moved by sediment flow (Villa and Sorressi 2000; Bertran and Lenoble 2003, 2007, 2009, 2012). Additionally, other taphonomic processes, such as the action of carnivores or burrowing (Villa and Sorressi 2000; Lyman 1994a; Behrensmeyer 1978), or the solifluction (e.g., Hjort et al. 2014) could have further altered evidence of previous occupations. Regarding the duration of occupation, the presence of carnivores complicates its understanding (Rosell et al. 2010, 2017). The presence of both accumulation agents complicates the palimpsest characteristics of archaeological sites (Fosse et al. 1998; Stiner 2002). According to the model indicator used to identify occupations, the percentage of carnivore activity is relevant. Short-term occupations show a high percentage of carnivore modifications, while long-term occupations show a low percentage (Table 1). The reassessment and a subsequent comparison were conducted to observe the reliability of the indicators. Among sites interpreted as long-term occupations, it is seen that all exhibit a low percentage of carnivore damages, while differences emerge among short-term occupations (Fig. 5). For example, at the Navalmaíllo site, levels F and D are defined as hunting camps (e.g., Moclán et al. 2021), while at El Salt level X and the Abric Romaní levels L and Oa, a low percentage of carnivore damage is observed, as well as a high amount of human modifications (Pérez 2019; Fernández-Lazo 2010; Gabucio et al. 2016) (Fig. 5).

Carcass transport

Another criterion proposed for measuring the duration of occupation is the indicator of carcass transport from the hunting camp to the residential site. Ethnoarchaeological studies play an important role in this reconstruction (e.g., Binford 1978b; O'Connell et al. 1992; Lyman 1994b). It is rare that the place where the animal resource is acquired coincides with the group's residence space, where resources are shared (Binford 1984; Vaquero 2008; Díez and Rosell 1998). In the selection of skeletal parts to transport, crucial factors emerge in the decisions made by human groups, such as the size of the prey, the time of acquisition of the animal, the number of available carriers, and the distance from the camp (O'Connell et al. 1988, 1990; Marín et al. 2017; Schoville and Otárola-Castillo 2014). Additionally,

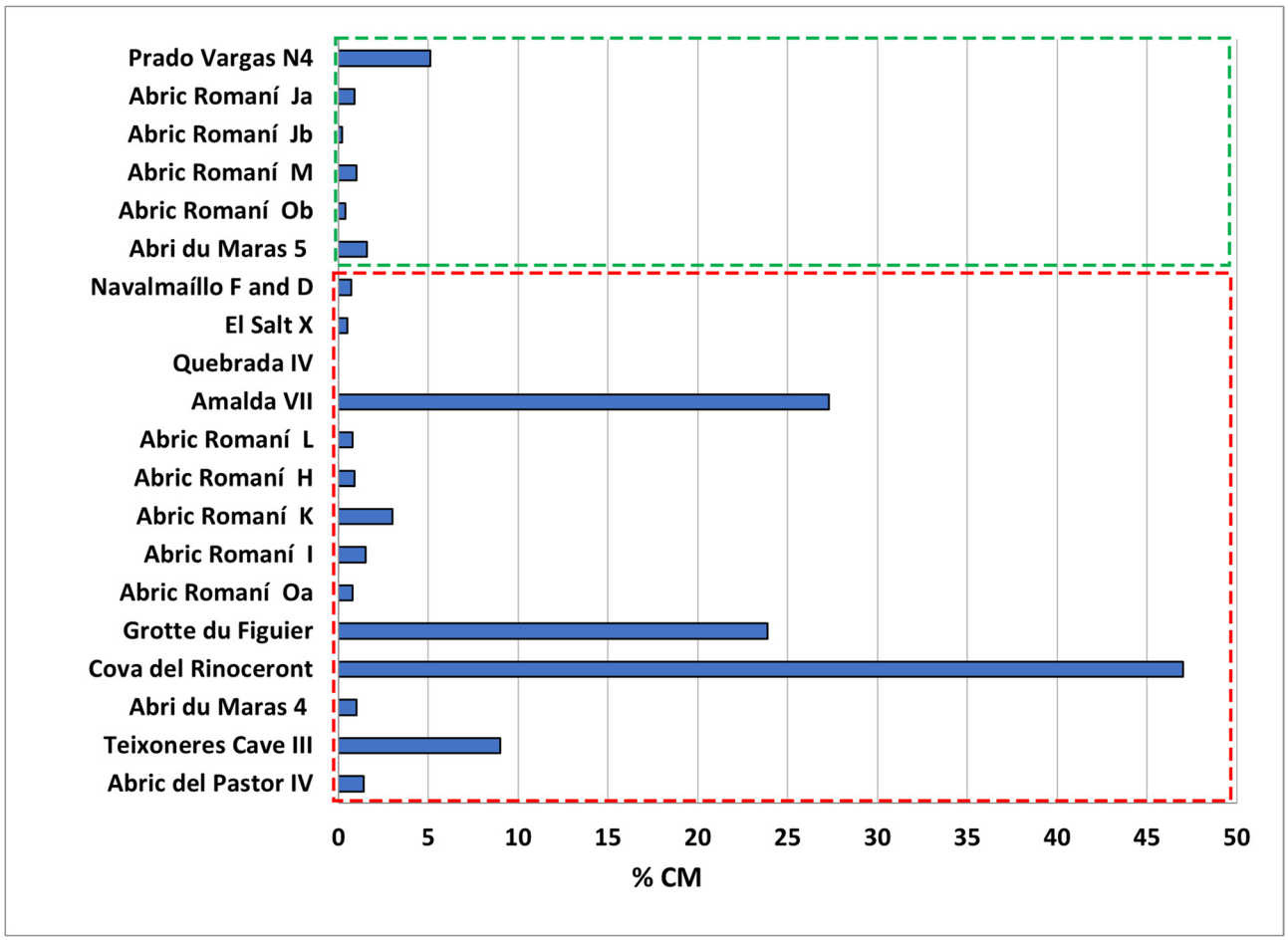

Fig. 5 Percentage of carnivore modifications for each site based on their duration. Short-term occupations are in the red rectangle, and long-term occupations in the green triangle. Only sites with complete data have been included. See Supplementary information to look for the additional references used for each archaeological context

Oliver (1993) introduces a new crucial factor: the technology available for processing the animal, distinguishing between pre-fire, post-fire, pre-boiled bones, and post-boiled bones.

