

Using the Three-Dimensional Capabilities of GPR to Reinterpret the Roman Town of *Mariana* (Corsica)

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Abstract

From a magnetic survey conducted in 2006 over the roman town of *Mariana* (Corsica) it was concluded that the town extended over most of the prospection area. A possible industrial zone was detected, and the orientation of most buildings suggested a close relationship to the excavated parts. No clear road traces could be detected, except for one of east-west alignment. The 2007 GPR survey over the clearest building structure detected in the magnetic survey showed that this building originally had a regular plan. Shallower walls run through the original structure, and appear east and west of the original building. This gives a possible explanation for the absence of a road network in the magnetic survey: zones devoid of structures in the early phases are possible locations for roads. The GPR survey also allowed a clearer analysis of a magnetically 'empty' area. A few linear anomalies, very weak in the magnetic survey, can be connected to GPR traces more to the south. This contradicts the hypothesis that this area represents the forum of *Mariana*.

Keywords

Ground-penetrating radar, fluxgate gradiometer survey, Roman period, Corsica, archaeological interpretation

1. Introduction

Mariana, situated in the valley of the Golo (North-East Corsica, *Fig. 1*) was founded as a Roman *colonia* by Marius in 100 BC. Its main development took place at the beginning of the Roman Empire, but the town flourished again in the Late Roman and Early Christian period, when it became a bishop's seat. Several excavations were conducted in the 1930s by Leschi and Chauvel, but the location of the trenches is unknown. Further excavations took place in the 1970s in the area south of the former cathedral of Santa Maria Assunta (*La Canonica*) (Moracchini-Mazel 1971; 1974). Roman houses and *tabernae*, an early medieval cathedral (replaced by the *Canonica*) and the medieval bishop's palace were unearthed (*Fig. 2*). These excavations were taken up again in 2000 and they continue until the present day, as part of the research project 'Mariana and the lower valley of the Golo from Iron Age to Medieval times' (Pergola forthcoming).

When compared with the hypothetical town limits derived from aerial photographs (*Fig. 1*), the excavations around the *Canonica* are eccentric and do not represent the town centre from the Early Empire. This was the main motive for a survey of the unexcavated area within the town, and of its immediate surroundings, starting in 2005 (Verdonck

and Vermeulen 2007). This survey included aerial photography, field walking, geomorphological research and test excavations. Additional information was derived from historical cartography.

Mariana is attractive for geophysical prospecting since there has been little recent development over the site. As the first assessment of the potential for geophysics on the site, a fluxgate gradiometer survey was conducted in September 2006. A smaller area was further investigated with ground-penetrating radar (GPR) in September 2007, in the fields north of the *Canonica* (*Figs. 2* and *4*). There the town centre with the *forum* was most likely to be found, and the results of the aerial photography were not very clear. This paper presents the results of both geophysical prospecting.

2. Methodology

2.1. Data collection

Grids of 20 by 20m were laid out using a total station Leica TCR 307, and the distance to a number of surrounding features (houses, roads, field boundaries) was measured so that the grid system could be fit into the cadastral plan of the town of Lucciana. Overall, the survey conditions were very good. The two fields were surrounded by metal fences, but there were

