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1 **Detecting human activity areas in Middle Palaeolithic open-air**
2 **sites in Northern France from faunal remains spatial distribution.**

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Abstract

The detection of Middle Palaeolithic human activity areas represents a methodological challenge at the boundary between two disciplines: archaeology and spatial analysis. During the course of the past decades, with the democratisation of tools such as Geographic Information Systems (GIS), prehistorians have developed a wide diversity of methods for the study of the spatial organization of occupation levels. We must now choose the best adapted method to our spatial problems, our archaeological contexts, but also our set of geographic data, from the existing methods. In this context, we devised a new spatial analysis protocol, highlighting archaeological and spatial criteria that constrained our choice of methods and estimating their reproducibility. The construction and application of our protocol is based on the Middle Palaeolithic open-air sites of Caours and Beauvais, situated in the North of France. On account of the ideal preservation conditions at these sites, they are propitious candidates for spatial analysis. In addition, these sites rank among those with the most abundant faunal remains of the region and our study focuses on this category of remains. The combined use of two methods of spatial analysis – K-means clustering and Kernel Density Estimation – enables us, on one hand, to effectively detect human activity areas, their number and their distribution. On the other hand, this protocol contributed to their characterisation and the description of their role for the functioning of the occupation level. For both of the studied sites, we brought to light several areas of butchery activities organized around a combustion zone. In the case of Caours, areas of specific butchery activities, devoted to one or two species, were identified.

Key words: Spatial Analysis, Human Activity Area, Middle Palaeolithic, Northern France, Faunal Remains, Geographic Information Systems

31 1. Introduction

32 Approaching the ways in which territories were occupied is often considered to be a goal in
33 archaeology. This scale of analysis is notably important for Palaeolithic research, where
34 archaeological sites are mere “windows of observation”, indicators of a much vaster exploited
35 area (Soriano, 2013), which can be referred to as “an inferred area” or “an area non-identified
36 by the excavation, but approached through data derived from the excavation” (Bracco, 2000).
37 One of the ways of obtaining information on the scale of geographic occupation and
38 exploitation is through the comparison of the function of several contemporaneous sites from
39 the same chronoclimatic phase (Bracco, 2001, 2000; Jaubert and Delagnes, 2007). Today,
40 different angles of approach enable us to describe the function of a site, including the type of
41 activities carried out there as well as the relationship between them (Locht and Patou-Mathis,
42 1998; Loch, 2002; Vaquero et al., 2017, 2012). Translating and documenting the spatial
43 organization of site activities contributes tremendously to our understanding of interactions
44 between different human behaviours, and therefore site functions. To study these interactions,
45 it is imperative to accurately define areas of human activity in their number and distribution.

46 The description of the French Upper Palaeolithic site of Pincevent as “Magdalenian
47 habitations” (Leroi-Gourhan and Brézillon, 1972, 1966) initiated a research impetus aiming to
48 identify the “latent structures” underlying the more or less dense concentrations of remains in
49 Palaeolithic levels. The first quantitative methodologies were hardly computerized, and were
50 extremely time-consuming and complex to set up (Hietala and Stevens, 1977; Kintigh and
51 Ammerman, 1982; Simeck and Larick, 1983; Whallon, 1974). They were thus barely used by
52 archaeologists, until the democratisation of statistical processing software and Geographic
53 Information Systems (GIS). During this period, lithic refits played an essential role in the
54 description of the spatial organization of occupation levels. They became not merely a base
55 for defining areas of human activity but also an extremely efficient tool for describing human
56 interactions (Cziesla, 1990, 1987; Hilbert and Fieldler, 1990).

57 The detection of areas of human activities during the Palaeolithic is one of the methodological
58 and archaeological issues that has undergone major developments over the past two decades
59 (Alperson-Afil, 2017; Alperson-Afil et al., 2009; Clark, 2017; Gabucio et al., 2017; Spagnolo et
60 al., 2018; Vaquero et al., 2017; Vaquero and Pastó, 2001). Due to increasingly vast excavated
61 surfaces and a growing number of remains, GIS, geomatics methods, and spatial analyses
62 have become integrated into the training of prehistorians. With the development of spatial
63 analysis for Palaeolithic sites, diversified methods have been applied to varied intra-site
64 archaeological contexts. The number of inter-site comparisons, however, has not likewise
65 been significantly developed, despite the great potential of this approach. This raises questions
66 as to the choice of the best adapted method with the most judicial parameters to provide
67 meaningful measurements for inter-site comparisons. Additionally, without a reproducible
68 methodology yielding comparable results, no study of the spatial organization between sites is
69 possible. This approach would be especially informative when applied to Middle Palaeolithic
70 contexts, as questions regarding the nature and diversity in Neanderthal behavioural variability
71 are ongoing.

72 The purpose of this article is to propose a spatial analysis protocol to effectively and objectively
73 identify archaeological human activities areas, here demonstrated in Middle Palaeolithic
74 occupation levels from Northern France. Based on an overview of recent spatial studies in
75 prehistory, we aim to choose the best-adapted methodology for our faunal remains datasets
76 and to estimate its reproducibility. We highlight in this study the success of this methodology

by applying it to two open-air Middle Palaeolithic sites in Northern France: Caours and Beauvais.

We chose these two sites based on the depth of previous research, including detailed stratigraphic, taphonomic, archaeozoological and technological studies. Such a precise context is essential to develop efficient spatial analysis.

2. Study context

We chose Northern France as our study area since the chronostratigraphic framework for this region is among the best documented for the European Middle Palaeolithic (J.-L. Locht et al., 2016). As a result of the quality of the pedosedimentary records and number of identified sites, this is a particularly advantageous region for the analysis of Neanderthal behaviour, and may provide valuable information regarding how territories were occupied during the Middle Palaeolithic. In this way, we aim to contribute new data to the Neanderthal palethnographic record in Northern France.

Caours and Beauvais were selected for this study as they are comparable in terms of site surface and the quantity of remains and are from different periods of the Middle Palaeolithic (Fig.1; Tab. 1). Both sites exhibit excellent preservation, making them ideal candidates for spatial analyses. As these are open-air sites there are also no topographic limits to restrict the occupation surface, resulting in a spatial signal which is less frequently blurred by the duration and the intensity of the successive occupations (Clark, 2017, 2016; Jaubert and Delagnes, 2007; Spagnolo et al., 2018). The additional interest in studying these two sites is their different bioclimatic contexts and from different isotopic stages: Beauvais (MIS 4) was settled in an arid steppe plain, while Caours (MIS 5e) was in a clearing near a river in temperate woodland (Antoine et al., 2006; Locht, 2001). Finally, they both rank among the sites with the richest faunal remains in the region.

Figure 1: Regional map of Northern France showing the location of the Palaeolithic sites of Caours and Beauvais (modified from GeoMapApp).

Taphonomic conditions often interfere with the conservation of faunal remains, and, as a result, the spatial analysis of Middle Palaeolithic faunal remains is underdeveloped in relation to the analysis of lithic remains. Apart from several rare exceptions (Gabucio et al., 2018), spatial studies are often limited to the distribution of remains classified by size, or by the degree of combustion for the study and identification of hearths (Böhner et al., 2015; Spagnolo et al.,

2018; Vaquero et al., 2017). Given this context, this article focuses on the application of our spatial analysis protocol to the faunal assemblages from the sites of Caours and Beauvais.

		Caours N4	Beauvais C2
Topography		NW slope	Depression at the base of a Tertiary mound
Chronostratigraphy		Isotopic stage 5e	Isotopic stage 4
TL date/burnt flint		122.8 ± 8.6 ka BP	55.6 ± 4 ka BP
Excavated surface		358 m ²	763 m ²
Chaînes opératoires		Discoid and Levallois	Discoid
Number of lithic artefacts	burnt	79	1
	total	1 271	11 700
Main species		Red deer, roe deer, aurochs	Reindeer
Number of faunal remains	burnt	557	185
	fractured	100	42
	striations	3	3
	total	1611	861

Table 1 : Comparative table of the main characteristics of the sites of Caours and Beauvais (table modified after (Locht, 2001), data from Caours issued from (Locht et al., 2016)).

2.1. The level 4 of the site of Caours

Caours is located in the basin of the Somme River, in the valley of the Scardon (a tributary of the right bank of the Somme River). The calcareous tufa formation which makes up the Caours sequence is preserved over thousands of meters squared, in the confluence of the Scardon and the Ducreat stream (Antoine et al., 2006) (Fig. 2). Archaeological levels are registered in a sub-horizontal fluvial sequence underlying a tufa dome on the alluvial plateau of Etouvie.

