The Hidden Reserve: Predictive Modelling of Buried Archaeological Sites in the Tricastin-Valdaine Region (Middle Rhone Valley, France)

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Abstract

Over the past ten years, a number of archaeological surveys have been carried out in the Tricastin-Valdaine region (Middle Rhône Valley, France). The results of these surveys, which included digging trenches on many locations, indicated that many more sites are hidden below the surface than can be inferred from traditional field-walking data alone. In order to illustrate this effect, a predictive modelling study was carried out, using both the "old" and the "new" data from the area. The paper demonstrates that the use of data on buried sites strongly influences the outcome of the predictive model, as well as the estimation of the actual site quantities involved. This also implies a reassessment of existing theories of site location in the area. Ultimately, the results of the study make a strong case for the use of sub-surface surveying methods in any sedimentary area.

Key words: predictive modelling, χ^2, site-to-area proportions, K_j-method, survey methods, buried sites, Holocene geomorphological evolution, Rhône valley

1. Introduction

The middle Rhône Valley is located at the boundary of the Mediterranean, central European and alpine climate zones. Within the middle Rhône Valley, the Tricastin-Valdaine region is an area of 1086 km^2 located on the eastside of the river Rhône. The area consists of two distinct zones: to the north, the Valdaine Basin comprises the valleys of the Roubion and Jabron rivers, surrounded by Secondary pre-alpine hills. The most important town in this area is Montélimar. To the south, the Tricastin forms a broad transitional zone between the riverbed of the Rhône, the lateral Holocene alluvial fans and the Tertiary pre-alpine hills. The most important towns in this area are Pierrelatte, St-Paul-Trois-Châteaux and Bollène.

Due to its location at a climatic and geological boundary zone, both vegetation and geomorphological processes in the middle Rhône Valley are highly sensitive to climate change and anthropic impact. The area is known to have a complex history of erosion and sedimentation since the beginning of the Holocene (Brochier et al. 1991, Berger 1996, Berger et al. 1997, Berger et al. 2000, Berger in press (1), Berger in press (2), Berger and Brochier in press). Because of this landscape dynamic many archaeological remains are known to be buried below the current surface, especially in the alluvial plain of the Rhône. The purpose of this study is to show that the use of the results of traditional field-walking survey (which will not detect buried sites) for analysing the relationship between site location and landscape characteristics can lead to both a wrong representation of the distribution of the sites with regard to landscape units, and of actual site quantities. This has been achieved by creating a qualitative predictive map of the area, and by performing a quantitative extrapolation of site densities for the sedimentary areas where most buried sites are found.

2. The predictive model

2.1. Introduction

For most predictive modelling studies, the relation of site location to one or more landscape characteristics is inferred by applying an overlay of the known site locations on the cartographic background available. This overlay is then subjected to a quantitative analysis of the observed distribution pattern, an approach also known as inductive modelling (Dalla Bona 1994). In most cases this analysis is done assuming that the known site sample is representative for the total population. However, this is not necessarily true.

First of all, the method of survey determines which sites will be discovered. It is clear that buried sites will not be detected by means of field walking. However, augering and digging trenches are relatively expensive forms of survey, which are not usually available to amateurs, and even professional archaeologists will not use these forms of survey unless there is a clear necessity. In practice, this means that in most archaeological site databases the number of buried sites will be underestimated.

Furthermore, when the size of the area actually surveyed is not known, there is no information available on the absence of sites, which is equally important for the statistical analysis of site location preference.

Thirdly, the area surveyed (and therefore the site sample) is not usually representative of the total study area. This may be a consequence of difficult access of the terrain, for example because of steep slopes, or because of a research bias for certain areas.

Fortunately, the situation for the Tricastin-Valdaine region is different, as we have both detailed records of buried sites, as well as a mapping of the surveyed zones. However, the current study cannot account for a fourth distorting factor, the differential visibility of archaeological surface remains under different types of land use.

2.2. The Taphonomical map: An interpretation of the landscape in terms of sedimentation and erosion

In order to get a grip on the history of sedimentation and erosion of the area, the landscape has to be interpreted in terms of its geomorphological and pedogenetic history. In order to arrive at a map that could be used as a taphonomical base layer, various geological and soil maps have been digitized, and combined in a GIS. They then have been interpreted into in taphonomical terms.

The only base maps available for the whole region are the geological maps 1:50,000 of France. The following sheets have been digitised:

Sheet:	Name:	Publisher:	Year:
842	Crest	BRGM	1976
866	Montélimar	BRGM	1979
XXX-39	Valréas	BRGM	1964
914	Orange	BRGM	1971

These maps have been edited where necessary. The geological map units have then been assigned to one of the 18 taphonomical categories distinguished.

The basic geological information has then been updated with other available information on the geological and pedological conditions in the area. This information comes from three sources:

1. a classified remotely sensed image of the Tricastin area (Tounsi et al. 1997);
2. a delimitation of the main pedological and sedimentary units obtained during fieldwork in the Valdaine (Berger 1996) and Tricastin (Berger et al. 1997); and
3. existing 1:25,000 pedological maps of the area (Bornand 1967, 1971).

Essentially, the remotely sensed image gives detailed information on the location of old riverbeds, alluvial fans, terraces and *cuvettes* in the Tricastin. The fieldwork data provides additional information on the location of colluvial and alluvial deposits (colluvium, alluvial fans, alluvium and *cuvettes*). The pedological maps have been used to find the actual extent of alluvial and colluvial deposits in the Roubion and Jabron valleys, to find the location of stable Pleistocene terraces and alluvial fans in the Valdaine, and the distribution of colluvial deposits and *cuvettes* in the Tricastin. The additional information has been used to update the reclassified geological maps. The final taphonomical map is therefore a patch of several maps of varying scale and precision.

2.3. The archaeological dataset

The archaeological site sample consists of data coming from various sources. Data collected by means of field walking was taken from Beeching et al. (1995) and Berger (1996). Data collected by means of digging trenches was taken from Berger (1996), Berger et al. (1997, 2000), and from the archaeological surveys and excavations for the TGV Méditerranée (the high-speed railway connection between Lyon and Marseille), which were carried out between 1995 and 1998. Of course the latter method of fieldwork will result in the detection of buried sites, and this data therefore forms the most important part of the archaeological database. Data on other sites has been collected from literature, and from the archaeological map of the regional archaeological service of the Rhône-Alpes region.

