



HAL
open science

To boldly go where no one has gone before: integrating social factors in site location analysis and predictive modelling, the hierarchical types map

Antonin Nüsslein, Laure Nuninger, Philip Verhagen

► To cite this version:

Antonin Nüsslein, Laure Nuninger, Philip Verhagen. To boldly go where no one has gone before: integrating social factors in site location analysis and predictive modelling, the hierarchical types map. Digital Archaeologies, Material Worlds (Past and Present), Proceeding of the 45th Computer Applications and Quantitative Methods in Archaeology Conference (CAA 2017 ATLANTA, USA), Universität Tübingen, pp.15-31, 2020, 10.15496/publikation-43234 . hal-01678020

HAL Id: hal-01678020

<https://hal.science/hal-01678020v1>

Submitted on 9 Jun 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution - NonCommercial - NoDerivatives 4.0 International License

To boldly go where no one has gone before: integrating in site location analysis and predictive modelling, the hierarchical types map

Antonin Nüsslein

9a rue de la Mairie 67970 Oermingen, France nusslein.antonin@gmail.com

Laure Nuninger

Chrono-Environnement MSHE C.N. Ledoux - CNRS, Besançon, France laure.nuninger@univ-fcomte.fr

Philip Verhagen

Vrije Universiteit Amsterdam, Netherlands j.w.h.p.verhagen@vu.nl

ABSTRACT

Over the years, predictive modelling has been characterized as being environmentally deterministic, a-temporal, or even as a way of ‘effectively de-humanising the past’. Over the past ten years, however, spatial analysis of settlement patterns has progressed substantially, paying much more attention to the role of socio-cultural factors and the analysis of settlement pattern dynamics. In this paper, we will present an approach to site location analysis and predictive modelling that can be characterized as essentially data driven, yet is very much theoretically informed, and which has focused primarily on facilitating comparisons between various chrono-cultural contexts. Our experiments, that have been carried out since 2010, have mainly used data from the Roman period in various regions of France, but the general ideas and workflow can easily be transferred to other settings. To enrich the approach new developments were tested to understand the role of settlement hierarchy and its influence on the subsequent development and structuring of settlement patterns. These new developments were applied to three case study carried out in the north-east of France.

KEYWORDS

site location analysis, predictive modelling, socio-cultural factors, temporal factors, Roman period

1. INTRODUCTION

In this paper, we present a new method to analyse the role of socio-environmental variables in rural settlement system development, with special emphasis on the role of the hierarchical structure of settlement. This method was developed as part of the PhD research conducted by the first author, in a case study for the Roman period in the Alsace-Lorraine region (NE France; Nüsslein 2016a). This work is based on several research projects carried out in France between the 1980s and 2010s (Nuninger et al. 2012a; Favory, Nuninger & Sanders 2012; Nuninger, Sanders et al. 2006). The main interest of this long-term research is to study the dynamics of settlement systems and land use with a socio-environmental perspective and with a diachronic and transcultural comparison approach, in order to investigate the durability of the systems and the resilience of past societies.

This research started in the eastern Languedoc in the 1980s and was led by Jean-Luc Fiches, François Favory and Claude Raynaud (Fiches 1987; Favory 1989; Raynaud 1989; Favory & Fiches 1994; Favory et al. 1987; Favory, Ouriachi & Nuninger 2011). In the beginning of the

1990s two projects led by Sander van der Leeuw (Archaeomedes 1 and 2; Van der Leeuw 1998; Archaeomedes 1998; Van der Leeuw et al. 2003; Van der Leeuw et al. 2005) enlarged the regional focus to the Rhône valley, and initiated a partnership between French and Dutch scholars working on spatial analysis. Later on, within the framework of two other projects called Archaedyn 1 and 2 (led by François Favory and Laure Nuninger; Favory et al. 2008, Nuninger et al. 2008; Gandini et al. 2008; Gandini, Favory & Nuninger 2012), researchers from Slovenia were associated and brought new case studies. Around 2010, a new collaboration was developed between the French and Dutch, called IHAPMA (Introducing the Human Factor in the Predictive Modelling for Archaeology), bringing in an additional case study in the Netherlands (Nuninger et al. 2012b; Verhagen et al. 2013a and b; Nuninger et al. 2016; Verhagen et al. 2016), and finally the Alsace-Lorraine region. An original methodology to study changes in the settlement system and land use was built step by step over all these projects. This has given us a common reference to perform interregional comparison on a solid basis (Favory, Nuninger & Sanders 2012).

In the IHAPMA project we were in particular interested in the estimation of human impact on rural settlement choices, and mainly for the Roman period. The issue was to analyse changes in settlement location during the Roman period to better understand what drove the choices of past communities: the environmental conditions, the potential for movement or control, or socio-economic considerations - or all of them? In order to estimate the weight of each factor we combined the 'French' approach, mainly based on multivariate statistical analyses and classification, and the 'Dutch' approach, mainly based on predictive modelling methods. Predictive modelling is used here as a scientific tool to detect change from one period to another, and not for heritage management purposes (Nuninger et al. 2012b; Verhagen et al. 2013a).

In this project, we put special emphasis on socio-environmental variables, and it is the computation and analysis of one of these social variables that we will present in this paper: the hierarchical structure of the settlement systems. This variable was originally defined by the Archaedyn team (Fovet in Nuninger et al. 2012c; Mathian & Tannier in Favory, Nuninger & Sanders 2012), but we adapted it to a raster environment and we developed the model as an operational GIS tool. It was then applied and analysed for the first time on three regional case studies in the Alsace-Lorraine region.

2. THE SETTLEMENT OF THE COUNTRYSIDE BETWEEN MOSELLE AND RHINE IN THE ROMAN PERIOD

During Antiquity, the area between the Moselle and Rhine rivers was a region in which many historical events occurred (Gallic Wars, Germanic invasions, battles in Late Antiquity). These events successively changed its administrative and political organization. The main aim of the PhD research was to study, through spatial modelling and comparative approaches, the evolution of the settlement of micro-regions in a large and complex area between the 1st c. BC and the 5th c. AD.

The three study areas are located in Alsace and Lorraine (fig. 1). Two are located on the Plateau Lorrain (zone 1 "Entre Alsace Bossue et Pays de Bitche", zone 2 "Entre Seille et Nied") and one in the Plaine d'Alsace (zone 3 "Basse vallée de la Bruche"). They are well known by survey and excavations. Their size varies between 300 and 600 km². All of them were more or less systematically surveyed by field walking and in addition about 10 to 15% of the sites were excavated. The number of Roman settlements per zone varies from 65 to

more than 300 and at least 30% can be dated at the century scale.

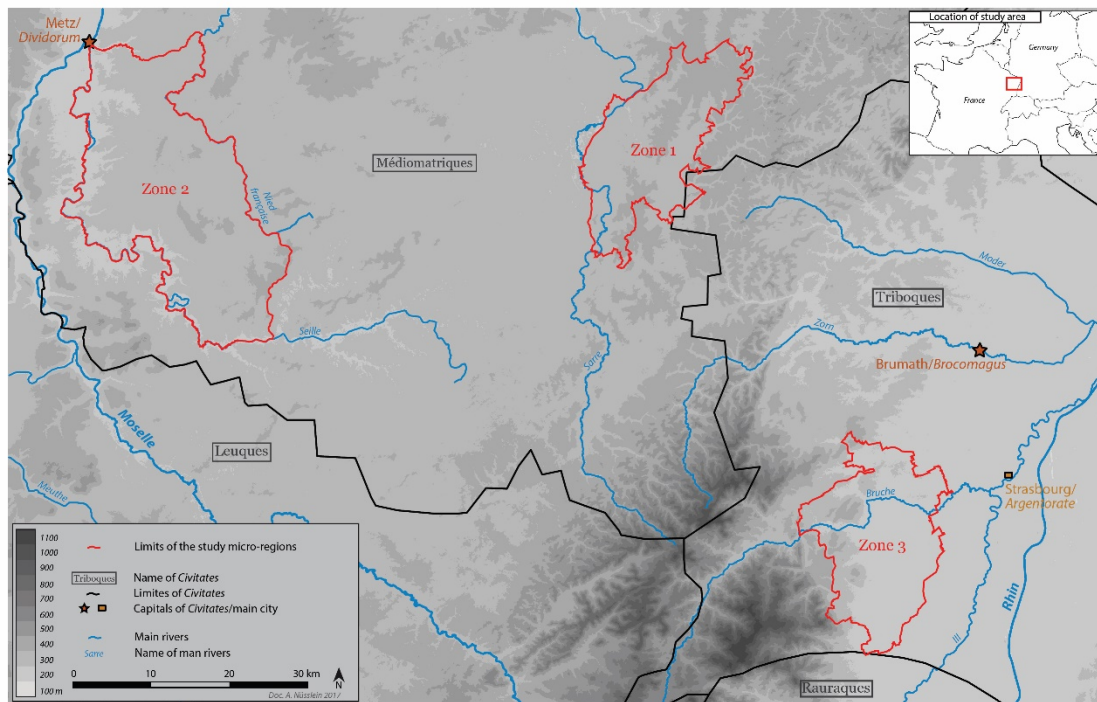


Fig. 1. Map of the study areas in Alsace and Lorraine.

