Estimating the "memory of landscape" to predict changes in archaeological settlement patterns

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Estimating The ‘Memory of Landscape’ to Predict Changes in Archaeological Settlement Patterns

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Abstract: In this paper, we present 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 others influencing site location preference, and can be used as input for predictive models. The computed values equate to an index of long-term land use intensity. We will first discuss the method used for creating the land use heritage map, for which kernel density estimates are used. We will then present the use of these land use heritage maps for site location analysis in two study areas in SE France. Earlier analyses showed that the influence of the natural environment on settlement location choice in the Roman period is limited. In contrast, land use heritage seems to have a stronger influence on the placement of new settlements. We will discuss the implications for predictive modelling of settlement patterns.

Keywords: Predictive modelling, settlement pattern analysis, socio-cultural variables, memory of landscape, heritage map

Introduction

The IHAPMA project[1] (Nuninger *et al*. 2012a; Verhagen *et al*. 2013) aimed to perform cross-regional comparison and predictive modelling of the location of rural Roman settlements by analysing both environmental and socio-cultural factors influencing site location in two areas of southern France (Argens-Maures and Vaunage), and in the region of Zuid-Limburg in the Netherlands. For this purpose, we developed a protocol that can be easily implemented for different regions and time periods, using contextual analysis, statistical comparison, and predictive modelling of site location as the primary tools to gain a better understanding of cross-regional diachronic patterns of occupation. It distinguishes between environmental factors (such as slope, aspect, and solar radiation), socio-environmental factors (such as visibility and accessibility), and socio-cultural factors (such as the duration of previous occupation and hierarchical network structures; Fig. 1).

In this paper, we will focus on the duration of previous occupation as a site location factor, and use the sub-model we developed to compute a map of ‘land use heritage’ (Nuninger *et al.*, in press) to analyse the effect of ‘memory of landscape’ on settlement location choice. For this, we defined the concept of ‘memory of landscape’ at a very basic level of meaning, taking into consideration that the occupation of archaeological settlements also reflects human investment in the surrounding area. 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 constitutes 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 then 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 use the resulting map to perform site location analysis and predictive modelling, discuss the results and explore the perspective for a comparative approach.

1 Research context: duration of previous occupation and land use heritage

1.1 Duration of previous occupation

Many archaeological rural sites in France, dating from the 2nd c. BC to the 7th c. AD, show a discontinuous occupation with clear phases of abandonment followed by reoccupation after one or more generations. In cases where the site itself is not reoccupied, new settlements may 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 proved by extensive rescue excavations, such as 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 changes or new ways of life (Hamerow 2012), but the successive occupations in the surroundings 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, that is, a 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

[1] ‘Introducing the human (f)actor in predictive modelling for archaeology’.

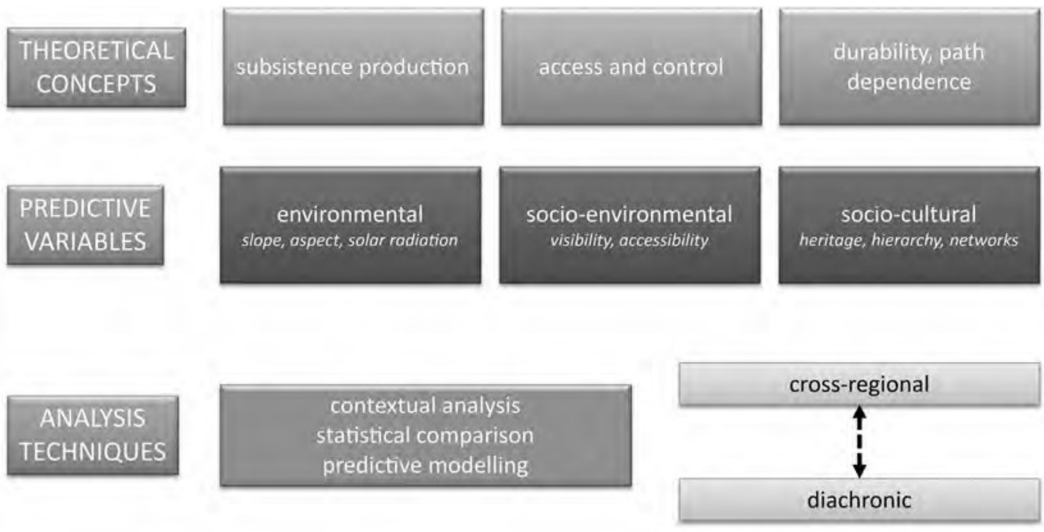


Fig. 1. Building blocks of the IHAPMA predictive modelling protocol.

past activities are embedded in the land used by generations of people and recognized as a heritage by contemporaneous communities (Nuninger *et al*. 2012b; Favory *et al*. 2012).

1.2 The concept of 'land use heritage' and predictive modelling

This concept provides an opportunity to reconsider predictive models and their heuristic power for settlement pattern characterisation over time. Predictive modelling methods were often criticized 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, predictive modelling was 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' (2004). And lastly, predictive modelling was criticized because it is 'concerned only with sites and fails to take broader theoretical developments about off-site activity into account' (Kay and Witcher 2009).

In our view, using the value of 'land use heritage' as a socio-environmental factor in predictive modelling 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 the land for agro-pastoral activities and consequently make 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 to define such a variable, with a high spatial (systematic field surveys) and chronological resolution (precision of the settlements' dating).