According to the general indicator for identifying occupation duration (Table 1), short-term occupations are characterized by different transport strategies compared to long-term occupations, which involve transporting the entire carcass or the best portions (e.g., Marín et al. 2020). Both types of occupation show the presence of prime carcass parts, with the exception of Quebrada Cave level IV (short-term occupation), where transport strategies are linked to prey size (Real et al. 2020). The primary difference between occupation types lies in the processing of the carcass: long-term occupations show intensive butchering with all phases present, while short-term occupations exhibit variations depending on prey size. For instance, in long-term sites like Saint Marcel and Abri du Maras level 5 (dated between 70 and 90 ka), the entire carcass is processed (Daujeard and Moncel 2010; Marín et al. 2020), a pattern not observed in short-term sites. An exception to this indicator is level N4 at Prado Vargas, where initial butchering occurred at the hunting site (de la Fuente Juez et al. 2023).

Lithic characteristics

Among the various proposals for distinguishing occupation types, the lithic record stands out as a significant component to consider. Many of these proposals, with the notable exception of associating specific technological systems with occupation durations, are rooted in the research of Kuhn (1989, 1992, 1995). According to Kuhn, short-term occupations are characterized by high mobility, the use of exogenous raw materials, assemblages with few lithic remains, a high percentage of tools, and fragmented reduction sequences. In contrast, long-term occupations

are associated with low mobility, reliance on local raw materials, and complete or nearly complete lithic reduction sequences.

Each of these features is analysed in detail below, with a discussion of the strengths and limitations of the applied parameters provided at the end.

Raw material

The notion of raw material is notably employed in discussing the duration of occupations. The choice of raw material is underpinned by the concepts of mobility and occupation length, as the distance from procurement areas may influence the quantitative and qualitative selection of what was transported. Kuhn (1989) promotes the creation of two types of contexts upon which the indicator used for identifying the duration of occupations is based. The first of the two contexts involve high mobility, non local raw materials, and short-term occupations, while the second context involves low mobility, local raw materials, and long-term occupations (Table 1). Specifically, mobility refers to how hunter-gatherers organised themselves to address issues related to resource procurement (Kelly 1983). Beyond the distinction between 'residential mobility' and 'logistical mobility' (Binford 1980), the concept of 'foraging radius' was introduced. Foraging radius refers to the daily distance covered by hunter-gatherers from their residential camps. This distance is crucial for obtaining food and other essentials for survival (Morgan 2008; Binford 1982). While readily identifiable in ethnographic contexts, the foraging radius has proven extraordinarily complex to pinpoint in prehistoric settings (Morgan 2008). Despite numerous studies on mobility, determining the actual distance remains challenging. Even if there is extensive research to define the concept of local and exogenous raw materials (Geneste 1985, 1989), it is difficult, if not impossible, to quantify the distances travelled for their procurement. Fernández Peris et al. (2008) place the concept of 'local' within a range of less than 5 to 20 km and categorise exogenous raw material' within the distance of 30 to 100 km. Gómez de Soler et al. (2020), in their study of Abric Romaní, initially considered a 16-kilometre radius as the boundary for local raw material procurement. Examining the P level, this boundary has been expanded to 24 km, with almost half of the utilised chert coming from that distance. Similarly, certain authors, such as Brantingham (2003), attribute some resource procurement to the result of fortuitous encounters with geological outcrops. Some researchers (e.g., Turq 2000, Gómez de Soler et al. 2020) categorise materials as local when collected within a range of 5–10/15 km, semi-local between 15–25 km, and non-local when exceeding 25 km. Despite the extensive research on raw material sourcing, it is essential to acknowledge certain limitations in using raw materials as an indicator of occupation duration. The proportion of specific resources, which can be classified as either local or non-local, may not solely depend on distance from procurement areas but also on technical or cultural factors. For instance, preferences for particular resources or the quality of available materials could significantly influence raw material selection.

Additionally, economic and social factors might have played a primary role. Periodic expeditions by specific segments of a group, aimed at retrieving crucial resources located at great distances—an idea already highlighted by Binford (1980)—could have resulted in the presence of non-local materials. Such expeditions suggest the existence of intergroup relationships and exchanges that may have further shaped the availability of raw materials within lithic assemblages.

These considerations highlight the complexity of interpreting raw material use and caution against overly simplistic correlations with occupation duration. Instead, broader dynamics, including social, cultural, and economic factors, should be taken into account to refine our understanding of raw material distribution and its implications. Further insights, as reported in Carbonell (2012), emphasise the significance not only of distance but also of other elements such as the integrity of the *chaîne opératoire*, on-site or off-site flaking, that is the type of lithic elements knapped at the site versus those introduced as a mobile toolkit.

In the current study, despite the use of Kuhn's model (1989) to identify the duration of occupations (e.g., Daujeard and Moncel 2010; Marín et al. 2020; Picin et al. 2020a; Bargalló et al. 2020; Leierer et al. 2019; Vaquero et al. 2019; Carbonell 2012), it is highlighted in particular a case where the temporal indicators of occupation duration are not applied. This occurs at Teixoneres Cave unit III and in the Level IV of Quebrada Cave (51–43 ka BP) (Table 2). This last assemblage is identified as a short-term and recurrent occupation through the analysis of seasonality, which is confirmed by the exploitation of carcasses, taphonomy, and stone tool refitting, as well as by the predominance of local raw materials (Real et al. 2019, 2020; Eixea et al. 2016, 2021). Nevertheless, the relevant distance for the raw material procurement areas is situated between five and eight kilometres. Furthermore, it is underscored that the absence of a universal criterion for defining local and exogenous raw materials poses challenges in categorising the nature of the raw material. For example, even though Abri du Maras level 4 is considered in its entirety, the raw materials are described as local/semi-local in subunit 4.1 (~ 49 and 40 ka) and mostly local in sub-level 4.2 (~ 57–45 ka), despite the distance falling between 3–30 km for sub-level 4.1 and 15–30 km for 4.2 (Table 2) (Moncel et al. 2021).

Table 2 Comparison of *Levallois* (L) and Discoid (D) knapping techniques between sites classified by long and short-term occupations, along with the distance of their raw material procurement. "-" means no information available. Please refer to the Supplementary Information for additional references used and furtherdetail

Archaeological site	Raw material	Knapping method
LONG-TERM OCCUPATIONS		
Prado Vargas N4	Local	Mostly D
Abric Romaní Ja	5–25 km	Mostly D
Abric Romaní Jb	5–25 km	Mostly D
Abric Romaní M	5–16 km	D
Abric Romaní Ob	10–16 km	Mostly L
Saint Marcel	Local/Semi-local	D
Abri du Maras 5	Local	D/L
SHORT-TERM OCCUPATIONS		
Navalmaíllo F and D	5–20 km	L/D
El Salt X	5–25 km	L/D
Amalda VII	-	L/D
Quebrada Cave IV	5–8 km	Mostly L
Abric Romaní L	14–16 km	D
Abric Romaní K	15–20 km	D
Abric Romaní H		D/L
Abric Romaní I	5–15 km	D
Abric Romaní Oa	15–25 km	Mostly L
Abri des Pêcheurs	Local	D
Le Figuier	-	D
Cova del Rinoceront	-	hierarchical structure similar to that characterising the *Levallois*
Cova del Gegant	-	L/D
Abri du Maras 4	-	Mostly L
Abri du Maras 4.1	3–30 km	-
Abri du Maras 4.2	15–30 km	-
Teixoneres Cave III	Local and non-local	L/D
Abric del Pastor IV	15 km	L/D

