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The spatial patterning of the social organization of modern foraging *Homo sapiens*: A methodological approach for understanding social organization in prehistoric foragers

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ABSTRACT

Individualized households are the most important institution in the organization of modern human foragers. These households interact and use space in a highly organized manner, which is reflected in the creation of single or multiple domestic areas per household. These areas, when composed of primary refuse, leave diagnostic material clusters which are potentially identified archaeologically. Although the number of domestic areas can be more easily detected than the number of households responsible for them, here it will be shown that modern spatial algorithms are very effective at documenting the multi-cluster nature of modern human immediate-return foraging camps. At the heart of this observation lies the potentiality of tracing back in time this particular social organization and the question of how other pre-*Homo sapiens* hominins were socially organized.

1. Introduction

Humans do not interact in space randomly. Clarke (Clarke, 1979, 1977) argued that human behavior was in essence spatially organized. As a matter of fact, space is essentially lawful in itself, and "it is through its lawfulness that space interacts with society" (Hillier, 2014). From this perspective, it has been argued that space is configurational; meaning that it results from simultaneously existing relations in which humans play an essential part (Hillier, 2014). Given that space is the physical scenario where social dynamics occur, one would expect that specific social structures would produce debris-generating behaviors that could be spatially patterned.

From an evolutionary perspective, it is very difficult to apprehend the social structure of any given prehistoric human group in a Paleolithic context from the analysis of the fauna that they consumed and their use of raw materials and tools. A very under-exploited potential to approach those social structures exists in the analysis of the spatial distribution of materials resulting from human use of space. However, this is a very complex endeavor, since it requires the preservation of the original spatial properties of debris in fully-anthropogenic sites. Most Paleolithic sites are palimpsests and have undergone variable post-depositional distortion introduced by biotic and physical agents, mostly during biostratinomy. In addition, to fully understand the social use of the space, large open areas, preferably non-constricted by physical space (i.e., caves), are required to minimally approach a sizeable space that could reflect differential use by a human group. This implies large open air excavations spanning hundreds of square meters. A third objection is that ethnoarchaeological analogues are of limited value, because they reflect the modern social structure of *Homo sapiens* and this could be very different from that of any other hominin in the past. This is why ethnoarchaeology cannot be used descriptively. As Kent (1987) stressed, archaeological patterning must be with a capital P, that is avoiding direct ethnographic analogy. However, ethnoarchaeology is essential to build, through middle-range research, referents that could help us link social behavior and spatial patterning. As Binford (1983:9) justified it, one should "attempt to delineate patterns in the use of space (behavior) in their interrelationship to cultural material".

Spatial analysis and ethnoarchaeological work had their golden age by the late 1970s and 1980s (Binford, 1978; Carr, 1987, 1984; Gladfelter and Tiedemann, 1985; Gould, 1980; Gould and Yellen, 1987; Hietala and Larson, 1984; Hodder and Orton, 1976; Kent, 1987; Kintigh and Ammerman, 1982; Newell, 1987; Whallon, 1974; Wobst, 1977; Yellen, 1977). This promoted a bloom of different analytical techniques to study debris clustering and scattering patterns (see Table 1).

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Table 1
Most common analytical techniques to study debris clustering and scattering patterns including their pros and cons.

Method	Objective and procedure	Shortcomings	Application	Reference
Unconstrained clustering	Analyzes size, shape and density of depositional areas	The scale of the analytical units is held constant across the space and artifact classes. Not good to detect locally segregated use of the space.	Ethnoarchaeological assemblages	Whallon (1974)
Polythetic association	Analyzes sets of coarranged artifact classes	It is applied to the whole habitational area, pooling debris in primary deposition areas and secondary deposition areas, creating averages that do not realistically represent segregated use of the space by sectors	Archaeological assemblages	Carr (1984, 1987)
Contiguity-anomaly	Delimits depositional areas regardless of their size and absolute density (see contrast with unconstrained clustering). It provides statistically significant differentiation of specific local density from background density.	It assumes inter-cluster similar density and homogeneity values. It also establishes variance comparison against the total area. It assumes stark contrast between cluster and non-cluster areas.	Archaeological assemblages	Gladfelter and Tiedemann (1985)
Factor analysis	It defines spatially overlaid depositional assemblages on the same depositional areas by finding congruent attribute properties.	The general assumptions of palimpsestic differentiation are strictly logical and not well contrasted against experimental or ethnoarchaeological analogues	Archaeological assemblages	Binford & Binford (1966)
Grid unit clustering	It targets similar compositional units within depositional areas	It uses a global threshold of statistical significance	Ethnoarchaeological assemblages	Newell (1987)
Fourier method (FM) and digital spatial filtering (DSF)	It measures densities of artifact types on a grid system. This provides digitally expressed densities, whose shape is analyzed via FM. DSF then filters the density shapes by smoothing them.	Density variations are dependent on grid unit size, grid interval, and cutoff values for filters. It depends much on the analyst's expertise.	Archaeological assemblages	Carr (1987)
K-means analysis	It creates cluster analysis minimizing intra-cluster variance while maximizing inter-cluster distances	It does not measure spatial association of item classes and cannot deal with overlapping distributions. Also, cluster shape is usually circular because of the use of a root mean squared radius	Archaeological and ethnoarchaeological assemblages	Kintigh and Ammerman (1982)
Nearest neighbour	It measures associations of item classes followed by clustering	Size of area influences density and the resulting statistic.	Archaeological assemblages	Hodder and Orton (1976); Whallon, 1974
Presab	It uses k-means and other techniques to create multiclass clustering. It is grid and coordinate based	Clusters must be internally homogeneous. If not, drawbacks are similar to unconstrained clustering.	Archaeological and ethnoarchaeological assemblages	Blankholm (1991)

The application of spatial analyses to ethnoarchaeological studies soon revealed a high diversity of patterns, which potentially rendered inadequate the use of ethnographic analogues. Habitation units in camp organization could be circular (i.e., the ring model) (Yellen, 1977), linear (Hitchcock, 1987) or without any shape pattern (Binford, 1987b). Inter-household distances could be short (Yellen, 1977; Fisher and Strickland, 1991; Bartram et al., 1991; O'Connell et al., 1991; Marlowe, 2010) or variable and long (Gould, 1980; Binford, 1991; Gargett and Hayden, 1991; Hitchcock, 1987). This created skepticism about the potential use of general analogues in the interpretation of the past. Hodder (1987) went as far as to declare that "there can be no general theory and no universal method for measuring and interpreting activity residues, except in relation to physical, nonhuman processes of decay and deposition". In 1991, two emblematic edited volumes (Kroll and Price's "The Interpretation of Archaeological Spatial Patterning" and Gamble and Boismier's "Ethnoarchaeological approaches to mobile campsites") displayed part of the methodological, ethnoarchaeological and theoretical differences and shortly after their publication, archaeological spatial analysis targeting the interpretation of social structures, organization of space, differentiation of residential and special purpose camps and the identification of domestic space went almost into hibernation. This is particularly unfortunate, because there has never been such an array of spatial statistical techniques, as in the present. Spatial statistics have reached such a maturity that specialized publication venues exist for this purpose (e.g., Spatial Statistics Journal).

An important part of the controversial interpretation of the ethnoarchaeological models was based on the varying contracting-expanding forces that act in different types of human socio-economic structures (e.g., immediate-return or delayed return societies) (Woodburn, 1982). By neglecting "labels" (i.e., different types of social and economic organization), the apparent diversity of organizing spatial patterns encountered was not properly interpreted and prevented the development of useful analogues (see Discussion).

However, this pioneering effort in reconstructing social use of space in modern foragers exposed a structural universal feature of modern humans. Probably, the most universal element in modern foragers, regardless of the socio-economic structure (immediate/delayed return) is the clear nucleation of reproductive cells in human groups (mostly via pair-bonding) that create the institutional figure of households (i.e., families). Here, the use of the term household is restricted to the most elementary family unit (parents and immediate non-adult offspring). Households are the essence of modern foraging bands. They adopt a variety of forms (monogamous, polygynous, polyandrous, mixed), although the most common expression in most hunter-gatherers is monogamy (one reproductive partner at a time). These reproductive units in their cooperation with others determine interhousehold distances. The most conspicuous expression of the social use of the space by this specific socio-economic reproductive behavior is that each household generates its own high-density patch(es) of debris. This is reflected in the multi-cluster nature of most human foraging camps, especially those occupied for short periods of time and where no cleaning or maintenance is carried out (Bartram et al., 1991). Even when maintenance is performed, it is common to find that each household has a secondary refuse area (Fisher and Strickland, 1991; O'Connell et al., 1991), highlighting this secondary multi-cluster nature of camps as an expression of the direct reflection of social structures and their use of the space in time.

One of the most relevant observations of the presence of individualized households in modern foragers is that, despite the distorting effect of post-depositional processes, these households can be potentially identified through the analysis of their respective clustering and homogeneous attributes (Gregg et al., 1991). This brings us back to the time in

which the spatial identification of households in the upper Paleolithic was made without intensive use of ethnographic analogues. Excavations in the Magdalenian open-air site of Pincevent (France) exposed a series of exceptionally preserved clusters of hearths and debris which were interpreted as belonging to separate households (Julien, 1984; Leroi-Gourhan and Brezillon, 1972). Subsequent similar discoveries were carried out at the Magdalenian sites of Verberie (Audouze et al., 1981; Zubrow et al., 2010) and Étiolles (Enloe, 1991; Olive, 1988). Earlier evidence of individualized households was found at several Gravettian sites, namely the Pavlovian "mammoth dwellings", which were identified not just on the basis of spatially-discrete associations of hearths and debris, but also the presence of habitat structures created with bones and rocks (Gavrilov et al., 2015; Iakovleva, 2015; Nigst and Antl-Weiser, 2012; Svoboda et al., 2016). In a recent volume entitled, "The Magdalenian Household: unraveling domesticity", Zubrow et al. (2010) stress the importance of documenting the domestic space of the household to determine the social structure behind it (nuclear or extended family) and the identification of domestic activities, such as cooking, usually carried out at the main hearth of the domestic space.

The identification of household and hearth was so tight that hearth pattern analyses and hearth-related analytical tools were developed. Binford's (1996, 1987a) ethnographic referent for the study of hearths prompted the development of software-specific tools and models such as the "ring and sector" analysis (Stapert, 1989), which were successfully applied to some middle Paleolithic contexts (Henry, 2012; Stapert, 1989).

