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Landscape Archaeology in Central Europe

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Estimations of population density, which consider regional variability, are an important key variable in archaeology as they have consequences not only for the environmental but also for the economical and social domains. In this paper, a ten-step procedure of a consistent group of methods is described which deals with the data required for estimations of population density at different scale levels (from excavation to large-scale distribution maps). For distribution maps, a method is presented by which densities of sites are displayed using optimal isolines. These demarcate so called 'settlement areas' at scales of between 1:25,000 and 1:2.5 million. Our knowledge of the density of households from key areas with the most complete archaeological records is upscaled for the regions within these isolines. The results of this procedure are estimations of population density for the early Neolithic (Bandkeramik, 51st century BC*) and the Roman period (2nd century* AD*) for regions with some 10,000 km².*

A simple statistical/graphical method is developed to analyse the relationship between settlement areas, soils, and precipitation. Taking into account the aspects of preservation of sites and the intensity of archaeological observations, an analysis of patterns of land use shows that in prehistory not all areas suitable for use were in fact incorporated into settlement areas. For prehistory, the idea of a most optimised use of land up to its carrying capacity (as it has been proposed for at least 50 years) can be falsified for specific areas. A large number of empty regions with good ecological conditions but lacking in settlement activity can be discussed as resulting from culture historical processes. As an example, the separation of areas inhabited by groups of different identities is discussed. The amount of used space (in terms of 'settlement area') however, increases from the early Neolithic to the 4th century BC *from 5% to more than 40% . The increase between the Neolithic and the Iron Age is understood in terms of technological developments in farming systems. The percentage of areas with suitable conditions actually utilised between the Bandkeramik and Iron Age increases from 31.1% to 67.5% in the area covered by the Geschichtlicher Atlas der Rheinlande, and is much higher still in the Roman period (84.3%). State societies seem to use the land more efficiently compared to non-state systems. This is becoming even clearer on consideration of the intensity of human impact.*

Large-scale distribution maps dividing the Neolithic in five periods were analysed. In each of the periods large settlement areas seem to be characterised either by the development of specific cultural innovations or by exchange of a specific raw material. In the course of time, the size of settlement areas in a specific region fluctuates markedly. It is most plausible to assume that this is due to a remarkable mobility of seemingly sedentary populations. Individual families recombine to new socio-cultural units every few hundred years.

The relationship between size of settlement areas and the number of households can be used to develop ideas relating to the flow of exchange goods. An example for the Bandkeramik considering the Rijckholt-Flint is presented. The combination of the number of households and the percentage of this raw material in the specific settlement areas visualises the amount needed and the amount transferred to other settlement areas in the neighbourhood. A future economical archaeology could use this information to develop ideas relating to the importance of the economic sector, ie, 'procurement of flint' in relation to the 'production of foodstuffs' according to the time required for each group of activities.

In the last section, the relationship between settlement areas and human impact is discussed. For the periods of subsistence economy, it is argued that the size of the population and its farming system are the two most important factors. For example, in Bandkeramik settlement areas, approximately 2% of

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the forest covering the landscape was cut down; in Roman times, and depending on the intensity of farming, this reaches magnitudes of between 20% and 50%. Although some of the methods and arguments used in this paper may be exchanged for better ones in the future, it is already apparent that a consistent system of methods is essential to transfer results of analyses on a lower scale level as input on a higher level and vice versa.

INTRODUCTION – HISTORY OF RESEARCH AND THEORIES

In this paper, the term 'Landscape Archaeology' is understood as a collection of approaches dealing with historical processes relevant on scales larger than an excavation. Even processes concerning areas larger than the distribution of a specific archaeological culture are the topic of landscape archaeology. One might consider 'community areas' as defined by E. Neustupny (1991) as the basic elements of landscape archaeology, each area using a part of the landscape with a specific economy, the society organised by its social structure and legitimised by its cognitive system.[1]

Levels of scale and 'source criticism'

It seems that the term landscape archaeology was invented, possibly independently, in two disciplines of archaeology. In *Classical Archaeology* the approach was introduced in order to understand the rural countryside as an agrarian complement of the political, urban, religious, or economical centres, these having been the main foci of interest since the early days of this discipline. The enormous amount of finds typically encountered during excavations of these centres required a concept by which the mechanisms of production could be better understood. The corresponding theoretical framework is the 'Modernism' as propagated by Meyer (1895) and Rostovtzeff (1957). The method chosen to investigate larger areas of the surrounding landscape, with its much lower density of features, is survey. The theoretical framework employed in order to understand the subsistence economy of the hinterland is the 'Minimalism' for example of Bücher (1893) or Finley (1973). Pleket, who compares the sector of handicraft production in the towns and agrarian production in the hinterland, proposes a synthesis of the two theoretical positions (1990). The relationship between urban centres and the necessary production of foodstuffs in their vicinities is encountered in the term *Agrarstadt* which had already been introduced by Beloch (1886). Examples of landscape archaeology in Greece are found in Bintliff & Howard (1999) and in Italy in Lloyd (1991). One can summarise by stating that in the field of Classical Archaeology our knowledge is based upon two levels of complementary scales: centres investigated by excavations, and the rural countryside known from surveys.

In *Prehistoric Archaeology* the concept of landscape archaeology is based upon the concept of 'Settlement Archaeology' as defined in Germany by Jankuhn in the 1950s. Theoretically, large-scale excavations and surveys were integrated in this approach. However, in practice, *Siedlungsarchäologie* focused on the largest excavations possible. In Germany for instance, at least five large-scale projects may be counted as representative of this approach, these include the *Siedlungsarchäologie des Neolithikums auf der Aldenhovener Platte* (1971–1981), and the *Siedlungsarchäologische Untersuchungen im Alpenvorland* (1983–1993). On the smaller level of excavation, natural sciences were incorporated into research so that many new aspects of the economy of past societies could be understood. Jankuhn introduced *Siedlungskammern* as a concept between the level of excavation and survey. *Siedlungskammern* are areas with natural borders where, for example, a relation between the number of houses and the space available for economic activities is distinguishable. The history of surveys can be traced back to Tode and his *Archäologische Landesaufnahme* (1928 with other predecessors). This kind of approach is a key concept of institutions responsible for Cultural Resource Management. In Poland, the 'Sites and Monuments Record' project (SMR, in polish AZP) is today nearing completion (Barford *et al.* 2000). A programme encompassing systematic surveys incorporating the whole of Germany failed; nevertheless, resulting publications represent important case studies (eg, Kersten 1939 for

Schleswig-Holstein). The reaction to this failure was the development of a programme for the complete inventory of finds from collections (see, for instance, Schwarz 1955).

For the interpretation of archaeological surveys and collection inventories for areas ranging from a few hundred square kilometres up to a few 10,000 km² (using maps of 1:25,000 up to 1:500,000) Jankuhn formulated the concept of *Quellenkritik* (*source criticism*) in analogy to the historism of the 19th century. An explicit methodology was not defined, but factors of bias for many archaeological distribution maps were presented as examples. Specific areas were recognised as being distorted by differing archaeological observation intensity or specific conditions of preservation. In later studies theoretical examples of artificial distribution patterns were discussed (Schier 1990, 44 with fig. 2, 46 with fig. 3). Much less work was invested in identifying areas of best observation and preservation. However, upscaling of data believed to be representative to larger areas is already observed in the work of settlement archaeologists (Kossack (1974, 314), for example, expected *c.* 100 houses to have existed in the whole area of Archsum in the decades at the beginning of the Christian era, on the basis of a small excavated area). This procedure is, in fact, in accordance with the concept of source criticism as discerned by 19th century historians. After the first step (definition of the research aims = heuristics) and the source criticism (second step), the six-step hermeneutics after Droysen requires a completion of data in step 3 (pragmatic interpretation) (Goertz 1995, 110 *et. seq.*).

Another important focus of the theoretical interest within prehistory during the 19th and 20th centuries in Europe was *Culture History* (the theoretical direction interested in the development of archaeological cultures on a time scale of some 100 years for the Neolithic or later periods; not to be confused with the *Kulturkreislehre* as a kind of hyper-diffusionism; the competing group of theories can be summarised under the term Evolutionism, which is interested in longer time scales whereby spatial relations are of less importance). In many cases, the interpretation of Culture History focus on larger scale areas (e.g. 1:1 million (Mio) or 1:2.5 Mio). The interest in this respect lies in *processes of diffusion* as networks of influences or migrations.

Both disciplines, Classical and Prehistoric Archaeology, conduct fieldwork on at least two scales: small areas known by excavations, and large areas known by surveys. Often maps of sites or specific types of finds or features are produced on much larger scales. To interpret these maps and the results of surveys a consideration of 'source criticism' is required. In this paper, suggestions are made as to how small scale data can be transformed into a larger scale incorporating a rural landscape. This is seen as a central key to understanding historical processes in larger areas, which are impossible to excavate or survey in their entirety.

Human–environment interaction

The relation between human and environment has long been a topic of academic interest. In Germany, for example, Schliz recognised the relationship between the distribution of loess soils and the Bandkeramik settlements about 100 years ago (1906, 335). Gradmann 'explained' this relation by his *Steppenheide-Theorie* (1933, 266; he believed that areas not covered by a dense forest were preferred by the first farmers in the Atlantic period because it did not require them to cut down trees for their fields and settlements). The general motivation behind these and similar approaches was to explain how land use was adapted efficiently to the environment in the different periods of prehistory. Seen from the spectrum of theories available today, many of these ideas could be understood in terms of Cultural Ecology (see for example Bargatzky's textbook from 1986). Graham Clark emphasises the stability of long periods in prehistory (referring to the work of Evans-Prichard with the Nuer in West Africa 1952, 7 *et seq.*): 'The adjustment between the economic system ... and ... external environment was so perfect that there was no room for any substantial improvement, so long as both these factors remained constant.' The introduction of population pressure as a driving force in history is in line with this argumentation (Jarman *et al.* 1982, 6 *et seq.*). During the last few decades, however, examples have been discussed in anthropology, which do not support the idea of optimal use of landscape up to its carrying capacity (eg, Sahlins 1972 in the chapter focusing on 'Underproduction'). The importance of these two different theoretical positions for specific historical situations can be better understood if regions with optimal ecological conditions for the technical development of the time are compared with the size of regions with archaeological finds (see p. 21–34).

Several methods introduced by the New Archaeology of the 1960s aimed at analysing the human-environment relation. In different approaches human behaviour was interpreted as an optimising strategy: Optimal Foraging Theory (developed for Biology by Charnov 1976; an application in Archaeology in Winterhalder & Smith 1981), Linear Programming (developed for economics by Dantzig 1947; an application in archaeology by Keene 1981) and – most important for the topic of this paper – *Site Catchment Analysis* (SCA; using theories of the geographers von Thünen 1826 and A. Weber 1909; adapted for archaeology by Vita-Finzi & Higgs 1970; for a summary of all these methods see D.L. Clarke 1977). The spatial choice of locations is explained through the assessment of the resource potential of the area exploited from a site. (Higgs 1975, 223 *et seq*. presented a 'concise guide to field methods' and the preliminary conclusions of the Cambridge school were published by Jarman *et al.* 1982). Because SCA was focused from the very first on the neighbourhood of known archaeological sites, empty areas between these sites could not be identified. From today's perspective, it can be stated that no interest existed to falsify the hypothesis of an optimal use of land up to the carrying capacity. An interest in comparing the ecological properties of regions with and without archaeological finds developed only with the methods of Geographical Information Systems (GIS) used for example in the context of predictive modelling (see below).

Returning now to SCA, for this type of analysis some decisions and discussions are of importance: A decision on the *scale of the maps* describing the ecological properties of the vicinity of sites is necessary. In the first applications of Site Catchment Analyses the maps used to present archaeological sites had a scale of between *c.* 1:100,000 and 1:350,000 (eg, Barker 1975). Applications of Site Catchment Analysis in Central Europe have so far focused on small-scale maps (especially 1:25,000, eg, Linke 1976; Saile 1998). However, at the same time, physical and ethnographical evidence was discussed, which indicated that an area of economical importance could be located at a distance of some kilometres. In this paper we argue that the scale of the maps used should reflect the accuracy of archaeological knowledge on location of fields and other areas of economical importance (see p. 26–32). The results obtained seem to prefer a larger scale, which delimits the effort necessary, allows better interregional comparisons, and helps to produce maps with simple structures to describe patterns of land use.

The arbitrary delimitation of the catchment as the *territory of economical interest* either by a given walking distance or by a geometrical radius of a circle around the site was considered to be a problem very early in Site Catchment Analysis. In their first applications site catchments were designated with a radius of up to 10 km for hunter-gatherers (or 2 hours walking distance) and up to 5 km for farmers (or a corresponding walking distance). In Central Europe, small areas around sites were chosen (eg, in landscapes without marked differences in height this corresponded to a circle with a radius of 750 m; cf Linke 1976; Saile 1998). The reason behind such a step is likely to lie in the assumption that the smaller is the scale of analysis, the more accurate the results are likely to be. In this paper an 'optimal' neighbourhood of sites is derived by a spatial analysis of the distribution of sites (see p. 9–11). Again, the results obtained seem to propose the use of larger catchment areas in a magnitude as used in the time when Site Catchment Analysis was developed. Using the upscaling procedure – as described below – to visualise regional differentiated densities of population even an approximation of the percentage effectively used in these catchments can be achieved (see p. 40–2). This differentiation is necessary if the environments of sites from different cultural contexts are to be compared, as for example the settlements of early farmers and the towns of the Roman Empire.

Another point of discussion was the relation of today's ecological properties of an area to its properties in a specific period of the past. Classifications of soil and its fertility, information derived from elevation models, such as slope and exposition, as well as climatic data, such as precipitation and temperature, were analysed, and even so-called phenological data were incorporated (eg, beginning of apple blossom as an indicator of the beginning of spring, eg, Schwitalla 1996, 95 *et seq*.) and ripening of elderberries as an indicator of the onset of autumn). In temperate zones, these phenological data are related more to temperature than to rainfall. In order to use these observations, it is assumed that people of a far past most probably deduced climatic properties of a region (as well as soil properties) by its vegetation cover. The *stability of ecological parameters* in time was a point of criticism which Site Catchment Analysis had to deal with: did the potential of the different types of landscapes change between prehistoric times and today so that the former potential cannot readily be recognised? Consequently, this case must be argued separately for each of the variables used in an analysis.

In temperate Europe, human use has influenced the developments of *soils* in an understandable way. However, for the high resolution *Digital Elevation Model (DEM)* of lowlands, it has been argued that many features are produced by modern interferences, such as highways and railways, and do not reflect the surface of the past (Gerlach *et al.* 2005). The *climatic* variability of the temperate zones of Central Europe is quite limited. Only in the high mountains limited periods of cold temperature, and in dry areas periods with low precipitation, could be a problem even in the Holocene. However, both precipitation and temperature are especially dependent on global patterns of high- and of low-pressure regions, and these were probably quite variable in the last millennia. In many cases, Site Catchment Analyses resulted in a formal description of ecological characteristics of a neighbourhood of archaeological sites; in other cases, a regional diachronic comparison was achieved. In future synchronic and diachronic comparisons on a larger scale are supposed to become more important.

From around the 1980s onwards, empirical observations of the human-environment relation were used to construct *Predictive Maps* for the aims of Cultural Resource Management programmes (Kunow & Müller 2003). As the quality of archaeological data is considered rather poor due to the problems encountered in source criticism, perhaps we should deploy our knowledge of human-environment relations in order to gain more information about those archaeological sites still to be found? At present, logistic regression and the 'Dempster Shaver' algorithm appear to be the most interesting methods for approaching this. For the first time, the different importance of specific ecological parameters becomes apparent here, and it seems useful to measure their efficiency. Other results of predictive modelling are maps of areas with high archaeological potential. A whole range of analytical possibilities is offered by analysing the differences between these potential maps and the areas where archaeological sites are really known. Comparison of archaeologically observed and ecologically expected behaviour allows us to develop a methodology to control the known factors affecting source criticism (preservation or archaeological observation intensity). It is perhaps even more important to integrate processes of culture historical development in the interpretation of large scale distribution patterns as already advocated by Kruk (engl. translation 1980, VII of the polish text from 1973, 11): '… despite the importance of environmental conditions, environmental determinism must be ruled out as the major factor conditioning settlement location in this period [Neolithic], since Neolithic societies, not withstanding the laws of Liebig and Shelford (referring to Odum) made a conscious choice of the most desirable habitats rather than adapt to unfavourable surroundings. For this reason the factors behind the spatial configuration of the settlement pattern' should be looked for in the domains of 'cultural processes and especially … the economic structure of the community.' From this point of view, the comparison of culture history with human-environment relation is one of the tasks of landscape archaeology.

It seems that today the role of man is often understood as degrading his environment to the worse. The case studies referred to are often the emerging states of the Mediterranean or other parts of the world, as well as societies experiencing ecological difficult situations (Greenland or the Sahara). In these discussions 'sustainability', 'vulnerability', 'resistance', and 'resilience' of systems are topics of discussion (Redman 1999, fig. 3.3). It will be a future task to enquire as to whether specific human-made alterations did not improve the ecological situation in single cases. For example the vegetation cover in the temperate zone of Central Europe in the Atlantic period with its large proportion of lime trees seems not to have been an environment characterised by a marked biodiversity. It is certainly not the only task of palaeoecology to produce a picture of past times as a golden age.

Analyses on possible aspects of past perception of landscape (eg, viewshed analyses) focus in most cases at the level of single sites. Therefore, these can be considered much more as aspects of 'settlement' archaeology. These approaches could, however, become more important when possibilities of intercultural comparisons become visible. Another viewpoint related to the cognitive system is the concept of 'ritual landscapes' (Raetzel-Fabian 2000) used to understand the surroundings of Stonehenge for example (Woodward *et al.* 2001) or in approaches dealing with rock art (Lenssen-Erz 2005, 172). In this paper, the viewpoint is focused on population density as a key variable, which also allows access to the domains of economy and social relations and even to the cognitive system in mutual interaction with demography.

LEVELS OF SCALE

Figure 1 summarises the data required, the methods used, and the results obtained in an approach to visualise regional differentiated population densities. In this diagram, specific methods can be exchanged. The particular importance is a consistent logic of argument which permits a transformation of data from one scale level to another. The scales in Figure 1 form a triangle. This is because an archaeological culture (topmost level) is usually based on the results of a large number of excavations (lowest level). Upscaling transfers data in a generalising way from a lower to a higher level. Downscaling argues from the top downwards. General knowledge of the highest archaeological level consists of concepts of mutual influences or migrations. Downscaling derives specific consequences for a special region of limited extension.

On the lowest scale, on the level of *excavation*, houses or graves can be found and possibly dated. The next level of so called *key areas* is an intermediate scale between the size of excavations and larger scale distribution maps. Key areas range in size from some tens up to a few hundred square kilometres, and are

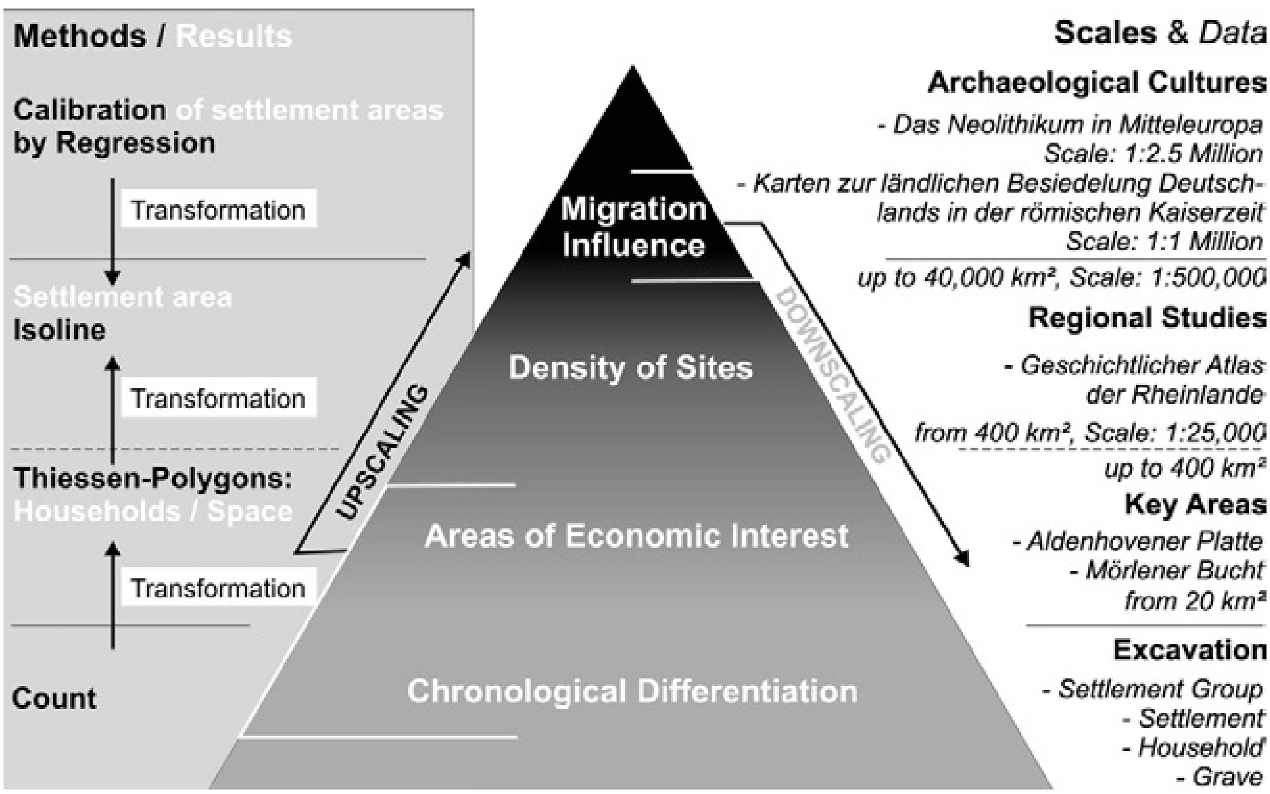

Fig. 1.
Hierarchical model of scale levels designed to achieve estimations of population density

characterised by the best observation density available. If all, or at least most, of sites are known in these areas, the space available per household or per person can be estimated. As an example of such key areas, the Bandkeramik settlements of the Aldenhovener Platte with its intensive excavations, and those of the Mörlener Bucht with its intensive surveys, are used (Zimmermann *et al.* 2004, 49 *et seq*., Schade 2004). The Early Neolithic Bandkeramik is one of the best-known archaeological cultures in Germany. On the Aldenhovener Platte, in a small region of *c.* 150 km^2 located in the lignite mining area between Cologne and Aachen, all Bandkeramik sites have been excavated either completely or using such methods that the number of contemporaneous houses can be estimated in a reliable way. Without going too much into detail (both larger settlements with a rather high density of houses and smaller settlements are known), about one square kilometre of land was available per household in the middle of the 51st century BC. This result is also supported by the surveys of the Mörlener Bucht (see below).