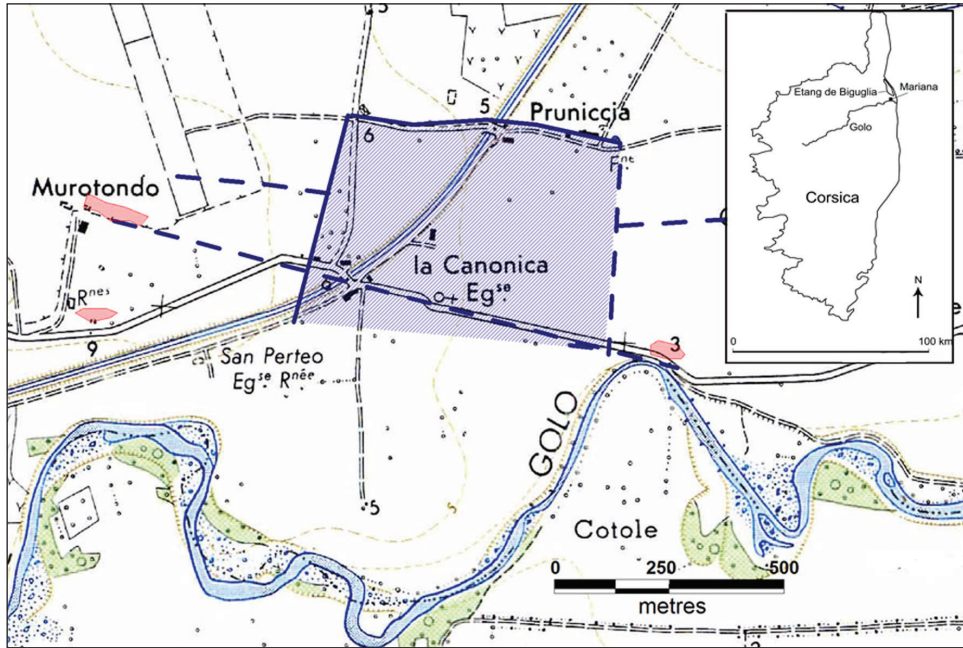


Fig. 1. Hypothetical perimeter of Mariana. Within the town, the Canonica and the nearby excavations are eccentric (Corsi et al. 2009).



Fig. 2. Aerial photograph of the Canonica and the nearby excavations (photograph F. Vermeulen).

few other physical obstructions and the grass was maintained short by sheep grazing.

The details on the fluxgate gradiometer and GPR surveys in *Mariana* are given in tables 1 and 2. The instruments used were a Geoscan Research FM256 fluxgate gradiometer and a Sensors & Software pulseEKKO PRO.

configuration	gradiometer
elevation of lower sensor	0.35m
elevation of upper sensor	0.85m
inline distance	0.25m
line separation	0.50m
traverse mode	parallel
resolution	0.1 nT
size of individual grids	20 x 10m
surface surveyed	13000m ²

Table 1. Fluxgate gradiometer survey parameters.

Antenna frequency	500 MHz
operating mode	step mode (odometer wheel)
inline distance	0.05m
line separation	0.25m
sampling interval	0.20 ns
time window	80 ns
stack	8
surface surveyed	1200m ²

Table 2. GPR survey parameters.

2.2. Data processing

The magnetometer data were processed using Geoplot 3.00. First, extreme values (over 100 nT), caused by metal fences and shallowly buried iron debris were replaced by dummy values. Furthermore, zero mean grid was applied and a few grids were developed to eliminate the drift from the magnetometer, still present after taking drift measurements in the field. A low-pass filter was used to eliminate high-frequency noise. As the inline distance of the sample was different from the line separation, a sinc interpolation



Fig. 3. Result of the fluxgate gradiometer survey in Mariana in 2006.

was applied to obtain an equal sampling density in both directions.

For the GPR measurements, the processing was done in Matlab 7.4, combined with MATGPR, an extensive freeware plug-in for GPR data analysis developed by A. Tzanis (Tzanis and Kafetsis 2004). A fixed gain was constructed, sufficiently enhancing the later reflections without enhancing the noise too much. Filtering occurred by means of a band-pass filter with cut-off frequencies 150 and 600 MHz. The background was removed by subtracting the mean of all traces from each individual trace. Diffraction hyperbolas were treated with a one-dimensional F-K migration algorithm, available in MATGPR. Migration was performed using a uniform velocity. Best results were obtained using a velocity of 0.07 m/ns, and time-to-depth conversion occurred using this velocity. As the site is flat, no corrections were made for the topography. Small differences in the number of traces per line were corrected using a linear interpolation.

Visualisation occurred by means of vertical sections and horizontal depth-slices, created by calculating the root mean square of the reflected amplitude of the radar waves within depth windows of 5cm thickness (Fig. 5). In the depth-slices, white represents high amplitudes (strong reflections), black represents low amplitudes (weak reflections). Moreover, a three-dimensional interpretation model was created (Neubauer *et al.* 2002, 154–155; Leckebusch 2003, 222) by demarcating areas with high reflectivity representing probable archaeological structures in each individual depth-slice, and then stacking these interpretation layers by assigning them to a specific depth (Fig. 7).