If household archaeology has long been applied to European Gravettian and Magdalenian sites, by attempting to identify individualized household units, no evidence has been produced to support such a type of social organization prior to this period. Were hominins other than *Homo sapiens* socially organized in a different way? If so, how would we approach their social structures if they have no modern equivalent? Recent refits of the same bones in several different hearths obtained at the well-preserved Middle Paleolithic site of Abri Romani (level J) show that most of those hearths were used at the same time, suggesting that hearth use was collective and not for individual households since individual bone specimens from same elements were refitting in between hearths (Rosell et al., 2012). However, at this site, individual hearts also exist spaced at about 1 m from each other near the shelter wall, which seemed to have played a different role from carcass butchery and consumption.

If Middle Paleolithic (and older) sites were used for shorter time intervals than Upper Paleolithic sites, they could have been more readily exposed to the action of other biotic agents resulting in greater distortion of the original assemblages. It could be argued that post-depositional distortion may confound spatial patterning as originally formed by humans. Multiple-cluster is not a characteristic exclusive of European Upper Paleolithic sites. Before linking this characteristic to the presence of individualized households, archaeologists should establish a tighter link between ethnoarchaeologically documented individual households (and their associated domestic areas) and their respective debris patterns. Can we identify individual households (or specific domestic areas) once a residential camp has been abandoned? Can households have more than one cluster associated? If the answers to these questions have any chance of positively contributing to our understanding of Pleistocene social structures, despite the potential differences between modern humans and pre-modern humans, they should be based on analyzing immediate-return societies, ideally in the same type of environments where prehistoric Paleolithic humans lived. Here, we face a methodological problem. Although general sketches of debris distribution exist in studies of several residential and special purpose camps from foragers in various geographic areas, there is a paucity of studies where the debris has been mapped individually piece by piece. Without this information, modern spatial techniques cannot be applied.

The present work will use a selected group of !Kung (Yellen, 1977) and Kua (Bartram et al., 1991) foraging camps, where complete information exists on their formation and where individual bone fragments have been mapped, in order to link material debris to specific households and understand the attributes that material clusters must have to effectively use them as indicators of individual households. Our null hypothesis is that: a) clusters from households should relate to number of people (per time unit) in each of them; b) there can be multiple clusters per household; c) household clusters should be homogeneous in their attributes to differentiate them from other collective special purpose areas and, d) the location of the cluster should not necessarily be indicative of the location of the domestic area (unless differentiating primary from secondary refuse). Once a heuristic link is established at the synchronic level (formation of a site by humans in a similar space-time unit), the following step should be to study the potential palimpsestic effect of redundancy in the occupation of the site. This latter point should require the development of taphonomic studies at a spatial scale.

2. Samples and methods

2.1. Samples

Three Kua camps studied by Bartram et al. (1991) (Kanni//am//odi, //oabe 1, Kunahajina) and one !Kung camp studied by Yellen (1977) (//Gakwe Dwa 2) were used for the present study. These camps were selected because most bone refuse had been carefully mapped at the specimen level and information existed about the number of occupants, number of households, duration of occupation and resources brought into the camp. Although the number of available camps with this detailed information amounts to slightly >25 (combining Yellen's and Bartram's data set), only four were selected, because they represent a range of short (days) single occupation camps and long (months) multiple occupation camps. We analysed several of the other camps studied by Yellen and Bartram, and the results were similar to those reported here. For the sake of clarity and brevity, we decided to show four of the camps that represent all the variability documented in Yellen's and Bartram's larger sample. All of them (when occupied by multiple households) display the multi-cluster pattern described here.

2.1.1. Camp 1: Kanni//am//odi: household group 7

This dry season camp was occupied by three households in 1985. Three individual families resided in the three connected domestic areas in the windbreak area; each of them with their respective hearth. Morning and evening activities were carried out in front of the windbreak and midday activities were moved to the shade of the back of the windbreak. This pattern was maintained when at the end of the dry season, the three households moved to the east to new huts (to shelter from potential rain), in which midday activities were performed on the back of the windbreak and morning and evening activities were carried out in front of the huts (Bartram et al., 1991).

2.1.2. Camp 2: //oabe 1

This short-term camp was used by 14 people during the rainy season in 1986. There was a single windbreak and a daily shift in the use of space produced multiple debris clusters. Nine juvenile/neonatal bovid carcasses were brought into the site, and 704 of the 773 resulting bone specimens were precisely mapped. Three hearths were used as the locus of butchery, consumption and primary refuse. Due to the short time occupation, no maintenance was performed. Five hearths situated to the east were primarily used to make fire for smoking, although some bones were deposited there after consumption. A similar daily transfer of domestic activities as documented in the previous camp was observed east of the southernmost domestic hearth. Bartram et al. (1991) found that axial bones were clustered around nuclear areas whereas long bones were found more scattered in primary refuse areas in the west of the camp, where the cooking hearths were. Individual carcass remains were found around the three main hearths.

2.1.3. Camp 3: Kunahajina

This late rainy season/cool dry season camp was occupied for 8 days and then abandoned and reoccupied for three months. In the first short occupation, three huts were made aligned to the west. In the longer occupation, an arched pattern of structures (totaling seven huts) was documented, although not all of them were made and used at the same time. A total of 21 mammal carcasses were introduced to the camp. Most bone refuse was accumulated and abandoned by the domestic areas. Bone clusters were associated with areas of food consumption. Sweeping of the front of the huts created nearby areas of secondary refuse in the form of scatters. In one case, instead of cleaning, one hut was abandoned and residents moved 6 m west and built a new hut. No indication was given regarding the number of households (Bartram et al., 1991).

2.1.4. Camp 4: //Gakwe Dwa 2

This !Kung camp was occupied by 7 households (26 people: 18 adults and 8 juveniles) for seven days in July. Honey gathering was the most important activity during the occupation, and hunting played a secondary role. Despite the short amount of time, enough debris was deposited on the ground to make spatial patterns of the households visible. Yellen (1977) indicated the presence at the camp of 6 familiar households. Gregg et al. (1991) identified 7 distinctive clusters in this camp using a k-means approach. All refuse is primary. The short occupation did not result in the modification of the primary refuse patterns.

2.2. Methods

During the 1970s and 1980s, several quantitative techniques were applied to the study of spatial analysis in archaeology (see review of the main ones in Table 1). The contrasting of different methods against the control of an ethnoarchaeological example, showed that k-means (and associated methods) were the most accurate way of detecting clustering for individual household/domestic areas (Blankholm, 1991; Gregg et al., 1991; Kintigh and Ammerman, 1982). For this reason, a more robust version of the k-means approach will be used here to compare with more recent GIS-based methods. In the 1990s until the present, statistical spatial analysis has morphed into more graphic approaches stemming from the use of GIS tools (Allen and Zubrow, 1990; Chapman, 2006; Conolly and Lake, 2006; Green, 1990; Mehrer and Wescott, 2005; Nakoinz and Knitter, 2016; Tripathi, 2005; Wheatley and Gillings, 2003). Some of these GIS tools are very useful because they can discern the clustering and scattering effects from patterns in a way that traditional cluster analysis could not because of the integration of all, or most, points in clustering decisions. Several recently developed algorithms allow removing the distracting effects of scattering and focus on intensity zones, creating more efficient clustering decisions. We will combine both approaches here, to observe how the interpretation of controlled assemblages may be biased using one, or the other, approach.

2.2.1. Statistical method for mapping intensity

Material debris initially accumulated in the form of clusters may undergo dynamic loss of intensity due to post-depositional processes. Carnivore intervention and human trampling can create a scattering effect that may in some cases hide the presence of original clusters. Statistical analysis tools can be used to remove the noise introduced by scattering processes and outline the boundaries of remaining clusters in a way that removes the subjectivity of naked-eye appreciation from standard mapping. Smoothed density maps are one of these tools.

In the present work, density maps were made by using bandwidths selected by sigma values, which control the degree of smoothing. To select the optimal bandwidth, Diggle and Berman's mean square error cross-validation method and the likelihood cross-validation method were used (Berman and Diggle, 1989). Diggle and Berman's method assumes a Cox process. The likelihood method assumes an inhomogeneous Poisson point pattern. All mapping methods took into account corrections for edge effects. This method ensures that real (i.e., mathematically contrasted) clusters can be differentiated from scatters. Here, given the inhomogenous and overall little intense nature of the assemblages, the likelihood cross-validation method was preferred, after contrasting both methods, which yielded similar results. Mapping was carried out considering lower-intensity (red maps) or higher-intensity (polychromic maps). Given the high density of points, a spatial approach to hot zones (i.e., areas with specially elevated intensity) was also used. This was made by using sharpening methods involving likelihood methods, as well as by using a Dirichelet-Voronoi estimator via an adaptive density approach (Baddeley et al., 2015). This involved using 30 repetitions of a specified fraction ($f = 0.1–0.5$) of randomly selected points used to create a Dirichelet tesselation and averaging the results. Here, we selected an intermediate specified fraction of 0.3. This adaptive density approach was emphasized when there was disagreement on the optimal number of clusters when using two different algorithms (see below).

The graphic and statistical analyses were made with the R (www.r-project.org) "spatstat", library.

2.2.2. Clustering method

The PAM (Partitioning Around Medoids) method organizes data into a number of clusters around medoids. It is a more robust method than k-means, especially when in the presence of outliers, because it minimizes the sum of pairwise dissimilarities in contrast to the sum of Euclidean distances. Medoids are referred to as objects within clusters whose average dissimilarity to the other objects in each cluster is minimal. Medoids are similar to centroids, but differ from these in being real elements within the data set, instead of being averaging points in the Euclidean space of any given cluster. The algorithm was implemented by Kaufman and Rousseeuw (1990) as an improvement of k-means methods. K-means is highly susceptible of bias when in the presence of outliers. The more robust PAM method uses a dissimilarity matrix, instead of Euclidean distance and, therefore, minimizes dissimilarities instead of the sum of Euclidean distances. Two R libraries ("cluster" and "fpc") were used for the analysis. The function "pamk" was used to determine the correct number of clusters, using the average silhouette width. Subsequently, the "pam" function (including the selected number of clusters) was used to plot the resulting graph.

As a complement to the "pamk" algorithm, we also used a bootstrapping clustering method with a CBI (Cluster Bootstrap Interface) of k-means as described in Fang and Wang (2012). Several ($n = 50$) bootstrap samples were drawn from the original sample and the number of clusters is derived by optimization of bootstrapped pairs. We compared the number of clusters selected by both algorithms.

