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Abstract

We describe a combination of methods applied to obtain reliable estimations of population density using archaeological data. The combination is based on a hierarchical model of scale levels. The necessary data and methods used to obtain the results are chosen so as to define transfer functions from one scale level to another. We apply our method to data sets from western Germany that cover early Neolithic, Iron Age, Roman, and Merovingian times as well as historical data from AD 1800. Error margins and natural and historical variability are discussed. Our results for nonstate societies are always lower than conventional estimations compiled from the literature, and we discuss the reasons for this finding. At the end, we compare the calculated local and global population densities with other estimations from different parts of the world.

Keywords

settlement archaeology, population density, site density, Bandkeramik settlements, LBK culture, Aldenhovener Platte, Rhineland, Germany, Neolithic.

Cover Page Footnote

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Estimations of Population Density for Selected Periods Between the Neolithic and AD 1800

ANDREAS ZIMMERMANN,[1] JOHANNA HILPERT,[1] AND KARL PETER WENDT[1]

Abstract We describe a combination of methods applied to obtain reliable estimations of population density using archaeological data. The combination is based on a hierarchical model of scale levels. The necessary data and methods used to obtain the results are chosen so as to define transfer functions from one scale level to another. We apply our method to data sets from western Germany that cover early Neolithic, Iron Age, Roman, and Merovingian times as well as historical data from AD 1800. Error margins and natural and historical variability are discussed. Our results for nonstate societies are always lower than conventional estimations compiled from the literature, and we discuss the reasons for this finding. At the end, we compare the calculated local and global population densities with other estimations from different parts of the world.

History of Research

Typically, archaeologists dare to estimate population density only in situations of exceptional observation intensity and preservation conditions. The outcome, calculated for small regions, is then generalized for larger ones. The resulting density based on archaeological evidence is understood as a lower limit, on the assumption that it is impossible to find all sites. To identify an upper limit for the population density under consideration, archaeologists introduce the carrying capacity as a threshold regarding ecological conditions and available techniques of food production. Estimations of population density using this line of reasoning were compiled by one of us for central Europe for the periods between the Upper Paleolithic and the migration period (Zimmermann 1996).

Two contradicting preconceptions exist on how to transfer densities from small well-observed areas to larger regions. One idea is based on the assumption that societies and their technical abilities were optimally adapted to their environment in the past. This notion can be traced back to Graham Clark (1952) and the

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KEY WORDS: SETTLEMENT ARCHAEOLOGY, POPULATION DENSITY, SITE DENSITY, BANDKERAMIK SETTLEMENTS, LBK CULTURE, ALDENHOVENER PLATTE, RHINELAND, GERMANY, NEOLITHIC.

new archaeology of the 1960s and 1970s. According to this concept, it seems reasonable to scale up observations from small well-observed areas to larger regions with similar ecological conditions. The opposite idea can be found, for example, in papers by Herbert Jankuhn. Jankuhn's textbook on "settlement archaeology" was quite influential in Germany (Jankuhn 1977). For Jankuhn the existence of *Ödmarken* (empty spaces) between Germanic tribes, as described by the classical authors of antiquity, seemed realistic (Jankuhn 1961–1963: 26). We argue that only those calculations that consider the possible existence of empty areas can provide reliable lower values for population densities. Another important term introduced by Jankuhn is *Siedlungskammer*. The concept of a "key area" used in this paper is a generalization of this term.

In his writings Jankuhn also demanded what he called source criticism (*Quellenkritik*), a term well established in German humanities by the historicism of the 19th century. Droysen, for example, formulated a six-step hermeneutic, from which the second step was dedicated to source criticism (Droysen, *Historik*, 37–91, according to Goertz 1995: 110–112). In today's textbooks for undergraduates of prehistoric archaeology, *innere und äussere Quellenkritik* is a topic of the curriculum (e.g., Eggert 2001: 105–121). However, no method was proposed by Jankuhn or others on how to introduce *Quellenkritik* as an analytical tool in the concept of settlement archaeology. In this vacuum, it is up to individual archaeologists to decide whether archaeological distribution maps are ever representative or whether in specific cases a distribution pattern is representative enough. A solution to overcome these problems is presented in this paper by means of isolines that depict site densities. The corresponding concept for visualizing find densities was introduced to archaeology by Mads Malmer (1962).