For time periods in which large centres dominate areas of a size impossible to observe in their entirety using archaeological field methods, the concept of the key area possibly has to be replaced partly by other approaches (for example using mean size of settlements of a sample of a larger region as it is done for the *vici* in the section Population density in … the Roman period, below). However, for the agrarian countryside of the Roman period the key area concept once again proves useful for analysing the *villa rustica* structure.

The level of *regional studies* deals with much larger areas ranging from some 100 up to a few 10,000 km^2 in size. At this level, the most reliable method involves the definition of 'optimal' isolines which can be used to describe site densities (method described in the next section). This method results in the 'settlement areas' inside the selected isoline. The *Geschichtlicher Atlas der Rheinlande* (GAR)[2] with a scale of 1:500,000 represents the upper border of this scale level. At this level, the location of sites is mostly determined using literature only. The dissertations of Schier (1990) and Saile (1998), which encompass about 1000 km^2 each, serve as examples for smaller regional studies. Their work is based on maps with the scale of 1:25,000. Sites are selected after inspection of finds. At this level, the location accuracy of individual sites is assumed to be high.

On *large-scale distribution maps* of 1:1 Mio or even for larger areas, isolines can also be used to estimate the size of distribution areas. However, the location accuracy is assumed to be low. Therefore, internal empty spaces, which may express specific environmental conditions, cannot always be recognised. It is for this reason that the size of settlement areas obtained for large-scale distribution maps has to be reduced by a regression analysis. It is only after that procedure that the settlement areas fit the magnitude of the corresponding settlement areas on the level of regional studies. The maps for the rural settlements in the time of the Roman Empire (Bender 1997; 1:1Mio) and of *Das Neolithikum in Mitteleuropa* (Preuß 1998; 1:2.5 Mio) are examples for studies conducted at this level.

ISOLINES

Isolines were first used in archaeology by M. Malmer (1962, 697 *et seq*. referring to a paper from 1957). He used this method to describe density of *types of finds* in Schonen/Sweden using the term 'isarithm' for what is termed isoline in this paper. In the procedure used here, the density of *sites* in a landscape is analysed. Point distribution patterns with many different properties (clusters, empty spaces, areas of regular spaced features and so on) specific for small patches sometimes require a graphical reduction of information, as achieved by the isolines.

Isolines as a method to describe site densities

Density can be described as the inverse of the size of empty spaces between find spots. The size of empty spaces is determined by calculating the 'largest empty circles' between sites (Preparata & Shamos 1988, 256 *et seq*.; 207 fig. 5, 18; an illustration in the context of an archaeological paper in Zimmermann *et al.* 2004, fig. 5). The radius of the empty circles is a measure for the distances between sites: the larger the distances the lower the density of sites. Although other measurements for calculating distances between sites or their density could be used, the method using the largest empty circles seems to us best adapted to the geometry of data in point distribution maps.

After calculating the distances between sites in the sense of largest empty circles, one of the usual methods for obtaining isolines can be used. We use the statistical interpolation method of Kriging to do so (Haas & Viallix 1976). In Figure 2 the isolines of 3 km and 4 km distance between the sites are presented as an example. The key area of the Aldenhovener Platte is located predominantly in an area with distances smaller than 3 km between sites. The space inside this isoline contains no empty areas with a radius larger than 3 km (or with a diameter larger than 6 km).

As an alternative experiments were carried out to calculate isolines with Kernel Density Estimation.[3] It could be possible to derive the necessary bandwidth for the kernels evaluating the density distribution of the Largest Empty Circles. However, we did not succeed in also finding a reliable and independent

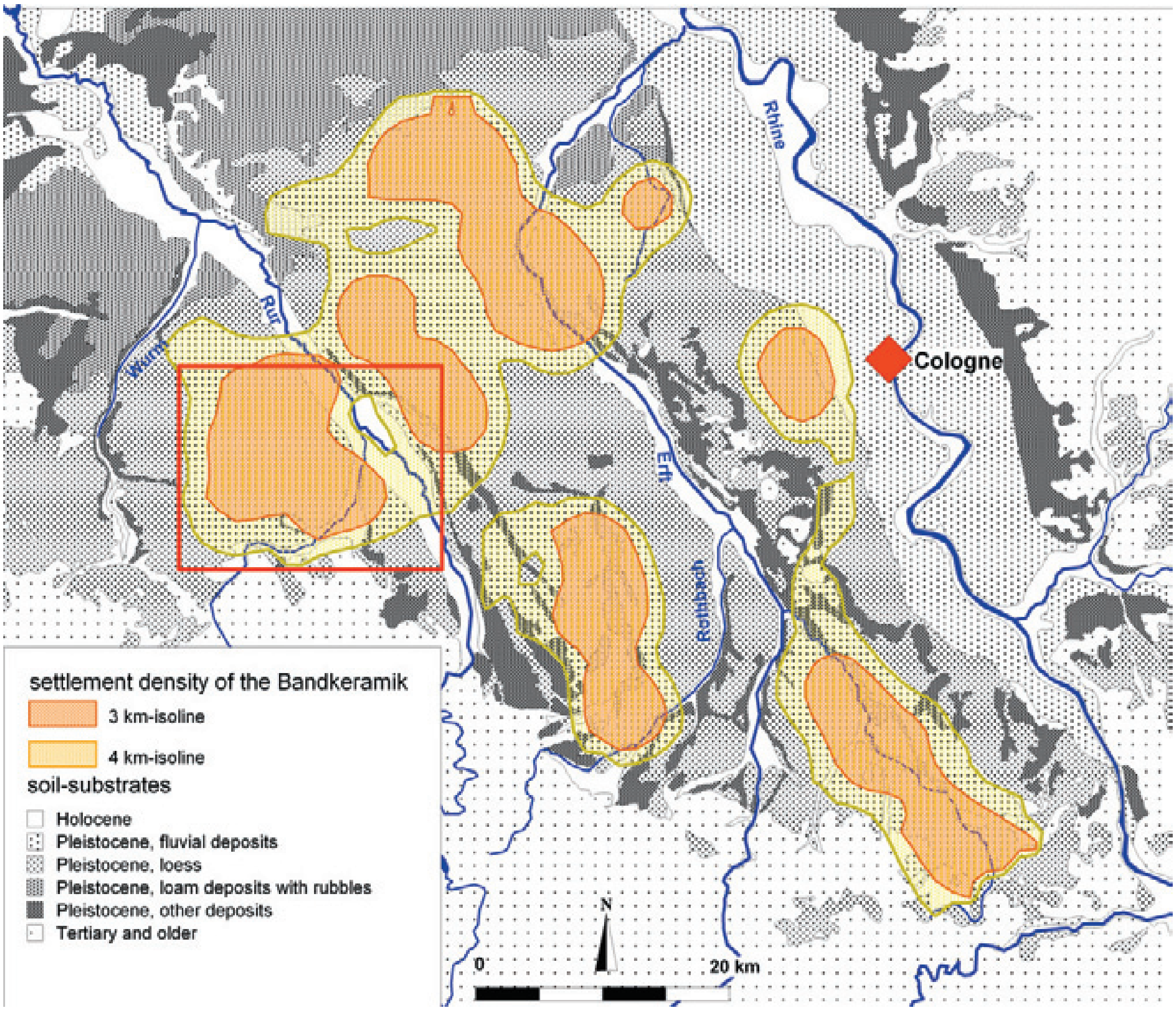

Fig. 2.
Isolines of 3 km (concentrations of settlements) & 4 km distance (optimal isoline circumscribing settlement areas) of Bandkeramik sites in the northern part of the GAR I. Rectangle: key area of Aldenhovener Platte (Fig. 15) (map after Modderman 1970, Taf. 1, modified)

method for choosing the 'optimal isoline'. Although it is possible to find valid isolines with both methods, in the moment we prefer the combination of Largest Empty Circle and Kriging because of better reliability.

Choosing the 'optimal isoline' to define 'settlement areas'

Mostly isolines are used to visualise differences in density of sites. The intention of the work presented here is to identify the area for which upscaling information obtained by the analysis of key areas seems reasonable. Therefore, in the best case, a single isoline has to be selected which divides areas with many sites from those with only few ones. By comparing the point distribution pattern of the Bandkeramik with specific isolines (Fig. 2) it becomes clear that the 3 km and the 4 km isoline reproduce the point distribution pattern quite well. The 5 km isoline traces the borders of regions with environmental conditions preferred by the early Neolithic people, but already contains some empty areas.

Looking for statistical criteria derived from the individual dataset one could think of the number of sites within a specific isoline and the number of areas with a specific density of sites (Zimmermann *et al.* 2004, 53 *et seq.*). A third criterion seems to be the most reliable. It is the *increase of included space* (Table 1). An isoline is a candidate for being an optimal one when a clear maximum becomes visible in the sequence of consecutive isolines. Indeed in analysing many archaeological distribution maps a maximum increase of included space was found in each case at the border of areas with a dense settlement pattern. That is true for the scale level of the GAR as well as for maps at the scale of central Europe. And for the Bandkeramik as well as for the Roman Empire it seems archaeologically reasonable to upscale density of households identified at the scale level of key areas to the settlement areas enclosed by the so called 'optimal isoline'. This statistical criterion was chosen just as a heuristic means to obtain reasonable and reliable regions, suitable for upscaling household or population density derived from numbers of graves. Probably the reason why such a maximum characterises an archaeologically especially interesting isoline is that in this situation many isolated smaller areas with higher site densities are joined to much larger units, while the next isolines

TABLE 1: STATISTICAL PROPERTIES OF THE BANDKERAMIK ISOLINES FOR THE GAR I (210 SITES)

Km isoline	*No. enclosed areas*	*Sites*			*Included space*	
		no.	*%*	*increase/ km*	*km²*	*increase/ km*
1	1	11	5		9.0	
				52		115
1.5	8	37	18		66.5	
				66		359
2	17	70	33		246.0	
				68		615
2.5	19	104	50		553.3	
				46		875
3	17	127	60		990.8	
				34		1132
3.5	13	144	69		1557.0	
				26		1408
4	10	157	75		2260.8	
				32		1249
4.5	7	173	82		2885.5	
				22		1065
5	8	184	88		3418.2	
				8		1045
5.5	8	188	90		3940.9	
				8		1077
6	7	192	91		4479.4	
				2		912
6.5	7	193	92		4935.2	
				2		880
7	6	194	92		5375.1	
				6		851
7.5	8	197	94		5800.5	
				2		875
8	7	198	94		6238.3	
				0		815
8.5	7	198	94		6645.8	
				0		900
9	7	198	94		7095.9	
				4		931
9.5	7	200	95		7561.4	
				0		905
10	8	200	95		8014.0	
				1.2		1247
12.5	6	203	97		11,132.2	
				0.4		1533
15	5	204	97		14,965.8	
				0.4		1376
17.5	4	205	98		18,406.7	
				0.4		1565
20	3	206	98		22,318.8	
				0		1118
22.5	1	206	98		25,114.6	

with decreasing site densities form frames around areas already joined by isolines at higher site densities.

However, in many cases the archaeological important maximum of increase of included space is not the global but just a *local maximum*. In calculations for the GAR, for the large scale maps of the rural settlements at the time of the Roman Empire (Bender 1997) as well as for *Das Neolithikum in Mitteleuropa* (Preuß 1998) isolines between 1 km (Roman time) and 15.5 km (early phase of young Neolithic; time of Bischheim) delimit settlement areas as used for our analysis. Only for the middle phase of the young Neolithic (time of Michelsberg I–III) does the 21.5 km line seems to be interesting. Typically 70%–90% of the sites are enclosed by the optimal isoline. It can be expected that other maxima of increase of included space exist circumscribing regions with much larger distances between sites corresponding to specific types of landscape or to cultural borders.

It is evident that not all sites are located inside the optimal isoline. In the Bandkeramik example, 76% of all sites are situated within the optimal 4 km isoline. In many cases, the *sites outside* consist of isolated settlements. Some of them could develop into groups of settlements by increased archaeological observation intensity. Others could be camps of special purpose or sites interesting for other reasons. A Site Catchment Analysis could help to distinguish such cases. As long as they do not develop to extended settlement areas as the result of an improvement of archaeological fieldwork (see p. 20–1), they are quantitatively of minor interest for demographic analysis.

There are data sets where *no maximum* can be found between isolines; instead, with increasing distance between sites, a continuous increase of space is to be observed. Typically, these data sets represent periods where our archaeological knowledge is poor. Another special case is a distribution with *more than one maximum* in its range of isolines. A historical interpretation for one of these rare data sets is presented for the young Neolithic (*Jungneolithikum*) of Central Europe (see p. 37–40). In this period, with a probably more centralised settlement system in many regions (compared to the Bandkeramik for example), it is understandable that isolines are identified as optimal which include much larger empty spaces. Theoretically, the existence of different settlement systems in different regions within one and the same map could cause problems.

Another aspect is the *scale of the map* analysed. For regional studies based on small-scale maps of 1:25,000, isolines of larger density (and smaller empty spaces) are recognised as optimal. As an example, for the Bandkeramik the 3 km and the 2 km isoline have to be chosen for the regional studies conducted by Schier (1990) and Saile (1998) in areas of approximately 1000 km²; for studies of some 10,000 km², based on a map of 1:500,000 or even larger, the 4 km isoline is identified as optimal (see below). This difference should not be understood in terms of different settlement patterns only (Zimmermann *et al.* 2004, 71) but it also reflects in a way the 'completeness' or the intensity of archaeological analysis, which is of course better for small-scale studies. The selection of the optimal isoline reflects in this respect the 'level of representativity' of a map. Because isoline selection is recognised to be scale dependent, diachronic comparisons are only reasonable for one and the same scale.

There is also a dependency on the *chronological scale* chosen. Because the resettlement of the lower Rhine basin after the beginning of the middle Neolithic (see p. 32–7) shows a certain delay, the resulting size of settlement area is smaller compared to regions with a continuous development. In this respect, the size of isolines is an average density over the complete length of period under consideration.

After the discussion of possible problems, the selection of the optimal isoline for the Bandkeramik using the map from the GAR I is presented as a *practical example*. The key area of the Aldenhovener Platte is encompassed by the 3 km isoline. This line visualises concentrations of settlements (so called *Siedlungsverbände*). The maximum increase in space characterises the 4 km isoline as optimal. Therefore, upscaling the density of the key areas to the region included by the 4 km isoline implies that not all Bandkeramik sites have been found thus far.

Another maximum of increase of 'settlement areas' can be observed at 15 km and 20 km: this is the outer border of Bandkeramik settlement distribution in the Rhineland and includes nearly all sites (97 % or more). It is not to be expected that all these regions were used in an intensity as the Aldenhovener Platte (see p. 32–7).

In Roman times (see p. 14–19), the 1 km and the 2 km isoline mark the maximum increase in space. The lower density seems to be more characteristic for areas with sub-optimal ecological conditions. Analysing the publications of the Roman period from some key areas results in a density of *villae* not much larger than the outcome of an analysis of the *villae* inside the 1 km isoline of the whole GAR III (Cüppers & Rüger 1985). In this case, a map in the scale of 1:500.000 is not much less representative than small-scale analyses (Tables 2–3). The reason is the better visibility of the Roman stone architecture in comparison with Bandkeramik settlements. According to this observation, no specific upscaling procedure seems to be needed in the region of the *Geschichtlicher Atlas* for Roman *villae* for a time when most of them were being built in stone.

It is clear that densities of finds per surface unit can also be easily presented using isolines (eg, Hodder & Orton 1976 with their 'trend surface analysis', 155 *et seq*.). In the example of Bintliff and Howard (1999, map 2), a reliable method would be required to define a reasonable borderline between areas with farm buildings and the adjacent fields.

The general advantage of the proposed method is the transformation of point distribution maps into areas (within isolines). In this form, areas can be much better compared to each other and with other types of data represented in areas, as for example soil maps.

ESTIMATIONS OF POPULATION DENSITY

Population density is recognised as one of the key variables of human societies. General ideas important for estimations of population density in the field of European archaeology are described elsewhere (Zimmermann 1996). For the central periods of Classical Archaeology even census-data exist. However, due to bias, for example, against slaves, women, and children, other information must also be considered. Written information on the number of soldiers is also important for understanding the conditions of specific battles. For conclusions that are more general however, in both Classical Archaeology as well as in prehistory, the carrying capacity of a specific historical situation is considered as an upper limit for estimations of population density. On the other hand, observations of archaeological sites are used to recognise a lower limit because there are always still some sites to be found. However, the analysis of land use patterns presented below does raise doubts on the assumption that land was used intensively up to carrying capacity. Therefore, a 10-step methodology is proposed in this paper, which focuses more on the archaeological evidence. The single steps are formulated for the Bandkeramik with its settlement groups, for the Roman times with its *villae* understood as single settlements, and for the necropoles of the Hunsrück-Eifel Culture.

Observation based analyses at the level of excavation:

1. A time horizon with a sufficient density of observations is selected according to results of chronological analysis based on excavations. Sites, which are not dated to the required accuracy, may be treated using Aoristical Analysis (D. Mischka 2004).
2. Houses or graves of chosen age are counted per settlement or per necropolis.

TABLE 2: ROMAN PERIOD. AVERAGE SPACE AVAILABLE PER VILLA & NUMBER OF INHABITANTS IN THE KEY AREAS OF THE ALDENHOVENER PLATTE, HAMBACHER FORST, KROMME RIJN (NL), & THE REGIONAL STUDIES OF THE WETTERAU & THE NECKAR AREA

Region	Observations *in closed thiessen polygons (CTP)*		Deduction *villa/km²*	Estimations *per villa*	
	no. of villae	*km²*		*no. of persons*	*km² used land*
Aldenhovener Platte	40	23.4	1.7		
Hambach	21	25.7	0.8	10–20 (30)	0.5
'Kromme Rijn' (NL)	86	70.9	1.2		
Wetterau	61	235.6	0.3	25 (40–50)	1.0
Neckar	173	744.8	0.2		

Values in brackets: maximum values; for references see explanations in the text

TABLE 3: ROMAN PERIOD. DENSITY OF VILLAE & AGRARIAN POPULATION IN THE REGION COVERED BY THE GAR III.

Density classes	*No. villae*	*CTP km²*	*villae/km²*	*mean no. persons*	*product of villae & persons*
1 km isoline	1756	1797.8	0.98	10–20	17,560–35,120
2 km isoline	1654	7505.7	0.22	25–50	41,350–82,700
Outside isoline	508			25–50	12,700–25,400
Sum					71,610–143,220

CTP: Closed Thiessen Polygons. Compare similar density of villae in key areas and regional studies Table 2

Observation based analyses at the level of key area:

3. Selection of key areas with a well-founded knowledge concerning patterns of land use (eventually with regard to an analysis of regular distances between sites by triangulation; eg, Saile 1998, 178 *et seq*.).
4. Construction of Thiessen-Polygons around sites (Roman *villae*), settlement groups (Bandkeramik), or necropoles (Hunsrück-Eifel Culture). Only the closed polygons in the interior of the key area are considered; open polygons at the periphery are discarded.

Deduction at the level of key area:

5. Mean density of households or necropoles per square kilometre in key areas. If working with settlement groups the different size of settlements has to be considered.

Deduction at the level of regional study:

6. Computing isolines of site density and selection of optimal isoline to define settlement area (see above). The result is a map as Figure 2. Upscaling of mean density of households or necropoles to settlement area (for the spatial relation of settlements and graves see eg, Nortmann 2002).
7. For settlement based analysis: addition of average number of households for the sites outside isoline. The sum of 6) and 7) is the number of households in the area under consideration.
   For necropolis-based analysis: Addition of number of graveyards outside settlement area.
   Numbers estimated for households or for necropoles are most reliable quantities.

Assumptions:

8. For settlement based analysis: estimation of arithmetic mean of persons per household.
   For necropolis-based analysis: estimation of percentage of people buried. The average number of related persons belonging to one generation can be deduced.

Deduction at the level of regional study:

9. For settlement based analysis: multiplication of number of households with average number of inhabitants. If towns of a size not comparable with agrarian settlements or large military units exist (as in Roman times) their numbers must be added.
   For necropolis-based analysis: multiply number of graveyards by the average group size.
10. To obtain a 'global' population density the number of people has to be divided by square kilometre of the research area. This quantity considers also areas outside settlement areas.

The quantity most reliable in this estimation process is the number of households or the number of necropoles as derived in step 7. An important decision is the selection of the optimal isoline (6). Maximum increase of included space by the specific isoline is proposed as a heuristic means of obtaining estimations, which can be best compared with one another. Most problematic in this procedure is the assumption 8 – the mean number of persons per household and the percentage of persons believed to be buried in necropoles. It would be ideal to match the number of persons per household and the number of related graves. However, most archaeological data sets do not allow this comparison. For the number of persons per house the number of beds could be a relevant quantity. However, the better the information available to archaeologists the more demanding they seem to become. Therefore, even in situations as at Pompeii, the number of beds is critically discussed

(Wallace-Hadrill 1994, 113) although this information has a better quality than possible intercultural comparisons. Information of this kind, however, exists only in exceptional cases. The number of people living in urban settlements seems to be just as uncertain as the number of people per household. However, for towns the consequences of different decisions are more far-reaching. In future, it should be possible to determine an average density of households for specific types of towns, and considering public spaces and buildings as well as parts of buildings related to handicraft or commercial activities. The definition of the part of the map for which the 'global' population density is calculated in step 10 is also an extremely sensitive decision. For this, an explicit method is still needed. All other problems, such as incomplete archaeological observations (in regions with good archaeological knowledge and a long history of research) or uncertainties of dating, will turn out to be in most cases of minor importance.

Population density of the Early Neolithic in Central Europe

In the example of the Bandkeramik, it is proposed that the density of households observed in the key areas of the Aldenhovener Platte and the Mörlener Bucht be upscaled to all regions inside the optimal isoline. Here, it is argued (see above) that the 4 km isoline should be chosen. A transfer of the household density to all areas inside the 4 km isoline of altogether 2261 km² in the map from the GAR I results in 2261 households. A total of 55 sites lie outside the isoline (granted that most of these sites represent settlements or settlement groups, this number was missing in the calculations by Zimmermann *et al.* 2004, 73). Assuming that an average number of 7.25 households existed in each of these settlement groups (observed at the Aldenhovener Platte: Zimmermann *et al.* 2004, table 5) a total of 2660 houses would have existed in the 51st century BC. Therefore 0.070 households/km² existed at this time and in the region covered by the *Geschichtlicher Atlas* (2660/37,989 km²; see Table 10, below, with 3,734,410 ha where a classification of soil units is possible. An earlier calculation refers to a smaller area of 32,000 km, which was better adjusted to the geographical distribution of Bandkeramik sites. To make the periods comparable also in respect to the environmental analyses, all future calculations will refer to the larger area.) This estimation includes the lower mountain ranges and lowlands. In these types of landscape, no Bandkeramik settlement is expected to be found by future research. Nevertheless, they have to be considered in an estimation of population density because they were most probably used seasonally (Kalis & Zimmermann 1988).