3. Results

3.1. Camp 1: Kanni//am//odi: household group 7

The density maps captured well the cluster shared by Huts 4 and 3, as well as the cluster from Hut 2 (which had three hearths) (Fig. 1). Hut 1 did not have an associated cluster. The closest one is the cluster associated with the back of windbreak (WB) 1, where midday activities were carried out. The same is documented for the densest clusters at the back of WB2 and WB3. There is hardly any cluster in front of the windbreaks, because each of them created a secondary refuse area by their respective ash dumps, so that the three WB units had three associated clusters of secondary refuse several meters north of their respective domestic areas. These clusters were less dense than those documented behind the windbreaks because the latter are primary refuse that was not cleaned. Maintenance of the front of the windbreaks caused part of the original refuse to remain near the WB hearths and part to be dumped away. Interestingly, all the refuse clusters created (3 secondary and 1 primary by the WB units and 2 primary by the huts, as well as 3 primary

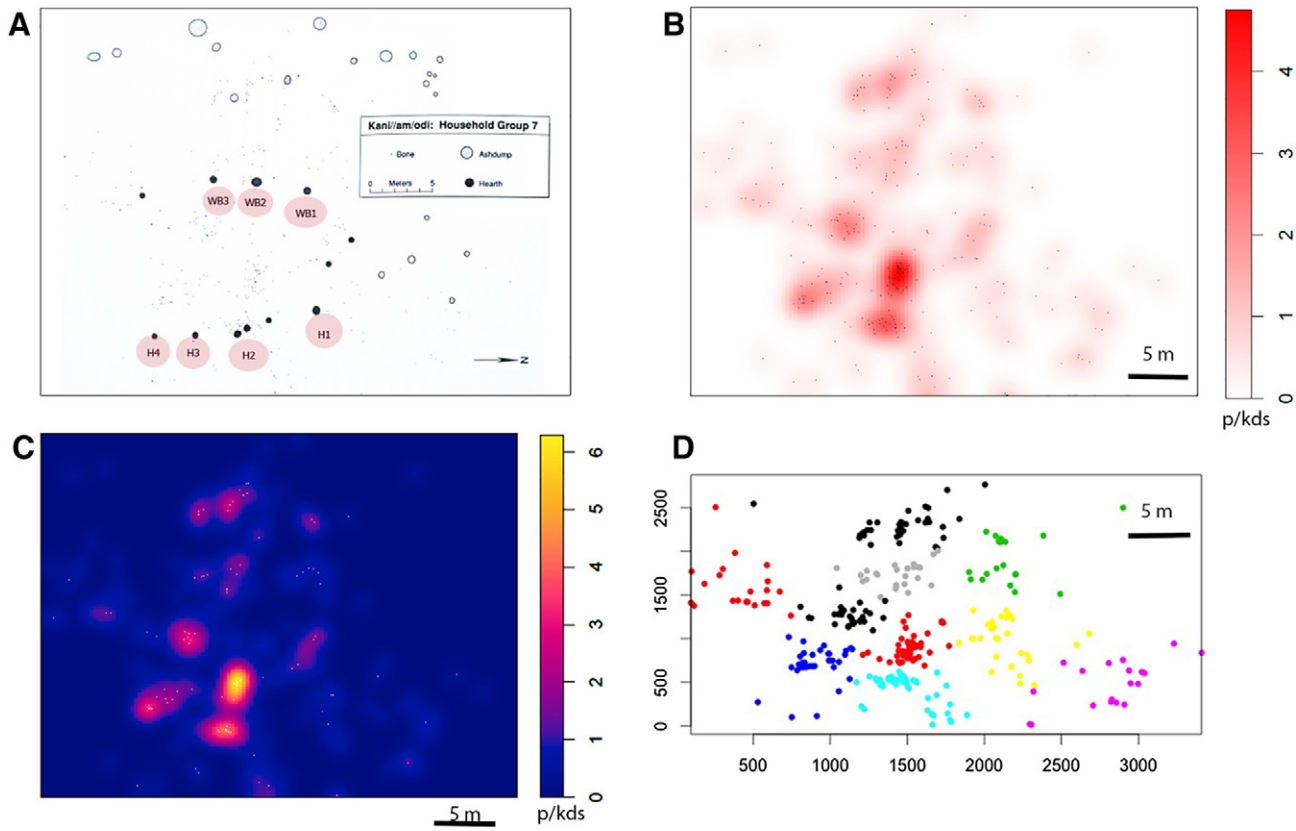

Fig. 1. A, Distribution of bone refuse, hearths and ashdumps in Kani//am//odi:HHG7 (modified from Bartram et al., 1991). Color ovals show location of households; key: WB (windbreak), H (Hut). B, Intensity map with the individual bone specimens overlaid. C, Intensity map with sharpening effect showing cluster distribution. D, Distribution of individual bone specimens according to their clustering group (each in different color), as determined by the PAM method (axes show pixel distances). Bar scales: p/kds(estimated pieces per kernel density surface).

in between the huts and the WB units), could be detected. Only Hut 1 remains invisible (probably because it is a single individual associated to Hut 2) and Huts 3 and 4 (probably kin-related) share one single cluster. The important element is that despite being difficult to interpret as domestic units, all the clusters created by the three households were spatially identifiable.

A PAM analysis including the scattered bones as well as those in patches show 10 clusters (Fig. 2). This optimal number was also selected by the bootstrapping clustering method with a CBI k-means. The two additional clusters uncovered by this solution include the low-density primary refuse in front of the WB hearths. In contrast with the density map, which excluded scattered elements, the PAM clustering includes all bones and provides complementary evidence of the multi-cluster nature of the refuse generated by three households in this camp. The spatial configuration is not the same as that obtained with the density map, but the location is similar. It is interesting to note that both analytical approaches detected a similar number of clusters.

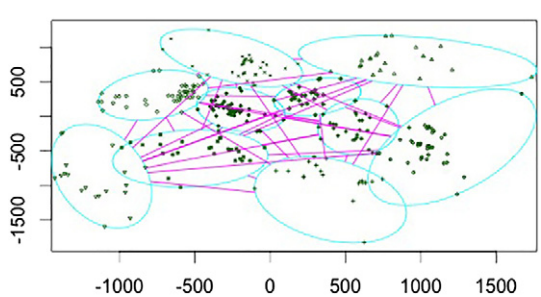

Fig. 2. Clustering solution (both factors explain 100% of point variability) of Kani//am//odi:HHG7 resulting from the PAM method.

3.2. Camp 2: //oabe 1

The density maps detect very well the three main clusters around the domestic hearths to the west (Fig. 3). They also detect a fourth less dense one to the southeast, corresponding to the hearth close to the roasting pit and where domestic activities were moved at certain times of the day because of the presence of shade. Although a fifth lower-density cluster is hinted by one of the density maps (corresponding to the area with hearths used mainly for smoking and some marginal food consumption), the other map does not show it.

The PAM algorithm yielded an optimal number of 5 clusters; each of them corresponding to the five domestic areas described (Fig. 4). The bootstrapping clustering method with a CBI k-means, in contrast, suggested 3 as the optimal number. In this case, the latter algorithm seems to detect well the densest clusters corresponding to the main domestic areas of the three households. The PAM algorithm, in contrast, detected better all the domestic spaces, regardless of their intensity.

The adaptive density approach showed that three was the number of clusters identified by intensity peaks, each corresponding to one of the three households represented (see below Fig. 9). This analysis showed how in the case of short-term camps where maintenance is not carried out and debris distribution is composed of primary refuse, individual households can be identified.

3.3. Camp 3: Kunahajina

This site had a combination of mild clustering and substantial scattering created by maintenance (Fig. 5). In contrast to Kanni//am//odi, maintenance did not create piling of secondary refuse at some distance from the domestic space. Most secondary refuse occurred in the

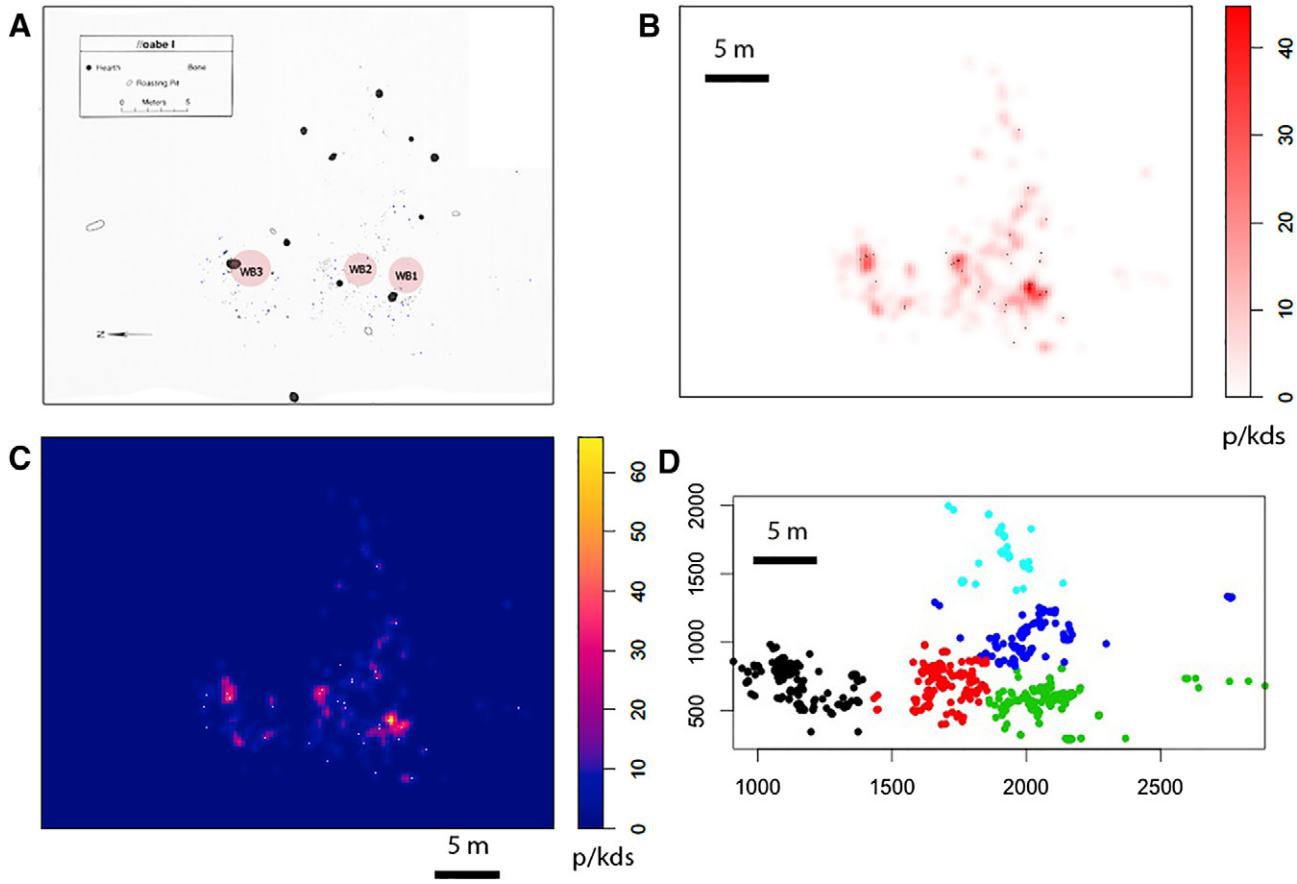

Fig. 3. A, Distribution of bone refuse, hearths and ashdumps in //oabe 1 (modified from Bartram et al., 1991). Color ovals show location of households. Key: WB (windbreak). B, Intensity map with the individual bone specimens overlaid. C, Intensity map with sharpening effect showing cluster distribution. D, Distribution of individual bone specimens according to their clustering group (each in different color), as determined by the PAM method. Bar scales: p/kds(estimated pieces per kernel density surface).