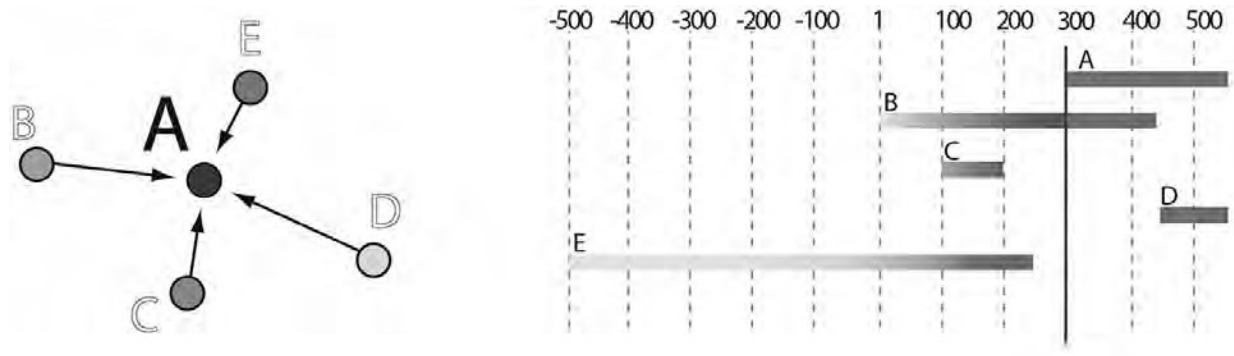
It is important to note that predictive modelling is used here as a tool to explore the archaeological data in order to assess the factors influencing the location choice of rural settlements and their ability to perpetuate. Under no circumstances, should the IHAPMA models be considered as tools to predict 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 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.

2 Specifying the computational model

For the creation of a new settlement we have to consider the potential attractiveness of the degree of anthropization, as well as the potential competition for land. In geography and ecology, anthropization is defined as the transformation of spaces, landscapes, or natural environments through human action. Settling close to an area with a high degree of anthropization potentially offers better opportunities to develop a new exploitation because it can benefit from the landscaping created by previous occupations. If the occupation of a location continues, however, then a new settlement cannot be established in or close to this location.

In order to compute the value of 'land use heritage' for each location in the landscape we have used a moving window with a kernel density function. The rationale and specifics for the computational modelling of the 'land use heritage' are explained in more detail in Nuninger *et al.* (in press). In this paper, we only provide the basic calculations involved.

Within the surroundings of a location A, a number of settlements (B–E) are found, dating from various periods (Fig. 2). Basically, for location A, the 'heritage' is a function of the geographical distance to the previous occupations located in its neighbourhood — B, C, D, and E — as well as the duration of these previous settlements. For each input cell location, a statistic of the heritage values within a specified neighbourhood is therefore computed, based on the number and duration of previous settlements.



B = 100 x 1 + 100 x 0.8 + 100 x 0.6
= 240
C = 100 x 0.8
= 80
D = 0
E = 50 x 1 + 100 x 0.8 + 100 x 0.6 + 100 x 0.4 + 100 x 0.2 + 100 x 0
= 250

FIG. 2. 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.

2.1 Spatial weighting

From a practical point of view, we have modelled this principle using a distance decay function within a radius of 1000 m, corresponding to the area exploited by a settlement and its immediate surroundings. The distance decay function was implemented using a kernel matrix, based on the Epanechnikov kernel weighting function (Silverman 1986; Epanechnikov 1969). We want to stress here that this function was only chosen as a model to represent the spatial influence of 'land use heritage', and is therefore not used in its classical sense of a statistically optimized smoothing function.

The Epanechnikov-function produces a relatively large smooth surface around each location with a rapid fall-off on the edges. For a set of sites, it thus produces large smooth surfaces with few irregularities between sites. Assuming a continuity of land use between neighbouring sites, a surface density that is as regular as possible is best suited to our goals.

2.2 Temporal weighting

Since we are studying rural, agro-pastoral settlements, 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 the land will decrease from an agro-pastoral point of view. To take into account this progressive degradation, each of the settlements B–E is 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. 2).

3 Application and results

3.1 Comparing new settlement distribution and land use heritage

We compared the distribution of new settlements to the resulting land use heritage maps for two study areas in southern France, the Argens-Maures region (Var, Provence region) and the Vaunage region (Gard, Languedoc region). For these regions, the dating of sites is sufficiently precise to distinguish period ranges per century. The land use heritage value was computed for each century between the 2nd c. BC and the 5th c. 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

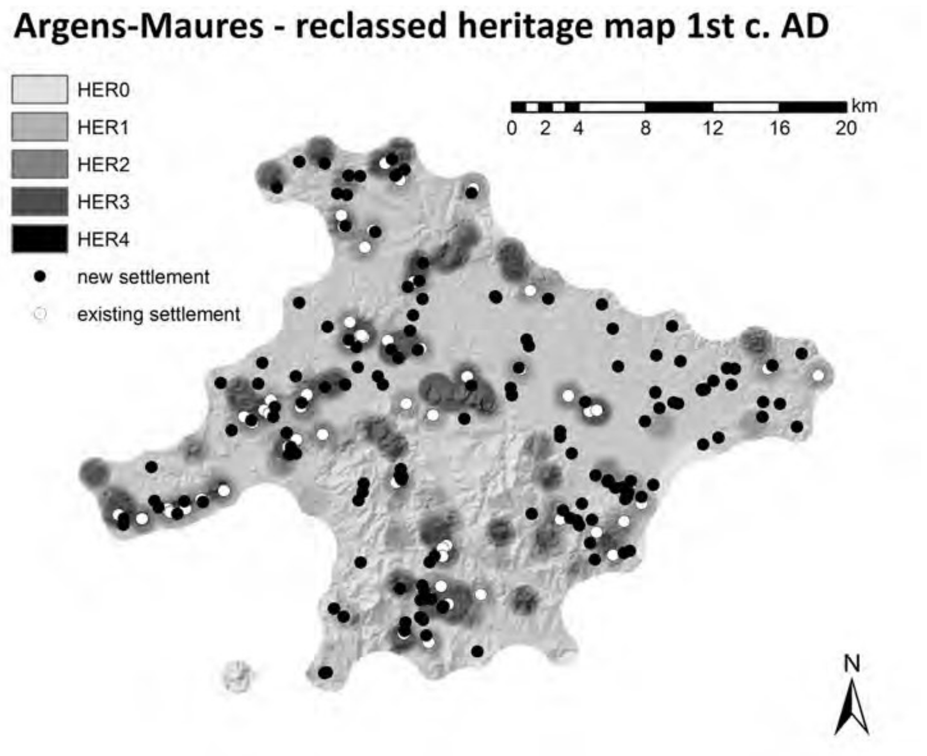


Fig. 3. Reclassified land use heritage map of the Argens-Maures region for the 1st c. AD, with archaeological sites. 'Existing settlements' are locations already occupied in the 1st c. BC, with continuing occupation in the 1st c. AD.