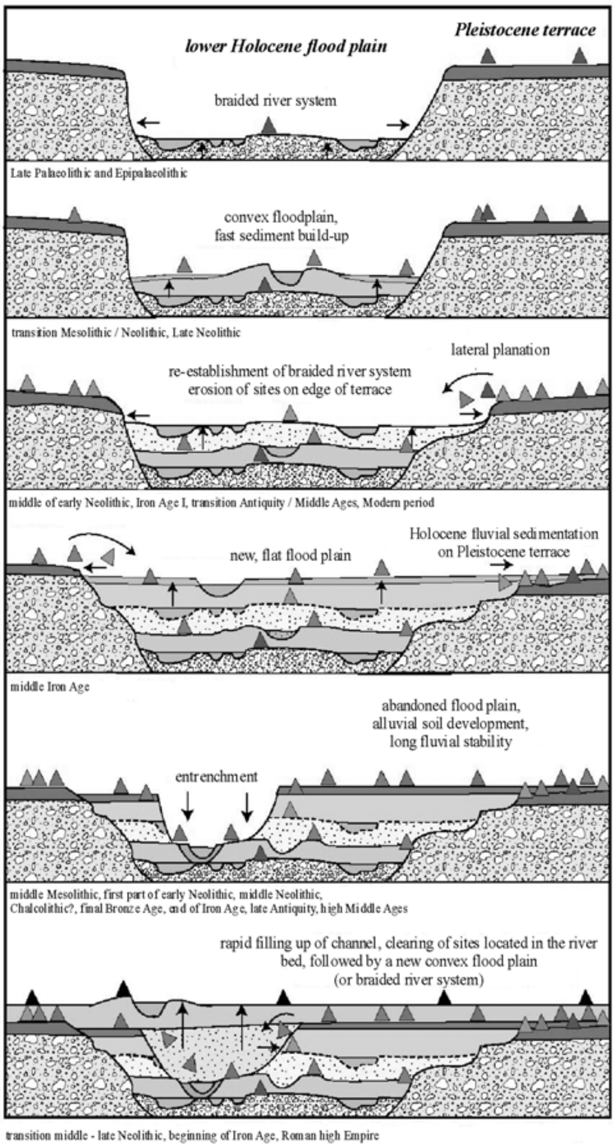

Figure 1: The influence of river dynamics on site location and preservation in the lower alluvial plains of the middle Rhône Valley (adapter after Butzer, 1982). River changes play a predominant role during the Holocene in the occupation and exploitation of the fertile alluvial soils of the lower flood plain. A pattern emerges of phases of fluvial stability coupled to dense occupation, alternating with phases of instability coupled to depopulation.

At the regional scale, the relationship between site location dynamics and geomorphological evolution is currently understood in terms of fluvial systems (Berger 1996, in press (1), in press (2)) and can be schematized for the Holocene period according to figure 1. In the Rhône hydrological system, the fluvial regime of the rivers changes depending on variations in the ratio of liquid and

Period	visible	not visible	total
Epipalaeolithic and Mesolithic	57	8 (12.3 %)	65
Early Neolithic	21	17 (44.7%)	38
Middle Neolithic	57	28 (32.9%)	85
Late Neolithic and Chalcolithic	73	43 (37.1%)	116
Bronze Age	24	87 (78.4%)	111
Iron Age	42	53 (55.8 %)	95
Total	274	236 (46.3%)	510

Table 1: Distribution of archaeological sites over 6 chronological periods, and the proportions of visible and non-visible sites.

solid flows. Anastomosed or braided channel systems are unattractive for settlement, except for seasonal activity (Epipalaeolithic, the middle of the early Neolithic, first Iron Age). Flat or convex floodplains, associated with meandering river courses, are more favourable for settlement, but frequent flooding can be a restraint to occupation (late Neolithic, middle Iron Age, Roman high Empire). The most favourable situation is a meandering river system together with a deep entrenchment of the riverbed, which stabilizes the floodplain for a long period of time (middle to late Mesolithic, middle Neolithic, final Bronze Age, second Iron Age). Evidence is found for a cyclic alternation between stability of watercourses and expansion of occupation in the flood plains on the one hand, and instability of watercourses and depopulation of these same areas on the other hand.

From the sources mentioned, a comprehensive archaeological database was constructed, containing the location of 510 pre- and proto-historic sites and probable sites, discovered in different taphonomic contexts (buried in situ, buried in secondary position, washed down slopes; see Berger in press and Berger et al. 2000 for more details). For each site it was documented whether the site was visible at the surface, or if it had been covered by sediment. The term “site” is not synonymous with find spot in this case. A single find spot may have produced evidence for occupation in more than one period; each of these occupation phases has been stored as a separate site in the database. The occupation phases distinguished have then been regrouped into six different chronological periods (table 1). This was done in order to obtain a sufficiently large number of sites per period. The number of sites needed for a reliable analysis of site location in relation to the taphonomical map is approximately 40. For the early Neolithic, this requirement is not met, but the other periods do have sufficient sites to carry out a site location analysis.

2.4. The site sample: Dealing with the problem of representativity

In order to see if non-random sampling influences the site location analysis of the study area, the available site sample was divided into a visible sample and a full sample that also included the non-visible sites. These samples for each period have then been analysed using two geographical analysis windows: the full study region and the area surveyed. In the case of the visible sites, this only encompassed the field walked zones. In the case of the full sample, both the trenched and field walked zones were included (table 2). Because of the small number of sites involved, it was not possible to carry out a separate analysis for the trenched

Window	E/M	EN	MN	LN	BA	IA	Total
FULL(VIS)	57	21	57	73	24	42	274
SURV(VIS)	46	12	35	41	9	14	157
FULL(ALL)	65	38	85	116	103	95	502
SURV(ALL)	51	23	53	60	45	43	275

Table 2: Distribution of the archaeological sites over the analysis windows. Figures in grey indicate situations where the results of the analysis will be unreliable (n < 40). Windows: FULL(VIS) – whole study region, visible sites; SURV(VIS) – surveyed zones, visible sites; FULL(ALL) – whole study region, all sites; SURV(ALL) – surveyed and trenched zones, all sites. Periods: E/M – Epipalaeolithic/Mesolithic; EN – early Neolithic; MN – middle Neolithic; LN – late Neolithic; BA – Bronze Age; IA – Iron Age.

zones alone. However, the chances of finding a non-visible site in the trenched zone are much larger than in zones that have only been field walked. As the trenched zone only constitutes a relatively small portion of the total surveyed zone, the actual importance of non-visible sites may be larger than is suggested by the predictive modelling.

3. The predictive model: Methods applied

In order to analyse the relationships between archaeological site location and the taphonomical map, three separate analyses were undertaken:

3.1. χ^2 test

A χ^2 test is often used as a first step to see if any statistically significant patterns between site location and map units can be observed. The method has first been suggested by Hodder and Orton (1976), and has been applied on a number of occasions in the Netherlands for predictive modelling purposes (Verhagen 1995). However, χ^2 in itself does not say anything about the relative importance of map units for site location, and its application as the only statistical tool for predictive modelling has therefore been criticised on a number of occasions (Wansleeben and Verhart 1992, van Leusen 1996, Kamermans and Rensink 1999).

