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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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7 Abstract

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

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

30

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; Locht, 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

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

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

82 2. Study context

83 We chose Northern France as our study area since the chronostratigraphic framework for this
84 region is among the best documented for the European Middle Palaeolithic (J.-L. Locht et al.,
85 2016). As a result of the quality of the pedosedimentary records and number of identified sites,
86 this is a particularly advantageous region for the analysis of Neanderthal behaviour, and may
87 provide valuable information regarding how territories were occupied during the Middle
88 Palaeolithic. In this way, we aim to contribute new data to the Neanderthal palethnographic
89 record in Northern France.

90 Caours and Beauvais were selected for this study as they are comparable in terms of site
91 surface and the quantity of remains and are from different periods of the Middle Palaeolithic
92 (Fig.1; Tab. 1). Both sites exhibit excellent preservation, making them ideal candidates for
93 spatial analyses. As these are open-air sites there are also no topographic limits to restrict the
94 occupation surface, resulting in a spatial signal which is less frequently blurred by the duration
95 and the intensity of the successive occupations (Clark, 2017, 2016; Jaubert and Delagnes,
96 2007; Spagnolo et al., 2018). The additional interest in studying these two sites is their different
97 bioclimatic contexts and from different isotopic stages: Beauvais (MIS 4) was settled in an arid
98 steppe plain, while Caours (MIS 5e) was in a clearing near a river in temperate woodland
99 (Antoine et al., 2006; Locht, 2001). Finally, they both rank among the sites with the richest
100 faunal remains in the region.



101
102 **Figure 1: Regional map of Northern France showing the location of the Palaeolithic sites of Caours and Beauvais (modified**
103 **from GeoMapApp).**

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

109 2018; Vaquero et al., 2017). Given this context, this article focuses on the application of our
 110 spatial analysis protocol to the faunal assemblages from the sites of Caours and Beauvais.

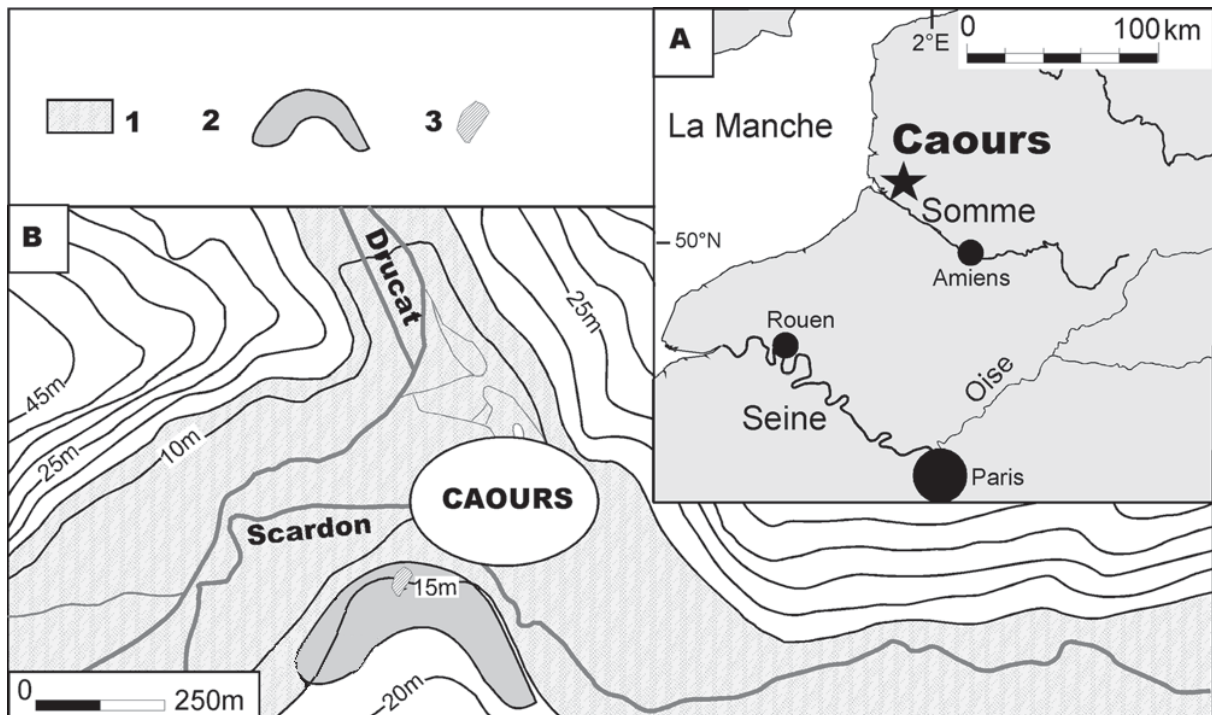
		Caours N4	Beauvais C2
Topography		NW slope	Depression at the base of a Tertiary mound
Chronostratigraphy		Isotopic stage 5e	Isotopic stage 4
TL date/burnt flint		122.8 ± 8.6 ka BP	55.6 ± 4 ka BP
Excavated surface		358 m ²	763 m ²
Chaînes opératoires		Discoid and Levallois	Discoid
Number of lithic artefacts	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)).

111

112 2.1. The level 4 of the site of Caours

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



118

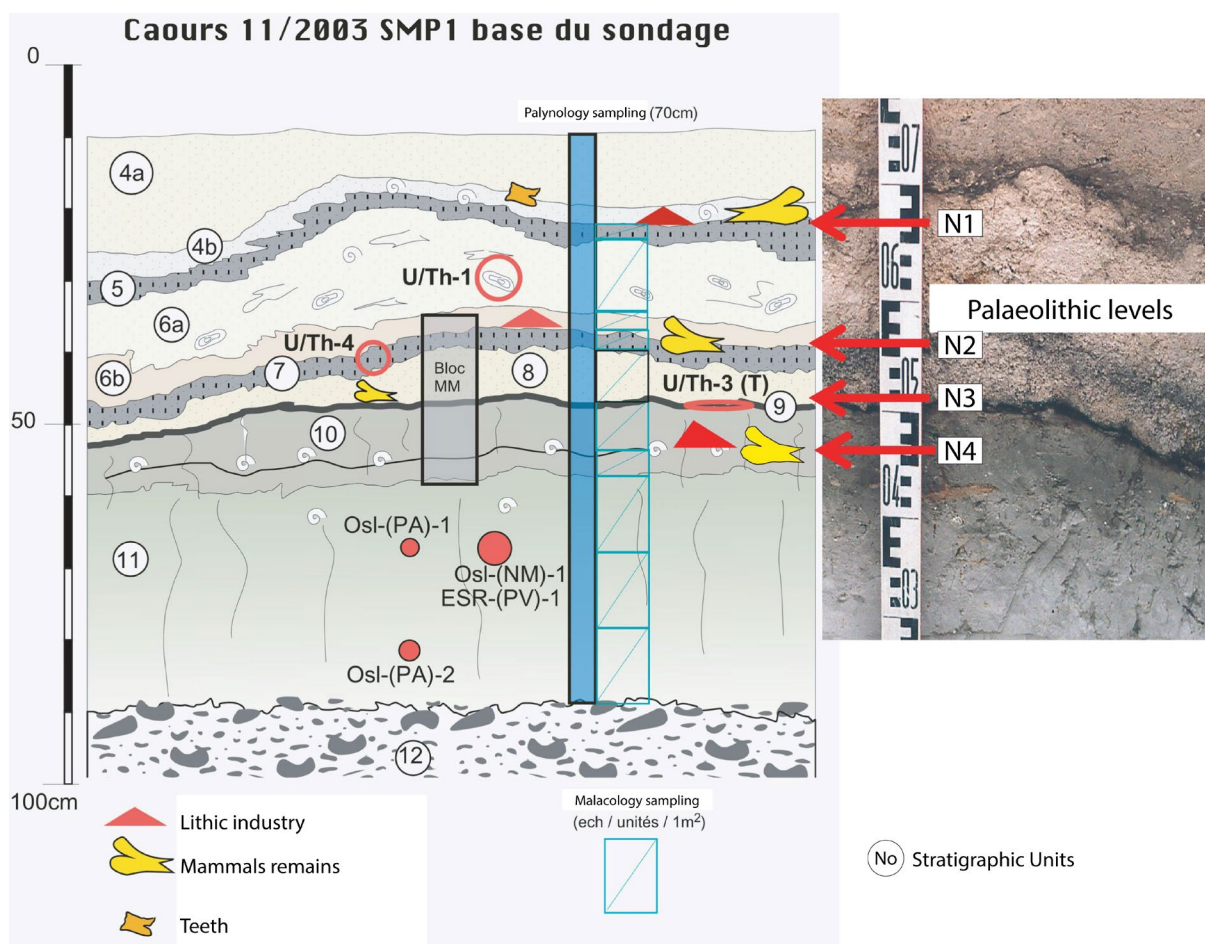
119 Figure 2: Location (A) and geomorphological context of the site of Caours. 1 - Present day marshy bottom valley, 2 -
 120 Extension of the Caours tufa, 3 - Former quarries. (Antoine et al., 2006)

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

125 2.1.1. Stratigraphy and Taphonomy

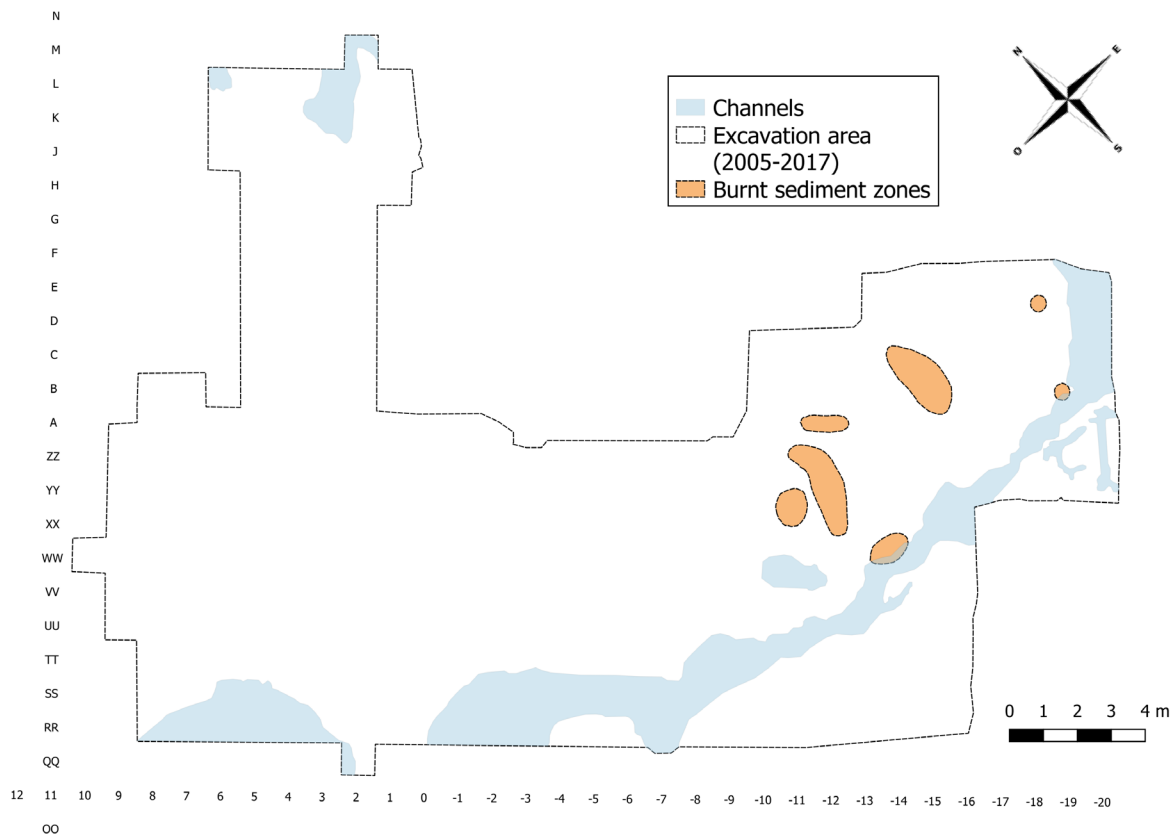
126 To describe the complex stratigraphy of Caours, researchers have correlated the results from
 127 sedimentology, geochemistry, malacology, micropaleontology, and studies of palaeobotany.
 128 The synthesis of these results suggests an attribution of that sequence to the Eemian isotopic
 129 stage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

