Observations of Land Use during the Neolithic Using Exploratory Spatial Data Analysis: Contributions and Limitations

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The settlement pattern analysis in archaeology implies some methodological questions. In this paper, we question some issues about the use of geostatistical methods for the observation of land use transformations during the Neolithic. We have developed two examples in Burgundy (France): the first one on a regional scale and the second one on a micro-regional scale. Using different ESDA approaches (Ripley'K function, Nearest Neighbour Distance, Kernel Density Estimation), we would like to underline what the methodological and archaeological contributions and their limits are. Both experiences point out that the results obtained depend not only on the analytical scale, but also on the quality and the quantity of the studied data. The contribution of this paper is to prove that scale, quality and quantity, are three essential parameters for the "reflexive approach" when using spatial statistics in landscape problems.

Keywords: Settlement analysis, ESDA, Spatial patterns, Ripley'K function, the Kernel Density Estimation Method

1. Introduction

The TEPANEO research program deals with territory, environment and agricultural practice changes from the Neolithic to the middle-Bronze Age, in central-eastern France. It has been carried out by palaeoecologists and archaeologists. The aim was to reconstruct land use, the degree of human impact and changes in territorial organisation, using palaeoecological and archaeological approaches.

First of all, the study investigated to what extent the dynamics of archaeological and environmental changes were correlated. Our aim was then to bring together the indicators of human activity, its characterization and evolution over time. Besides this methodological objective, our aim was to evaluate human/environmental interactions, and to understand how human activities observed in archaeology could be seen at a environmental level, and vice versa. The first results, recently obtained in the Berry region (Région Centre, France) are at the origin of this research program (VANNIÈRE and MARTINEAU, 2005).

Palaeocological investigations were carried out on cores performed in peatlands and are based on sedimentological, palynological and anthracological approaches. Environmental reconstructions and anthropogenic bio-indicators show that human impact spatially changes from the Middle- to Late-Neolithic.

During the middle-Neolithic, vegetation cover appears moderately impacted by agropastoral activities but scattered around a wide territory with numerous settlements. While, with the transition toward the final-Neolithic, environmental transformations linked to human activities seem stronger, but less sites are concerned.

These results allow us to propose that the middle-Neolithic was characterized by a greater dispersal and a homogeneous distribution of settlements, and that a clustering of settlements occurred during the final-Neolithic. This hypothesis of territory organisation changes has also been suggested by archaeological surveys in the Rhône valley (BEECHING *et al*., 2000) and in the Jura Mountains (PÉTREQUIN *et al*., 2005).

The second phase of this program began in 2009. It aimed at testing this hypothesis of changing patterns of land use (territorial) occupation, using available archaeological data and taking a statistical and spatial approach. The paper presents this methodological approach.

We will look at the methodological choices made and the results obtained. We will also examine the question of the relevant spatial resolution of the studied phenomena, correlated with the nature of the archaeological data to be used.

2. Databases

To test this territorial transformation hypothesis, two databases were built on two analytical scales: a regional scale in Burgundy, and a micro-regional scale: in two sectors of the Seine valley (Figure 1).