In order to better comply with the limitations of the χ^2 test (the demand of having at least 5 expected sites per map category, which is in turn dependent on the size of the site sample; see e.g. Thomas 1976) the taphonomical map was reclassified into 9 categories. Even so, in some cases the statistical requirements could not be met. In these cases, Yates’ correction has been applied to calculate χ^2. It should however be pointed out that in the case of less than 40 observations, the application of χ^2, even with Yates’ correction, should be regarded with suspicion.

3.2. Ratio of site to area proportions

The ratio of site (p_s) to area (p_a) proportions is a simple and straightforward way to look at the importance of certain map categories for site location. This ratio has for example been used in the Netherlands to create the Indicative Map of Archaeological Values (Deeben et al. 1997). However, it does not provide a relative weighting of the categories according to size. This problem is best illustrated by taking the zero site case: a large unit without sites will be less important for site location than a small unit without

1	colluvial deposits (1,14,18)
2	stable Pleistocene alluvial fans and terraces (2,9)
3	unstable Pleistocene alluvial fans and terraces (3,10)
4	recent alluvial fans, terraces and riverbeds (4,5,6,7,8)
5	*cuvettes* (11,12)
6	loess formations (13)
7	resistant rocks (15)
8	intermediate rocks (16)
9	soft rocks (17)

Table 3: Reclassification of the taphonomical map into 9 categories.

sites (in order words, it is statistically more significant). Calculated p_s/p_a values however, will give a value of 0 for both units, thereby attributing them equal importance.

In order to account for this effect, Atwell and Fletcher (1985, 1987) suggested calculating a statistic that is described as a relative weight factor for each map unit. In the case of three map-units a, b and g, the following weights are calculated:

$$A = \frac{a^{'}bc}{a^{'}bc + ab^{'}c + abc^{'}}$$

$$B = \frac{ab^{'}c}{a^{'}bc + ab^{'}c + abc^{'}}$$

$$C = \frac{abc^{'}}{a^{'}bc + ab^{'}c + abc^{'}}$$

where

a, b, c = area proportion of map units α, β and γ,
a', b', c' = site proportion of map units α, β and γ.

This is arithmetically equivalent to dividing each p_s/p_a value found by the sum of all p_s/p_a values, from which it follows that the relative weights calculated with the Atwell-Fletcher method are only normalised p_s/p_a calculations. They will therefore not fully solve the problem of relative weights.

Apart from that, the p_s/p_a calculations do not say anything about the statistical significance of the observed pattern. Atwell and Fletcher (1985, 1987) suggest to test the significance of the pattern by means of comparing the weights to those obtained by simulated site location patterns, a method applied by Wansleeben and Verhart (1992) and Kamermans and Rensink (1999). This analysis depends on the creation of random site distribution maps against which to test the actual pattern. Unfortunately, a random point generating routine is not supplied with ARC/INFO (which was used for the Tricastin-Valdaine model), and time did not permit us to write a separate routine, so the simulation was not performed for this study.

3.3. K_j method

A more complex method of assessing the importance of map categories for site location is the use of the K_j parameter. This parameter was developed by Wansleeben and Verhart (1992), and is defined as follows:

$$K_j = \sqrt{\left(p_s\left(p_s - p_a\right)\right)} .$$

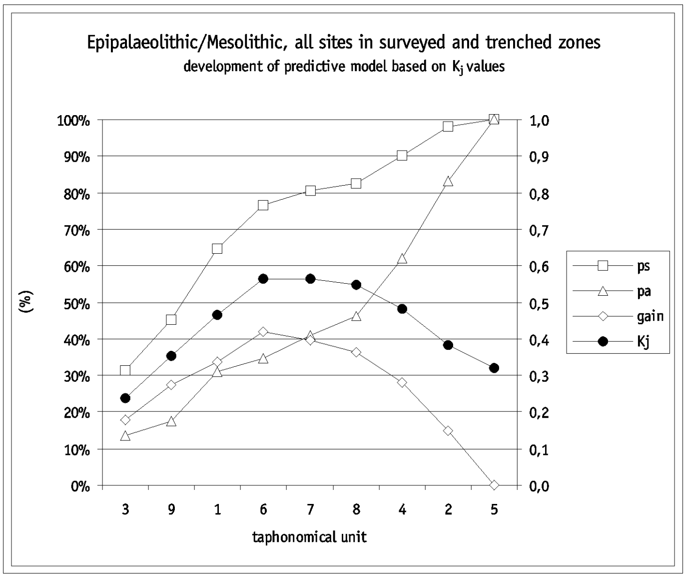

Figure 2: Example of the development of the K_j model for the Epipalaeolithic/Mesolithic period, all sites in surveyed and trenched zones. Units 3, 9, 1 and 6 have a strong positive predictive power, units 7 and 8 are more or less neutral, and units 4, 2 and 5 have a strong negative predictive power.

In the original equation, $p_s - p_a$ is divided by p_w (the proportion of the area without sites); however, this modification is only useful when (hypothetical) site surfaces are used, which is not the case for this model. K_j is calculated for each map category. The category that yields the highest K_j value is considered most successful. In an iterative procedure K_j is calculated again, including the next most successful category in the model until all categories have been included. The utility of K_j is that it takes into account the relative importance of the observed site densities: a small unit with high site densities will not necessarily be considered the most successful. Each time K_j is calculated, the gain ($p_s - p_a$) can be calculated to assess the performance of the model. A model with high predictive power will have high gain values (Kvamme 1989).

Wansleeben and Verhart (1992) state that the actual performance of the model increases as long the value of K_j increases on each consecutive run. However, we find in a number of instances that the gain is dropping while K_j is still increasing. This is because the equation attributes a higher weight to categories that contain a large number of sites. A gain of 40% can be achieved by a model that contains 50% of the sites on 10% of the surface, but also by a model that contains 80% of the sites on 40% of the surface. The K_j method decides that in the latter case the model performs better, although the gains obtained are equal. However, for the purposes of archaeological resources management, it seems that a model based on gain values is more useful, as the total surface to be considered is smaller.

In the cases that were analysed for this study, we often see categories that contribute strongly to the increase in gain and K_j. Other units will only have a limited effect on the total gain, and there are also units that will strongly decrease the gain of the model. In other terms, these groups may be said to have a positive, neutral and negative predictive power (or high, intermediate and low to use a more traditional terminology). These groups may easily be identified by plotting the development of the model in a graph, and one example of these is given in figure 2.