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



140
 141 **Figure 3: Detailed description of the sediment sequence of Caours and the location of the archaeological levels inside (J. Loch et al., 2016)**
 142

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



149

150

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

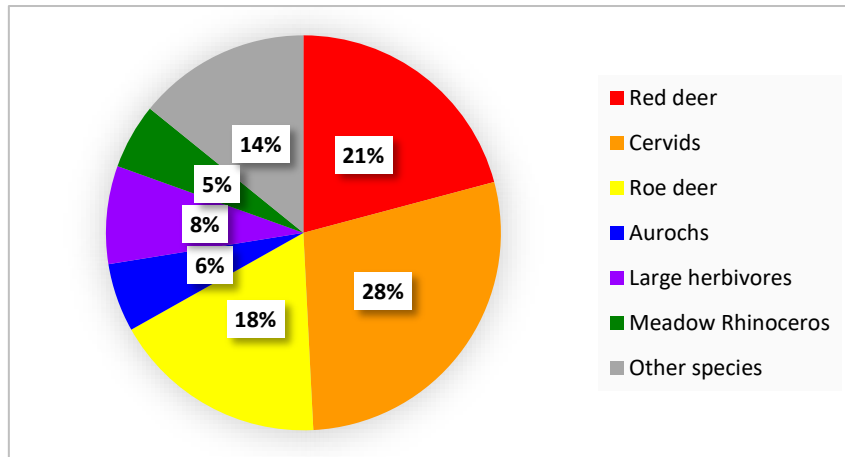
151 In level 4 of Caours, cracked fluvial silt zones, darker than the original silt, were identified and
 152 interpreted as burnt sediment markers (Fig. 4) (Locht et al., 2010, 2009). These zones are
 153 characterized by a high quantity of charcoals and some burnt bones and heated flint pieces.

154 2.1.2. Faunal remains

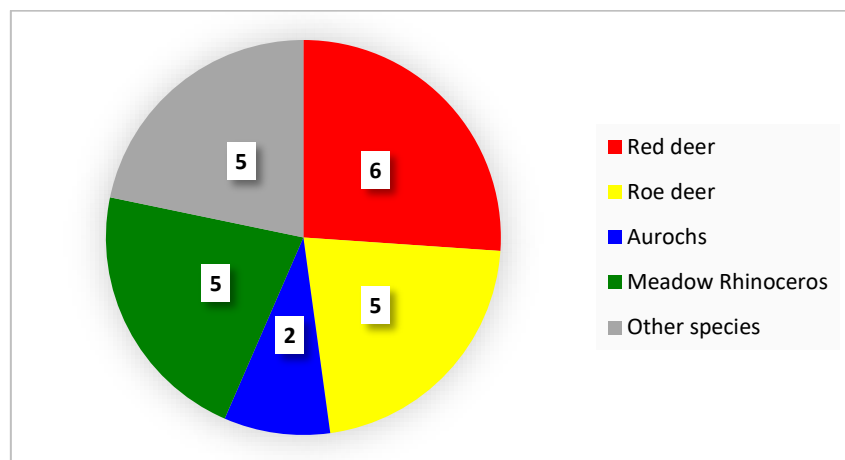
155 The faunal assemblage of the level 4 of Caours is representative from a temperate period with
 156 the red deer, the roe deer, the aurochs and the meadow rhinoceros (Antoine et al., 2006;
 157 Sévêque, 2017). Species determination suggested a mosaic landscape of park-wooded
 158 meadow type, with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

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

164

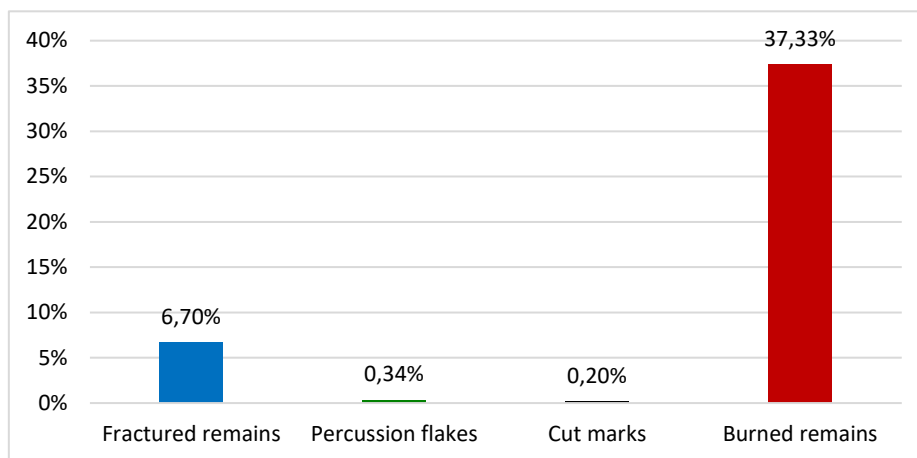


165 **Figure 5 : Distribution diagram of taxa of the level 4 of Caours according to the percentage of identified remains (based**
166 **on the data from P. Auguste and N. Sévêque)**



167 **Figure 6 : Distribution diagram of taxa of the level 4 of Caours according to the Minimal Number of Individuals (based on**
168 **the data from the excavations between 2005 and 2016 from (Sévêque, 2017))**
169

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



174 **Figure 7 : Histogram of the percentage of faunal remains bearing anthropogenic traces in level 4 of Caours (based on the**
175 **data from P. Auguste and N. Sévêque)**
176

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

182 Based on the anatomic representation of each species, researchers proposed a difference of
 183 treatment between cervids and big herbivores like aurochs. For the cervids, the first
 184 disarticulation steps would have been processed on the killing site. Then, the parts were
 185 brought to the butchery site of Caours where these were highly exploited from defleshing to
 186 bone fragmentation aiming to extract the marrow. For the larger herbivores, it appears that
 187 nearly only members were brought from the killing site to Caours (Sévêque, 2017). For all of
 188 these species, the animals' parts mostly bring to the site of Caours were the most alimentary
 189 useful parts (Tab. 2). The faunal accumulations clearly demonstrate that Caours was a
 190 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 %

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

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

195 2.1.3. Lithic remains

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

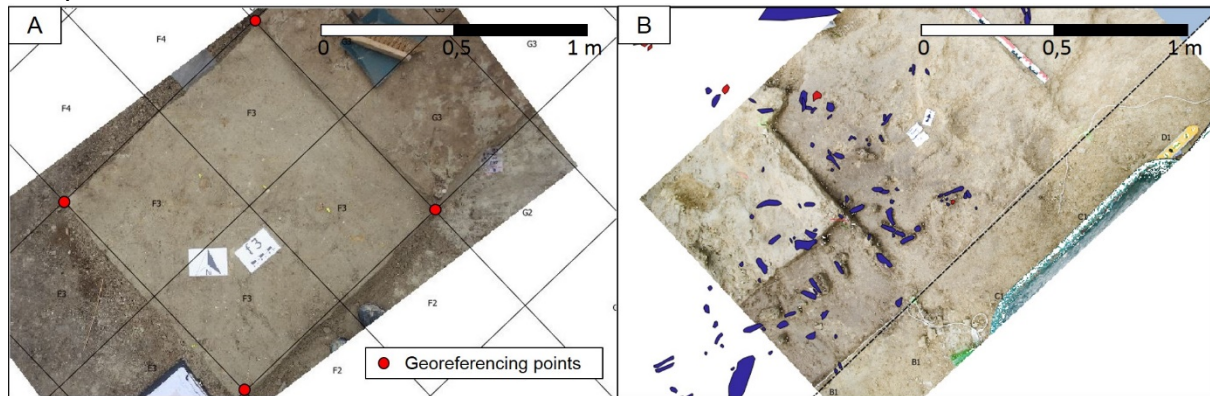
201 Level 4 of Caours present 1271 artefacts discovered between 2005 and 2017. Discoid debitage
 202 was almost exclusively used for the rapid production of flakes with a back opposite the cutting
 203 edge-backed knives (Antoine et al., 2006). 73 burned lithic artefacts were found in level 4, near
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

205 2.1.4. Spatial data

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

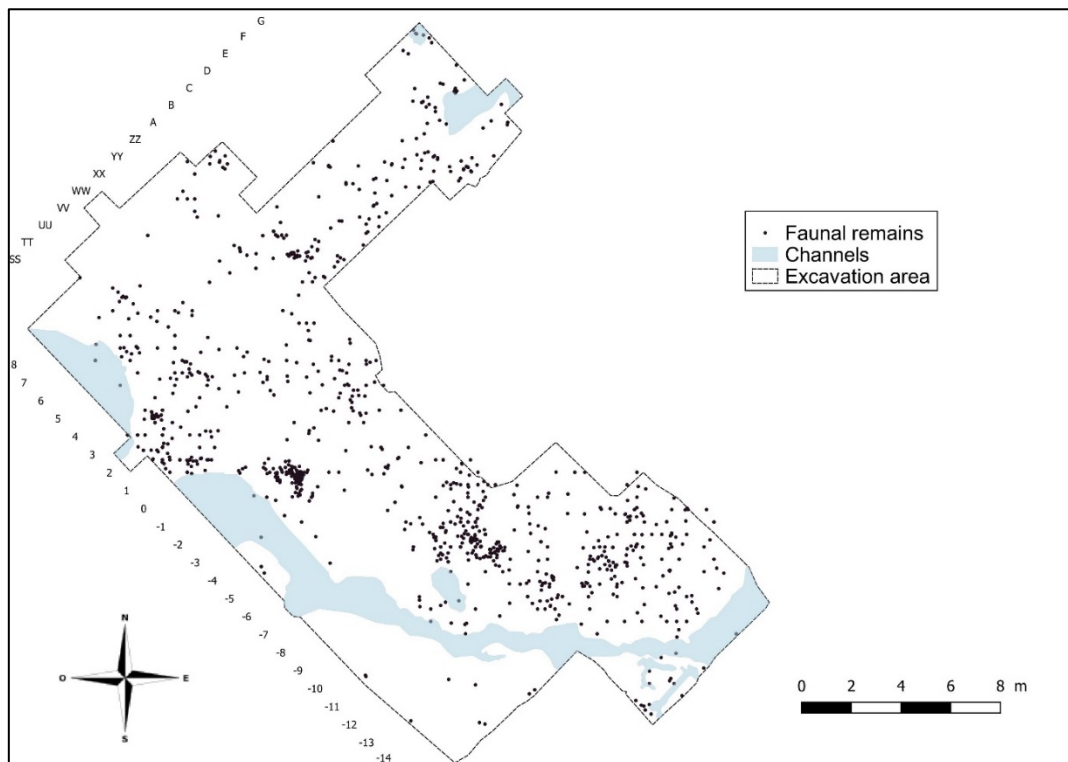
209 recording of the remains, the photos of the excavated squares are first georeferenced with the
 210 QGIS software used for the management of our set of data (Fig. 8A). We then render the limits
 211 of each remain to obtain a layer of georeferenced polygons (Fig. 8B). The coordinates of the
 212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

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



217
 218 **Figure 8 : (A) Example of georeferencing of one of the ortho-photos taken for level 4 from the square F3. (B) Example of**
 219 **Computer Aided Drawing of the faunal remains (in blue) and the lithic remains (in red) during the excavation of Caours**
 220 **2016.**

221 For the site of Caours, our analysis represents the first spatial study of the occupations. Figure
 222 9 shows the distribution of faunal remains through level 4 of Caours. Based on that first
 223 distribution map, researchers proposed the hypothesis of a faunal remains distribution as
 224 concentrations zones.

