An Application of Predictive Modelling in the Tiber Valley

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Abstract. This paper presents the preliminary results of an inductive predictive modelling experiment on data from the middle Tiber valley, Italy. The work forms part of the British School at Rome's Tiber Valley Project, studying settlement patterns in the middle river valley. The aims are to broaden understanding of settlement patterns via predictive modelling, and in particular to evaluate unevenness in survey coverage, survey bias and past settlement location preferences. The predictive modelling method chosen was an application of the statistical Weights of Evidence extension for ESRI ArcView GIS. The results highlight associations between Roman settlement and environmental themes that provide moderate predictive potential and suggest that further experimentation might prove valuable.
Keywords: Inductive predictive modelling; Survey archaeology; Tiber valley; Roman settlement

1. Introduction

The aim of this paper is to apply predictive modelling techniques in order to further understanding of settlement in the middle Tiber valley. This area is one of the most intensively surveyed regions of the Mediterranean, yet even here the extent of archaeological knowledge is uneven and some areas have yet to be subjected to any systematic survey at all. Since 1997, the area has been the focus of the British School at Rome's Tiber Valley Project under the direction of Dr. Helen Patterson. The aim of the project is to study the changing landscape of the middle Tiber valley from protohistory to the medieval period (Figure 1). It examines the impact of the growth, success and transformation of the city of Rome on the history of settlement and economy in the river valley (for a description of the project, see Patterson and Millett, 1998; Patterson et al., 2000; Patterson, 2004).

2. The Dataset

The data used in this analysis have been generated through a restudy of the material from John Ward-Perkins' South Etruria Survey carried out between the 1950s and 1970s, and their integration with data from more recent field work and numerous published surveys and excavations. The data were collected and integrated by two Leverhulme-funded fellows, Helga Di Giuseppe and Rob Witcher; the restudy of the South Etruria survey material was undertaken by twelve ceramic specialists (see Patterson et al. 2004). The data are housed in a relational database, which now totals some 5000 findspots. As well as the management and archiving of data, this systemisation also opens up potential for spatial analyses. Each record includes spatial coordinates which enable visualisation within a GIS. The precision of field recording for the bulk of sites is 100 metres, and this relatively coarse resolution is reflected in the predictive model.

3. Background of Application

The process of data collation emphasised that, whilst most areas have produced some evidence of human activity, not all areas have been subject to the same level of systematic study. For example, it became apparent that there was a marked contrast in the numbers and chronological development of sites on either side of the river Tiber. In order to assess whether this was a genuine pattern, or a product of uneven survey, a small field survey was undertaken in the Sabina Tiberina on the east bank (Di Giuseppe et al., 2002). The results suggest that the contrasting patterns of ancient settlement on either bank of the Tiber are a product of different histories of, and approaches to, landscape archaeology. In particular, higher densities of settlement were located, including sites from periods which are difficult to recognise due to limited quantities of material culture (for example, the late antique).
Since the South Etruria Survey commenced in the 1950s, some areas have been lost to quarrying and development, and many individual sites have been destroyed by erosion. It seems likely, that many undiscovered sites have also been permanently lost. There are also several areas in South Etruria which were, and which remain, inaccessible, including military training areas and the Vatican Radio antenna farm. Predictive modelling offers the possibility to explore the potential archaeological significance of all these different gaps and inconsistencies. Indeed, such work is of importance if we are to evaluate the significance of existing settlement patterns and trends.

4. Theoretical Issues with Predictive Modelling

The majority of published applications of predictive modelling concern North American case studies (see papers in Westcott and Brandon, 2000). In Europe, applications of the technique have focussed in the north, particularly the Netherlands and Germany (see papers in Lock and Stančič