The quantitative analysis of a distribution map is often deemed problematic, as the map tends to be already outdated at the time of its publication, with new sites having become known since its compilation. This is also true for the Bandkeramik in the GAR I. Today a total of seven sites are unaccounted for (or the area inside the optimal isoline circumscribing the specific sites is considered too small). The maximum estimation error would occur if each of these sites represent a group of settlements also with 7.25 houses. According to this assumption in the middle of the 51st century, the density of households would only increase to 0.071 per km². However, an increase to 0.08 would only occur if 379 houses from 52 settlement groups dated to the middle of the 51st century were discovered outside the settlement areas. Therefore, the estimation of density of households seems to be quite robust as far as archaeological observations are concerned. To obtain an estimation of population density, an assumption of an average number of people per Bandkeramik house is needed. As already stated, this quantity is uncertain. Using a number of six inhabitants (according to Lüning 1988, 38 ann. 33; supported by Dix & Kleefeld 2005, fig. 1: at Kleve on the lower Rhine a remarkably stable average of 5.8 persons are known to have resided per house during *c.* AD 1775–1780) a 'global' population density of 0.42 persons per km² (P/km²) results.[4] The number of households is a quantity, which is archaeologically well accessible. However, to assess the importance of human impact one needs to make assumptions with respect to the average number of people per household. The size of areas needed to produce the necessary foodstuffs is to be visualised at the scale level of key area first (see p. 40–2). The results can then be upscaled to larger regions.

The estimation of 'global' population density for the Bandkeramik is much smaller compared to earlier suggestions (in the range of 1.5 p/km² to 2.0 p/km² summarised in Zimmermann 1996). The difference between earlier estimations and the new one is the result of different theoretical approaches. Estimations featuring high population densities result from the assumption that all loess areas were used to the maximum intensity. This assumption is based on the thesis of most efficient land use up to the limit of carrying capacity as presented in the introduction. In the case of areas with favourable ecological conditions but without archaeological sites, this was explained either by poor preservation or by low intensity of archaeological observations (Source criticism). A consideration of the known archaeological sites only leads to the low estimation of population density presented here. In this respect, both estimations might be seen as limiting values. However, the question remains if it is reasonable to assume a most effective land use for all time periods, which would also imply that enough people existed to do so. Analysing patterns of land use for different periods with regard to ecological parameters raises doubts as to whether that is correct in every case. We transform information only to regions where archaeological sites are known in an appropriate density. Otherwise, an 'over-correction' for missing sites can be expected.

Population density during the Metal Ages and the Roman period

For periods other than the Bandkeramik, the increasing variability of archaeological features has to be considered. During the Iron Age, not only did villages exist with structures roughly comparable to Bandkeramik settlements, today easily detectable due to their location in areas used by modern agriculture, but we also have graves covered by *tumuli*, which have been well preserved in forests. In this case, it has been shown to be more profitable to calculate maps with separate isolines for the densities of settlements and graves. The resulting 'settlement area' is the sum of regions with both settlements and graves. It is assumed that graves are not dug too far from settlements (Nortmann 2002).

In this way, the size of the settlement areas represents a crude proxy for population density. The settlement areas of the Bronze and Iron Ages calculated using the maps from the GAR II were larger than that of the Bandkeramik by a factor of 8.2. However, the upscaling procedures for the areas characterised by settlements have still to be developed and the procedures for the uplands characterised by tumuli is a work in progress (Wendt *et al.* in press).

The agrarian production unit during the Roman period was the *villa rustica* and similar types of settlements. A main focus on cereal production is assumed for most sites known only from surface finds. For a minority of them other types of function may be possible but the difference is not expected to change results much for neither the magnitude of population density nor for the general amount of agrarian production (W. Gaitzsch & Th. Fischer pers. comm.). Nevertheless, we should recognise that variability in the classifications of survey sites in archaeological maps of the Roman period by different authors may be due to other specific questions at hand. Perhaps, in a later stage of the analysis, possible consequences could be considered concerning the range of the estimation errors.

The density of *villae* (Table 2) is determined in the key areas of the Aldenhovener Platte (Lenz 1999, 72, tab. 17), the Hambacher Forst (Gaitzsch in press), and the 'Kromme Rijn' (Kooistra 1996, 39 *et seq*.), and for the regional studies in the Wetterau (Saile 1998) and the Neckar area (Hüssen 2000). As a period with an optimal archaeological knowledge, the second half of the 2nd century AD is chosen. For this period, it can be assumed that more or less all *villae* were in use. A density of about 1.7 villa/km² is obtained for the Aldenhovener Platte if those *villae* are also considered which have thus far not been dated (Appendix 1a; working with the dated *villae* only reduces the density to 1.2 villa/km²). For the regional studies in the Wetterau and in the Neckar region, a density of 0.3 and 0.2 villa/km² is obtained. These values can be compared with calculations for the 2nd century AD in six sub-regions of the southern part of the Roman province *Germania inferior* (Gechter & Kunow 1986, 377 *et seq*.). Best comparable to the key areas is the neighbouring Rheinbacher Lößplatte (Gechter & Kunow 1986, 382) with a density of 0.9 sites/km². In the other areas of *Germania inferior* the density ranges between 0.1 and 0.5 sites/km². Several estimations of an arithmetic mean exist for how many people lived in a *villa*. For some *villae,* the number of their graves is known (Gaitzsch 2002, 270). The size of farmland seems to be related to the density of *villae* and the number of their inhabitants; a minimum number of 10–15 persons without seasonal workers is discussed (*ibid*., 269). If we include those seasonal workers helping during the labour intensive periods of the year in spring and autumn, a total of 20 people (30 inhabitants in Bender 1997, 330) and a size of perhaps 50 ha for the farmland is assumed. An estimation of this kind is presented for a region with a high density of *villae* (eg, Gaitzsch 2002, 269). Hüssen proposes a size between 50 ha and 100 ha for the vicinity of Heilbronn (2000, 133). The topographic situation of the *villae* from Hardthausen a.K.-Lampoldshausen 'Hörnle, Langengrund, Sponwiese' seems to confirm an estimation of 50 ha up to 70 ha. In these cases, even the location of some fields can be identified and a differentiation between fields and pasture seems possible (Hüssen, 2000, fig. 57, 59, 60).

For a *villa* with a size of 100 ha of farmland, an average of perhaps 25, and up to 50 inhabitants (inc. 25 workers) is expected (eg, Gaitzsch 2002, 270; Sommer 1988, 302 and already Wolf 1913; according to Kilchner 1981 with reference to the Swiss cemeteries at Courroux (Kt. Jura) and Allschwil (Kt. Baselland) up to 50 persons including children but without *villae* owners). For areas with a high density of *villae* as on the Aldenhovener Platte, an average field size of 100 ha can be excluded because the space is simply not sufficient. Therefore, fields of this size can only be expected in areas with a low density of *villae*.

It is interesting to notice that, for Roman times, the density of *villae* in the key areas has the same magnitude as inside the 1 km isoline mapped with the data from the much bigger scale of the GAR III. This confirms the observed density in regions of a high density at a larger scale (Tables 2–3) and is most probably due to the good visibility of Roman stone architecture. An explicit upscaling procedure from key areas to regional studies is not necessary in this case.

A lower density of *villae* (2 km isoline) in the GAR III corresponds approximately with the observations in the regional studies of the Wetterau and the Neckar region. Because some of these areas with lower density are situated in regions of less ecological suitability and because it seems not unreasonable to assume that, in large part, the once existing *villae* are already known, we tend to suppose a larger number of inhabitants and more farmland for the *villae* within the 2 km isoline (Tables 2–3). It is possible that in some areas of the 2 km line a higher density of *villae* existed; however, the assumption of a larger number of persons for each of them reduces the possible estimation error. For the 508 *villae* outside the isolines, the number of inhabitants and size of production area are assumed to be of the same magnitude as inside the 2 km area.

In Roman times, not all people produced their own foodstuffs. Many lived in smaller or larger concentrations of households (Table 4). Today's estimations as to the number of persons living in urban settlements all seem to be quite generalised assumptions. In the future, it may be possible to specify these estimations. In towns, the number of *insulae*, the size of public spaces and buildings, as well as the proportion of the room for handicraft and commercial activities are observations which will become more precise with future fieldwork. The number of floors per *insula* and the number of its inhabitants have to be estimated in order to arrive at a more accurate number of people living in towns.

For the 36–7 Raetian *vici*, which were related to the military forts along the *limes*, the number of inhabitants should be at least similar to the number of soldiers in the corresponding forts (500–1000 persons; Czysz 2005, 209). In the Rhineland it is not unusual to use a factor of 1.5 to estimate the inhabitants of the same type of *vici* (750–1500, mean: 1125 persons/*vicus*) and to assume 500 people as a mean value for the civil *vici* (Th. Fischer pers. comm.). In this paper, an estimation with respect to the

TABLE 4: URBAN SETTLEMENTS & VILLAGES IN THE 2ND HALF OF THE 2ND CENTURY AD IN THE REGION COVERED BY THE GAR III

Name/no.	*Type*	*Sum of inhabitants*	*Source*
Xanten	Town	at least 20,000	Bender 1997
Köln	Town	at least 25,000	Bender 1997
Trier	Town	15,000	Bender 1997
21	*vici* by hectare	21,910–43,820	Appendix 2b
65	other *vici*	67,817–135,633	Mean App. 2b
Sum	range:	149,727–239,453	mean: 194,590

After Bender (1997, 287–8); Rothenhöfer (2005, 25); Sommer (1988, 302); and Appx 2b–e. Mean values of minimal 1043.3 persons and maximal 2086.7 persons (Appx 2b) are used to estimate the range of population of those 65 vici without information about their size different sizes of *vici* is preferred. The number of stripe-houses (*Streifen Häuser*) of an individual *vicus* is deduced by an upscaling procedure according to the area covered by the site. The arithmetic mean is used only if the size of a site is unknown. A typical example is the *vicus* of Güglingen-Steinäckern in Baden-Württemberg where an area of 1.3 ha with 18 stripe-houses and associated pits has been excavated (Fig. 3; Kortüm & Neth 2004, 165–8) which is an average density of about 14 (13.8) houses per hectare. The number of inhabitants of a Roman stripe-house was estimated for the *vici Grinario* (*Köngen*: Sommer

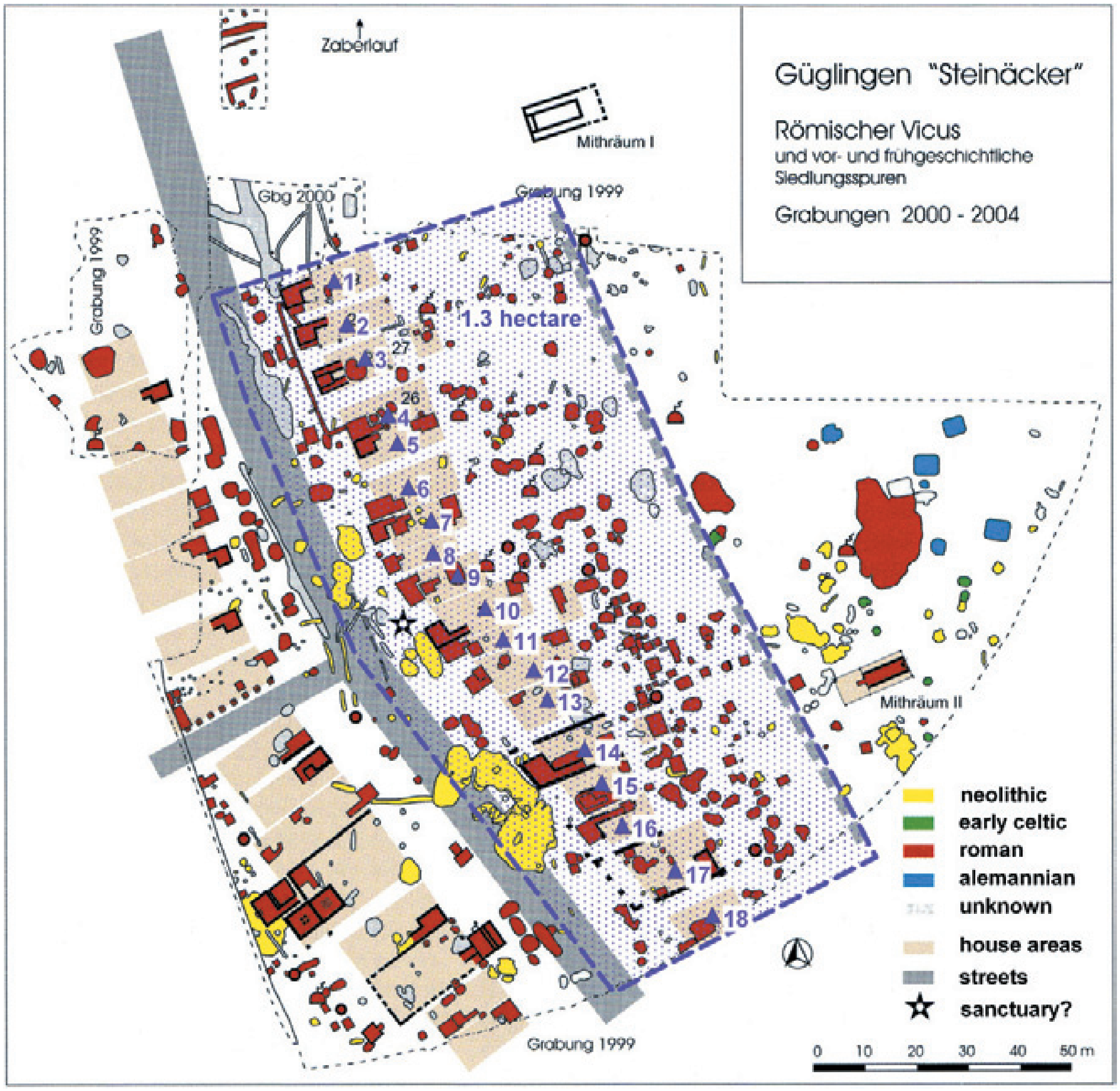

Fig. 3.
Basis for the calculation of houses per hectare in *vici*. Violet polygon = considered area (1.3 ha), violet triangles & numbers = considered house structures (after Kortüm & Neth 2004, 165, fig. 149)

1988, 302) and *Lopodunum* (*Ladenburg*: Sommer 1998, 116, 158) where 5–10 persons would have probably lived in one such house. The outcome of the combination of the density of houses per hectare and the estimated number of inhabitants is an average value between 70 and 140 persons per hectare (P/ha). This value can be used to estimate the population of those *vici* whose area is known through excavation, by geomagnetic prospection, artefact scatters, phosphate analysis, or the position of furnaces, graveyards, and other structures limiting the housing area (Heimberg 2000, 216). Several compilations of the size of *vici* have been published (Kunow 1988, 60, Tab. 1; Heimberg 2000, 216 and annotations 49 and 50; Rothenhöfer 2005, 266, appx 5). It can be debated whether the estimations of Kunow should be used or the more recent compilations. The judgments of Heimberg and Rothenhöfer are very similar and disagree only in the single case of Bonn Rheinaue (Heimberg 30–40 ha, Rothenhöfer 60 ha according to the scatter of artefacts). In this paper, a calculation referring to Rothenhöfer is presented as an example (Appendix 2b–d). This procedure allows estimation of the population of those *vici* whose area is known through excavation or by geomagnetic prospection. The results fit very well with estimations for *Augusta Raurica* (Kaiseraugst, 188.7 P/ha), *Lopodunum* (Ladenburg, 100 P/ha) within Baden-Württemberg (Sommer 1988a, 302; 100 P/ha), Billig (Heimberg 2000, 216, 80 persons per hectare), and – most important for the region of the GAR III – a generalised estimation for the *vici* in the southern part of *Germania inferior* (Rothenhöfer 2005, 26; 80–100 P/ha). It could be discussed whether larger values of population numbers from outside the *Geschichtlicher Atlas* (Appendix 2c) should also be taken into consideration. However, much larger estimations with up to more than 200 persons per hectare (Appendix 2d) were presented for the Raetian *vici Cambodunum* (Kempten, 228.6 P/ha) and *Augusta Vindelicum* (Augsburg, 153.8–220.8 P/ha). We did not dare transfer such values to the lower Rhine Basin. The lower limit of the average number of 1043 persons/*vicus* for the GAR III (Appendix 2b) corresponds with the generalising estimation of 1125 persons/*vicus* discussed above disregarding the size of the *vici*; the upper limit of an average number of 2086.7 persons/*vicus* with regard to its size nearly doubles the competing generalising estimation discussed above.

Bender used another, in itself consistent, way to estimate the number of persons for some of the more important *vici* and the *coloniae* (Appendix 2e). He determined much larger areas for these sites (probably including empty areas) but with a much lower density of people (11.1–66.7 P/ha). In the case of *Bonna*, where two *vici* were pooled, Bender arrives at about 15,000 people; our estimation according to size (based on the number of stripe-houses in Güglingen-Steinäcker) and number of people per hectare suggests a population of between 7000 and 14,000 people.

Very accurate information, summarised in Table 5, exists for the numbers of military personnel. It is a quite specific situation that two legions had their base camp in the area covered by the map from the GAR in this time. In addition, the two largest towns (Cologne, *Colonia Claudia Ara Agrippinensium* and Trier, *Colonia Augusta Treverorum*) of *Germania inferior* were located in this region, so that the number of inhabitants here is expected to be larger than in other regions of Germany occupied by the Romans.

In the case of the Roman period, the accuracy of the 'global' estimation of population density can be checked against the production of foodstuffs and the number of known graves. First, the production of cereals will be discussed because the arguments needed for this purpose allow at the same time to assess the intensity of human impact (see p. 40–2).

A total of 304,000 ha of agrarian production area (Table 7) has to be balanced out against the nutritional demands of about 325,000 people (a bit less than the average sum of people; Table 6). To simplify the argument it is assumed that neither import nor export of foodstuffs occurred. Of course,

TABLE 5: NUMBER OF SOLDIERS IN THE MIDDLE OF THE 2ND CENTURY AD IN THE REGION COVERED BY THE GAR III.

No.	*Type*	*Mean no. persons*	*Sum soldiers*
2 (1 in Bonn, 1 in Xanten)	castel of legion		12,600
18	auxiliar castels	750	13,500
Sum			26,100

this does not really concur with the situation as it is known for the Roman period. The large-scale transport of goods by ship or road was, generally speaking, now possible for the first time.

We know for example of imported figs and even oysters; for the late Roman period there is even written evidence for the import of cereals from Britain to the lower Rhine (Ammianus 18, 2, 3–4). In fact, import and export of limited quantities of cereals certainly occurred. However, in principle, the economic situation of *Germania inferior* and *superior* would have been more stable if an independent procurement of foodstuffs had been possible.

A further simplification is the preliminary assumption that all agrarian production areas comprised fields for the production of cereals. In Roman times gardens existed (in the sense used by our palaeobotanists) with vegetables, fruits, and herbs as well as meadows for grazing horses and other animals. In fact, it should be a future aim to elaborate an economical model for the agrarian production system of the Roman times adapted for the situation in Central Europe. The aim of balancing agrarian production areas (assuming a dominance of cereal production) with the demands of people living in the area covered by the GAR III is simply our way of cross-checking our estimations of the number of people and the area available for agrarian production in this region (Tables 8–9). As a by-product of this reasoning, we arrive at an open land proportion of about 49% for areas with a high density of *villae* and of about 22% in the areas of low density.

The most recent estimations calculated for the southern part of *Germania inferior*, which covers an area of 7000 km² and is dominated by loess (2000 km²), have suggested a total of 140,000–180,000 persons (not including members of the military) corresponding to a density of 20–25.7 persons/km² (P/km²; Rothenhöfer 2005, 26). Another estimate based only on the evidence from human graves belonging to the agrarian population of the Jülicher Börde has resulted in a calculated density of 4 P/km² (Gaitzsch 2002). The number of missing graves is explained partly by the fact that seasonal workers were buried elsewhere; a further difference can probably be ascribed to the fact that a certain number of graves have not yet been found. In a specific way, each of these estimates confirms the results obtained according to the data presented in this paper. They result in a density between 10.8 and 17.9 P/km² within the region occupied by the Romans west of the Rhine as covered by the *Geschichtlicher Atlas*. This is a total of 247,437 to 408,773 persons estimated to have been living in an area of 22,848 km². According to this estimate, this density larger than that observed at the beginning of the Neolithic by a factor of

TABLE 6: NUMBER OF PEOPLE IN THE MIDDLE & 2ND HALF OF THE 2ND CENTURY AD IN THE REGION COVERED BY THE GAR III

No. people in *villae rusticae* (Table 3)	71,610–143,220
No. people in urban settlements & villages (Table 4)	149,727–239,453
Military personnel (Table 5)	26,100
Sum of people – range	247,437–408,773
Sum of people – average	328,105
Demand of cereals per year (1 kg/person/day)	90,315–149,202 tons

Demand according to Kreuz (1995)

TABLE 7: SIZE OF AGRARIAN PRODUCTION AREAS IN THE REGION COVERED BY THE GAR III

	No. villae	*Mean size agrarian production zones (ha)*		*Product (ha)*
1 km isoline	1756	50	(49%)	87,800
2 km isoline	1654	100	(22%)	165,400
Known outside isoline	508	100		50,800
Sum				304,000

Percentages in brackets: proportion of openland

TABLE 8: MAXIMUM PRODUCTION OF CEREALS IN THE MIDDLE & 2ND HALF OF THE 2ND CENTURY AD IN THE REGION COVERED BY THE GAR III

Size of agrarian production area (Table 7)		304,000 ha
Fallow land 50%		152,000 ha
Remaining fields		152,000 ha
10% used to produce the seeds needed the next year		15,200 ha
Production area of cereals for consumption		136,800 ha
Annual production of	0.8 t/ha (Kreuz 1995)	109,440 t
	~2.0 t/ha (Reynolds 1990)	273,600 t
	wheat 0.4 – 1.8 t/ha (Rothenhöfer 2005)	54,720–246,240 t
	dinkel 0.9 – 3.6 t/ha (Rothenhöfer 2005)	123,120–492,480 t
	barley 0.4 – 2.0 t/ha (Rothenhöfer 2005)	54,720–273,600 t

TABLE 9: BALANCE OF PRODUCTION & DEMAND FOR CEREALS IN THE MIDDLE & 2ND HALF OF THE 2ND CENTURY AD IN THE REGION COVERED BY THE GAR III

Annual production	54,720–492,480 t
Annual demand for cereals (Table 6)	90,315–149,202 t
Worst scenario (408,773 persons, 0.4 t/ha)	*– 94,482 t*
Best scenario (247,437 persons, 3.6 t/ha)	*+ 402,165 t*
Average scenario (325,000 persons, 1.0 t/ha)	+18,175 t

aproximately 30. In contrast to the Bandkeramik nearly all land optimally suited to agricultural production was in use during the Roman period (Fig. 10). An interpretation of this observation might refer to improved conditions of living provided by a state society.

It goes without saying that the estimation of population density for the Roman period presented here is open to improvement in many of its details. For example, an increase in the number of large excavations at different types of *vici* would certainly help to render our calculations more precise. Additionally, the consideration of a further key area in a region with sub-optimal ecological conditions would also help improve our result. Fortunately, spreadsheet analysis allows us not only to correct single values but also to evaluate the corresponding consequences. This will also apply for the results of future fieldwork. As in our study of the Bandkeramik the main issue is that our work is carried out using a consistent logic, as only then can information be successfully transferred from one scale level to another. This said we are confident that the magnitude of our estimates presented here will remain stable as they fall within the range of other estimates based on other methods.