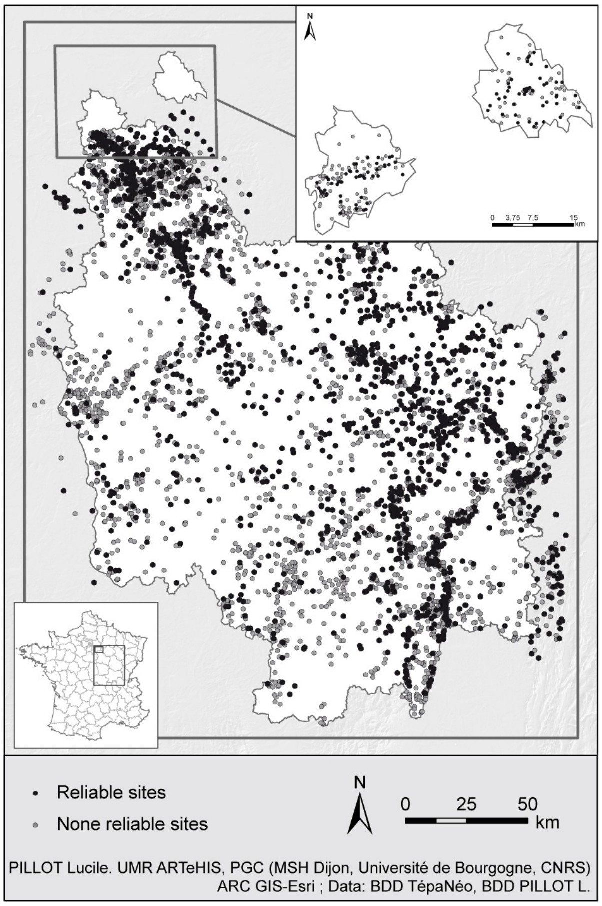

Figure 1: *Studied area: Burgundy and the Seine Valley.*

Each area is described by a specific inventory with specific criteria. For Burgundy, the database includes an inventory of 11000 sites dated between 5500 and 1500 BC. The sites are described with relative chronology, spatial coordinates, nature and the types of discoveries (habitat, funerary, indications...). For the Seine Valley, 200 sites dating between 5500 and 2000 BC are included in the inventory. As their different chronological phases are integrated, these settlements are chronologically better known and studied.

On the one hand, for the regional scale, the priority of the inventory was the quantity of available information, with restricted semantic descriptors. All the archaeological information discovered over two centuries has been recorded in a database with a descriptor that defines the quality or reliability of the archaeological source. High density point locations indicate the history and the importance of the archaeological research. To work on a different scale, the Saône Valley, one of the most studied areas, has been extracted.

On the other hand, for the micro-regional study, as the area concerned was better-known, the archaeological information gathered was checked and enhanced, focusing on the quality, precision and accuracy of the data that was going to be used.

The Burgundy database brings together thousands of sites or indications of sites, with no precise localization or description. Moreover, due to the intrinsic problems of archaeological data, the chronology of a large part of these sites is uncertain, without any description of the chronological phases. Clearly, the significant number of uncertain sites raised a large number of problems when trying to reconstruct the conditions of space organization at a given time. In order to observe territorial transformations, working with similar data between Middle and Late Neolithic, we have decided to eliminate all the sites with problems to interpret the analysis results. These problems are: wrong coordinates, no description or no chronological phases, and sometimes “Neolithic period” is only mentioned.

For the Seine Valley, the data are is better known and described than the data from the Burgundy area, the information has been selected to use similar data, because the description and the quality can be differenced in the two periods. On the figure 1, the grey points are the sites kept and the black points are the eliminated sites.

3. Exploratory Spatial Data Analysis

The Exploratory Spatial Data Analysis methods (ESDA) were used to qualify, quantify and visualize territorial transformations, and to test the hypothesis that the human occupation conditions changed throughout time. ESDA is a “Collection of techniques to describe and visualize spatial distributions, identify atypical locations (…), clusters or hot spots and suggest (…) other forms of spatial heterogeneity” (ANSELIN, 1994). Exploratory spatial data analysis was then carried out to identify any possible spatial particularities, local clusters or hot spots (ANSELIN, 1994, 1999; CRESSIE, 1993; FOTHERINGHAM *et al*., 2000; ZANINETTI, 2005).

The methods are suitable for each specific data like geostatistical data (when the point data collection is a sample of a continuous distribution) or like lattice data (when we have got a complete collection of discrete spatial locations). An archaeological inventory is never complete, but point location for archaeological sites does not represent a sample of a continuous phenomenon. It seems necessary to consider archaeological data as a complete collection of information.

