

# Estimating “Land Use Heritage” to Model Changes in Archaeological Settlement Patterns

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## **Abstract**

This paper describes a method to calculate a “land use heritage map” based on the concept of “memory of landscape”. Such a map can be seen as one variable among many others that can influence site location preference and can be used as input for archaeological predictive models. The computed values equate to an index of long-term land use intensity. This index aims to assess the influence of previous occupation of the landscape on settlement location, in particular Roman rural settlements. The method was applied on a micro-region located in Southern France in order to test its workability. It is concluded that the method is potentially suitable for incorporating the influence of previous occupation in predictive modelling but still needs further refinement in order to be more generally applicable.

**Keywords:** Predictive Modelling, Path Dependency, Land Use, Roman Rural Settlement, Kernel Density Estimates

## **Introduction: What would be the Best-Suited Location in a Landscape?**

What would be the best-suited location in a landscape for a Roman rural settlement? Would it be an environment that was never settled, offering the best soils and an advantageous topographic position; a site that was occupied before offering, for example, building materials that were left behind; or an environment that had already been adapted by clearances, parcellation or soil improvements? Despite many attempts over the last 40 years to explain location preferences of ancient rural settlements, these questions remain relevant as no clear answer has appeared (Favory & Fiches, 1994; Gaffney & Stančič, 1991; Goodchild, 2007; Greene, 1986; Kay & Witcher, 2009). Most of the studies to date have used general considerations, whether environmental, political, cultural or climatic, to explain settlement patterns and evolutions. But regional studies based on large and systematic surveys show a complex picture, describing various situations, varying

over time and geographical space (Nuninger, Tourneux & Favory, 2008; Van der Leeuw, Favory & Fiches, 2003). Analysing the weight of various environmental and social factors with a cross-cultural approach, in order to understand site location preferences, remains a great challenge for a better understanding of past territories.

The IHAPMA project *Introducing the human (f)actor in predictive modelling for archaeology* (Nuninger et al, 2012a; Verhagen et al, 2013) aimed to perform cross-regional comparisons of settlement location choices by analysing the environmental context of rural Roman settlements in two areas of Southern France and in the region of Zuid-Limburg in the Netherlands. We developed a protocol for site location analysis and predictive modelling using both environmental and socio-cultural factors that can be easily implemented for different regions and time periods. The “socio-cultural” factors we used are potential path density (Verhagen et al, 2013), visibility and previous occupation of the site. Each variable is part of the global predictive model.

In this paper, we will focus on the sub-model developed to compute a map of land use intensity per time slice of one century. Considering that the occupation of archaeological settlements also reflects human investment in the surrounding area, we have used the concept of “memory of landscape” with a very basic meaning. When rural communities settle somewhere, they reshape the landscape by delimiting parcels, clearing woodlands, draining wet areas, improving the quality of the soil, etc. We can therefore assume that the duration of rural settlement occupation is an index of long-term land use intensity, which may be considered as an opportunity for new settlers to benefit from these previous investments. This index is calculated in the sub-model for every location of the studied areas using a kernel operator. The resulting map of land use heritage is included in the global predictive model as a variable. The aim is to estimate the weight of social investment in the landscape and its effect on subsequent settlement location choices.

After a general overview of the research context, the paper will focus on the sub-model used to compute the map of land use heritage. We will then discuss the results and explore the perspective for a comparative approach.

## **Research Context: Prior Occupation, Neighbourhood Legacy and Land Use Heritage**

### **Prior Occupation and Neighbourhood Legacy**

Many archaeological rural sites in France (from the second century BC to the seventh century AD) show a discontinuous occupation with clear phases of abandonment before reoccupation after one or more generations add one reference: (Ouzoulias et al, 2001). While the site itself might not be reoccupied, new settlements might be created in its surroundings, in the area that was previously exploited. This type of historical pattern came to light through field surveys in the 1980s and was more recently proven by extensive rescue excavations, for example in Northern France. These discoveries highlight a certain continuity of land use, even if some settlements are abandoned. New occupations and new landscape structures may indicate socio-economic change or new ways of life (Hamerow, 2012) but the successive occupations in the surrounding of a former settlement point to a higher value of managed landscapes. As such, the surroundings are not only a set of natural characteristics that are more or less interesting for a community to settle but they become a real landscape, i.e. an historical object, which includes the investments of previous generations on the land. From this point of view we can think in terms of “memory of landscape”, considering that past activities are embedded in the land used by generations of people and recognised as a heritage by contemporaneous communities.