Figure 2: Location (A) and geomorphological context of the site of Caours. 1 - Present day marshy bottom valley, 2 - Extension of the Caours tufa, 3 - Former quarries. (Antoine et al., 2006)

The site of Caours is composed of two separate excavation sectors which have not been stratigraphically connected. For this study, we focus on level 4 of the second excavation sector, excavated manually on a superficies of 360 m². Level 4 is the only level currently that has identified significant traces of combustion zones at Caours.

2.1.1. Stratigraphy and Taphonomy

To describe the complex stratigraphy of Caours, researchers have correlated the results from sedimentology, geochemistry, malacology, micropaleontology, and studies of palaeobotany. The synthesis of these results suggests an attribution of that sequence to the Eemian isotopic stage – 5e – (Antoine et al., 2006; Loch et al., 2009). The multiple absolute dating made on the sediment and the remains of Caours – U/Th, OSL, ESR, and Thermoluminescence – also confirms the attribution of these occupations to the Eemian (Antoine et al., 2006). However, the four occupations of sector 2 are too close in time to be dated individually.

The level 4 of Caours, the oldest one in the sector 2, is localized at the base part of the stratigraphic unit 10 (Fig. 3). This unit is a clay calcareous compact silt with numerous terrestrial molluscs (*Cepaea*) often fragmented and concentrated at two centimetres from the unit base. According to the stratigraphic and palaeobiological analysis, the human occupation took place in the border of an alluvial plain, on a terrestrial environment occasionally covered by calcareous silt flood deposits. The floods allowed a quick preservation of the archaeological remains, avoiding important perturbations of the level (Antoine et al., 2006).

Figure 3: Detailed description of the sediment sequence of Caours and the location of the archaeological levels inside (J. Loch et al., 2016)

Downslope springs, having a various strength through time, have locally incised some of the archaeological levels (Figure 4: location of channels incising the level 4). For the archaeological remains moved into these channels, most of faunal and lithic refitting give evidence of short-distance movements. Nonetheless, these channels often incised several archeological levels, mixing up their artefacts. In this context, we have excluded the remains from the channels of level 4 for our spatial analysis.

Figure 4 : Spatial distribution map of burnt sediment zones and channels incising level 4 of Caours.

In level 4 of Caours, cracked fluvial silt zones, darker than the original silt, were identified and interpreted as burnt sediment markers (Fig. 4) (Locht et al., 2010, 2009). These zones are characterized by a high quantity of charcoals and some burnt bones and heated flint pieces.

2.1.2. Faunal remains

The faunal assemblage of the level 4 of Caours is representative from a temperate period with the red deer, the roe deer, the aurochs and the meadow rhinoceros (Antoine et al., 2006; Sévêque, 2017). Species determination suggested a mosaic landscape of park-wooded meadow type, with clearly dominant forest areas. This also confirmed the levels attribution to the Eemian.

After the excavations of summer 2017, the level 4 of Caours has documented 1492 faunal remains, primarily well preserved. Considering the number of remains as well as the minimum number of individuals, red deer is the majority species. The most represented species after it are, in order, roe deer, aurochs, and meadow rhinoceros (Fig. 5 and 6).

Figure 5 : Distribution diagram of taxa of the level 4 of Caours according to the percentage of identified remains (based on the data from P. Auguste and N. Sévêque)

Figure 6 : Distribution diagram of taxa of the level 4 of Caours according to the Minimal Number of Individuals (based on the data from the excavations between 2005 and 2016 from (Sévêque, 2017))

The important quantity of faunal remains bearing anthropogenic traces (spiral fracture, cut marks, burning traces) suggests the anthropic origin of the level 4 of Caours (Fig. 7). That is confirmed by the low rate of remains bearing carnivores traces or impacted by climate-edaphic agents (Antoine et al., 2006; Sévêque, 2017).

Figure 7 : Histogram of the percentage of faunal remains bearing anthropogenic traces in level 4 of Caours (based on the data from P. Auguste and N. Sévêque)

The anthropogenic traces highlight the practice of different human activities during this occupation. Bones bearing cut marks or spiral fractures attest to butchery activities, and the high quantity and nature of the burned bones suggest anthropogenic and voluntary combustion of faunal remains. Finally, some indirect evidence additionally may suggests the practice of pelting activities in level 4 (Sévêque, 2017).

Based on the anatomic representation of each species, researchers proposed a difference of treatment between cervids and big herbivores like aurochs. For the cervids, the first disarticulation steps would have been processed on the killing site. Then, the parts were brought to the butchery site of Caours where these were highly exploited from defleshing to bone fragmentation aiming to extract the marrow. For the larger herbivores, it appears that nearly only members were brought from the killing site to Caours (Sévêque, 2017). For all of these species, the animals' parts mostly bring to the site of Caours were the most alimentary useful parts (Tab. 2). The faunal accumulations clearly demonstrate that Caours was a butchery site, intermediate between killing site and occupation site (Auguste, 2012).

Food Utility	Red deer		Cervids		Roe deer		Aurochs	
	Number of remains	Percentage	Number of remains	Percentage	Number of remains	Percentage	Number of remains	Percentage
High	23	29,5 %	55	51,9 %	14	21,2 %	6	28,6 %
Medium	13	16,7 %	12	11,3 %	11	16,7 %	6	28,6 %
Low	22	28,2 %	18	17,0 %	6	9,1 %	8	38,1 %
Antlers			8	7,5 %	1	1,5 %		
Isolated teeth	20	25,6 %	13	12,3 %	34	51,5 %	1	4,8 %
Total of remains	78	100,0 %	106	100,0 %	66	100,0 %	21	100,0 %

Table 2 : Distribution of the remains from the main species from level 4 of Caours depending on their food utility (based on the remains determination of P. Auguste and N. Sévêque)

Furthermore, faunal remains analysis support the hypothesis of a brief occupation during the summer for the level 4 of Caours (Antoine et al., 2006; Sévêque, 2017).

2.1.3. Lithic remains

The raw material for the lithic industry of level 4 of Caours has a local origin. This flint comes from the gravel at the base of the alluvial plateau on which is settled the human occupations. Knapping activities were carried on by direct percussion with a hard hammerstone. The low quantity of lithic remains and their typo-technological characteristics suggest a limited flakes' production for immediate use on animal carcass processing.

Level 4 of Caours present 1271 artefacts discovered between 2005 and 2017. Discoid debitage was almost exclusively used for the rapid production of flakes with a back opposite the cutting edge-backed knives (Antoine et al., 2006). 73 burned lithic artefacts were found in level 4, near the burned sediment zones.

2.1.4. Spatial data

For the site of Caours, the implementation of a Computer Aided Drawing (CAD) system for archaeological remains in the field enables us to obtain a set of geolocalised data ready for mapping the distribution of the archaeological material, straight after the excavation. After the

recording of the remains, the photos of the excavated squares are first georeferenced with the QGIS software used for the management of our set of data (Fig. 8A). We then render the limits of each remain to obtain a layer of georeferenced polygons (Fig. 8B). The coordinates of the centre of each polygon in each layer of remains are then extracted to constitute a dot plot representing the archaeological objects.

All the coordinates of the remains from both sites were transposed into the French Reference System of Lambert-93 Coordinates (EPSG 2154) to facilitate the subsequent comparison of results.

Figure 8 : (A) Example of georeferencing of one of the ortho-photos taken for level 4 from the square F3. (B) Example of Computer Aided Drawing of the faunal remains (in blue) and the lithic remains (in red) during the excavation of Caours 2016.

For the site of Caours, our analysis represents the first spatial study of the occupations. Figure 9 shows the distribution of faunal remains through level 4 of Caours. Based on that first distribution map, researchers proposed the hypothesis of a faunal remains distribution as concentrations zones.

Figure 9 : Distribution map of the faunal remains from level 4 of Caours.

2.2. The level 2 of the site of Beauvais

The archaeological site of Beauvais was discovered in the west of the same-named town, near a locality called La Justice. It is located on the north-eastern foothill of a mound from the Tertiary period, located itself in the border of a 90 m N.G.F. (*Nivellement Général de France*) altitude plateau (Fig. 10). The Tertiary substrate at the foothill was shaped by successive erosion phases digging a well-marked depression safe from the dominant winds. This particular topography certainly played a role in the settlement of human occupations. Furthermore, the Tertiary mound could constitute a landmark overhanging the valley of the Thérain, localized about 30 meters below (Locht et al., 1995). Additionally, the topographic location of the site of Beauvais allowed the quick accumulation of a thick sequence of sediments, sealing human occupations.