adjacent areas to the huts and the nearby bushes (Bartram et al., 1991). It could be argued that for the prolonged occupation period, a maximum of six huts were occupied at the same time. The density maps detected

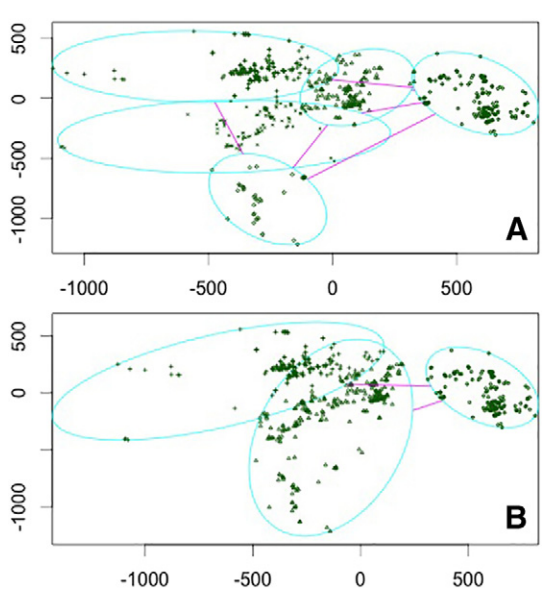

Fig. 4. Clustering solution (both factors explain 100% of point variability) of //oabe 1 resulting from the PAM method.

the clustering of the two southern huts as well as of two of the northern huts. In both cases, more than one cluster was found associated with some of the huts. The area to the west failed to show any significant debris from the short occupation period or from two of the huts of the long-term occupation. However, the fact that density maps could be used to detect at least four domestic areas with associated clustering is not far from the total of six huts originally present during the long-term occupation. Most of the clustering documented is related to secondary refuse areas, in contrast with the pattern documented in //oabe 1.

The bias introduced by the combination of clustering-scattering of secondary refuse has produced non-informative results when considering the k-means algorithms. The PAM algorithm selected an optimal number of two clusters. This was supported by the bootstrapping clustering method with a CBI k-means. In both cases, the selection implied splitting the camp into a western cluster and an eastern cluster (Fig. 6). The present case is a good example of failure of k-means (and associated) approaches to the differentiation of original domestic areas and households.

3.4. Camp 4: //Gakwe Dwa 2

The smoothed density maps show a series of clusters that correspond to the densest clusters in the domestic areas of six of the seven households reported by Yellen (1977) (Fig. 7). Three cluster groups were detected in the north. One corresponding to a set of five clusters corresponding to two adjacent habitation units and the other less

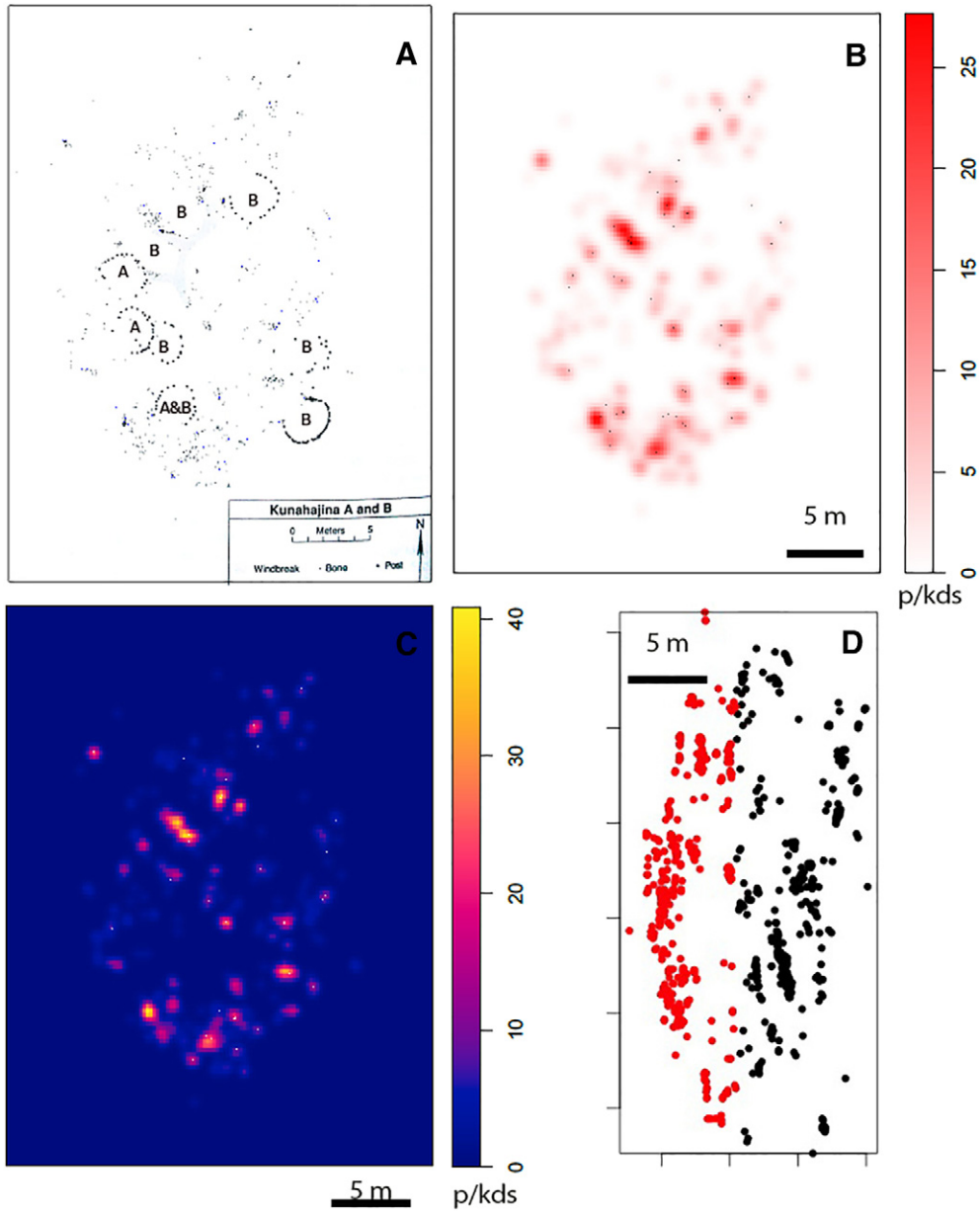

Fig. 5. A, Distribution of bone refuse, hearths and ashdumps in Kunahanija (modified from Bartram et al., 1991); key: A (short occupation), B (long occupation). B, Intensity map with the individual bone specimens overlaid. C, Intensity map with sharpening effect showing cluster distribution. D, Distribution of individual bone specimens according to their clustering group (each in different color), as determined by the PAM method. Bar scales: p/kds(estimated pieces per kernel density surface).

dense cluster to the northwest corresponding to another household. Right south of this one, two low-density clusters corresponding to another household were detected. To the southeast of them, two multicluster sets (showing the highest degree of intensity) can also be identified. Each set corresponds to a single household. An elongated cluster in the south indicates the location of the sixth household. This primary refuse patterning is a good example of combination of single and multi-cluster pattern for different households. The pattern documented here is very similar to the seven k-means cluster solution obtained by Gregg et al. (1991).

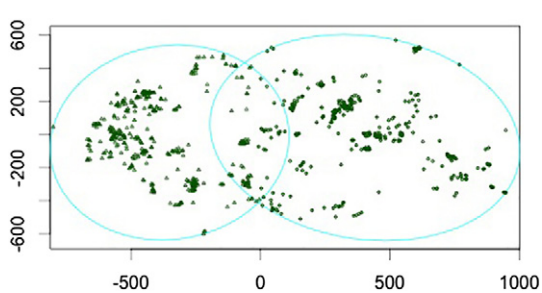

Fig. 6. Clustering solution (both factors explain 100% of point variability) of Kunahanija resulting from the PAM method.

The PAM algorithm yielded an optimal number of 5 clusters. The biggest one comprises the two northeastern households and their surrounding scatters. The following one includes the northwest household debris. To the south of it, the next cluster includes the debris of two households. The remaining two clusters represent most of the debris of one household each (Fig. 8). The combined solution of the PAM algorithm and the density maps is very close to the original number of individual households. This example illustrates, the same as was documented in //oabe 1, that when the pattern is composed mostly of