Based on these ideas, C. Raynaud defined two variables to describe the capacity of settlements to perpetuate themselves through time (within

the context of the *Archaeomedes Project*; Durand-Dastès et al, 1998). Here, a settlement is defined as one phase of occupation of a single site. It means that for one archaeological site with multiple periods of occupation, we record as many settlements as there are periods of continuous occupation, separated by a demonstrated abandonment of the site (Nuninger et al, 2012b). The first variable, “prior occupation”, aims to measure, at a defined location, the impact of an occupation in the century or centuries preceding the implantation of a new settlement. The ability of a settlement to benefit from the investments made by prior occupants is assessed, both in built spaces (e.g. the re-use of walls, levelled ground, or other built structures) and in rural space (e.g. the re-use of or benefit from roads, water supply, earthworks, stone removal, soil improvements, etc.). The second variable, “neighbourhood legacy”, aims to calculate the degree of human investment in the space surrounding a settlement. For each settlement, the sum of the duration of occupation of all the settlements found within an area of 500 m radius around the studied settlement is then calculated (fig. 1). Although the obtained numerical values are entirely relative, they are good indicators to assess and compare the degree of opportunism in the development of a geographic area. “Prior occupation” and “neighbourhood legacy” were used to classify settlements in order to distinguish “pioneering” ones, which are created in empty areas, from “opportunistic” settlements, which re-occupy places previously occupied, with a modulation of their degree of opportunism according to the temporal distance separating them from the previous occupation (Favory et al, 1999).

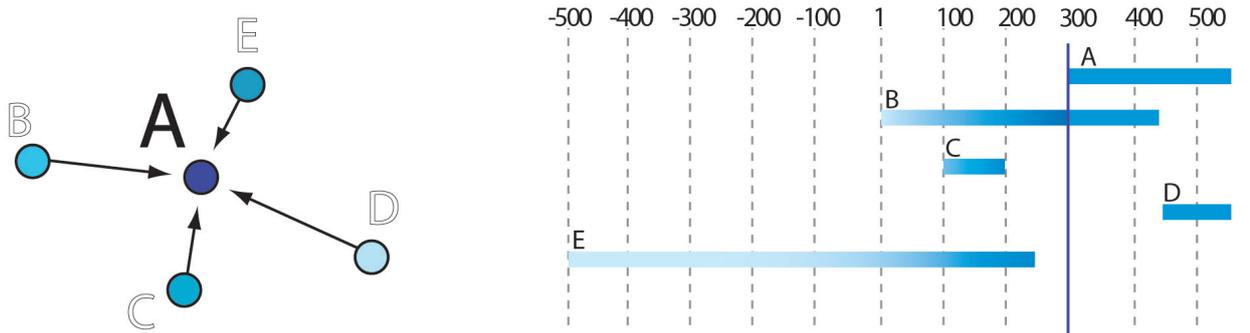
## The Concept of “Heritage” and Predictive Modelling

Departing from the concept of “neighbourhood legacy”, we defined the concept of “land use heritage”. The differences between both concepts are threefold. First, the heritage variable is not site-based but cell-based. It means that not only

the sites but also each location in the landscape is described by a value representing the intensity of previous occupation in its surroundings. Second, the weight of the land use heritage value decreases with the distance within the calculation radius. And third, the weight of the land use heritage value is also time-dependent: a previous settlement deserted several centuries before the beginning of the period under study will have a lower impact on the heritage value than a settlement still in use just before the time period under consideration.

This concept provides an opportunity to reconsider predictive models (PM) and their heuristic power for settlement pattern characterisation over time. Predictive modelling methods were often criticised in the past because of the dominance of environmental characteristics, which was considered reductionist and in a way “effectively de-humanising the past” (Wheatley, 2004). In addition, PM were considered to be anti-historical since the correlation between behaviour and environmental characteristics is taken into account as a contemporary phenomenon, while “in reality, the behaviour and activities that structure the spatial patterns in archaeological landscapes are just as much a product of historical as contemporary factors” (Wheatley, 2004). And lastly, PM were criticised because it is “concerned only with sites and fails to take broader theoretical developments about off-site activity into account” (Kay & Witcher, 2009).