These sites are not all the same: their size varies between 100 m² to 100 ha, and their wealth and longevity are very variable. Based on these observations, we can assume different functional roles of the settlements within the system. This is why a hierarchic-functional typology of the settlements was created, based on the method developed in the Archaeomedes and Archaedyn projects, using a combination of correspondence analysis and hierarchical clustering (Van der Leeuw et al. 2003; Favory et al. 1999; Bertonecello et al. 2012a). "The principle is that of a convergence of multiple indices whose combination makes sense in the a posteriori interpretation by the archaeologist and allows him to identify a typological-functional hierarchy" (Favory, Nuninger & Sanders 2012). This analysis resulted in 9 different, hierarchic-functional classes of settlements, depending on several variables but in particular the surface area of the settlement, its duration of life, and the quality of the material used for construction (fig. 2 and table 1). The settlements are thus classified into hierarchically ranked groups of settlements that can be interpreted from agglomerations to small farms. When we analyse the sites according to this classification, we can see that the micro-regions have very different settlement compositions. In zones 1 and 2, the habitats are mainly isolated (villas and farms) whereas in zone 3 the habitats are mainly grouped (villages and hamlets).

	Variables
<i>A</i>	Area
<i>B</i>	Materials use for the construction (wood, stone, mortar, etc.)
<i>C</i>	Level of confort (presence of hypocauste, bath, etc.)
<i>D</i>	Diversity of ceramic artefact
<i>E</i>	Other artefacts (iron, silver, tools, etc.)
<i>F</i>	Craft activities
<i>G</i>	Duration of life

<i>H</i>	Date of creation of the settlement
----------	------------------------------------

Table 1. Variables used to create the hierarchic-functional typology of the settlements (Nüsslein 2016a).

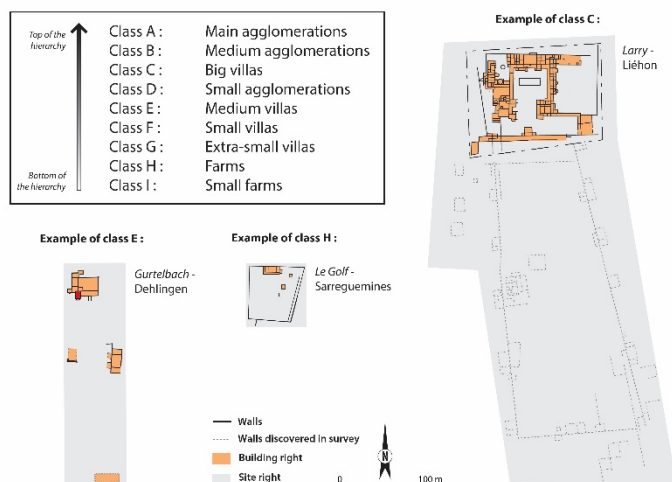


Fig. 2. Typological-functional hierarchy of the settlements.

However, as mentioned by Favory, Nuninger & Sanders (2012), it should be noted that these are "properties associated with the settlement referring to various periods" and no time variable is taken into account in the analysis. "Thus the existence of entities refers to an abstract a-temporal level" and does not illustrate the internal evolution of habitats. Indeed, the excavations show that the studied habitats sometimes follow long development trajectories in which they move up in the hierarchical ranking, and then decline (Nüsslein 2016b). Moreover, some sites of similar status at the beginning of the Roman period will develop more strongly than their neighbours. What are the local factors explaining these different phenomena?

After this step of classification and site study, the structuring spaces generated by the sites were studied using a number of statistical and geospatial tools (for example: density, dispersion/concentration, distances between sites, etc.). These analyses showed that the areas presented clear differences in occupation over the centuries. The second question then is: what type of socio-environmental factors can explain these variations in time and space?

To answer these two questions, the local conditions of settlement creation were studied based on the variables developed in the previous studies cited and focusing, in particular, on the relationship between settlements according to their rank within a spatial and dynamical perspective. For this, a new tool was developed in a GIS environment so as to compute a raster map of the hierarchic-functional structure of the settlement system.

3. THE MAP OF HIERARCHIC-FUNCTIONAL STRUCTURE OF THE SETTLEMENT SYSTEM

3.1 THE ORIGINAL CONCEPT

In the different cases studied in the previous projects, it was observed that different types of settlements are often spatially associated (Favory et al. 1994; Favory et al. in Archaeomedes 1998; Nuninger et al. 2006; Bertonecello et al. 2012a and 2012b). The issue was how to

qualify, with a synthetic index, the neighbourhood of a location according to its potential in terms of territorial organization?

There are many different types of hierarchical-functional assemblages, consisting of multiple, interacting occupations. Based on these observations, the Archaedyn and the IHAPMA teams suggested further analysis by characterizing each portion of space (place, grid cell) by quantitatively describing its neighbourhood using a set of environmental and archaeological attributes. Among the archaeological variables, we will illustrate the "heritage" index and the "hierarchical-functional structure" index.

The first one is based on the concept of "neighbourhood legacy", characterizing the accumulated investment in the landscape at a time t . It gives the possibility to compute heritage maps where each cell gets a value calculated by the accumulated length of occupation in the neighbourhood at a time t , weighted by temporal and spatial distance (Favory, Nuninger & Sanders 2012; Nuninger et al. 2016; Verhagen et al. 2016).

In parallel, and based on the same idea of characterizing the social context, Élise Fovet suggested to identify the level of "hierarchical organization" of the settlement pattern within clusters of settlements defined by a segmentation of the space based on a density map (see Nuninger et al. 2012c; Bertoncetto et al. 2012a).

In order to determine the level of hierarchical organization of settlement within each sector, two indicators were calculated:

1. The hierarchical variety of the settlements which shows the degree of diversification of the settlement types (number of different classes) and
2. The differentiation of the classes present in each sector based on standard deviation.

For an equivalent value of the variety, we can distinguish:

- (a) a low range—i.e., a high homogeneity—which indicates the association of settlements belonging to hierarchically close classes (e.g., classes 1 and 2, or classes 5 and 6),
- (b) a high range or a strong differentiation when classes are extreme (e.g., classes 1 and 6).

Then both indicators were combined so as to indicate the degree of settlement organization within a sector, i.e., the value of the "hierarchical-functional structure. It makes it possible to distinguish poorly structured sectors (non-diversified settlement types with similar hierarchical levels) from highly structured sectors (highly diversified and exhibiting a broad spectrum of settlement classes, see fig. 4).

In this approach, the result is largely dependent on the identified aggregates or sectors used for the analysis and the solution adopted remains problematic with respect to monitoring regional comparison. To overcome this problem, H el ene Mathian and C ecile Tannier (see Favory, Nuninger & Sanders 2012) proposed to compute a value based on a neighbourhood analysis using a regular point cloud and taking account of the hierarchical ranking of the settlements. Thus the distance to the closest neighbours of the settlement was calculated according to their hierarchical level. As a result, the potential of a place n can be defined with respect to the structuring level of the settlement system that surrounds it at a time t , using the same index created previously by Fovet. This approach takes into account the entire spatial region studied rather than just its occupied area, including the marginal or totally abandoned areas, which help us understand the types of land use and the organization of the settlement systems.

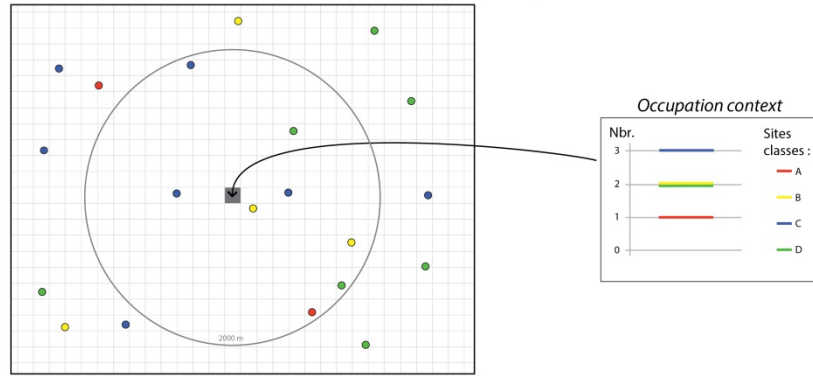
While the concept and the general method were already designed to determine systematically the value of the hierarchical-functional structure within a study area, its application within a GIS environment remained to be developed. This new step was the work done within the PhD of the first author who adapted the method and developed a tool for ArcGIS. This tool was then used in three regional case studies for comparison.