- Tertiary mound from "La Justice"
- Rescue excavation from 1993
- Test pits from 1996
- Planned excavation from 1997
- Test pits from 1999

Figure 10: Location and geomorphological context of the site of Beauvais (Locht, 2004).

We chose to study level 2 of Beauvais as it is the richest in faunal remains. It was manually excavated over 763 m².

2.2.1. Stratigraphy and Taphonomy

The sediment sequence of Beauvais is primarily composed of aeolian sands attesting cold and dry environmental conditions typical of open steppe biotope (Locht et al., 1995). The calcareous shells of fossils contained in the sediments contributed to the success of the faunal remain preservation of Beauvais (Locht and Patou-Mathis, 1998). That preservation state of faunal remains is quite exceptional for this type of environment (Fig. 11) (Locht et al., 1995; Loch and Patou-Mathis, 1998).

Level 2 of Beauvais is located between the stratigraphic units 6b and 7 and it deposited mainly on the lower part of the depression. Unit 6b is a homometric aeolian brown-yellow sand with concentrations of reworked fossils shells. In higher parts of the depression, the contact between units 6b and 7 is intensively deformed by gélifluxion. Unit 7 is made of Tertiary grey-green sands, azoic for most, but locally including some fossils shells (Fig. 11).

Figure 11: Detailed description of the sediment sequence of Beauvais and the location of the archaeological levels inside.
Modified from (Locht, 2004)

The dating of the two levels of Beauvais was a difficult task. The environmental data, from faunal remains, suggested the isotopic stage 4. However, since that type of sediment sequence was never described for the Weichselian stage, stratigraphic data rather proposed the isotopic stage 6. The discovery of another quaternary sequence in Villers-Adam brought the missing elements to that problem and allowed to assign the human occupations of Beauvais to the isotopic stage 4, between 55-65 ky BP (Locht and Patou-Mathis, 1998).

In level 2 of Beauvais, ashy zones were observed and identified as concentrations of burned bone dust (Locht and Patou-Mathis, 1998). Larger burned bones are concentrated above these ashy zones.

2.2.2. Faunal remains

Excavations of level 2 of Beauvais has resulted in 855 faunal remains. Considering the number of remains as well as the minimum number of individuals, the reindeer is the majority species. However, we also note the presence of horse, steppe bison, and mega-herbivore remains – woolly rhinoceros, woolly mammoth – in smaller quantities (Locht and Patou-Mathis, 1998;

Auguste, 2012) (Fig. 12 and 13). These species attest to a steppe environment with cold, arid, and continental climate, type “mammoth steppe”.

Figure 12 : Distribution diagram of taxa of the level 2 of Beauvais according to the percentage of identified remains (based on the data from M. Patou-Mathis)

Figure 13 : Distribution diagram of taxa of the level 2 of Beauvais according to the Minimal Number of Individuals (based on the data from (Locht, 2004))

Taphonomic studies of the faunal assemblage have confirmed its anthropic origin and the anecdotal role of carnivores. Moreover, researchers detected a high rate of bones bearing spiral fracture or/and burned traces as well as the existence of bones bearing cut marks (Fig. 14). Finally, the anthropic origin of the faunal corpus of level 2 is confirmed by the predominance of young individuals and adults in the prime age (Locht and Patou-Mathis, 1998; Locht, 2004).

Figure 14 : Histogram of the percentage of faunal remains bearing anthropogenic traces in level 2 of Beauvais (based on the data from M. Patou-Mathis)

That anthropogenic traces highlight the practice of different human activities during the level 2. Bones bearing cut marks or spiral fractures attest to butchery activities, and it appears that most of the burned bones are fractured and defleshed reindeer bones fragment smaller than 5 cm and rich in *spongiosa*. The researchers suggested the hypothesis of the use of these bones as fuel (Locht and Patou-Mathis, 1998; Loch, 2004).

Like in Caours, there is an observed treatment difference between cervids and big and mega-herbivores. The remains of reindeer present traces attesting to most of the animal carcass treatment steps: disarticulation, defleshing, and the fracture of bones to extract the marrow. Additionally, all the anatomical parts of the species are represented, suggesting that complete animals were brought to level 2 of Beauvais. For horse and bison, only some parts of the animal were brought to the site and few spiral fractures have been identified. For mammoth and rhinoceros, cranial parts dominate but one talus of rhinoceros bear traces of tibiotarsal disarticulation. For these species, these elements question the possibility of the intake of meat parts without any bones on the site (Locht and Patou-Mathis, 1998; Loch, 2004). Finally, for all of species, the animals' parts mostly bring to the site of Beauvais were the most alimentary useful parts (Tab. 3).

Food Utility	Reindeer		Bison		Horse	
	Number of remains	Percentage	Number of remains	Percentage	Number of remains	Percentage
High	166	47,70%	3	37,50%	5	14,71%
Medium	74	21,26%	2	25,00%	7	20,59%
Low	42	12,07%	2	25,00%	8	23,53%
Antlers	26	7,47%				
Isolated teeth	40	11,49%	1	12,50%	14	41,18%
Total of remains	348	100,00%	8	100,00%	34	100,00%

Table 3 : Distribution of the remains from the main species from level 2 of Beauvais depending on their food utility (based on the data from (Locht and Patou-Mathis, 1998; Loch, 2004))

The meat and marrow quantity as evidenced by the seven reindeer found in level 2 of Beauvais suggests a relatively brief occupation by a small prehistoric hunters group. A study of seasonality also supports the hypothesis of a brief occupation during the late summer/early fall (Locht and Patou-Mathis, 1998; Loch, 2004).

2.2.3. Lithic remains

Three different types of flint, all with local origin, were used in Beauvais as raw material for knapping activities. Knapping technic used in level 2 is direct percussion with a hard hammerstone (Locht, 2004).

Level 2 of Beauvais counts 1947 lithic artefacts, most of them are distributed through only 320 m². The main *chaîne opératoire* produced flakes and pseudo-Levallois points through the discoid debitage method. Some of them have been retouched to accommodate the prehensile part of the artefact. This particular retouch evokes the morphology of backed knives (Locht, 2004). Researchers evoked the hypothesis that the numerous flakes in level 2, presenting that back opposite the cutting edge, may have been used for butchery activities (Locht, 2001).

Only one burned lithic artefact was found in level 2, near the ashy zones.

2.2.4. Spatial data and first spatial study

Archaeological remains found in Beauvais were registered in the three spacial dimensions. A spatial study had already been conducted for this site – without using GIS – based on calculating the density of remains and the study of the faunal and lithic refits (Locht and Patou-Mathis, 1998; Loch, 2004, 2001). We will thus use this site as a reference for our new protocol by comparing the results of our analysis to the former more empirical approach.

Figure 15 shows the distribution of faunal remains through level 2 of Beauvais.

Figure 15 : Distribution map of the faunal remains from level 2 of Beauvais.

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2.2.4.1. Spatial study of burned faunal remains

331 The first part of the spatial study, conducted by M. Patou-Mathis and J.L. Locht, aimed to
 332 identify potential non-built hearth and to localize their centres. The criteria used to that purpose
 333 are:

- 334 • Percentage of burned bones regarding non-burned ones in a defined area;
- 335 • Percentage of burned spongiosa regarding burned compacta in a defined area;
- 336 • Percentage of big or mega-herbivores' burned bones in a defined area;
- 337 • Percentage of burned bone splinters in a defined area;
- 338 • Percentage of calcined bones regarding carbonized ones in a defined area.

339 A large hearth, having been used several times, has been identified in level 2. It is localized in
 340 a one-meter diameter and 40 cm depth depression. Ashy zones, identified as concentrations
 341 of burned bone dust, are localized directly under that hearth (Fig. 16).

342

343 Figure 16 : Distribution map of burned faunal remains, backed flakes, and ashy zones from level 2 of Beauvais (modified
 344 from (Locht, 2004))

2.2.4.2. Spatial study of other faunal remains

Several criteria were used to study the remaining faunal remains:

- Spatial distribution of remains sort by species;
- Spatial distribution of remains sort by anatomical parts;
- Percentage of bones rich in meat and marrow in a defined area;
- Percentage of bones bearing anthropic traces in a defined area.

Three high remains density zones were identified in level 2 of Beauvais (Fig. 17). Using the criteria describing above, researchers proposed that specific human activities have been carried out in each of these zones:

- Zone I: Disarticulation and “culinary preparation”;
- Zone II: Disarticulation and wastes resulting from this activity;
- Zone III: Defleshing and wastes resulting from this activity.