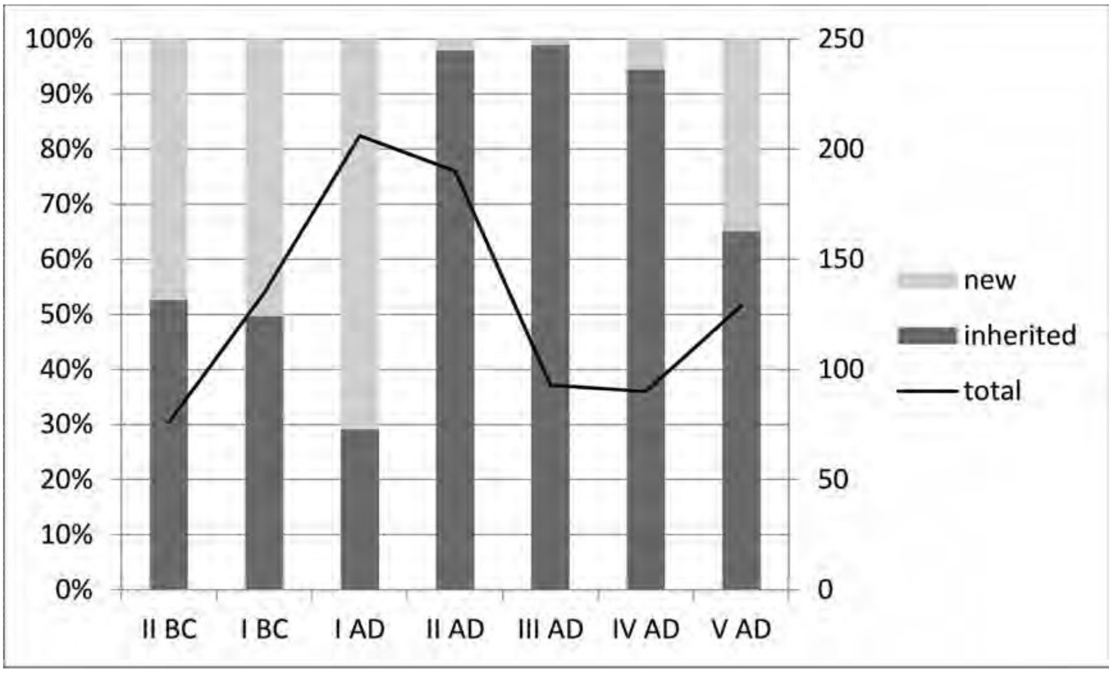


Fig. 4. Development of settlement numbers per century for the Argens-Maures region.

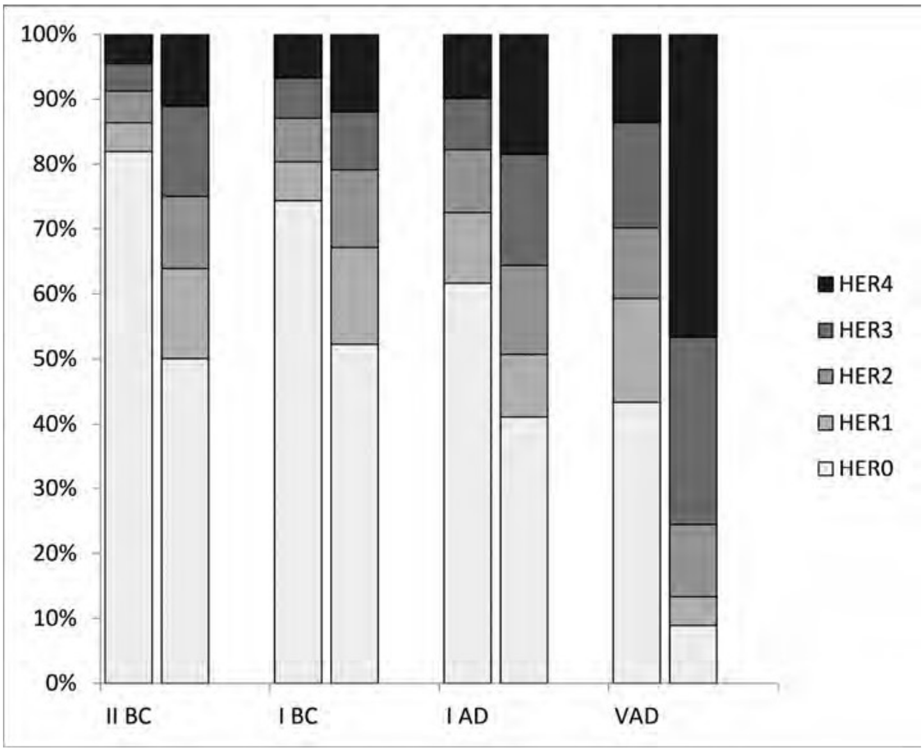


Fig. 5. Histogram comparing the expected (left bar) and observed (right bar) proportions of new settlements for each time period and heritage class for the Argens-Maures region.

In order to compare between periods and with other areas, the reclassification is based on the quantile method, for positive land use heritage values. This creates similar statistical distributions for all periods, allowing us to compare the relative ranges of inherited land use intensity, whatever their absolute value. Figure 3 shows an example of a reclassified heritage map.