It is important to note that, within sites identified as short-term occupations, the majority present non-local raw materials (Table 2), which seems to contradict Kuhn's 1989 model and the indicators used so far to identify occupations. In general, the absence of a defined value to specify what is meant by local and non-local means makes it difficult to identify the distances of the raw material for the considered sites. Indeed, for example, both Abric Romaní level Ja dated to 50ka (long-term occupation) and El Salt level X (short-term occupations) show the same distance for the raw material (5–25 km) (Table 2) (Carbonell 2012; Machado and Pérez 2016). Lastly, concerning brief stopping places, defined as very short human presence, high mobility, and exogenous raw material; they exhibit the use of local raw material. This is the case of Abri des Pêcheurs or Cova del Rinoceront dated between (Daujeard and Moncel 2010; Moncel and Lhomme 2007; Moncel et al. 2008; Daujeard et al. 2012a, 2014; Daura et al. 2015; Rivals et al. 2016; Sanz and Daura 2018) (Table 2).

Knapping methods

Several scholars (e.g., Picin and Carbonell 2016; Picin et al. 2020a; Carbonell 2012; Vaquero and Pastó 2001; Vaquero et al. 2007, Vaquero 2012; Vaquero et al. 2019; Cascalheira and Picin 2020; Chacón et al. 2013) emphasise differences in knapping methods - discoid and *Levallois* -related to the duration of occupation. This contrast stems from the distinctive features of each technique. Discoid technology is noted for its lower degree of predetermination, but prolific. Furthermore, its enhanced versatility results in its ability to be applied to a broader range of raw materials compared to *Levallois* (Delpiano et al. 2018; Eixea et al. 2016, 2021). This characteristic renders it less constrained by ecological limitations, particularly in situations lacking high-quality raw materials, and it is easily adaptable for exploitation of local resources (Turq et al. 2017).

The discoid method requires fewer preparation and maintenance for the extraction process compared to the

Levallois method, and it is in consequence associated with short duration activities (Carrión et al. 2008; Bertola and Peresani 2000; Picin et al. 2020a; Real et al. 2019). On the other hand, *Levallois* is related to an elevated conceptual elaboration, and typically linked with higher quality and non-local raw materials (Navazo Ruiz et al. 2021). Thus, some scholars argue that the techno-economic analyses of a *Levallois* assemblage could provide descriptive comparisons to reconstruct planning depth, specialised activities, and determine whether a site occupation was ephemeral or prolonged. Turq et al. (2017) consider the model developed by Delagnes and Rendu (2011), which associates each mobility pattern with a distinct technological system. This model links lithic production to strategies for hunting large ungulates, and suggests that a greater use of the discoid method is related to more opportunistic hunting. The conducted review highlights some incongruences in this argument, as it has been observed that the majority of sites identified as long-term occupations have a higher prevalence of the discoid method (Table 2).

Conversely, among short-term occupations, there are cases of discoid and *Levallois* knapping techniques coexisting. Teixoneres Cave unit III is one of them, also showing a connection between the choice of one or the other method and the type of raw material quality. Specifically, the discoid technique is adopted for local raw materials (mainly quartz), which are of lower quality, while the *Levallois* method is employed for the non-local raw materials that present higher quality (e.g., flint) (Bustos-Pérez et al. 2017; Picin et al. 2020b) (Table 2). Contrary to that, there are other sites, such as in the Quebrada Cave level IV (Eixea et al. 2016; Real et al. 2020), where *Levallois* artefacts were crafted using non-optimal quality raw materials, all of which were autochthonous. Regarding long-term occupations, despite the indicator suggesting the use of the *Levallois* method, none of the sites analysed exhibits exclusive use of this technique (Table 2).

Chaîne opératoire

The concept of '*chaîne opératoire*', or 'operational sequence' (also known as 'core reduction sequence') is borrowed from French social anthropologists and has been widely used by researchers in Prehistory. This integration occurred initially within the realm of lithic studies (e.g., Geneste 1985; Boëda 1988), emerging from the need to determine the technical activities involved in the production of lithic tools. Its conceptual framework aims to understand the comprehensive technology and different stages that play a role in transforming raw materials into tools (Bar-Yosef and Van Peer 2009). The concept of the *chaîne opératoire* is used in the model as one of the indicators applied to define the duration of occupation. It suggests that long-term occupations are characterized by complete or mostly complete knapping sequences.

The rationale behind this indicator reflects the idea that the longer residing in a site, the more need there is to knap *in situ*. For this reason, it is expected to find all or almost all phases of the lithic sequence.

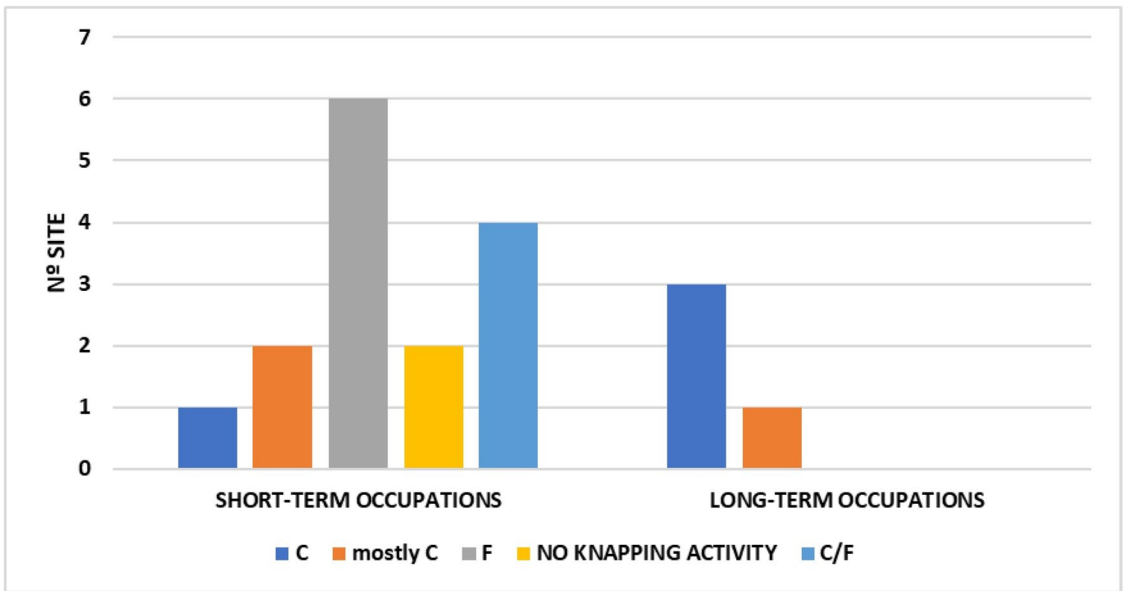

Fig. 6 *Chaîne opératoire* comparison among archaeological sites categorised by long-term and short-term occupations. C: Complete; mostly C: mostly complete; F: Fragmented; C/F: simultaneous presence of complete and fragmented *chaîne opératoire*. See Supplementary information to look for the additional references used for each archaeological context.