3.2 CREATING THE MAP OF HIERARCHICAL-FUNCTIONAL STRUCTURE

To create the maps, Nüsslein (2016a) used a hierarchical-functional typology and a contextual approach. Compared to the method developed by Mathian and Tannier, the approach differs in two major points: 1- instead of a point cloud, a raster environment was used to calculate the value of the "hierarchical-functional structure" and 2- the choice of the radius was not based on nearest neighbours analysis, but was decided after testing a series of radii using the method developed by François-Pierre Tourneux (Tourneux 2000; Nuninger et al. 2012b; Verhagen et al. 2013a).

For each cell in space, the hierarchical context that develops there is established. This "context" is representing the profile of one cell according to the assemblage of settlements surrounding this cell (fig. 3, step 1). To define the size and morphology of the "surroundings", we chose to use a 2000 m radius around each cell. The size of the radius was fixed according to its statistical significance to get enough variability locally and regionally. Once all the "contexts" were computed for each cell in each micro-region, we obtained a series of profiles describing the cells in the same way in the three case studies (fig. 3, step 2, a). An automatic k-means classification was then performed on the whole set of cells to group those with similar context profiles together. The result of the classification makes it possible to distinguish five main context categories (fig. 3, step 2). The results of this new classification were then mapped (fig. 3, step 2). Each cell on the raster map indicates the presence of each category of the hierarchical-functional contexts, which refers to what we call the "hierarchical type of context". According to the assumption that a settlement can interact with its neighbors, we can assume a sort of complementarity between settlements of the same hierarchical-functional rank and between various ranks. Based on this hypothesis, when considering the choice of a place to settle or the potential of development for a new occupation, it could logically be presumed that the hierarchical type of context is a variable playing a role. In other words, according to its hierarchical type of context a portion of space (cell) will presumably be more or less attractive to settle.

Step 1 : Calculation of hierarchical context for each point of space within a radius of 2000 m



Step 2 : Classification of contexts and creation of the map

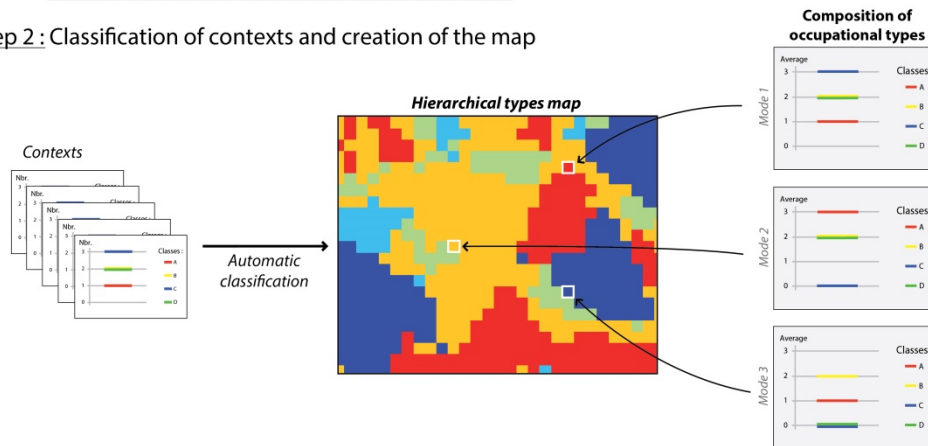


Fig. 3. Protocol for the map of hierarchic-functional structure of the settlement system.

In order to qualify the attractiveness, the statistical composition of each category of the hierarchical-functional context on the map (fig. 3 step 2, b) was analysed in order to interpret their level of hierarchical organization. As in the method developed by the ArchaeDyn collective for each category, we computed the two indicators: the hierarchical variety of the settlement and the range based on standard deviation. The level of hierarchical organization for each category was then defined by the combination of both indicators (fig. 4). We estimate that the more a type contains various types of settlement, and the larger its typological dispersion, the higher its level of organization.

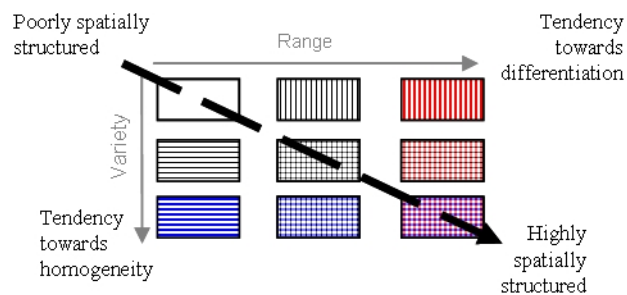


Fig. 4. Different combinations of the indices of hierarchical variety and range showing different levels of hierarchical organization of settlement patterns (after Fovet in Nuninger et al. 2012c).

Each category of the hierarchical-functional context was then ranked from 1 to 5 according to their level of hierarchical organization, from an unstructured to a very structured social

landscape (tab. 1 and fig. 5).

Categories ranked by their level of hierarchical organization	Interpretation
Level 1	This type represents a settlement system with a high hierarchical variety but with a low typological dispersion. This type thus presents a low level of structuring.
Level 2	This type, which has a medium level of structuring, displays a moderately varied assemblage and an average typological dispersion. Observing the spatial configuration of this type, we can see that these are large isolated villas or small aggregates, composed of a large villa and one or two small settlements in the periphery.
Level 3	Dense settlement but not very varied, showing an average typological dispersion. This assemblage, with a level of structuration comparable to the previous type, is composed of small aggregates mixing small and medium-sized villas accompanied sometimes by small farms.
Level 4	This settlement system has a medium level of structuring and is not very varied, but there is a very strong typological dispersion. This assembly is composed of medium-sized agglomerations around which sometimes gravitate some small farms.
Level 5	These are the most structured and most complex settlement systems. The settlement is varied and the hierarchical dispersion is very strong: the gap between small and large habitats is important but includes intermediate sites. Morphologically, this type shows small sets whose main settlements are large and medium-sized villas, around which gravitate many farms and small villas.

Table 2. Categories of the hierarchical-functional context ranked according to their level of hierarchical organization, from unstructured to very structured.

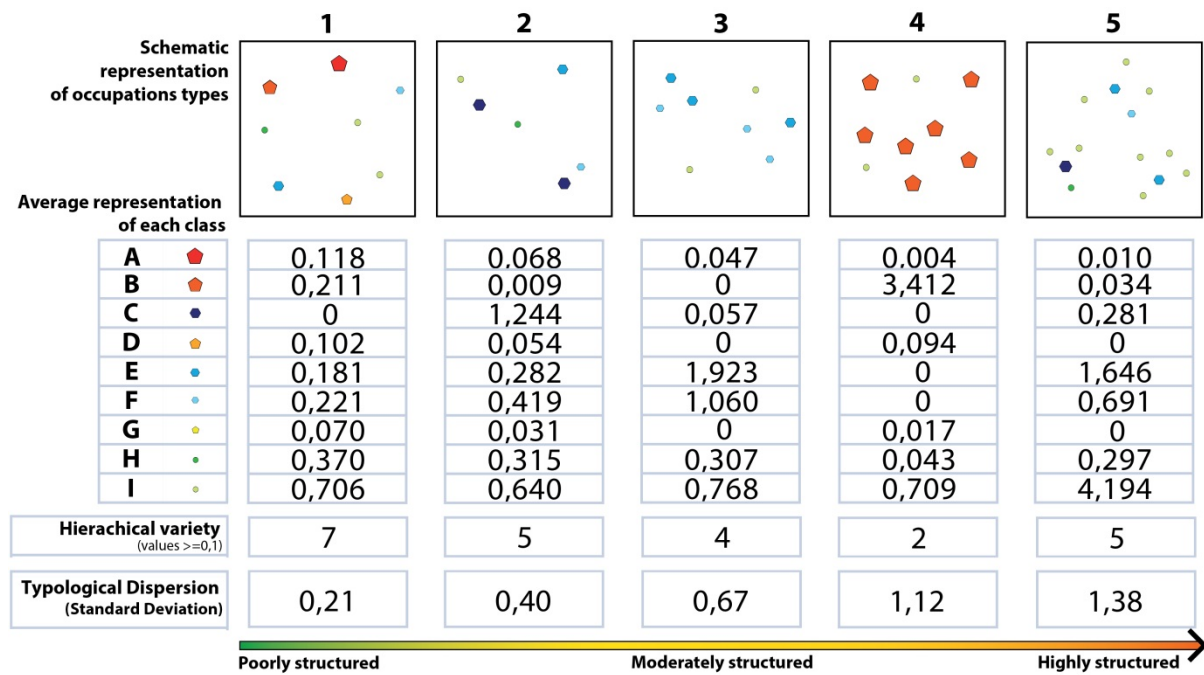


Figure 5. Categories of the hierarchical-functional contexts, ranked from 1 to 5

3.3 INTEGRATING THE FACTORS IN SITE LOCATION ANALYSIS AND PREDICTIVE MODELLING

In order to analyse the potential attractiveness of each cell according to the level of hierarchical organization in its surrounding, we used a predictive model based on χ^2 -tests and relative gain calculations developed in previous works (Wansleben & Verhart 1992; Verhagen 2007). This analysis aimed to see if any significant site location preferences could be established and how strong the preferences are. The predictive values were computed for periods of one century. For each century n , the model looked at the location of new settlements according to the pre-existent hierarchical context in century $n - 1$. For example, the predictive value of new site locations for the 2nd c. AD is calculated using the category of the hierarchical-functional context of the 1st c. AD. The analysis was done for 1st to 4th c. AD, the periods for which sufficient sites were available for quantitative analysis.