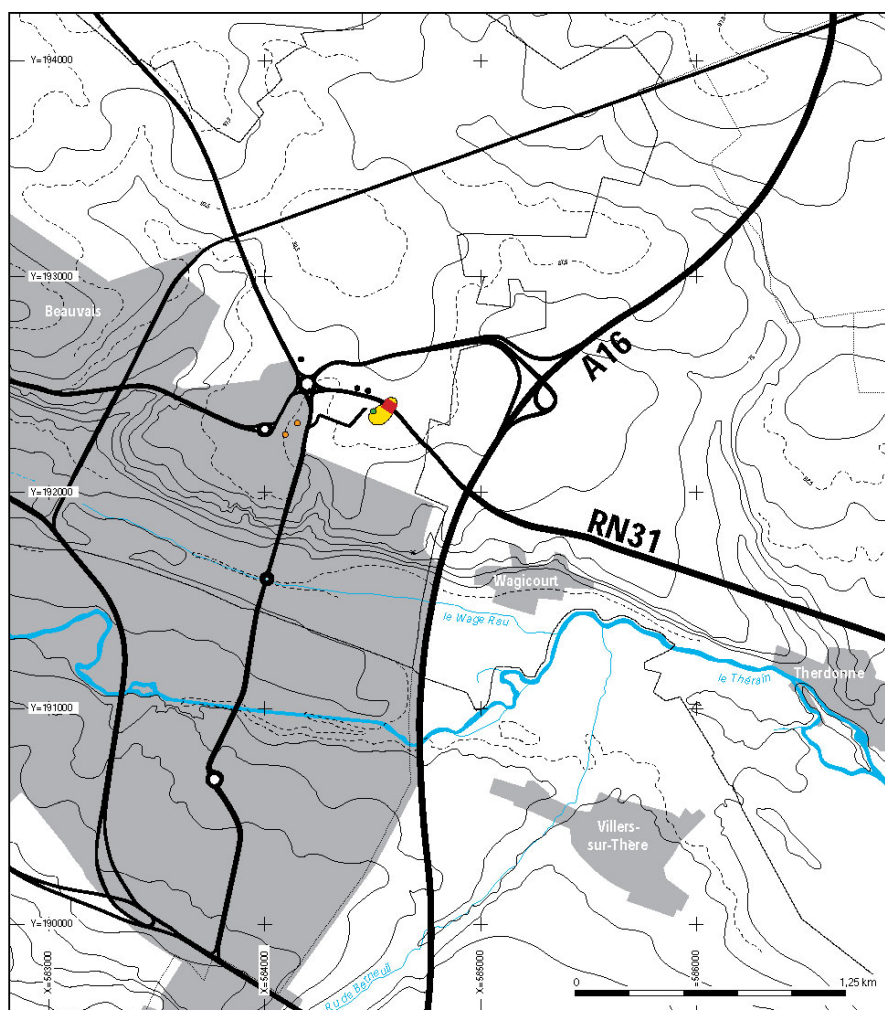


225
 226 **Figure 9 : Distribution map of the faunal remains from level 4 of Caours.**

227

2.2. The level 2 of the site of Beauvais

228 The archaeological site of Beauvais was discovered in the west of the same-named town, near
 229 a locality called La Justice. It is located on the north-eastern foothill of a mound from the
 230 Tertiary period, located itself in the border of a 90 m N.G.F. (*Nivellement Général de France*)
 231 altitude plateau (Fig. 10). The Tertiary substrate at the foothill was shaped by successive
 232 erosion phases digging a well-marked depression safe from the dominant winds. This
 233 particular topography certainly played a role in the settlement of human occupations.
 234 Furthermore, the Tertiary mound could constitute a landmark overhanging the valley of the
 235 Thérain, localized about 30 meters below (Locht et al., 1995). Additionally, the topographic
 236 location of the site of Beauvais allowed the quick accumulation of a thick sequence of
 237 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).

238

239

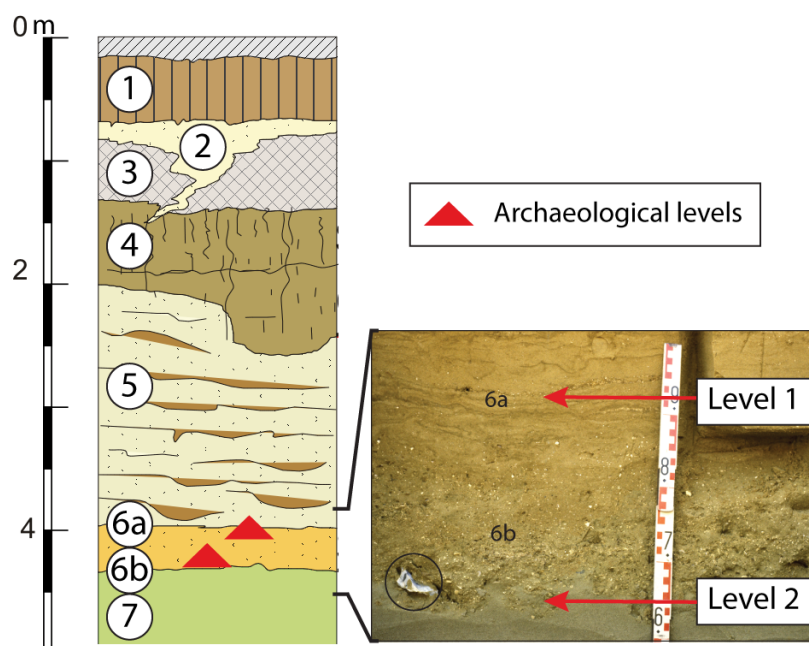
240 We chose to study level 2 of Beauvais as it is the richest in faunal remains. It was manually
 241 excavated over 763 m².

242

2.2.1. Stratigraphy and Taphonomy

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

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



254

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

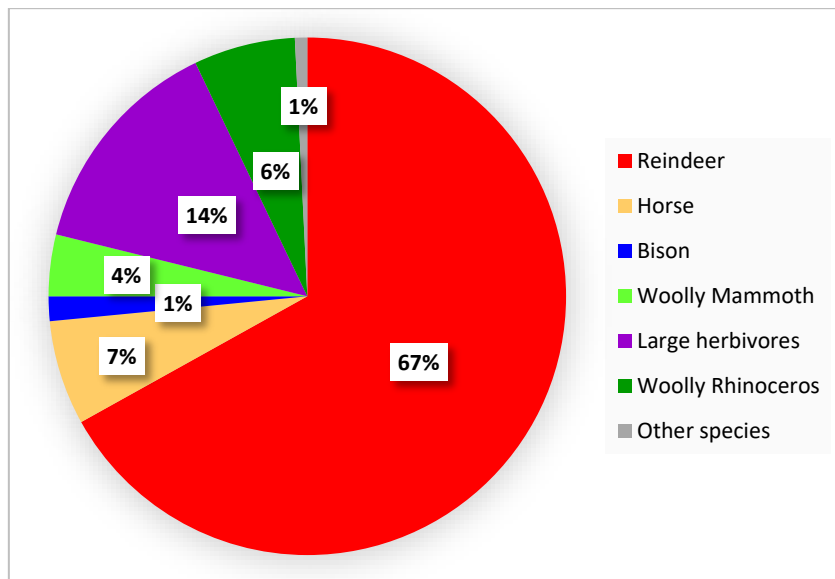
257 The dating of the two levels of Beauvais was a difficult task. The environmental data, from
258 faunal remains, suggested the isotopic stage 4. However, since that type of sediment
259 sequence was never described for the Weichselian stage, stratigraphic data rather proposed
260 the isotopic stage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

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

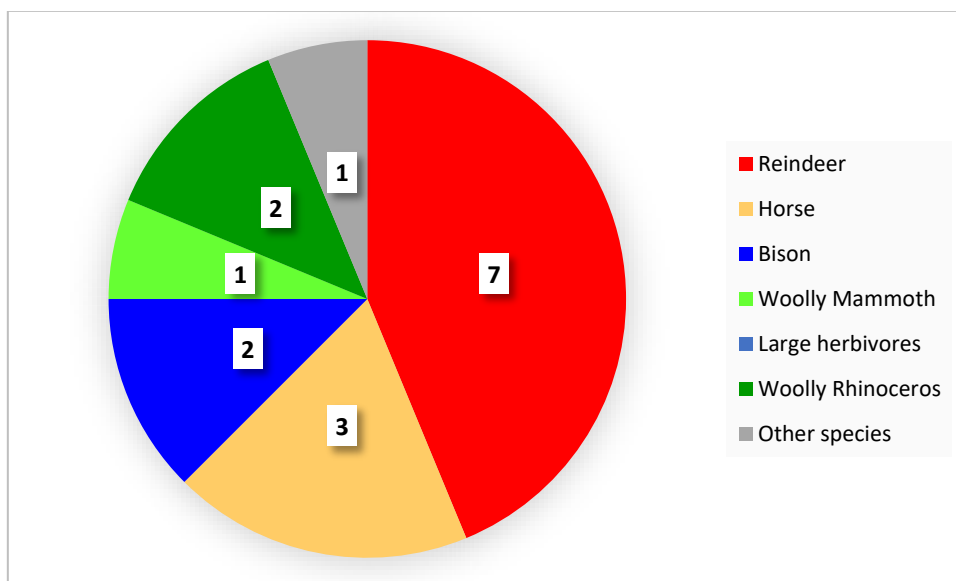
266 2.2.2. Faunal remains

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

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

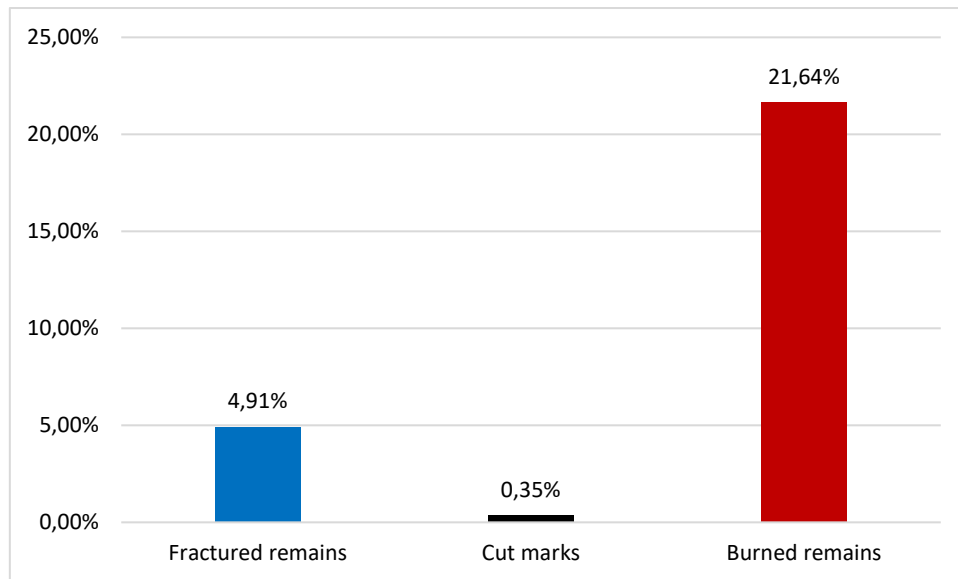


273
 274 **Figure 12 : Distribution diagram of taxa of the level 2 of Beauvais according to the percentage of identified remains**
 275 **(based on the data from M. Patou-Mathis)**



276
 277 **Figure 13 : Distribution diagram of taxa of the level 2 of Beauvais according to the Minimal Number of Individuals (based**
 278 **on the data from (Locht, 2004))**

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



285

286
287

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)

288 That anthropogenic traces highlight the practice of different human activities during the level
289 2. Bones bearing cut marks or spiral fractures attest to butchery activities, and it appears that
290 most of the burned bones are fractured and defleshed reindeer bones fragment smaller than
291 5 cm and rich in *spongiosa*. The researchers suggested the hypothesis of the use of these
292 bones as fuel (Locht and Patou-Mathis, 1998; Locht, 2004).