Figure 17: Location of the different human activities areas in level 2 of Beauvais describing by M. Patou-Mathis and J.L. Locht (Locht and Patou-Mathis, 1998; Locht, 2004).

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2.2.4.3. Spatial study of lithic artefacts

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In level 2, researchers observed that backed flakes are distributed all over the excavation area

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but two concentration zones were identified. The first one is associated with reindeer remains

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nearby the hearth and the second is located in the south-east part of the level. The hypothesis

364

of the existence of two knapping activities pole in level 2 of Beauvais was evoked (Locht, 2004).

3. Interpretative framework

3.1. Concept of random spatial organization

In mathematics, the Complete Spatial Randomness (CSR) of a point pattern is a well-defined concept. When disciplines such as archaeology or biology attempted to apply this concept to natural or cultural phenomena, however, deviations emerged, introducing confusion. In mathematics: "The simplest theoretical model for a spatial point pattern is that of complete spatial randomness, in which the events are distributed independently according to a uniform probability distribution over the region R " (Gatrell et al., 1996). In archaeology, the concept beneath the random distribution of an artefacts assemblage often implies that its anthropological origin is not detected or certain. Archaeological remains, represented by a dots cloud, may have a complete random spatial distribution, mathematically, but still may have a clear anthropogenic origin. Conversely, it is also possible that the distribution of archaeological material could be clustered but the result of some geological phenomenon (Miller, 2011). According to Taylor et al., (1978), in a biological study, a behavioral definition can be given to spatial randomness "[...] as that disposition of individuals in space which results from a lack of response of any one individual to any other or to its environment." Similarly, we can consider the spatial organization of archaeological remains as a response from a human group to its environment, vital needs, or socio-cultural criterion. From this perspective, the complete spatial randomness of an archaeological level appears to be as unlikely as it is for a biological phenomenon (Taylor et al., 1978). Instead of testing the randomness of an archaeological remains spatial distribution, we should discuss the probability of detecting a spatial organization that may reflect human past activities (Taylor et al., 1978).

3.2. Definition of human activity area

In archaeology, we define a human activity area as a restricted zone where one or several related activities were practiced. This area concentrates some remains from this activity (products or waste) and associated materials (raw material or tools) (Flannery and Winter, 1976; Merrill and Read, 2010). Therefore, in Prehistory, activity areas are often considered as artefacts accumulations or clusters. Ethnographic investigations have demonstrated, however, a wide range of variability in the size, shape, and artifact density of artefact clusters. It has less been discussed, though, that an activity area could be distinguished as a lower density zone surrounded by a high density of remains (Carr, 1984; Merrill and Read, 2010). It is still true that, if we detect the clusters, we may detect the low-density zones as well. Therefore, the detection of spatial patterns with mathematical parameters can be applicable and beneficial to archaeologists.

Spatial information inherent in archaeological datasets is always fragmentary. Before discussing the preservation processes of an archaeological layer, the nature and organization of human behaviour and activities notably have the strongest impact on the spatial signal readability hundreds of thousands years later (Clark, 2017; Schiffer, 1975; Spagnolo et al., 2018). A long-duration occupation could lead to one layer of mixed artefacts, or to domestic units precisely spatially delimited. Furthermore, practicing several activities in the same area could lead to a very high-density and very visible cluster. Nevertheless, this cluster will be very difficult to interpret due to the multiple activities represented (Merrill and Read, 2010). Different activities also produce artefacts with different chances of preservation, with differential preservation presenting various degrees of information about the activities in question (Schiffer, 1975). For example: a single flake of knapping waste selected from all recovered debitage, will not provide the same information about the knapping method as a retouched tool, the desired end-product from the knapping activity. The artefacts don't provide the same

information either when they are discarded in situ, where the activity was practiced, or in a waste zone, or during site abandonment.

For a holistic understanding we must add known taphonomic processes to the behavioral situation; then, we surely can imagine the challenges of detecting human activity areas. The impact of each of these filters is complex to dissociate. However, the past few decades of research have allowed the identification of means to reconstruct the fragmentary spatial signal and human activity areas. Now, we will present the principal means' list, which could be applied in a large variety of contexts. This non-exhaustive list must be informed by the interpretive context, and in this example is specific to our study region and chronocultural framework.

3.2.1. Spatial data analysis

For a Palaeolithic site, the spatial analysis will allow for the detection of artefact density variations within an archaeological level. These analyses will highlight artefacts accumulations – or clusters – by opposition to lower density zones or even empty zones. This objective has been pursued through a large variety of methods by Prehistorians, but is here demonstrated through previously used and familiar methodologies in a novel way which will be presented in detail further in this article.

3.2.2. Archaeological data analysis

To specify the location of a human activity area, we first need to identify its presence within the occupation level (Schiffer, 1975). This principle may seem trivial but, the less the researched activity is precisely described, the more it will be difficult to identify. Generally, we detect human activity within an archaeological level by the identification of a characteristic artefacts from that activity. Helped by our study region and chronocultural framework, we can then identify the behavioral chain related to this activity and the other artefacts product or used by it (Schiffer, 1975). Then, those artefacts may be localized, and their co-occurrences may strengthen our confidence in the human activity area location.

3.2.3. Cross-checking of the results from the two disciplines

To increase our confidence in the analyses, this part of the study characterizes the limitations of the spatial units identified in the archaeological remains by geomatic methods.

The locations of artefacts resulting from a certain activity is usually not sufficient to assume its cluster as a human activity area. It is also very important to take into account the percentage of each artefact classes to assist the preliminary investigations. For example, an artefact cluster which contains only one bone with a cut mark cannot directly be identified as an area of butchery activity. In contrast, if 50 % of the bones of a cluster had cut marks on their extremity, we can rationally propose a location for some butchery activity, and, even, further disarticulation steps. The co-occurrence of some artefacts classes may also confirm and support the locations of human activity: if in the same cluster as the bones with surface modifications of butchery we find bones with disarticulation cut marks and bones with spiral fractures, our hypothesis of location of butchery activity area is strengthened. Nevertheless, we always must remember the ambivalence of interpretation in Palaeolithic tools: a core could be a knapping waste, a raw material source, or a hammer to fracture bones.

It is also important to remember that while not all artefacts are discarded where they were produced or used, some of them have a greater chance to be discarded after an activity in situ. These artefacts are important indicators and can potentially differentiate between activity areas and waste zones. For example, a bone percussion flake, result from the bone's spiral fracture

to extract marrow, often remains in the location of the primary fracture. In the same way, the smallest flint chips from knapping activities are more likely to stay in situ than the largest artefacts, such as a core, – which has been demonstrated to have the potential to be used in other ways, or to be transported to waste zones.

The detection of an activity area can additionally be an integral starting point to identify other related behavioural locales. Hearths are often described as agents structuring the living space in Prehistory, and, if an archaeological level is well preserved with minimum post depositional movement, it will be one of the most fixed structures. Therefore, it could be the starting point to identify other activities areas related to fire directly or indirectly (cooking activities, sleeping areas...) (Vallverdú et al., 2012).

3.3. Specificity of our interpretative framework

Our study focuses on faunal remains from two open-air sites from Middle Palaeolithic from Northern France. Principal activities in this chronocultural framework, that could be identified from the faunal remains, are linked to animal carcasses treatment from hunting or scavenging. This includes all butchery steps from the meat and marrow extraction to meat processing for consuming or transporting. The other activities highlighted by faunal remains are related to the construction and use of a combustion feature, or, hearth. In this context, bones could be used as fuel, or it could constitute the leftovers from a meal.

The nature and location of anthropogenic traces on faunal remains are often characteristic of the treatment of an animal carcass. For example, marrow extraction could be highlighted by a spiral fracture on a long bone, or disarticulation of the lower limb by several cut marks on a femoral head. However, food utility varies considerably amongst all skeletal elements. High utility segments, such as the hind limb of an aurochs, are rich in meat or marrow, but others, like an aurochs' autopods, are much less nutritionally dense, and will be quickly discarded. Nevertheless, even low utility elements such as the autopods can provide useful information such as cut marks related to the removal of animal skin. Therefore, if an identified cluster is only composed of high food utility remains, there is strong likelihood it recognizes an area of butchery activity.