Among the analysed sites identified as long-term occupations, all display complete or mostly complete *chaîne opératoire* (Fig. 6).

Conversely, the application of the indicator becomes more complicated when considering short-term occupations. In this case, three descriptions can be highlighted. Some sites agree with the model used to identify the occupation, as they present a fragmented *chaîne opératoire*, while others exhibit a knapping sequence that is complete or almost complete (Fig. 6). Lastly, archaeological assemblages such as Teixoneres Cave unit III and Navalmaíllo Rock Shelter Levels F and D, document autochthonous raw materials and on-site knapping, unlike non-local raw materials, were introduced at the site as final products (e.g., Picin et al. 2020b; Márquez 2013) (Fig. 6).

Retouched tools

Among the features used to identify the duration of occupation, retouched tools deserve a separate discussion. Vaquero (2008) argues that retouch represents the use history of a lithic tool. A retouched tool, accompanying the human group, enjoys an extended lifespan — from its initial production, through being carried along, to its actual usage. In this context, it surpasses the longevity of an unretouched flake, despite the unretouched items also being part of the toolkit. Generally, Neanderthals' tools are multipurpose with a low degree of functional specialisation. The rate of retouched tools is low and the majority are realised with exogenous raw material (Romagnoli et al. 2022; Barroso Ruíz 2003; Bustos-Pérez et al. 2017; Chacón et al. 2007). The greater presence of retouched tools made from exogenous raw materials can be explained by their use in toolkit production. According to the model for identifying the duration of occupations, long-term occupations exhibit a lower percentage of retouched tools, while short-term archaeological sites are characterised by a higher percentage of retouched tools (Table 1).

However, several authors, such as Kuhn (2004a, b), Kuhn and Clark (2015), and Riel-Salvatore and Barton (2004), relate the percentage of retouched tools to the artefact density in order to infer occupation duration. In fact, it's rather odd that this index is missing from this analysis (if not included, at least mentioned). Yet, other elements must also be considered in these analyses, including the quality and use of raw materials, as well as the overlap of different occupational events. Multiple short-term occupations, repeated over time, can lead to results similar or equivalent to those observed in long-term occupations.

Contrary to the model, however, there are some of the revised sites interpreted as long-term occupations, where retouched tools are represented in relatively high percentages, such as the case of Saint Marcel (approximately 35%) (Moncel et al. 2015). In the same manner, most short-occupation sites show a high percentage of retouched tools. Additionally, as brief stopping places, Cova del Rinoceront is noteworthy, presenting almost 15% of the tools in the site retouched (Daura et al. 2015).

Discussion

The indicators to identify the duration of Neanderthal occupations (Bargalló et al. 2020; Carbonell, 2002, 2012; Vaquero and Pastó 2001; Vaquero et al. 2007; Vaquero 2012; Vaquero et al. 2019; Leierer et al. 2019; Cascalheira and Picin 2020; Moclán et al. 2021, 2023; Mallol et al. 2013; Mellars 1996; Marín et al. 2020; Moncel and Rivals 2011) considered different aspects whose application need to be discussed.

Application of zooarchaeological parameters to the interpretation of occupations

When applying **taxonomic diversity** for the identification of the duration of occupation, this parameter is often applied without adequate consideration of other factors that might influence this rate. There are three main aspects to consider when evaluating taxonomic diversity at the archaeological level (Blasco et al. 2013).

- The first is environmental availability, which affects the extent of environmental diversity accessible to human populations in a specific context. This involves actual constraints imposed by the distribution and availability of prey. The ecological context in which the site is located, along with the availability, variability, and predictability of resources, significantly influences the taxonomic profile encountered (Burke 2000). For this reason, an environmental context characterised by a mosaic environment promotes high taxonomic diversity. Finally, environmental changes and pressure influence human adaptive strategies and, consequently, diet, favouring the hunting of certain taxa - the most available ones - over others (Vaquero et al. 2012).
- The second factor is influenced by human behaviour, as capturing prey often requires decision-making. In a setting characterised by diverse faunal availability, hominids could select specific animals to hunt. Within this framework, the focus is on decisions shaped by contingent circumstances and economic strategies that consider the energy expenditure associated with the quality of resources, as explained by the principles of the Optimal Foraging Theory. This model assumes that resource selection is driven by the need to maximize

energy returns relative to acquisition costs, although human behaviour may also be influenced by cultural standards, social dynamics, and technological constraints (e.g., Blasco and Fernández Peris 2012; Blasco et al. 2013; Bettinger 2009; Vaquero 2012).

- Finally, the third factor is influenced by the type and duration of occupations. Prolonged human presence, contributing to enhanced territorial control, fosters a high variability of species potentially hunted. However, both the enduring human presence resulting from extended occupations and the existence of brief, repetitive occupations produce a similar taxonomic record. This phenomenon is attributed to the palimpsest effect. The low sedimentation rates occurring in sites such as caves and shelters, play an important role on the superposition of occupations, making them difficult to differentiate and, in consequence, mixing up different events and creating a pseudo-taxonomic diversity. In contrast, for short-term occupations, the most abundant taxa usually reflect the taxonomic availability in the immediate surroundings, without following a selection criterion (David and Kramer 2001). In addition to this, there is a possibility that sites were used as seasonal hunting places. In these sites, it would be expected a selective hunting of species (Bökonyi 1972; Speth and Davis 1976; Burke 2000). The abundance of specific taxa in the area during specific periods of the year may have prompted human presence in a site. This greater availability does not exclude the possibility that other less available species could have also been hunted.

When considering taxonomic diversity, other aspects are not considered, such as the volume of the archaeological record in relation to sedimentation rates, the influence of carnivore activity, or the potential spatial structuration and occupation (Blasco et al. 2013). Moreover, it seems that most short-term occupations with high species variability result from brief but repetitive occupational events. Occupations during different seasons of the year could explain the high taxonomic diversity in a site. Also, carnivore activity, as observed in brief stopping places where traces of human occupation are extremely scarce, can contribute to high species diversity, as carnivores contributed with additional prey to the archaeological record.