293 Like in Caours, there is an observed treatment difference between cervids and big and mega-
294 herbivores. The remains of reindeer present traces attesting to most of the animal carcass
295 treatment steps: disarticulation, defleshing, and the fracture of bones to extract the marrow.
296 Additionally, all the anatomical parts of the species are represented, suggesting that complete
297 animals were brought to level 2 of Beauvais. For horse and bison, only some parts of the
298 animal were brought to the site and few spiral fractures have been identified. For mammoth
299 and rhinoceros, cranial parts dominate but one talus of rhinoceros bear traces of tibiotarsal
300 disarticulation. For these species, these elements question the possibility of the intake of meat
301 parts without any bones on the site (Locht and Patou-Mathis, 1998; Locht, 2004). Finally, for
302 all of species, the animals' parts mostly bring to the site of Beauvais were the most alimentary
303 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%

304
305

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; Locht, 2004))

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

310 2.2.3. Lithic remains

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

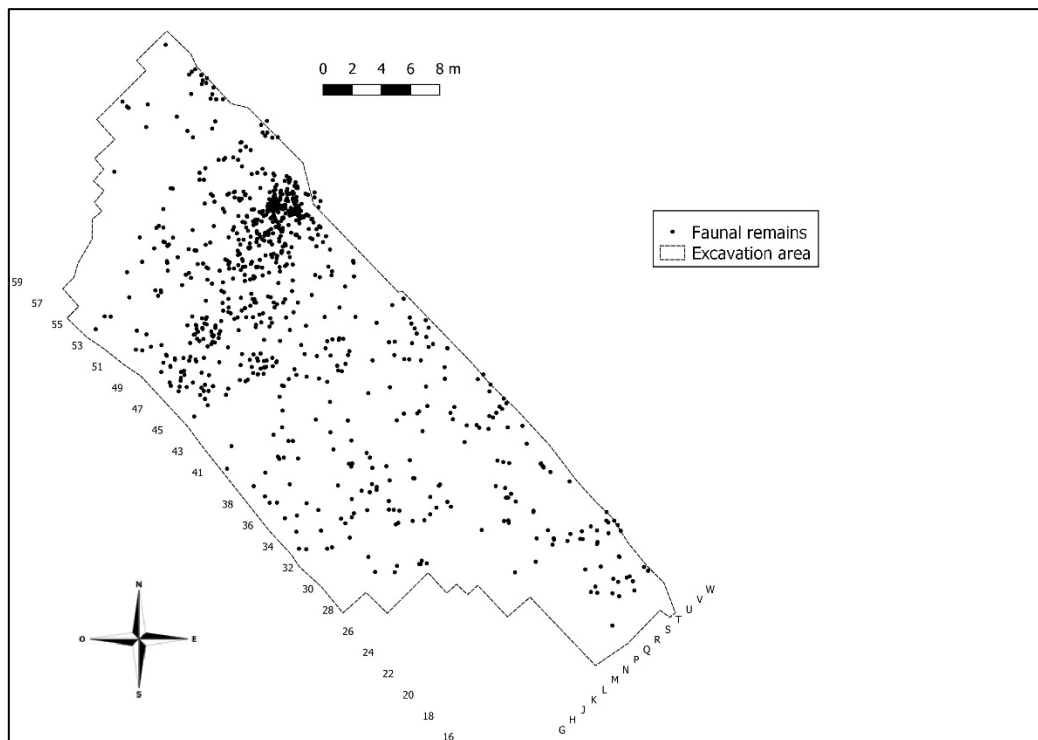
314 Level 2 of Beauvais counts 1947 lithic artefacts, most of them are distributed through only 320
315 m². The main *chaîne opératoire* produced flakes and pseudo-Levallois points through the
316 discoid debitage method. Some of them have been retouched to accommodate the prehensile
317 part of the artefact. This particular retouch evokes the morphology of backed knives (Locht,
318 2004). Researchers evoked the hypothesis that the numerous flakes in level 2, presenting that
319 back opposite the cutting edge, may have been used for butchery activities (Locht, 2001).

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

321 2.2.4. Spatial data and first spatial study

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

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



328

329

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

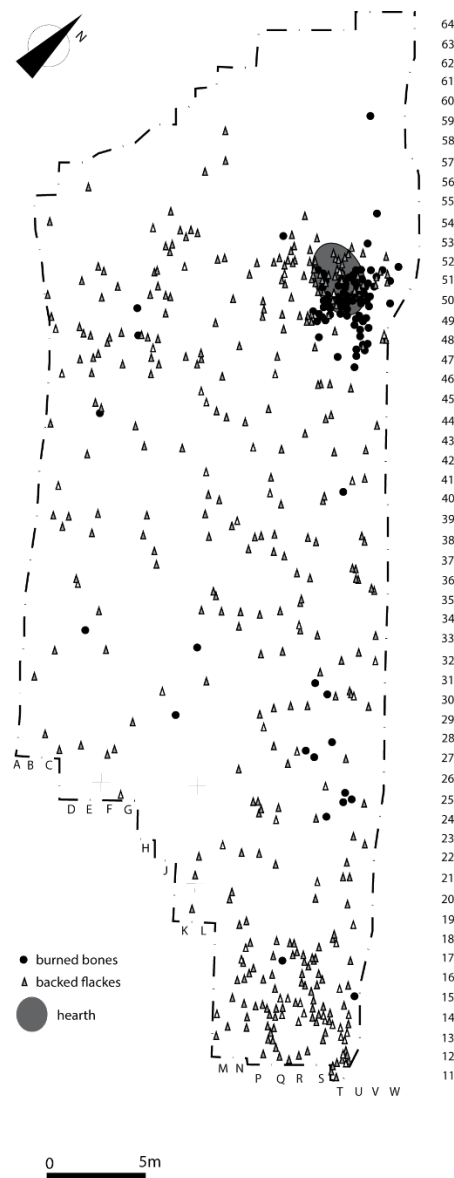
330

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
344

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

345

2.2.4.2. Spatial study of other faunal remains

346

Several criteria were used to study the remaining faunal remains:

347

- Spatial distribution of remains sort by species;

348

- Spatial distribution of remains sort by anatomical parts;

349

- Percentage of bones rich in meat and marrow in a defined area;

350

- Percentage of bones bearing anthropic traces in a defined area.

351

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:

352

353

354

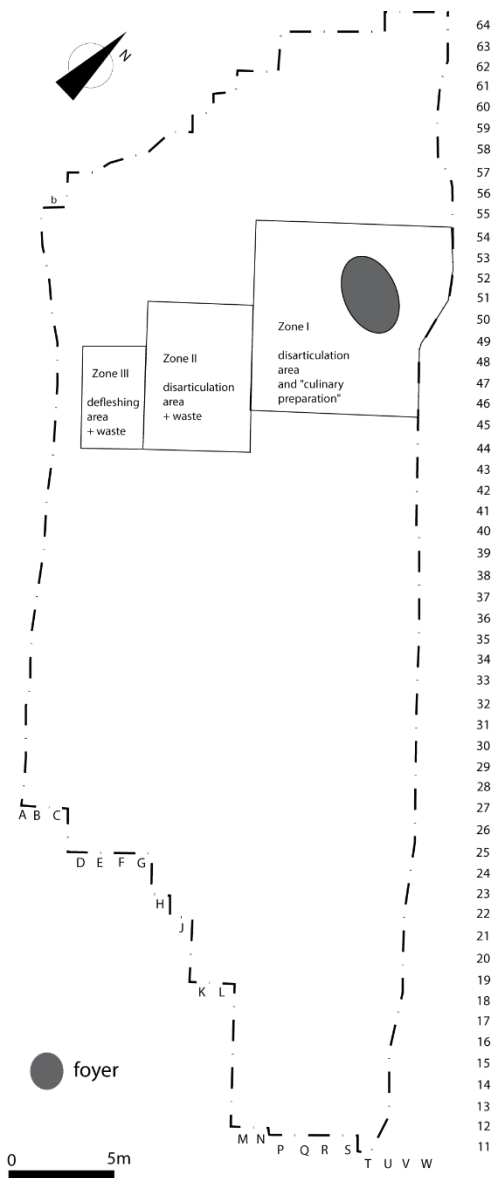
- Zone I: Disarticulation and “culinary preparation”;

355

- Zone II: Disarticulation and wastes resulting from this activity;

356

- Zone III: Defleshing and wastes resulting from this activity.



357

358

359

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).

360

2.2.4.3. Spatial study of lithic artefacts

361 In level 2, researchers observed that backed flakes are distributed all over the excavation area
362 but two concentration zones were identified. The first one is associated with reindeer remains
363 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).

365 3. Interpretative framework

366 3.1. Concept of random spatial organization

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

387 3.2. Definition of human activity area

388 In archaeology, we define a human activity area as a restricted zone where one or several
389 related activities were practiced. This area concentrates some remains from this activity
390 (products or waste) and associated materials (raw material or tools) (Flannery and Winter,
391 1976; Merrill and Read, 2010). Therefore, in Prehistory, activity areas are often considered as
392 artefacts accumulations or clusters. Ethnographic investigations have demonstrated, however,
393 a wide range of variability in the size, shape, and artifact density of artefact clusters. It has less
394 been discussed, though, that an activity area could be distinguished as a lower density zone
395 surrounded by a high density of remains (Carr, 1984; Merrill and Read, 2010). It is still true
396 that, if we detect the clusters, we may detect the low-density zones as well. Therefore, the
397 detection of spatial patterns with mathematical parameters can be applicable and beneficial to
398 archaeologists.

399 Spatial information inherent in archaeological datasets is always fragmentary. Before
400 discussing the preservation processes of an archaeological layer, the nature and organization
401 of human behaviour and activities notably have the strongest impact on the spatial signal
402 readability hundreds of thousands years later (Clark, 2017; Schiffer, 1975; Spagnolo et al.,
403 2018). A long-duration occupation could lead to one layer of mixed artefacts, or to domestic
404 units precisely spatially delimited. Furthermore, practicing several activities in the same area
405 could lead to a very high-density and very visible cluster. Nevertheless, this cluster will be very
406 difficult to interpret due to the multiple activities represented (Merrill and Read, 2010). Different
407 activities also produce artefacts with different chances of preservation, with differential
408 preservation presenting various degrees of information about the activities in question
409 (Schiffer, 1975). For example: a single flake of knapping waste selected from all recovered
410 debitage, will not provide the same information about the knapping method as a retouched
411 tool, the desired end-product from the knapping activity. The artefacts don't provide the same

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

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

421 3.2.1. Spatial data analysis

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

428 3.2.2. Archaeological data analysis

429 To specify the location of a human activity area, we first need to identify its presence within the
430 occupation level (Schiffer, 1975). This principle may seem trivial but, the less the researched
431 activity is precisely described, the more it will be difficult to identify. Generally, we detect human
432 activity within an archaeological level by the identification of a characteristic artefacts from that
433 activity. Helped by our study region and chronocultural framework, we can then identify the
434 behavioral chain related to this activity and the other artefacts product or used by it (Schiffer,
435 1975). Then, those artefacts may be localized, and their co-occurrences may strengthen our
436 confidence in the human activity area location.