In our view, using the value of “land use heritage” as a socio-environmental factor in PM offers a new way to “re-humanise” the past and to take into account the historical process of pattern construction. Indeed, for each location in the landscape at a certain point in time, we assume that settlement location preferences are not only guided by natural advantages but by previous human investment to improve soils for agro-pastoral activities consequently making it more attractive for a community to settle. The historical process is effectively taken into account as the model uses, for each period of one century, the previous occupations as a variable. We need to highlight here the importance of a good database



$$\begin{aligned}
 B &= 100 \times 1 + 100 \times 0.8 + 100 \times 0.6 \\
 &= 240 \\
 C &= 100 \times 0.8 \\
 &= 80 \\
 D &= 0 \\
 E &= 50 \times 1 + 100 \times 0.8 + 100 \times 0.6 + 100 \times 0.4 + 100 \times 0.2 + 100 \times 0 \\
 &= 250
 \end{aligned}$$

Fig. 1. Calculation of the temporal weighting of “land use heritage” for a hypothetical settlement A. The duration of occupation of each settlement within A’s surroundings is weighted according to the temporal distance, and then summed to a total value of land use heritage of  $240 + 80 + 250 = 570$  for settlement A.

cultural considerations. Such a choice can be debated but in this case it is justified by the objective to perform inter-regional and diachronic comparisons which must be based on a common analysis protocol.

### Specifying the Computation Model

to define such a variable, with a high spatial (systematic field surveys) and chronological resolution (precision of the settlements’ dating).

It is important to note that PM are used here as a tool to explore the archaeological data in order to assess the factors influencing the location choice of rural settlements and their ability to perpetuate. Under no circumstances, should the IHAPMA PM be considered as a tool to predict the presence of archaeological sites for heritage management purposes. In addition, we have to specify that no ideas of social transmission are embedded in the concept of “land use heritage”. This variable is one index among others that can be used to qualify landscape without any

Within the surroundings of a location A, a number of settlements (B-E) are found, dating from various periods (fig. 1). Basically, for location A, the “heritage” is a function of the geographical distance to the previous occupations located in the neighbourhood, i.e. B, C, D and E, as well as the duration of these previous settlements. The value of “land use heritage” for A will be the same as its “neighbourhood legacy”, unless geographical distance and duration of occupation are weighted (see below). The model not only takes settlements into account but is embedded in the whole landscape since each location can be considered as a potential place to settle.

Gaussian function	$K(u) = \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}u^2}$
Epanechnikov-function	$K(u) = \frac{3}{4}(1 - u^2) \mathbf{1}_{\{ u  \leq 1\}}$

Fig. 2. Explanation of Gaussian and Epanechnikov-Functions.

## Kernel Density Map: Land Use Heritage Map

In order to compute the value of “land use heritage” for each location in the landscape, i.e. for each cell of a grid representing the studied area, we have used a moving window with a kernel density function. For each input cell location a statistic of the values within a specified neighbourhood around is computed based on the “neighbourhood legacy” calculation. This radius was originally fixed at 500 m, i.e. about 80 hectares. This value was arbitrarily chosen and represents a surface of exploited landscape that is considered large enough for the subsistence needs of an average Roman settlement.

According to ethnographic literature, and assuming a farming system based on fallow and light animal traction, a radius of 500 m is enough to feed a small group of fifteen people including an infield of eighteen hectares and an outfield of 60 hectares (Mazoyer & Roudart, 1997). Historical texts provide references on various sizes of landholdings in Antiquity according to periods or type of production (e.g. Goodchild, 2007). Generalisations based on the classification of plot size made by White (1970) point out that a 500 m radius is the maximum for a smallholding, having an area of between 10-80 *iugera*, i.e. between 2.5 and 20 hectares, of infield. Following these references, from a theoretical point of view, one can consider that a 500 m radius is likely to capture on average the area landscaped by the average size of site found in most of the areas studied (Gandini et al, 2008; Van der Leeuw, Favory & Fiches, 2003).

For the creation of a new settlement we have to consider the potential attractiveness of the degree of anthropisation as well as potential competition for the land. In other words, if the occupation of location continues, then in theory a new settlement B cannot be established on this location. Nevertheless, settling in the surroundings of an area with a high degree of anthropisation potentially offers better opportunities to develop a new exploitation because it can benefit from the landscaping created by previous occupations. While the “neighbourhood legacy” variable is binary, making a clear distinction between the area theoretically exploited and its surroundings, in our model we introduce a “fuzzy” logic, considering that the benefits of investment will decrease proportionally to the distance to the area previously exploited. From a practical point of view, we have modelled this principle using a distance decay function within a double radius, i.e. 1000 m, corresponding to the area exploited and its surroundings.