In addition to what has been said, a notable challenge when interpreting Late Neanderthal occupations lies in the ambiguity surrounding the definition of low or high taxonomic diversity. The research published by Blasco et al. (2013) designates up to three species as 'dominant taxa', with any species exceeding this count labelled as 'non-dominant species'. Moreover, the same analysis defines a faunal record as exhibiting high taxonomic diversity when it incorporates more than fifteen species. Thus, there is no consensus in the existing literature to establish a range number to clearly define what is understood as 'low' or 'high' taxonomic variability. The response to this gap could be addressed by employing Simpson, Spearman, and Shannon indices (Faith and Du 2018; Faith and Gordon 2007). These indices are employed in archaeology, each serving to the degree of taxonomic diversity, assess the concordance between classifications related to two variables, and measure biological diversity in a sample. Despite the emergence of contradictory cases, observing taxonomic diversity does not seem unreasonable, as long as the need to carefully consider all the factors mentioned earlier and apply them to individual archaeological contexts before using this feature to identify the duration of the occupation is clear.

Connected to the discussion on taxonomic diversity is the application of the **hunting spectrum** within the indicators. A distinct aspect, intricately connected to the concept of occupation duration, warrants specific attention: the 'specialised hunting spectrum'. This strategy during the Mousterian has been widely questioned (Chase 1989; Costamagno et al. 2006; Mellars 2004; Grayson and Delpech 2002), while it is broadly employed in the Upper Palaeolithic (Klein 1989, 1998; Klein and Cruz-Uribe 2000; Klein et al. 2004; Mellars 2004). Recent studies have suggested that specialised hunting is already documented in the Middle Palaeolithic, similarly to how this hunting strategy persists in much later periods (e.g., Adler et al. 2006; Gaudzinski 2006; Costamagno et al. 2006; Daujeard et al. 2019; Yeshurun et al. 2007; Delagnes and Rendu 2011), and prompting a revaluation of archaeological assemblages. From these data, it emerges that the indicator for identifying occupations based on the hunting spectrum has some shortcomings, mainly due to the lack of a clear definition of what specialised hunting is (Costamagno et al. 2006; Chase 1987). Binford (1968) or David and Enloe (1993) described specialised hunting as a collective activity involving a large number of prey, emphasising the importance of collective effort for their processing and preservation. This strategy requires a high level of collaboration and the anticipation of prey movements. Mellars (1973) and White (1982) proposed that specialised hunting is characterised by a significantly higher frequency of a particular species compared to other exploited taxa. Connected to this aspect, the difficulty arises in truly understanding whether it involves 'obligate' choices (linked to environmental availability) or 'deliberate' specialisation. This latter concept is also tied to the knowledge of Neanderthal groups that, moving through the territory, knew the areas to find abundant faunal resources at specific times of the year (for example, a herd of horses). Lastly, Burke (2000), quantifying the number of species to define specialised hunting, identifies it as a representation of a single taxon. She defines selective hunting when the prevalent species are one or two. The more

pronounced presence of certain species compared to others challenges the hypothesis of specialised hunting and opens up two possible interpretations. The first interpretation sees the identification of these faunal records as the result of selective hunting (Burke 2000; Moncel et al. 2015). The second would be related to the greater availability of such taxa in the surrounding environment.

Considering these reflections, does the evidence support the notion of specialised hunting, or are we consciously choosing the resource that we know will be most available at a given moment? This does not exclude the possibility of integrating less available species into the diet but present in the surrounding environment.

According to the indicators currently used to identify the duration, short-term occupations should present a varied hunting spectrum, while in long-term occupations, the prevalence of certain species over others would be observed. While much effort has been invested in defining specialised hunting – albeit without reaching a unanimous consensus – there is a lack of clarity regarding the definition of the term 'varied'. Furthermore, reflecting on this matter, it is important to highlight an additional aspect. If occupations were brief but repeated at different times of the year, it might be misleading to incorrectly identify the taxa obtained during various occupations and in different seasons as belonging to a single occupational period. Similarly, a long-term occupation across various seasons could favour the availability of more species to hunt. In light of these considerations, the hunting spectrum appears not to be particularly useful for the purpose of identifying human occupation. In conclusion, the hunting spectrum, along with taxonomic diversity to some extent, is also linked to the ability to identify faunal remains. High levels of fragmentation or inadequate preservation of bone surfaces could indeed hinder taxonomic and taphonomic identification. Consequently, we may fail to identify all species present in the assemblage and those that were hunted.

Once hunted, the prey had to be transported to the residential site, where they were shared with the rest of the group. From the conducted review, it is evident that the duration of the occupation does not influence **the transportation of the carcass** and the selection of anatomical elements brought to the base camp. Apparently, regardless of the duration, it was much more convenient to transport the best pieces to meet human dietary needs, even if the stay was brief. In addition, we must consider a further aspect. O'Connell (1988), while observing the transportation of carcasses by the Hadza, argued for the necessity of individually examining each carcass field processing and transport event to fully comprehend them, as this variability is masked when the faunal remains from these events are aggregated in a single assemblage. In light of all these aspects, this characteristic does not seem to work well when identifying the duration of occupations. Therefore, it would probably be better not to consider it or to associate this element with more reliable data. On the contrary, the observation of the **number of human modifications** appears to be useful and applicable. Despite some cases contradicting the indicator, it appears that the characteristic related to the percentage of anthropic modifications plays a role in the identification of the duration of occupation.

In addition, within human modifications, **the percentage of burned bones** has been overlooked. Following the model used by certain authors (Marín et al. 2020; Daujeard and Moncel 2010), a substantial presence of burned remains may be related to a higher intensity of human occupations. However, it is important to note burned bones can result not only from cooking but also from other factors, some of which may be accidental or due to subsequent fires in previously inhabited sites (e.g., Yravedra et al. 2017; Morin 2010; Gifford-Gonzalez 1993; Rosell 2001). Additionally, a significant occurrence of burned bones might indicate the outcome of repeated occupations. Furthermore, it remains challenging to discern whether a high intensity of human occupations truly reflects long-term stays.