CALIBRATING BANDKERAMIK AND ROMAN POPULATION DENSITY ON LARGE SCALE DISTRIBUTION MAPS

Unfortunately, large-scale site distribution maps are still lacking for the Bronze and Iron Ages in Germany. For these periods there exist only maps of specific types of finds. Maps are available for the Neolithic of Central Europe (Preuß 1998), and for the Roman period in Germany a map has been compiled by Bender (1997, maps 1–9). The Neolithic case is considered first. Upon analysing the distribution map of Bandkeramik sites in Central Europe the 4 km isoline is again identified as the optimal boundary of settlement areas (Fig. 4). This is linked to the results of our land use analysis (see p. 21–34). On this large scale, the 4 km isoline includes areas approximately 1.3 times as large as the corresponding areas observed on the smaller scale. One of the reasons for this is the spatial precision error, which renders interior empty spaces invisible, such as larger river valleys. This effect is neutralised by using a regression analysis (Zimmermann *et al.* 2004, 80 *et seq.* & fig. 15; Appendix 3a). This step of the analysis can be elaborated for future applications which will consider additional regional studies. Once applied, this method can be used to estimate the number of contemporaneous households per settlement area. These estimations allow a modelling of the flow of flint artefacts as described below under Economic and Social Relations.

A comparative analysis of the five Neolithic periods of Central Europe discussing the culture historical context is presented under Culture History below. Additionally, at this scale level, those sites lying outside the isoline are, of course, not without historical interest. These might even include special purpose sites or small settlement areas, which played an extremely important role in upholding contact between larger settlement regions. Quantitatively however, they will not influence the density of households substantially (Figs 4–5).

Maps for Roman rural settlements have been presented by Bender (1977, 364 *et seq*.). The 1 km isoline was selected as a limit for the agrarian centres. The optimal isoline delimiting 'settlement areas' at this scale is the 2.5 km line. The frequency of *vici* and *municipiae* from Bender's large scale maps must be calibrated in such a way that they match with the regional study from the GAR III. One possible solution would be to transfer the frequency of *vici* from the *Geschichtlicher Atlas* to a larger area. Eighty-six *vici* are reported in the GAR III. Bender (1997) records only the larger of them (28) in this region. Therefore, it is to be expected that on maps of a smaller scale outside of the GAR III the existence of some more *vici* would become visible. Perhaps the relationship of smaller to larger *vici* can be transferred from the Rhineland to the areas outside of the region covered by the GAR III. Following this argument, the 110 larger *vici* and *municipiae* in the other regions of Germany reported by Bender should be completed by 170 expected smaller *vici*. The other parts of the estimation procedure follow the Roman example in the GAR III. Data are presented in Appendix 3 c–f. The result has to be corrected again by a regression coefficient quite similar to the Bandkeramik study (Appendix 3b).

SOURCE CRITICISM (PRESERVATION OF SITES AND INTENSITY OF ARCHAEOLOGICAL OBSERVATION)

The method used to describe site densities by isolines also allows the development of a formal procedure for a critique of the analysed data. The intensity of archaeological observation for example can partly be controlled by producing *maps with overlaying isolines of different periods* (Fig. 6). In the example from the GAR, finds from the Bandkeramik period are practically missing along the Rothbach (Zimmermann *et al*. 2004, 63, 70). On the other hand, Urnfield period sites are well known from this area, and the Roman and early medieval periods are also well represented. It is extremely unlikely that archaeologists or local collectors systematically discarded Bandkeramik finds but kept those of later periods.

Therefore, missing archaeological observation is probably not the reason behind the lack of Bandkeramik sites along the Rothbach. It would also be difficult to argue that erosion has destroyed Bandkeramik sites. This is because it is generally assumed that most intensive erosion did not begin until Roman or early medieval times. Archaeological features from the Bandkeramik are generally not less deep than features from later periods. Therefore, erosion should not be regarded as the sole cause for the reduced density of sites in this area. Consequently, it should be concluded that, during the Bandkeramik, the area along the Rothbach was not used to the same intensity as other areas of equal suitability (see p. 21–34).

Observations of other kinds also corroborate the existence of small areas used to only a limited extent in specific periods. For example, along the Wurm valley palynologists indicate that human impact was reduced in Bandkeramik times. Furthermore, between the Bandkeramik sites of the Aldenhovener Platte and the settlements of the Hambacher Forst a clear division exists along an empty band measuring 1 km in width, centred on the River Rur. It should be noted that this contradicts the regular distances otherwise observed in the centre of the settlement formations in this area. Here two different kinds of exchange networks for flint artefacts support the idea of different identities (Zimmermann 2002). However, this concept still has to be confirmed by an analysis of the ceramic decoration.

All these observations, made in a region with an otherwise excellent archaeological record, indicate that, during the Bandkeramik, the landscape was not being used to its full carrying capacity. This behaviour is now interpreted as resulting from the need for physical demarcation between various small social groups, numbering in size between several hundred or maybe 1000 individuals, each with its own identity.

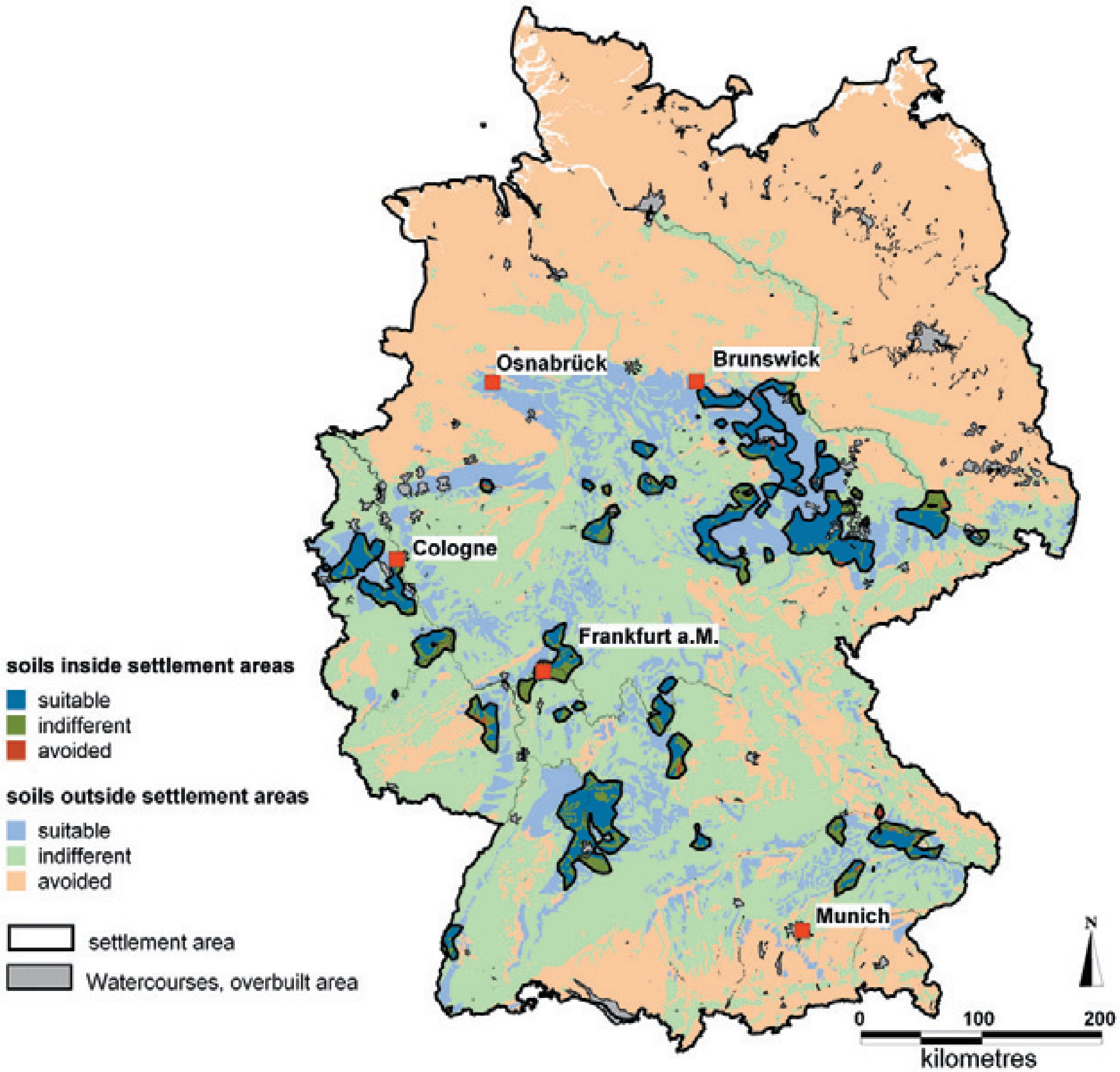

Fig. 4.
Optimal isolines (4 km) of Bandkeramik (5500–4950 BC). Data according to Preuß (1998). The other periods of the Neolithic are presented in Fig. 12. For the Bandkeramik three classes of soil suitability are differentiated according to the BÜK 1000 & the method described in paragraph "Patterns of land use"

PATTERNS OF LAND USE

The analysis presented here is embedded in the context of the research in the Rhein-LUCIFS group of projects. Its aim is to consider all the Rhine-catchments or at least large parts of it for further analyses. Therefore, large-scale maps for all Germany are used to describe the environmental properties of landscapes. Small-scale structures of a few hundred metres diameter are not visible in using this approach. The large scale of the analysis presented here is, as far as we know, the first attempt of this kind within the sphere of Central European archaeology for a long time. Therefore, it seems useful to measure the

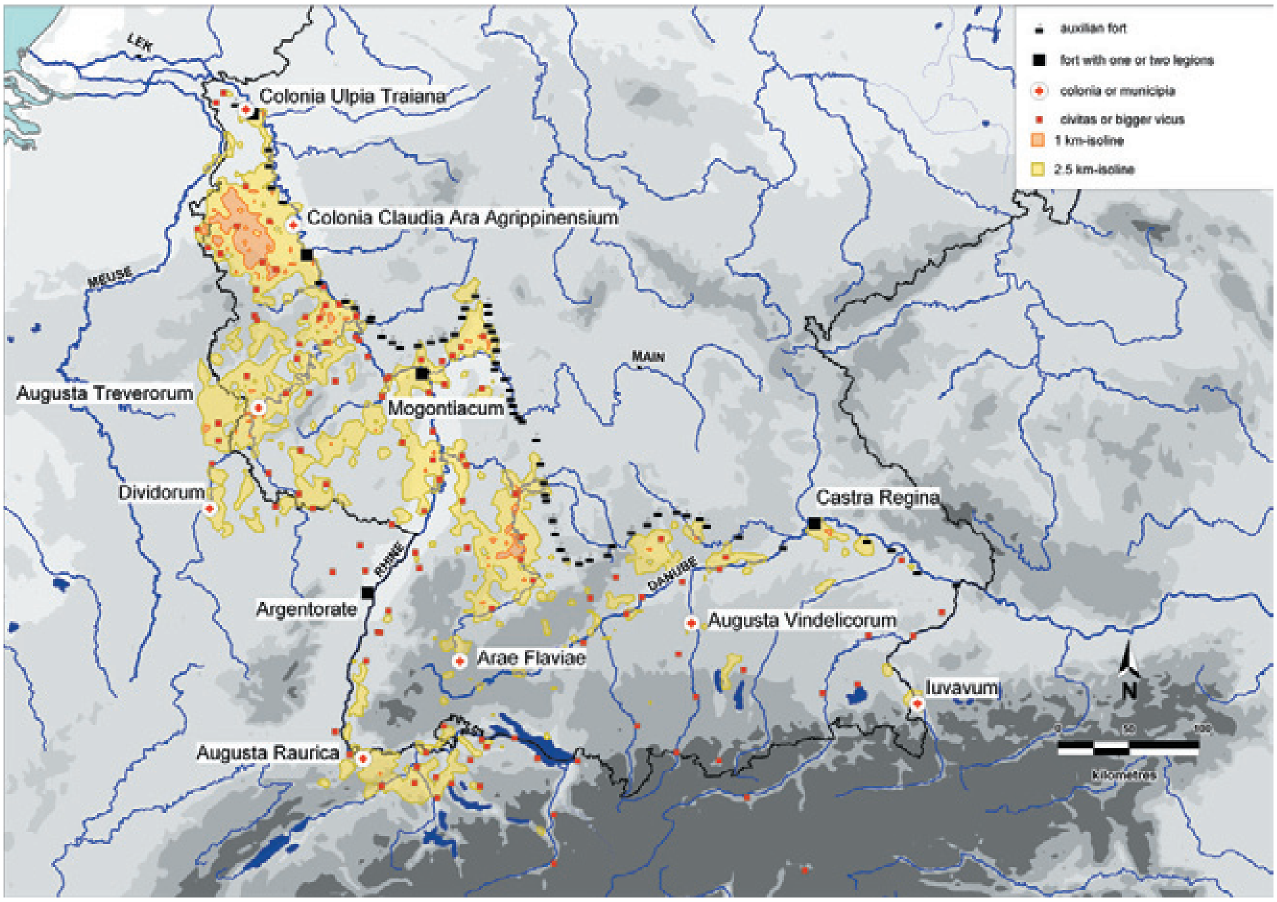

Fig. 5.
Isolines of Roman agrarian settlements in Germany and its vicinity (data according to Bender (1997, 364 et seq.)). [Colonia Ulpia Traiana-**Xanten**, Colonia Claudia Ara Agrippinensium-**Köln**, Augusta Treverorum-**Trier**, Mongontiacum-**Mainz**, Dividorum-**Metz (F)**, Argentorate-**Straßburg (F)**, Augusta Raurica-**Basel (CH)**, Arae Flaviae-**Rottweil**, Augusta Vindelicorum-**Augsburg**, Castra Regina-**Regensburg**, Iuvavum-**Salzburg (A)**]

efficiency of this approach (by analogy with the gain of predictive modelling) to understand how selective it is in its discrimination in favour of areas with suitable environmental conditions for specific periods of the past. In this way, it should be possible to compare results of analyses on different scales using perhaps more complex methods and other kinds of data or referring to its data in a different way.

With regard to the different methods used and data sets analysed, until now, as described in the introduction, a very simple research design with a sequential introduction of variables is chosen. Only soil units of preferred locations are divided into those with much and others with only sparse rainfall per year. A sequential introduction of variables also allows a focus on relevant threshold values for variables, which occur on an interval or proportional scale, such as temperature and precipitation. The alternative, a simultaneous introduction of variables, would result in a large number of very fine-grained entities (a special soil unit with specific attributes of precipitation and temperature for example). The resulting small frequencies can lead to misinterpretations. Even for the sequential introduction of variables with higher frequencies of specific soil units, for example the loess types 35 and

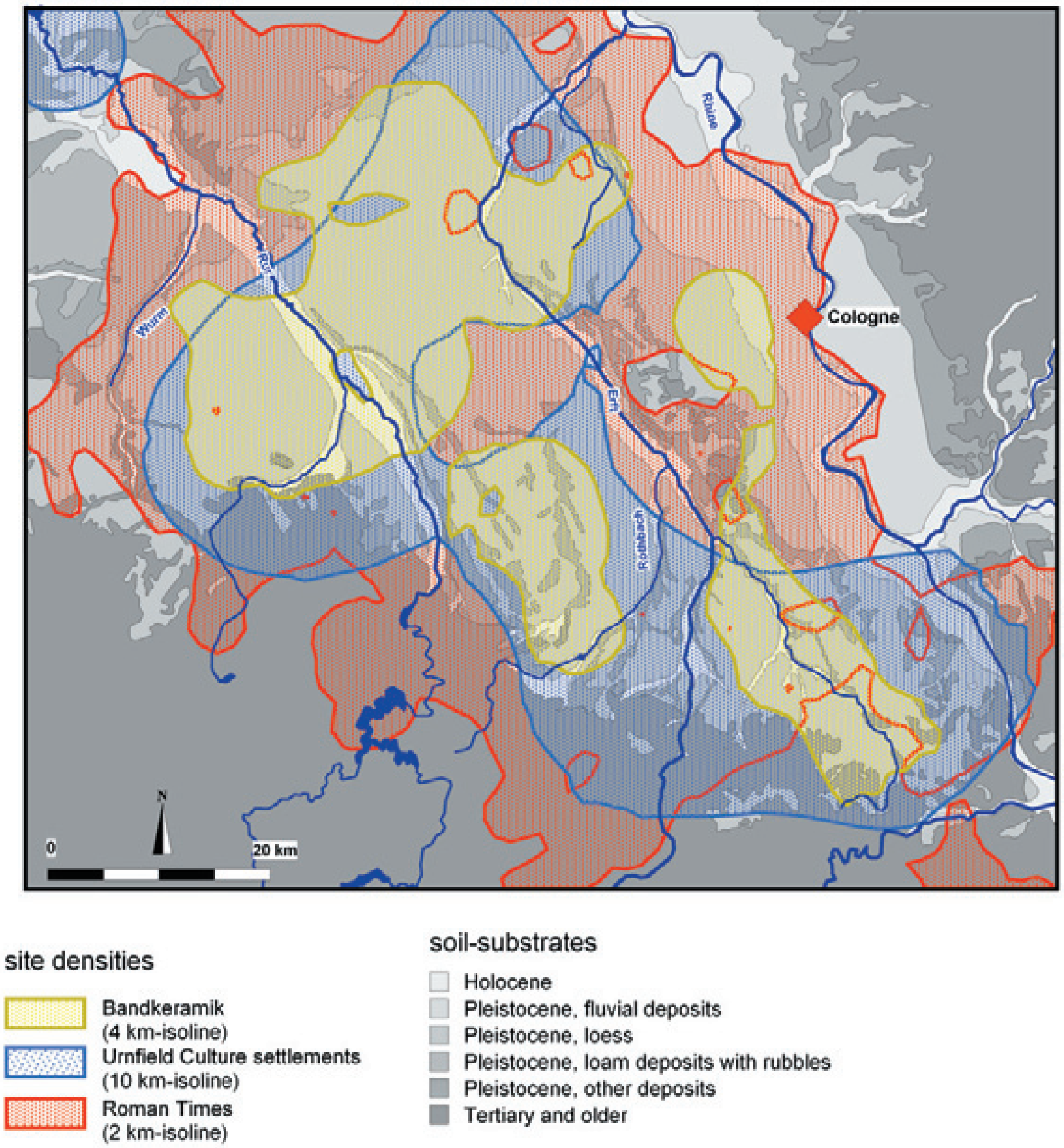

Fig. 6.
Map of optimal isolines for the Bandkeramik, Urnfield Culture, & Roman times for the area covered by the GAR I-III (Richter & Claßen 1997; Joachim 1997; Cüppers & Rüger 1985) (map after Modderman 1970, Taf. 1, modified)

40 are classified as 'indifferent' when considering the Bandkeramik in the area covered by the GAR I alone because these soil types cover only 1.1% (a little more than 400 km²) of the map. However, an analysis of these relations on a larger scale, ie, in the whole of Germany, shows that these soil units actually represent preferred settlement areas at the time of the Bandkeramik.

In the temperate zones of Central Europe, soil has proven to be a very important ecological parameter in different approaches (eg, in predictive modelling by Münch (2004)). Their relative consistency in the past and the present is another reason to refer to this kind of information. Therefore, soil is the first variable of the analysis presented here. That seems useful although human use has influenced the development of each group of soils in a specific way. The soil map used is the *Bodenübersichtskarte* 1:1,000,000 (from the *Bundesanstalt für Geowissenschaften und Rohstoffe in Berlin* 2004; abbreviated to BÜK 1000). All soils known from Germany are unified in this synopsis into 69 so called *Bodengesellschaften* (soil units) or *Leitbodengesellschaften* (routing soil units; urban areas, industrial dumps, and lakes are not considered in our analysis). This compilation considers the genetical type of soil as well as its sediment substrate. The 69 units are assigned to six groups:

1. coastal soils,
2. sandy and clay soils,
3. soils from broad river valleys,
4. soils from loess areas,
5. soils from the lower mountain ranges and
6. soils from the higher mountains.

Climate has probably changed considerably in the time between the Atlantic period and the present. Nevertheless, empirically the efficiency of the analysis is improved considerably by introducing the variable rainfall per year (average rainfall in the years 1961–1990 according to *Deutscher Wetterdienst*). Maps showing phenological data, which are mostly temperature dependent in Central Europe, are inspected only visually at this stage. In this respect, the possibilities of large-scale comparisons can be presented. Information derived from elevation models (DEM) will be important for mountainous regions with respect to decisions concerning the location of sites on a small scale only. Therefore, DEM data are not being considered in the ongoing analysis.

A method to analyse the relation between soil and land use

The method used to analyse the relation between soil and land use in the past is a simple graphical-statistical approach. The aim of our analysis is to identify the suitability of each location for use by prehistoric man. In a first stage of the analytical sequence, only the soil map is analysed according to the eight-step analysis described below. Precipitation is considered separately using the same procedure. The result is that eg, 97.8% of Bandkeramik settlement areas are located in regions with 800 mm rainfall or less. The threshold is very clear. The less rainfall the more the size of observed settlement areas exceeds the size of expected areas. Both analyses are linked, dividing only all suitable soil units in parts with less than 800 mm rainfall from parts with more. The resulting table of the modified soil map is again analysed according to the eight-step analysis and the procedure is presented in Table 10. The efficiency of the analysis of the Bandkeramik in the area covered by the GAR I is summarised in Table 11.