## Spatial Weighting

The calculation of the degree of investment weighted to distance was achieved by using a non-linear distance decay function within a 1000 m radius around each location of the map, i.e. each grid cell. The distance decay function was implemented in the model using a kernel matrix. This kernel matrix was defined using a Python script based on classical kernel weighting functions used in non-parametric estimation techniques (Silverman, 1986). Two functions were tested, the Gaussian and the Epanechnikov-function as described by Silverman (1986: function 4.5; fig. 2).

The application of the Gaussian function tends to emphasise the location of the previous occupation instead of its context. In this way, the legacy variable corresponds more to the variable “prior occupation” on the same location. The Epanechnikov-function is producing a slightly larger smooth surface around each location with a rapid fall-off on the edges. For a set of sites,

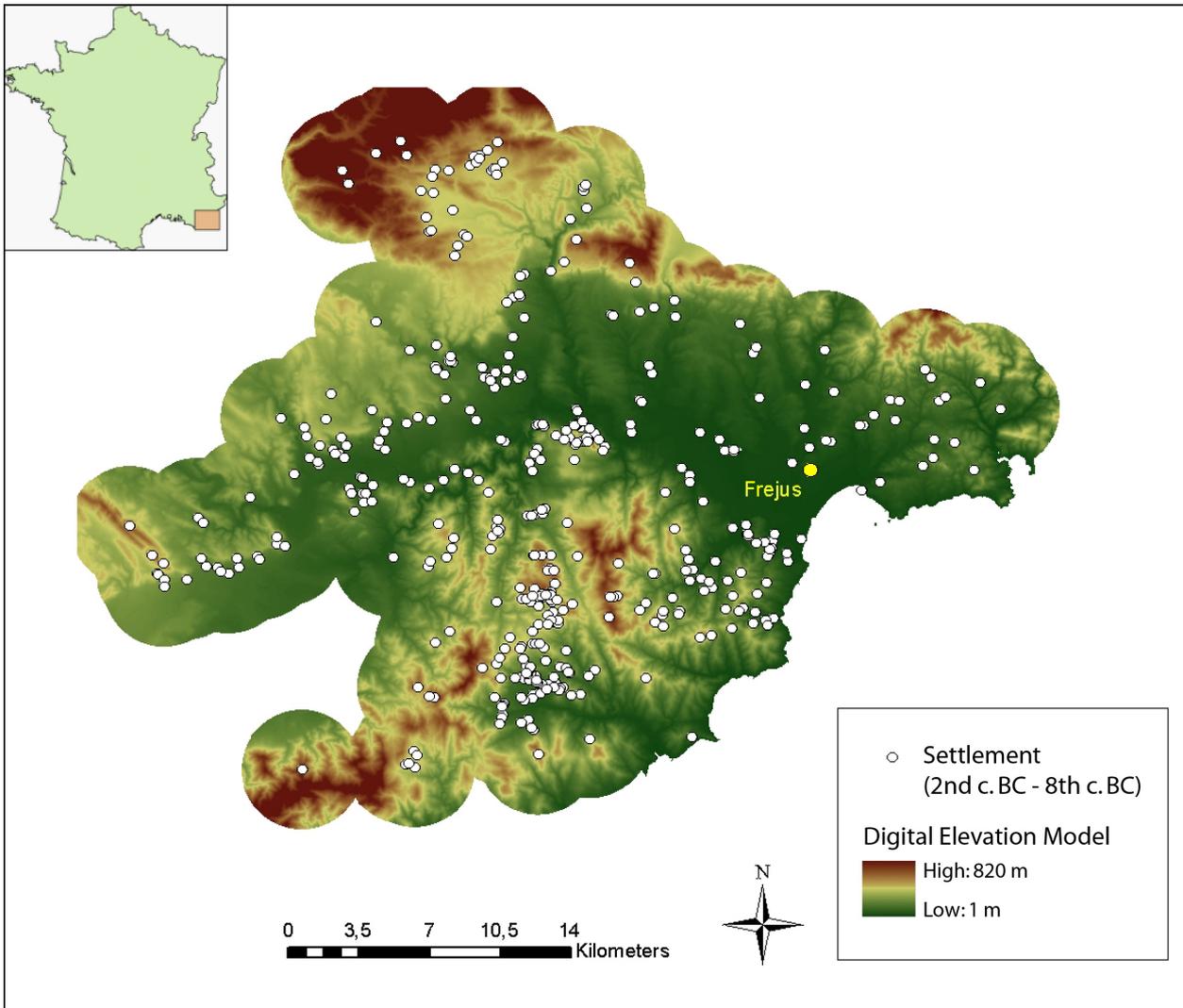


Fig. 3. Map of the Argens-Maures region (Var, France) with archaeological sites.