No.	Taphonomical unit	km^2	p_a	n	p_s	$K_{j(MAX)}$	rank	$p_{s(CUM)}$	$p_{a(CUM)}$	gain
1	colluvial deposits	6.6436	13.5%	10	0.1961	0.4663	3	64.7%	31.1%	33.6%
2	stable Pleistocene alluvial fans and terraces	10.4040	21.1%	5	0.0980	0.3828	8	98.0%	83.1%	14.9%
3	unstable Pleistocene alluvial fans and terraces	6.6368	13.4%	16	0.3137	0.2372	1	31.4%	13.4%	17.9%
4	recent alluvial fans, terraces and riverbeds	7.8804	16.0%	3	0.0588	0.4809	7	90.2%	62.0%	28.2%
5	cuvettes	8.3500	16.9%	1	0.0196	0.3187	9	100.0%	100.0%	0.0%
6	loess formations	1.7188	3.5%	6	0.1176	0.5660	4	76.5%	34.6%	41.9%
7	resistant rocks	3.1048	6.3%	2	0.0392	0.5637	5	80.4%	40.9%	39.5%
8	intermediate rocks	2.5740	5.2%	1	0.0196	0.5466	6	82.4%	46.1%	36.3%
9	soft rocks	2.0788	4.2%	7	0.1373	0.3519	2	45.1%	17.6%	27.5%
	TOTAL	49.3912	100.0%	51	1.00					

Table 4: Example of the calculation of K_j for the Epipalaeolithic and Mesolithic, using the surveyed and trenched zones with the full site sample. n = number of observed sites.

4. The predictive model: Results of site location analysis

4.1. Epipalaeolithic and Mesolithic (ca. 12,000-6800 BP; Azilian, Sauveterrian and Castelnovian cultures)

The calculated χ^2 values (with Yates' correction) for the Epipalaeolithic and Mesolithic sites indicate that the taphonomical units are significant for site location at the 99.9% probability level in all analysis windows.

When looking at the ratio of site to area proportions, it is clear that the loess formations show very high p_s/p_a values for all analysis windows. For the full study region, the unstable Pleistocene alluvial fans and terraces also have very high p_s/p_a values. However, in the surveyed zones the soft rocks seem more important. Low p_s/p_a values are observed for the recent alluvial fans, terraces and riverbeds, the intermediate rocks and the *cuvettes*. The recent alluvial fans, terraces and riverbeds are clearly less important for the visible sample than for the full sample. Even though only six buried sites have been observed for this period, they do seem to a have a (limited) effect on the analysis results.

The K_j model that was developed for all analysis windows is rather strong. Maximum K_j and gain values decrease when the surveyed zones are used instead of the full region, and the overall performance is weaker when the full sample is included. It is absolutely clear that map units 3, 1, 9 and 4 are the most important ones for site location. The models are less clear about the units with negative predictive power, so most shifts in ranking are observed for these categories. The pattern of site location observed largely conforms to the pattern obtained with p_s/p_a values, with one notable exception: the position of the loess formations is much less dominant than could be expected from the p_s/p_a calculations. This is because the actual gain obtained by including the small unit of loess formations first in the model is less than the gain that can be achieved by including the large unit of unstable Pleistocene alluvial fans and terraces. This clearly demonstrates that the K_j model is able to perform a relative weighting of map categories.

It can be concluded that the known site sample is representative for the area. Neither the restricted analysis, nor inclusion of the non-visible sites leads to drastic changes in observed site location preference. The most important units for site location are the unstable Pleistocene alluvial fans and terraces, the colluvial deposits, the soft rocks and the loess formations. The observed pattern is distinct, as is demonstrated by the high maximum K_j and gain values observed.

It seems that Epipalaeolithic/Mesolithic settlement is strongly concentrated on the intermediate elevations (with the exception of the stable Pleistocene alluvial fans and terraces), avoiding both the humid zones and the hills. This under-representation of settlements in landscape units that are marked by numerous geomorphological events since the end of the Late Glacial is probably the consequence of taphonomical bias. The observed absence of buried sites can be attributed to strong erosion of the recent alluvial fans, riverbeds and the lower reaches of the *cuvettes* between 6400-6200 BP, associated with the first evidence of agropastoral activity in the south of France and an abrupt hydroclimatic event (Berger 1996, Berger and Brochier in press). Furthermore, the Epipalaeolithic/Mesolithic sites found are usually small in size and are characterised by a dispersed lithic scatter, and as such are difficult to detect, even by means of trenching. A geographical bias of Epipalaeolithic/Mesolithic sites is observed for the Valdaine basin. This bias may be the result of selective surveying.

4.2. Early Neolithic (ca. 6500 – 5800 BP; Cardial and Epicardial cultures, and the transition of Cardial to Chassean)

The total number of early Neolithic sites is only 38, which means that calculated χ^2 values are not reliable.

When looking at the ratio of site to area proportions, it is clear that the loess formations show very high p_s/p_a values for the full study region. The unstable Pleistocene alluvial fans and terraces and colluvial deposits also have very high p_s/p_a values. Low p_s/p_a values are observed for the resistant and intermediate rocks. However, in the surveyed zones the position of the loess formations is less dominant. When including the non-visible sites in the sample, the recent alluvial fans, terraces and river beds become much more important, largely at the expense of the loess formations and colluvial deposits. This again illustrates the importance of including these sites in the analysis, even when working with small samples.

The models developed with the K_j method are unstable. Both maximum K_j and gain values are variable. Units 1, 3 and 6 seems to be most important for site location. It is also obvious that by including the non-visible sample, the importance of recent alluvial fans, terraces and riverbeds becomes much larger.

It is difficult to draw conclusions about site location preference for the early Neolithic because of the low number of sites. This low density is in part the consequence of the major erosion phase occurring between 6400 and 6200 BP (Berger and Brochier in press). The K_j model for the full sample indicates one important change compared to the Epipalaeolithic and Mesolithic: the important position of the recent alluvial fans, terraces and riverbeds. Since only the earliest horizon of early Neolithic occupation is destroyed or reworked, this implies that the more recent horizons have been preserved under younger alluvial deposits.

4.3. Middle Neolithic (ca. 5800 – 5000 BP; Chassean culture)

The calculated χ^2 values (with Yates' correction where applicable) for the middle Neolithic sites indicate that the taphonomical units are significant for site location at the 99.9% probability level. For the visible sample however, the number of sites drops below 40 for the surveyed zones, which makes the χ^2 calculation unreliable.

For the full study region, the unstable Pleistocene alluvial fans and terraces and the loess formations have the highest site densities. Very low site densities are found on the resistant and intermediate rocks. For the surveyed zones, the most important units are the soft rocks and the unstable Pleistocene alluvial fans and terraces, and low densities are observed for the *cuvettes*, resistant rocks and intermediate rocks. When comparing the visible sample to the full sample, there is marked increase in p_s/p_a for the recent alluvial fans and riverbeds, again pointing to the importance of the non-visible sites for the analysis.

The calculation of K_j for the visible sites results in strong models with high maximum K_j and gain values. However, when the non-visible sites are included in the models, they are considerably weaker. In spite of this, the importance of units 1, 3 and 9 is very clear for both the visible and full sample. Although the recent alluvial fans, terraces and riverbeds become more important when looking at the full site sample, the effect is less marked than for the early Neolithic.