1. The soil map is overlain by a map with the settlement areas belonging to a specific period.
2. The space of the different soil units (rows in Table 10) is determined for the areas inside and outside the isoline (columns in Table 10). In most cases entities with a pixel size of 100 x 100 m are used. In the cases of regional studies focusing on areas of about 1000 km² a smaller cell size was used.
3. Expected values of soil units within a settlement area are calculated as Expected Value = Sum of Row (Total size of a soil unit) x Sum of Column (Sum of space inside the isoline)/Total Area of Analysis (Sum of total size). The expected value would result if size of space inside and outside of settlement areas for a specific soil unit were proportional to the overall relation between settlement areas and total region of analysis.
4. A value measuring a use index of a soil unit ('Suitability') in the period under consideration is calculated. This value is also provisionally called 'Chi-Index' by analogy with the Chi-Square-Test. 'Suitability' = (Observed [Inside isoline]–Expected)/Expected. In the statistical test, the difference (Observed–Expected) is squared; to determine the suitability of a soil unit the sign has to be kept. Therefore, our expression is not squared.
5. Soil units are sorted according to the Chi-Index. Positive values indicate suitability, negative values characterise soil units, which tend to be avoided. The Chi-Index is used for the X-Axis on Figure 7.
6. A downward cumulation of the percentages of pixels inside settlement areas (blue column in Table 10; blue line, reaching 100% at the side of suitable soil units at the right in Fig. 7); upward

TABLE 10: SOIL UNITS (BODENGESELLSCHAFTEN ACCORDING TO BÜK 1000) & PRECIPITATION

Soil unit	*Percipi-tation*	*Inside (ha)*	*Expected (ha)*	*Suita-bility*	*Outside (ha)*	*Total size (ha)*	*Cumulated inside (%)*	*Cumulated outside (%)*	*Class limits*	*Sum of untyp. values (%)*
54	1	11,601	1256.8	8.2	12,183	23,784	100.0	0.3	8.0	94.5
48	1	12,024	1380.1	7.7	14,094	26,118	94.1	0.7	6.5	88.8
39	1	233	37.3	5.2	473	706	88.0	0.8	5.2	88.7
42	1	111,959	18,272.5	5.1	233,840	345,799	87.9	7.4	4.2	38.5
40	1	4027	963.1	3.2	14,199	18,226	31.2	7.8	3.0	36.9
35	1	3608	957.7	2.8	14,517	18,125	29.1	8.2	2.2	35.5
11	2	5293	1944.9	1.7	31,514	36,807	27.3	9.1	1.2	33.7
55	2	541	308.6	0.8	5300	5841	24.6	9.2	0.5	33.6
8	2	13,093	10,227.5	0.3	180,459	193,552	24.3	14.3	0.0	32.0
49	2	4556	5753.6	-0.2	104,329	108,885	17.7	17.3	-0.3	32.7
60	2	9775	17,394.6	-0.4	319,411	329,186	15.4	26.3	-0.5	36.8
16	2	2059	4959.5	-0.6	91,798	93,857	10.4	28.9	-0.6	38.3
62	2	328	1056.4	-0.7	19,664	19,992	9.4	29.5	-0.7	38.7
59	2	14,371	54,163.8	-0.7	1,010,658	1,025,029	9.2	58.0	-0.8	60.0
58	2	2309	12,710.8	-0.8	238,238	240,547	2.0	64.8	-0.8	65.5
15	2	1103	7625.0	-0.9	143,198	144,301	0.8	68.8	-0.9	69.0
53	2	421	4659.2	-0.9	87,753	88,174	0.2	71.3	-1.0	71.3
52	2	30	3151.9	-1.0	59,618	59,648	0.0	73.0	-1.0	73.0
`unused'	2	0	50,507.4	-1.0	955,833	955,833	0.0	100.0		
Sum		**197,331**			**3,537,079**	**3,734,410**				

(1=less than 800 mm annual rainfall, 2 = more rainfall or not divided, according to *Deutscher Wetterdienst*) inside and outside Bandkeramik settlement areas (defined by the optimal 4km isoline) for the region covered by the GAR I ('unused' soil units 2: 6, 7, 10, 17, 19, 22, 31, 46, 47, 51, 61, 63–6 mot differentiated concerning precipitation class; 35, 40, 42, 48, 54 with more than 800 mm rainfall; the remaining soil units do not occur in this map). For graphical representaion, compare Fig. 7

TABLE 11:BANDKERAMIK IN THE GAR I. EFFICIENCY OF DISCRIMINATION BETWEEN SUITABLE & AVOIDED LOCATIONS ACCORDING TO SOIL (BÜK 1000) & TO PRECIPITATION (DEUTSCHER WETTERDIENST; FOR DETAILS SEE TEXT) INSIDE & OUTSIDE SETTLEMENT AREAS (4 KM ISOLINE)

	Locations	*Inside settle -ment areas*	*Suitable & indifferent cumulated*	*Outside settlement areas*	*Sum*
% of total area	Suitable	3.8 (3.6)		7.7 (7.0)	11.6 (10.6)
	Indifferent	1.0	4.8	20.1	21.1
	Avoided	0.5		66.8	67.3
Sum		5.3		94.7	100
% of settlement areas	Suitable	72.7 (68.8)			
	Indifferent	18.1	90.8		
	Avoided	9.2			
Sum		100			
% of settlements		76		22	100

Values are summarised according to Table 10. Values in brackets refer to the local analysis of the GAR I; the remaining values for suitable soils consider that, in the large-scale analysis for the whole of Germany, soil units 40 and 35 also belong to preferred locations. For cartographic representation, see Fig. 8

cumulation of percentages of pixels outside settlement areas (green column in Table10; green line, reaching 100% at the left side in Fig. 7). Both cumulated percentages are plotted on the Y-Axis of Figure 7.

7. In order to locate an optimal discrimination between suitable and avoided soil units for each pair of soil units along the suitability axis (at the red Class limits in Table 10, each with the mean X-value of the two succeeding soil units) the sum of untypical observations is calculated (percentage of suitable soils outside and of avoided soils inside the settlement area). This is the Y-Value of the third line in red in Figure 7.
8. In most cases a graph is created with three classes of soil: suitable (suitability >2 in Table 10), indifferent, and avoided (suitability <0.6); in other examples a graph with two classifications evolves: suitable and avoided. In such cases 'suitable' corresponds approximately to 'suitable' and 'indifferent' in the three-category classification. In every case the classification is derived by the data; there is no arbitrary differentiation as in predictive modelling.

Efficiency of analysis

In the most efficient approach, as much as possible of 'settlement areas' are concentrated in the smallest regions with apparently suitable conditions. The efficiency obtained is dependent on scale, method, and the ecological parameters used. As an example, factoring in precipitation to the analysis of soil units reduces the apparently suitable regions outside the Bandkeramik settlement area in the GAR I by 6.4%.

It can be observed that 72.7% of the Bandkeramik settlement areas are in suitable locations (Table 11). All suitable locations (including regions outside Bandkeramik settlement areas) cover only 11.6% of the total space (considering only soil and no precipitation, suitable locations including type 35 and 40 would add up to nearly 18% of total space instead of the 11.6% in Table 11). Accepting additionally indifferent locations as areas of possible use, then 90.8% of settlement areas are concentrated on 32.7% of total space (11.6 + 21.1). As already stated, 76% of all Bandkeramik sites are located inside the settlement areas determined by the 4 km isoline in the GAR I (the sites outside are considered not to be of importance for the magnitude of population density – see above). The settlement area is concentrated on only 5.3% of the total space of this map. The result of this procedure seems to be quite successful compared with the efficiency of logistic regression in Predictive Modelling. Münch observes, in her analysis in Lusatia (Lausitz), between 30% and 40% of sites from all periods to be located in 33% of the space. Between 60% and perhaps 82% of the sites are located in 66%

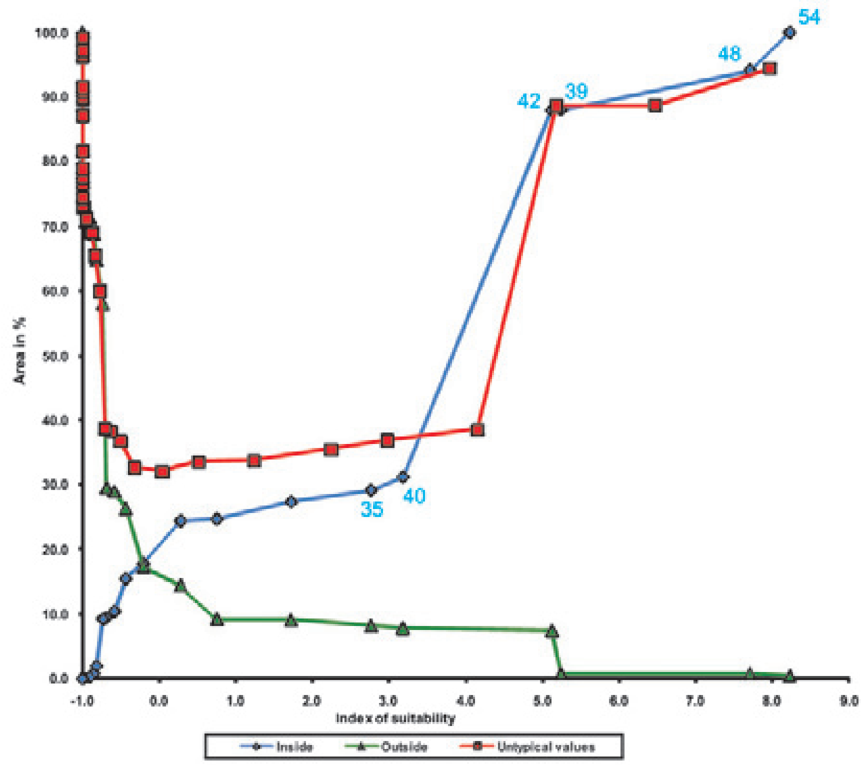

Fig. 7.
Cumulative diagram showing 'suitability' of soil units for the Bandkeramik in the region of the GAR I according to Table 10. The optimal limit between suitable & indifferent soil units using GAR data only would be defined between soil unit 42 & 40 (with <800 mm rainfall per year). Considering patterns of the whole of Germany units 40 and 35 also belong to preferred locations

of the space (2004, fig. 119); however, human environment relations of the Iron Age are more difficult to describe compared with Stone Age data (see below).

The efficiency of this analysis is assessed comparing the size of suitable locations and of settlement areas. Very similar results are obtained upon comparing suitability with site frequencies. The success of the analysis based on a large scale map (1:1 Mio), and considering the environment in a radius of some kilometres around archaeological sites (4 km for the Bandkeramik according to optimal isoline) challenges the presumption which has emerged over the last two decades that better results are obtained from smaller scales and smaller catchments. For the Celtic Fields in Britain, mean distances of 1–2 km between settlements are not unusual (Fries-Knoblauch 1999). This is confirmed by ethnological evidence (Bakels 1978, tab. 1; Jarman *et al.* 1982 tab. 7). Distances between settlements and areas used to feed animals are correspondingly larger (and for cattle larger than for sheep and goat as well as for pigs). However, for most archaeological sites the location of these economic activities around settlements cannot be determined precisely. Probably this uncertainty is better reflected by maps of a larger scale and by an analysis of a larger neighbourhood, although by this approach only a smaller proportion of the catchment can be expected to have been used for fields. Therefore, working on small scale maps suggests accuracy in most cases not provided by archaeological information. However, whether a scale of one to some hundred thousand, as already proposed by Vita-Finzi and Higgs (1970), or 1:1 Million is the better choice has still to be decided.

Archaeological sites from prehistoric periods are only represented in a small part of the suitable areas (in the Bandkeramik in only 3.8% of 11.6% of possible space). This can be visualised on a map as in Figure 8. Predictive modelling produces similar maps on a smaller scale; they are, however, much more highly resolved. Therefore, general structures are less easy to recognise.

In this example, areas with suitable conditions but without archaeological sites are easy to identify. Here, we must tackle the question as to why these areas are empty. Is it due to:

1. missing archaeological observations,
2. erosion, or
3. historical borders developed during the Bandkeramik?

For certain small areas it is possible to develop hypotheses to distinguish between these three possibilities via a critique of data (see p. 20–1).

Several additional ecological parameters besides the soil could be discussed in order to understand why a fraction of the seemingly suitable area was not used. The integration of variables derived from a Digital Elevation Model (DEM) does not promise an explanation for the 7.7% of suitable land not used during the Bandkeramik. Settlements of this period are concentrated in regions of Germany lacking a marked relief. In the lowlands, modern changes in landscape disturb DEMs, so no substantial improvements of the results are to be expected here either. Furthermore, the inspection of phenological maps in relation to temperature distribution does not lead us to believe that these factors will help improve the situation. Apple blossom as an indicator of the beginning of spring commences in all the loess areas of the lower Rhine basin at approximately the same time; the ripening of elderberries as an indication of a pleasant autumn occurs earlier along the Rhine and the Erft; however, no relation to Bandkeramik land use can be detected.

Considering precipitation, however, reduces the amount of unused and seemingly suitable loess soils. Loess soils not used during the Bandkeramik in the eastern part of the lower Rhine Basin and in the west of the *Bergisches Land* are located mainly in areas with a modern precipitation rate of more than 800 mm per year, equivalent to 6.4% of the entire area. Only the small area around the only settlement with Oldest Bandkeramik in Niederkassel-Uckendorf, Rhein-Sieg-Kreis, is situated in an area with less rainfall (700–800 mm). It is assumed that the relative proportion of rainfall in different regions was the same in the Atlantic period as it is today. Regions west of the Rhine generally receive less rainfall than regions east of the Rhine. For Germany, areas with more than 800 mm rainfall per year seem to have been avoided by Bandkeramik settlers. This behaviour could be understood assuming that in the Atlantic period precipitation was somewhat increased and considering that '... wheat and barley do not generally prosper where rainfalls exceeds 900 mm' (Jarman *et al.* 1982, 120; however, in the analysis of the Iron Age distribution maps the 800 mm threshold is also identified, see below). Therefore, precipitation can be used to better define smaller suitable areas by comparison with analysing soils alone. Nevertheless, Figure 8 demonstrates that west of the Rhine appropriate loess soils were not used in the Bandkeramik period because of high precipitation.

The results of the analysis of the relation between soils and land use patterns for the Iron Age (Hallstatt C up to La Tène B) are summarised in Table 12 and Figure 9. The point data from the GAR II are complemented by Schönfelder (1992), Ickler (2007), and Tutlies (2007. For details, compare Wendt *et al.* in press). Settlements are known from regions that are generally comparable with the Bandkeramik; however, graves and *tumuli* are mostly found in the forests of the lower mountain ranges. Accepting areas with either graves or settlements in appropriate density as 'settlement areas' leads to a two-fold classification of soil types when soil units alone are analysed: suitable and avoided. An analysis of precipitation leads to three classes: suitable (again up to 800 mm rainfall per year), indifferent (800 –1200 mm), and avoided (more than 1200 mm). It has been determined that a total of 22.0% of the area considered comprises 'suitable' soil. This is an area much larger than it was the case during the Bandkeramik. However, this value can surely be improved if we consider slope, since the areas characterised by *tumuli* in the Hunsrück-Eifel Culture are located in the lower mountain ranges along the river Moselle (Mosel).

The topography of this landscape is characterised by a much more marked relief. Therefore, flat plateaus with less than 10° slope were generally used

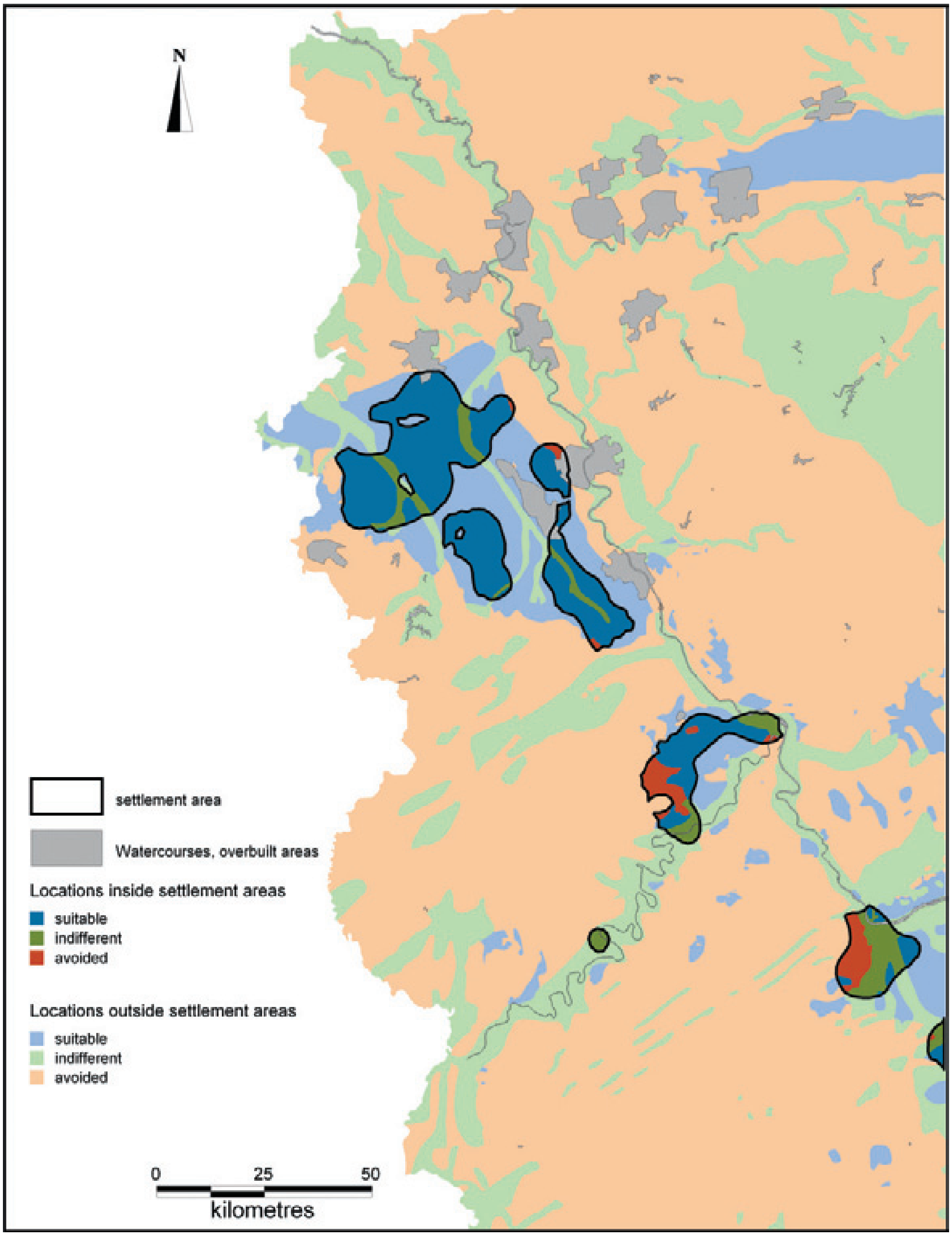

Fig. 8.
Suitability of locations for the Bandkeramik in the GAR I. Settlement area – 4 km isoline; soil units 35 and 40 classified as suitable. For percentage of areas of different type see Table 11. In Figs 8–10 soils are according to BÜK 1000; precipitation according to *Deutscher Wetterdienst*

TABLE 12: IRON AGE (HALLSTATT C–LA TÈNE B). EFFICIENCY OF DISCRIMINATION BETWEEN SUITABLE & AVOIDED LOCATIONS ACCORDING TO SOIL (BÜK 1000) & PRECIPITATION (DEUTSCHER WETTERDIENST) INSIDE & OUTSIDE SETTLEMENT AREAS

	Locations	*Inside settlement areas*	*Suitable & indifferent cumulated*	*Outside settlement areas*	*Sum*
% of total area	Suitable	14.8		7.1	22.0
	Indifferent	18.1	32.9	21.7	39.8
	Avoided	10.4		27.8	38.2
Sum		43.3		56.7	100
% of settlement area	Suitable	34.2			
	Indifferent	41.7	76.0		
	Avoided	24.0			
Sum		100			

For cartographic representation of results see Fig. 9

for graves (and probably for the adjacent settlements and fields), and the steep slopes could only be used for grazing cattle. Distinguishing both classes of slope would help to reduce the amount of 'suitable' area. Experiments with a DEM 1:1,000,000 for the whole of Germany demonstrated that its resolution was not sufficient. A future incorporation of slope in the analysis would require an upscaling procedure to estimate flat and steep areas for all the relevant lower mountain ranges.

However, the consideration of the slope does not help us to explain the differences between the archaeology encountered in the Hunsrück-Eifel area and that of the *Bergisches Land* east of the Rhine. Although these two areas share a similar topography and landscape, the latter lacks a comparable density of *tumuli* (Fig. 9). This task cannot be solved by simply integrating DEM information into the analysis. The *Bergisches Land* can, however, be excluded from the 'suitable' landscapes because of high rainfall of, occasionally, more than 1200 mm per year in the last decades. In those regions used intensively by the Hunsrück-Eifel-Kultur, with high density of *tumuli*, precipitation seems to be lower. In fact, 1200 mm per year seems to be an upper threshold value for the amount of rainfall tolerable in the Iron Age. Their consideration in the analysis of suitability considerably reduces the percentage of land with seemingly appropriate ecological conditions. However, this extension of the method does still not explain why in the northern Eifel not all suitable areas were used in a similar density as in the distribution of the Hunsrück-Eifel-Kultur.

A certain weakness of the pooled analysis of the distributions of graves and of settlements becomes visible when considering the soil units of larger valleys. The Fluvisol/Gleysol of unit 8 with the 'avoided' category on Figure 9 belongs, in a separate analysis of settlements only (in their relation to soil units), to areas which were 'suitable' for use. This is an indication that the result of the analysis is not satisfying in this respect. It is possible that an analysis on a smaller scale could correct this problem.

The marked increase of usable land during the Metal Ages most probably reflects improved farming techniques, which enabled the integration of a broad spectrum of landscapes into the range of potential farmland. The use of new techniques, developed since the Neolithic period (eg, the use of milk, of ploughs in different stages of development, and manure for the fields, etc), facilitated this type of subsistence economy outside of environments with optimal ecological properties. In fact, the size of settlement areas increased from about 5% in the Bandkeramik to more than 43% in the Iron Age (Fig. 11 horizontally; based on Tables 11 & 12). However, this dramatic increase in areas potentially usable as farmland did not necessarily mean that all land suitable was used. Considering soil and precipitation, 7% of suitable land is located outside settlement areas. It is for this reason that the Iron Age proves particularly difficult when applying prognostic modelling. In contrast to the Bandkeramik, regions with indifferent ecological conditions existed, for example, in the northern Eifel, for which we have to assume an only limited use in this period (until new archaeological evidence proves to the contrary).