We analysed the distribution of new settlement locations in the Argens-Maures region for the 2nd c. BC, 1st c. BC, 1st c. AD, and 5th c. AD. During the 2nd, 3rd, and 4th c. AD a drastic decrease in settlement density is observed, so the analysis could not be performed for those centuries (Fig. 4). Table 1 and Figure 5 show the results of the analysis for the remaining centuries. The χ^2 values all point to a settlement distribution that is significantly influenced by the land use heritage variable (p-values all < 0.0001). The tendencies are not extreme, however, as can be observed from the relative gain values per heritage category. In all analysed centuries, new settlements are under-represented in no-heritage (HER0) areas (relative gains from -0.21 to -0.34). The situation is different, however, for areas with (very) high heritage values (HER3 and HER4). During the 2nd and 1st c. BC there is no clear tendency to favour areas with a high heritage value. The attractiveness of high- and very high-heritage areas increases during the 1st c. AD. This becomes clearer during the 5th c. AD, where especially class HER4 shows a marked positive relative gain (0.33). The 5th c. AD therefore shows the strongest contrast in settlement preference, with clear negative gains in classes HER0 and HER1 and positive gains in classes HER3 and HER4. This clear tendency to favour areas with high heritage is partly explained by the fact that 37.7% of the settlements created during the 5th c. AD reoccupy previous settlements that were deserted, usually during the 2nd c. 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 classes HER3 and HER4.

In the Vaunage region, we also observe a strong decrease in settlement densities after the 1st c. AD, but in this case the recovery already starts in the 4th c. AD (Fig. 6). Consequently, the analysis could not be performed for the 2nd, 3rd, and 5th c. AD. Table 2 and Figure 7 show the results of the analysis for the remaining centuries. Again, the χ^2 values all point to a settlement distribution that is significantly influenced by the land use heritage variable (p-values all < 0.001), but the tendencies are somewhat different than those for the Argens-Maures region. The no-heritage areas (HER0) are under-represented in all periods (relative gains between -0.37 and -0.15), but less so for the 1st and 4th c. AD (relative gains between -0.18 and -0.15). We can observe that in the 2nd c. BC new settlements have a clear preference for class HER3 (relative gain 0.29), but not for the very high heritage HER4 area (relative gain 0.05). In the 1st c. BC, new settlements tend to prefer both the HER3 and HER4 areas (relative gains 0.14 and 0.30). In the 1st c. AD, new settlements do not seem to have a preference for any particular heritage value. In the 4th c. AD, however, we observe a strong tendency for new settlements to favour areas with very high heritage (HER4; relative gain 0.40), while the other zones all have negative gains. This pattern of reoccupation of previous settlement locations is quite similar to what is observed in the Argens-Maures region in the 5th c. AD.

Tab. 1. This table shows, for each class of land use heritage in the Argens-Maures region, 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 χ^2 value indicates the difference between observed and expected values, normalized by the expected ones. An increasing χ^2 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 ($p_S - p_A$; Wansleeben and Verhart 1992).

2nd century BC								
Heritage value	**Observed new settlements**	**Expected new settlements**	**ps**	**pa**	**χ2**	**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
Total	**36**				**25,978**			
p-value					0,000			
1st century BC								
Heritage value	**Observed new settlements**	**Expected new settlements**	**ps**	**pa**	**χ2**	**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
Total	**67**				**19,619**			
p-value					0,001			
1st century AD								
Heritage value	**Observed new settlements**	**Expected new settlements**	**ps**	**pa**	**χ2**	**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
Total	**146**				**39,343**			
p-value					0,000			
5th century AD								
Heritage value	**Observed new settlements**	**Expected new settlements**	**ps**	**pa**	**χ2**	**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
Total	**45**				**56,841**			
p-value					0,000			

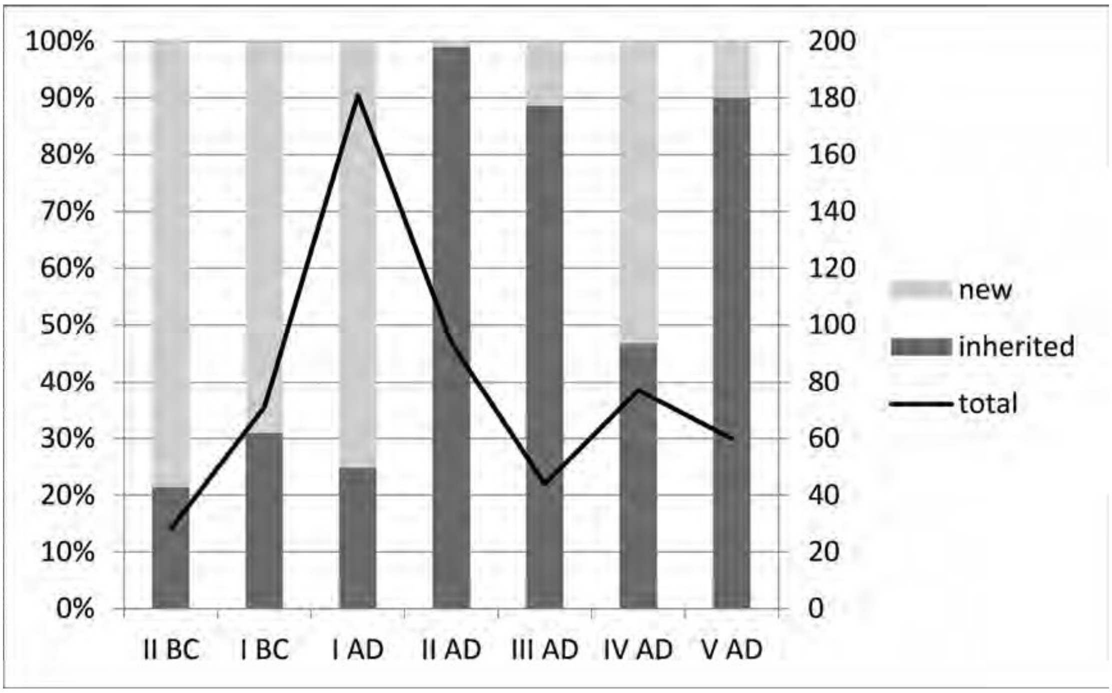


Fig. 6. Development of settlement numbers per century for the Vaunage region.