it produces larger smooth surfaces and fewer irregularities between sites. The choice of the Epanechnikov-function therefore seems better justified given the aim of the estimation of land use heritage. Indeed, we are more interested in the potential attractiveness of the landscape context of the site than of the site itself. In addition, in this approach, the sites are not considered to be self-sufficient. As such, they are considered as part of a network, managing and developing land for a community (Nuninger et al, 2012b; Favory,

Nuninger & Sanders, 2012). Assuming a continuity of land use between neighbouring sites, a surface density that is as regular as possible is better suited to our goals.

### Temporal Weighting

The original “neighbourhood legacy” variable defined the degree of human impact on the space surrounding the establishment studied as the sum of the lengths of time during which the area was occupied before the creation of the settlement under consideration. This calculation does not take into account the temporal distance of the previous

2nd century BC								
Heritage value	Observed new settlements	Expected new settlements	ps	pa	Chi square	Kvamme's gain	Indicative value	Relative gain
0	18	29,501	0,500	0,819	4,484	-0,64	0,61	-0,32
1	5	1,592	0,139	0,044	7,295	0,68	3,14	0,09
2	4	1,757	0,111	0,049	2,864	0,56	2,28	0,06
3	5	1,537	0,139	0,043	7,801	0,69	3,25	0,10
4	4	1,613	0,111	0,045	3,535	0,60	2,48	0,07
<b>Total</b>	<b>36</b>				<b>25,978</b>			
p-value					0,00003			
1st century BC								
Heritage value	Observed new settlements	Expected new settlements	ps	pa	Chi square	Kvamme's gain	Indicative value	Relative gain
0	35	49,817	0,522	0,744	4,407	-0,42	0,70	-0,22
1	10	4,011	0,149	0,060	8,944	0,60	2,49	0,09
2	8	4,501	0,119	0,067	2,721	0,44	1,78	0,05
3	6	4,192	0,090	0,063	0,780	0,30	1,43	0,03
4	8	4,480	0,119	0,067	2,766	0,44	1,79	0,05
<b>Total</b>	<b>67</b>				<b>19,619</b>			
p-value					0,00059			
1st century AD								
Heritage value	Observed new settlements	Expected new settlements	ps	pa	Chi square	Kvamme's gain	Indicative value	Relative gain
0	60	90,018	0,411	0,617	10,010	-0,50	0,67	-0,21
1	14	15,897	0,096	0,109	0,226	-0,14	0,88	-0,01
2	20	14,130	0,137	0,097	2,439	0,29	1,42	0,04
3	25	11,555	0,171	0,079	15,646	0,54	2,16	0,09
4	27	14,401	0,185	0,099	11,022	0,47	1,87	0,09
<b>Total</b>	<b>146</b>				<b>39,343</b>			
p-value					0,00000006			
5th century AD								
Heritage value	Observed new settlements	Expected new settlements	ps	pa	Chi square	Kvamme's gain	Indicative value	Relative gain
0	4	19,514	0,089	0,434	12,334	-3,88	0,20	-0,34
1	2	7,173	0,044	0,159	3,731	-2,59	0,28	-0,11
2	5	4,895	0,111	0,109	0,002	0,02	1,02	0,00
3	13	7,314	0,289	0,163	4,419	0,44	1,78	0,13
4	21	6,104	0,467	0,136	36,355	0,71	3,44	0,33
<b>Total</b>	<b>45</b>				<b>56,841</b>			
p-value					0,0000000001			

Tab. 1. This table shows, for each class of land use heritage, and for each analysed century, the number of observed new settlements compared to expected ones and their proportions (denoted  $p_s$  and  $p_a$ ). The Chi square value indicates the difference between observed and expected values, normalised by the expected ones. An increasing Chi square value indicates a higher degree of dependence between settlement creation and the land use heritage class. Its statistical significance is represented by the p-value. Three indicators of the strength of location preference are given in the last three columns: Kvamme's gain ( $1 - p_a/p_s$ ; Kvamme, 1988), indicative value ( $p_s/p_a$ ; Deeben et al, 1997) and relative gain ( $p_s - p_a$ ; Wansleben & Verhart, 1992).