The analysis of the relationship between soils,

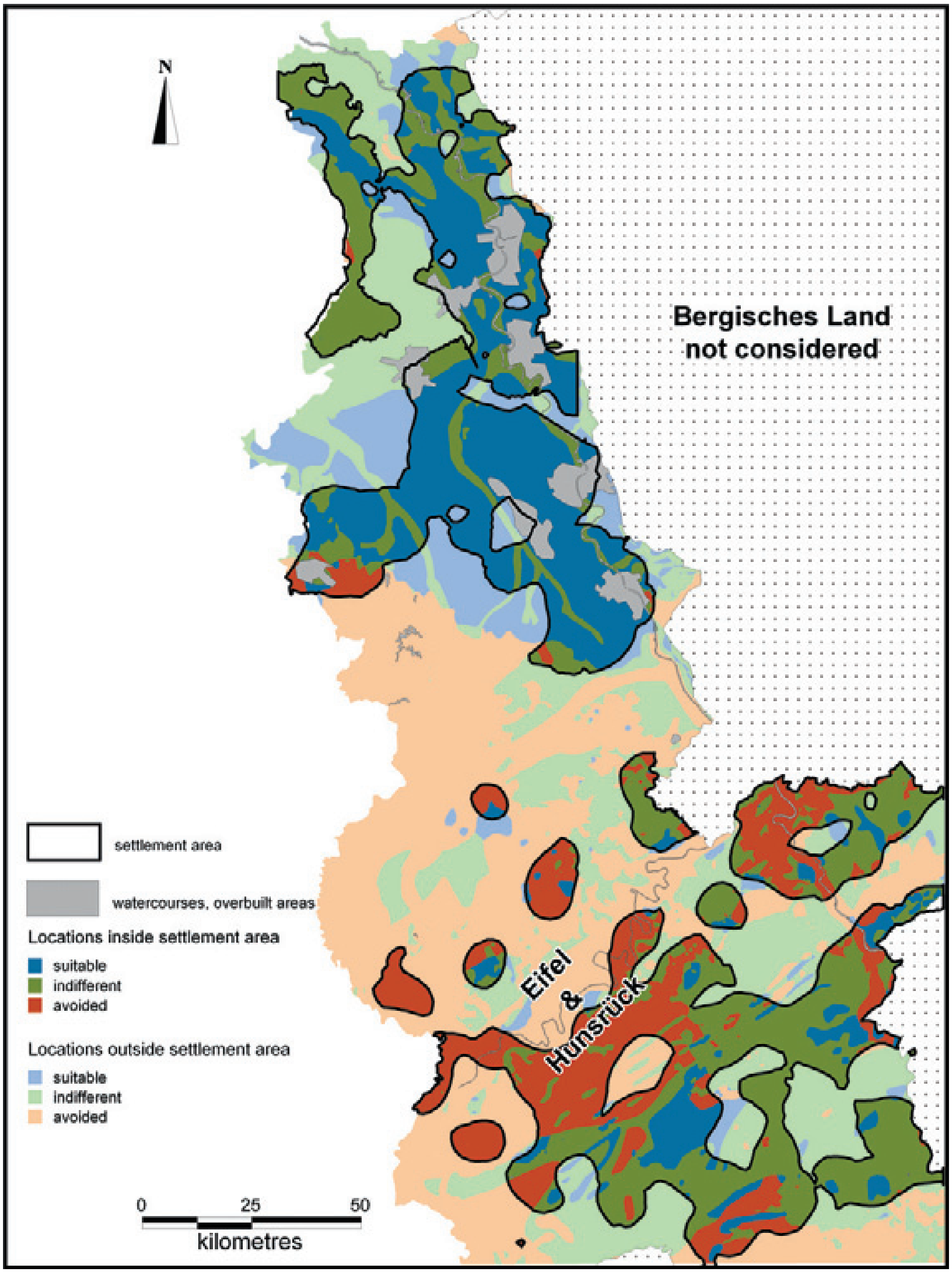

Fig. 9.
Suitability of locations for the Iron Age (Hallstatt C–La Tène B) in the GAR II. Optimal isoline for settlements – 7 km line, for graves – 5 km line. For size of areas of different type see Table 12

precipitation, and the Roman pattern of land use results again in three groups of soil units: suitable, indifferent, and avoided. By this time, however, the optimal soils are used almost in their entirety, ie, only 2.0% of soil of this quality is situated outside settlement areas (Table 13). Is, then, the effectiveness in state societies higher and does population density lie nearer to carrying capacity? It is in this line of understanding that, in the vicinity of the centres Xanten, Köln, and Trier, and along the roads connecting different high density settlement regions, that many agrarian sites are to be found located in landscapes with indifferent and even generally avoided soils. Furthermore, a sufficient density of sites is also reached in areas with indifferent soils but which lie in the neighbourhood of good soils (Fig. 10).

In Roman times, the area within the grave and settlement isolines (34%) is even smaller than during the Iron Age with about 43% (Fig. 11, horizontally). Land use in Roman times is more concentrated. Also the percentage of used areas referring to suitable location is much larger in the Roman Period (Fig. 11, vertically). The area of all suitable land however, seems to decrease in comparison with the Iron Age dramatically (Tables 11–13). However, in Roman times the size of indifferent locations is remarkably high. To sum up, the dependency on optimal ecological conditions decreased prior to the Roman period but now the best land is used much more intensely.

As a result of the existence of large regions with apparently suitable ecological conditions but which were unused in prehistoric times, it appears that an upscaling for these time periods from key areas to regions with a similar environment is not appropriate. Archaeological distribution maps of Central Europe seem to be much more accurate than often expected. On the other hand, this approach might be of interest for state societies, such as those of the Roman and medieval periods. Maps such as those in Figures 8–10 as well, as the outcome of so-called predictive modelling, open two important lines of interpretation: First, this allows us to develop a methodology to control factors affecting source criticism. Secondly, a controlled approach can be developed which helps us to integrate processes of culture historical development into the interpretation of large scale distribution patterns.

CULTURE HISTORY

Whereas small empty zones between settlement areas can be easily tested, for example by archaeological survey, this is quite impossible for larger regions. At this level of scale, it is processes of culture history that are usually discussed. In a way, this section follows a suggestion made by Kruk (1980, vii) whereby culture history should be considered in the interpretation of distribution maps.

Two prior conditions are used in our approach:

1. The size of one ‘settlement area’ is proportional

TABLE 13: ROMAN PERIOD IN THE GAR III. EFFICIENCY OF DISCRIMINATION BETWEEN SUITABLE & AVOIDED LOCATIONS ACCORDING TO SOIL (BÜK 1000) & PRECIPITATION (DEUTSCHER WETTERDIENST) INSIDE & OUTSIDE SETTLEMENT AREAS (2 KM ISOLINE) IN THE AREA OF ROMAN OCCUPATION WEST OF THE RHINE.

	Locations	*Inside settlement areas*	*Suitable & indifferent cumulated*	*Outside settlement areas*	*Sum*
% of total area	Suitable	11.0		2.0	13.0
	Indifferent	16.4	27.4	26.9	43.3
	Avoided	6.6		37.0	43.6
Sum		34.0		66.0	100
% of settlement area	Suitable	32.3			
	Indifferent	48.2	80.5		
	Avoided	19.5			
Sum		100			
% settlements		87.0		13.0	100

For cartographic representation of results see Fig. 10

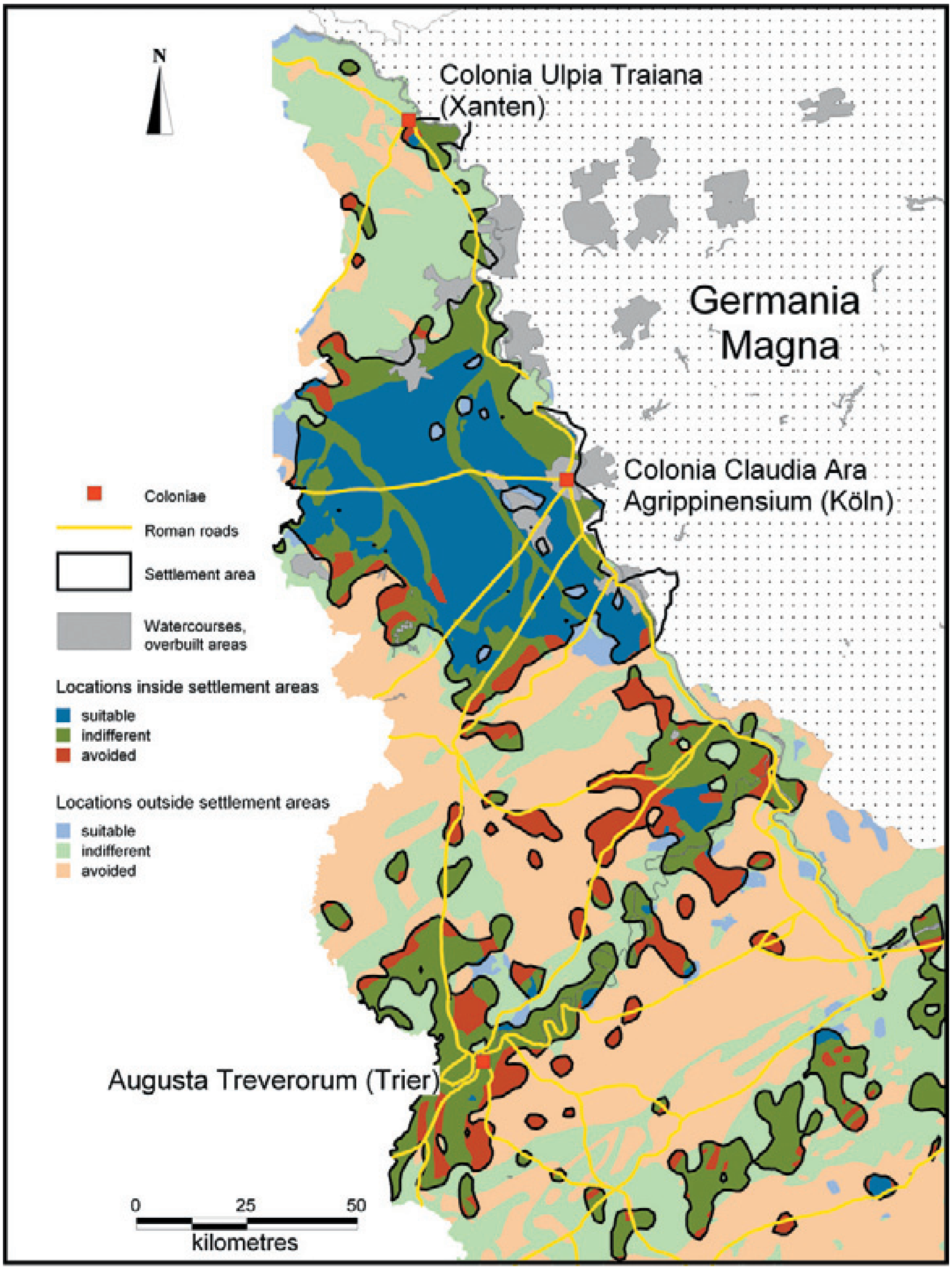

Fig. 10.
Suitability of locations for the Roman period in the GAR III west of the Rhine. Settlement area 2 – km isoline. *Germania Magna* not considered. For size of different types of areas, see Table 13

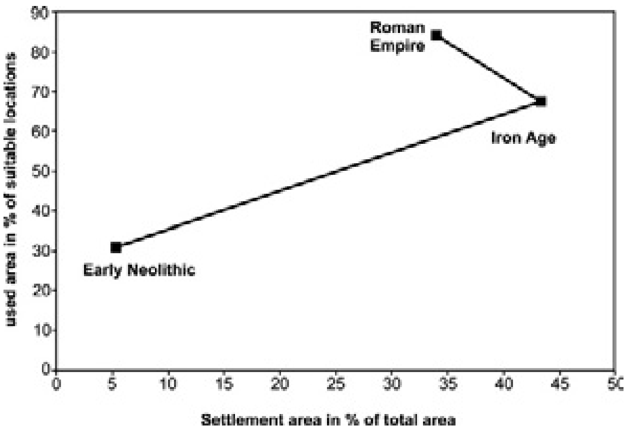

Fig. 11.
GAR. Size of suitable locations & their intensity of use in the developement of time

to the amount of people living there in comparison with other settlement areas of the same period. This assumption seems reasonable because prehistoric (ie, pre-Roman) societies in Central Europe are generally considered to have been dependent on an agrarian subsistence economy. It is important that the description of settlement areas via isolines does not mislead. It must be stressed that those parts lying outside of these areas were sometimes definitely settled and other regions were not void of seasonal human activity. However, there are so many people expected to have lived in the area within the isolines that the small number of persons living outside does not matter quantitatively.

2. The specific geographic location of settlement areas creates special conditions for the development of every single cultural entity in time and space. These conditions are to be considered in downscaling procedures. In times of low population density, communication between a large settlement area with a comparatively large population and a small settlement area with a much smaller number of individuals was very much an asymmetrical process. For the small group it would have been highly important to maintain exchange networks. For the large group it may have been useful but was not necessary to their survival. In the cases discussed here, the larger regions always seem to have been those influencing the smaller areas.

The maps from *Das Neolithikum in Mitteleuropa* (Preuß 1998) are divided into five chronological periods after Lüning (1996), each with a duration of between 350 and 1100 years. Some of the following cultural historical interpretations are not new. However, we are considering quantitatively weighted settlement areas. The most interesting point to be discussed is the existence of regions with suitable ecological properties but without a corresponding density of finds.

For the Bandkeramik (5500–4950 BC), a large area with suitable soil units but without settlements in an appropriate density is to be observed between Osnabrück and Brunswiek (Fig. 4). Phenological data and their relation to temperature do not help to decipher this pattern. Central and eastern parts of Germany, with their more continental conditions, have yielded large numbers of finds from this period. Here, the temperatures tend to be lower in the spring (as indicated by the later onset of the apple blossom) as well as in the autumn (elderberries). Today, the precipitation rate for the region between Osnabrück and Braunschweig is below 800 mm/year. This is also the case in other regions of central and western Germany and the lower Rhine basin, all of which have a well attested Bandkeramik settlement record. Sielmann suggested in his papers from the early 1970s that Bandkeramik expansion had occurred along two routes (Sielmann 1971; 1976). The 'ecological zone A' (*Ökologiekreis A*), characterised by a more continental climate, followed approximately the course of the river Elbe, and the second 'ecological zone B', which led through southern Germany, followed the Danube. The lower Rhine basin in western Germany, with its more atlantic climate, should also be assigned to the B region. The large empty area between Osnabrück and Braunschweig with its low density of Bandkeramik settlements is situated between the two aforementioned 'ecological zones', and could have resulted from these expansion processes. However, since both climatic zones tend to be rather mixed in western Germany, it is difficult to pin down ecology as the responsible factor. However, the lower density of finds in the west of the Westphalian loess *Börde* could in fact be related to the amount of rainfall (at present in excess of 800 mm/year in the Ruhr Basin (*Ruhrgebiet*) between

Dortmund and Essen). A decrease in communication density between the lower Rhine basin and Westphalia, documented in the smaller size of flint tools and an increase of splintered pieces in the assemblage from Bochum, serves to confirm the role of ecological conditions and, at the same time, the validity of the large scale map.

Raw materials of importance were distributed from large settlement areas. One of them is the lower Rhine Basin (Rijckholt-flint-type; Zimmermann 1995, fig. 37). Another is north-eastern Bohemia with the Aktinolith-Hornblendschiefer (probably from the area of Jistebsko in the Iser mountains: Šrein *et al.* 2002, Šreinová *et al.* 2003). The innovations behind the middle Neolithic transition at the beginning of the 5th millennium also evolved in large settlement areas. In central Germany, this process is characterised by the development of the Stichbandkeramik and in western Germany, in the Neckar area, this transition is characterised by the sequence Hinkelstein, Großgartach, Rössen.

During the middle Neolithic (4950–4600 BC) most settlement areas seem to decrease in size. One simple explanation for this is that this time period is the shortest analysed in this context; a further reason, however, could be a higher concentration of settlements. The northern part of the upper Rhine valley is one of the few regions where the size of settlement area increases substantially, while the settlement area in the lower Rhine Basin experiences a marked decrease (Fig. 12a). The Rijckholt-flint-type exchanged by the people living there had already lost its importance during the 50th century. This is mirrored by a discontinuity of settlements between the Bandkeramik and middle Neolithic observed in the lower Rhine Basin in the 49th century BC. One might discuss whether a change in residential rules in the two preceding centuries had resulted in a shift of population from these more northern parts to the south (Zimmermann *et al*. 2006). A further region with a marked increase in settlement area during the middle Neolithic is lower Bavaria. It was here that the important Abensberg-Arnhofen chert (*Hornstein*) was to be found which was to become a desirable commodity for people living even in distances of a few 100 km from the extraction area.

For both the young Neolithic (4600–3500 BC; Fig. 12b) and for the late Neolithic, the 4 km isoline was no longer determined optimal as it had been in the preceding time. For these periods, those areas chosen as settlement areas have been shown to have much lower site densities (12.5 km isoline in a central European scale). This difference to earlier periods is most probably linked to the fact that society was now organised in much larger units (see p. 37–40).

The analysis of the site distribution map for the young Neolithic results in a table showing two maxima of spatial increase in the interior of particular isolines (the corresponding table for the Bandkeramik with only one maximum is presented in Table 1). This is true of both the map from *Das Neolithikum in Mitteleuropa* as well as of the map from the GAR. The maximum in the range of higher densities falls between 5.5 km and 6 km. The chronological analysis of excavated enclosure camps shows that in these groups of sites one enclosure camp is succeeded by another in the course of time (Zimmermann *et al*. 2006). The maximum of lower densities, between 12.5 km and 15 km, corresponds to distances of up to 30 km (diameter of largest empty circle) between such small groups of sites, and seems to represent more a 'settlement area' as understood for the other periods discussed.

As outlined in the following section, the isolines now show much lower densities compared to the early and middle Neolithic. This is due to the increased size of centres, and to the fact that these now lie further apart. The cultural centre of the earlier part of the young Neolithic develops along the Rhine in the form of the Michelsberg Culture. It was during the Michelsberg phase that the enclosure camp of Urmitz was constructed in the Neuwied basin, this being the largest architectural structure (Boelicke 1977) in Germany before the *Oppida* civilisation of the late La Tène period. The internal communication network is again stabilised by the exchange of Rijckholt-Flint from the very north-western distribution region of the Michelberg culture in Figure 12b. The size of settlement areas seems to be much larger compared with earlier parts of the Neolithic. Besides the lower settlement density this is partly due to the longer duration, especially of the young Neolithic but also of the later periods of the Neolithic as well. The later Michelsberg phase is contemporaneous with the development of Baalberge at about 3800 BC in the Elbe-Saale region of central Germany. Now, after the cultural discontinuity beginning at the end of the Stichbandkeramik the Elbe-Saale region remained one of the most important cultural centres of Central Europe until the Bronze Age. At this time in south-

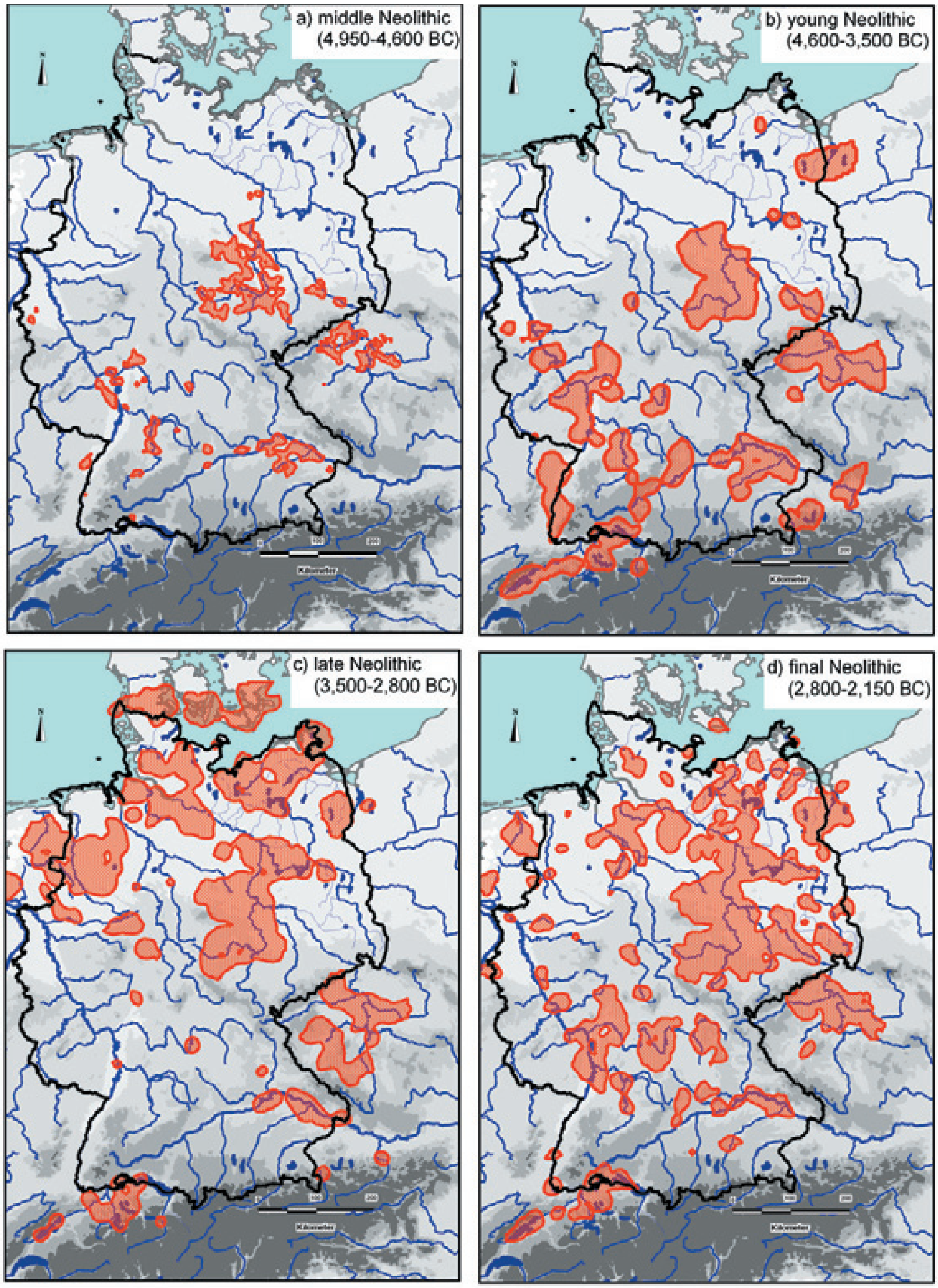

Fig. 12a–d.
Settlement areas of Neolithic periods according to Preuß (1998). Bandkeramik as in Fig. 4

western Germany and in Switzerland settlements located along the lakeshores became increasingly important. An idea as to the magnitude of the distances overcome by direct human mobility at this time is provided by the late Michelsberg settlements on the Alpine border (Matuschik 1992). The distance between the settlement area of Michelsberg on the upper Danube and the sites of the same age in southern Bavaria easily reaches the magnitude of 200 km. Direct contact between these areas has to be postulated due to the development of the Altheim culture in the later young Neolithic in the interjacent region.

In the late Neolithic (3500–2800 BC; 12.5 km line), after a crisis at the transition of periods regions with lakeshore settlements once again reached a size comparable with those of the preceding period. Most important at this time was the opening up of an enormous area of thereto unused land in northern Germany, comprising sandy and clay soils. This development is probably due to the regular use of the plough, which meant that light soils such as sand could be more easily cultivated than heavier soils. Different patterns of human behaviour can be observed in the loess areas. Large regions along the Rhine (with ecological properties preferred in earlier and later periods) take on the status of a periphery (Zimmermann *et al.* 2006). In pollen diagrams, however, this period is characterised by a substantial change in the vegetation cover. The forest becomes more open than ever before. This is assumed to be the consequence of an economy with emphasis on animal farming. People living in the lower Rhine Basin probably consumed fewer cereals and more milk, meat, and fat. This behaviour would result in a decreased population density. Using regional analyses alone, the existence of different patterns could not be recognised. Only in the final Neolithic (2800–2150 BC; 9 km line; Fig. 12d) can the areas along the Rhine once again be assigned to those landscapes with an average intensity of use. As previously mentioned, the Elbe-Saale region of central Germany kept its status as the most important cultural centre in Germany in the late Neolithic. With the exception of the lakeshore regions in south-western parts of Germany, all other large settlement areas in the late Neolithic are characterised by either megalithic structures, enclosure camps, or both. It is quite clear that architecture of this kind did not exist in areas of low population density outside the settlement areas depicted in Figure 12c.