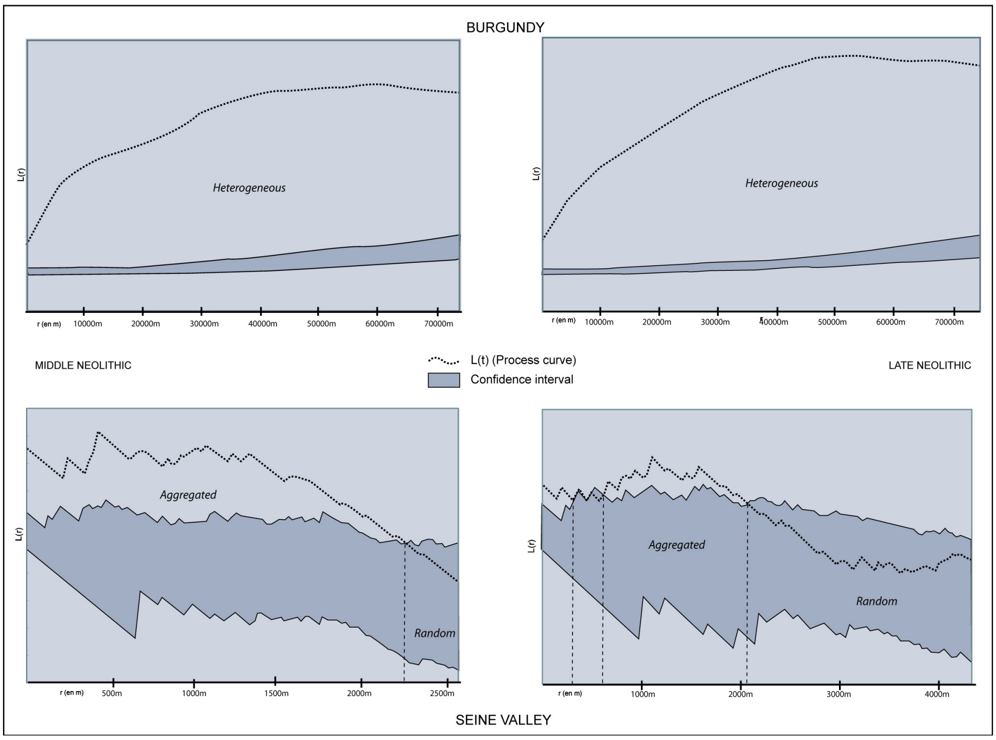

Figure 2: *Correlogramm of Burgundy and the Seine Valley.*

The methods which will be used belong to a category of point pattern analysis involving the ability to describe patterns of point event locations, and test whether there is a significant occurrence of point clustering in a particular area (RIPLEY, 1977). Those methods will raise some questions: what is the scale of concentration points or clusters? Where are these clusters or hot Spots? Which is the probability density?

What's difficult about ESDA application is the constitution of the data corpuses, because of archaeological investigation problems.

3.1. Global analysis: the Ripley'K function

The first method used concern a global spatial statistic for point pattern without weighting, the Ripley'K function. This function considers the complete distribution of all the distances in the point pattern. The distribution is compared to a reference distribution called a homogeneous Poisson process under complete spatial randomness (calculated with Monte-Carlo Simulation) and the function tests three hypotheses: the uniqueness (if there is one and only one archaeological site or occupation by coordinates); the homogeneous stationarity (if an archaeological site or occupation can be localized in any place) and the isotropic process (if there is any absence of orientation in the localizations) (RIPLEY, 1981; CRESSIE, 1993; ZANINETTI, 2005).

The process results are drawn with a correlogram with the calculated confidence interval (Figure 2). If the curve is above the confidence interval, the process is aggregated: there are some clusters in point pattern. If the curve is between the confidence interval, the process is random. If the curve is under the confidence interval, the process is regular.

Ripley'K function is a multiscalar tool, used for studying data organisation, defining spatial structures in a homogeneous space and comparing different areas. This method was used in archaeology for example by A. Bevan and J. Conolly in order to analyze land use occupation of the Kythera Island in Greece (BEVAN and CONOLLY, 2006).

3.2. The Nearest-Neighbour distance

The nearest-neighbour distance is a local analysis for finding clusters or "hot spots" (ZANINETTI, 2005). A cluster is a geographic area representing a small percentage of the study area which contains a high percentage of the studied phenomenon. Our aim is to find these point groups and compare the two different periods. The method used compares the real distribution with a random distribution, and gives a number of clusters drawn graphically. Like the parameters for the distance, the measure used corresponds to the peak of K-Ripley in correlogram.

In archaeology, K. Schwartz has implemented this method as well as Ripley's K analysis for finding hypothetical camp sites in delimiting clusters with artifact locations (SCHWARTZ, 2008).

3.3. The Kernel Density Estimation method (KDE)

This method is a non-parametric way of estimating the probability density function based on point location (SILVERMAN, 1986; ZANINETTI, 2005). KDE calculates the density for each cell of a grid overlaid on the map. It measures the distance between each cell and each point and determines the weight for the cell (LONGLEY *et al*., 2005). The density estimate is the sum of each weight. The weight depends on: the distance from cell to point, the radius or bandwidth around each point, and the method of interpolation or function. The higher influence is given by the bandwidth (SILVERMAN, 1978). With a small bandwidth: kernel estimate will appear spiky, whereas a large bandwidth obscures details but generalizes. It could be subjectively defined, by eye, with knowledge and hypothesis or it can be estimated with an automatic choice like K-Ripley function for example, with the peak of correlogram as for the nearest neighbour distance. We have tested both.