It can be concluded that the known visible site sample is representative of the area. However, the inclusion of the non-visible sites shows that there is a strong effect of underestimation of the importance of the recent alluvial fans, terraces and riverbeds. A preference can be observed for the unstable Pleistocene alluvial fans and terraces, the colluvial deposits and soft rocks. Compared to the Epipalaeolithic and Mesolithic however, the recent alluvial fans, terraces and riverbeds are more important, at the expense of the loess formations. As the K_j models developed for the full sample for the middle Neolithic are not very strong, this implies that settlement is more dispersed than during the Epipalaeolithic and Mesolithic.

4.4. Late Neolithic (ca. 5000 – 3700 BP; including Chalcolithic)

The calculated χ^2 values (with Yates' correction where applicable) for the late Neolithic sites indicate that the taphonomical units are significant for site location at the 99.9% probability level, with the exception of the visible sample for the surveyed zones.

The p_s/p_a ratios obtained for the full study region show that the loess formations and the unstable Pleistocene alluvial fans and terraces have the highest site densities. No very low site densities are found. In the restricted zones, the most important units are the soft rocks, the loess formations and the unstable Pleistocene alluvial fans and terraces. When comparing the visible sample to the full sample, there is a marked increase in p_s/p_a for the recent alluvial fans and riverbeds for the surveyed and trenched zone, again pointing to the importance of the non-visible sample for the analysis.

The calculation of K_j for the full study region produces a weaker model than for the surveyed zones. It is clear that unit 3 is the most important unit for site location; however, the models differ considerably in attributing a ranking to most other units. For the full sample, the recent alluvial fans, terraces and riverbeds are clearly more important than for the visible sample. In all cases, the *cuvettes* and stable Pleistocene alluvial fans and terraces have a negative predictive power.

It can be concluded that the known site sample is not representative of the area, as the performance of the K_j models differs considerably when looking at the restricted zones. From the available data it can be deduced that the higher elevations (soft rocks, intermediate rocks and resistant rocks) may have been neglected in previous surveys. Furthermore, the inclusion of the non-visible sites shows that there is a very strong effect of underestimation of the importance of the recent alluvial fans, terraces and riverbeds. A preference can be observed for the recent alluvial fans, terraces and riverbeds, unstable Pleistocene alluvial fans and terraces, and soft rocks. As the K_j models developed for the full sample for the late Neolithic are not very strong, this implies that settlement is rather dispersed. In fact, during this period a slight shift in occupation towards the higher elevations is observed.

4.5. Bronze age (ca. 3700 – 2700 BP)

The calculated χ^2 values for the Bronze Age sites are not reliable for the visible site sample, as it only includes 24 sites. For the full sample the calculated value (with Yates' correction when applicable) is significant for site location at the 99.9% probability level for the whole region, but for the surveyed zones it is not.

When looking at the p_s/p_a ratios obtained for the visible sample, the soft rocks clearly exhibit the highest values when looking at the whole region. However, when looking at the surveyed zones, the resistant rocks are most important, followed by the soft rocks and unstable Pleistocene alluvial fans and terraces. Low values are found for the loess formations, intermediate rocks and stable Pleistocene alluvial fans and terraces. When including the non-visible sample, the resistant rocks seem most important when looking at the whole region. Within the surveyed zones, the recent alluvial fans, terraces and riverbeds are most important. The observed patterns seem highly irregular; however, when looking at the two reliable samples, it is obvious that a change in importance can be observed from resistant rocks to recent alluvial fans, terraces and riverbeds.

When looking at the models developed with the K_j method, it is clear that the performance of the models is better when only looking at the visible sample. The inclusion of the non-visible sample results in a more important position for the recent alluvial fans, terraces and riverbeds. When looking at the surveyed zones for the full sample, the importance of the resistant rocks for site location is clearly diminished.

Obviously, the visible site sample is wrongly representing both the quantities of Bronze Age sites, as well as their distribution in the landscape. The visible sample contains relatively more sites on resistant rocks. This can be related to a small amount of cave settlements on this unit near Donzère, which are not included in the surveyed zones. This is due to the history of regional archaeological research, which privileged karstic areas (secondary calcareous formations) until the last decade (Berger et al. 2000). Apart from that, the role of the recent alluvial fans, terraces and riverbeds is clearly underestimated when only looking at the visible sample. When looking at the total sample, a preference is found for site location on recent alluvial fans, terraces and riverbeds, unstable Pleistocene alluvial fans and terraces, and soft rocks. The preference for the river valleys, together with an increasing importance of the *cuvettes* indicates that humid zones become more important for settlement. However, the K_j models developed for the full sample are not very strong. Together with the low χ^2 values found this implies that the settlement pattern is highly dispersed and might even be randomly distributed. This is certainly due to the strong increase in occupation during the final Bronze Age (3200-2700 BP). The original settlement pattern may however have been more strongly concentrated in the alluvial plains. Many Bronze Age sites have been found in secondary position down terrace slopes or in river channels as a consequence of a major erosion phase between 2700 and 2300 BP (known as the first Iron Age hydroclimatic crisis), following a long phase of fluvial stability during the Bronze Age period (Berger et al. 2000). This might imply that many more have been totally destroyed in this period.

4.6. Iron age (2700 – 2200 BP; Hallstatt and La Tène cultures)

The calculated χ^2 values for the Iron Age sites are not reliable for the visible sample in the surveyed zones, as only 25 sites are found there. In the other cases, the calculated values (with Yates' correction when applicable) indicate that the taphonomical units are not significant for site location at the 99.9% probability level for the whole region, with the exception of the visible site sample for the whole study region.

The p_s/p_a ratios obtained for the visible site sample for the full study region indicate three important units: the resistant rocks, the soft rocks and the *cuvettes*. For the surveyed zones, the resistant rocks are clearly the most important. When looking at the full sample for the whole region, very little difference in site density is found. However, in the restricted zones the resistant rocks show the highest p_s/p_a ratios. It is interesting to observe that the importance of the resistant rocks increases when looking at the surveyed zones: this seems to indicate that more sites (fortified *oppida*) may be found on this unit, but may have been overlooked outside the surveyed areas.

The calculation of K_j results in rather weak models, with the exception of the visible sample for the restricted zones. This better performance for these zones is associated with the clear preference for resistant rocks in these windows. A dramatic shift in importance is observed for the recent alluvial fans, terraces and riverbeds when looking at the full sample for the full region and the surveyed and trenched zones.

The known site sample is not representative for the whole region, as the performance of the K_j models is stronger for the surveyed zones. The large differences in K_j and gain values between the visible and full sample indicate that the visible sample is not representative for the actual settlement distribution. From the full sample it can be concluded that the recent alluvial fans, terraces and riverbeds, resistant rocks and unstable Pleistocene alluvial fans and terraces are most important for site location. The important position of resistant rocks is related to the existence of hill forts. Most of the sites found by trenching under alluvium can be identified as small farm sites dated to the second Iron Age.