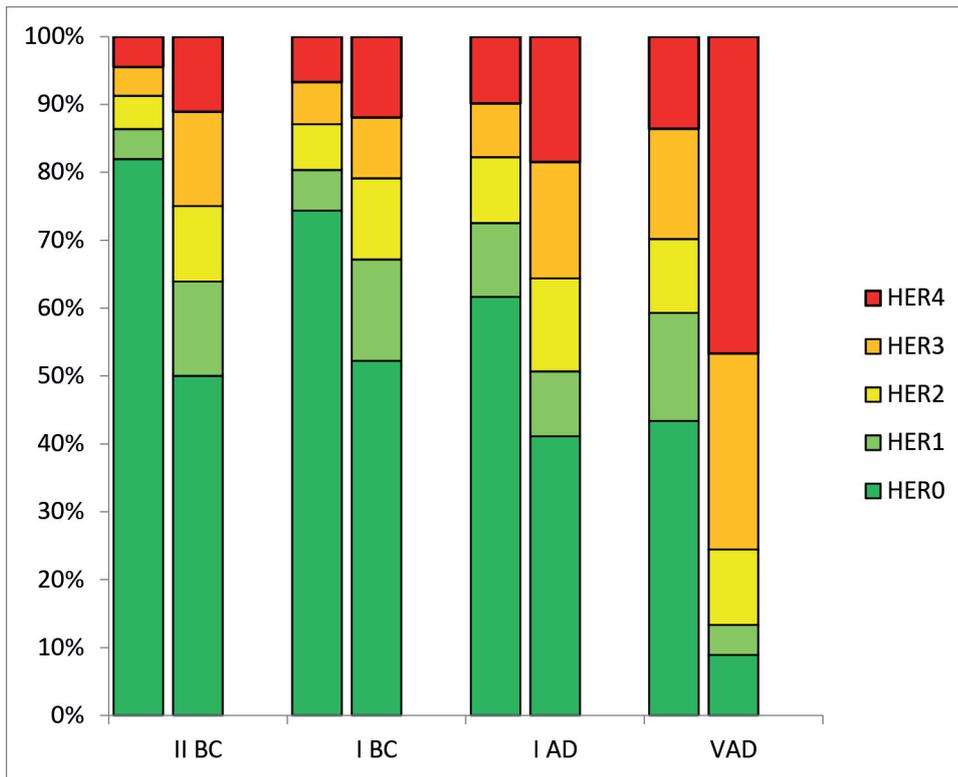


Fig. 4. Histogram comparing the expected (left bar) and observed (right bar) proportions of new settlements for each time period and heritage class.

occupations to the creation date of the settlement analysed (fig. 1). In other words, a settlement B that was occupied for one century four centuries before the beginning of the period under study will have the same legacy value as a settlement C that was occupied for one century in the century prior to the period under study. From a theoretical point of view, this would imply that time has no effect on managed landscapes, even if they are not maintained. However, since we are studying rural settlement within an agro-pastoral framework we assume that farmers worked the land, maintained terraces and cleared land, among other things. When the land is abandoned nature takes over and the value of land will decrease from an agro-pastoral point of view. To take into account this progressive degradation, each of the settlements B-E will be weighted according to its duration of occupation, relative to the start of settlement A's

occupation. The weight of duration will decrease by 0.2 per century, implying that after five centuries the influence of previous occupation will no longer be considered (fig. 1).

## Application and Results

The land use heritage model was tested on one of the French study areas: the Argens-Maures area in eastern Provence (Var) (fig. 3). This region was to a large extent systematically surveyed and the sites are dated sufficiently precisely to distinguish period ranges per century. The land use heritage value was computed for each century between the second century BC and the fifth century AD and corresponds to the heritage value at the very beginning of each century. Then, we reclassified the raw land use heritage value into five classes: HER0 - no heritage  
HER1 - low heritage  
HER2 - medium heritage  
HER3 - high heritage  
HER4 - very high heritage

In order to compare between periods and with other areas, the reclassification is based on the quantile method, for positive land use heritage values. As this will create similar statistical distributions for all periods, it is thus possible to compare the relative ranges of inherited land use intensity, whatever their absolute value.