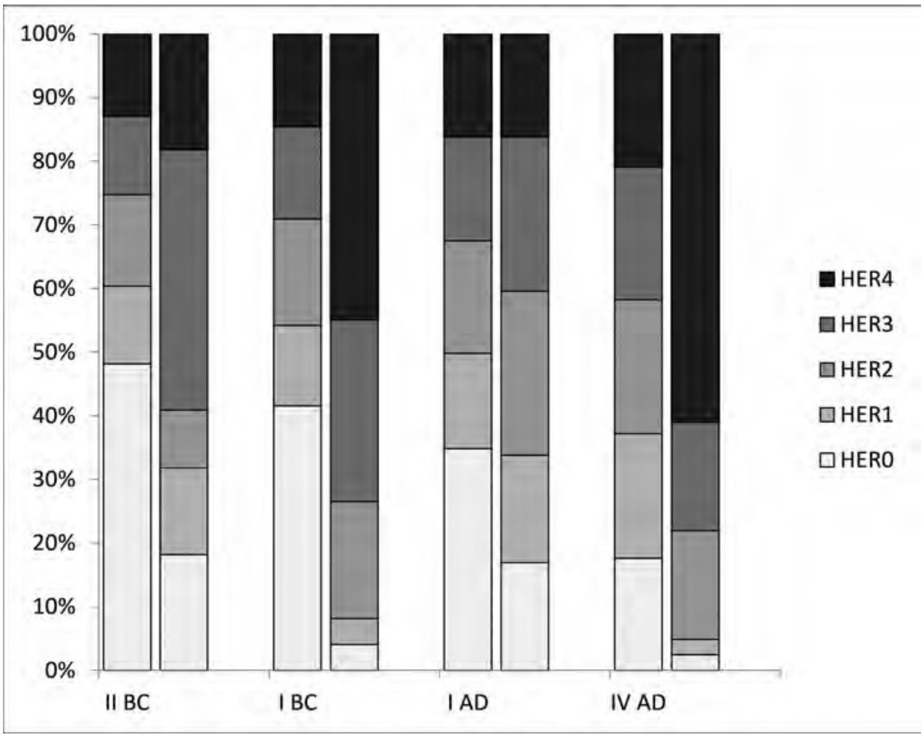


Fig. 7. Histogram comparing the expected (left bar) and observed (right bar) proportions of new settlements for each time period and heritage class for the Vaunage region.

Tab. 2. This table shows, for each class of land use heritage in the Vaunage region, and for each analysed century, the number of observed new settlements compared to expected ones, and their proportions.

2nd century BC								
Heritage value	**Observed new settlements**	**Expected new settlements**	**ps**	**pa**	**χ2**	**Kvamme's gain**	**Indicative value**	**Relative gain**
0	4	10,598	0,182	0,482	4,107	-1,65	0,38	-0,30
1	3	2,682	0,136	0,122	0,038	0,11	1,12	0,01
2	2	3,165	0,091	0,144	0,429	-0,58	0,63	-0,05
3	9	2,711	0,409	0,123	14,591	0,70	3,32	0,29
4	4	2,844	0,182	0,129	0,470	0,29	1,41	0,05
Total	**22**				**19,635**			
p-value					0,001			
1st century BC								
Heritage value	**Observed new settlements**	**Expected new settlements**	**ps**	**pa**	**χ2**	**Kvamme's gain**	**Indicative value**	**Relative gain**
0	2	20,368	0,041	0,416	16,564	-9,18	0,10	-0,37
1	2	6,197	0,041	0,126	2,842	-2,10	0,32	-0,09
2	9	8,189	0,184	0,167	0,080	0,09	1,10	0,02
3	14	7,105	0,286	0,145	6,691	0,49	1,97	0,14
4	22	7,141	0,449	0,146	30,919	0,68	3,08	0,30
Total	**49**				**57,097**			
p-value					0,000			
1st century AD								
Heritage value	**Observed new settlements**	**Expected new settlements**	**ps**	**pa**	**χ2**	**Kvamme's gain**	**Indicative value**	**Relative gain**
0	23	47,373	0,169	0,348	12,540	-1,06	0,49	-0,18
1	23	20,396	0,169	0,150	0,333	0,11	1,13	0,02
2	35	23,996	0,257	0,176	5,046	0,31	1,46	0,08
3	33	22,207	0,243	0,163	5,246	0,33	1,49	0,08
4	22	22,029	0,162	0,162	0,000	-0,00	1,00	-0,00
Total	**136**				**23,164**			
p-value					0,000			
4th century AD								
Heritage value	**Observed new settlements**	**Expected new settlements**	**ps**	**pa**	**χ2**	**Kvamme's gain**	**Indicative value**	**Relative gain**
0	1	7,218	0,024	0,176	5,357	-6,22	0,14	-0,15
1	1	8,033	0,024	0,196	6,158	-7,03	0,12	-0,17
2	7	8,634	0,171	0,211	0,309	-0,23	0,81	-0,04
3	7	8,557	0,171	0,209	0,283	-0,22	0,82	-0,04
4	25	8,558	0,610	0,209	31,591	0,66	2,92	0,40
Total	**41**				**43,697**			
p-value					0,000			

3.2 Comparing land use heritage and environmental context

In order further to analyse the effect of land use heritage on the location of new settlement, site locations were also compared to an environmental context map, based on combined slope, aspect, and solar radiation values within a 250 m circular neighbourhood around each grid cell (Verhagen *et al*. 2013). Preferences for environmental contexts in the Argens-Maures region are relatively weak for all analysed periods (reflected in modest values of χ^2), with the exception of the 1st c. AD, when we can observe a clear preference for south-facing, moderately sloping terrain (Tab. 3). In the Vaunage region, preferences are not very strong either, although we can observe in all periods a general avoidance of sloping terrain, and a preference for slightly to moderately sloping, south-facing terrain (Tab. 4; note that the classification for both regions does not reflect the same environmental contexts).