To estimate the importance of this social factor against the topographical one in the evolution of site location preferences, the predictive values were also computed for the geo-environmental context. The methodology used was exactly the same as the one developed in previous work by the IHAPMA team (Nuninger et al. 2012b; Verhagen et al. 2013a). The geo-environmental context is based on three groups of variables (slope, aspect and solar radiation) computed using the IGN DTM with a resolution of 50m¹. For solar radiation the qualitative value from cold to very warm is determined according to the medium value of the theoretical solar radiation per year calculated on the three micro-regions. The extent of the context was defined by an appropriate radius, which provided the most statistical contrast in the context profiles. The geo-environmental context profile was calculated for each cell in each region. Then, a Principal Component Analysis (PCA) followed by a Maximum Likelihood Classification were done on the whole cells giving a final map with six categories of geo-environmental contexts (table 3).

¹ based on the IGN BD ALTI® 25m, <http://professionnels.ign.fr/bdalti>.

Categories of geo-environmental context (topography)	Interpretation
1	South to east aspect, very warm to warm environment with medium (4-8%) to steep (8-15%) slopes.
2	South to west aspect, warm to medium-fresh environment with flat area (à-2%) or weak slopes (2-4%)
3	West aspect, warm to fresh environment with medium to steep slopes. This context is marked by a strong mix of criteria
4	No or north, east aspect, medium-warm to medium-fresh environment with flat areas
5	North to east aspect, fresh to medium-warm environment with flat area to medium slopes. This context is marked by a strong mix of criteria
6	North to east aspect, cold to fresh environment with medium to steep slopes.

Table 3. Categories of geo-environmental context.

4. RESULTS

4.1. THE MAP OF HIERARCHICAL-FUNCTIONAL STRUCTURE

Before integrating the geo-environmental variable in site location analysis, we would like to comment on the evolution of hierarchical organization and the differences observed between the study areas.

In the 1st c. BC, space is sparsely occupied in all study regions. However, the intensity of occupation is high around the main settlements (Nüsslein 2016a), such as the villas in zone 1 and 2 (in reality, these sites are still farms at this period). The maps show that the sectors where level 1 (table 2) is developing dominate in all micro-regions. The spaces still have a low level of hierarchical organization. Globally, for all the micro-regions, in this century the most important sites are established, from which settlement will intensify and expand, in the most structured sector.

In the 1st c. AD, occupation becomes more intense (fig. 6). The main settlements are expanding in space. In all micro-regions, level 1 still dominates, but weakens in favour of more structured assemblages. It is now confined to the newly settled peripheral spaces. Level 3 becomes most important. In the zones 1 and 2 the assemblages that combine medium and small villa type of settlements take up more place in the centre of the areas previously occupied, thanks in particular to the densification of settlement. The settlement system appears to become more complex. In zones 1 and 2, the densification of space also allows the emergence of level 5, the most organized. Its extent is still very limited but it will increase in

the next centuries. This level of hierarchical organization appears in an area where a highly structured set of villas and small farms is developing.

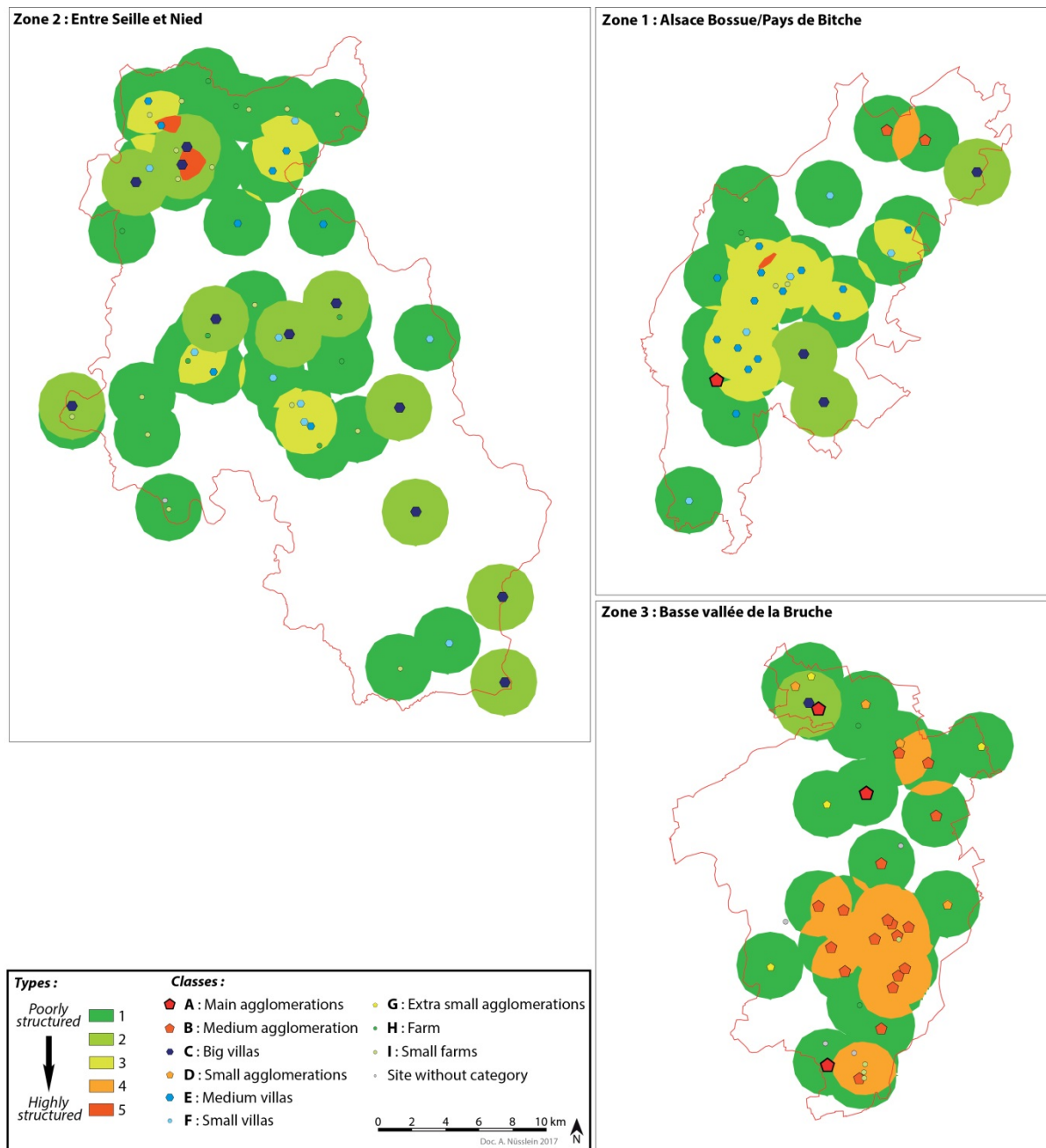


Fig. 6. Maps of the hierarchical-functional structure for the 1st century AD.

In the 2nd c. AD, the settlement system is very dynamic, and small settlements appear in the surroundings where the main settlements are located. They are founded in close proximity to the larger ones and increase the intensity of occupation in many parts of the space. Concerning the hierarchical organization of spaces, the configuration changes strongly in the zone 1 and 2 where the settlement pattern seems to become more complex and the main habitats develop. The increased density of population there leads to an increase in the level of organization. Concretely, on the maps, this phenomenon is illustrated by the increase in the number of contexts occupied by level 3 and 5, which appear in sectors formerly characterized by level 1 and 2.