Methodological Advances

Our own contribution to a method for estimating population density was initiated by the opportunity to contribute to the international LUCIFS framework of projects (Land Use and Climatic Influence on Fluvial Systems during the period of agriculture) [for further information, see, e.g., Dix et al. (2005) and Houben et al. (2006)]. This group of projects (mostly carried out by geographers) is concerned with the human impact on fluvial systems since the beginnings of agriculture. The main task of the archaeological project within the Rhine-LUCIFS research group is to determine the amount of open farmland during specific time periods (K. P. Wendt and J. Hilpert are the other archaeologists, and A. Dix is the historical geographer of our team). As a first step, we estimated regionally differentiated population densities in the Rhineland.

As a consequence of the cooperation with geographers, we developed an explicit hierarchical model of scale levels. In this group a map with a scale of 1:25,000 is termed small scale in comparison with a map of 1:1 million. One object of research is to find specific transfer functions to scale upward between levels for each application.

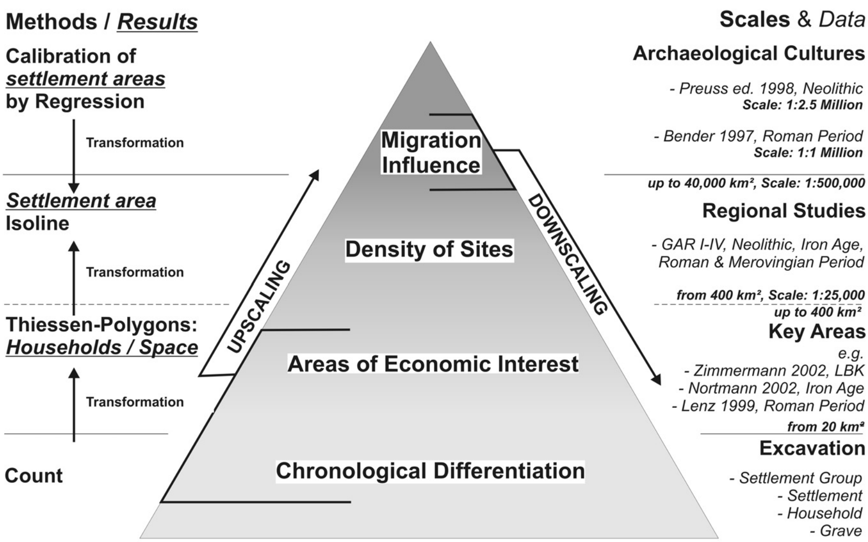

Figure 1. Hierarchical model of scale levels designed to achieve estimations of population density.

The hierarchical scale model is presented in Figure 1, which summarizes the methods used, the results obtained, and the data needed. In this diagram specific methods can be exchanged. Of importance is a consistent logic of arguments that allows data to be transformed from one scale level to another by using a transfer function. The scales in Figure 1 form a triangle because an archaeological culture (topmost level) is usually represented by many excavations (lowest level). Upscaling transfers data in a generalizing way from a lower to a higher level.

On the lowest scale, on the level of excavation, houses or graves can be found and possibly be dated. The next level of so-called key areas is an intermediate scale between the size of excavations and larger distribution maps. Key areas are some 10 up to a few hundred square kilometers in size and are characterized by the best observation density available. If all or at least most of the sites are known in these areas, the space available per household or per person can be estimated. As an example of key areas, the Bandkeramik settlements (Linearbandkeramik, or LBK, culture) of the Aldenhovener Platte with its intensive excavations are used (Zimmermann et al. 2004: 49–50, 56–61). The Early Neolithic Bandkeramik is one of the best known archaeological cultures in Germany. In the Aldenhovener Platte, a small region of approximately 150 km² 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 into details, it can be stated that about one household per square kilometer existed in the middle of the 51st century BC.

The level of regional studies deals with much larger areas, ranging from hundreds of square kilometers up to tens of thousands of square kilometers in size. The scale of maps varies between 1:25,000 and 1:500,000. Depending on the size of the region, sites are selected after individual inspection of finds or according to the literature. Location accuracy of individual sites is assumed high. At this level it is necessary to use a valid and reliable method to distinguish between settlement areas with many sites and areas that were less intensively used, which have only a few sites. For the goals of the LUCIFS research group, a combination of methods was developed. The first component was to measure the density of sites using the largest empty circle (Preparata and Shamos 1988) and using the distance between the vertex of a Thiessen polygon and its closest three sites to quantify this value. The next component was to interpolate site densities using ordinary kriging (Haas and Viallix 1976) and to visualize these densities with isolines. Finally, an outer border of dense site distribution was determined using the criterion of the maximal increase of space (Zimmermann et al. 2004: 53–54). The alternative is to use kernel density estimation (Baxter et al. 1974). The problem here is to derive a reliable bandwidth and to obtain a reasonable outer border. If, for a first approximation, kriging is used, then the criterion of maximal increase of space leads to the most reliable outer border. However, in a few cases kriging produces annoying edge effects. Then kernel density estimation can help to improve the result. Mostly both methods produce valid and similar results.