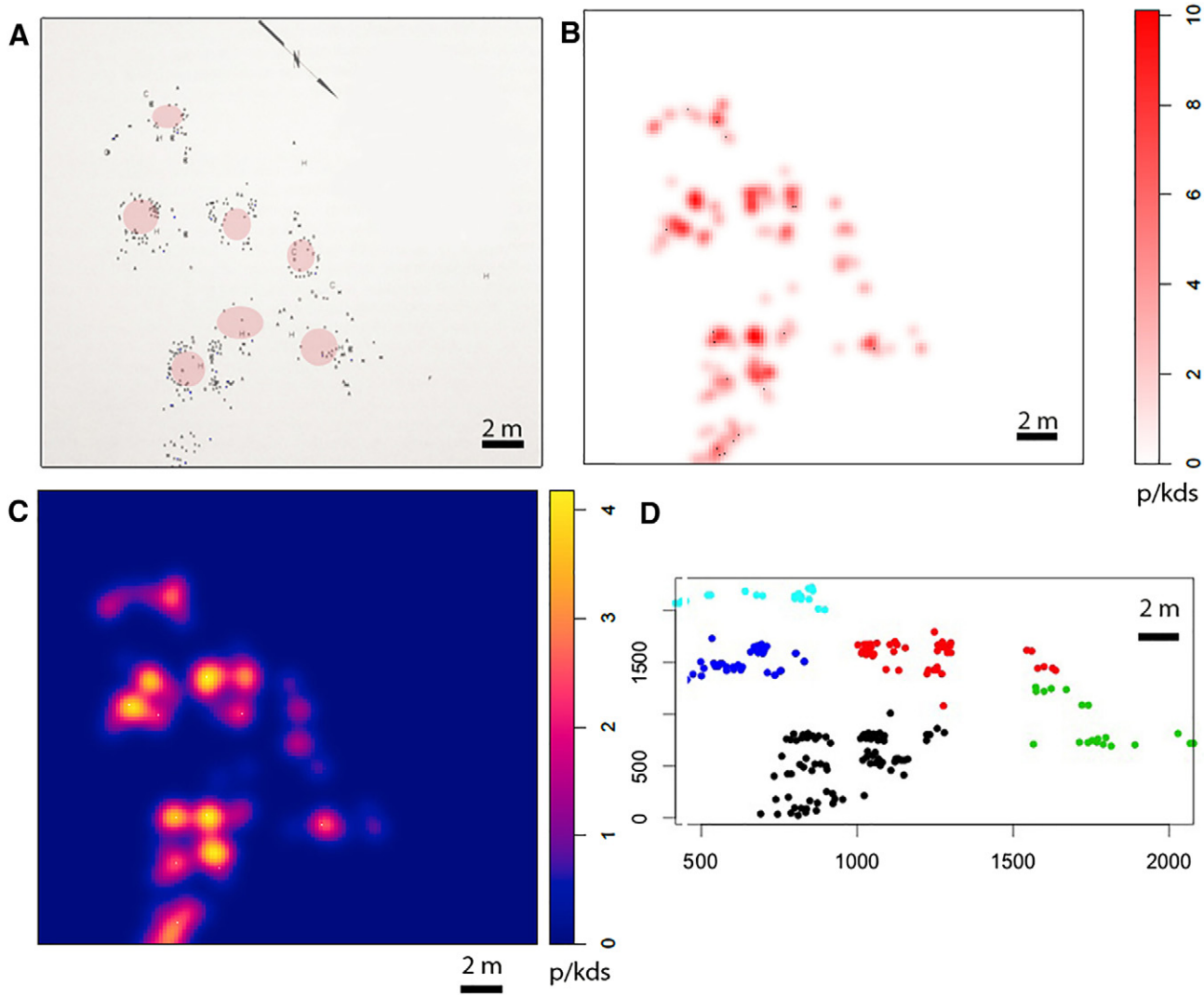

Fig. 7. A, Distribution of bone refuse, hearths and ashdumps iat //Gakwe Dwa 2 (modified from Bartram et al., 1991); color ovals show location of households. B, Intensity map with the individual bone specimens overlaid. C, Intensity map with sharpening effect showing cluster distribution. D, Distribution of individual bone specimens according to their clustering group (each in different color), as determined by the PAM method. Bar scales: p/kds(estimated pieces per kernel density surface).

primary refuse, good estimations of the original number of households and activity areas can be made.

3.5. General results

Intensity maps are a good graphical method of detecting clustering debris resulting from social use of space in modern foragers´ camps. They have identified most domestic and refuse areas for Kanni//am//odi, all domestic areas and household locations for //oabe 1 and //Gakwe Dwa 2 and four of the seven clustering areas associated to domestic spaces in Kunahajina. In contrast, the k-mean/medoid-based algorithms seem to be most effective when camps are composed strictly of primary refuse. The clear separation of primary and secondary refuse in Kanni//am//odi resulted in similar observations made with density maps and the PAM algorithm. Density maps detected the five different debris-accumulating areas of //oabe 1 and the intensity peaks signaled the location of the three households. The PAM algorithm did not differentiate among the five domestic areas, but identified the clustering of the three households. Only in the highly-modified camp of Kunahajina, caused by the local redistribution of secondary refuse, did the density maps work much better at identifying clustering and domestic area location than the PAM algorithm. At //Gakwe Dwa 2, the density maps showed clustering for six spatial units (each corresponding to a household). The PAM analysis showed five different clusters. In most cases, the PAM algorithm included debris in the same cluster from different households. In general, the inferences drawn from the density maps seem more reliable. A final proof of this is reflected in the intensity "hot spot" maps made using the adaptive density algorithm (Fig. 9). The solution is rather conservative for Kanni//am//odi (4 peaks representing two households), in which the orange pattern shows 8

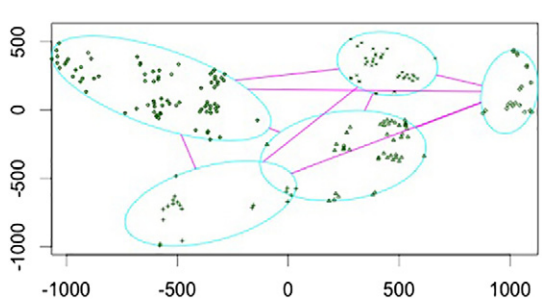

Fig. 8. Clustering solution (both factors explain 100% of point variability) of //Gakwe Dwa 2 resulting from the PAM method.

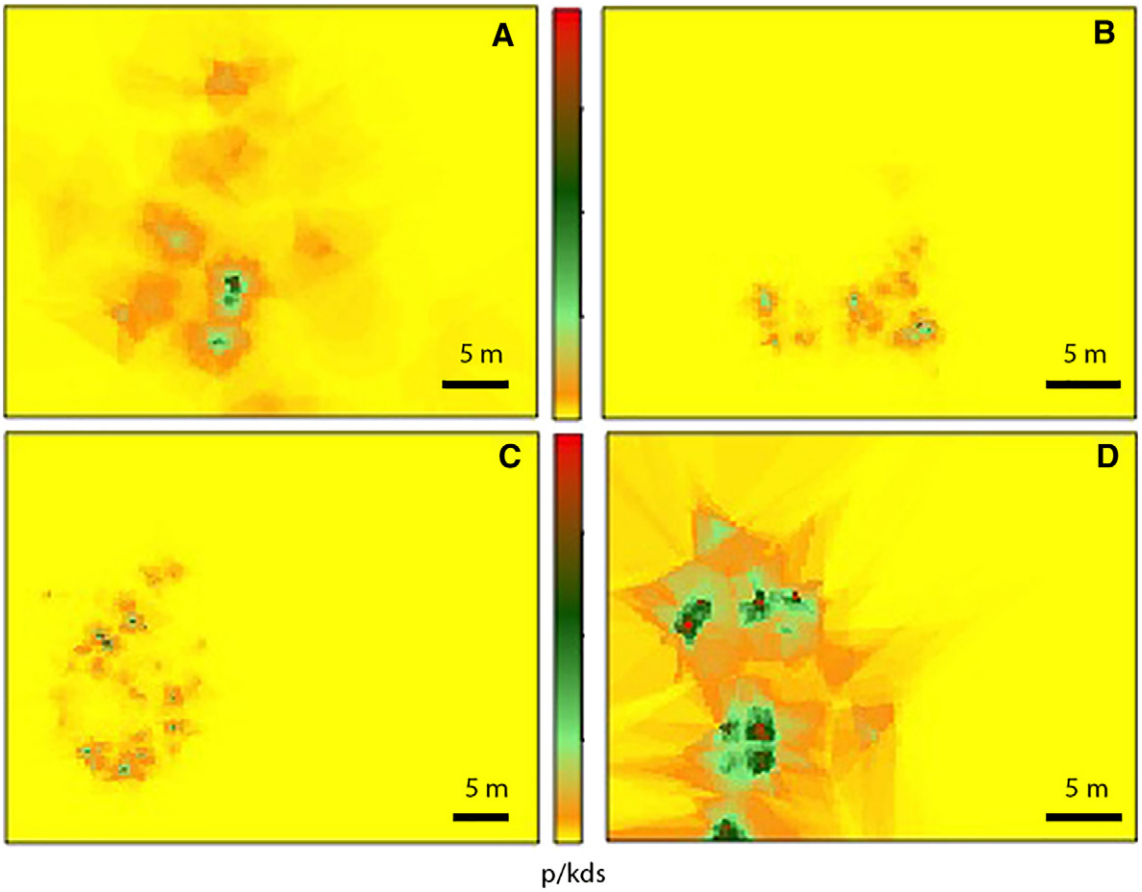

Fig. 9. Intensity "hot spot" maps made using the adaptive density algorithm. A, Kani//am//odi:HHG7. B, //oabe 1. C, Kunahajina, //Gakwe Dwa 2. Orange color shows activity areas. Red/green peaks show highest density located at households activity areas. Bar scales: p/kds(estimated pieces per kernel density surface).

out of the 10 clusters originally identified. For //oase 1, the three households are clearly identified and four activity areas are observed (orange color). Interestingly, this algorithm spotted seven clusters for Kunahajina, most of them belonging to individual households. For //Gakwe Dwa 2, 8 small clusters were identified or, given the immediate adjacency of some of them, 4 multi-cluster sets. Only 4 of the original households were well identified, however, the activity areas corresponding to each of the six household are clearly visible (Fig. 9D, orange color).

These methods document one important element of human social organization of space: every single camp was composed of multiple clusters corresponding to several individualized households. This stresses the potential use of this approach to understand archaeological clustering. This means that although we could not be sure (when using density estimates alone) of the number of households represented in any given archaeological context, if density estimates can be coupled with tests of homogeneity of composition in each cluster, one could make tentative estimates of potentially identifiable domestic areas. Archaeologists could use this evidence to trace back in time when the typical socio-economic structure of *Homo sapiens* emerged.

4. Discussion

Finding universals in modern foragers has been a difficult task because of modern human intrinsic behavioral plasticity and its related ecological variability. A major contributor to this situation has also been that some researchers have tried to avoid classification labels stemming from socio-economic structures (e.g., "egalitarian" or "immediate-return"), thinking that such definitions are "vacuous non-analytical assertions" and "idealist's beliefs" on system-state conditions (Binford, 1991). To some, behavioral theory building must be based on adaptive variables (not necessarily structures), since these are directly shaped by the environment (Binford, 2001, 1992, 1991, 1984, 1981, 1978). This 20th century process approach overlooks that even the same environmentally-triggered variables could lead to different social behaviors only because social structures are systems with different endogenous emergent properties. Diverse social structures will react differently to the same environmental stimuli. Binford's approach, following the tenets of the New Archaeology and Cultural Ecology, place the emphasis on external factors (i.e., environment) and human adaptation is foremost the result of extrinsic dialectics between environmental uncertainty and risk.