3. Results and interpretation

3.1. Fluxgate gradiometer survey

In figure 3, the results of the fluxgate gradiometer survey carried out in September 2006 are shown. An interpretation plan is presented in Fig. 4 (Verdonck 2006). In general, there is a weak magnetic contrast between



Fig. 4. Interpretation of the fluxgate gradiometer survey:
1 and 6: Buildings, 2: Street, 3: Industrial debris, 4: Kilns(?), 5: Probable archaeological feature.

the geology (mainly gravel and river boulders deposited by the river Golo) and the archaeological structures, mostly constructed from the same materials. The building structures are linear negative anomalies. Most of the anomalies have the same orientation as the excavated part of *Mariana* near the *Canonica* church. The clearest building plans could be discerned in the northern part of the field 1 (Fig. 4, No. 1). The orientation of two walls, found in a 12 by 2m test excavation (Fig. 6, No. 13), corresponds with the results of the fluxgate gradiometer survey. The walls have brick facades, although the negative magnetic anomalies suggest that they have a lower magnetic susceptibility than the surrounding soil. Another example of this can be found in Gaffney *et al.* (2000, 92–94).

Notwithstanding the dimensions of the surveyed area (13000m²), no clear traces of streets were found in the town, except one of east-west alignment (Fig. 4, No. 2). This street was not detected as a magnetic anomaly, but rather as the linear absence of anomalies, perhaps indicating that the streets were not metalled in this quarter of the town (Gaffney *et al.* 2000, 89). The absence of other linear areas may be explained by the fact that *Mariana* has known several occupation phases, with modifications in the road system.

A few strong anomalies in the southern part of field 1 (some 50m south of the east-west street) are thought not to be caused by shallowly buried recent iron objects, but suggest the presence of industrial activity. Anomaly No. 3, with values of up to 150 nT might represent heaps of industrial debris (slag). In area No. 4, there are a number of oblong anomalies with high altitude, suggesting thermoremanent structures such as kilns. Anomaly No. 5 is probably anthropogenic, but it is difficult to determine its function. Other anomalies could be of archaeological interest, but could also be of modern origin.

In the northern field (Fig. 4, field 2), the magnetic contrast between the archaeological features and the