437 3.2.3. Cross-checking of the results from the two disciplines

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

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

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

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

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

466 3.3. Specificity of our interpretative framework

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

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

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

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

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

506 4. Methods

507 4.1. Acquisition of the spatial and archaeological data

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

513 4.2. Palaeolithic spatial analysis

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

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

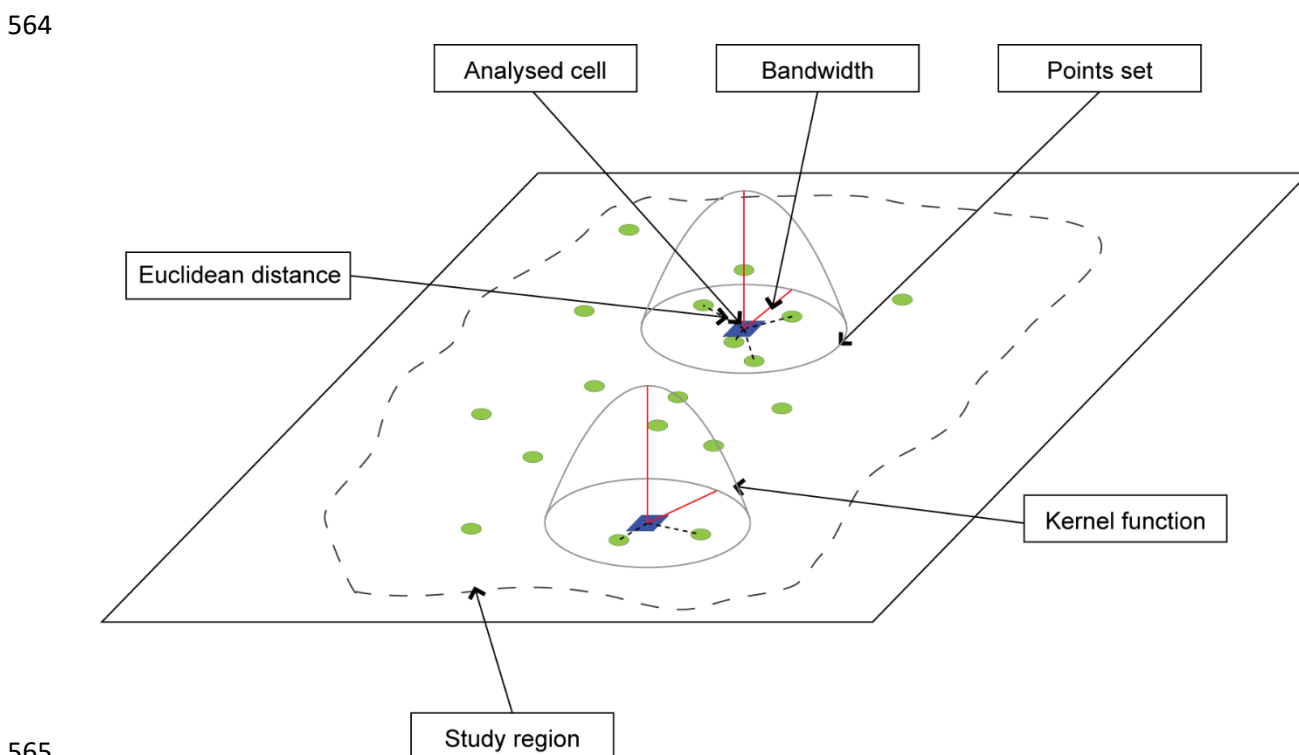
539 For the detection of human activity areas, one of the greatest methodological challenges is the
540 choice of the spatial analysis method for the characterization of the distribution of the
541 archaeological remains. This choice must be guided by several parameters, some of which
542 are linked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

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

551 4.3. Our spatial analysis protocol

552 4.3.1. Kernel Density Estimation (KDE)

553 Kernel Density Estimation (KDE) is an increasingly used modelling approach in
554 archaeology (Alperson-Afil et al., 2009; Clark, 2016; Spagnolo et al., 2018; Thacher et al.,
555 2017). It consists in calculating a histogram of simple smoothed bivariate frequencies
556 (probability density, 2D geographic space), via a kernel type function. This method proposes
557 to estimate the density of remains for each cell of a defined resolution grid, according to the
558 number of remains in the vicinity of the analysed cell and their distance from the latter (Fig.
559 18). The vicinity of the studied cell is described as a circle with a research radius – or
560 bandwidth– defined by the user (Gatrell et al., 1996). With this same method, we can thus
561 produce a series of results: a density of remains model for each research radius. The larger
562 this radius, the more the result will tend towards a single concentration zone of remains. The
563 smaller the radius, the more the result will tend towards a concentration zone per remain.



565
566 **Figure 18 : Illustration of the Kernel Density Estimation method (modified after Gatrell et al., 1996).**

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

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

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

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

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

600 4.3.2. K-means clustering

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

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

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

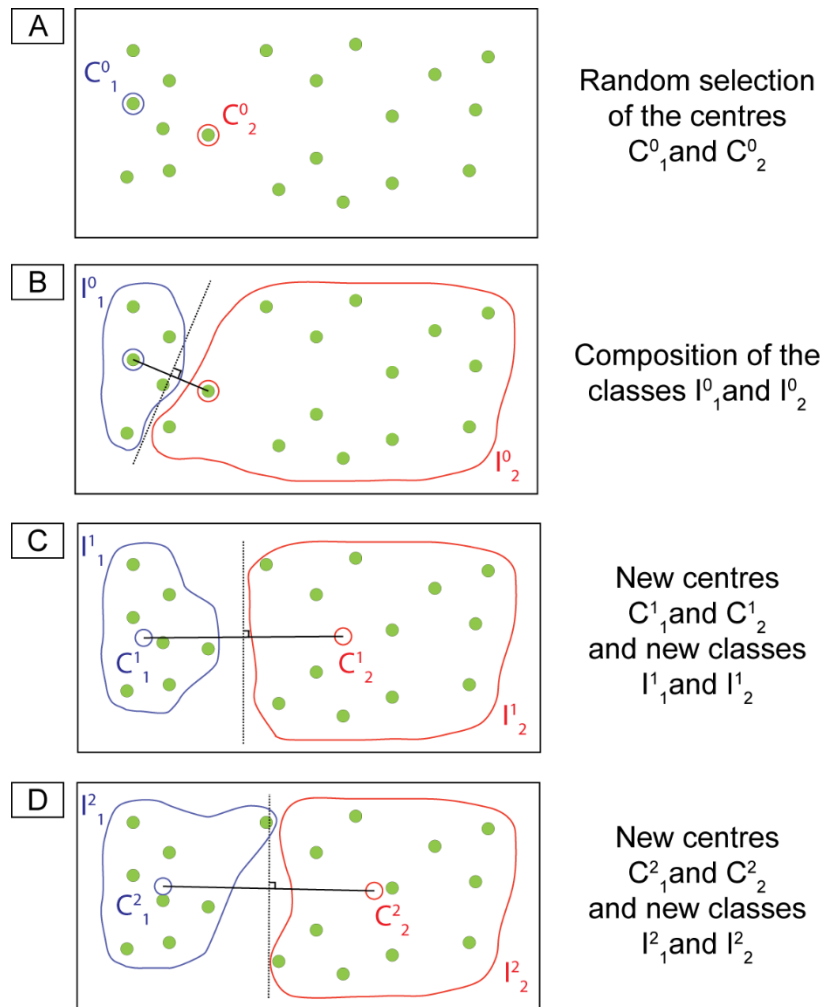


Figure 19 : Illustration of the K-means clustering method (modified after (Lebart et al., 2000)).

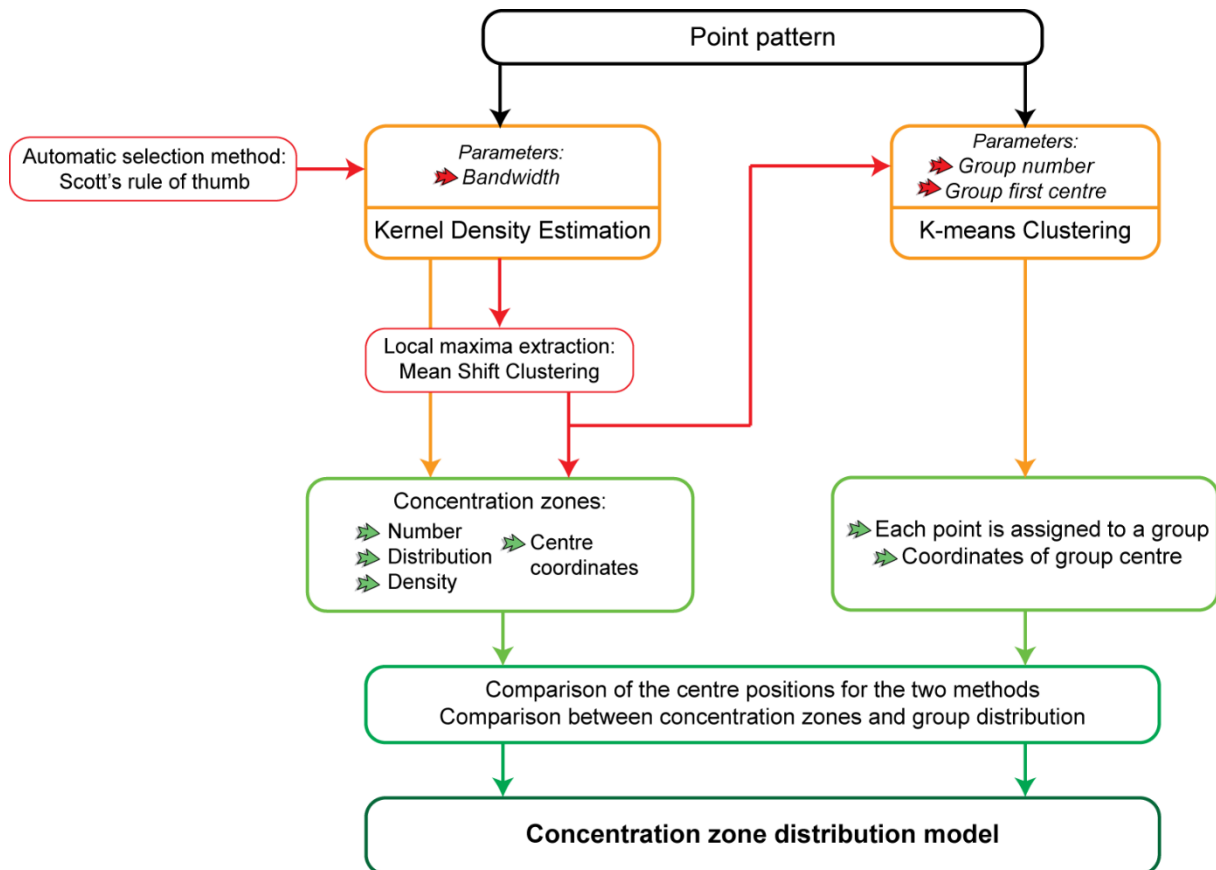
4.3.3. Two combined methods for a stronger protocol

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.

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



644
 645 **Figure 20 : Description of our spatial analysis protocol.**

646 4.3.4. Application to archaeological data

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

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

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

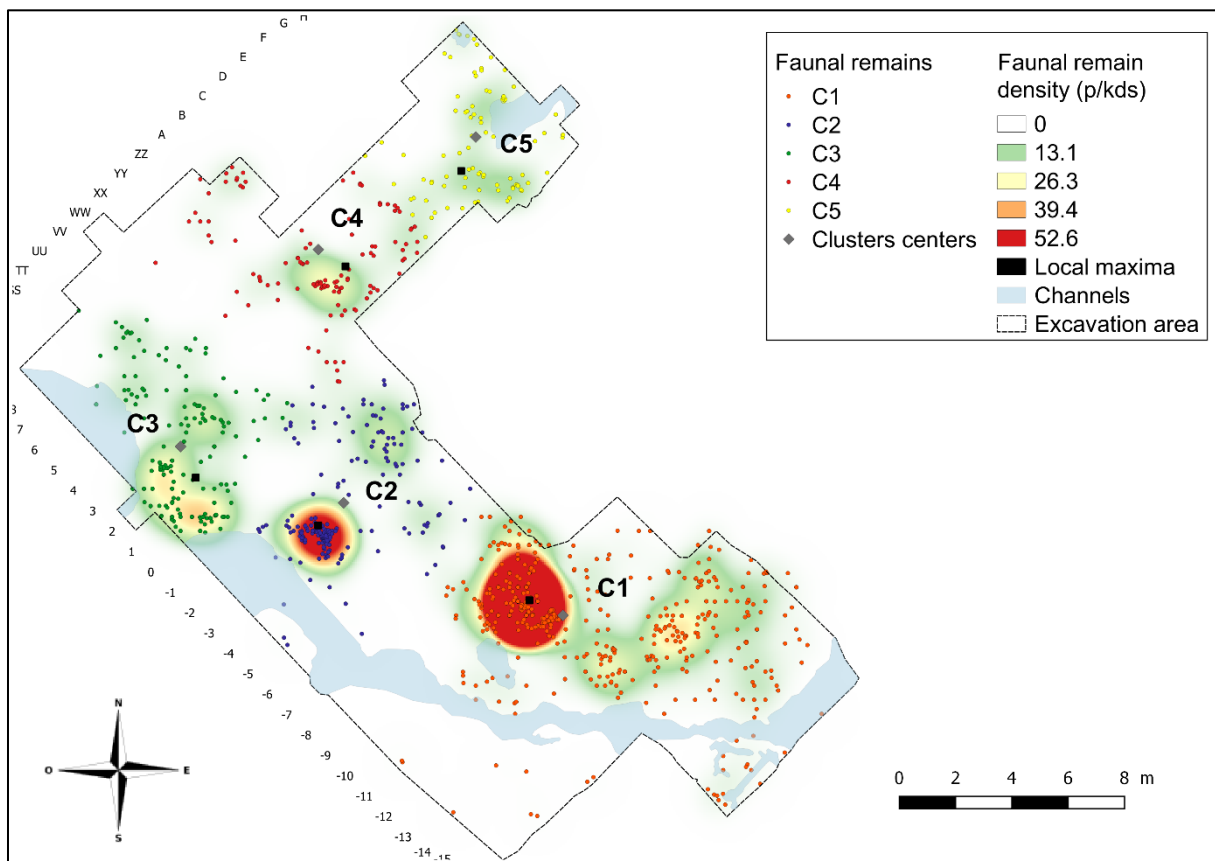
660 to compare the proportions of bones bearing anthropogenic traces in a concentration zone and
661 the whole level. Since our sample size is sometimes too small, we chose to use the exact
662 binomial test. In our context, that conformity test aims to prove that an observed proportion is
663 not conformed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

665 5. Results

666 5.1. Level 4 of the site of Caours

667 5.1.1. Spatial distribution of the faunal remains

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



674

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).