An alternative to this approach is to consider that despite the retroactive interaction between human societies and environment, internal factors determining social relations condition such interaction, instead of being the result of passive socio-structures morphed by external physical processes. This approach would be more evolutionary in the sense that it allows groups with different social properties compete for the adaptation to the same environments through time, thereby allocating selection on different *loci*: individuals and groups. It is in this context that definitions encapsulating socio-economic structures matter. The spatial organization of an "egalitarian" group practicing immediate-return socio-economy differs (in some aspects, drastically) from another practicing "non-egalitarian" delayed-return socio-economy even when adapting to the same type of environment. Binford's "Nunamiut-centered" perspective failed to address this duality efficiently and his critique of the "typical hunter-gatherer" or of the household as the core of the society, the importance of food sharing, the

relevance of kinship and its link to food sharing -in sum, the "hunter-gatherer way of life" as widely portrayed in anthropology- is mostly flawed due to failure in appreciating this economic differentiation, beyond the perception of different gradients along a continuum of social evolution as shaped by the environment. This social evolution could, in fact, result from the tension between opposite forces, with deep roots in the human evolutionary past (Boehm, 1999), between group-operating egalitarian mechanisms and individually-based wealth accumulation leading to inequality and social differentiation.

Immediate-return societies are highly inter-individually dependent, food obtainment and food sharing is a collective enterprise, the social structure revolves around kinship, affines (although not exclusively) and others, mechanisms are implemented to avoid accumulation of resources or social differentiation of wealth, bands are highly mobile, group composition is open and highly variable, and meta-group relations are commonly peaceful and non-territorial (Woodburn, 1982).

Delayed-return societies are more individually independent when obtaining food, but more behaviorally dependent when creating moral codes to justify and respect individual property. Despite the multiple flavors in the social structure of delayed-return groups, food sharing may be as restricted as to each individual household, social structure revolves around kin and non-kin in similar terms (in some groups with more emphasis on the latter), storage leads to wealth differentiation (in some groups even to private land property), bands are more sedentary, the social tissue is not as open as in immediate return groups and meta-group relations are more conflictive and territorial than in immediate-return societies (Woodburn, 1982).

Despite the theoretical glamour of depicting these two forms of social structure along a continuum, no clear examples (non-caused by the clash of these traditional foraging societies and modern industrial societies) exist that could provide intermediate links between one form and the other. Foraging groups classified as one form, or the other, display most of the features that identifies one label versus the other. The Nunamiut models, as useful as they were for the development of middle-range theory and ethnoarchaeology, cannot be used to question general patterns in other socio-economic structures and were not even properly explained within a general anthropological theory. Let us emphasize that the Nunamiut modern behavioral patterns have also been highly impacted by additional "individual-independence" factors created by modern technology, such as the use of rifles for hunting. This gave away "old ways" of behavior when hunting was communal and people lived closer to each other. This, obviously, has an immediate effect on the social use of space (by rendering communality unnecessary or limited) and the material debris patterns generated in one case (the present) and the other (the past) may differ drastically. So, to what extent can modern Nunamit represent ethnoarchaeologically useful referent frameworks to understand past populations, when they are not even good proxies to explain past Nunamiut behaviors? This objection was also raised by Service (1962) when criticizing Steward's (1936) arguments about "composite bands", because he saw that these groups could result from the disorganization introduced by acculturation and oppression resulting from contact with the modern industrialized society. Binford (1991: 127) did not engage with these arguments and simply put them aside by arguing that their defense resulted from the wish of Steward to "speculate on the essential characteristics of the pristine hunting and gathering band". However, such arguments need to be addressed if models derived from these impacted groups are to be used as analogues for the past.

A clear example of the profound changes introduced by acculturation of foragers and food producers with modern industrialized societies can be observed in the drastic changes underwent by several Iroquois communities when they engaged in contact with early colonizers. Soon after the contact, the Seneca adopted European technology, modified their subsistence, with a higher emphasis in food production, switched to living in individual houses and abandoned extended-family longhouses (Jordan, 2002). Short thereafter, the typical Iroquois matriarchal social organization must have undergone some transformation or readjustment. The dramatic social changes in the Iroquois communities were directly reflected in the different use of the space by those communities. Residential camps became less dense, households more spatially distant and scattering along the landscape became ubiquitous.

Whitelaw's (1991) extensive database for foraging societies showed that the densest communities (i.e., the most closely spaced households) are the most traditional in character. The lowest densities were reported for the most westernised settlements, which further stresses the impact of acculturation by modern industrialized societies. Whitelaw (1991: 149) argued that these differences in spatial behavior should be analyzed in the context of acculturation and cultural change, since "the regular relationships with residential density are of interest in the present investigation to the degree that traditional patterns of social organization play a greater role in the integration of the members of less acculturated communities, and to the extent that social patterns of interaction are more directly related to economic cooperation in a subsistence economy". When split by social unit type, Whitelaw's sample showed that traditional extended families and local band groups account for almost all the high-density communities, whereas "composite" groups with acculturation impact display low densities in general. Whitelaw also showed that in groups where storage allows "the self-assumption of risk" (delayed-return groups), resources are mostly obtained by individual households and a little margin for cooperation results in wider inter-household distances, a fact contrasted with the densely populated residential camps of more inter-dependent households, such as immediate return foragers.

Bettinger's (1980) interpretation of Binford's processual new archaeology as confounding causes with effects, which builds "from assumptions about consequences and tailors its processes to fit those assumptions" is adequate here (Bettinger et al., 2015). Bettinger et al.'s (2015) critique to the new archaeology as lacking a general theory of culture and behavior is also well supported (e.g., Dominguez-Rodrigo, 2012) and it is one of the weak points of the neofunctionalist approach. We concur with Bettinger et al. (2015) in their view that "the new archaeology did not have a general theory capable of supporting a body of limited theory about hunter-gatherers". Culture and social systems therein are not the mere consequences of adaptation, but the determinants of any given adaptive pattern. These systems are not dictated by adaptive processes but adopt a dialectic interaction with the environment. They are not the results of processes; they are an essential part in the shaping of those processes. Bettinger et al. put it very elegantly:

"What matters is that all anthropological theories that proceed from generalization about consequences to inferences about processes are fundamentally flawed. They deny any possibility of developing a truly evolutionary theory of *cultural process* in which *ideas and the motives of the individuals* -the most distinctive part of the thing we call culture- have any active part, or in which selection can play a definable role akin to that which it has in the natural sciences. Instead, they are required to envision processes in superorganic teleological terms. The conceptualization and explication processes is subverted, and the explanation of consequences (i.e., why something is or why it happened) suffers accordingly. In Darwinian theory, evolutionary outcomes (consequences) are purely opportunistic, ungoverned by any grand design, so the locus and action of reproduction and selection must be specified exactly to produce any expectation about consequence at all (Bettinger et al., 2015: 284)".

Neo-Darwinian behavioral models, such as those differentiating the asymmetry of gene transfer (biological) and "meme" transfer (cultural) information (i.e., dual-inheritance models) realistically position the locus of selection on the causes instead of on the consequences. These approaches incorporate multilevel selection, with selection occurring both at the individual, as well as at the group level. Individuals, organized in cultural groups, have therefore a major input in socio-subsistence decisions, and they determine the resulting social use of space. This is why socio-structural categories are of utmost relevance: delayed-return models are not useful to understand immediate return

adaptive socio-economic behaviors and viceversa. The Nunamiut "composite bands" displayed a high degree of social independence, which was reflected in seasonal camps exhibiting high separation among households in Spring-summer camps (average of inter-household separation ≥70 m) and those in Fall-Winter camps exhibiting half that distance (average of inter-household separation = 29 m). Despite Binford's (1991) attempts to interpret this high spatial separation as the result of individual uncertainty-risk strategies (i.e., labour organization) which created spatial separation by age groups and not exclusively by kinship, the latter still remains a strong component on the spatial organization of modern Nunamiuts. Distances between living units are still very correlated with kinship proving that physical distance is social distance and to a certain extent, even kinship distance (see example in Wiseman, 2014). Likewise, alternative (and equally important) interpretations were neither tested nor even considered. For example, Gould and Yellen (1987), through an inter-ethnographic comparative approach, showed that there seem to be a relationship between predation risk and degree of inter-household separation. Immediate-return groups in Africa, where predation risk is high, show short distances in between households (Bartram, 1993; Marlowe, 2010; Yellen, 1977). In contrast, those in environments with low to no predation risk show higher separation. Likewise, duration of occupation also shows to influence inter-household separation (Kent, 1987). Both effects can be observed within the Nunamiut. Despite the risk of bears pointed out by Binford (1991), no clear evidence exists showing that bears approach Nunamiut camps on a regular basis, and in spring-summer camps, even small children have their own tents separately from their parents; something that would probably not occur if bears were a persistent risk. Likewise, short-term occupation in specialized logistical camps results in much more clustered spatial distribution of households than in long-term residential camps. It is also true that in these specialized camps, households are less independent because they are engaged into collective cooperation for obtaining food resources. Therefore, in the Nunamiut, like in most other foraging communities, predation risk and length of occupation (as well as degree of communal cooperation) seem to represent important variables determining inter-household distances, regardless of whether age groups or kinship are more influential in how individual households are spatially associated.

The observation that these variables determining the social use of space could be similarly influential in a delayed-return group like the Nunamiut or immediate return societies like the !Kung (Yellen, 1977), the Efe (Fisher and Strickland, 1991, 1989) and the Hadza (Marlowe, 2010) underscores that there may be two-level universals: those found within each category of socio-economic structure and those that are found cross-culturally in foraging societies regardless of socio-economic structure. Whitelaw (1991) carried out the most comprehensive study of site structure in modern foragers, analyzing 800 communities from 112 hunter-gatherer cultures. He showed that several patterns were shared and therefore could potentially be used as cross-cultural universals.

1. There is a negative correlation between population and occupational density (persons/area). Individual households in high-population communities are more distantly spaced than in low-population (<50 people) communities. The reason is linked to longer periods of residence in high-population aggregations.
2. There is a correlation between length of occupation and occupation density. The densest communities are occupied for short periods of time.
3. In aggregate camps, different bands create separate camps to maintain the separate identity of each. This is expressed via greater distance in between bands, "with distinct clusters of structures separated from each other by larger intervening distances than occur between structures within such a cluster" (Whitelaw, 1991: 165).
4. Different environments promote different social behaviors, through higher or lower cooperation. In deserts, cooperation for food obtainment is low (mostly plants and small animals) since provisioning can be effectively carried out by individual households. As a result, the spacing between households can be very large. In tropical forests and savannas, acquisition of fauna is a cooperative endeavor, resulting higher clustering of households. Cooperative behavior is mostly necessary for the obtainment of animal protein. What this environmental variable hides is the impact of cooperation in determining distances between reproductive units. The more cooperation in any given group, the shorter the distances among households and vice versa.
5. Residential spacing is higher in communities occupied for long periods of time. Expectation of anticipated mobility (i.e., length of time people expect to occupy a site) play a role in camp size and organization (Kent, 1991).