In the framework introduced here, our spatial study is based on the results of the archaeozoological analyses conducted by Patrick Auguste and Noémie Sévêque for Caours (Antoine et al., 2006; Auguste, 2012; Sévêque, 2017) and Marylène Patou-Mathis for Beauvais (Locht and Patou-Mathis, 1998; Locht, 2004). Among these data, we use the specific and anatomic identification of the remains, as well as their food utility. For both occupations, food utility will be expressed by the MGUI (Modified General Utility Index), which was already used for the faunal analyses of Beauvais site (Binford, 1978; Lee Lyman, 1985). We use the three classes of food utility proposed by Speth (Speth, 1987). The food utility for mega-herbivores, such as the rhinoceros or the mammoth, is not used here. The transport and processing of these carcasses are radically different to those of other herbivores. As a result, the food utility is not calculated for these herbivores from Beauvais and rarely used for Palaeolithic occupations (Metcalf and Jones, 1988).

It is difficult to identify hearths from the Middle Paleolithic, as they are often not formally constructed and are difficult to preserve. In an open-air context, the chance of a combustion feature to be disturbed by climate-edaphic agents are even more likely. Therefore, the preservation of burned bones and ashy spots within the two archaeological levels of our study is quite exceptional. Nonetheless, for the Middle Palaeolithic, the discussions are often still open about how to identify the primary positions of combustion structures. The distribution of burned bones, sorted by combustion degree, could provide useful information to assist with

this outstanding question. If the bones are clearly sorted by combustion degree, with highest combustion degree in the structure's center and the lowest combustion degree in the periphery, this could support the hypothesis of the hearth primary position.

4. Methods

4.1. Acquisition of the spatial and archaeological data

Archaeological remains can be recorded in space in two ways: as polygons – rendering the limits of each remain – or as dot plots – where the coordinates of each point correspond to the centre of the archaeological object. For Middle Palaeolithic sites, dot plot recording is the most widely used method. Therefore, we based our protocol on this type of data, so that it would be easier to reproduce.

4.2. Palaeolithic spatial analysis

The detection of Palaeolithic human activity areas involves a two-part study: one part based on geomatics, solely linked to the spatial data of the remains, and another part based on the interpretative context, linked to their archaeological characteristics. Today, it has been well established that Palaeolithic human activity areas correspond mostly to spatial concentrations of remains resulting from one or several activities (Gabucio et al., 2018; Jayalath et al., 2015; Schiffer, 1972; Simeck and Larick, 1983; Whallon, 1973). If we wish to accurately define these zones of concentration – their number, localisation, and density – we must study the distribution of these remains. However, the defined concentration zones cannot be systematically assimilated to human activity areas. In other terms, these concentrations do not always correspond to the result of one or two clearly identifiable and individualised human activities in the living space. Only the characterization of the remains composing them enables us to verify and define the associated activities. This will be illustrated by several examples in this article.

Most of the spatial methods currently used for the Palaeolithic belong to the family of exploratory analyses (*Exploratory Spatial Data Analysis* or ESDA). These methods are based on the resolve to “let the data speak for themselves” (Anselin, 1999). In other words, they propose to explore the distribution of a spatial phenomenon with the least possible preconceptions as regards the structure of the latter. Indeed, it is rare to be able to directly read the spatial organization of a Palaeolithic level, as numerous and diverse factors impact our interpretation (Simeck and Larick, 1983; Stapert, 1990). This is the first reason for which prehistorians opt for this type of analysis. The second reason is linked to the type of results proposed by the exploratory analyses, which are not absolute results, but a series of possible results associated with reliability indicators (Anselin, 1999). In this way, our interpretative framework can, and indeed must, help to set the parameters of these analyses in order to propose a reliable result in keeping with the archaeological context.

For the detection of human activity areas, one of the greatest methodological challenges is the choice of the spatial analysis method for the characterization of the distribution of the archaeological remains. This choice must be guided by several parameters, some of which are linked to the archaeological context (size of the dataset, studied surface...), and some to the type of results that correspond to our set of problems (density map, number of groups of remains...). Even if we only consider the archaeological parameters, the choice of the analysis method can be extremely variable from one site to another for a same region and a same bioclimatic phase. It thus appears obvious that the selection of a single analysis method, adapted to all Middle Palaeolithic sites, is completely unrealistic. However, we can choose the best adapted analysis method to the archaeological data and our set of problems for each

occupation level. The mathematical results will not be systematically comparable from a statistical viewpoint but at least we will be in a position to compare their interpretations.

4.3. Our spatial analysis protocol

4.3.1. Kernel Density Estimation (KDE)

Kernel Density Estimation (KDE) is an increasingly used modelling approach in archaeology (Alperson-Afil et al., 2009; Clark, 2016; Spagnolo et al., 2018; Thacher et al., 2017). It consists in calculating a histogram of simple smoothed bivariate frequencies (probability density, 2D geographic space), via a kernel type function. This method proposes to estimate the density of remains for each cell of a defined resolution grid, according to the number of remains in the vicinity of the analysed cell and their distance from the latter (Fig. 18). The vicinity of the studied cell is described as a circle with a research radius – or bandwidth– defined by the user (Gatrell et al., 1996). With this same method, we can thus produce a series of results: a density of remains model for each research radius. The larger this radius, the more the result will tend towards a single concentration zone of remains. The smaller the radius, the more the result will tend towards a concentration zone per remain.

Figure 18 : Illustration of the Kernel Density Estimation method (modified after Gatrell et al., 1996).

Grid resolution only has a slight impact on the results, but the research radius is one of the fundamental parameters of this analysis. The way it is defined determines the results and in particular, the reproducibility of the analysis. The high variability of the methods used to this end results from the complexity to find one single method adapted to the largest diversity of datasets – size, distribution schema... (Harpole et al., 2014). Among the methods applied to Palaeolithic contexts, the trial and error approach is one of the most developed (Alperson-Afil et al., 2009; Böhner et al., 2015; Clark, 2017; Neruda, 2017; Oron and Goren-Inbar, 2014). This approach is relatively simple to apply but is extremely time-consuming and not very objective, which raises reproducibility issues (Harpole et al., 2014). Some prehistorians combine KDE results with other spatial analysis in order to optimize the parameters of the

former (Spagnolo et al., 2018; Thacher et al., 2017). Lastly, there are a wide variety of automatic methods designed to choose an optimal search radius for a specific dataset. This category of methods is not very often used in archaeology (Domínguez-Rodrigo and Cobo-Sánchez, 2017), but it is efficient on account of its degree of adaptation to the size of the dataset and to the overall distribution schema (Harpole et al., 2014).

The choice between these three categories of methods, must clearly be guided by the characteristics of the dataset and the archaeological context. Using another spatial analysis or automatic selection methods is more reproducible than the approach by trial and error. However, a genuine problem emerges during their application to archaeological data. The latter are generally not inclined to respect a regular schema of spatial organization, and therefore it is imperative to apply a finer and unique approach adapted to each dataset. In our case, the use of another spatial analysis, in addition to a method of automatic selection – Scott's rule of thumb (Scott, 1992), could constitute the best solution.

The last parameter to set for KDE is the type of kernel function used. Although this parameter has a less significant influence on the final result of the analysis, it is up to the user to choose it, depending on the weight accorded to the points near the analysed cell in relation to the most distant points. Here, we chose a quartic function giving more weight to the remains near the analysed cell, and less to those further away, with a gradual decrease in this weight.

For this method, we use the statistical R software (version 1.0.136), and in particular, the “bw.scott” function, the “spatstat” package, adapted to the statistical analysis of dot plot. We then present the results of the KDE via the Quantum GIS type software (version 2.14.1). In software environments of this type, the maps presenting bivariate histograms resulting from KDE are commonly called Heatmaps.

4.3.2. K-means clustering

K-means clustering is a method of automatic classification which optimally partitions a set of individuals according to one or several variables, into a defined number of classes – or groups. Here, we will consider a spatial application of this method, classifying the remains according to their spatial coordinates (Kintigh and Ammerman, 1982; Rigaud and Simek, 1991; Simeck and Larick, 1983; Yvorra, 2003). For a given number of groups, the different partitioning possibilities will be tested by an iterative clustering system around mobile centres. The final aim is, on one hand, to minimize the average distance between the remains and the centre of their groups, and on the other hand, to maximize the distance between the centres of gravity of each of the groups (Kintigh and Ammerman, 1982) (Fig.19).

There are two ways of defining concentration areas of remains with this method: as dispersion ellipses or polygon envelopes. In both cases, it is important to note that there may be an overlap of the concentration areas – in the same way as for human activity areas. The number of groups, as well as the coordinates of their centres (used for the first iteration of the process) make up the primary parameters of the analysis. If they are defined in a random way, the analysis is not reproducible.

Here, we will use the R statistic software and the “spatstat” package.

Figure 19 : Illustration of the K-means clustering method (modified after (Lebart et al., 2000)).