Within the discussion on anthropogenic modifications and their relation to the duration of occupation, it is crucial to complement this information, whenever possible, with other characteristics. The aim is to understand whether there exists a correlation between increased **carnivore activity** and diminished human activity, and *vice versa*. This inquiry is significant since the assessment of anthropogenic modifications contributes to the identification of occupation duration within the indicators (e.g., Marín et al. 2020; Daujeard and Moncel 2010; Daujeard et al. 2012b). According to this indicator, long-term occupations exhibit high human modifications, short-term occupations show an intermediate value, while brief stopping places show a low value. Nevertheless, the factor of repetitiveness could influence the indicator. Some sites previously identified as short-term occupations (e.g., Navalmaíllo levels F and D, El Salt X, and Abric Romaní level L), show high levels of anthropic activity (see citations previously mentioned referring to these sites). Moreover, among the sites recognized as long-term occupations, some display a low percentage of anthropic modifications and a greater presence of carnivore damage (Fig. 7). In cases where the percentage of human modifications is low, such as in levels Jb and Ob of Abric Romaní (Fig. 7) (Rosell et al. 2012a; Gabucio et al. 2016), there does not appear to be an increase in carnivore activity. Therefore, there appears to be no correlation between the two values, a conclusion supported by the observation that lithic artefacts display a high percentage (Carbonell 2012; Eixea et al. 2021). In fact, the relationship between human occupation and the absence of carnivores, and *vice versa*, is not so straightforward. In

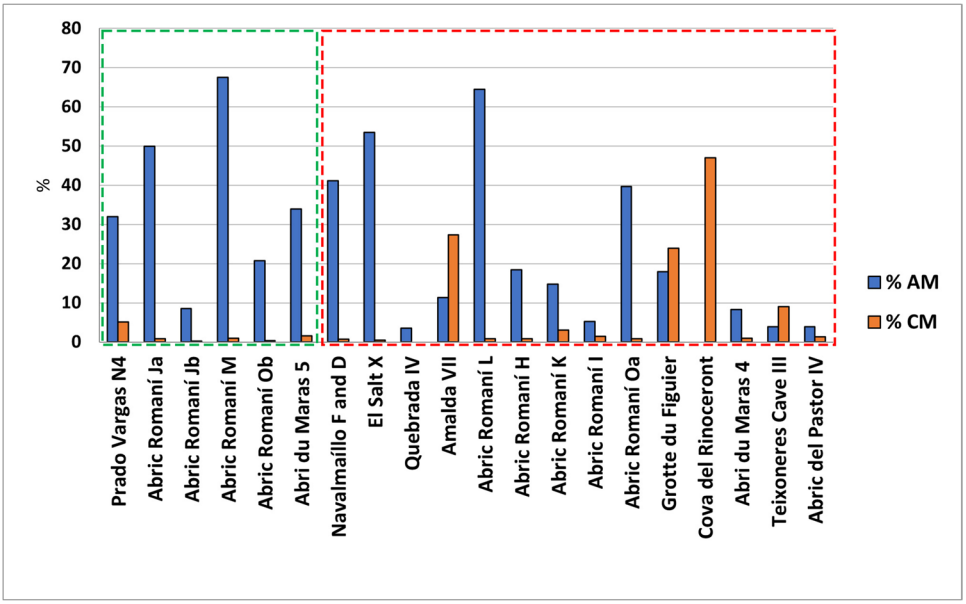

Fig. 7 Percentage of carnivore modifications for each site based on their duration (green: long-term occupations and red: short-term occupations). Only sites with complete data have been included. See Supplementary information to look for the additional references used for each archaeological context

some cases, the inhospitable conditions (such as flooding) of the shelter or cave could prevent neither human presence nor that of carnivores.

Other cases where differences are recorded are short-term occupations such as Navalmaíllo levels F and D, El Salt X, and levels L and Oa of Abric Romaní (Fig. 7). These assemblages show a high percentage of anthropogenic modifications and a low representation of carnivore damages (refer to the previous citations). All these sites record brief but repeated occupations. It cannot be ruled out that the presence of repeated occupations (hence the high number of anthropic traces) would explain the lower presence of carnivores. Despite this hypothesis, there have been cases where short and repeated occupations with a high percentage of traces due to carnivore activity were observed, such as Amalda Cave I level VII and Le Figuier site (MIS 3 or 4) (Yravedra 2010; Moncel et al. 2015). Consequently, even for sites characterised by short but repeated occupations, there is no relationship between human and carnivore occupation. Also, the presence of carnivores that move bones to consume them elsewhere (e.g., Arilla et al. 2020; Camarós et al. 2013), and the possibility that information about human activity is lost cannot be excluded. Lastly, concerning brief stopping places, the extremely brief human presence justifies a more consecutive occupation by carnivores.

In conclusion, the feature works well for long-term occupations, but not for short-term ones, which likely exhibit a more diverse occupational pattern that may not fit into a single definition. Seeking to identify the reasons for this opens up a range of explanations that are challenging to pinpoint in the archaeological record. Among these, the hypothesis of lower/higher occupational intensity, possibly related to a smaller/larger human group size, emerges. Alternatively, there may be a need to reconsider the concept of short and move beyond the stark dichotomy between short and long. Also, some occupations classified as short-term occupations may indeed exhibit a variety of durations, some more prolonged than others. This phenomenon can be observed in sites such as Navalmaíllo levels F and D and El Salt X, thereby explaining deviations from the general indicator. In this way, the concept of short-term occupations could also be expanded.

Application of lithic parameters to the interpretation of occupations

In relation to the relevant aspects of lithic studies, there are several factors to consider when examining the **distance of the raw material**. First of all, the concept of local raw materials would be more intensively exploited as occupation length increased and on the other hand, short-term camps would correspond to higher mobility and higher percentages of non-local raw materials (Richter 2006). The mentioned model is grounded on the idea that the existence of non-local raw materials might indicate a brief occupation, where a group of individuals did not require or have the time to resupply their tools with local resources. Instead, they utilised resources sourced from different locations. However, some authors contradict this indicator (e.g., Picin et al. 2020b; Real et al. 2020, 2019; Geneste 1988). In particular, Picin et al. (2020b, p. 2) argues, 'in high-mobility contexts, the number of lithic items in non-local raw materials (> 20 km) is generally lower than the number of artefacts knapped in local sources'. This would indicate, contrary to the previous statement, that short-term occupations would exhibit a higher presence of local raw materials. This seems to align

to the majority of results obtained by the reviewed data on the raw material used in various Spanish and South-eastern French sites (Table 2). It can explain a more opportunistic use of resources available in close proximity, perhaps preferring to preserve non-local raw materials for continuing the journey. Additionally, one might arrive at a site serving only as a temporary stop and not have access to sharp-edged toolkit items. Therefore, the presence of which artefacts are found and their state of wear, especially if they do not exhibit double patination, should also be considered.