During the 3rd c. AD, the hierarchical structure of the spaces remains stable in zones 1 and 3 (fig. 7). In zone 2, the situation seems to evolve in the 3rd century. It shows a decrease in the representation of level 1 in favour of level 3. This evolution is due to the abandonment of certain isolated peripheral habitats but also to the densification of sectors already occupied where they are set up. New small sets emerge, composed of small and medium-sized villas. The process of increasing the level of structuring of the settlement, which seems already to have been accomplished in zones 1 and 3, thus seems to continue in zone 2. Finally, note that where occupation is most intense, the level of hierarchical organization is high.

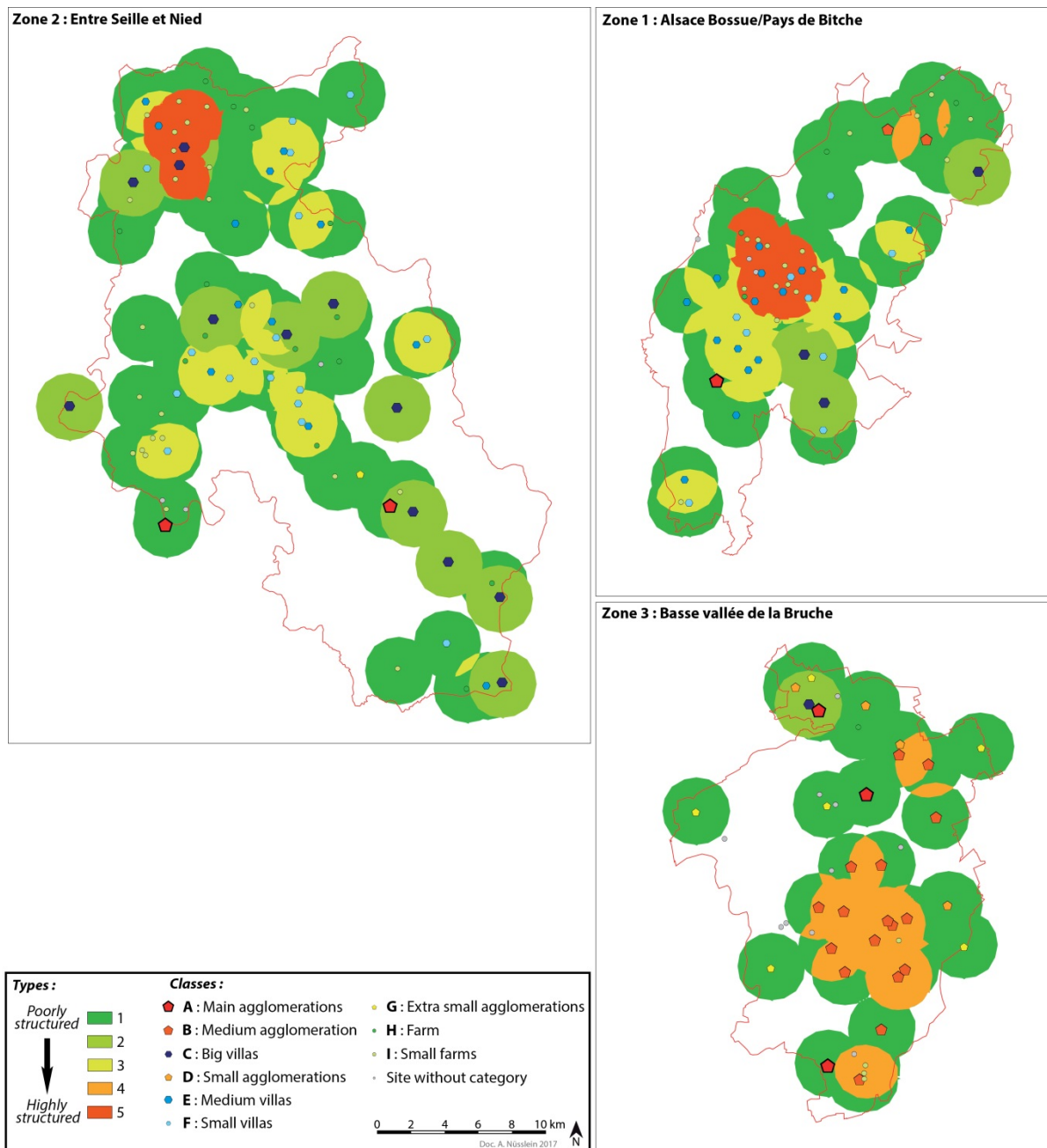


Fig. 7. Maps of the hierarchical-functional structure for the 3rd century AD.

In the 4th c. AD, settlement systems change with an apparent decrease (fig. 8). The peripheral spaces are abandoned and the most intensively exploited and structured sectors are

abandoned. However, some densely occupied areas, where large habitats are located, remain busy. Maps of the hierarchical-functional structure of the settlement system, show that overall, in all micro-regions, the settlement system apparently becomes less complex and the level of structuring of the spaces diminishes. However, where large villas subsist, the settlement seems to resist better.

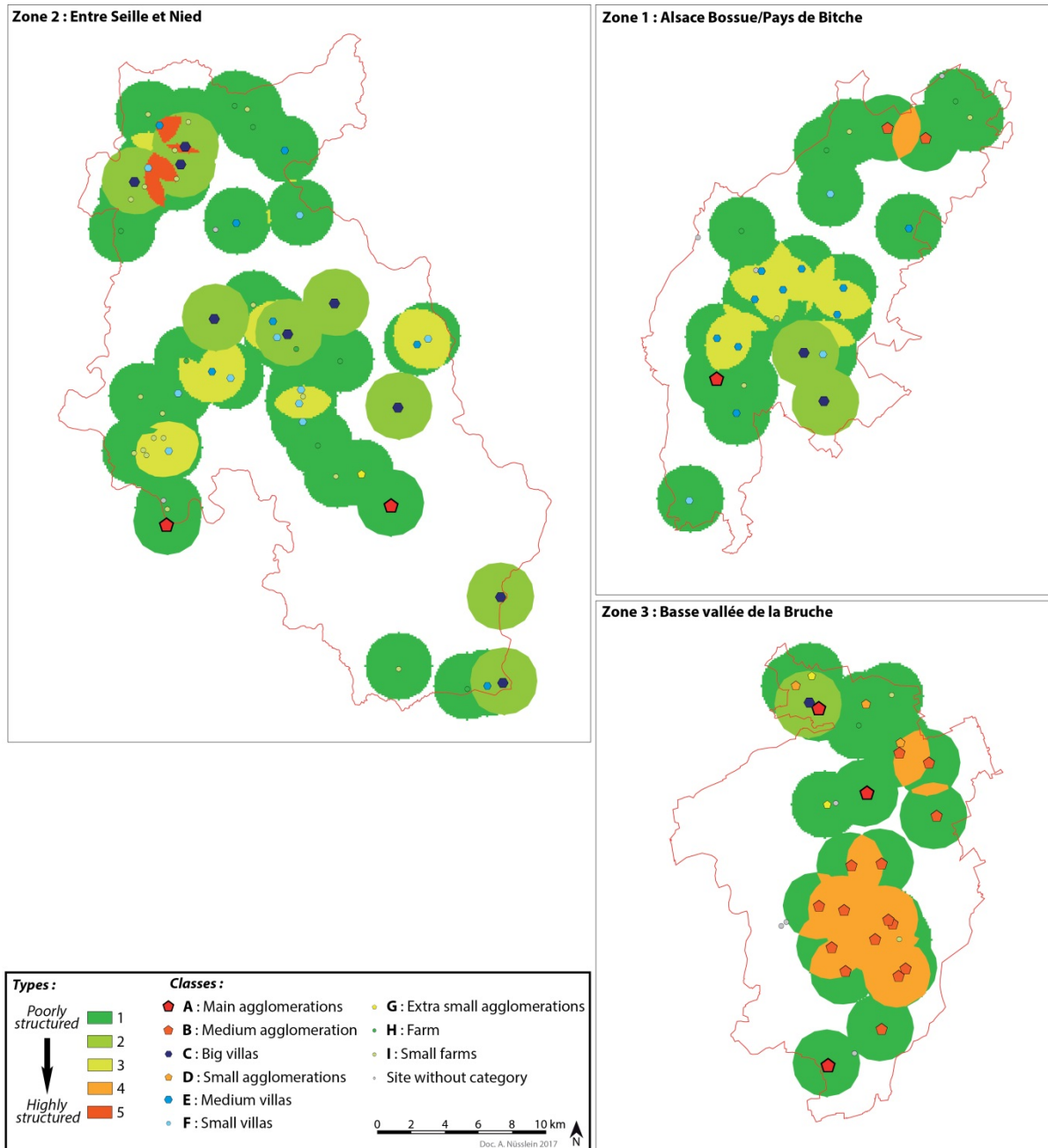


Fig. 8. Maps of the hierarchical-functional structure for the 4th century AD

4.2. RESULTS OF SITE LOCATION ANALYSIS AND PREDICTIVE MODELLING USING GEO-ENVIRONMENTAL FACTORS

In order to test the relevance of this variable and to see its importance, we first apply the protocol only with geo-environmental factors. The classification is composed of six classes of environmental contexts, ordered from 'warm' to 'cold' (table 3, fig. 9). Here we present only

the results for the three micro-regions presented in this paper. The comparisons are based on an analysis of the full dataset, so including both existing and new settlements.