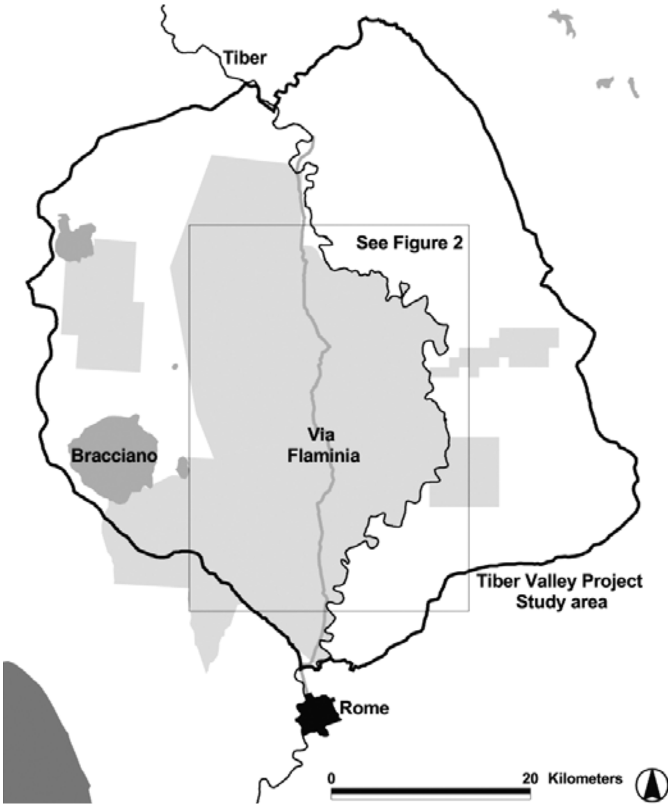

Fig. 1. Location of Tiber Valley Project study area, main field surveys (in grey) and predictive model case study area (see Figure 2).

1995; García Sanjuán and Wheatley 2002). Some of this work is research-driven, but much concerns Cultural Resource Management where predictive modelling has come to form part of the planning process. There exist very few published applications in the Mediterranean (see van Leusen 2002: 146–9). As well as Gaffney and Stančič's (1991) study of the island of Hvar, there is recent work by Kamermans (2000) in the Agro Pontino to the south of Rome and Stančič and Veljanovski (2000) on the island of Brac.

Of all the analytical techniques that have flourished since the widespread adoption and use of spatial technologies, predictive modelling has been the most heavily criticised, particularly in Europe. Ebert (2000), and more recently Wheatley (2004), have outlined a number of criticisms of inductive or data-driven predictive modelling. These criticisms can be grouped as two main points: 1) 'prediction as explanation'; 2) environmental determinism.

First is criticism of predictive modelling as explanation. However, predictive modelling does not aim to explain, it aims to identify patterns. It is the task of the archaeologist to explain and interpret these patterns, not the model. The second criticism is that predictive modelling is 'anti-historical' because it "assumes [patterns are] wholly a product of the immediate surroundings of the individuals and communities" (Wheatley 2004). This argument relates to the observation that most variables used within predictive models are environmental (for example, slope, distance to water, etc.) and that non-environmental data are excluded. As a result, the approach is deemed to be 'environmentally deterministic': environmental replaces human agency. However, this wider argument is built on a confusion of correlation with causation. In common with any other statistical techniques, it is explicit in predictive modelling that statistical association does not imply a direct relationship between variables. This returns to the first point; predictive modelling describes not explains; it does not inherently exclude the agency of knowledgeable individuals to structure their lives. Indeed, Wheatley (2004) himself notes that "this is not to deny that correlative predictive models may be telling us something about the behaviour of people in the past". US applications have produced relatively powerful models based on environmental variables, and it is wrong to dismiss this predictive power on the grounds of how the results are interpreted.

In general, these arguments betray a series of broader misplaced and latent concerns. Firstly, that any attempt to involve environmental variables in an archaeological study is 'determinism' by another name. Secondly, that quantification and statistical analyses are reductionist, and thirdly that 'prediction' is antithetical to free agency. Briefly, these may be rebutted with the following responses: discussion of environment does not presuppose determination (for much more subtle approaches, see Ingold 2000); statistical analyses, if appropriately used, become rigorous, repeatable investigations to supplement not replace interpretation; and thirdly, as such studies merely describe, it is up to the archaeologist, not the models, to ensure that individuals are granted appropriate agency. Perhaps the solution is to place less emphasis on prediction, and more on simple data exploration and pattern recognition, perhaps under the guise of data modelling.