675
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5.1.2. Spatial distribution of the faunal remains bearing anthropogenic traces

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

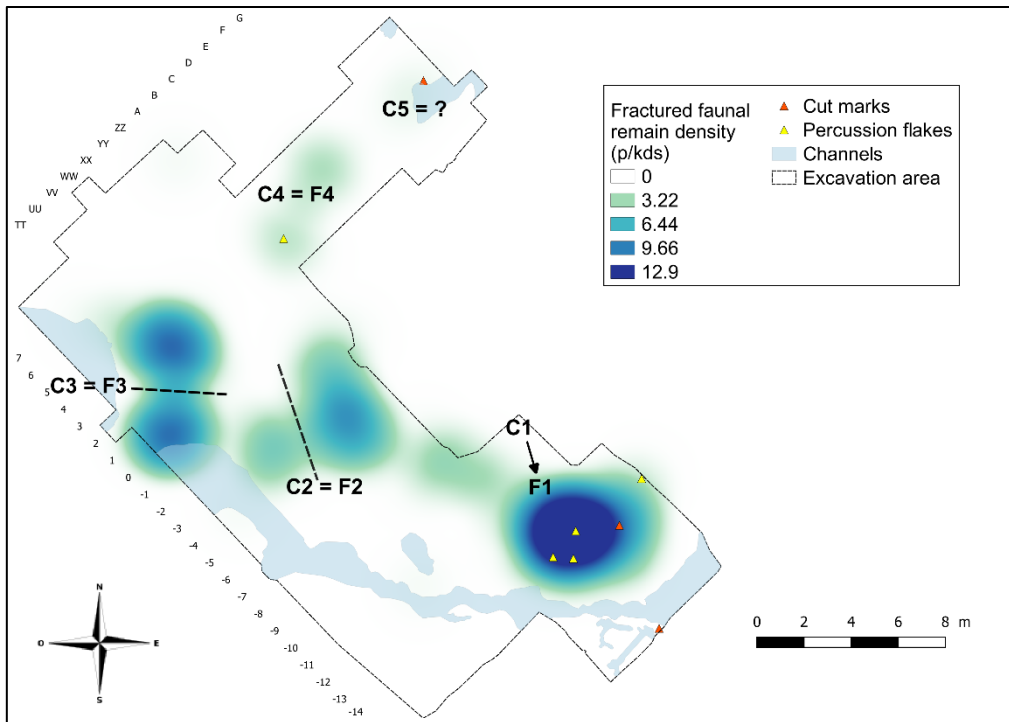
681 Zone C1 is subdivided into two distinct areas: a high-density zone of burnt remains and a
682 fracture zone (respectively B1 and F1 in figures 22 and 23). In zone C1, the result from the
683 binomial test on fractured remains shows a p-value of 0.0291, at the 5% significance level
684 (Tab. 4). That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

687 Zones C2 and C3 correspond each to a fracture zone (respectively F2 and F3 in figure 22).
688 For both, we distinguish a possible subdivision into two subzones (dashed line in figure 22).
689 Zone C4 exhibit a low density of remains bearing spiral fractures and C5 present none. In zone
690 C3, the result from the binomial test on fractured remains shows a p-value of 2.86E-04, at the
691 5% significance level (Tab. 4). That means that the proportion of fractured remains in C3 is
692 highly significantly different from the whole level, in this case, greater. In zone C2, C4, and C5,
693 the result from the binomial test on fractured remains shows a p-value greater than 0.05, at
694 the 5% significance level (Tab. 4). That means that the proportion of fractured remains in each
695 cluster is not significantly different from the whole level.

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

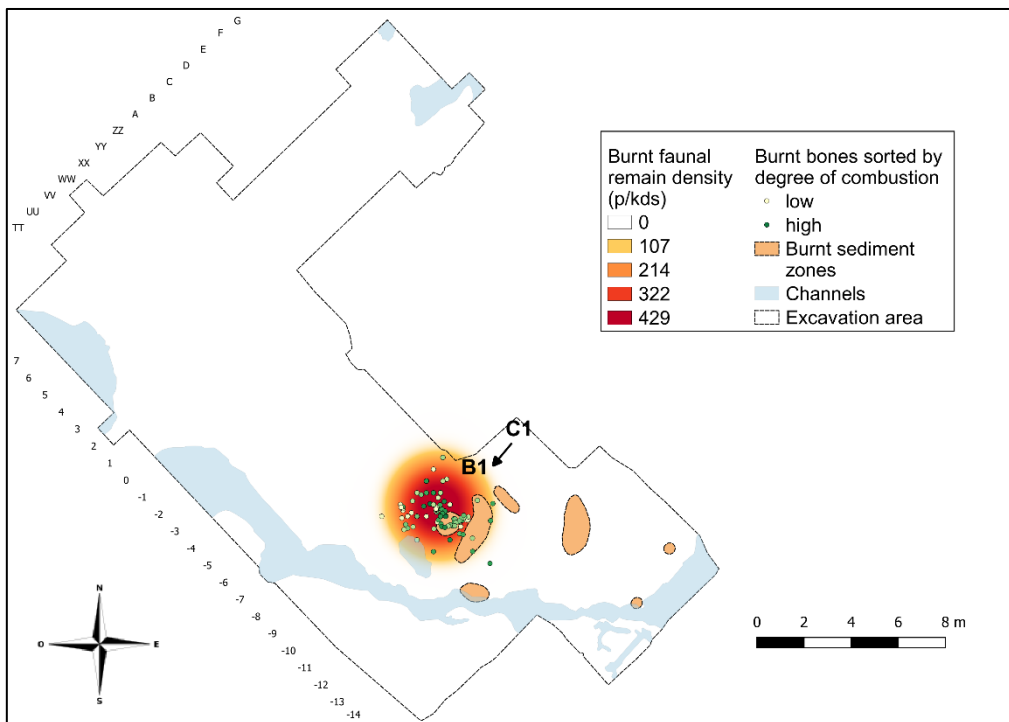
Cluster	Total of remains	Fractured remains			Burned remains		
		Number	Percentage	Exact binomial test	Number	Percentage	Exact binomial test
				p-value			p-value
C1	918	45	4,90%	0,0291	556	60,57%	2,20E-16
C2	201	20	9,95%	0,08785	0	0,00%	2,20E-16
C3	183	26	14,21%	2,86E-04	0	0,00%	2,20E-16
C4	117	5	4,27%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

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



709

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



713

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

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

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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.

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

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- 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).

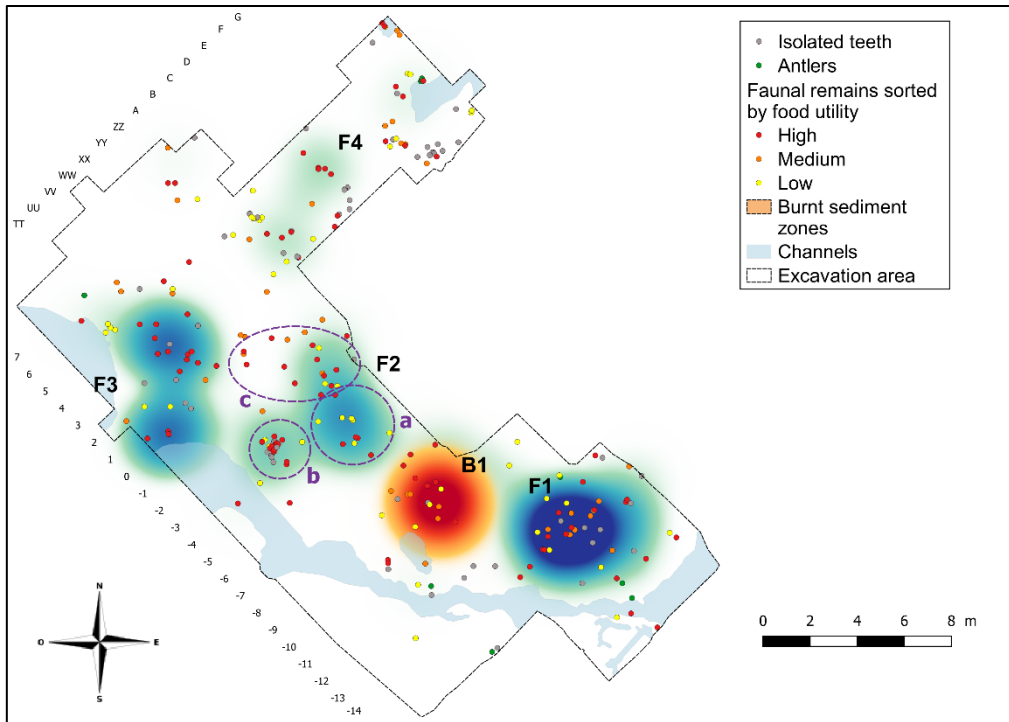
731
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Figure 25 highlights that the other large and mega-herbivores remains are distributed in small groups in the periphery of fracture zones (encircled in orange). Most of the roe deer remains follow the same tendency (encircled in green in figure 25).

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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.

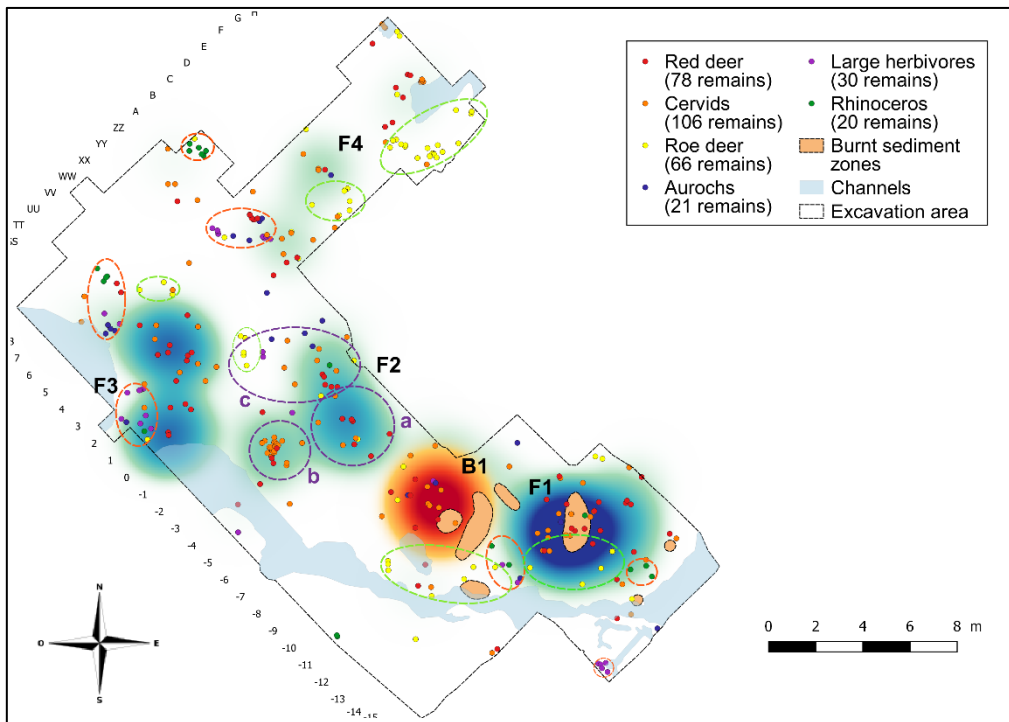
737



738

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.