Quantifying the distance covered for raw material procurement in kilometres allows us to discuss the origin and its relation to defining human occupations (Corona et al. 2021). This proves to be useful, although additional variables could be considered. In recent years, there has been taken into account the availability and the quantity of lithic resources in a specific area (Soto et al. 2018). The availability of raw materials in a particular region defines the potential interest of this territory for the procurement of raw materials (e.g., Clark 2022). Many factors, such as the abundance, quality, size of rocks, distance, and the route required to procure raw materials, may have influenced the selection of raw materials acquired (Wilson 2007; Kuhn 1992). Regarding distance, the linear distance model (in km) provides only a partial estimate of the distance travelled for material procurement, as it does not account for geomorphological features of the terrain, such as slopes, watercourses, or dense vegetation, which can extend the route and increase the time and energy required for transport. For a more accurate estimate, it would be useful to adopt multiple measures, such as weighted distances, which take the type of terrain into account, and distance-time, which reflects the actual travel time, considering practical challenges posed by the landscape and the energy cost, including the physical exertion involved (ten Bruggencate et al. 2017; Field et al. 2022; Fano et al. 2016; Henry et al. 2017; Geneste 1991). A model that combines geographical variables with mobility strategies could provide a more precise estimate of the effort required for material procurement (e.g., Ekshtain et al. 2016; Browne and Wilson 2011; Turq et al. 2013). Authors such as Wilson (2007) and Binford (1980) have already emphasized the importance of integrating topography and vegetation into distance modelling, to provide an analysis that goes beyond linear distance and addresses the challenge of applying a single model to all contexts. Considering only the case of Abric Romaní, several types of flint from the same outcrop location (same distance) were identified, but of different quality. The quality determines the flaking technique that was applied (Gómez de Soler et al. 2020) but it is also necessary to consider the complexity of extraction (Ataman et al. 1992) and the difficulty of reaching the extraction area. These factors depend on a series of elements defined as geographical and geological factors (e.g., steepness of the landscape, type and thickness of vegetation, and the strength of water courses) that influence the time taken by the base camp to reach the quarry site and return (Wilson 2007; Elston 1992; Binford 1980, 1982; Kelly 1983; Premo 2015; Grove 2020; Fernández-Laso et al. 2011).

Other equally crucial factors, albeit challenging to identify, if not impossible, are represented by fatigue and the desire for a certain variety of resources. These elements must have interacted with broader societal or cultural factors such as technological needs, mobility strategies, group organisation, and territorial limits to determine whether a resource becomes more or less available or desirable than another in a specific situation (Binford 1989; Torrence 1989; Raven 1992; Kuhn 1995, 2004a; Wilson et al. 2016).

Flint, for example, turns out to be the most abundant raw material, although not the only one. Despite this, geological differences influence the mechanical properties and quality of the raw material subject to flaking. Indeed, the presence of a single raw material through geochemical analysis can demonstrate that it actually comes from different outcrops. Actually, petrography, can provide valuable insights into the environment where the rocks used for crafting stone tools originated and aid in identifying the sourcing areas with greater precision (e.g., Abrunhosa et al. 2020; Gómez de Soler et al. 2020). Nevertheless, in several sites a large quantity of raw materials has been found, especially when chert is scarce or exhibits little internal homogeneity, or when the blanks are very small. In this scenario, low-quality raw materials were used (e.g., quartzite, limestone, sandstone, mudstone, hornfels, schist) (Duran and Soler, 2006; Fernández Peris et al. 2008; Picin et al. 2020a, b; Rios-Garaizar et al. 2020; Prieto et al. 2021; de Lombera-Hermida et al. 2021). Despite quartz being considered a low-quality raw material, analyses conducted by Abrunhosa et al. (2019) on its functionality do not indicate functional disadvantages. Moreover, the scholars argue that the extensive use of quartz was not solely due to its availability in the surrounding area but also because of its suitability and for an extended period.

Contrary to the temporal indicator used to define occupations based on the **knapping method**, Vaquero (2012) argue that the selection and use of expedient reduction methods were not necessarily influenced by the duration of occupation or mobility patterns. In fact, both production methods exhibit considerable technological flexibility, allowing for the use of diverse resources (e.g., Picin et al. 2020a, Vaquero 2012; Romagnoli et al. 2016b). Discussing the possible correlation between the type of knapping sequence and raw material, some researchers (e.g., Eixea et al. 2016; Romagnoli et al. 2016a) contend that knapping technique is not inherently linked to the quality of raw material, contrary to claims made by other authors (e.g., Navazo Ruiz et al. 2021; Gómez de Soler et al. 2020). Our comparative analysis clearly shows that some archaeological assemblages associated with short-term occupations exhibit both knapping techniques. In fact, in several archaeological levels (Table 2),

the presence of the *Levallois* technique is also documented, and in some cases, it is known whether the raw material is local or non-local. For instance, at Teixoneres Cave Unit III, there is a coexistence of two knapping sequences in relation to the type of raw material: higher-quality (non-local - *Levallois*) and lower-quality (local quartz - Discoid) (Picin et al. 2020b). Regarding the Discoid technique, Delpiano et al. (2018, p. 3) state that "the Discoid method is also present as an exclusive technology, and is thus not only a supporting procedure for the maximisation of production and the exploitation of local resources". Similarly, as demonstrated in our analysis, the use of the *Levallois* method for lower-quality raw materials (see also de Lombera-Hermida et al. 2021; Rios-Garaizar et al. 2015) challenges the temporal indicator used to identify occupations, which traditionally associates the *Levallois* technique almost exclusively with flint (Boëda 1994) or simply with high-quality raw materials.

Another aspect to discuss is the application of the element concerning **the *chaîne opératoire***. In the context of its completeness or lack thereof as an element for defining occupation, this study has shown that not all examined sites align with the indicator. In fact, there are several aspects to consider. The foremost is the difference between raw materials' quality (e.g., Picin et al. 2020b). Additionally, within the same type of raw material, one can encounter minor and major difficulties in flaking.

A characteristic that appears effective for identifying the duration of occupations is related to **knapping strategies.** Although there are cases where short-term occupations do not present complete reduction sequences, the number of such sites is relatively limited. Consequently, the indicator aligns well with instances where the fragmentation of reduction sequences corresponds to the origin of the raw material (local or non-local). As noted earlier, it is reasonable to assume that non-local raw materials were brought to the site as part of toolkits and may exhibit more fragmented sequences since they were not knapped on-site. However, as demonstrated by studies conducted at sites such as the Oscurusciuto and Molare rock shelters, a more precise assessment of reduction sequence fragmentation could benefit from an integrated spatial and technological analysis of RMUs (Raw Material Units) (e.g., Marciani et al. 2016; Spagnolo et al. 2019, 2020a,b); This approach, unlike mass studies, allows for the observation and quantification of specific behavioural chains at a higher temporal resolution, providing a more detailed understanding of the patterns and dynamics of knapping activities. If implemented, such an integrated analysis could yield valuable insights into site-use intensity, technological organization, and mobility strategies, further refining the interpretation of occupation duration and raw material management.

In addition, we should extend this reflection to **retouched tools**. The longer the time spent at a site, the greater the need to introduce raw materials and produce new artefacts, as the initially brought resources may become insufficient. Despite the indicator suggesting a high percentage of retouched tools for short-term stays at a site and a high number of retouched tools indicating long-term occupations (Table 1), the relationship between retouched tools and *in-situ* knapped material holds significant interpretative value. Also, additional aspects require consideration when assessing the occupation duration. Firstly, a core left knapped *in situ* will likely yield a higher percentage of remains compared to artefacts brought into the cave as part of the toolkit (e.g., Martín-Viveros et al. 2020). Secondly, it is essential to acknowledge the potential presence of unretouched artefacts among the tools introduced into the site (Vaquero 2008). Therefore, it becomes essential to consider various factors, with particular emphasis on the relationship between transported materials and those fractured *in situ.*

There are other factors commonly used in studies to define occupations. However, their diagnostic value is limited.