Both land use heritage and environmental context were then combined in a predictive model that was created using the MaxEnt software package (Phillips *et al*. 2004; 2006; Phillips and Dudík 2008; Elith *et al*. 2011). MaxEnt is a general-purpose predictive modelling tool, designed to work with presence-only data, such as archaeological sites. It is based on the principle of minimizing the relative entropy (dispersedness) between the probability densities estimated from the sample data and

Tab. 3. This table shows, for each environmental class in the Argens-Maures region, and for each analysed century, the number of observed new settlements compared to expected ones and their proportions. The characterization of the environmental classes is as follows: 1 – flat and slightly sloping, moderately warm, S- and E-facing; 2 – slightly and moderately sloping, warm, S-facing; 3 – steeply sloping, very cool, W-, N-, and E-facing; 4 – steeply sloping, very cool and very warm, E-, S-, and W-facing; 5 – steeply sloping, very warm, S-facing. NB: these classes represent the environmental characteristics within a 250 m neighbourhood around each grid cell.

2nd century BC								
Environmental class	**Observed new settlements**	**Expected new settlements**	**ps**	**pa**	**χ2**	**Kvamme's gain**	**Indicative value**	**Relative gain**
1	4	3,372	0,111	0,094	0,117	0,16	1,19	0,02
2	4	9,349	0,111	0,260	3,060	-1,34	0,43	-0,15
3	10	8,444	0,278	0,235	0,287	0,16	1,18	0,04
4	9	8,715	0,250	0,242	0,009	0,03	1,03	0,01
5	9	6,119	0,250	0,170	1,356	0,32	1,47	0,08
Total	36				4,829			
p-value					0,305			
1st century BC								
Environmental class	Observed new settlements	Expected new settlements	ps	pa	x2	Kvamme's gain	Indicative value	Relative gain
1	3	6,276	0,045	0,094	1,710	-1,09	0,48	-0,05
2	28	17,399	0,418	0,260	6,459	0,38	1,61	0,16
3	9	15,715	0,134	0,235	2,870	-0,75	0,57	-0,10
4	17	16,220	0,254	0,242	0,037	0,05	1,05	0,01
5	10	11,389	0,149	0,170	0,169	-0,14	0,88	-0,02
Total	67				11,245			
p-value					0,024			
1st century AD								
Environmental class	Observed new settlements	Expected new settlements	ps	pa	x2	Kvamme's gain	Indicative value	Relative gain
1	10	13,676	0,068	0,094	0,988	-0,37	0,73	-0,03
2	79	37,915	0,541	0,260	44,521	0,52	2,08	0,28
3	16	34,246	0,110	0,235	9,721	-1,14	0,47	-0,12
4	22	35,346	0,151	0,242	5,039	-0,61	0,62	-0,09
5	19	24,818	0,130	0,170	1,364	-0,31	0,77	-0,04
Total	146				61,633			
p-value					0,000			
5th century AD								
Environmental class	Observed new settlements	Expected new settlements	ps	pa	x2	Kvamme's gain	Indicative value	Relative gain
1	2	4,215	0,044	0,094	1,164	-1,11	0,47	-0,05
2	16	11,686	0,356	0,260	1,593	0,27	1,37	0,10
3	13	10,555	0,289	0,235	0,566	0,19	1,23	0,05
4	7	10,894	0,156	0,242	1,392	-0,56	0,64	-0,09
5	7	7,649	0,156	0,170	0,055	-0,09	0,92	-0,01
Total	45				4,770			
p-value					0,312			

from the landscape. While there is some debate regarding its utility for precise predictions (Peterson *et al*. 2007; Kondo *et al*. 2012), it is a convenient tool to compare the contribution of different variables to prediction results. A useful feature is that it can also integrate measures of reliability of data coverage through so-called bias maps. In the case of the Argens-Maures region, we have therefore introduced a measure of reliability of the data according to the intensity of investigation and the field survey conditions (soil visibility) by attributing a weight of 1, 2, and 3 to areas with increasing quality of survey (no or partial survey or bad visibility conditions, systematic survey with medium visibility conditions, and systematic survey with optimal visibility conditions; Bertoncello *et al*. 2012; Fig. 8). For the Vaunage region, such a correction was not necessary since the whole area was surveyed systematically.

Tab. 4. This table shows, for each environmental class in the Vaunage region, and for each analysed century, the number of observed new settlements compared to expected ones and their proportions. The characterization of the environmental classes is as follows: 1 – slightly and moderately sloping, moderately cool, N- and W-facing; 2 – sloping, no particular preference for solar radiation or aspect; 3 – moderately sloping, warm, S-facing; 4 – flat, moderately cool, no particular preference for aspect; 5 – flat to slightly sloping, moderately warm, S-facing. NB: these classes represent the environmental characteristics within a 250 m neighbourhood around each grid cell.