To give an example of the results, we will first focus on the first century AD in the Argens-Maures area (tab. 1). 146 settlements were created during this century, and even while many of them (41%; fig. 4) are located in areas without land use heritage, the comparison between their expected and observed distribution per class of land use heritage shows a tendency to favour areas with high heritage values (HER3 and HER4). The relative gain for both classes is positive (0.09) whereas the "no-heritage" class shows a negative gain (-0.21). The exercise becomes more interesting when comparing locational preferences over time (fig. 4). Due to the drastic decrease in settlement creation after the first century AD, corresponding to a general tendency in Roman Gaul, it is not relevant to analyse the second, third and fourth century AD. The number of new settlements is too low to distinguish any statistically significant pattern.

Nevertheless, the experiment allows comparing the situation at both ends of the studied period. Whatever the century (second century BC, first century BC, first century AD, fifth century AD), new settlements are under-represented in no-heritage (HER0) areas (from -0.21 to -0.34 relative gain). Whereas the first century BC and first century AD show a gain of approximately -0.20, both ends of the period are more affected by this tendency (second century BC with -0.32 and fifth century AD with -0.34). However, the situation is different for areas with (very) high heritage values (HER3 and HER4). During the second century BC there is no clear tendency to favour areas with a high heritage value: the over-representation of new settlements in the areas of high heritage (HER3) is equivalent to their over-representation in low-heritage (HER1) areas (both with weak relative gains: respectively 0.10 and 0.09). The intensity of heritage does not seem

to greatly influence settling choices during the first century BC, except maybe towards the low-heritage areas (HER1) which are slightly favoured by the new settlements (relative gain 0.09). As noted above, the attractiveness of high- and very high-heritage areas increases during the first century AD. This becomes clearer during the fifth century AD where classes HER3 and HER4 show marked positive relative gains (0.13 and 0.33) whereas low-heritage zones are avoided (HER1: -0.11). For the whole period under study, the fifth century AD shows the strongest relative gain values, respectively negative and positive, both for no to low values of heritage (HER0 and HER1) and high to very high values of heritage (HER3 and HER4). The clear tendency to favour areas with high heritage is partly explained by the fact that 37.7% of the settlements created during the fifth century AD reoccupy previous settlements that were deserted, usually during the second century AD. But the newly created settlements (which do not reoccupy a previous settlement site) also show the same tendency to favour areas with high heritage values: 50% of them are created in a very high-heritage area (HER4) and 64% altogether in high or very high-heritage areas (HER3 and HER4). This observation reinforces previous observations made for the Languedoc region in Southern France (for the Medieval period (tenth-eleventh centuries AD); Fovet, 2005) where new settlements returned to landscape contexts already in use in previous periods. Despite the difference in time period, the same tendency has to be emphasised: settlement is anchored in specific zones, even if a potentially large extent of the landscape remains unoccupied. Indeed, in the Argens-Maures region, it is interesting to notice that the proportion of "virgin" areas (HER0) is very high whatever the period (never below 40% of the total area). These observations make the case for a reinforced process of path dependency at the end of the Roman period and Early Middle Ages. This process of path dependency could have started during the first century AD when new settlements tend to favour areas with high heritage values.