For zone 1, the model has a low maximum relative gain for all settlements dated in Antiquity (= the whole Roman period; 7.2%). Thus, there is no evidence of geo-environmental determinism according to this index. Indeed, we observe that there are no really attractive or repulsive contexts. However, for settlements dated per century, the model presents better predictive values than for all settlements, but the maximum gain values remain low. Overall, it is interesting to note that the evolution of the maximum gain shows that when the population increases, the spatial distribution of habitats in the contexts becomes more homogeneous and when the numbers decrease, the differences become more significant.

The model presents a higher predictive value for all settlements from Antiquity in zone 2 than in zone 1. The choice is more pronounced. This sector also has a different geo-environmental profile from the other micro-regions. This illustrates the existence of different strategies in the two micro-regions.

In zone 3, the model has a greater maximum relative gain than recorded in the other micro-regions for all settlements dating in Antiquity (23.6%). Apart from the fact that context 2 is the most attractive one during almost the whole of Antiquity, the strategy adopted by the settlements of this zone is different from what was observed for the other micro-regions. The choices here are more marked and remain virtually the same throughout the period studied. Despite the increase or decrease in the number of establishments, the predictive values do not change and the preferentially exploited environments remain the same.

To conclude, we can see that the model based on geo-environmental factors has a low predictive value for two of the three micro-regions. It does not show a very clear influence of geo-environmental factors for site location in the Roman period, which confirms the results obtained in our earlier studies (Nuninger et al. 2012b).

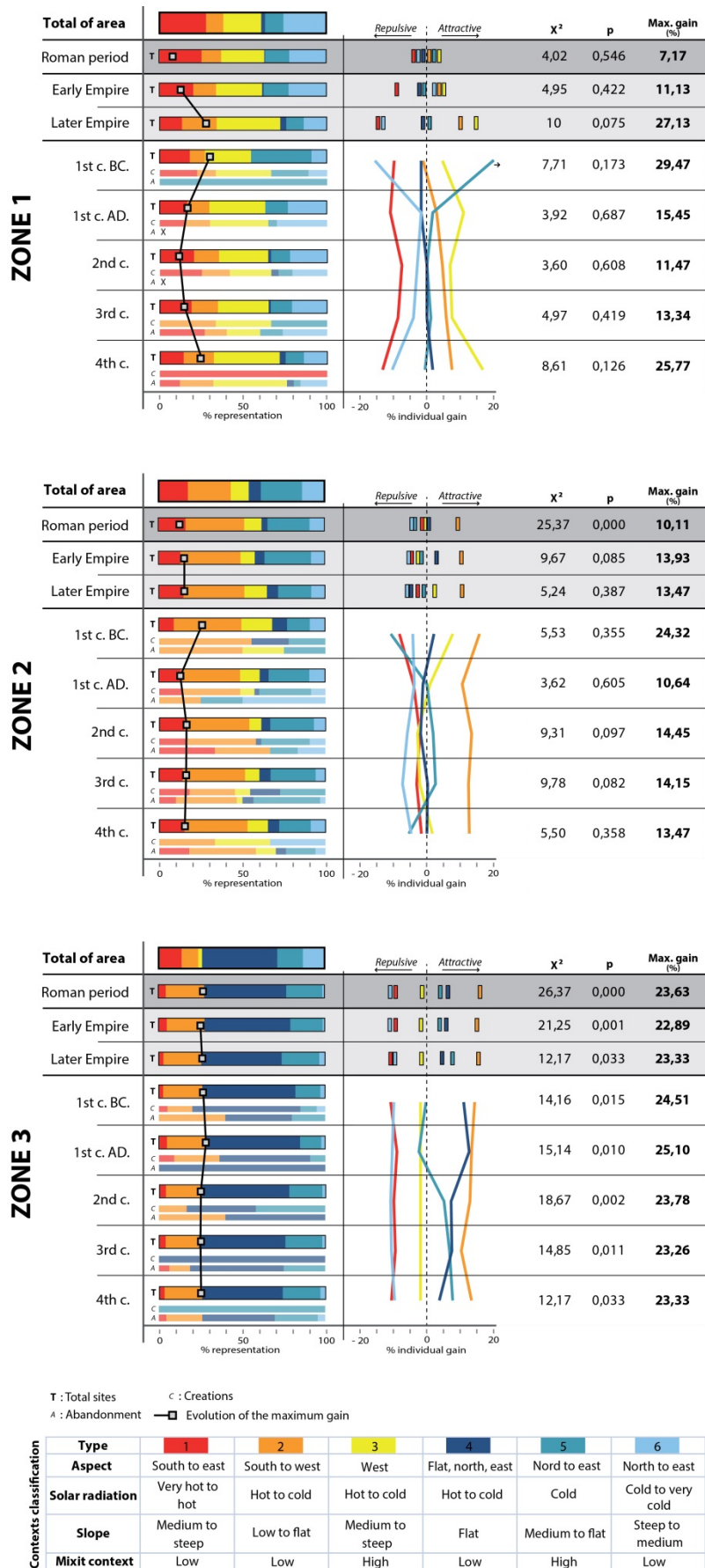


Fig. 9. Results for the geo-environmental factors.

4.3. RESULTS WITH THE MAP OF HIERARCHICAL STRUCTURE

Next, we applied the protocol for the variable 'hierarchical structure' (fig. 10). Here, the comparisons are based on an analysis of the newly created settlements.

In micro-region 1, in the 1st c. AD, the settlements are established in the areas previously occupied by types 1 and 3. In the 2nd century there is an increase in the maximum relative gain. This is due to the fact that a large number of new sites are established in an environment that is moderately structured (type 3) and which becomes very attractive. In the 3rd century the choices become even more pronounced as the most structured spaces (type 5) are preferred. Overall, structured occupancy types (types 5 and 3) are more attractive than contexts with low levels of structuring (types 1 and 2). In the next century, the situation is somewhat balanced because of the numerous abandonments that occur in types 3 and 5. The sectors occupied by these two types are nevertheless more attractive than the other categories.

In zone 2, at the beginning of Antiquity, the areas characterized by moderately structured contexts attract most settlements (types 2 and 3). In the 2nd c. AD, the maximum relative gain is increasing, and new settlements always favour contexts that were weakly to moderately structured in the previous century. In the 3rd century, contrary to what can be observed in zone 1, the settlements do not necessarily prefer a location in the sectors that were most hierarchical in the previous century. In the following period, the situation changes little. Nevertheless, the less hierarchical contexts are now less attractive, the settlements preferring to remain in environments characterized by types 3 and 5.

In zone 3 in the 1st c. AD, new settlements are predominantly found in contexts that do not have the highest structuring values (types 1 and 2). The most attractive category nevertheless gathers contexts of type 4. In the next century, the less structured environments of type 1 become repulsive. During the 3rd century, type 4 decreases but the situation is not changing very much. However, in the 4th century, the maximum relative gain increases because of numerous abandonments in the zones with type 1. Habitats thus refocus in contexts that are most structured.

To conclude, these analyses clearly confirm the importance of this variable that has strong predictive power. There are also differences between micro-regions and types of hierarchical structuration. In zone 1, the structured sectors strongly attract settlement in the early Roman period. This attraction becomes less marked later and the situation tends to balance. In zone 2, the choices are less pronounced, and it is found that the settlements located in the most structured areas, that is, the areas dominated by the main settlements, are more resistant during Late Antiquity. In zone 3, settlements favour an establishment on the most structured forms of occupation, throughout the whole of the Roman period.

It should also be noted that this variable seems to play an important role in the internal development of sites. Indeed, we have seen from other analyses that the sites, installed at the beginning of the Roman period and which will later find themselves in a structured hierarchical context, will evolve more strongly. Conversely, small sites that set up later in such context will evolve very little, but they will be more sustainable.