747

5.2. Level 2 of the Beauvais site

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5.2.1. Spatial distribution of the faunal remains

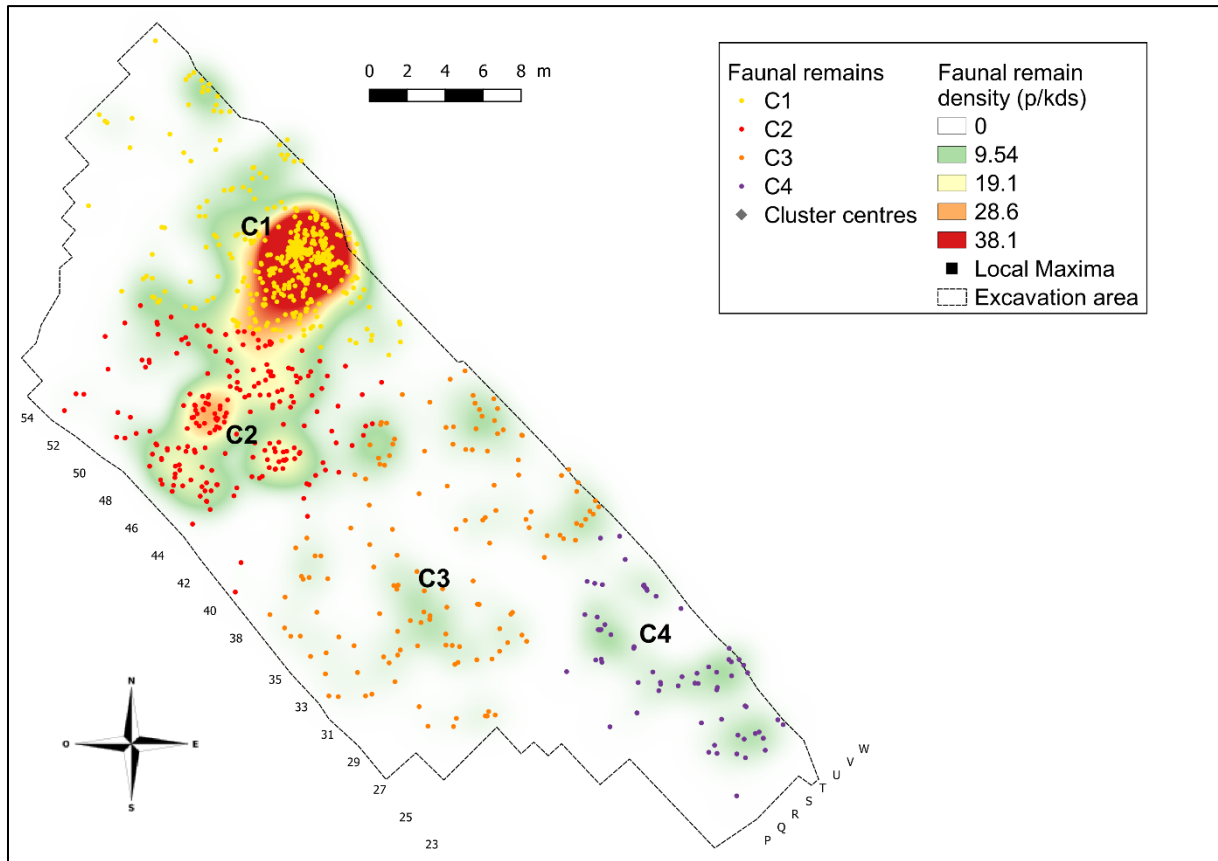
749

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.

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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).

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5.2.2. Spatial distribution of the faunal remains bearing anthropogenic traces

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

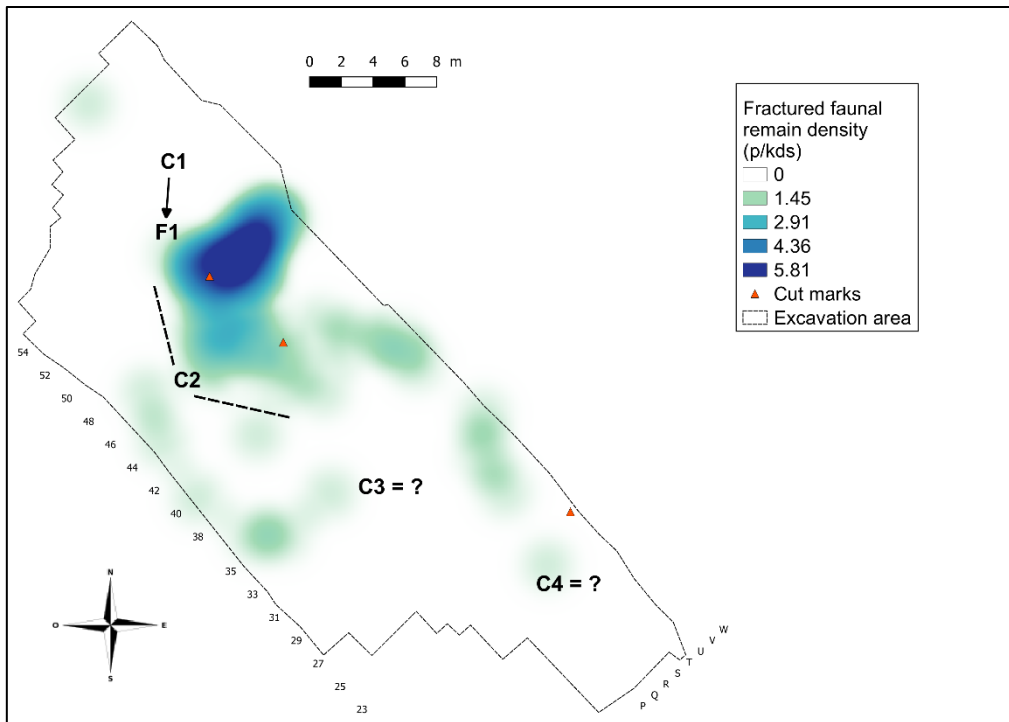
765 Zone C1 is subdivided into two subzones: a zone with a high density of burnt remains (B1
766 in figure 28) and a fracture zone extending until the upper part of zone C2 (F1 in figure 27).
767 The lower part of zone C2 and the totality of C3 and C4 correspond to numerous small groups
768 of bones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

772 The burnt remains from level 2 of Beauvais are almost all concentrated in zone B1.
773 However, the distribution of burnt bones according to their degree of combustion does not
774 reveal any clear distribution pattern (Fig. 28). In zone C1 to C3, the result from the binomial
775 test on burned remains shows a p-value lower than 0.001, at the 5% significance level (Tab.
776 5). That means that the proportion of burned remains in each cluster is highly significantly
777 different from the whole level. For zone C1, the proportion is significantly higher, for C2 and
778 C3 significantly lower. In zone C4, the result from the binomial test on burned remains shows
779 a p-value greater than 0.05, at the 5% significance level (Tab. 5). That means that the
780 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

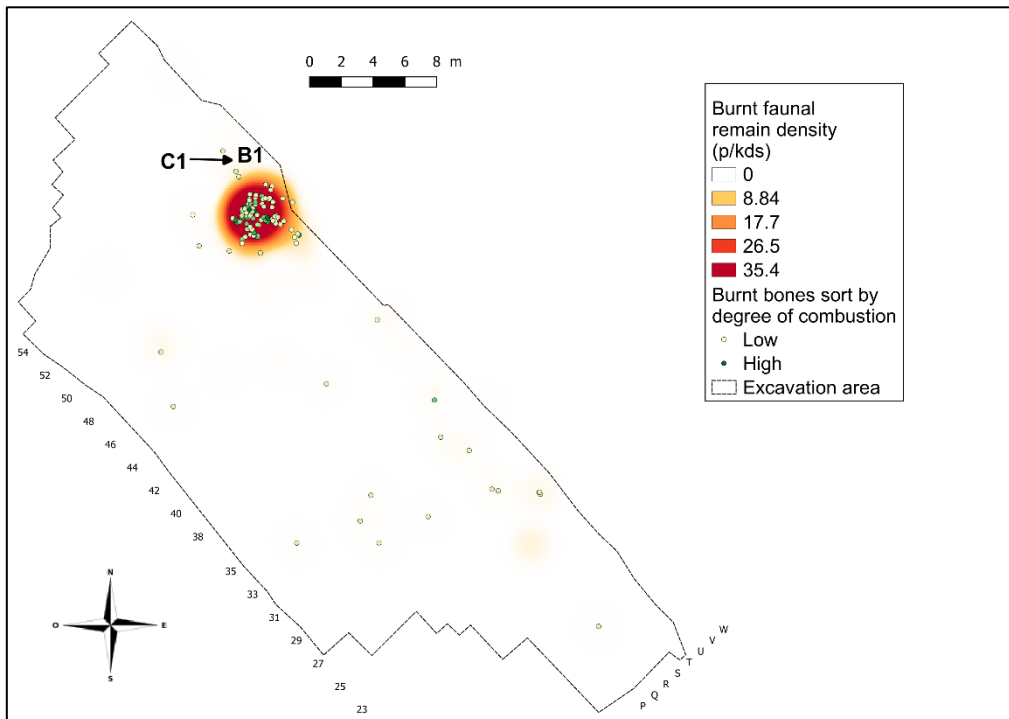
781 **Table 5: Proportions of remains bearing anthropogenic traces (spiral fracture and combustion marks) and the results of**
782 **the binomial test comparing these proportions to the whole level 2 of Beauvais (green: highly significant difference**
783 **between the cluster and the whole level; orange: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

784



785

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



789

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

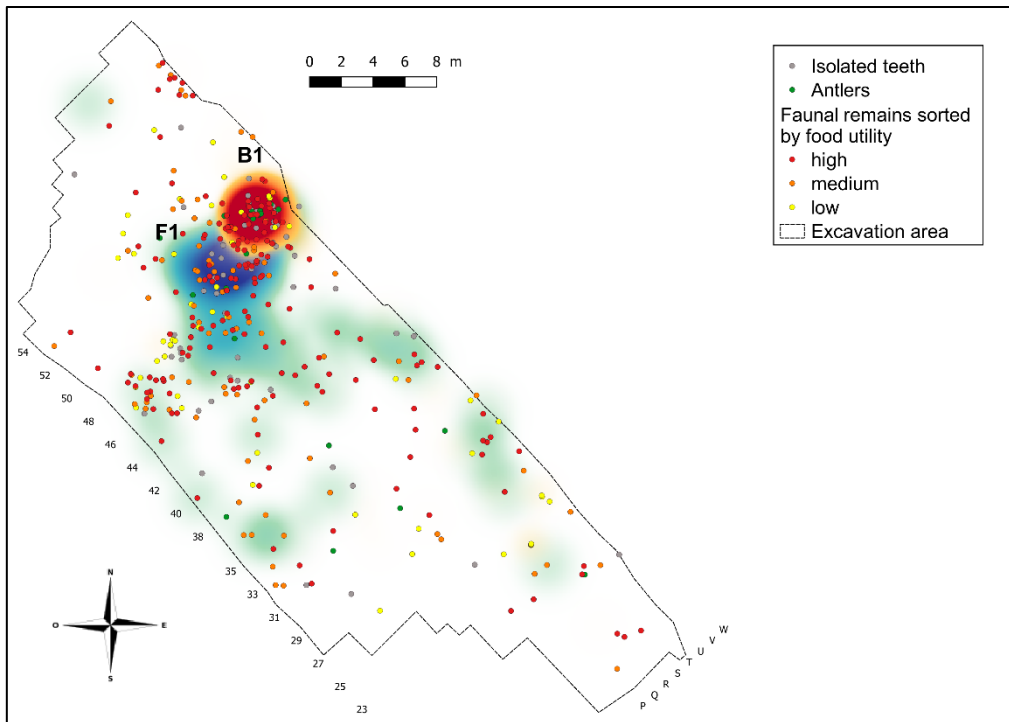
793

794 5.2.3. Spatial distribution of the faunal remains classified by food utility
795 and species