For the function, the normal function was chosen for each map of both periods because the result is a continuous estimation. To calculate the spatio-temporal changes, the method of dual KDE has been employed using the quadratic function which seems more suited to observe local and punctual phenomenon and transformations through time. The dual KDE gives maps which indicate areas of increasing and decreasing concentration (JANSENBERGER and STAUFER-STEINNOCHER, 2004).

We have used one extension of the method: the Percent Volume Contour (PVC). There are two contours (the 95 PVC and the 50 PVC) which localize areas in which the data density surface is respectively 95% or 50% of the volumes. It permits the delineation of denser areas.

The use of KDE in archaeology isn't yet globally widespread since the paper of M.J. Baxter, C.C. Beardah and J. Wright in 1997 (BAXTER *et al*., 1997). We can notify the study of J.O. Santos and his colleagues about the production locations with ceramics density (SANTOS *et al*., 2006).

4. Results and interpretation

4.1. Local and global analyses: contrasted results

Statistical methods allow the observations of land use transformations between Middle and Late Neolithic. Nevertheless, their use requires methodological reflections, in particular the parameters and the resolution definitions.

The small scale

At this analysis level, using a global or local method of analysis, there are no variations between the results of the Middle Neolithic and those of the Late Neolithic. Indeed, the starting hypothesis of this study implies that there could have been a change in the clusters size and their distribution in space. Indeed, if there was a concentration of sites during the Late Neolithic,clusters should be more prominent than for the earlier period. When we use global analysis, cluster sizes are almost the same. We obtain complex correlograms for both periods (Figure 2): the function has positive values that stay above the confidence interval. We can consider with this kind of diagram, that the distribution is heterogeneous (PÉLISSIER and GOREAUD, 2001). It shows that for both periods, the point pattern seems significantly aggregated from 4.5 km to 6.5 km. Moreover, "hot Spot" calculations validate this observation: cluster areas seem unchanged. Indeed for the nearest-neighbour distance, the results don't seem to be efficient. For the small scale, clusters seem to be the same for each period. They are localized in the most studied sectors where the archaeological investigations have been very intense throughout the two last centuries: Saône and Yonne valleys.

The results obtained are thus influenced very much by the research context: it is already known. Nevertheless, there is an increase of cluster numbers. Indeed, there are 20 clusters for the Late Neolithic, whereas there are only 13 for the Middle Neolithic period. It could mean that there is an intensification of the areas that were already occupied during Middle Neolithic, and an establishment of new clusters during the Late Neolithic. The global or local small-scale analysis, thus supply biased results. We perceive a "noise", but it is damaged by the problems of the data quality. Indeed, for the large dataset, as Burgundy, results are consequences of source effects.

The large scale

At a level of large analysis, methods of global and local analysis supply clearer results in terms of change. With Ripley's K statistics we can feel changes. It shows us that the structure of the distribution and the size of clusters changed over time. Late Neolithic curves are not the same as those of the Middle Neolithic period. For the Late period, it reveals a Cox process or a doubly stochastic Poisson process (Figure 2). The term "doubly stochastic" was introduced by D.R. Cox (COX, 1955) . It can be viewed as a two step randomization procedure. It corresponds to the presence of clusters which can be localized in a global random process. For the Late Neolithic, the function remains in the long distance confidence interval between 300 m and 2.1 km. It means that from 300 m to 2.1 km, the structure of point pattern seems more aggregated, whereas for the Middle Neolithic, a point pattern is significantly aggregated between 0 and 3.5 km. The Late Neolithic clusters are smaller than the ones of Middle Neolithic: they are denser but more reduced. It seems that there is a dispersion of the occupation during the Middle Neolithic, but a concentration during the following period.