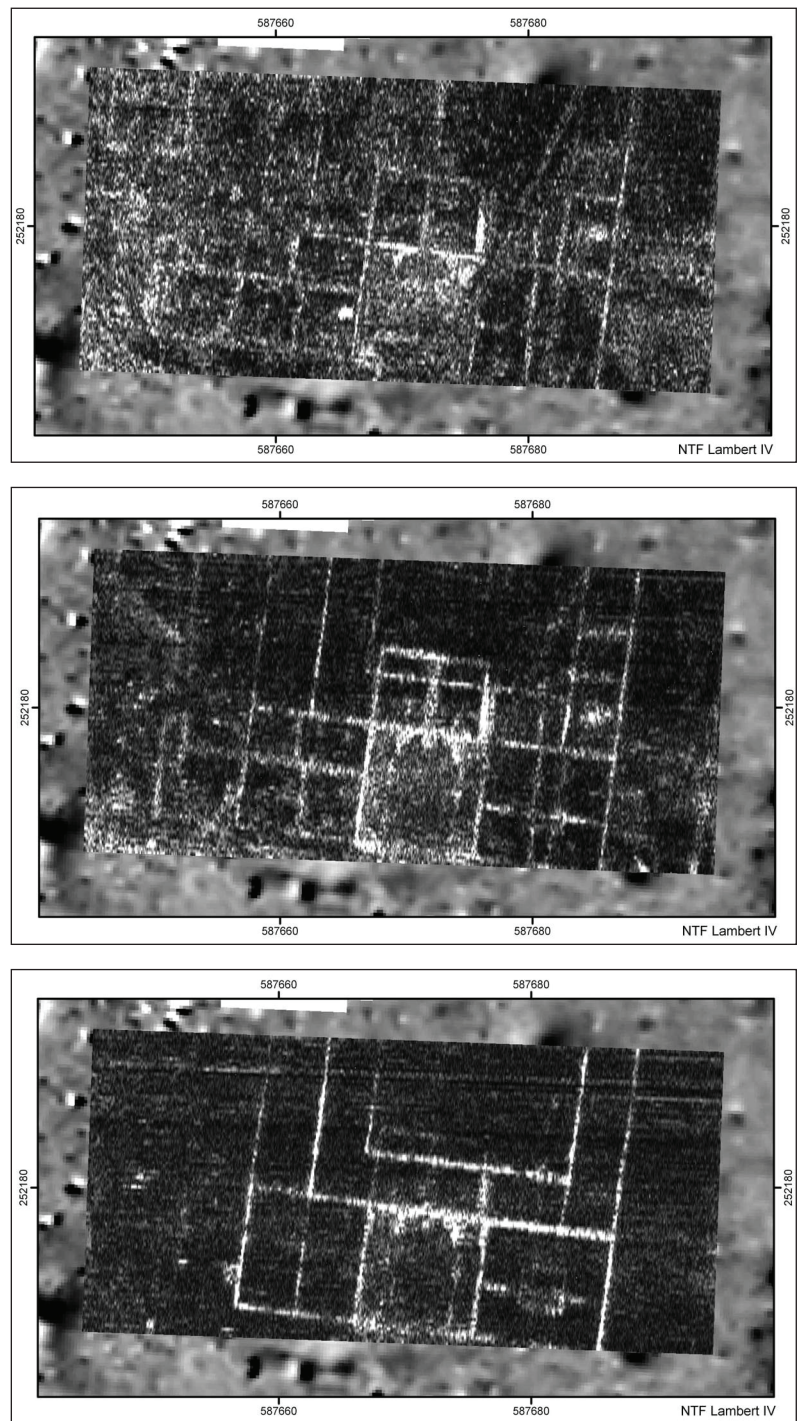


Fig. 5. Depth-slices resulting from the GPR survey: (top) depth = 35–40cm, (middle) depth = 60–65cm, (bottom) depth = 90–95cm.

soil was very weak, probably because the foundations are not well preserved. However, the orientation also corresponds to the excavated remains around the *Canonica*. A rectangular structure consisting of walls, probably buried very shallowly, with parts still visible above the surface (No. 6). Possible structures inside the rectangle are masked by a very strong anomaly originating from iron debris and pieces of agricultural machinery that could not be moved during the survey. This is the possible location of one



Fig. 6. Interpretation of the results from the GPR survey.

1: Courtyard, 2: Portico, 3–5: Rooms, 6: Corridor(?), 7–10: Shallower constructions, probably of later date, 11–12: Possible northward continuation of portico walls, 13: Test excavation.

of the excavation trenches from the 1930s. A number of plans from these unpublished excavations are available, but so far none has been located.

3.2. Ground-penetrating radar survey

Figs 5, 6 and 7 illustrate the results and interpretation of the GPR survey conducted in September 2007 over the area with the clearest building plans in the magnetic data (Verdonck 2007). The southern part of a 29m wide building with a 16m wide courtyard and a 4m wide portico was revealed, recorded so far for a length of 24m. The maximum depth of the foundations was approximately 1.5m

(Fig. 5, bottom and Fig. 6, Nos. 1–2). The walls are approximately 0.5m thick. South of the courtyard are three rooms of approximately 10 by 9m (Fig. 6, Nos. 3–5). On the western side of the building, a third wall runs parallel to the exterior portico wall, forming a corridor of 5m width (Fig. 6, No. 6). This parallel wall was confirmed during the test excavation (Fig. 7). Of the three rooms south of the courtyard, the middle appears to have a semi-circular apse at its northern end. In the eastern room, a square structure was detected. The building might be interpreted as part of a large house, or more probably as a public building, perhaps as baths