These broad patterns through such a heterogeneous sample show that there are cross-cultural regularities in the spatial behavior of hunter gatherers. If labels (e.g., immediate vs. delayed return) are avoided, because they are artificial ways of differentiating socio-economic structures, then the forces behind those structures should be quantified, which would require a more complex approach. For instance, the degree of cooperation and household inter-dependence determines inter-household distances. This force is more powerful than alternative explanations for the phenomenon, such as duration of occupation. For instance, among the Kua (Bartram et al., 1991), long-term camps may display very close association of households, because subsistence is totally collective. Inter-household distances may reflect degrees of interdependence and cooperation, but not necessarily social organization. This needs to be revealed within the material debris spatial patterns; in modern foragers, the household-specific single or multiple clustering nature.

One may feel tempted to interpret each cluster (or a set of spatially close clusters) in any given archaeological context as the result of individual households, especially if they are associated with hearths. We argue that for such interpretations to be scientifically convincing, they must be based not just on intensity of items, but also on the spatial distribution of attributes. For example, the properties of each cluster must be similar if they indeed represent separate households as opposed to special activity areas (Gregg et al., 1991). That is, similar types of tools should be used for similar types of activities at each household, and this should be reflected in similar attributes on the resulting debris (i.e., similar use wear patterns, similar bone modification resulting from butchery and consumption, etc.). We stress that the next step of intrasite spatial archaeology must be the spatial analysis of attributes given the items composing each discrete cluster documented. This has only marginally approached (e.g., Binford, 1987b; Gnivecki, 1987; Gregg et al., 1991; Newell, 1987) and should be further developed in the future.

In the virtual absence of adequate ethnoarchaeological analogues for the spatial analysis of attributes, these must be derived from statistical methods that take into account spatial heterogeneity and diachrony; that is considering archaeological space as palimpsestic (Carr, 1987; Gregg et al., 1991). It should be emphasized that ethnoarchaeology is an adequate tool to understand prehistoric social use of the space provided it used non-descriptively and through the study of relations of variables through middle-range research (Binford, 1987b, 1978; Kent, 1987). This is not new. In order for the resulting middle-range research to be heuristically used when applied to the past, it is important to differentiate between socio-economic structures of the analogues, because patterns will certainly differ, and they may be poorly understood as highly variable when considered without taking the socio-economic structure (including the impact of the degree of acculturation) into account.

The present study has contributed to the debate of the use of ethnoarchaeologically-derived data and models to interpret Pleistocene archaeological sites. It has shown that a cross-cultural universal

(individualized households) are an essential part of modern human socio-economic organization. This multiple household pattern can be identified ethnoarchaeologically. This work has also shown that each individual household is capable of simultaneously using more than one activity/domestic area, creating multiple clusters at a time. This *Homo sapiens* essential structure should now be traced back in time. As Binford (1987a, b: 503) argued, "development of frames of reference phrased in terms of cross-culturally valid determinant conditioners of behavior are necessary before differing organizations of behavior… can be seen by archaeologists".

One of the characteristics of the camps analyzed in the present work is that, regardless of whether the analyzed clusters are primary or secondary refuse, the number of bone specimens preserved is too small compared to many archaeological sites. The number of bone specimens documented in these camps are certainly below the amount of bones reported, for instance, for the early Pleistocene sites of Olduvai Gorge, which implies a much greater number of visits to those sites, a higher number of occupants, or both.

The multi-cluster patterns reported here are formally similar to those reported for other highly cooperative and inter-household dependent foragers, such as the Hadza (O'Connell et al., 1991; Marlowe, 2010), the Efe (Fisher and Strickland, 1991) and the Batek (Endicott and Endicott, 2008; Lye, 1997). The analytical methods can successfully identify most of the clusters created by the camp occupants at the patch (density maps) and patch-plus-scatter (PAM) levels. This is especially true when most of the refuse is primary. When most of the refuse is secondary, the k-mean/medoid-based algorithms do not identify well neither domestic areas nor household locations. This encourages the use of density maps over other algorithms, or a combination of both, when taphonomic evidence exists about the primary depositional nature of refuse. In secondary refuse contexts, the debris accumulating trend is centrifugal; that is, it expands the radius of scattering. Centripetal trends are only found in primary refuse contexts.

It has been shown here that in most cases individual households are responsible for the creation of more than one cluster (two or three on average) resulting from the switching of the *loci* where activities are performed depending on the time of the day. The presence of shade seems to be the most influential factor determining where activities are performed and at what time of the day. The association of clusters with the domestic areas of each household is evident for the primary refuse, but not as much for the secondary refuse. It is also evident that clusters of materials depend on the location of hearths. For similar occupation time (e.g., Kani//am//odi and Kunahajina), some camp areas may be maintained and others not, with primary refuse deposited in the domestic area, or in the immediate periphery of it, and secondary refuse occurring between 4 and 8 m away from it. The multiplication of clusters may render the identification of individual households challenging, but the spatial analysis of attributes (with homogeneity of inter-cluster components) should provide a more solid ground for quantifying them (Gregg et al., 1991).

Uncovering patterns in the way debris accumulate and scatter is one part of the goal of spatial analysis. The other more daunting one is the challenge of interpreting them. In 1991, it was assumed that spatial analysis had reached a dead end (Kroll and Price, 1991: 301–303), because it was assumed that "quantitative analyses have rarely been successful in identifying meaningful sets of tools or activity areas". The failure was methodological: quantifying debris is not enough. It was necessary to go beyond the spatial patterning of debris and compare it to the spatial pattern of a specific set of technological and taphonomic attributes. These would provide additional spatial patterning which could be layered and, thus, provide multivariate information on specific activities with which the overall patterning could be understood. As far back as 1991, it was admitted that quantitative methods could identify the original spatial patterns from any given well-preserved site (Kroll and Price, 1991). The present work confirms this claim. The next step was understanding what these patterns mean. Very little has been advanced since then. In order to do so, it was mandatory to analyze site formation (i.e., taphonomically) from a spatial point of view. This has not been done. It was also necessary to combine multiple-attribute (use wear analyses, typology, technology, paleotopography, phytoliths, biomarkers) lines of evidence from a spatial point of view. This is also in its infancy.

5. Conclusions

Here, we have shown that: a) the original spatial patterning of modern ethnoarchaeological assemblages can be well identified and understood; b) that humans are multi-cluster generating creatures because of their social structure formed around individualized households or reproductive units; c) that this feature is documented in any type of camp and, d) that this variable patterning shows that modern humans are multi-cluster creating agents at the single household level. It remains challenging to identify the number of households at any given site given the multiple clustering nature of a single household.

This creates new questions. All the documented patterning is structured around the cooking areas structured around hearths. Would a similar socio-economic structure have shown the same spatial pattern in absence of hearths? How far back in time can archaeologists push the occurrence of individualized (single- or multi-clustered) household social structure observed in modern humans? Will we ever be able to understand pre-*Homo sapiens* social organization beyond the generalizations of prehistoric human groups as being "highly-cooperative" or engaging into "collective use of resources"? At the bottom of these questions lies the more fundamental one of whether we can get rid of our own social template to uncover forms of social organization that have no modern counterpart.

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References

Allen, K.M.S.,.S.W., Zubrow, E.B.W., 1990. Interpreting Space: GIS and Archaeology. Taylor & Francis.
Audouze, F., Cahen, D., Keeley, L.-H., Schmider, B., 1981. Le site magdalénien du Buisson Campin à Verberie (Oise). Gallia Prehistoire 24, 99–143.
Baddeley, A., Rubak, E., Turner, R., 2015. Spatial Point Patterns: Methodology and Applications With R. CRC Press.
Bartram, L.E., 1993. An Ethnoarchaeological Analysis of Kua San (Botswana) Bone Food Refuse. University of Wisconsin–Madison.
Bartram, L.E., Kroll, E.M., Bunn, H.T., 1991. Variability in camp structure and bone food refuse patterning at Kua San hunter-gatherer camps. The Interpretation of Archaeological Spatial Patterning, Interdisciplinary Contributions to Archaeology. Springer, US, pp. 77–148.
Berman, M., Diggle, P., 1989. Estimating weighted integrals of the second-order intensity of a spatial point process. J. R. Stat. Soc. Ser. B Stat Methodol. 51, 81–92.
Bettinger, R.L., 1980. Explanatory/predictive models of hunter-gatherer adaptation. Adv. Archeol. Method Theory 3, 189–255.
Bettinger, R.L., Garvey, R., Tushingham, S., 2015. Hunter-Gatherers: Archaeological and Evolutionary Theory, Interdisciplinary Contributions to Archaeology. Springer, US.
Binford, L.R., 1978. Nunamiut Ethnoarchaeology.
Binford, L.R., 1981. Bones: ancient men andmodern myths. New York: Aca-demic Binford Bones: Ancient Men and Modern Myths 1981.
Binford, L.R., 1983. In Pursuit of the Past. Thames and hudson, London.
Binford, L.R., 1984. Butchering, sharing, and the archaeological record. J. Anthropol. Archaeol. 3, 235–257.
Binford, L.R., 1987a. Searching for camps and missing the evidence. In: Soffer, O. (Ed.), The Pleistocene Old World, Interdisciplinary Contributions to Archaeology. Springer, US, pp. 17–31.
Binford, L.R., 1987b. Researching ambiguity: Frames of reference and site structure. In: Kent, S. (Ed.), Method and Theory for Activity Area Research: An Ethnoarchaeological Approach. Columbia University Press, New York, pp. 449–512.