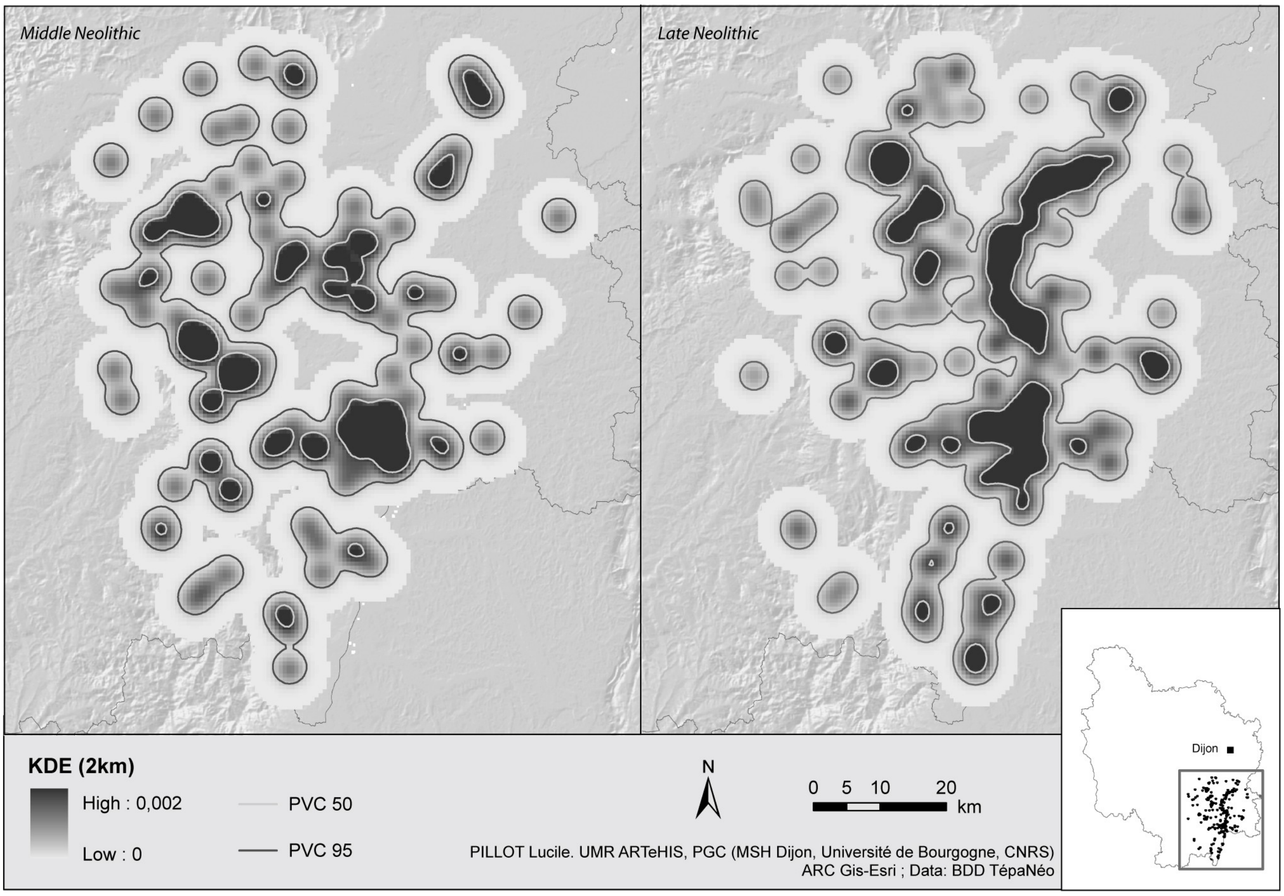

Figure 3: *KDE of Saône Valley (extract area of Burgundy) for Middle and Late Neolithic.*

Local analyses, such as KDE, confirm this dispersal/concentration phenomenon (Figure 3). KDE shows a trend towards aggregation, but with a constriction in space. For these method applications, we have used 50 PVC. For the Saone sector, there is less than 50 PVC but more significant 50 PVC surfaces which were occupied. For the end of the period, data seem well clustered: some of the Middle Neolithic 50 PVC seem aggregated by Late Neolithic clustered areas. For the Seine-Yonne sector, occupation concentration has appeared since the 2d Middle Neolithic. Since the end of the Middle period, it appears that the 50 PVC areas increased over time. At a large level, land use changes seem more noticeable, because the data has been checked well.