Among the temporal indicators of occupation duration, the most immediate and easily deducible, but also the most debatable one is **the number of archaeological remains (NR)**. This parameter is also defined as 'material assemblage accumulation density' (Conard and Prindiville 2000; Leierer et al. 2019). It represents the count of the number of remains (lithic and faunal) found in an archaeological level and has been normally associated with the duration of occupations (Table 1). According to the indicator interpretation, long-term occupations present a high density of archaeological remains, while short-term occupations present few archaeological materials (e.g., Bargalló et al. 2020; Leierer et al. 2019; Cascalheira and Picin 2020; Moclán et al. 2021, 2023; Marín et al. 2020; Moncel and Rivals 2011). The main limitation of the NR (number of artefacts) method for assessing the duration of occupations lies in the concept of the completeness of the archaeological record. As highlighted by Schiffer (1972), completeness refers not only to the quantity of physical artefacts found but also to the quality of those artefacts, including both lithic and, in particular, faunal remains. The discrepancy between what is found and what was actually present at a site can be influenced by specific behaviours, such as preventive maintenance or cleaning of the working areas, which are characteristic of long-term occupations. These behaviours can lead to the loss of artefacts, both quantitatively and qualitatively, such as in cases where faunal remains are removed or discarded.

Therefore, the number of artefacts recovered may not accurately reflect the true duration or intensity of an occupation, as the cleaning and maintenance processes could reduce the number of visible remains, despite indicating a continuous and organized use of the area. This factor must be considered when inferring the duration of occupations,

as a high artefact count does not necessarily imply a long occupation, especially if systematic cleaning or maintenance activities have been carried out.

The results of this study show that the majority of long-term occupation sites exhibit high density, while only level Jb of Abric Romaní seems to contradict this affirmation, presenting a low number of remains (Carbonell 2012). Regarding the short-term occupation sites identified, there is a growing number of sites that do not correspond to the indicator. Noteworthy are the cases of Teixoneres Cave unit III (Rosell et al. 2017), where a particularly high number of remains is recorded (35,826 NR), and Cova del Coll Verdaguer, which despite being a brief stopping place, shows a high number of archaeological remains (Daura et al. 2017). This latter case continues to demonstrate the influence of carnivores in the assessment of elements used for the identification of duration.

Another aspect to consider when discussing the number of remains is the repetitiveness of occupations. Archaeological sites repeatedly occupied could present a greater number of archaeological remains. Furthermore, it is important to carefully consider the various excavation methodologies and the different approaches applied for the study of the archaeological remains. Moreover, concerning lithic remains (Table 1) and the utilisation of the number of remains to define occupation, this study reveals several contradictions. Among the sites identified as long-term occupations, Prado Vargas level N4 and Saint Marcel exhibit a low number of lithic remains found (Navazo Ruiz et al. 2021; Moncel et al. 2015). Regarding short-term occupations, Navalmaíllo levels F and D, Quebrada Cave level IV and Teixoneres Cave unit III appear not to align with the indicator described (Eixea et al. 2016; Márquez et al. 2016; Picin et al. 2020b). Among sites defined as brief stopping places that should present an extremely low number, Abri des Pêcheurs shows a higher NR even when compared to other brief stopping places used for this study (Daujeard and Moncel 2010). The raw material used and its degree of fragmentation is another important point to keep in mind. Another aspect to consider when discussing the number of remains (NR) relates to the excavation technique, as NR becomes an arbitrary value if not derived from an extensive excavation. Excavating a restricted area does not provide the same interpretative framework as excavating a broader area and analysing the number of remains (NR) in relation to the total duration of occupation.

The **number of cores** is another element that was excluded from this evaluation. Even if cores are usually associated with long-term occupations (Table 1), it is more accurate to consider not only the exclusive number of cores but also the relationship of the percentage of cores to the total lithic remains. Considering all the reasons described, we believe that these aspects, particularly without a multidisciplinary perspective, may provide distorted identifications.

Conclusions

Identifying the duration of the Late Neanderthals' occupations proves to be a challenging task. There are various characteristics to consider, and for each, numerous variables can impact every element and every archaeological assemblage.

Several elements have emerged by comparing the results from contemporaneous sites in Spain and south-eastern France. One aspect is the considerable diversity observed in the data across sites identified as short-term occupations. Based on this evidence, we argue that there are diverse forms of short-term occupation, suggesting that the term 'short-term occupation' encompasses not only brief occupations but also those that occurred at different points in time. In fact, the same ethnoarchaeological definition of short-term occupations includes from a few hours to a few days. Therefore, it is likely that an occupation lasting a few days, albeit short, will show different archaeological data compared to sites that were occupied for shorter periods. This significant variability within the concept of short-term occupation becomes even more evident when analysing the results of assemblages from Southeast France and comparing them to what is named as brief stopping places. This definition, primarily used by French scholars, represents a type of site occupation where human presence, unlike that of carnivores, is extremely limited. In these instances, the anthropogenic contribution to the site's formation is minimal, while there is a notable presence and carnivore activity. Objectively, although they fall under the category of short-term occupations, they differ greatly from the latter and highlight the complexity of encompassing brief occupations under a single definition. Introducing the concept of different types of short-term occupations, we may better explain the differences found within assemblages identified as such.

Another aspect to consider when trying to understand the diversity of occupations is the repetitiveness of occupational events. Short but repeated occupations can produce archaeological data that may mislead our interpretations. Therefore, the variability among sites has been compared to assess the extent to which the repetitiveness of occupations, even if short-term, impacts them. Although repetitiveness may explain certain differences observed among sites identified as short-term, it cannot account for all variations.

It is also necessary to consider that the indicators we are applying to define occupations may include characteristics that are not truly useful or that we are not considering in their complexity.

In addition, we must not forget the importance of the context of study. This means tailoring the indicators for defining the duration of occupations to specific archaeological contexts. Only in this way can we consider the variables of each archaeological context effectively.

In any scenario, to reduce the likelihood of interpretive errors when discerning the duration of occupations, it is advisable to conduct a multidisciplinary analysis. This study entails examining relevant characteristics from multiple disciplinary fields. Frequently, each category or distinct disciplinary sector is evaluated in isolation, without presenting a comprehensive overview, contrary to common practice. This highlights the significance of incorporating a multidisciplinary approach to accurately define the duration of occupations, rather than relying solely on a few elements, risking the provision of partial or inaccurate information. However, it is important to identify which elements are more functional and which are not, and, in any case, to reflect on all aspects that could have influenced the data and compromised an objective interpretation.

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Data availability No datasets were generated or analysed during the current study.

Declarations

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