4.3.3. Two combined methods for a stronger protocol

Our spatial analysis protocol is based on the combined use of KDE and K-means clustering (Fig. 20). As described in parts 3.3.1 and 3.3.2, these methods are based on different characteristics of the dot plot (Tab. 1). In this way, the nature of the results is different and provides complementary information.

The first stage of our study is the application of KDE to the group of studied remains. The research radius, the main KDE parameter, is set using the automatic selection method *Scott's rule of thumb* (Fig. 20). The density map extracted from this analysis proposes a first glimpse of the number of zones with concentrations of remains, with their distribution and their relative density. The extraction procedure of the local maximums – Mean Shift Clustering (Cheng, 1995) – enables us to localise and to count the high-density peaks from a KDE generated map, thereby refining our zones of concentrations of remains.

The second stage of our protocol is the application of K-means clustering, which assigns each remain to a group – or concentration zone. The number of groups into which the remains are distributed is defined by the number of high-density peaks issued from KDE. In the same way, the coordinates of the centres of the groups, for the first iteration of the analysis, are those of the KDE peaks of density. In this way, one of the methods fills the gaps of the other to build up a stronger approach.

Finally, the results of both methods can then be compared in order to better judge the reliability of the results. We will pay particular attention to the position of the KDE peaks of density in relation to the position of the centres of gravity of the groups defined by K-means clustering. In addition, we will compare the distribution of the zones of high concentrations of remains defined by KDE to that of the groups of remains defined by K-means clustering. If these results are in agreement, we can consider them to be reliable enough to form the basis of our spatial study.

Figure 20 : Description of our spatial analysis protocol.

4.3.4. Application to archaeological data

First of all, we applied our protocol “blindly” to all the coordinated faunal remains for an occupation level in order to discern the number and distribution of the concentration zones of remains. Secondly, we tried to confirm whether these zones really correspond to human activities.

For Middle Palaeolithic occupations, butchery activities are the principal agent of the faunal remains’ accumulation. However, other activities as pelting or fire maintenance can also be potential agents. Moreover, the same remains concentration zone can result from several of these activities carried out near each other. To identify which activities created a concentration zone, we need to study its remains natures. Firstly, we applied our protocol to faunal remains bearing anthropogenic traces (spiral fractures, combustion). Secondly, we have studied the distribution of the faunal remains depending on their food utility or species.

Finally, we calculated the percentage of bones bearing anthropogenic traces in a concentration zone to estimate the activity intensity for this one. We performed statistical tests

to compare the proportions of bones bearing anthropogenic traces in a concentration zone and the whole level. Since our sample size is sometimes too small, we chose to use the exact binomial test. In our context, that conformity test aims to prove that an observed proportion is not conformed to the theoretical one. Here, we will use the R statistic software and the function “binom.test” from the “stats” package.

5. Results

5.1. Level 4 of the site of Caours

5.1.1. Spatial distribution of the faunal remains

Figure 21 shows that faunal remains from level 4 of Caours are distributed among several well-identified concentration zones. Concentration zones C1 and C2 were already discernible on the faunal remains distribution map (Fig. 9), but our protocol enabled us to detect three other less dense zones – C3, C4 and C5. Nonetheless, we can't identify with certainty C4 and C5 as clusters due to their isolation within the excavation area. Figure 21 also highlight that the concentration zones contrast with quasi-empty zones of faunal remains.

Figure 21: Distribution of faunal remains (NSP = 1611) in level 4 of the Caours site. The result of Kernel Density Estimation (bandwidth: 1.58 m) is represented by the coloured gradient (green to red, unit: *estimated pieces per kernel density surface*). The faunal remains (scattered dots) are coloured according to the group attributed by K-means clustering (solution with 5 groups).

5.1.2. Spatial distribution of the faunal remains bearing anthropogenic traces

Figures 22 and 23 show that most of the previous remains' concentration zones correspond to concentrations of bones bearing spiral fracture and/or burnt traces (from now called fracture zone and combustion zone). Our first model of five concentration zones must be adapted here based on these new data.

Zone C1 is subdivided into two distinct areas: a high-density zone of burnt remains and a fracture zone (respectively B1 and F1 in figures 22 and 23). In zone C1, the result from the binomial test on fractured remains shows a p-value of 0.0291, at the 5% significance level (Tab. 4). That means that the proportion of fractured remains in C1 is significantly different from the whole level, in this case, lower. We observe that most of the percussions flakes and the cut marks are located in zone F1 (Fig. 22).

Zones C2 and C3 correspond each to a fracture zone (respectively F2 and F3 in figure 22). For both, we distinguish a possible subdivision into two subzones (dashed line in figure 22). Zone C4 exhibit a low density of remains bearing spiral fractures and C5 present none. In zone C3, the result from the binomial test on fractured remains shows a p-value of 2.86E-04, at the 5% significance level (Tab. 4). That means that the proportion of fractured remains in C3 is highly significantly different from the whole level, in this case, greater. In zone C2, C4, and C5, the result from the binomial test on fractured remains shows a p-value greater than 0.05, at the 5% significance level (Tab. 4). That means that the proportion of fractured remains in each cluster is not significantly different from the whole level.

The burnt remains from level 4 of Caours are all concentrated in zone B1 (Fig. 23). Moreover, the results from the binomial test on burned remains show that all clusters p-values are lower than 0.05, at the 5% significance level (Tab. 4). That means that the proportions of burned remains of each cluster are highly significantly different from the whole level one. For zone C1, the proportion is significantly higher, for C2 to C4 significantly lower. Some of the burnt sediment zones are located in the direct periphery of the burnt remains but the others are under and near fracture zone F1. We observe the following tendency: the remains with the highest degree of combustion are located in the centre of zone B1 and the remains with the lowest degree are located on the periphery.

Cluster	Total of remains	Fractured remains			Burned remains		
		Number	Percentage	Exact binomial test	Number	Percentage	Exact binomial test
				p-value			p-value
C1	918	45	4,90%	0,0291	556	60,57%	2,20E-16
C2	201	20	9,95%	0,08785	0	0,00%	2,20E-16
C3	183	26	14,21%	2,86E-04	0	0,00%	2,20E-16
C4	117	5	4,27%	0,3581	0	0,00%	2,20E-16
C5	88	2	2,27%	0,1305	0	0,00%	2,20E-16

Table 4: Proportions of remains bearing anthropogenic traces (spiral fracture and combustion marks) and the results of the binomial test comparing these proportions to the whole level 4 of Caours (Light green: significant difference between the cluster and the whole level; strong green: highly significant difference between the cluster and the whole level; orange: none-significant difference between the cluster and the whole level).

Figure 22: Distribution of faunal remains bearing anthropogenic traces in level 4 of the Caours site. The result of Kernel Density Estimation for the spiral fractured remains is represented by the colour blue (research radius: 2.78 m) (unit: estimated pieces per kernel density surface).

Figure 23 : Distribution of faunal remains bearing combustion traces in level 4 of the Caours site. The result of Kernel Density Estimation for the burned remains is represented by the red gradient (research radius: 3 m) (unit: estimated pieces per kernel density surface).

5.1.3. Spatial distribution of the faunal remains classified by food utility and species

The remains identified in combustion zone B1 are primarily cervids, in particular red deer, with high food utility (Fig. 24 and 25). The same observations are made for the fracture zone F1.

Fracture zone F2 seems to present a more complex sub-organization, with three currently discernable sub-complexes:

- Subzone F2a is defined by an accumulation of cervids remains, in particular red deer, with low food utility.
- Subzone F2b is made up of cervids remains, particularly red deer, with high food utility.
- Subzone F2c, located between zones F2a and F3, was already visible in figure 21. It is composed of large and mega-herbivores remains and a small proportion of roe deer, with high food utility (Fig. 24 and 25).

Figure 25 highlights that the other large and mega-herbivores remains are distributed in small groups in the periphery of fracture zones (encircled in orange). Most of the roe deer remains follow the same tendency (encircled in green in figure 25).

Fracture zone F3 regroups cervids remains, in particular red deer, with high food utility. Finally, zone F4 contains a high proportion of roe deer remains mixed with other cervids, with high food utility.

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739 **Figure 24 : Distribution of the faunal remains classified by food utility in relation to zones of burnt and**
 740 **broken remains, level 4 of the Caours site. The density of broken remains is represented by the gradient of**
 741 **blue and the density of burnt remains by the gradient of red.**

742

743

744 **Figure 25 : Distribution of the faunal remains classified by taxon in relation to zones of burnt and broken**
 745 **remains, level 4 of the Caours site. The density of broken remains is represented by the gradient of blue**
 746 **and the density of burnt remains by the gradient of red.**

5.2. Level 2 of the Beauvais site

5.2.1. Spatial distribution of the faunal remains

Figure 26 shows a high concentration zone of remains in the northwest of the excavation zone and a lower density zone to the south of the former - respectively C1 and C2. The other faunal remains are dispersed as small accumulations over the whole excavated area and may be divided into two subsets – C3 and C4 in figure 26.