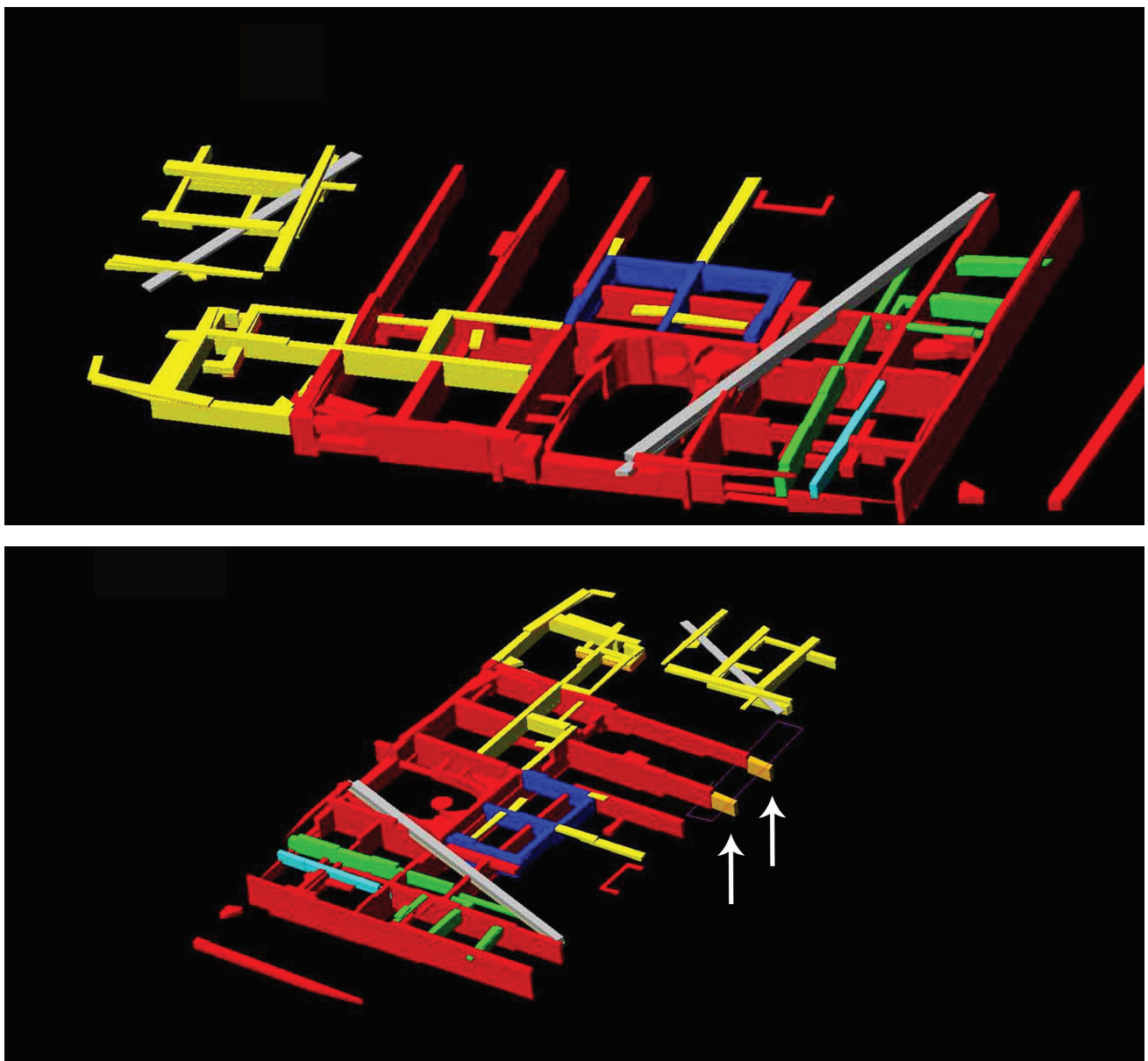


Fig. 7. Three-dimensional interpretation of the GPR data. The structures in blue, yellow and green are assumed to be later additions to the original building in red. Recent drains are indicated in grey. In the lower image, the arrows show the agreement between the walls revealed by GPR and the excavated parts of the wall (in orange).

or a *gymnasium*. No strong evidence of stone floors was found inside the building.

In the shallower slices (at a depth of 0.30 to 0.85m) further internal divisions are present, as well as rooms east and west of the building (*Fig. 5, top and middle, Fig. 6, Nos. 7–9*). A building situated on its north-western side (*Fig. 6, No. 10*) has a slightly different orientation from the rest of the structures detected in *Mariana*. Given its depth, it is probably related to a structure consisting of river boulders observed near the southern limit of the test excavation trench. It is tempting to suggest that these features belong to a later (late Roman?) phase in the history of *Mariana*. However, this can only be confirmed by further excavations.

The GPR prospecting provided further indications on two important questions remaining after the fluxgate gradiometer survey. One is the problem of the apparent absence of the road system in *Mariana*, the other is the location of the *forum*.