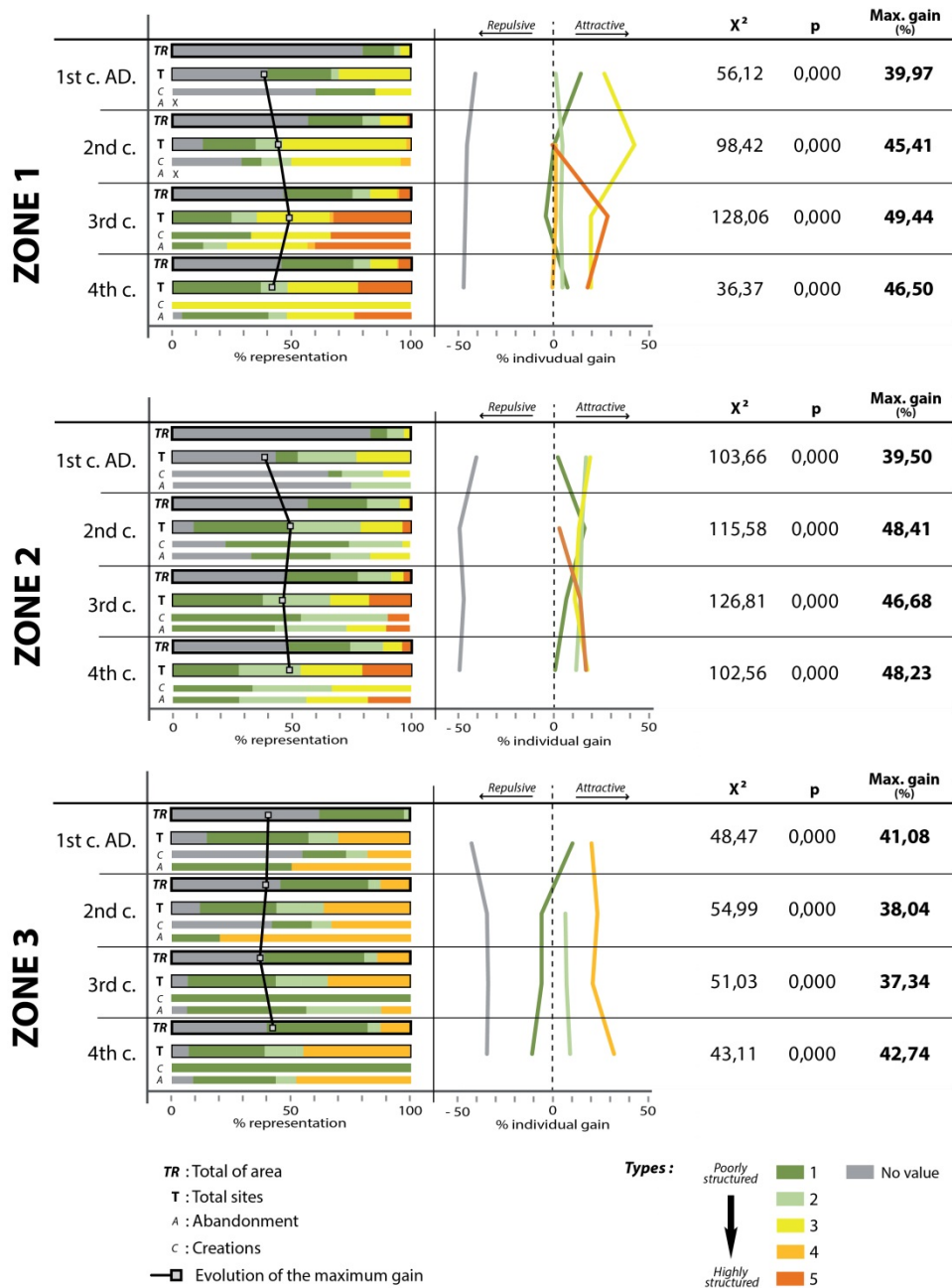


Fig. 10. Results for the socio-environmental factors based on the map of the hierarchic-functional structure.

5. CONCLUSION

The results of this research highlight the diversity of habitat types, spatial patterns and dynamics between Rhine and Moselle during the Roman Period. The study clearly shows that socio-environmental parameters have a very important influence on the trajectory of sites and on the development of the settlement patterns.

More generally, the study presented in this paper shows the importance of taking socio-environmental variables into account in site location analysis, the development of the sites studies, and predictive modelling studies. We want to emphasize, and this is one of the key elements we have highlighted in this study, that the evolution of settlements patterns depends

not only on geo-environmental conditions, but that socio-environmental parameters have a very important influence on the societies we are studying. Concerning the way forward, we believe that the variable "map of hierarchical structure" can be further improved and made more efficient. A next step is to integrate this variable directly with other geo-environmental and socio-cultural parameters in site location analysis.

For the moment, this study confirms the interest of predictive modelling tools to approach the complexity of settlement system trajectories. The method allows for diachronic and regional comparisons, but we have to test it at a larger level on many case studies.

REFERENCES

Archaeomedes 1998 *Des oppida aux métropoles, Archéologues et géographes en vallée du Rhône*. Paris: Anthropos.

Bertoncello, F, Fovet, E, Gandini, C, Trément, F and Nuninger, L 2012a Spatio-temporal dynamics of settlement patterns in central and southern Gaul from 800 BC to 800 AD: models for long-term interregional comparison. In: Gandini, C, Favory, F, and Nuninger, L (eds.) *Settlement Patterns, Production and Trades from the Neolithic to the Middle Ages. ARCHAEDYN, Seven Millennia of Territorial Dynamics, Final Conference, Dijon, 23-25 june 2008*. Oxford: Archaeopress. pp. 51–64.

Bertoncello, F, Fovet, É, Tannier, C, Gandini, C, Lautier, L, Nouvel, P and Nuninger, L 2012b Configurations spatiales et hiérarchiques du peuplement antique: des indicateurs quantitatifs pour une confrontation interrégionale. In: Bertoncello, F and Braemer, F (eds.) *Variabilités environnementales, mutations sociales: actes des XXXIIèmes rencontres internationales d'archéologie et d'histoire d'Antibes 20-22 octobre 2011*. Antibes: Éditions APCDA. pp. 175–190.

Favory, F 1989 Occupation des sols en Narbonnaise : présentation d'une pratique collective. *Archéologie en Languedoc*, 1989 (2/3): 29–35.

Favory, F, Fiches, J-L and Girardot, J-J 1987 L'analyse des données appliquée à la typologie des sites gallo-romains dans le Beaucairois (Gard) : matériel de prospection et environnement paysager : essai méthodologique. *Gallia*, 45: 67–85.

Favory, F and Fiches, J-L (eds.) 1994 *Les Campagnes de la France méditerranéenne dans l'Antiquité et le Haut Moyen Âge*. Paris: Éditions de la Maison des Sciences de l'Homme.

Favory, F, Girardot, J-J, Raynaud, C and Roger, K 1994 L'habitat gallo-romain autour de l'étang de l'Or (Hérault). Hiérarchie, dynamique et réseaux du IIe s. av. au Ve s. ap. J.-C. In: Mactoux, M-M and Geny, E (eds.) *Mélanges Pierre Lévêque*. Besançon: Les Belles-Lettres. pp. 123–215.

Favory, F, Girardot, J-J, Nuninger, L and Tourneux, F-P 1999 Archaeomedes : une étude de la dynamique de l'habitat rural en France méridionale, dans la longue durée (800 av. J.-C.-1600 ap. J.-C.). *AGER*, 9: 15–35.

Favory, F, Nuninger, L, Bertoncello, F, Fovet, É, Gauthier, E, Poirier, N, George-Leroy, M, Oštir, K, Saligny, K, Trément, F and Weller, O 2008 *ArchaeDyn. Dynamique spatiale du peuplement et ressources naturelles: vers une analyse intégrée dans le long terme, de la Préhistoire au Moyen Âge. ACI Espaces et territoires (contrat ET28, 2005-2007)*. Paris: Ministère Délégué à la Recherche et aux Nouvelles Technologies.

Favory, F, Ouriachi, M-J and Nuninger, L 2011 The Transformation of Rural Structures in Southern Gaul between the 1st Century BC and the 1st Century AD. The Case of Eastern Languedoc. In: Moosbauer, G and Wiegels, R (eds.) *Fines imperii - imperium sine fine? Römische Okkupations- und Grenzpolitik im frühen Prinzipat. Beiträge zum Kongress 'Fines imperii - imperium sine fine?' in Osnabrück vom 14. bis 18. September 2009*. Rahden: VML GmbH. pp. 157–184.

Favory, F, Nuninger, L and Sanders, L 2012 Integration of geographical and spatial archeological concepts for the study of settlement systems. *L'Espace géographique*, 41(4): 295–309.

Fiches, J-L 1987 L'espace rural antique dans le Sud-Est de la France : ambitions et réalités archéologiques. *Annales. Economies, Sociétés, Civilisations*, 42(1): 219–238.