Binford, L.R., 1991. When the going gets tough, the tough get going: Nunamiut local groups, camping patterns and economic organization. Ethnoarchaeological Approaches to Mobile Campsites. International Monographs in Prehistory, Ann Arbor, pp. 25–137.
Binford, L.R., 1992. Seeing the present and interpreting the past—and keeping things straight. In: Rossignol, J., Wandsnider, L. (Eds.), Space, Time, and Archaeological Landscapes, Interdisciplinary Contributions to Archaeology. Springer, US, pp. 43–59.
Binford, L.R., 1996. Hearth and home: the spatial analysis of ethnographically documented rock shelter occupations as a template for distinguishing between human and hominid use of sheltered space. Middle Paleolithic and Middle Stone Age Settlement Systems. ABAC O. Edizioni, Forli, pp. 229–239.
Binford, L.R., 2001. Constructing Frames of Reference: An Analytical Method for Archaeological Theory Building Using Ethnographic and Environmental Data Sets. University of California Press.
Binford, L., Binford, S., 1966. A preliminary analysis of functional variability in the Mousterian of Levallois Facies. Am. Anthropol. 68, 238–295.
Blankholm, H.P., 1991. Intrasite Spatial Analysis in Theory and Practice. Aarhus Universitetsforlag.
Boehm, C., 1999. Hierarchy in the Forest: Egalitarianism and the Evolution of Human Altruism.
Carr, C., 1984. The nature of organization of intrasite archaeological records and spatial analytic approaches to their investigation. Adv. Archeol. Method Theory 7, 103–222.
Carr, C., 1987. Dissecting intrasite artifact palimpsests using Fourier methods. Method and Theory for Activity Area Research, pp. 236–291.
Chapman, H., 2006. Landscape Archaeology and GIS. Tempus Pub Limited.
Clarke, D.L., 1977. Spatial Archaeology. Academic Press.
Clarke, D.L., 1979. Spatial information in archaeology. Spatial Archaeology.
Conolly, J., Lake, M., 2006. Geographical Information Systems in Archaeology. Cambridge University Press.
Dominguez-Rodrigo, M., 2012. Toward a scientific-realistic theory on the origin of human behavior. Stone Tools and Fossil Bones: Debates in the Archaeology of Human Origins 11.
Endicott, K.M., Endicott, K.L., 2008. The Headman was a Woman: The Gender Egalitarian Batek of Malaysia. Waveland Pr Inc.
Enloe, J.G., 1991. Am. Antiq. 56, 751.
Fang, Y., Wang, J., 2012. Selection of the number of clusters via the bootstrap method. Comput. Stat. Data Anal. 56, 468–477.
Fisher, J.W., Strickland, H.C., 1989. Ethnoarchaeology among the Efe pygmies, Zaire: spatial organization of campsites. Am. J. Phys. Anthropol. 78, 473–484.
Fisher, J.W., Strickland, H.C., 1991. Dwellings and fireplaces: keys to Efe Pygmy campsite structure. Ethnoarchaeological Approaches to Mobile Campsites 1, pp. 215–236.
Gargett, R., Hayden, B., 1991. Site structure, kinship, and sharing in aboriginal Australia, in: the interpretation of archaeological spatial patterning. Interdisciplinary Contributions to Archaeology. Springer, US, pp. 11–32.
Gavrilov, K.N., Voskresenskaya, E.V., Maschenko, E.N., Douka, K., 2015. East Gravettian Khotylevo 2 site: stratigraphy, archeozoology, and spatial organization of the cultural layer at the newly explored area of the site. Quat. Int. 359–360, 335–346.
Gladfelter, B.G., Tiedemann, C.E., 1985. The contiguity-anomaly technique for analysis of spatial variation. For Concordance in Archaeological Analysis: Bridging Data Structure, Quantitative Technique, and Theory, Westport, Kansas City, MO, pp. 474–501.
Gnivecki, P.L., 1987. On the quantitative derivation of household spatial organization from archaeological residues in Ancient Mesopotamia. Method and Theory for Activity Area Research, An Ethnoarchaeological Approach, pp. 176–235.
Gould, R.A., 1980. Living Archaeology, New Stud. Archaeol. Cambridge University Press.
Gould, R.A., Yellen, J.E., 1987. Man the hunted: determinants of household spacing in desert and tropical foraging societies. J. Anthropol. Archaeol. 6, 77–103.
Green, S.W., 1990. Interpreting Space: GIS and Archaeology: GIS and Archaeology. Taylor & Francis.
Gregg, S.A., Kintigh, K.W., Whallon, R., 1991. Linking ethnoarchaeological interpretation and archaeological data. The Interpretation of Archaeological Spatial Patterning, Interdisciplinary Contributions to Archaeology. Springer, US, pp. 149–196.
Henry, D., 2012. The palimpsest problem, hearth pattern analysis, and Middle Paleolithic site structure. Quat. Int. 247, 246–266.
Hietala, H., Larson, P.A., 1984. Intrasite Spatial Analysis in Archaeology, Monographs of the Physiological Society. Cambridge University Press.
Hillier, B., 2014. Spatial analysis and cultural information: the need for theory as well as method in space syntax analysis. In: Paliou, E., Lieberwirth, U., Polla, S. (Eds.), Spatial Analysis and Social Spaces. DE GRUYTER, Berlin, Boston.
Hitchcock, R.K., 1987. Sedentism and site structure: organizational changes in Kalahari Basarwa residential locations. Method and Theory for Activity Area Research, pp. 374–423.
Hodder, I., 1987. 9. The meaning of discard: ash and domestic space in Baringo. Method and Theory for Activity Area Research: An Ethnoarchaeological Approach, p. 424.
Hodder, I., Orton, C., 1976. Spatial Analysis in Archaeology.
Iakovleva, L., 2015. The architecture of mammoth bone circular dwellings of the Upper Palaeolithic settlements in central and Eastern Europe and their socio-symbolic meanings. Quat. Int. 359–360, 324–334.
Jordan, K.A., 2002. The Archaeology of the Iroquois Restoration: Settlement, Housing, and Economy at a Dispersed Seneca Community, ca. AD. 1715–1754. PhD diss. Columbia University.
Julien, M., 1984. L'usage du feu à Pincevent. Structures d'habitat du Paléolithique supérieur en Europe. Institute fur Urgeschichte, Tübingen, pp. 161–168.
Kaufman, L., Rousseeuw, P.J., 1990. Finding groups in data, 1990. N. Y. 22–52.
Kent, S., 1987. Method and Theory for Activity Area Research: An Ethnoarchaeological Approach. Columbia University Press.
Kent, S., 1991. The relationship between mobility strategies and site structure. In: Kroll, E.M., Douglas Price, T. (Eds.), The Interpretation of Archaeological Spatial Patterning, Interdisciplinary Contributions to Archaeology. Springer, US, pp. 33–59.
Kintigh, K.W., Ammerman, A.J., 1982. Heuristic approaches to spatial analysis in archaeology. Am. Antiq. 47, 31–63.
Kroll, E.M., Price, T.D., 1991. The Interpretation of Archaeological Spatial Patterning. Plenum Press, New York.
Leroi-Gourhan, A.,.n.d., Brezillon, M., 1972. Fouilles de Pincevent; essai d'analyse ethnographique d'un habitat magdalénien. Gallia-Préhistoire (Suppl. 7).
Lye, T.-P., 1997. Knowledge, Forest, and Hunter-gatherer Movement: The Batek of Pahang, Malaysia. Univ. of Hawaii, Manoa.
Marlowe, F., 2010. The Hadza: Hunter-gatherers of Tanzania. University of California Press.
Mehrer, M.W., Wescott, K.L., 2005. GIS and Archaeological Site location Modeling. CRC Press.
Nakoinz, O., Knitter, D., 2016. Modelling Human Behaviour in Landscapes: Basic Concepts and Modelling Elements, Quantitative Archaeology and Archaeological Modelling. Springer International Publishing.
Newell, R.R., 1987. Reconstruction of the partitioning and utilization of outside space in a Late Prehistoric/Early Historic Inupiat village. Method and Theory for Activity Area Research: An Ethnoarchaeological Approach, pp. 107–175.
Nigst, P.R., Antl-Weiser, W., 2012. Les structures d'occupation gravettiennes en Europe centrale: le cas de Grub/Kranawetberg, Autriche. l'Anthropologie 116, 639–664.
O'Connell, J.F., Hawkes, K., Jones, N.B., 1991. Distribution of refuse-producing activities at Hadza residential base camps. In: Kroll, E.M., Douglas Price, T. (Eds.), The Interpretation of Archaeological Spatial Patterning, Interdisciplinary Contributions to Archaeology. Springer, US, pp. 61–76.
Olive, M., 1988. Une habitation magdalénienne d'Etiolles: l'unité P 15. Mémoires de la société préhistorique française, p. 20.
Rosell, J., Cáceres, I., Blasco, R., Bennàsar, M., Bravo, P., Campeny, G., Esteban-Nadal, M., Fernández-Laso, M.C., Gabucio, M.J., Huguet, R., Ibáñez, N., Martín, P., Rivals, F., Rodríguez-Hidalgo, A., Saladié, P., 2012. A zooarchaeological contribution to establish occupational patterns at level J of Abric Romaní (Barcelona, Spain). Quat. Int. 247, 69–84.
Service, E.R., 1962. Primitive Social Organization. Random House, New York.
Stapert, D., 1989. The ring and sector method: intrasite spatial analysis of stone age sites, with special reference to Pincevent. Palaeohistoria 31, 1–57.
Steward, J.H., 1936. The economic and social basis of orimitive bands. In: Lowie, R. (Ed.), Essays in Anthropology Presented to Alfred Louis Kroeber. University of California Press, Berkeley, pp. 331–350.
Svoboda, J., Novák, M., Sázelová, S., Demek, J., 2016. Pavlov I: a large Gravettian site in space and time. Quat. Int. 406, 95–105 Part A.
Tripathi, A., 2005. Remote Sensing and Archaeology. Sundeep Prakashan.
Whallon, R., 1974. Spatial analysis of occupation floors II: the application of nearest neighbor analysis. Am. Antiq. 39, 16–34.
Wheatley, D., Gillings, M., 2003. Spatial Technology and Archaeology: The Archaeological Applications of GIS. CRC Press.
Whitelaw, T., 1991. Some dimensions of variability in the social organization of community space among foragers. Ethnoarchaeological Approaches to Mobile Campsites, pp. 139–188.
Wiseman, R., 2014. Social distance in hunter-gather settlement sites: a conceptual metaphor in material culture. Metaphor. Symb. 29, 129–143.
Wobst, H.M., 1977. Stylistic behavior and information exchange. For the Director: Research Essays in Honor of James B. Griffin, pp. 317–342.
Woodburn, J., 1982. Egalitarian societies. Man 17, 431–451.
Yellen, J.E., 1977. Archaeological Approaches to the Present: Models for Reconstructing the Past. Academic Press.
Zubrow, E., Audouze, F., Enloe, J.G., 2010. The Magdalenian Household: Unraveling Domesticity, SUNY Series, The Institute for European and Mediterranean Archaeology Distinguished Monograph Series. State University of New York Press.