In conclusion, these examples show that according to the analysis scale, local and global methods are not always adapted. For the Ripley's K statistics for example, it appears that the smaller the scale is, the more a heterogeneous process will be: it is necessary to apply this global method with an expanding scale and with fitting of these. This method is an interesting and relevant approach, because it is able to show how both the structure of the distribution and the size of clusters changed through time. In the same way, local methods as KDE give contrasted results according to the analysis scale, the size of the dataset and, indirectly, the source effects. These source effects will be reduced when working with changing scale and analysis levels.

4.2. Spatio-temporal evolution

Maps of changes give more support to validate our first hypothesis: how do clusters evolve in space and time? Globally, results are more significant for the small scale (Figure 4). During the Late Neolithic, there is an occupation increase in some sectors, especially in the two most studied sectors: the Yonne and Saône areas. Moreover, it seems that we have a moving of areas characterized by high density (dark sectors). There are a lot of areas with a significant decrease of density (clearer sectors), while some areas are affected by high increase. This confirms our hypothesis of concentration during the Late Neolithic. An intensification phenomenon has been observed, in areas already occupied during the Middle Neolithic, and the insulated poles have disappeared. We can conclude that there are territorial concentrations and constrictions in space in Late Neolithic.

5. Discussion and prospects

Geostatistical approaches give a confirmation of archaeological hypothesis in the same way as the palaeoenvironmental results. Agro-pastoral or social changes can be related to the different management of space by the neolithic societies, from dispersion to concentration in space. This work raises significant questions, which are related to methodological approaches, concerning the ESDA contribution in archaeological research, problems of data characterization, and necessity to work with different scales.

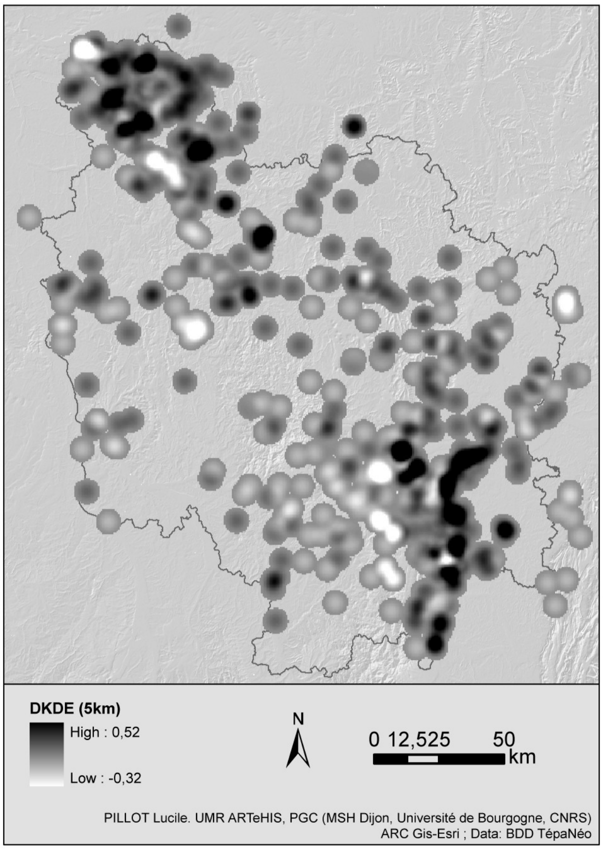

Figure 4: *Burgundy map of change.*

5.1. ESDA and archaeological results

The statistical analysis used lead to data « exploration » (ZANINETTI, 2005). These approaches allow the testing and exploration of archaeological data. Indeed, ESDA are informative and useful devices for finding, verifying and visualizing spatial data patterns (CONOLLY and LAKE, 2006). But, they are « manipulative » methods as well (ZANINETTI, 2005). From there, how can we know if our results are statistically significant? Indeed, there are no reliable analysis and no totally safe results. The map is a "unique exploratory tool" (BANOS, 2001). In fact, ESDA methods provide a way to observe the spatial organizations underlying unprocessed maps. By "combining these data smoothing or indicator calculation methods (…) with an increased number of snapshots, it is clearly possible to bring out spatial structures or put forward new hypotheses" (BANOS, 2001). However, questions remain about how to evaluate the reliability or robustness of these hypotheses? How to compare these spatial forms over time? Insofar as the statistical "sample" is based on archaeological information whose complex inventory properties are not measurable.