In the context of the current research, some other specific criticisms can be quickly addressed. Firstly, that predictive modelling is concerned only with sites and has failed to take broader theoretical developments about off-site activity into account. Whilst this is certainly a valid criticism, in this particular case, the vast majority of data derive from site-based survey conducted fifty years ago, long before such theoretical and methodological developments. Whilst not ideal, it would be wrong to discard these data as inadequate; as emphasised above, many of these sites no longer exist and thus these data form a unique record. A related issue is criticism that the technique deals only with a simple binary site or no-site, and the possibility of more than one site per unit of land (in this case 100 m^2) is not addressed. Whilst recent high-intensity survey suggests that more than one site per 100 m^2 is definitely a possibility, the precision of the original survey recording of 100 m precludes detailed consideration. A further criticism has noted that many applications lack sufficient data and as a result fail to differentiate between sites of different dates and types. For example, in his study of the island of Brac, Stančič (2000) used 29 sites covering four centuries across 395 km^2. The application presented here uses 288 villas dating to the first century AD to train the model and then tests it against a reserve of a further 288 first century villas across a total area of 1100 km^2. A final issue concerns the anachronistic nature of much environmental data used. Indeed, it is important to include variables which are as chronologically relevant as possible; hence in the present application, *modern* land use was deliberately excluded from the final model. However, such data should not be dismissed entirely. Whilst they may not necessarily inform about past settlement decisions, they may well shed light on recovery processes (in particular, visibility). It is therefore argued that predictive modelling should be seen as a heuristic tool for exploring data, for example, identifying distorting factors (such as post-depositional or recovery bias) that are significant problems with field survey data, as well as illuminating significant patterning in the archaeological record.

5. Methodology

As described above, the site data are stored in a relational database and are linked, via SQL commands, with ESRI ArcView GIS; the predictive models are developed using the Arc-WofE extension. The Weights of Evidence methodology is part of a larger group of multi-criteria decision-making techniques and has been used for potential mineral mapping (for an archaeological application of multi-criteria decision-making, see Goodchild (forthcoming)). It uses statistical associations between training points (in this case, early imperial villas) and different map layers (such as geology, aspect and slope) to calculate a set of weights, and it is therefore an inductive approach. These weights are then used to evaluate every combination of the different map layers in order to produce a single map (a unique conditions grid) of predicted site presence. The variables identified as useful are considered for any significance in understanding ancient land use or perception of the landscape (for an archaeological application of WofE, see Hansen n.d.).

The study area comprises c. 1100 km2 in the middle Tiber valley, to the immediate north of the city of Rome (Figure 1). A Digital Elevation Model was derived from contours and spot-heights from the Istituto Geografico Militare 1: 25 000 map series. From this, maps of slope, aspect and topographical form (ridge, peak, valley, etc.) were derived. Other themes include geology, modern land use, rivers, the locations of towns and consular roads. From the latter, three 'cultural' variables were derived: proximity to Roman consular roads, contemporary Roman towns and the city of Rome.

6. Results

The weights for each theme were calculated, taking into account the area of each attribute (for example, geology type) and the number of training sites present. Statistics indicate the association between sites and the attributes of each theme. For example, for geology, there is a strong aversion to alluvial areas; for topography there is strong preference for ridges and convex topographical forms; an aversion to areas less than 100 m from watercourses; and an aversion to slope greater than fifteen degrees. The individual attributes of different themes were manipulated into varying numbers of classes to assess the effects on association (for example, four or eight classes of aspect) and various filters were used to derive topographical features of different scale. In each case, the classification producing the strongest association was used. Statistics were also calculated for themes based on proximity or distance. As the size and number of classes affects the output, these had to be carefully defined. Weights were graphed to identify significant cut off points. In the case of rivers, a simple binary theme of < 100 m and > 100 m to nearest watercourse was used; for proximity to roads, three categories were used (< 1 km, 1–3 km, > 3 km); for proximity to towns, three categories were used (< 5 km, 5–10 km, > 10 km); and for proximity to Rome, four bands were used (< 20 km, 20–30 km, 30–40 km, > 40 km).

On the basis of these statistics, different combinations of themes were used to generate unique combination grids, or probability surfaces. The model was developed as an exploratory process, with various themes introduced and excluded from the model in order to identify those combinations which were most predictive. The extension includes a number of tests to ensure that the statistical assumptions of the model are not violated; in all the examples described here, these assumptions were upheld. The best model achieved with the themes listed above utilised just three environmental themes: geology (ten classes), topography (six classes) and slope (three classes). Particularly high probability combinations were level to gently sloping ground found on the tops of tufa ridges and spurs. The resulting probability surface is illustrated in Figure 2. Darker shades indicate higher probability; hence the alluvial soils of the Tiber floodplain show as pale areas.