Accepting for a moment the cultural historic interpretations presented above as given, one important conclusion can be drawn with respect to these seemingly sedentary societies. The periodical shift of cultural centres during the entire Neolithic period suggests a substantial mobility of these societies in the course of a few hundred years. The formation of archaeological cultures cannot be regarded as a sequence of regional continuities. Individual families recombine to new societies every few hundred years. These combinations can be analysed with respect to their possible cultural markers of identity.

ECONOMICAL AND SOCIAL RELATIONS

The analysis of flint assemblages from sites in western Germany has resulted in a map showing the varying ratios of raw materials found in different regions of Bandkeramik settlement (Zimmermann 1995b, figs 37–40; today these results could be refined using the data from Hauzeur 2006 and Schimmelpfennig 2004). In an area between Dutch Limburg and the Rhine-Main-region Rijckholt-Flint was of particular importance (see above).

The multiplication of these factors – proportion of Rijckholt-Flint and the estimation of the number of households (see p. 13–14) – results in an estimation of how much flint of this type would have been required by any given area. For example, in an area with 200 households and an average of 50% Rijckholt-flint, an amount sufficient for 100 households would have been needed. This demand is mapped in Figure 13 using coloured numbers. The black numbers indicate the derived flow of flint via exchange – this can be determined by calculating the demand in several succeeding areas.

In order to calibrate the demand for flint in weight it is necessary to use estimations made for the amount of flint used per household. It is evident that in areas where flint outcrops occurred in the near vicinity of sites, several kilograms were used every year. The estimations resulting from the excavation of sites in the area of the Aldenhovener Platte range in size from between 1 kg and 3.5 kg per household. In discussions at the European Association of Archaeologists

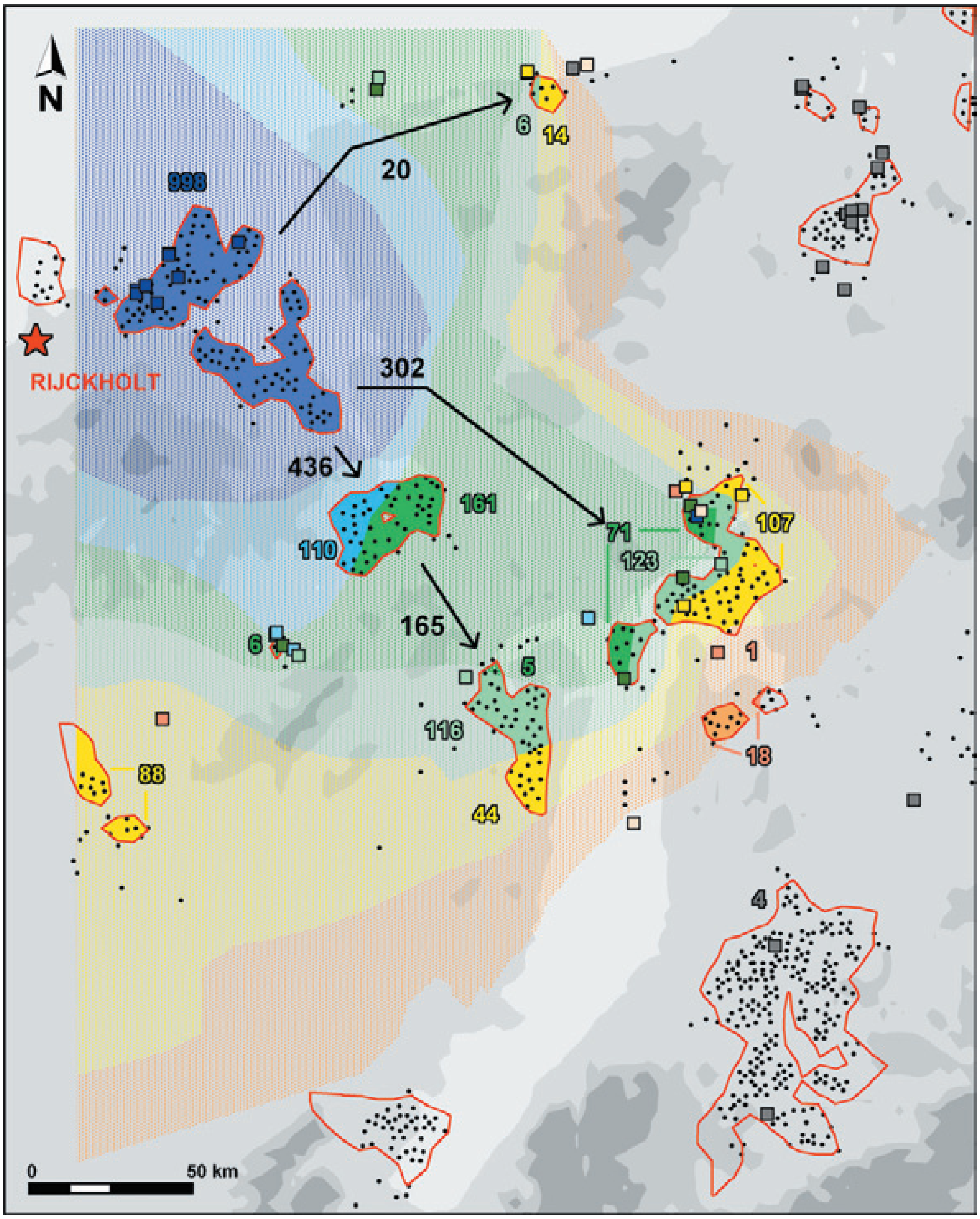

Fig. 13.
Flow of Rijckholt type flint (numbers in black) in north-western Germany (Zimmermann *et al*. 2004, fig. 16). Coloured numbers indicate number of households consuming this type of flint

conference in Lyon 2004, an even larger demand was also deemed possible in other contexts. In areas at a distance of, for example, 200 km from the sources only a few hundred grams seem to have been used. It would be interesting to estimate the demand for flint in a range of weights so as to better understand the conditions of exchange networks.

Based on these observations both the amount of flint produced and the corresponding demand can be balanced. Using our knowledge of the time needed for procurement and distribution, the *importance of a sector of economy* becomes visible. This can be used to calculate a balance sheet showing the central sector of subsistence economy on the one hand, ie, the production of foodstuffs, and the other secondary economical sectors, such as the procurement of flint raw materials, production of ceramics, or building houses and enclosure camps on the other. For these types of activities, the intervals of time have to be considered. They could be necessary for every day, every week, every generation, or for even larger intervals of time. It is a task for future study to compare these economical aspects from different periods. In this way, we may shed some light on the development of the division of labour in society. Landscape archaeology must provide economic archaeology with the regionally differentiated data it requires.

As for analyses conducted in the field of economic archaeology, a quantitative approach to landscape archaeology also allows for the formulation of hypotheses on *social relations*. Some methods relevant to this topic were presented by Hodder & Orton (1976, chap. 4 on settlement patterns, 53–97). This is also true for the methodology proposed in this paper. In this respect, the selection of the optimal isoline is of particular interest. As already outlined, the isolines selected at different levels of scale should not be compared directly. However, considering the representation of the different periods of the GAR I–III as well as the periods of *Das Neolithikum Mitteleuropas* for the Neolithic, isolines of quite high densities are characteristic for the early and middle Neolithic, whereas low densities are typical for the young and late Neolithic (Fig. 12). This corresponds with the general idea that in these periods a more centralised organisation of society was probably necessary for the construction of the large architectural features such as the ditched enclosures and the megalithic structures.

To better illustrate this line of interpretation, the simple hypothesis is used which implies that the size of a social unit is directly related to the average size of the enclosure camp constructed by its members. Therefore, in Figure 14 the average length of enclosure ditches during different Neolithic periods is compared with the specific isoline chosen for delimitation of the settlement area. The largest ditched enclosures of the Neolithic existed in the young Neolithic at about 4000 BC. In the same time period the settlement pattern is characterised by the lowest settlement density within the Neolithic (12.5

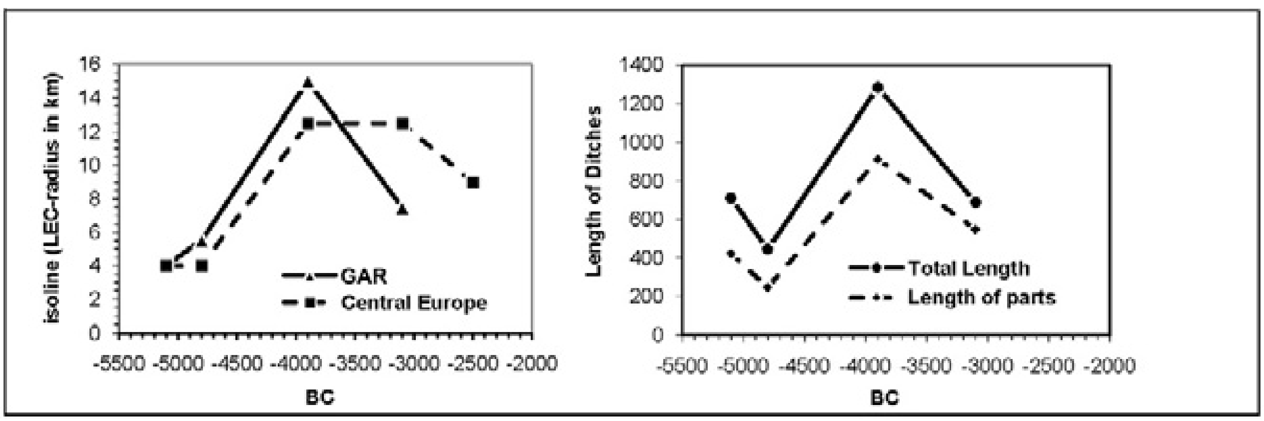

Fig. 14.
Optimal isoline for the different periods of the Neolithic in kilometres (left) & average length of ditches from enclosures in metres (right). The total length includes the sum in cases of several concentric ditches

km isoline). This correlation might be associated with the existence of larger groups at this time than in other periods of the Neolithic.

Therefore, the average length of enclosure ditches is used as a proxy for the amount of labour required for their construction. For enclosures with more than one ditch, the length of all parts was added to the total length. It is assumed that the larger the enclosure the bigger the group of people involved in its construction. In fact, the observed correlation seems not to contradict the general idea of a more centralised organisation of societies in the young and late Neolithic as implied by the selection of the isolines depicting a low density of sites during these periods.

HUMAN IMPACT

In this paper two consistent estimations of population density have been presented, one for the early Neolithic and the other for the Roman era. Both periods are archaeologically well attested and mark, on the one hand, a period with a very low population density and, on the other, a time with a quite high density (Zimmermann 1996, fig. 1). The generalised intensity of human impact, as visible in some pollen diagrams of the lower Rhine basin, was visualised by the first Eigenvector of a canonical correspondence analysis in an earlier paper (Kalis & Zimmermann 1997, fig. 1 referring to Birks *et al.* 1988). A long-term aim is to obtain estimations of population densities for periods with a less-sound archaeological record by means of *interpolations* based on *pollen diagrams*. In order to achieve this we must improve our knowledge of the catchment of the sites from which pollen are analysed. The catchments in the lowlands appear to be considerably smaller than catchments located in areas that are more mountainous. For this reason, we must explore how we can best integrate the results from different kinds of landscapes. This is a topic of another research project (Lechterbeck 2008).

However, simple linear interpolation will not suffice if we wish to arrive at estimations of population density via pollen diagrams. It is true that the intensity of human impact is partly derived from the number of people living in a given area. Another factor of influence is the *settlement system*. In a more centralised system, processes of impact should be better recognisable in the neighbourhood of the centres. In larger distance of settlements, human impact will be less easy to recognise. Sometimes large-scale architecture such as ditched enclosures (eventually with palisades) or specific megalithic graves was erected with much effort. The largest known structures existed as early as the young Neolithic (4600–3500 BC) and certainly in the late La Tène period from the last centuries BC, and of course in the Roman epoch. A regularly spaced settlement pattern might produce a less marked signal of impact but this would be identifiable in the entire settlement area. How we might address this factor via archaeological observations has been discussed in the previous section. The third important factor is the economy of the period under consideration. Of course, in pre-industrial and pre-state societies aspects other than the farming system, for example the *secondary sector of economy*, must also be considered. While in the Stone Age, the extraction sites for flint raw material never exceeded a size of up to a few hectares of open land at any given time. In the Iron Age, however, the proportion of land needed to extract iron ore, together with the forest necessary for procurement of firewood and charcoal is likely to have increased. The procurement of other metals and salt, the production of ceramics, and the cutting of timber for houses are other parts of the economic system whose impact for the environment during specific periods and in specific regions have still to be quantified.

In the subsistence economies prior to the Roman period, the *production of foodstuffs* represented the most important sector. During *periods of change* (eg, during the late Neolithic), it is likely that only small numbers of people were responsible for changing the vegetation of large regions in a furious fashion. For example, for this period it is discussed that forests were burnt in order to promote plants better suitable for feeding large herds of animals. This step would have changed the landscape dramatically. A farming system with an emphasis on animal husbandry, as perhaps practiced in the lower Rhine basin during the late Neolithic, would coincide with a population density which was well below the potential carrying capacity of this region. At this point, we realise that yet further tasks await us: we must integrate the results from both archaeobotanical and archaeozoological studies into the landscape approach. As a basic problem, the ratio of foodstuffs obtained from animals and from plants has to be addressed. At present, it appears that, for periods of change, interpolation by means of pollen diagrams is still rather difficult.

Much more typical are periods characterised by a more-or-less *sustainable farming economy*. In times prior to the late Neolithic there seems to have been a marked emphasis on the cereal producing sector; in the periods following the Urnfield phase a new equilibrium arises. For these times, the number of people represents the independent variable, and the amount of open land the dependent variable. In order to produce the necessary foodstuffs a certain amount of space is required. Following the introduction of a producing economy, the fields had to be cleared from forest and that part of the landscape required to feed domesticated animals had to be altered accordingly. Some examples exist visualising the size of fields and pasture for specific agricultural systems. For the Bandkeramik simulations for the Aldenhovener Platte (without pasture, Fig. 15, according to Zimmermann 2002, 27 *et seq.* and fig. 13) and the Mörlener Bucht (with pasture Ebersbach & Schade 2004, figs 3–7) have been presented. Another example concerns the time slices between the young and final Neolithic at Lake Zurich (3800–2400 BC; Ebersbach 2003, figs 11–13). For the Bandkeramik example our notion of the location of the fields in relation to the farmhouse must be revised at a later date. In the existing simulations this distance is minimised and results in one large field for the whole settlement. On the other

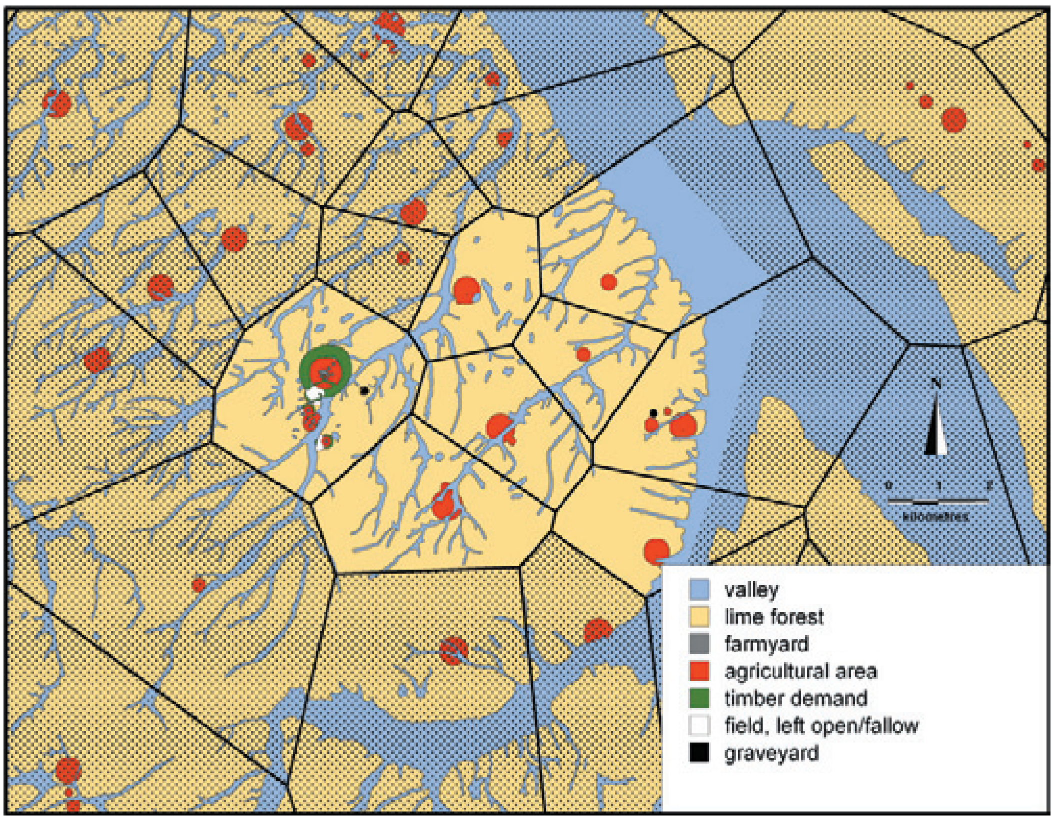

Fig. 15.
Key area of Aldenhovener Platte. Bandkeramik human impact by size of fields in the middle part of the Merzbach valley of the Aldenhovener Platte (middle 52nd century BC; house generation VII with timber demand). Closed Thiessen polygons in the centre of the map are not shaded. Here it is possible to measure the potential economic area as best as possible

hand, pollen-analytical evidence suggests that early and middle Neolithic fields comprised many small parcels of land, which were divided either by hedges or even by forest. Only in the late Neolithic is it assumed that fields of several households were joined. From the late Bronze Age (in southern Germany) or the early Iron Age (eg, in the lower Rhine basin) open land would have most definitely been divided into fields and grassland pasture. In earlier periods, animals relied on foliage for fodder only. Nevertheless, models of the spatial implications of population density still have to be formulated for most prehistoric periods. Together with our knowledge of the tools and of the methods used for specific economical production processes, the consumption of landscape will help to derive different consequences of human impact. The larger the open land the less is the ability of the vegetation and the soil developed to retain precipitation and the larger is potential for erosion. For example, in Bandkeramik settlement areas about 2% of the forest was cut down, as shown in Figure 15, in the Roman period between 20% and 50% of the landscape in settlement areas are assumed to be open land (Table 7).

Endnotes

[1]In this paper, the articles *Landschaftsarchäologie I* by Zimmermann (2002) and *Landschaftsarchäologie II* by Zimmermann *et al*. (2004) are briefly summarised; results of recent research are presented in more detail. A German version for the Roman period is published as: *Bevölkerungsdichte und Landnutzung in den germanischen Provinzen des Römischen Reiches im 2. Jahrhundert AD* by Wendt in cooperation with Zimmermann (2008). For this period, considered here in the section entitled '*Populations density in ... Roman times*', we are indebted to Thomas Fischer (Köln), Wolfgang Gaitzsch (Titz/Höllen), Hans-Markus von Kaenel (Frankfurt), Jürgen Kunow (Bonn), und Frank Siegmund (Basel) who assisted us in our considerations within a domain with which we were not familiar. Our work has been funded by the German Research Council (DFG) with the archaeological project within the framework of the Rhein-LUCIFS group, and by the project *Landschaftsarchäologie des Neolithikums* (LAN); the larger part of the latter project being funded by the *Stiftung zur Förderung der Archäologie im Rheinischen Braunkohlenrevier*. Lee Clare was so kind as to improve our English.

[2]The *Geschichtlicher Atlas der Rheinlande* contains among other maps a sequence of archaeological distribution maps from the Palaeolithic to medieval times. They will be abbreviated as GAR I – Neolithic (Richter & Claßen 1997), GAR II – Bronze and Iron Age (Joachim 1997), and GAR III – Roman period (Cüppers & Rüger 1985).

[3]We have to thank Irmela Herzog from the Rheinisches Amt für Bodendenkmalpflege Bonn, who provided us with a program to carry out these computations.

[4]In the recent MA thesis of Sara Schiesberg (2007) good arguments were presented to assume that 7–10 persons on average lived in a Bandkeramik house. Therefore, for a more recent calculation, a mean of 8.5 persons per house is used. The result is a population density of 0.6±0.1 P/km².