However, the weak performance of the K_j models for the full sample together with the low c^2 values can be taken as an indication that settlement distribution in the Iron Age is close to random. This is totally contradictory to the existing theories on Iron Age site location before the trenching campaigns started (cf. Odiot 1985).

4.7. Conclusions

The results of the site location analysis for the area point to large differences in reliability of the site samples. Especially for those periods where large numbers of sites have been discovered by trenching (notably the early Neolithic, late Neolithic, Bronze Age and Iron Age) it is clear that the sedimentary areas are much more important for site location than can be deduced from the visible site sample alone. Furthermore, the visible site sample is not always representative for the area, as becomes clear for both the late Neolithic and the Iron Age. Any predictive map to be made for the area will therefore have to include both the extent of the prospected zones as well as the information on buried site locations.

It also seems clear that site location characteristics become less pronounced in the later occupation phases. The strong preference for the intermediate elevations in the Epipalaeolithic and Mesolithic is gradually replaced by a rather dispersed settlement pattern in the Bronze Age and Iron Age. This can largely be attributed to the effect of differential conservation for the various periods. From the analysis results it follows that the definition of zones of Epipalaeolithic and Mesolithic settlements will be much easier than for the later periods. It may be possible that for these later periods, site location preferences are dependent on landscape elements that are not included in the taphonomical map, either because they are too small in size, or because the soil units that were aggregated to create the map are not particularly relevant. A more detailed reconstruction of the (palaeo-)landscape is therefore needed to arrive at an alternative explanation of site location preferences for these periods.

From the point of view of reliability, the best model will be based on the results of the full sample for the surveyed and trenched zones (analysis window SURV(ALL)). The results of the χ^2 test indicate that with the exception of the early Neolithic, sufficient

No.	Taphonomical unit	E/M	EN	MN	LN	BA	IA
1	colluvial deposits	6,2%	8,3%	7,3%	-0,1%	-2,3%	0,5%
2	stable Pleistocene alluvial fans and terraces	-13,2%	-16,7%	-9,7%	-14,4%	-21,1%	-14,1%
3	unstable Pleistocene alluvial fans and terraces	17,9%	12,6%	20,5%	16,6%	8,8%	5,2%
4	recent alluvial fans and riverbeds	-8,1%	18,8%	1,0%	2,4%	19,6%	12,0%
5	cuvettes	-14,9%	-12,6%	-13,1%	-11,9%	-1,4%	-7,6%
6	loess formations	8,3%	0,9%	0,3%	3,2%	-1,3%	1,2%
7	resistant rocks	-2,4%	-6,3%	-6,3%	0,4%	-1,8%	7,7%
8	intermediate rocks	-3,3%	-5,2%	-5,2%	-1,9%	-3,0%	-2,9%
9	soft rocks	9,5%	0,1%	5,2%	5,8%	2,5%	-1,9%

Table 5: Gain development of K_j models for each chronological period (full site sample, surveyed zones).

sites are available in order to construct a model for this window based on taphonomical categories. However, for the Bronze Age and Iron Age significance requirements are not met, so a predictive map based on the χ^2 test for these periods will not be very useful, as the settlement pattern can also be explained by a random distribution of sites. This leaves us with three periods where a useful predictive model based on the χ^2 test can be constructed with a high degree of confidence, the Epipalaeolithic/Mesolithic, middle Neolithic and late Neolithic. These models can then be weighted by means of p_s/p_a ratio, or by using the Atwell-Fletcher method.

It is interesting to observe that valid K_j models may still be developed in cases where the χ^2 test does not meet significance requirements. This is explained by the emphasis placed by the K_j method on the combination of large number of sites and large area units, whereas χ^2 can better be regarded as a measure of concentration of sites. The value of χ^2 depends on the difference between observed and expected sites. Within the total sample, this difference is potentially largest for small area units. In the case where 10 sites are found where only 1 was expected (a difference of 9), the resulting value of χ^2 will be 9.00. If 59 sites are found where 50 are expected however, χ^2 will only be 1.62. In the K_j model such a unit will nevertheless be considered more important than the smaller unit with only 10 sites (as is clearly observed for Epipalaeolithic and Mesolithic, where the strong concentration of sites on loess formations is not reflected in the K_j model).

It remains an open question if K_j models may be used when the number of available sites is very low. The results obtained for the early Neolithic seem to indicate that with low numbers of sites the models become unstable.

A simple method to arrive at a predictive map based on K_j is by plotting the development of the model, either by gain or by the value of K_j itself. Table 5 shows the gain per map category for each chronological period. These individual gain values can be used as a weight factor for each map category. If a qualitative mapping is desired, the mapping becomes a question of deciding on the limits between positive, neutral and negative predictive power (figure 4).

This method of weighting is preferable over the Atwell-Fletcher method. The actual ranking of the units obtained with the K_j method is different, reflecting their relative importance and the "zero site" categories are given different weights, depending on their size. However, the method applied does not say anything about absolute site densities. In order to compare the weights per period, a correction should be applied for the total amount of sites. When

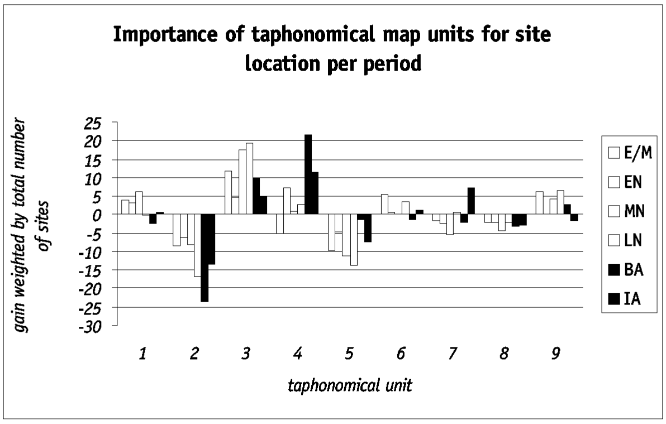

Figure 3: Development of the importance of the taphonomical map units for site location through time, by weighting the gain values from the K_j model by the total number of sites involved.

these weighed values are plotted in a histogram (figure 3) it is immediately clear which units are when important for site presence or absence.

5. Extrapolating site densities

Because of the relatively small number of sites per period in the trenched zones (which only occupy 0.4% of the area), and the fact that the area trenched is not fully representative of the total area, no model has been developed for the trenched zones alone. On the other hand, the trenched zones should give the most reliable estimate of site densities possible, because in theory no sites will escape discovery, whereas field walking will only yield those sites showing significant amounts of archaeological remains at the surface. Within the trenched zones we therefore have the most reliable site sample that can be obtained by means of archaeological survey.