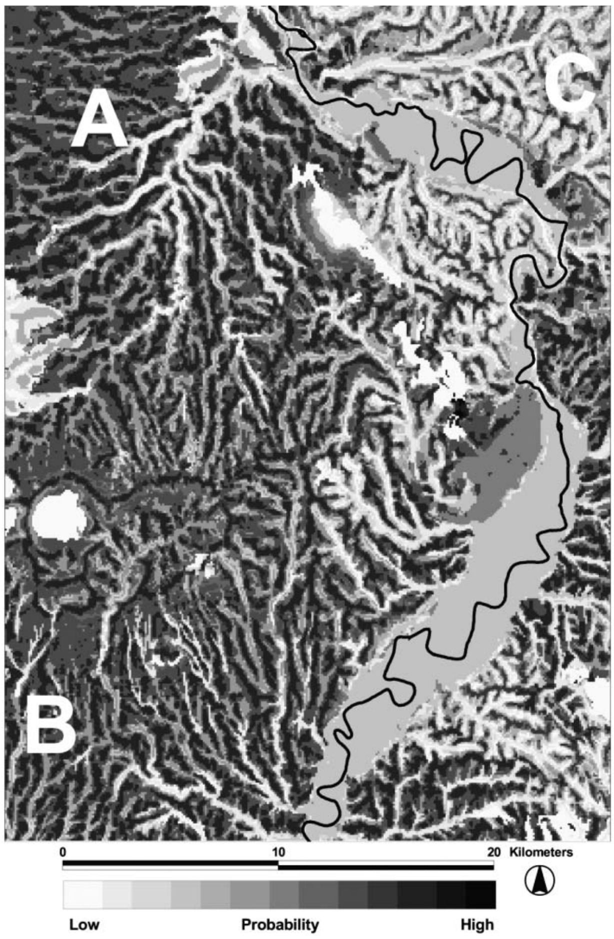

Fig. 2. Predictive model for early imperial villas in the middle Tiber valley. For location, see Figure 1. The river Tiber (in black) runs north-south. A = Central *Ager Faliscus*; B = area west of *Veii*; C = *Ager Foronovensis.*

The predictive model produced a highly complex and fragmented mosaic, in which areas of very low probability sit next to areas of higher probability. These results may suggest the very careful positioning of sites in relation, in particular, to topographical form. The significance of topography is reflected in the linearity of areas of differing probability.

Figure 3 shows the cumulative percentage of background cells (i.e. random) and site cells (i.e. the reserve villa sites) against the posterior probability value. This demonstrates that both the random and the site groups comprise large numbers of low probability cells and less of higher probability. However, the slower accumulation of site cells indicates that a greater percentage of sites occur on higher probability cells. Overall, the model has moderate predictive power, but clearly offers a better-than-chance method of predicting site location. It effectively predicts c. 20% of villas in just c. 6% of the area, weakening to c. 26% of villas in c. 53% of the area.

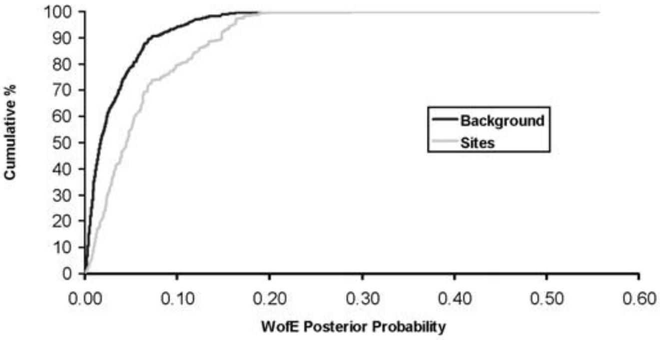

Fig. 3. Comparison of cumulative percentages of background and sites cells against WofE posterior probability.

The themes used in the model have both possible behavioural and recovery significance. For example, people may have avoided building sites in valley bottoms due to flooding or on steep slopes due to erosion. However there are also post-depositional possibilities: alluvium may cover sites located in valley bottoms, whilst the lack of cultivation on steep slopes (there is little use of terracing in this area) means sites are less likely to be discovered if they do exist. It is, of course, not straightforward to distinguish between past settlement location decisions and post-depositional and recovery issues. Of the themes used in the model, both cultural and environmental, it is clear that environmental themes have more predictive power. However, this is not to argue that they are more important in general than cultural factors, but that of the themes selected here, they have a more important role to play in prediction.

Land use and distance to Rome were employed in alternative models and both found to have high predictive power. However, both were excluded from further analysis as land use mapping refers to the modern landscape and seemed highly likely to reflect archaeological visibility (for example, pasture was low probability and vineyards high). Similarly, whilst it is possible that villa density was higher closer to Rome, archaeological activity/survey intensity has generally been much higher closer to the city. The current model therefore concentrates on those themes most clearly free of post-depositional and recovery problems. However, future work will attempt to use these and other themes specifically to distinguish between site location, post-deposition and recovery.