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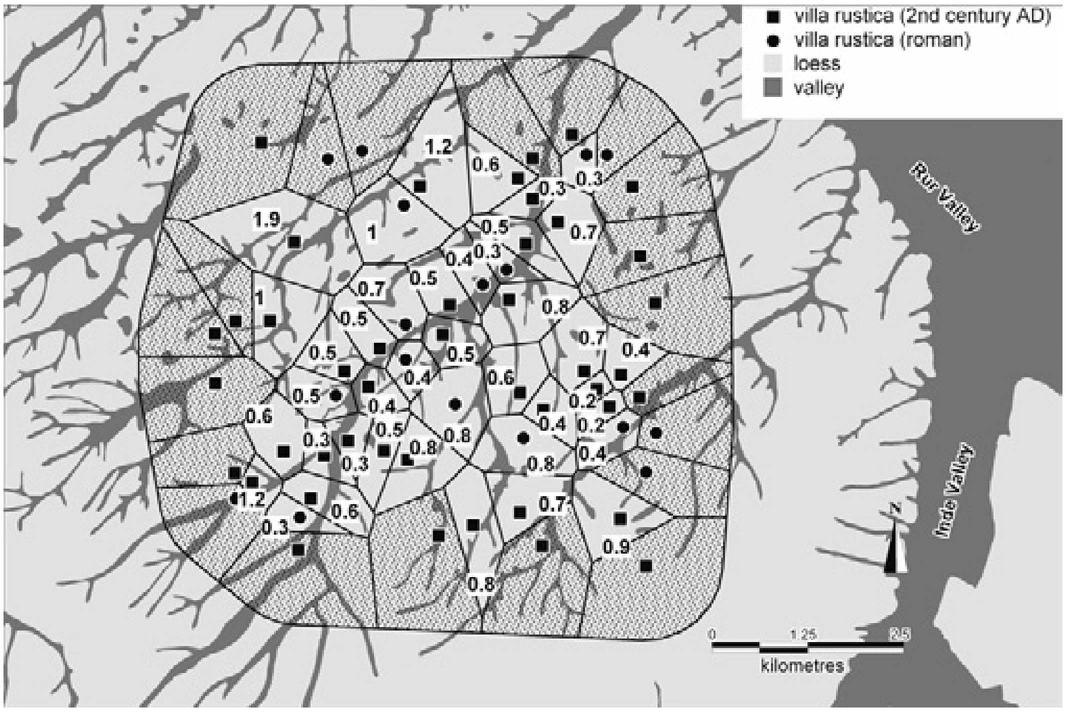
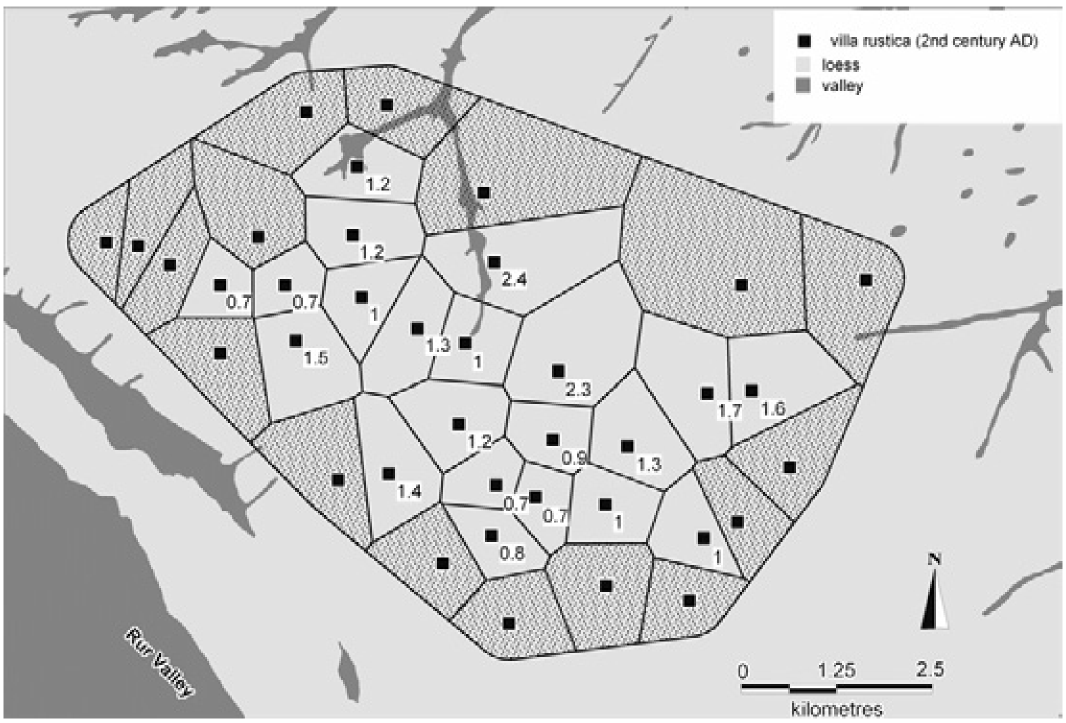
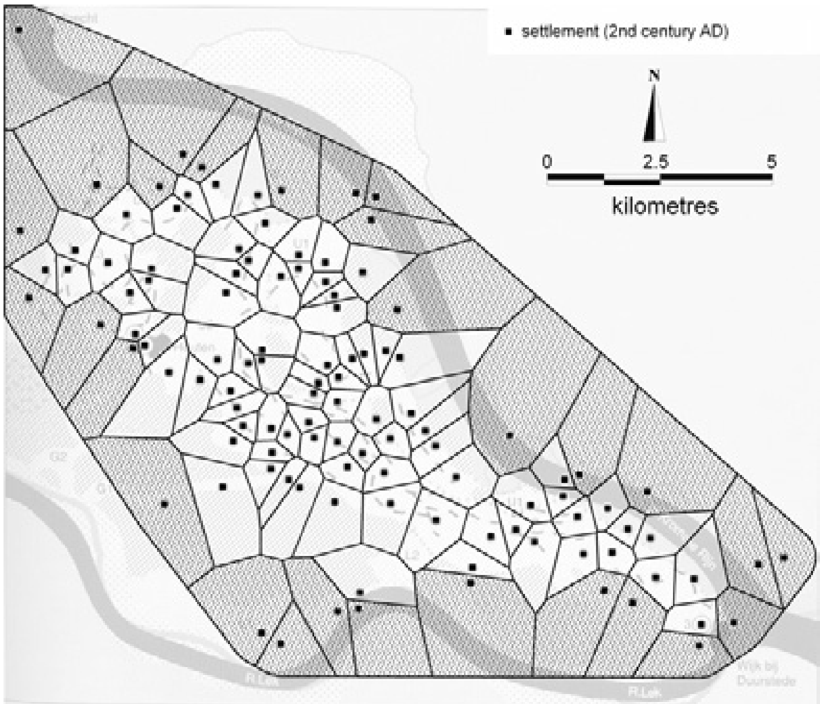


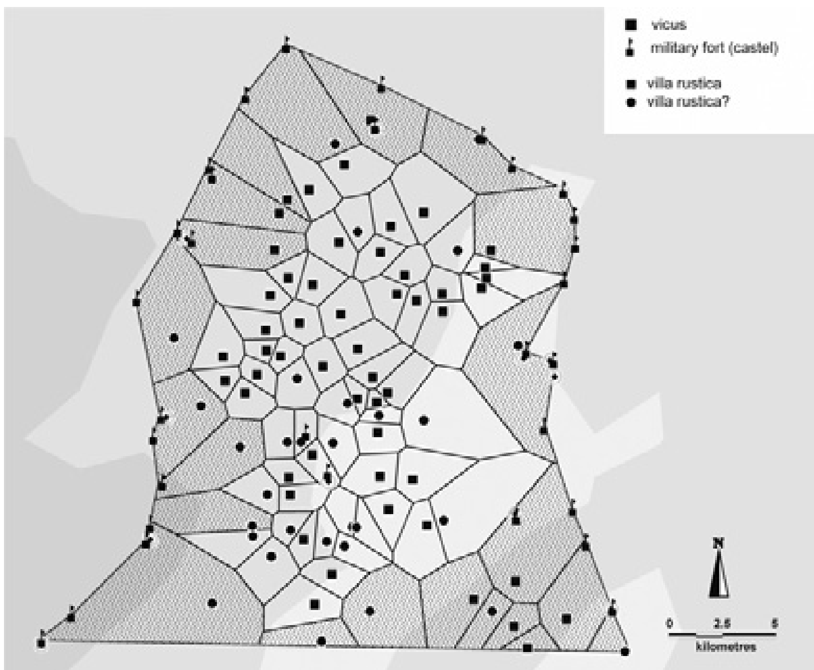
Appendix 1a.
Aldenhovener Platte. 40 villae & 23.4 km² in closed Thiessen Polygons (CTP) (after Lenz 1999)



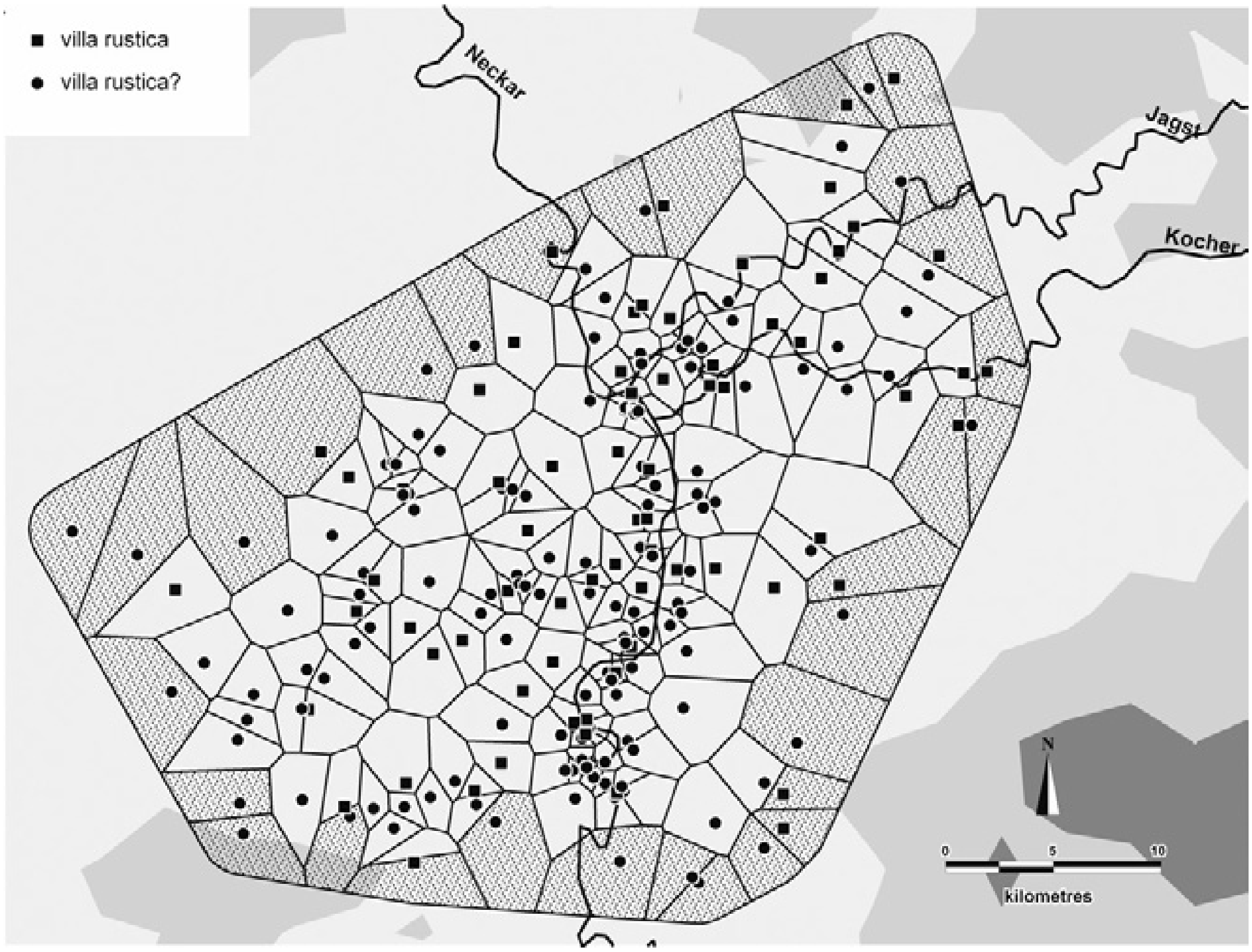
Appendix 1b.
Hambacher Forst



Appendix 1c.
'Kromme Rijn' (NL). 86 sites & 70.9 km² in CTP (after Kooistra 1996).
The Roman vicus/castel Fectio is not considered



Appendix 1d.
Wetterau. 61 villae & 235.6 km² in CTP (after Saile 1998)



Appendix 1e.
Neckar-area. 173 villae & 744.8 km² in CTP (after Hüssen 2000)

APPENDIX 2A. SIZE OF THE ECONOMIC AREAS OF ROMAN VILLAE FROM DIFFERENT REGIONS IN GERMANY

Region	*Estimated economic area*			*Reference*
	min.	*mean*	*max.*	
NL-Limburg	150		200	Gaitzsch 2002, 269
NL-Voerendaal	225		250	Willems 1988,
Jülicher Börde		50	50	Gaitzsch 2002, 269
Kr. Bergheim		100	100	Hinz 1969, 57
Hambacher Forst			50	Horn 1987, 148
Link. Erftufer		100	100	“, 148
Eifelvorland (Nideggen)		90	90	“, 148
Niedergermanien	60	65/80	120	Kunow 1986,
Nordeifel		90	90	v. Petrikovitz 1956, 99ff
Gallia Belgica	50		100	Rothenhöfer 2005, 40
Wetterau		100	100	Wolff 1913, 9f
	60		100	Baatz/Herrmann 2002, 97
	65		80	Gaitzsch 2002, 269
Pfalz	50		260	Bernhard 2003, 21–32
	100		120	Gaitzsch 2002, 269
Saarland	100		120	“, 269
Neckar	50		100	Hüssen 2000, 130
	50		60	Gaitzsch 2002, 269
Umland Rottenburg		120	120	Gaubatz-Sattler 1994, 204ff
Umland Heilbronn	50		60	Spitzing 1988, 145ff
Kocher-Jagst	50		150	Hüssen 2000, 130
Ballungsräume	50		60	“, 130
Oberrät. Limes	60		150	Moosbauer1997, 160
Rätien	65		80	Gaitzsch 2002, 269130“, 269
Baden-Württemberg	50		100	Sommer 1988
Isartal	100	100	300	Struck 1992, 243
	40		50	Gaitzsch 2002, 269

APPENDIX 2B. SIZES OF ROMAN VICI BY HECTARE IN THE SOUTHERN PART OF THE PROVINCE GERMANIA INFERIOR DURING THE 2ND CENTURY AD

Vicus	*Hectare*	*Households (hh)*	*5 pers./hh*	*10 pers./hh*
NL-Heerlen	15	210	1050	2100
NL-Maastricht	15	210	1050	2100
Aachen/Aquae Granni	24	336	1680	3360
Aachen-Schönforst	4	56	280	560
Bad Neuenahr-Ahrw.	1	14	70	140
Billig	10	140	700	1400
Bonn, canabae legionis	40	560	2800	5600
Bonn, vicus	60	840	4200	8400
Dormagen	8	112	560	1120
Elfgen	10	140	700	1400
Düren-Hoven	3	42	210	420
Jülich	15	210	1050	2100
Kornelimünster	4	56	280	560
Mariaweiler	15	210	1050	2100
MG-Mülfort	22	308	1540	3080
Neuss, Altstadt	10	140	700	1400
Neuss-Rosellen	24	336	1680	3360
Rheinb.-Flerzheim	6	84	420	840
Tüddern	9	126	630	1260
Wesseling	5	70	350	700
Zülpich	13	182	910	1820
Σ 21 vici	313	4382	21,910	43,820
mean			1043.3	2086.7

Area per vicus after Rothenhöfer (2005, 266–7); households after Güglingen-Steinäckern (Kortüm & Neth 2004, 165, fig. 149: 18 stripe-houses in an excavated area of 1.3 ha = 13.8 households/ha (rounded to 14), see Fig. 3); number of persons after Sommer (1988, 302; 5–10 persons/household = 70–140 pers./ha).

APPENDIX 2C. SIZE OF ROMAN VICI BY HECTARE IN THE NORTHERN PART OF GERMANIA INFERIOR, & IN THE PROVINCES GERMANIA SUPERIOR & RAETIA DURING THE 2ND CENTURY AD

Vicus	*Hectare*	*Households (hh)*	*5 pers. /hh*	*10 pers. /hh*	*Reference*
NL-Fectio	10	140	700	1400	Kooistra 1996, 54
NL-Traiectum 1	1.6	22.4	112	224	" 1996, 54
NL-Traiectum 2	2.2	30.8	154	308	" 1996, 54
Noviomagus	25	350	1750	3500	Bernhard 2003, 21-32
Tabernae	32	448	2240	4480	" 2003, 21-32
Eisenberg	8	112	560	1120	" 2003, 21-32
Nida	54	756	3780	7560	Baatz/Herrmann 2005, 291
Ladenburg	40	560	2800	5600	M.Zimmermann 2000, 19
Rottenburg	28	392	1960	3920	Gaubatz-Sattler 2000, 107
Heilbr.-Böckingen	30	420	2100	4200	Hüssen 2000, cat.no. 31b
Bad Friedrichshall	5	70	350	700	" cat.no. 119b
Bad Wimpfen	19	266	1330	2660	" cat.no. 148b
Jagsthausen	20	280	1400	2800	" cat.no. 262b
Neuenstadt a.K.	15	210	1050	2100	" cat.no. 383
Offenau	20	280	1400	2800	" cat.no. 403
Öhringen-West	26	364	1820	3640	Hüssen 2000
Öhringen-Ost	9	126	630	1260	"
Weißenburg	30	420	2100	4200	Csyzs et al. 2005, 211
Faimingen	40	560	2800	5600	"
Pocking	8	112	560	1120	", 501
Nassenfels	5	70	350	700	", 486
Straubing	40	560	2800	5600	M. Zimmermann 2000, 19
Σ 22 vici	467.8	6549.2	32,746	65,492	1488.5-2976.9 pers./vicus

Households after Güglingen-Steinäckern (Kortüm & Neth 2004, 165, fig. 149: 18; stripe-houses in an excavated area of 1.3 ha = 13.8 (rounded 14 houses/ha, see Fig. 3)); number of persons after Sommer (1988; 5–10 pers./household = 70–140 pers./ha)

APPENDIX 2D. SIZE OF ROMAN VICI BY NUMBER OF PERSONS

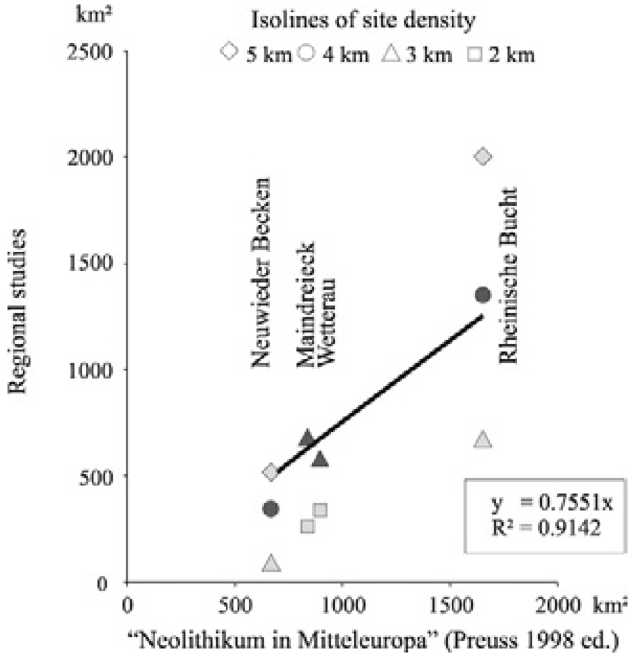
Vicus	*Hectare*	*Houses*	*Houses/ha*	*Pers./H*	*Pers./ha*	*Pers. /Vic.*	*Reference*
Köngen		**150–170**		**5–10**		**750–1700**	Sommer 1988, 302
Ladenburg	**45**	750–900	16.7–20	**5–6**	**100**	**4500**	Sommer 1998, 158
Augsburg	**65**				153.8–230.8	**10,000–15,000**	Czysz 2005, 213
Kempten	**35**				228.6	**8000**	Czysz 2005, 213
Regensburg						**7000–9000**	Czysz 2005, 213
Kaiseraugst	**106**	**18,000**	**17.0**	**5–8**	84.9–135.8	**9000–14,400**	Bossart *et al.*, 96–103

Bold letters = data from literature, standard letters = values deduced by size in ha

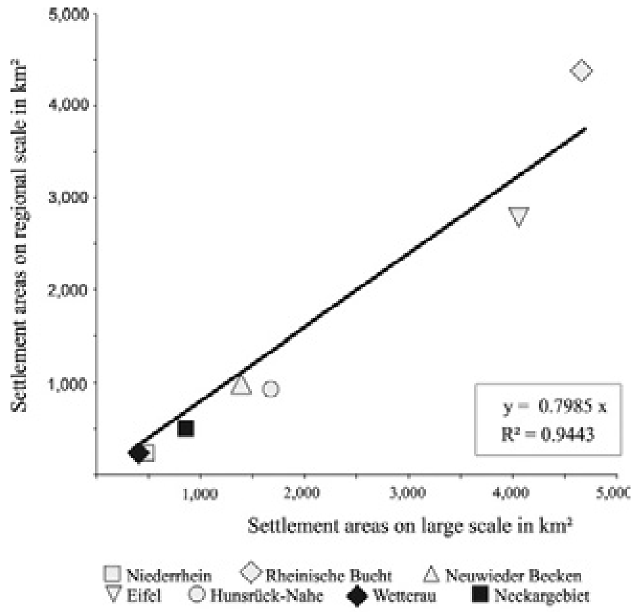
APPENDIX 2E. VICI AND COLONIAE

Colonia/vicus	*Extensions (km)*	*Hectare*	*Persons min.*	*Persons max.*	*Pers./ha*
CUT (Xanten)	**6 x 3**	1800		**20,000**	11.1
Mogontiacum (Mainz)	**6.5 x 2**	1300		**15,000**	11.5
CCAA (Köln)	**3 x 2**	600	**25,000**	**40,000**	66.7
CAT (Trier)	**3 x 1.5**	450	**15,000**		33.3
Bonna (2 vici)	**4 x 0.6–-0.7**	260		**15,000**	57.7
Novaesium (Neuss)	**3.5 x 1**	350		**15,000**	42.9

After Bender (1997, 287–8). Bold letters = data from literature, standard letters = values deduced by hectare



Appendx 3a.
Results of regression analysis of Bandkeramik settlement areas. Regional studies (vertical: Richter & Classen 1997; Saile 1998; Schier 1990) compared with large-scale distribution map (horizontal: Preuß 1998)



Appendix 3b.
Results of regression analysis of Roman settlement areas. Regional studies (Cüppers & Rüger 1985; Hüssen 2000; Saile 1998) compared with large-scale distribution map (Bender 1997), grey symbols = 2 km isoline, Wetterau 1.5 km isoline & Neckar area 2 km isoline.

APPENDIX 3C. DENSITY OF ROMAN VILLAE IN GERMANY AND ITS NEIGHBOURHOOD

Density classes	*No. villae*	*CTP km²*	*Area after regression*	*Villae/km²*	*Mean no. pers.*	*Product*
1 km isoline	1209	1621.0	2041.8	*0.6*	10–20	12,090–24,180
2.5 km soline	4439	25,765.1	20,573.4	*0.2*	25–50	110,975–221,950
Outside	1391				25–50	34,775–69,550
Range						*157,840–315,680*
Average	sum					236,760

After Bender (1997, fig. 13) & the deduced estimation of the rural population

APPENDIX 3D. ESTIMATED INHABITANTS OF ROMAN COLONIAE, CIVITATES & VICI IN THE ROMAN PROVINCES OF GERMANY

No. urban settlements	*Type*	*Mean no. persons*	*Sum of inhabitants*
	Xanten		20,000
	Köln		at least 25,000
	Trier		at least 15,000
	Mainz		15,000
	Kaiseraugst		9,000–14,400
	Rottweil		10,000–15,000
21 (Appx 2b)	*vicus/civitas*		21,910–43,820
22 (Appx 2c)	*vicus/civitas*		32,746–65,492
237 (170 est.)	*vicus/civitas*	1043.3–2976.9	247,262–705,525
Range			*395,918–919,237*
Average			657,578

Mean number of persons deduced for vici by hectare according to Appendix 2b = minimum value and Appendix 2c = maximum value (rounded)

APPENDIX 3E. ESTIMATED NUMBER OF SOLDIERS IN THE ROMAN PROVINCES OF GERMANY.

No.	*Type*	*Mean no. persons*	*Sum of soldiers*
5	castel of legion	6300	31,500
70	auxiliar castel	750	52,500
Sum			84,000

APPENDIX 3F. ESTIMATED NUMBER OF PEOPLE FROM AGRARIAN, URBAN & MILITARY SECTION & THEIR ANNUAL DEMAND FOR CEREALS IN THE ROMAN PROVINCES OF GERMANY.

No. people in *villae rusticae* (Appx 3c)	157,840– 315,680
No. people in urban settlements (Appx 3d)	395,918–919,237
Military personnel (Appx 3e)	84,000
Sum of people	637,758–1,318,917
Demand of cereals per year (1kg/person/day)	232,782–481,405 t