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

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

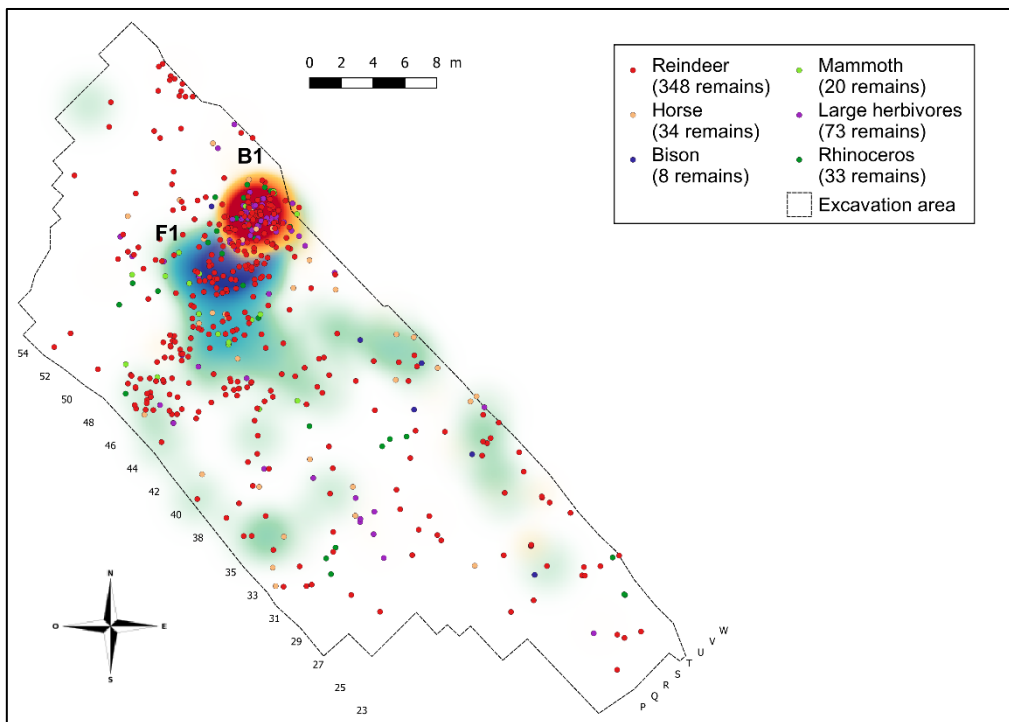
802 The remains dispersed over the rest of the excavation area mainly correspond to reindeer
803 remains with high food utility indexes (framed in purple in figures 29 and 30).



804

805 **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.**

807



808

809 **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.**

811

812

813 6. Spatial behaviours of the Neanderthals of Caours and 814 Beauvais

815 6.1. The Human activity areas of level 4 of Caours

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

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

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

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

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

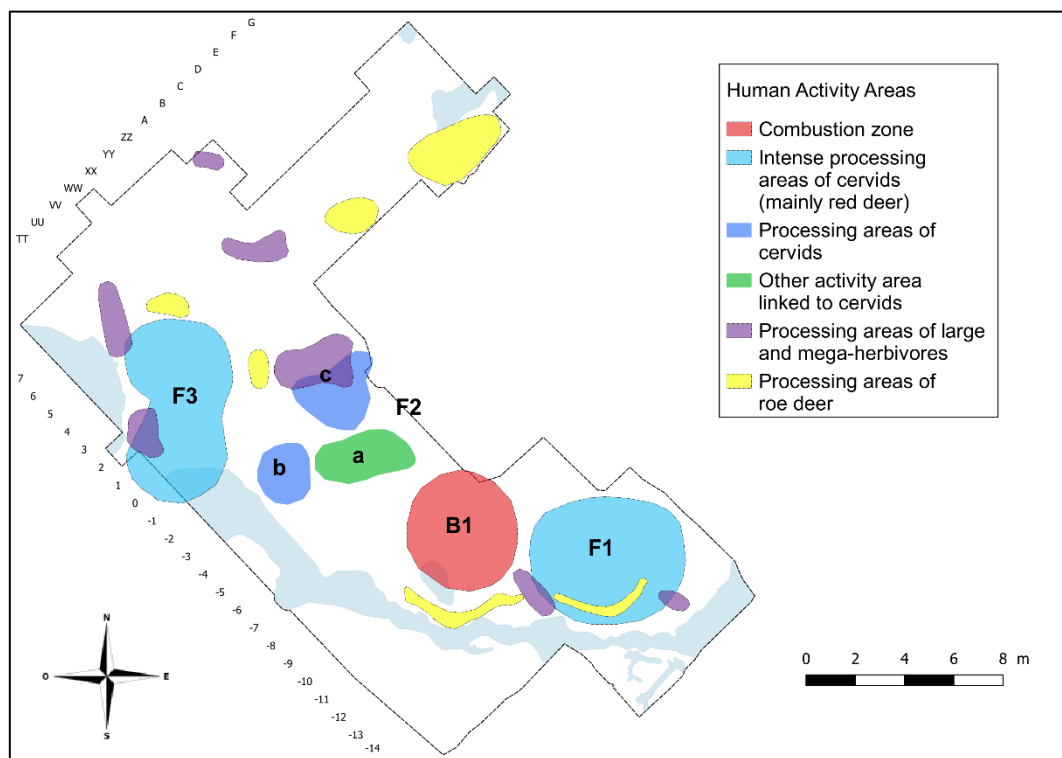
846 Based on the distribution of faunal remains sort by species and food utility, we discerned in
847 zone C2 a sub-organization as subzones F2a, F2b, and F2c. Fracture zone F2b, with high
848 food utility cervids remains, may correspond to a processing area of cervids, especially red
849 deer (Fig.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

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

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

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

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



867
868 **Figure 31: Interpretative map of human activity areas of in level 4 of Caours. The combustion zone and the**
869 **processing areas of cervids represent significant and well defined cluster using the spatial analysis**
870 **protocol from this study. Processing areas of large/mega herbivores and roe deer (purple and yellow)**
871 **represent the minimum envelope that encompass a specified taxon.**

872 6.2. The Human activity areas of level 2 of Beauvais

873 Using our spatial analysis protocol, we confirmed the first spatial studies' hypothesis of a
874 spatial organization of the faunal remains as concentration zones (Locht and Patou-Mathis,
875 1998; Locht, 2004). Previous spatial studies highlighted three high-density zones of faunal
876 remains, framed in light grey in figure 32. C1 zone detected through our analysis, although
877 slightly more extensive, seems to correspond to the zone I defined by Marylène Patou-Mathis.
878 Based on our first results, zones II and III may be fused into a single concentration zone.
879 Moreover, we detected two sets of small faunal remains accumulations distributed over the
880 rest of the excavated area. These less-dense accumulations were not mentioned in the first
881 spatial study. As the impact of other taphonomic factors was ruled out (details in part 2), we
882 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.

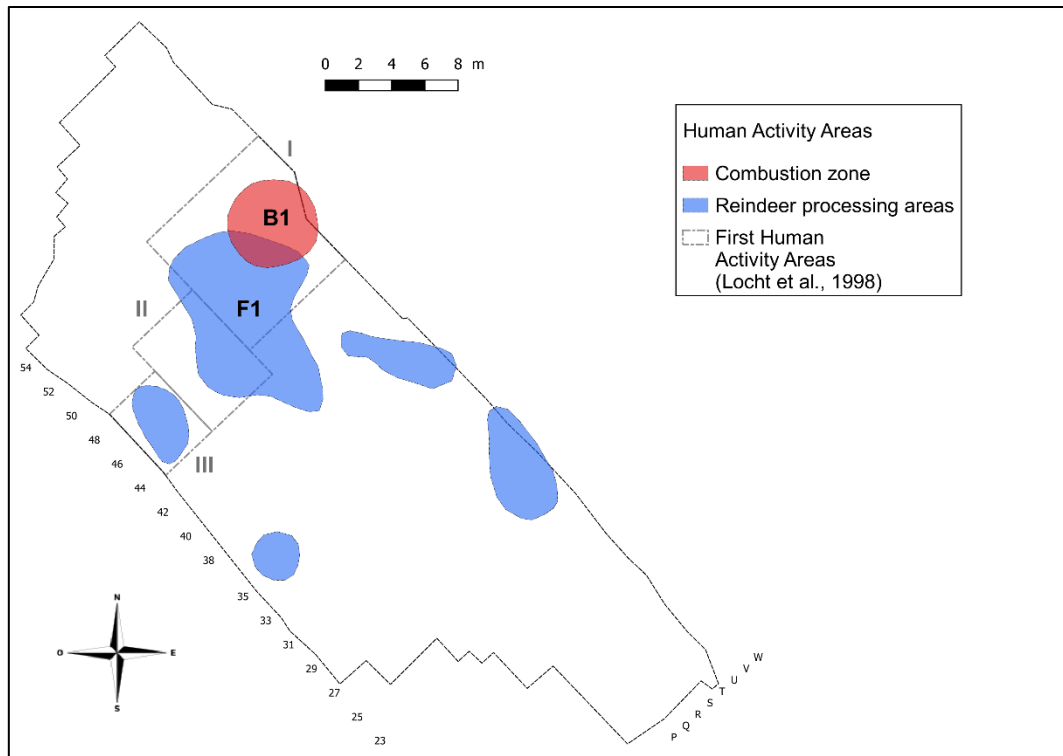
888 Zones C1 fractured remains' percentage, although weakly higher, is not significantly different
889 from the whole level. Even if a third of its remains are burned, retiring them doesn't change
890 that result. That means that, even if some butchery activities clearly took place here, we cannot
891 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; Locht,
909 2004). 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; Locht, 2004).



915

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

919 **6.3. Inter-site comparison**

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

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

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

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

936 For Caours as for Beauvais, the most extensive butchery area is in direct contact with the
 937 combustion zone. That confirms a close relationship between butchery activities and fire (Tab
 938 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	✓	

939

940

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	✓	

941

942

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

943 7. Conclusion

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

950 We proved that level 4 of Caours and level 2 of Beauvais exhibit an anthropogenic spatial
 951 organization as Human activity areas. That result may appear trivial, but it is rarely so clearly
 952 highlighted for Middle Palaeolithic sites in open-air contexts. Even more when the analysis is
 953 solely based on faunal material. In a cave or rock shelter contexts, the natural limits restrict the
 954 available occupation surface. In this way, agents that can potentially interfere with the spatial
 955 signal are amplified: successive reoccupations can lead to palimpsest effects or the spatial
 956 reorganization of the remains by humans (Gabucio et al., 2018; Pettitt, 1997; Vaquero et al.,
 957 2017). As a result, the study of these occupations is often linked to complex spatial problems.
 958 Researchers must continuously attempt to individualise the occupations while trying to identify
 959 the processes of space management (Gabucio et al., 2018; Spagnolo et al., 2018; Vaquero et
 960 al., 2017). In the two cases studied here, the levels' preservation is conducive to a relatively
 961 good individualization of the occupations. We can thus wonder if complex spatial behaviour –
 962 cleaning the living area, reorganization of the remains during the occupation – can also be
 963 detected for these sites with no physical limits.

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

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

972 As is often the case for rock shelters or cave sites, we highlighted different human activity
973 areas delimited in space: combustion areas and butchery areas. Although multiple hearths are
974 regularly observed in rock shelter or cave contexts, for Caours and for Beauvais, a single
975 combustion zone has been identified until now. Some similarities persist regardless of site
976 context, like a close relationship between animal carcass processing activities and fire (Locht
977 and Patou-Mathis, 1998; Spagnolo et al., 2018; Vaquero et al., 2017). However, it is often
978 complex to prove their contemporaneity. Complementary spatial analyses could add answers
979 to this question, like the study of faunal and lithic refits (Cziesla, 1990; Gabucio et al., 2018;
980 Vaquero et al., 2017). This approach could also clarify the relationships between the different
981 activity areas described for our two sites. Their combustion zone's location, at the centre of the
982 butchery activities, suggests a structuration of space around the fire. This pattern has already
983 been mentioned on several occasions in the literature on Neanderthal sites (Spagnolo et al.,
984 2018; Vaquero and Pastó, 2001).

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

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

998 [Acknowledgements](#)

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