Given this reliable sample, it is theoretically possible to perform an extrapolation of the actual amount of sites per map category. The units where most trenches have been dug are the zones of potential sediment accumulation during the Holocene, i.e. the recent alluvial fans, terraces and riverbeds, the colluvial deposits, the unstable Pleistocene alluvial fans and terraces, and the *cuvettes*. In these units, 0.71% of the total surface has been trenched. For these areas, a cautious prediction can be made of the total number of sites to be found. The total number of sites to be expected is

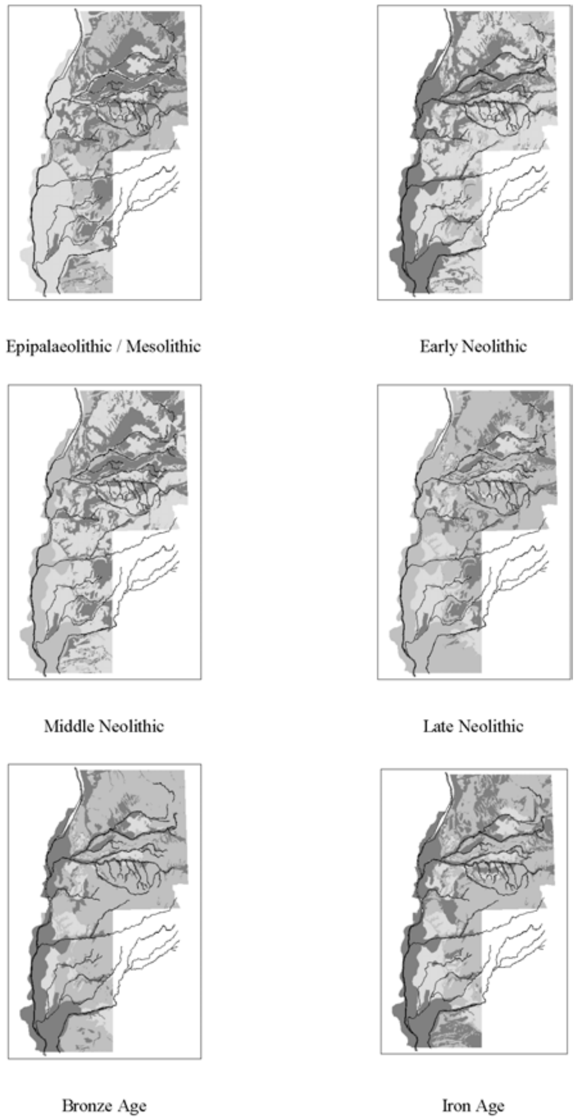

Figure 4: Predictive maps for each of the analyzed periods. Dark grey = positive; medium grey = neutral; light grey = negative.

simply a multiplication of the number of sites found per area unit and the total area:

$$X = N\frac{x}{n}$$

where

X = total number of sites
N = number of area units
x = number of sites found
n = number of area units analysed.

However, this extrapolation is not very useful when the error margin is not known. The standard error of the estimate (Shennan 1988:310) is given by:

$$s_x = N\left(\frac{s}{\sqrt{n}}\right)\cdot\left(1-\frac{n}{N}\right)$$

where

s = standard deviation of the sample.

All probabilistic sampling studies in archaeology depart from the assumption that basic sampling units like survey quadrats (Nance 1990), or even parcels of land (Kvamme 1990) can be defined. Casley and Lury (1982:75) state:

> If the total population of the area is very large, compared to the sample to be selected, the variance of, and hence the precision of estimates calculated from the sample data is a function of the absolute number of sample units, not the sampling fraction.

The basic problem to be solved in order to obtain reliable standard error estimates is therefore defining the size of the sampling units. The smaller these units are, the larger will be the standard errors. In the case of the trenched zones however, the term sampling unit is virtually without meaning, as we can assume that the area trenched has been sampled completely, and therefore no counts per area unit can be performed: the area trenched is equal to one sampling unit. However, with a sample size of 1, the standard errors can not be calculated. The only practical solution – although not an elegant one - is to use the mean surface of the sites as the basic sampling unit. In this case, each individual observation is either a site or a non-site (in statistical terms: we are dealing with a population of ones and zeros), and then the standard deviation of the sample can be calculated with (Shennan 1988:311):

$$s = \sqrt{\frac{p(1-p)}{n}}$$

where:

p = the proportion of interest.

Stratified sampling theory then allows us to narrow down the standard errors for the total sample somewhat by applying the following equation:

$$s_{st} = \sqrt{\sum\left(\frac{N_k}{N}\right)^2\cdot s^2}$$

where:

s_{st} = standard error for the complete sample
N_k = size of stratum k.

The site surfaces involved can of course not be measured with extreme accuracy. Although surface estimates have been made for most of the sites involved, these are given as ranges from 0.0-0.1 ha, 0.1-0.2 ha, 0.2-0.5 ha, 0.5-1.0 ha and so forth. The surfaces given in table 6 can therefore only be regarded as rather crude approximations (Epipalaeolithic/Mesolithic not included because of lack of buried sites).

When using the site surface estimates from table 6, the standard errors obtained in table 7 are relatively large. Obviously, the low number of "ones" compared to the "zeros" leads to this large standard error. Because of this, decreasing the number of zeros (large site surfaces; middle Neolithic) is more efficient in reducing the standard error than increasing the number of ones (more sites; Bronze Age).

The site surface estimations allow us to perform the same extrapolation for the field walked areas. In general, the estimated surfaces for the visible sites are much larger than for the non-visible sites, because of the spread of archaeological artefacts over the

Period	non-visible sites m^2	n	visible sites m^2	n
Epipalaeo-Mesolithic	-	-	78438.6	57
Early Neolithic	3029,4	17	73700.0	20
Middle Neolithic	6071,4	28	127590.0	50
Late Neolithic/Chalcolithic	4187,5	40	76890.6	64
Bronze Age	1323,5	85	38948.7	39
Iron Age	3533,3	45	16954.5	11
All periods	3653,5	215	78634.9	241

Table 6: Mean site surfaces for all periods. n = number of sites for which a surface estimate was available.