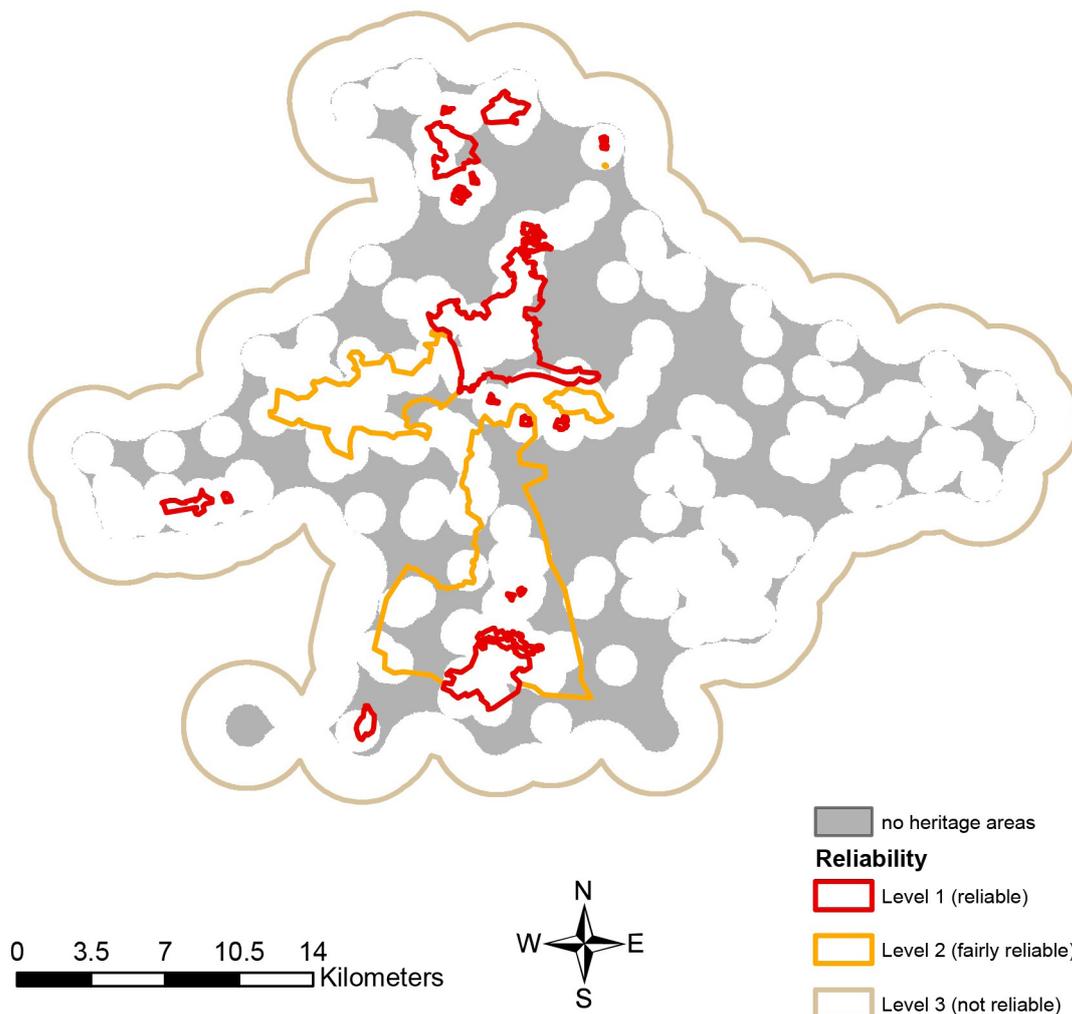


Fig. 5. Map showing the reliability of archaeological survey in the Argens-Maures area. A large proportion of the “no-heritage” area is found in zones of low reliability.

### Discussion and Perspectives

These preliminary results were obtained when testing the workability of the model and should be interpreted with caution. The Iron Age (eighth to third century BC) in the Argens-Maures region is probably less well studied than the Roman period so the resulting heritage values for the second and first century BC might be under-estimating the importance of previous occupation. In addition, for the Argens-Maures region, the under-

representation of new settlements in no-heritage areas has to be taken with caution, as it is probably partly related to different survey intensities in the region (fig. 5). The large no-heritage area could be attributed to three causes:

- 1) it includes some areas that are completely unsurveyed,
- 2) other factors are making these areas unattractive for settlement, or
- 3) path dependency is a discriminating factor, whatever the period, implying the reoccupation of managed landscapes at some point, even with a minimal investment.

Nevertheless, such assumptions deserve more attention and remain to be corroborated by systematic application of the model to other regions.

Apart from the representativeness of the studied database, the model itself requires thorough discussion as well. Given the observed variation of first-neighbour distances in various regions (Bertoncello et al, 2012) the use of a unique value for the radius based on ethnographic generalisation may not be appropriate when comparing various regions. Furthermore, the analysis of the preliminary results casts some doubts on the meaning of the land use heritage index, as defined in the model, from a PM perspective. Since the spatial weighting is site-centred, the land use heritage value is always higher at the location of the settlement. This is a problem when the pre-existing settlement continues its existence beyond the period considered for the land use heritage value because, from a PM perspective, new settlements will then be more attracted by places already occupied. However, the establishment of a new settlement in a location already occupied would be highly improbable. In those cases where the existing settlements are abandoned in a previous period, the location of the pre-existing settlements also remains the most attractive and the land use heritage index may thus be confused with the prior occupation index (Favory, Nuninger & Sanders, 2012).

To conclude, different functions for spatial weighting remain to be tested. In particular, in opposition to the circular neighbourhood kernel, an annular neighbourhood should be considered. An annular model would mimic a higher attractiveness of the surroundings of an occupied settlement rather than its immediate surroundings. Furthermore, the robustness of the model has to be evaluated using databases from different areas in order to compare the results.

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