Figure 26: Distribution of faunal remains (NSP = 861) in level 2 of the Beauvais site. The results of Kernel Density Estimation (research radius: 2.51 m) are represented by the gradient of colour (green to red, unit: estimated pieces per kernel density surface). The faunal remains (scattered dots) are coloured according to the group attributed by K-means clustering (4 group solution).

5.2.2. Spatial distribution of the faunal remains bearing anthropogenic traces

Figures 27 and 28 show that most of the remains' concentration zones detected previously correspond to concentrations of bones bearing spiral fracture and/or burnt traces. Here again, we must adapt our first model based on these new data.

Zone C1 is subdivided into two subzones: a zone with a high density of burnt remains (B1 in figure 28) and a fracture zone extending until the upper part of zone C2 (F1 in figure 27). The lower part of zone C2 and the totality of C3 and C4 correspond to numerous small groups of bones bearing spiral fractures (Fig. 27). In zone C1 to C4, the result from the binomial test on fractured remains shows a p-value greater than 0.05, at the 5% significance level (Tab. 5). That means that the proportion of fractured remains in each cluster is not significantly different from the whole level.

The burnt remains from level 2 of Beauvais are almost all concentrated in zone B1. However, the distribution of burnt bones according to their degree of combustion does not reveal any clear distribution pattern (Fig. 28). In zone C1 to C3, the result from the binomial test on burned remains shows a p-value lower than 0.001, at the 5% significance level (Tab. 5). That means that the proportion of burned remains in each cluster is highly significantly different from the whole level. For zone C1, the proportion is significantly higher, for C2 and C3 significantly lower. In zone C4, the result from the binomial test on burned remains shows a p-value greater than 0.05, at the 5% significance level (Tab. 5). That means that the proportion of burned remains in C4 is not significantly different from the whole level.

Cluster	Total of remains	Fractured remains			Burned remains		
		Number	Percentage	Exact binomial test	Number	Percentage	Exact binomial test
				p-value			p-value
C1	419	17	4,06%	0,497	153	36,52%	1,54E-11
C2	217	14	6,45%	0,2702	7	3,23%	3,68E-15
C3	147	9	6,12%	0,4436	15	10,20%	0,0002961
C4	72	2	2,78%	0,5862	10	13,89%	0,1166

Table 5: Proportions of remains bearing anthropogenic traces (spiral fracture and combustion marks) and the results of the binomial test comparing these proportions to the whole level 2 of Beauvais (green: highly significant difference between the cluster and the whole level; orange: none-significant difference between the cluster and the whole level).

Figure 27: Distribution of faunal remains bearing anthropogenic traces in level 2 of the Beauvais site. The result of Kernel Density Estimation for the spiral fractured remains is represented by the colour blue (research radius: 3.41 m) (unit: *estimated pieces per kernel density surface*).

Figure 28 : Distribution of faunal remains bearing combustion traces in level 2 of the Beauvais site. The result of Kernel Density Estimation for the burned remains is represented by the red gradient (research radius: 2.32 m) (unit: *estimated pieces per kernel density surface*).

5.2.3. Spatial distribution of the faunal remains classified by food utility and species

Most of the remains in level 2 of Beauvais are high food utility reindeer remains. However, we observe that most of them are concentrated in the combustion zone B1 and fracture zone F1 (Fig. 29).

Zone B1 is also composed, in smaller proportions, of horses, large (bison), and mega-herbivores (rhinoceros, mammoth) remains (Fig. 30). These species also constitute a smaller fraction of zone F1 and tend to be located on its outer edge.

The remains dispersed over the rest of the excavation area mainly correspond to reindeer remains with high food utility indexes (framed in purple in figures 29 and 30).

Figure 29: Distribution of the faunal remains classified by food utility in relation to zones of burnt and broken remains, level 2 of the Beauvais site. The density of broken remains is represented by the gradient of blue and the density of burnt remains by the gradient of red.

Figure 30: Distribution of the faunal remains classified by taxon in relation to zones of burnt and broken remains, level 2 of the Beauvais site. The density of broken remains is represented by the gradient of blue and the density of burnt remains by the gradient of red.

6. Spatial behaviours of the Neanderthals of Caours and Beauvais

6.1. The Human activity areas of level 4 of Caours

Using our spatial analysis protocol, we confirmed the field hypothesis of a spatial organization of the faunal remains as well-defined clusters. Some of these clusters were already detected during excavations, but our analysis precisely delimited them and highlighted some new ones with lower density (Locht et al., 2009). As the impact of other taphonomic factors was ruled out (details in part 2), we suggest that the level 4 spatial organization is anthropogenic.

Applying our protocol to the remains bearing anthropogenic traces, we showed that the clusters defined using strictly spatial criteria have real archaeological meaning. They correspond to areas where Humans practised butchery or combustion activities. The butchery activities highlighted by archaeozoological studies appear as fractured remains concentrations with generally high food utility. The variation of the fractured remains ratio in a cluster suggests different intensities of animal carcasses processing.

At first sight, zone C1 have a relatively low fractured remains percentage compare to the whole level. Nonetheless, we highlighted that more than half of its remains are burned ones. Extracting the burned bones from that cluster and considering only the zone F1 let appear a fractured remains ratio of 12.43%, which is significantly more than the whole level proportion. Moreover, the location of several percussion flakes in F1 supports the hypothesis of an intense *in situ* practice of marrow extraction. Archaeozoological studies also highlighted other steps of the butchery process, such as defleshing, disarticulation or pelting (Auguste, 2012; Sévêque, 2017). The cut marks in the F1 zone suggest the location of these specific butchery activities. Finally, based on its species proportions, we suggest that F1 corresponds to an intensive processing area of cervids, especially red deer (Fig. 31).

Zone C3 fractured remains percentage is the highest among all clusters. Again, based on its species proportions, we suggest that the F3 fracture zone corresponds to an intensive processing area of cervids, especially red deer (Fig. 31).

Zones C2, C4, and C5 fractured remains percentage are not significantly different from the whole level. Based on that results, we can't certify them as intensive butchery areas. However, we observed that the C2 fractured remains percentage is weakly higher than the whole level while the C3 and C4 ones are weakly lower. Furthermore, C2 regroup mostly red deer remains while C4 and C5 concentrate roe deer ones. These elements may suggest that specific butchery activities dedicated to different species were practised C2 and C4 / C5.

Based on the distribution of faunal remains sort by species and food utility, we discerned in zone C2 a sub-organization as subzones F2a, F2b, and F2c. Fracture zone F2b, with high food utility cervids remains, may correspond to a processing area of cervids, especially red deer (Fig. 31). Zone F2a, with low food utility cervids remains, could be considered as a different activity area. Zone F2c is composed of large and mega-herbivores remains with a small proportion of roe deer, all with high food utility.

As observed through zone F2c, large and mega-herbivores remains are located in the periphery of the intensive processing areas of cervids (Fig. 31). Archaeozoological studies showed a different treatment between cervids and large and mega-herbivores. For large and mega-herbivores, nearly only members were brought from the killing site to level 4 of Caours

(Auguste, 2012;Sévêque, 2017). We suggest that these different species treatments are materialized by species dedicated butchery areas (Fig. 31). The same conclusion could be made for the roe deer, also located in the periphery of the intensive processing areas of cervids (Fig. 31).

As evoked earlier, zone C1 present a significantly higher proportion of burned remains that the whole level. Our spatial analysis allowed us to precisely localize the combustion activities highlighted by first archaeological studies in one only zone B1. The distribution of the burnt remains, depending on their combustion degree, and the location of the zones of burnt sediments suggest that combustion zone B1 was located in a primary position.

Finally, the proximity of the combustion zone B1 and the fracture zone F1 suggests a close relationship between butchery activities and the combustion zone.

Figure 31: Interpretative map of human activity areas of in level 4 of Caours. The combustion zone and the processing areas of cervids represent significant and well defined cluster using the spatial analysis protocol from this study. Processing areas of large/mega herbivores and roe deer (purple and yellow) represent the minimum envelope that encompass a specified taxon.