On large-scale distribution maps (1:1,000,000 or even larger regions), 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 recognized. It is for this reason that the size of settlement areas obtained for large-scale distribution maps has to be reduced using a regression analysis. It is only after that procedure that one can approximate the magnitude of the corresponding settlement areas on the level of regional studies.

For dispersal models at the level of archaeological cultures or even on the continental or global scale, procedures of downscaling have to be developed; but that is not the topic of this paper.

Consequences

Source Criticism. The method used to describe site densities with isolines also allows the development of a formal procedure for a critique of the analyzed data. The intensity of archaeological observation, for example, can partly be controlled by producing maps with overlapping isolines of different periods (Figure 2). In the example from the *Geschichtlicher Atlas der Rheinlande* (GAR), finds from the Bandkeramik period are practically missing along the Rothbach (Zimmermann et al. 2004: 63 and 70). Urnfield period sites, though, are well known from this area, along with Roman and early medieval period sites. It is extremely unlikely that

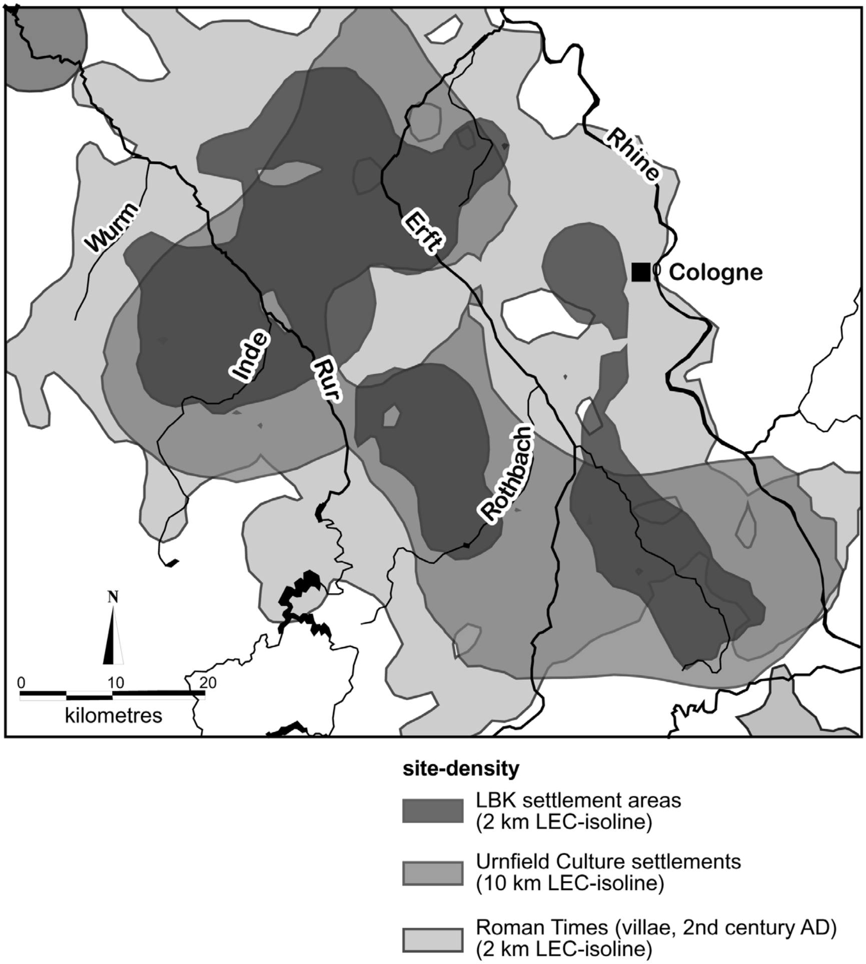

Figure 2. Optimal isolines for the Bandkeramik, Urnfield culture, and Roman times for an area covered by the *Geschichtlicher Atlas der Rheinlande* (Cüppers and Rüger 1985; Joachim 1997; Richter 1997).

archaeologists or local collectors systematically discarded Bandkeramik finds but kept those of later periods.