No.	Taphonomical unit		E/M	EN	MN	LN/C	BA	IA	ALL
1	Colluvial deposits, non-visible sites	X	-	198.7	993.4	0.0	794.7	0.0	1986.7
		s_x	-	197.2	217.9	0.0	393.7	0.0	606.8
	Colluvial deposits, visible sites	X	201.8	80.7	161.4	161.4	20.2	0.0	625.6
		s_x	56.7	37.4	49.6	51.5	19.1	0.0	83.3
3	Unstable Pleistocene alluvial fans and terraces, non-visible sites	X	-	154.6	154.6	154.6	77.3	77.3	618.2
		s_x	-	107.6	53.7	77.8	76.2	76.1	212.7
	Unstable Pleistocene alluvial fans and terraces, visible sites	X	193.5	41.5	193.5	152.0	41.5	13.8	635.6
		s_x	43.2	21.8	39.9	39.3	22.0	12.8	53.5
4	recent alluvial fans and riverbeds, non-visibles sites	X	-	1273.0	763.8	1273.0	1527.6	763.8	5601.2
		s_x	-	562.8	218.2	407.1	618.7	436.9	1141.0
	recent alluvial fans and riverbeds, visibles sites	X	36.3	36.3	72.6	36.3	36.3	0.0	217.7
		s_x	35.1	35.1	49.0	35.1	35.2	0.0	83.5
5	Cuvettes, non-visible sites	X	-	0.0	0.0	59.9	299.2	59.9	418.9
		s_x	-	0.0	0.0	42.5	131.2	58.7	153.8
	Cuvettes, visible sites	X	8.5	8.5	0.0	16.9	8.5	8.5	50.8
		s_x	7.4	7.4	0.0	10.5	7.5	7.5	17.7
	Total, non-visible sites	X	-	1626.2	1911.7	1487.4	2698.8	900.9	8625.0
		s_{st}	-	607.3	313.7	417.6	750.7	448.4	1321.7
		%	-	37.3	16.4	28.1	27.8	49.8	15.3
	Total, visible sites	X	440.0	166.9	427.5	366.7	106.4	22.3	1529.8
		s_{st}	82.0	57.6	82.3	76.5	47.3	15.5	133.8
		%	18.6	34.5	19.3	20.9	44.5	69.5	8.7

Table 7: Estimated number of sites (X) and standard error (s), all periods except Palaeo-Mesolithic.

surface by erosion and agricultural practices (table 6). This obviously means that the number of “zeros” will be substantially reduced, regardless of the number of sites involved.

The extrapolation of the amount of sites for the field walked zones yields the figures in table 7. The total number of sites calculated is much lower than the number obtained for the trenched zones. At the same time, standard errors are much smaller as well. An extrapolation based on the visible sites in the field walked zones is clearly strongly underestimating the number of sites to be found in the sedimentary zones. Furthermore, an extrapolation based on the larger site surfaces provides “false security” when it comes to the accuracy of the estimates.

Theoretically, it is possible to calculate the size of the area that is needed to bring back the standard errors to a more reasonable limit. This is done applying the following equation (Shennan 1988:310):

$$n = \left(\frac{ZsN}{d}\right)^2$$

where:

Z = confidence limit of the estimate in standard deviation units

d = desired tolerance of the estimate.

Z can be used to define a confidence limit for the results of the equation; a Z value of 2.0 equates to a confidence interval of 95.46%. A finite population correction (n / (1 + n/N)) should be applied afterwards obtain the correct values for the required sample size. The third column of table 8 shows the figures obtained when d is set to +/-10% for each single map category. These figures show that it will be necessary to trench about 26 times the area that has currently been trenched in order to obtain a 95.46% reliable estimate within 10% of the total number of sites to be found in the area covered by the four map categories. In general it

No.	Taphonomical unit	d (abs)	d (%)	n (%)	d (abs)	d (%)	n (%)
1	colluvial deposits	198.67	10.00%	15.94%	205.55	10.35%	15.05%
3	unstable Pleistocene alluvial fans and terraces	61.82	10.00%	38.61%	131.72	21.31%	12.17%
4	recent alluvial fans and riverbeds	560.12	10.00%	6.17%	419.79	7.49%	10.47%
5	*cuvettes*	41.89	10.00%	48.25%	105.44	25.17%	12.83%
	total area	862.50	10.00%	18.60%	862.50	10.00%	12.11%

Table 8: Calculated values of n for an accepted tolerance d of 10%, at the 95.46% confidence limit. Columns 1-3 show the results when d=10% for all map units, columns 4-6 show the results when d is weighed according to map unit size.

can be stated that the smaller the number of observed sites in a map unit, the more area needs to be trenched. This means that for statistically reliable estimations of site numbers per map category, the areas with low probabilities of site occurrence should be surveyed more intensively than the areas with high probabilities. In order to reduce the amount of area to be surveyed, while still achieving a tolerance of +/-10% for the whole area, the accepted tolerances for the individual map units may be weighed according to the units' size, as is shown in the last three columns of table 8. Of course trenching of such large areas is not feasible – it will therefore be more practical to combine field walking and augering for such an exercise.

6. Conclusions

We set out to investigate the effect of non-random sampling on the interpretation of site quantities and site location distribution in the landscape of the Tricastin-Valdaine region. The results of the predictive modelling have shown that this effect may be very strong indeed. Especially for the later periods, two effects are observed: firstly, the visible sample is not always representative of the sites found in the field walked zones, which means that certain types of sites are easily overlooked during a field walking campaign.

Secondly, the amount of buried sites is very large for the later periods. These sites are found in landscape units that will not yield a comparable amount of visible sites (this is especially true for the recent alluvial plains and riverbeds). An interpretation of site distribution based on the visible sample alone will therefore strongly underestimate the importance of the sedimentary zones for site location.

The actual quantities of sites extrapolated for the sedimentary zones are very large. Basically, it means that the total number of buried sites to be expected in the sedimentary areas is approximately four to seven times as large as the number of visible sites. The actual reliability of the estimate is difficult to judge, given the crude approximation of mean site surfaces that was used to obtain the sampling unit size. However, these mean site surfaces used are not unreasonable estimates, and obtaining more accurate size data will therefore not drastically change the outcome of the extrapolation because of the effect of the small site surfaces when compared to the total area.

The results of both the predictive modelling and the extrapolation strongly emphasize the need for sub-surface surveying methods in sedimentary areas. This need is long recognised in the Netherlands, where augering has become in integral part of archaeological survey in sedimentary areas, and has led to the discovery of many hitherto unknown buried prehistoric sites, sometimes at considerable depth (e.g. Haarhuis 1995, 1996). The results of the current study indicate that there is no reason to suspect that the situation in France will be very different.

As a last remark, it can be stated that the currently presented predictive model is not very specific for the later periods, as is demonstrated by the lower gain and K_j-values obtained. This means that the model is not very well suited as a tool to guide future surveys, or as an instrument to judge the effect of infrastructural and building activities on the archaeological record. Obviously, the model was not primarily constructed as a tool for archaeological resources management. It served to demonstrate that taphonomy is far more important for site location than was previously thought, and showed the need for a reassessment of both existing site location theory as well as research strategies. A useful model for archaeological resource management is better served by combining elements of the inductive and deductive lines of reasoning, which will probably result in models that make the most of our current archaeological knowledge (Verhagen et al. in press). This might include further research into the palaeogeography of the area, and the analysis of other site location parameters - which may be different for different archaeological periods or parts of the landscape.

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