6.2. The Human activity areas of level 2 of Beauvais

Using our spatial analysis protocol, we confirmed the first spatial studies' hypothesis of a spatial organization of the faunal remains as concentration zones (Locht and Patou-Mathis, 1998; Loch, 2004). Previous spatial studies highlighted three high-density zones of faunal remains, framed in light grey in figure 32. C1 zone detected through our analysis, although slightly more extensive, seems to correspond to the zone I defined by Marylène Patou-Mathis. Based on our first results, zones II and III may be fused into a single concentration zone. Moreover, we detected two sets of small faunal remains accumulations distributed over the rest of the excavated area. These less-dense accumulations were not mentioned in the first spatial study. As the impact of other taphonomic factors was ruled out (details in part 2), we confirm the previous studies' hypothesis that the level 2 spatial organization is anthropogenic.

883 Applying our protocol to the remains bearing anthropogenic traces, we showed that the clusters
884 defined using strictly spatial criteria have real archaeological meaning. They correspond to
885 areas where Humans practised butchery or combustion activities. The butchery activities
886 highlighted by archaeozoological studies appear as fractured remains concentrations with
887 generally high food utility.

888 Zones C1 fractured remains' percentage, although weakly higher, is not significantly different
889 from the whole level. Even if a third of its remains are burned, retiring them doesn't change
890 that result. That means that, even if some butchery activities clearly took place here, we cannot
891 describe that zone as an intensive processing area. Nonetheless, the presence of cut marks
892 may confirm that some of the butchery activities described by archaeozoological studies are
893 located in fracture zone F1. Based on its species proportions, we suggest that F1 corresponds
894 to a reindeers processing area (Fig. 32).

895 The upper part of zone C2 seems to continue reindeer processing area F1 (Fig. 32). Again, its
896 fractured remains' proportion doesn't allow us to describe that zone as an intensive processing
897 area. The same conclusion applies to zones C3 and C4. The lower part of C2 and the totality
898 of zones C3 and C4 constitute small fractured bones concentrations that may be interpreted
899 as punctual butchery actions but not as full-blown human activity areas.

900 The lack of remains bearing specific anthropogenic traces, as disarticulation or defleshing cut
901 marks, doesn't allow us to indubitably confirm the existence of the first's spatial study specific
902 butchery activity zones.

903 As evoked earlier, zone C1 present a significantly higher proportion of burned remains that the
904 whole level. Our spatial analysis allowed us to confirm the location of the combustion activities
905 highlighted by the first spatial study (zone B1). The distribution of the burned remains
906 depending on their combustion degree doesn't allow us to confirm the primary position of the
907 combustion zone B1, proposed by the first spatial study. However, that study also highlighted
908 that the combustion zone has been used several times (Locht and Patou-Mathis, 1998; Loch, 2004).
909 That could be the reason for the lack of classification by combustion degree of these
910 remains.

911 Finally, the proximity of the combustion zone B1 and the fracture zone F1 suggests a close
912 relationship between butchery activities and the combustion zone. That element may support
913 the previous spatial study's hypothesis of the existence of a "culinary preparation" area in zone
914 I i.e., our zone C1 (Locht and Patou-Mathis, 1998; Loch, 2004).

Figure 32: Interpretative map of human activity areas of in level 2 of Beauvais. The combustion zone and the processing area of reindeer represent significant and well defined cluster using the spatial analysis protocol from this study.

6.3. Inter-site comparison

For Caours as for Beauvais, our protocol detected new faunal remains' concentration zones, in addition to those already described in earlier studies. The density of these newly identified zones is lower. They are consequently less visible during the excavations and even during the first spatial studies.

The first results revealed that the clusters' count is relatively different from an archaeological site to the other. Level 4 of Caours shows a distribution of remains in several high-density zones with no evidence, at first sight, of a clearly dominant zone (Tab. 6). Level 2 of Beauvais presents numerous small remains' groups distributed in the periphery of a single high-density zone (Tab. 7).

For Beauvais and Caours, the previously identified concentration zones turned out to be mostly butchery areas. Level 4 of Caours shows more differentiated activity areas than level 2 of Beauvais (Fig. 31 and 32). Only Caours' level clearly exhibits butchery areas dedicated to certain species with different intensity degree of processing.

For each level, we showed that the highest remains' density zone corresponds to a combustion area. While our analysis confirmed the primary position of the combustion zone of Caours, they can't clearly certify the same for Beauvais.

For Caours as for Beauvais, the most extensive butchery area is in direct contact with the combustion zone. That confirms a close relationship between butchery activities and fire (Tab 6 and 7).

Caours, N4		Combustion zone	Butchery zone
Detection		✓	✓
Number		a single one	several
Details	Species	mixed	sort
	Food utility	mixed	sort
Spatial relationship with other activity areas	Combustion zone		✓
	Butchery zone	✓	

Tableau 6: Spatial organization criteria for level 4 of Caours.

Beauvais, N2		Combustion zone	Butchery zone
Detection		✓	✓
Number		a single one	a single one
Details	Species	mixed	mixed
	Food utility	mixed	sort
Spatial relationship with other activity areas	Combustion zone		✓
	Butchery zone	✓	

Tableau 7: Spatial organization criteria for level 2 of Beauvais.

7. Conclusion

Foremost, our study aimed to precisely adapt our methods' choice to the geographic and archaeological data. Thereby, our spatial analysis protocol turned out to be very effective for identifying human activity areas in levels from completely different bioclimatic contexts. Also, that protocol is reproducible for comparable sets of spatial data in similar states of preservation. In other words, for a level with a much smaller remains' number or a stronger palimpsest effect, the choice of analysis methods would need to be adapted.

We proved that level 4 of Caours and level 2 of Beauvais exhibit an anthropogenic spatial organization as Human activity areas. That result may appear trivial, but it is rarely so clearly highlighted for Middle Palaeolithic sites in open-air contexts. Even more when the analysis is solely based on faunal material. In a cave or rock shelter contexts, the natural limits restrict the available occupation surface. In this way, agents that can potentially interfere with the spatial signal are amplified: successive reoccupations can lead to palimpsest effects or the spatial reorganization of the remains by humans (Gabucio et al., 2018; Pettitt, 1997; Vaquero et al., 2017). As a result, the study of these occupations is often linked to complex spatial problems. Researchers must continuously attempt to individualise the occupations while trying to identify the processes of space management (Gabucio et al., 2018; Spagnolo et al., 2018; Vaquero et al., 2017). In the two cases studied here, the levels' preservation is conducive to a relatively good individualization of the occupations. We can thus wonder if complex spatial behaviour – cleaning the living area, reorganization of the remains during the occupation – can also be detected for these sites with no physical limits.

Part of the answer to that question lies in the list of spatial organization criteria that we established based on of the current study:

- The identification of the following human activity areas: combustion zone, butchery area
- The faunal remains clustered in these activity areas correspond to one, two, or several species
- The faunal remains clustered in these activity areas have the same food utility, or not
- The existence of spatial relationships between the activity areas

As is often the case for rock shelters or cave sites, we highlighted different human activity areas delimited in space: combustion areas and butchery areas. Although multiple hearths are regularly observed in rock shelter or cave contexts, for Caours and for Beauvais, a single combustion zone has been identified until now. Some similarities persist regardless of site context, like a close relationship between animal carcass processing activities and fire (Locht and Patou-Mathis, 1998; Spagnolo et al., 2018; Vaquero et al., 2017). However, it is often complex to prove their contemporaneity. Complementary spatial analyses could add answers to this question, like the study of faunal and lithic refits (Cziesla, 1990; Gabucio et al., 2018; Vaquero et al., 2017). This approach could also clarify the relationships between the different activity areas described for our two sites. Their combustion zone's location, at the centre of the butchery activities, suggests a structuration of space around the fire. This pattern has already been mentioned on several occasions in the literature on Neanderthal sites (Spagnolo et al., 2018; Vaquero and Pastó, 2001).

Butchery areas, identified in Caours and Beauvais, were also highlighted for many rock shelter and cave sites. Caours and Beauvais have been defined as butchery sites, an intermediary between the kill site and a potential longer duration habitat site.

For both, the distribution of butchery areas is not dependent on a limited surface where space must be left for other domestic activities (rest areas, built hearth, etc.). For level 4 of Caours, the butchery areas' location may have been influenced by other agents. The intensive butchery areas for red deer are very well delimited in space, while the processing of less frequent species (large and mega-herbivores and roe deer) took place on the periphery of the former areas. The agents underlying this spatial organization may be linked to the acquisition mode of the different species (scavenging, trapping or hunting) or directly to how they were processed (breaking of the bones to extract the marrow, transport of the whole carcass). The study of the skeletal elements constituting these areas could provide more elements to confirm or refute these hypotheses.

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