2nd century BC								
Environmental class	**Observed new settlements**	**Expected new settlements**	**ps**	**pa**	**χ2**	**Kvamme's gain**	**Indicative value**	**Relative gain**
1	4	3,802	0,182	0,173	0,010	0,05	1,05	0,01
2	2	5,340	0,091	0,243	2,089	-1,67	0,37	-0,15
3	5	5,274	0,227	0,240	0,014	-0,05	0,95	-0,01
4	4	4,941	0,182	0,225	0,179	-0,24	0,81	-0,04
5	7	2,642	0,318	0,120	7,188	0,62	2,65	0,20
Total	**22**				**9,481**			
p-value					0,050			
1st century BC								
Environmental class	**Observed new settlements**	**Expected new settlements**	**ps**	**pa**	**χ2**	**Kvamme's gain**	**Indicative value**	**Relative gain**
1	5	8,469	0,102	0,173	1,421	-0,69	0,59	-0,07
2	7	11,894	0,143	0,243	2,014	-0,70	0,59	-0,10
3	16	11,747	0,327	0,240	1,540	0,27	1,36	0,09
4	7	11,006	0,143	0,225	1,458	-0,57	0,64	-0,08
5	14	5,885	0,286	0,120	11,191	0,58	2,38	0,17
Total	**49**				**17,623**			
p-value					0,001			
1st century AD								
Environmental class	**Observed new settlements**	**Expected new settlements**	**ps**	**pa**	**χ2**	**Kvamme's gain**	**Indicative value**	**Relative gain**
1	24	23,505	0,176	0,173	0,010	0,02	1,02	0,00
2	15	33,011	0,110	0,243	9,827	-1,20	0,45	-0,13
3	41	32,603	0,301	0,240	2,163	0,20	1,26	0,06
4	32	30,547	0,235	0,225	0,069	0,05	1,05	0,01
5	24	16,333	0,176	0,120	3,599	0,32	1,47	0,06
Total	**136**				**15,668**			
p-value					0,003			
4th century AD								
Environmental class	**Observed new settlements**	**Expected new settlements**	**ps**	**pa**	**χ2**	**Kvamme's gain**	**Indicative value**	**Relative gain**
1	7	7,086	0,171	0,173	0,001	-0,01	0,99	-0,00
2	7	9,952	0,171	0,243	0,876	-0,42	0,70	-0,07
3	13	9,829	0,317	0,240	1,023	0,24	1,32	0,08
4	4	9,209	0,098	0,225	2,947	-1,30	0,43	-0,13
5	10	4,924	0,244	0,120	5,233	0,51	2,03	0,12
Total	**41**				**10,079**			
p-value					0,039			

The predictive modelling results for the Argens-Maures region clearly show that land use heritage has a higher contribution to the predicted probabilities than environmental context (Tab. 5). We can observe a change through time, however, with land use heritage gradually decreasing in importance from the 2nd c. BC to the 1st AD. In the 5th c. AD, however, land use heritage becomes extremely dominant. This pattern largely conforms to what is observed from analysing the distribution of new settlements compared to the land use heritage and environmental context maps. The accuracy of prediction, as measured through the Area Under Curve (AUC) statistic, is only poor to fair for the first three periods, but it is good for the 5th c. AD. For the Vaunage region, the results are very similar, although in the 1st c. BC we observe a stronger influence of land

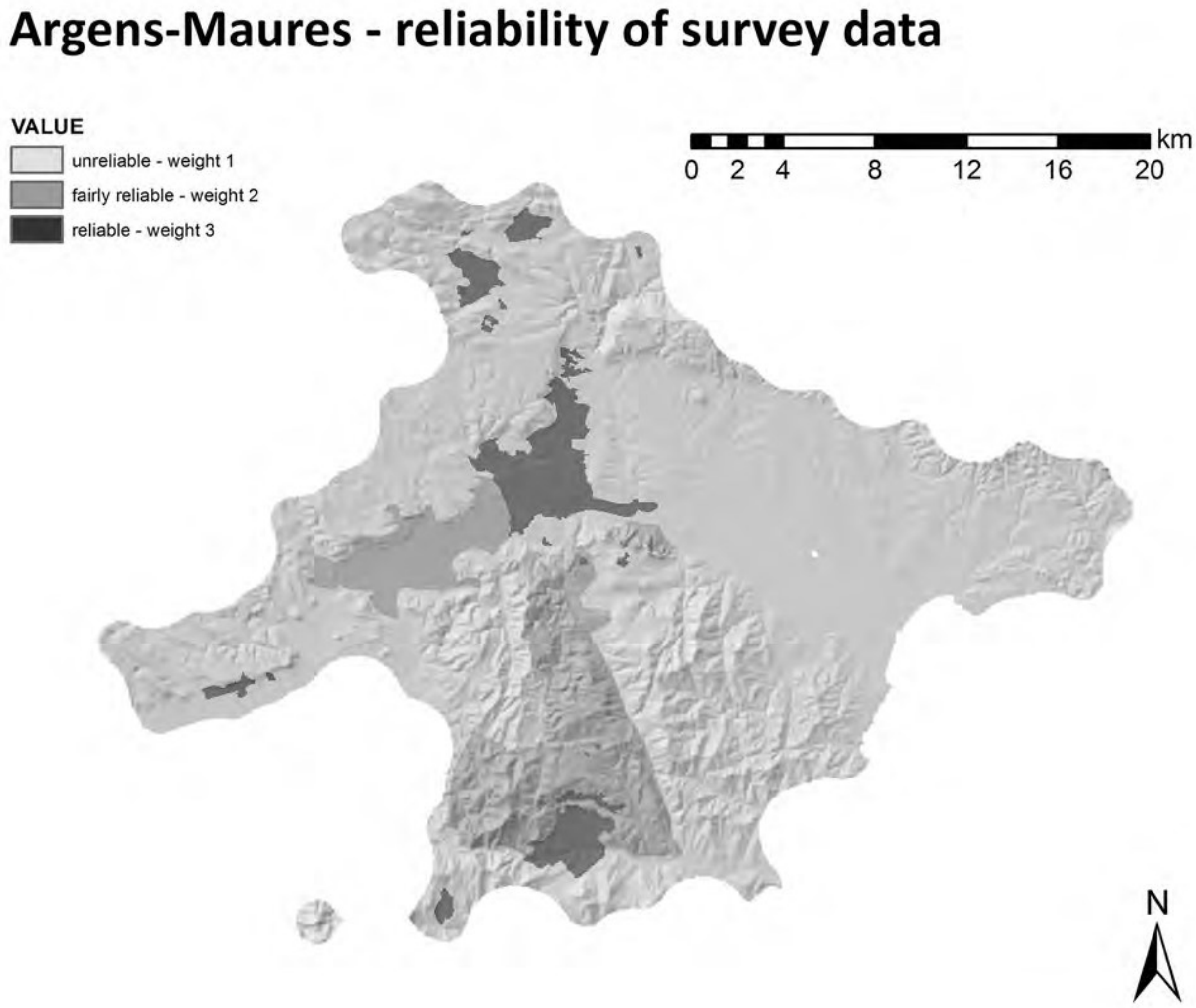


FIG. 8. MAP SHOWING THE RELIABILITY OF ARCHAEOLOGICAL SURVEY IN THE ARGENS-MAURES AREA. A LARGE PROPORTION OF THE 'NO-HERITAGE' AREA IS FOUND IN ZONES OF LOW RELIABILITY.

use heritage than in the Argens-Maures region (Tab. 6), and the accuracy of predictions is somewhat higher. In the Vaunage, this specific situation can be explained by the diffusion of small settlements around the pre-existing *oppida* from the 2nd c. BC and especially during the 1st c. BC (Nuninger 2004). By comparison, the Argens-Maures region shows a very limited occupation during the Iron Age, at least before the 2nd c. BC, even when taking into account survey bias and chronological uncertainty (Bertoncello 1999).