Therefore missing archaeological observations are probably not the reason behind the lack of Bandkeramik sites along the Rothbach. It would also be difficult to argue that erosion destroyed Bandkeramik sites, 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 of the reduced density of sites in this area. Consequently, it has to be concluded that the area along the Rothbach was not used at the same intensity as other areas of equal suitability during the Bandkeramik.

Observations of other kinds also confirm the existence of areas used only to a limited extent in specific periods. Along the Wurm valley, for example, human impact is classified as reduced in Bandkeramik times by palynologists (Zimmermann et al. 2004: 63).

All these observations, made in a region with an otherwise excellent archaeological record, indicate that the landscape was not being used to its nutritional carrying capacity during the Bandkeramik. This behavior is now interpreted as resulting from the need for physical demarcation between various small social groups, mirroring a kind of social carrying capacity. The size of these groups seems to range between several hundred and maybe 1,000 individuals. However, it is uncertain whether all Bandkeramik settlement areas were divided into such units.

If we accept that this empty space between different settlement areas existed in the past, then the question becomes whether ecological conditions made the area along the Rothbach less suitable for Bandkeramik people than other regions.

Land Use. Another application of the determination of settlement areas delimited by isolines is the question of ecological suitability of a landscape for people in a period of the past. A simple research design was chosen to compare the area of a specific soil (*Leitbodengesellschaft*) in combination with precipitation data located inside settlement areas with the area situated outside the settlement area (Wendt et al. 2009). We found that the area along the Rothbach belonged to the most suitable regions during the Bandkeramik (Figure 3).

However, the observation that in a single case an empty space between different "settlement areas" existed in Bandkeramik times does not allow us to interpret all empty spaces as historically given. When comparing land use diachronically, it becomes clear that because of progress in farming techniques, the size of usable land increased considerably during prehistoric times (Figure 4). For the Iron Age (and the Merovingian period) a certain preference for vicinity to the Rhine River can be recognized. One consequence of this preference is again that suitable land at a distance of perhaps more than a dozen kilometers from the Rhine is less regularly used. Here, suitable land seems to have existed that was not used to its full extent. For the state society of the Roman Empire this is not true to the same magnitude. In Roman times, nearly 90% of suitable locations were used, as proved by archaeological distribution maps.

Applications: Estimations of Population Density

We applied the upscaling procedure used to estimate population density in the Rhineland to five periods based on different sources of information at the level of the key area (Table 1).