The model obviously predicts where sites might be found if the same survey methodology were employed again. As such, the model replicates existing biases (such as more surveys in high visibility areas). Nonetheless, it still highlights potential unevenness in survey data. For example, the intensity of survey in the central Ager Faliscus (marked A on Figure 2) and to the west of the city of Veii (B) is known to be particularly low. On the basis of their similarity with other areas, the model suggests the probability of villas in these areas is high. However, these existing biases can be addressed through the integration of new and more systematic fieldwork into the model. Indeed, this addresses another of the criticisms made by Wheatley (2004), that predictive models are self-fulfilling prophesies as they reinforce existing biases – however, if such modelling is treated as iterative processes, with new results added in, models can be constantly refined.

With the current model, it is noticeable that there is some difference in probability between the two banks of the Tiber in the top third of Figure 2. Survey in both areas is relatively limited, but the area on the west bank (B) is of a similar nature (topography, geology, land use, etc.) to the better surveyed areas to the south; in contrast, the area to the east of the river (C) is relatively unlike other surveyed areas. The addition of results from recent survey work in this area to the model may help to even out this apparent contrast (Gabrielli et al. 2003).

Perhaps most striking is the similarity between early imperial villa location and some modern settlement. The model distinguishes very precisely between nucleated medieval centres on the one hand (low probability), and their suburbs and sprawling discontinuous developments of the last thirty years on the other (high probability). Modern land use was explicitly excluded from the analysis and there is unlikely to be a correlation as a result of the discovery of material during construction as the bulk of the data pre-date such developments. This might suggest possible similarities in the motives for both villa and modern settlement location decisions. In particular, these are open sites with little need, wish or requirement to nucleate. Most notably, they are on ridges. There are advantages to this, such as drainage and views, but also disadvantages such as exposure to wind and access to water. In the latter context, the widespread presence of cisterns in this area is interesting. But probably most important is the fact that roads tend to follow the ridges. The tufa landscape across much of this area has created narrow ridges, divided by steep valleys. The consular road, the Via Flaminia, follows such a ridge and avoids the need to cross any river for more than thirty kilometres north of the Milvian Bridge outside Rome (Fig. 1). However, this is only the most impressive example of countless other ridge roads (that is, non-consular roads) which were excluded from the model.

Finally, the model of early imperial villa location was applied to samples of sites from other periods. Prediction of Etruscan and mid-republican sites was as efficient as the prediction of sites of imperial date on which the model was based. Further work is required to interpret this situation, but two (not necessarily mutually exclusive) explanations for this similarity in site location parameters can be postulated. First, that settlement in all three periods is similarly located (despite such significant events as the construction of consular roads and the development of the metropolis of Rome). Second, that these patterns are largely the product of post-deposition and recovery, for example, issues of visibility.

Assessment of the unevenness of the data is vital if other aspects of the data are to be explored and developed. For example, work by Goodchild (forthcoming) on the agricultural production potential in the middle Tiber valley explores issues such as subsistence regimes, manpower and carrying capacities of land units through the use of historical and comparative evidence, as well as archaeological data. These and related issues such as demography, can only be reliably addressed through assessment of the completeness or otherwise of existing patterns.

7. Conclusion

In summary, the predictive power of the final model does not compare to that produced by some of the US models. For example, Dalla Bona (2000) achieves 90% of sites in just 12% of his study area. However, some key differences between US and European models can be identified. Firstly, most US models deal with very few sites. It is possible that there was greater selectivity of prime landscape locations, whereas in a 'full' and intensively exploited landscape such as that on the doorstep of Rome, it would seem likely that 'choice' was more about compromise. Further, in comparing the results presented here with US models, it is apparent that here we are dealing with more complex agricultural societies capable of altering the environment, be it through construction (such as cisterns) or exchange. Pressures to supply Rome with agricultural goods or the desire to live near Rome may have meant that environmental variables were increasingly less important over time.

Lower predictive power may be one reason for the lack of such work in the Mediterranean, but a more probable explanation is the very different development pressures and Cultural Resource Management processes. In particular, there are few areas (in Italy at least) about which absolutely nothing at all is known; the archaeological record is dense, pressures are great, and the extent of areas involved is comparatively small.

This is a preliminary attempt to evaluate the possibilities of predictive modelling in the middle Tiber valley. In particular, it makes use of a generic modelling package; whilst this provides a useful initial framework, future work will seek to move away from a blackbox approach and try to increase control over the process. Nonetheless, the initial results suggest that that predictive modelling is a useful heuristic tool to explore site location and archaeological process in this part of the Mediterranean.

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