When including the reliability of field survey in the prediction for the Argens-Maures region, the contribution of land use heritage clearly decreases, and it is no longer the dominant factor in the 1st c. AD. The temporal trend is still the same, however, and the accuracy of prediction does not change very much. The reduction of the importance of land use heritage for the prediction results can be explained by the fact that this variable is dependent on the known density of settlement. In areas that are poorly surveyed, the real settlement density will be higher than what is known from the survey record, not just because of the lower area coverage, but also because of the potential preferential discovery of larger and more conspicuous sites. Hence, land use heritage values in these areas will be underestimated. In the predictive model, this could lead to over-emphasizing the avoidance of no-heritage areas by new settlements.

4 Discussion and perspectives

The preliminary results presented here were obtained when testing the workability of the model and should be interpreted with caution. The Iron Age (8th to 3rd c. BC) in the Argens-Maures region is probably less well studied than the Roman period, so the resulting heritage values for the 2nd and 1st c. BC might be underestimating the importance of previous occupation. Nevertheless, the results are striking in showing that settlement creation in the later Roman period exhibits a clear preference for areas with high to very high heritage values, which we could interpret as a sign of path dependency. Moreover, land use heritage seems to be a more important location factor for new settlement than the environmental context in most periods, but since the predictive power of the models is not very high, we can suspect that other factors are involved as well. Soil type, for example, was not included in the

Tab. 5. Predictive modelling results for the Argens-Maures region, with and without bias filter.

	Model without bias filter	Environment (%)		Model with bias filter		
Period	Contribution of heritage (%)	Contribution of environment (%)	AUC	Contribution of heritage (%)	Contribution of environment (%)	AUC
2nd c. BC	73,6	26,4	0,719	63,0	37,0	0,688
1st c. BC	62,3	37,7	0,672	54,5	45,5	0,667
1st c. AD	56,4	43,6	0,694	32,3	67,7	0,695
5th c. AD	91,7	8,3	0,793	88,2	11,8	0,797

Tab. 6. Predictive modelling results for the Vaunage region.

	Model without bias filter	Environment (%)	
Period	Contribution of heritage (%)	Contribution of environment (%)	AUC
2nd c. BC	70,4	29,6	0,772
1st c. BC	84,6	15,4	0,813
1st c. AD	53,8	46,2	0,672
4th c. AD	89,1	10,9	0,772

analysis presented here, and could potentially be an important site location factor for rural settlements.

Another important result of the analysis is, as anticipated, that it allows for cross-regional comparison. Relatively subtle patterns of occupation dynamics in the Argens-Maures and Vaunage regions now become clearer, telling us more about the differences and similarities in the trajectories of both regions, which can be related to the general development of Roman occupation in the south of France. The strong decrease in the number of settlements after the 1st c. AD is well attested in many regions (Favory *et al*. 1999; Van der Leeuw *et al*. 2003; Gandini *et al*. 2008) and the results from the Archaeomedes project promoted a new reading of territorial dynamics in the Late Roman Empire. Instead of reflecting a political and economic crisis coupled to land abandonment and environmental degradation, the large-scale abandonment of sites might reflect a process of restructuration and stabilisation of the settlement pattern (Durand-Dastès *et al*. 1998). The choice for particular land areas is the result of this restructuration and does not necessarily imply a contraction of the exploited areas, which can be managed from fewer locations (Favory *et al*. 1999; Tourneux 2000; Fovet 2005). In other words, when settlement is contracting at the end of the Early Roman Empire, the remaining sites are located in preferential contexts, and the latest phases of creation (the 4th and 5th c. AD, also attested in many other regions) correspond to a firmer choice for particular environmental contexts (Nuninger *et al*. 2012a). This could explain the strong path dependency of the settlements created during the 4th and 5th c. AD, as they would thus benefit both from previous landscaping and anthropization of the area, and from the best environmental conditions selected by the earliest settlements. This process of stabilisation of the settlement configuration is now supported with a new argument by the calculation and analysis of land use heritage presented here, at least in the Vaunage and Argens-Maures regions, but it still needs to be demonstrated on a larger scale.

The 'land use heritage' model itself also deserves more thorough discussion and experimenting. The concept, in its current definition, potentially conflates two variables. In the case of an abandoned settlement, the land use heritage equates to the heritage of the abandoned settlement location and its surroundings. In the case of continuation of occupation, however, the location of the settlement itself is not available for occupation, and land use heritage is only relevant for the surroundings of the settlement. In the current model, no distinction can be made between these situations, making it impossible to analyse if we are dealing with reoccupation of an abandoned settlements, or with occupation in the surroundings of existing and/or abandoned settlements. An annular neighbourhood, for example, might make more sense in this case.

The modelling protocol, which was developed in ArcGIS, is still under construction, and progress has been relatively slow, since it is based on independent research efforts in three different institutes. Nevertheless, we aim to make it publicly available as soon as possible as a set of toolboxes that can be used by anyone interested, and that can be adapted to the specific characteristics of particular regions and/or time periods. In the longer term, however, we want to move towards an Open Source solution that would make it easier for other users to add functionality.

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