Besides, our starting assumption which consists in considering data as a whole collection of data, which can represent an archaeological reality, has a strong impact in archaeological interpretation. Also, it would be interesting to explore these approaches with resampling methods. Resampling approaches as bootstrapping, point out a group of methods which consist in doing statistical inference, in order to test the reproducibility of events. In an archaeological sense, it consists in filling out dataset with theoretical sites by repeatedly selecting samples from the initial dataset (BAXTER, 2001). Given the problems which archaeologists face, the interpretation of variability in their datasets and inability of classical methods to assist them under normal circumstances (i.e. small datasets, non-normal distributions), resampling can help them to think more carefully about data and its analysis. This approach could allow the improvement of the reading and interpretation of the results.

5.2. Data characterization

The application of statistical analysis raises the problem of the quality of archaeological data. Indeed, it appears that there are no absolutely suitable methods to compensate archaeological problems. Archaeological data have a lot of intrinsic problems related to the effects of archaeological investigation. Often, big archaeological databases are damaged by heterogeneous and incomplete inventories. Many of the inventoried sites are not shown to have been permanently occupied. Moreover, due to the intrinsic problems of archaeological data, the chronology of a large portion of these sites is uncertain. Clearly, it appears that the attempt to reconstruct the conditions of spatial organization, at a given time, is difficult when available data contain a significant number of uncertain sites and site indications. However, how can the space and its use be represented if the archaeological data is not totally reliable? How should these site indications be viewed? To what extent should they be included in the analysis? It seems more significant to take into account these intrinsic problems. We have to consider the quality and the reliability of our data in order to validate our results. That is why we want to compare results between reliable sites and the complete dataset with uncertain sites. Moreover, statistical analysis allows taking into account the most reliable sites, through weighted average. It doesn't seem inconsistent to establish a "hierarchy" between sites to discriminate the presence of indications in the analysis. Perhaps, a way for the next step of this research is to take the most significant weight by a "hierarchy", for the reliable sites as habitat or enclosures, because they are considered as notable marks of long-lasting human occupation. It seems essential to better characterize the data to obtain even more reliable results.

5.3. Mulstiscalar approach

Naturally, the quality of an inventory often involves treating a more restricted data sample. Our experience raises the question of scale, the phenomenon to be characterized, and also of the relationship between the quality and quantity of the available data according to this analysis scale. Issues of scale have a significant impact on the progress of research and the utility of the results. It is a theme which is very often treated in the archaeological research (LOCK and MOLYNEAUX, 2006), raising conceptual, methodological and interpretative questions. The study of the spatial distribution of sites by statistical approaches depends on the resolution and the shape of the study area. Indeed, as pointed out by A. Bevan and J. Conolly, one of the problems of these methods is "the effect of the size of the study area has on the detection of patterning" (BEVAN and CONOLLY, 2006). Now, we saw that analysis levels aren't always relevant for the result interpretation. It is necessary to work on other levels, in order to reduce source effects. The study of the spatial distribution of sites could be a multidimensional research. In the case of statistics as K-Ripley, adjustment of analysis scale has a major influence on the intensity and clustering tendencies of point distributions (BEVAN and CONOLLY, 2006). A constant up and down between large, small and intermediate scales could be an opportunity to improve our results. Indeed, these scales could provide complementary results. In our case, we could zoom in intermediate scales, such as the Saône sector. One of our perspectives is to explore other study areas with different scales (Seine and Yonne areas), in order to compare them. It will be possible to work up and down between local and global views, multiplying the fitted scales.

Conclusion

This paper has emphasized the thinking that it is necessary for the correct identification of changes in spatial distribution of archaeological sites over time. This approach requires precise analysis modalities and resolutions in order to observe land use transformation. In our opinion, the key challenge lies in finding the appropriate resolution between the phenomenon to be described and the data used to provide relevant results. Moreover there is a clear need to be able to overlap analysis at different scales in order to take into account the phenomenon complexity. A study focusing on a small scale involves working with uncertain data that generates "noise" when reading the results. Nevertheless, even when integrating this uncertainty bias, the quantity of data processed makes it possible to have a broad view in space and time. More than an end in itself, this step represents a tool for discussion, from which work hypotheses can be put forward. Secondly, these hypotheses can be applied to an area which is not only smaller, but also better known archaeologically speaking, and for which more data is thus available. This raises the question of the relationship between the quality and quantity of the available data according to this analysis scale. In conclusion, these experiments have shown the importance of a "reflexive approach" on the use of spatial statistics applied to archaeological research.

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