Gandini, C, Bertoncello, F, Gauthier, E, Nuninger, L and Trément, F 2008 Hierarchical typology and settlement pattern modelling at micro-regional scale. In: Posluschny, A, Lambers, K and Herzog, I (eds.) *Layers of Perception. Proceedings of the 35th International Conference on Computer Applications and Quantitative Methods in Archaeology (CAA), Berlin, Germany, April 2–6, 2007*. Bonn: Dr. Rudolf Habelt GmbH. pp. 278//CD-rom. [online access at http://proceedings.caaconference.org/files/2007/84_Gandini_et_al_CAA2007.pdf last accessed 21 July , 2017].

Gandini, C, Favory, F and Nuninger, L (eds.) 2012. *Settlement Patterns, Production and Trades from the Neolithic to the Middle Ages. ARCHAEDYN, Seven Millennia of Territorial Dynamics, Final Conference, Dijon, 23-25 June 2008*. Oxford: Archaeopress.

Nuninger, L, Sanders, L, Favory, F, Garmy, P, Raynaud, C, Rozenblat, C, Kaddouri, L, Mathian, H and Schneider, L 2006 La modélisation des réseaux d'habitat: trois expériences. *Mappemonde*, 3(83): 1–28.

Nuninger, L, Tourneux, F-P and Favory, F 2008 From Archaeomedes to Archaeodyn. In:

Posluschny, A, Lambers, K and Herzog, I (eds.) *Layers of Perception. Proceedings of the 35th International Conference on Computer Applications and Quantitative Methods in Archaeology (CAA), Berlin, Germany, April 2–6, 2007*, Bonn: Dr. Rudolf Habelt GmbH. pp. 272–277. [online access at http://proceedings.caaconference.org/files/2007/83_Nuninger_et_al_CAA2007.pdf last accessed 21 July 2017].

Nuninger, L, Bertoncello, F, Favory, F, Fiches, J-L, Raynaud, C, Girardot, J-J, Mathian, H and Sanders, L 2012a. Peuplement et territoire dans la longue durée: retour sur 25 ans d'expérience. In: Archambault De Beaune, S and Francfort, H-P (eds.) *L'archéologie en mouvement : hommes, objets et temporalités*. Paris: CNRS éditions Alpha. pp. 150–157.

Nuninger, L, Verhagen, P, Tourneux, F-P, Bertoncello, F and Jeneson, K 2012b Contextes spatiaux et transformation du système de peuplement : approche comparative et prédictive. In Bertoncello, F and Braemer, F (eds.) *Variabilités environnementales, mutations sociales: actes des XXXIIèmes rencontres internationales d'archéologie et d'histoire d'Antibes 20-22 octobre 2011*. Antibes: Éditions APCDA. pp. 139–154.

Nuninger, L, Saligny, L, Oštir, K, Poirier, N, Fovet, É, Gandini, C, Gauthier, E, Kokalj, Ž, Tolle, F and Zakšek, K, 2012c *Models and tools for territorial dynamic studies (chapter 1)*. In: Gandini, C, Favory, F and Nuninger, L (eds.) *Settlement Patterns, Production and Trades from the Neolithic to the Middle Ages. ARCHAEDYN, Seven Millennia of Territorial Dynamics, Final Conference, Dijon, 23-25 June 2008*. Oxford: Archaeopress. pp. 23-38.

Nuninger, L, Verhagen, P, Bertoncello, F and Castrorao Barba, A 2016 Estimating “land use heritage” to model changes in archaeological settlement patterns. In: *LAC 2014 proceedings* [online]. Amsterdam: Vrije Universiteit. [online access at <http://dx.doi.org/10.5463/lac.2014.60> last accessed 21 July 2017].

Nüsslein, A 2016a *Les campagnes entre Moselle et Rhin dans l'Antiquité. Analyse comparative des dynamiques spatiales et temporelles du peuplement de quatre micro-régions du 1er s. av. J.-C. au Ve s. ap. J.-C.* PhD thesis (unpublished). Strasbourg: University of Strasbourg.

Nüsslein, A 2016b Nuancer et améliorer l'analyse des systèmes de peuplement basée sur les données de prospection pédestres: l'étude de la dynamique d'occupation antique du Plateau Lorrain. *Archeologia e Calcolatori*, 27: 47–64.

Raynaud, C 1989 Archéologie du paysage autour de l'Étang de l'Or (Hérault). Choix, contraintes et méthode de prospection. *Archéologie en Languedoc*, 1989 (2/3): 59–83.

Tourneux, F-P 2000. *Modes de représentation des paysages*. PhD thesis (unpublished). Besançon: University of Franche-Comté.

Van der Leeuw, S E (ed.) 1998. *The Archaeomedes Project - Understanding the natural and anthropogenic causes of land degradation and desertification in the Mediterranean*. Luxembourg: Office for Official Publications of the European Union.

Van der Leeuw, S E, Favory, F and Fiches, J-L (eds.) 2003. *Archéologie et systèmes socio-environnementaux: études multiscalaires sur la vallée du Rhône dans le programme Archaeomedes*. Paris: CNRS Editions.

Van der Leeuw, S E and the ARCHAEOMEDES research team 2005 Climate, hydrology, land use, and environmental degradation in the lower Rhone Valley during the Roman period. *Comptes Rendus Geoscience*, 337(1): 9–27.

Verhagen, P 2007 Predictive models put to the test. In: Verhagen P. (ed) *Case Studies in Archaeological Predictive Modelling*. Leiden: Leiden University Press. pp. 115-168.

Verhagen, P, Nuninger, L, Bertoncetto, F, Tourneux, F-P and Jeneson, K 2013a Introducing the human factor in predictive modelling: a work in progress. In: Earl, G, Sly, T, Chrysanthi, A, Murrieta-Flores, P, Papadopoulos, C, Romanowska, I and Wheatley, D (eds) *Archaeology in the Digital Era. Papers from the 40th Annual Conference of Computer Applications and Quantitative Methods in Archaeology (CAA), Southampton, 26-29 March 2012*. Amsterdam: Pallas Publications. pp. 379–388 [online access at <http://www.jstor.org/stable/j.ctt6wp7kg> last accessed 21 July 2017].

Verhagen, P, Brughmans, T, Nuninger, L and Bertoncetto, F 2013b. The long and winding road: Combining least cost paths and network analysis techniques for settlement location analysis and predictive modelling. In: Earl, G, Sly, T, Chrysanthi, A, Murrieta-Flores, P, Papadopoulos, C, Romanowska, I and Wheatley, D (eds) *Archaeology in the Digital Era. Papers from the 40th Annual Conference of Computer Applications and Quantitative Methods in Archaeology (CAA), Southampton, 26-29 March 2012*. Amsterdam: Pallas Publications. pp. 357–366. [online access at <http://www.jstor.org/stable/j.ctt6wp7kg> last accessed 21 July 2017].

Verhagen, P, Nuninger, L, Bertoncetto, F and Castrorao Barba, A 2016 Estimating the “memory of landscape” to predict changes in archaeological settlement patterns. In Campana, S, Scopigno, R, Carpentiero, G and Cirillo, M (eds.) *CAA2015. Keep the Revolution Going. Proceedings of the 43rd Annual Conference on Computer Applications and Quantitative Methods in Archaeology*. Oxford: Archaeopress. pp. 623–636 [online access at

<http://www.archaeopress.com/Public/download.asp?id={77DEDD4E-DE8F-43A4-B115-ABE0BB038DA7> last accessed 21 July 2017].

Wansleben, M and Verhart, L B M 1992 The Meuse Valley Project : GIS and site location statistics. *Analecta Praehistorica Leidensia*, (25): 99–108.

FIGURES AND TABLES

Fig 1. Map of the study areas in Alsace and Lorraine.

Fig 2. Typological-functional hierarchy of the settlements.

Fig 3. Protocol for the map of hierarchic-functional structure of the settlement system.

Fig 4. Different combinations of the indices of hierarchical variety and range showing different levels of hierarchical organization of settlement patterns (after Fovet in Nuninger et al. 2012c).

Fig 5. Categories of the hierarchical-functional contexts, ranked from 1 to 5.

Fig 6. Maps of the hierarchic-functional structure for the 1st century AD.

Fig 7. Maps of the hierarchic-functional structure for the 3rd century AD.

Fig 8. Maps of the hierarchic-functional structure for the 4th century AD.

Fig 9. Results for the geo-environmental factors.

Fig 10. Results for the socio-environmental factors based on the map of the hierarchic-functional structure.

Table 1. Variables used to create the hierarchic-functional typology of the settlements (Nüsslein 2016a).

Table 2. Categories of the hierarchical-functional context ranked according to their level of hierarchical organization, from unstructured to very structured.

Table 3. Categories of geo-environmental context.