In comparison with the depth slices resulting from the GPR prospecting, the magnetic data are more like a palimpsest, where structures at different depths can often not easily be distinguished from shallower ones. Moreover, the magnetic data respond primarily to later, shallower layers with little evidence of the deeper, earlier phases. In the deeper GPR slices, it may be suggested that the empty spaces east and west of the original building complex (*Fig. 5, bottom*) represent possible north-south road alignments, which were abandoned as this area of the town became more intensively used and buildings were erected. Most probably these road alignments were not metalled. On the contrary, a part of the street south of the building, which had been proposed on the basis of the magnetic data, is clearly visible in the GPR depth slices (*Fig. 5, middle*).

The GPR data also allowed a reinterpretation of the magnetic data from the northern field (*Fig. 4, field 2*). A wall foundation running north-south appears to be the continuation of the internal wall of the eastern portico (*Fig. 6, No. 11*). The continuation of the external wall is less clear, although a few smaller magnetic anomalies may belong to it. Similarly, two parallel linear features may be part of the western portico and the external wall of the building complex (*Fig. 6, No. 12*). The presence of these anomalies necessitated a reinterpretation of the western part of the northern field, previously assumed to be the location of the *forum* on the basis of the absence of magnetic response.

Apart from the interpretation of the two-dimensional depth-slices, the GPR data were also visualised three-dimensionally (see *Fig. 7*).

4. Conclusion

The fluxgate gradiometer survey has produced new information about the extent, layout and zonation of Roman *Mariana*. The town covered the complete survey area of fields 1 and 2. Probable concentrations of slag and a zone of kilns belong to an industrial zone. The orientation of most structures suggests a close relationship with the excavated parts of the town near the *Canonica*. The GPR prospecting showed that a large building, detected during the fluxgate gradiometer survey, in its original phase had a regular plan with a courtyard, portico, three equally sized rooms and a corridor. Shallower structures probably belong to a later (late Roman?) phase in the history of *Mariana*. Whereas the gradiometer survey does not allow a real distinction between layers of different depth, in the GPR depth-slices areas without structures in the earlier phases may represent road alignments. The presence of walls in the western part of field 2 contradicts the hypothesis that this area was the location of the *forum*.

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The Bumpy Road to Incorporating Uncertainty in Predictive Modelling

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Abstract

One of the key problems of predictive modelling is the lack of tools to incorporate and map the uncertainties of the predictions made. Without explicit description of the varying quality of the archaeological and environmental data, statistical methods risk making inaccurate predictions. Hence, lacking adequate descriptions of bias and error, predictions often rely on expert judgement. But can expert judgement be quantified in such a way, that predictions can be made that will respect the experts' views, and at the same time reflect the uncertainties in the experts' opinions as well as in the available data? This paper reports an investigation into whether expert views can be quantified and incorporated in statistical predictions, for which we tested two potentially useful techniques, Bayesian inference and Dempster-Shafer theory.

Keywords

predictive modelling, Bayesian inference, Dempster-Shafer theory, uncertainty

1. Introduction

Anyone working with predictive models knows the slightly uneasy feeling that comes with looking at the brightly or pastel-coloured zones where the probability of encountering archaeological remains is considered to be 'high', 'medium' or 'low'. How can we be so sure that the low probability zones are really not interesting? And where do we draw the line between interesting and not interesting?

Concern over whether predictions can hold in the face of elusive social behaviour, complex geomorphological processes, research biases and data quality has created a painful awareness of the many sources of uncertainty inherent in the models. While we can use the available archaeological data to draw boundaries between high, medium and low probability, this does not tell us whether the predictions are reliable, as long as we can't specify the bias and error in the data set used. And even if we rely on expert judgement for 'correcting' or adjusting

predictions, we can expect experts to be uncertain as well, and to disagree among themselves.

Within the research project 'Strategic research into, and development of best practice for, predictive modelling on behalf of Dutch cultural resource management' (van Leusen and Kamermans 2005) we have investigated what methods are best suited for dealing with uncertainty in predictive modelling. For this, we have looked into two relatively new methods for developing predictive models, Bayesian inference and Dempster-Shafer theory. The study region chosen was the Rijssen-Wierden area (*Fig. 1*), where one of the first predictive models in the Netherlands was made (Ankum and Groenewoudt 1990). A more detailed account of the case study will be published in van Leusen *et al.* (2009).