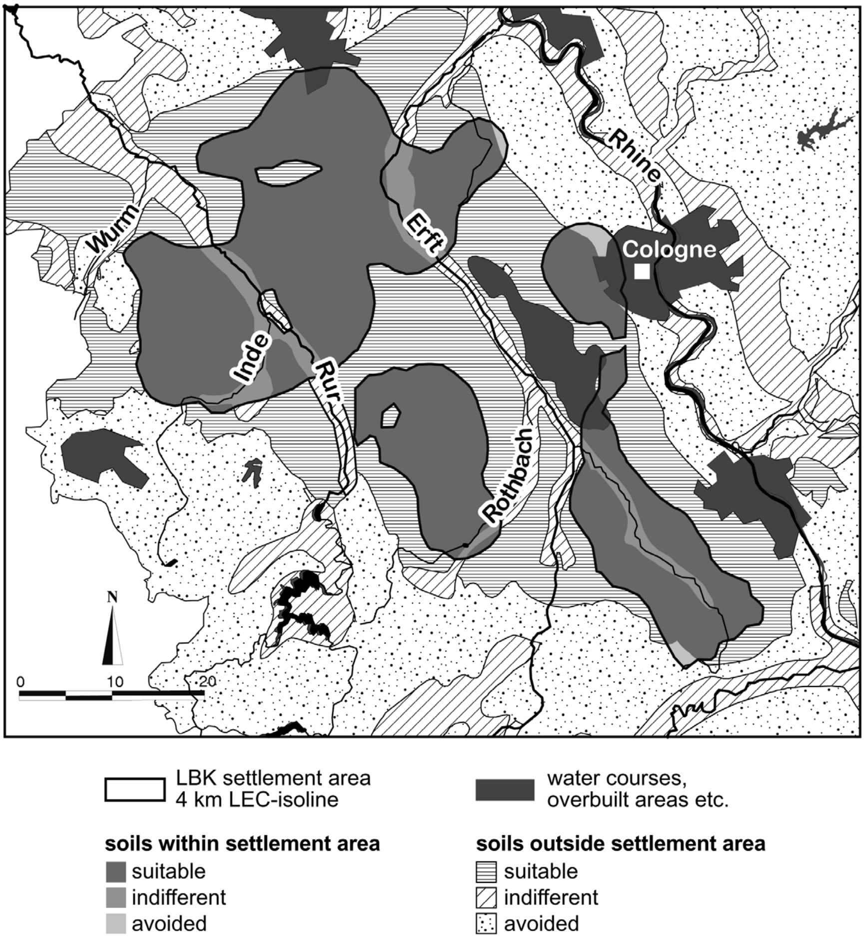

Figure 3. Suitability of locations for the Bandkeramik in the *Geschichtlicher Atlas der Rheinlande* (Richter 1997). Settlement area, 4 km isoline. Soils according to *Bodenübersichtskarte 1:1,000,000* (2004); precipitation according to Deutscher Wetterdienst (2006).

As one of the best known archaeological cultures of central Europe, the Bandkeramik period was chosen for the Early Neolithic. As the chronological target, we selected the middle of the 51st century BC as representative of the time between 5250 and 5050 BC. Most important for the analysis are large-scale excavations of the Neolithic settlements in the area of open lignite mining between Aachen and Cologne. The basis for the upscaling procedure is the number of contemporaneous households per square kilometer. The number of inhabitants and the average duration of a house are quantities to be discussed.

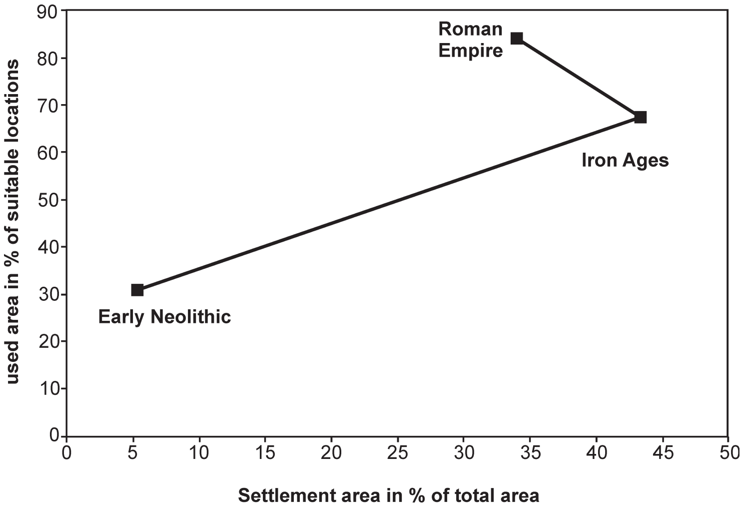

Figure 4. Size of suitable locations (horizontally) and their intensity of use (vertically) over time (LBK, Bandkeramik, Hallstatt C/La Tène AB and Roman period) considering soil [*Bodenübersichtskarte 1:1,000,*000 (2004)] and precipitation (Deutscher Wetterdienst 2006).

In fact, three independent estimations had to be carried out for the Iron Age. In the most fertile loess areas of so-called *Altsiedellandschaften* (long settled landscapes), graves are underrepresented and therefore settlements have to be analyzed. The basis for upscaling is the number of settlements per square kilometer. Because of the bad chronological resolution of Iron Age settlement ceramics, the average number of contemporaneous houses was set to 2 and the number of inhabitants per house has to be discussed. For the uplands of Hunsrück and Eifel, necropolises of tumuli are the archive to be used. In these regions, which are covered with extended forests today, preservation is generally good. A problem could be tumuli not yet found. In fact, we consider whether transmission of the concept of settlement areas in forested areas is reasonable. In the lowlands near the Dutch border, tumuli are the predominant kind of features as well. However, preservation is bad here. Therefore either the number of eroded graves has to be estimated or the number of households has to be derived from clusters of tumuli. We used both approaches, and the results do not differ significantly.

For the Roman period, the second half of the second century AD was chosen as the time slice, assuming that nearly all villas were existent at this time. The settlement area was divided into regions of high density and low density. Besides this differentiation, the density of villas in key areas and in distribution maps of larger regions does not seem to be different. The stone architecture of Roman buildings seems to improve the archaeological visibility in an optimal way. Therefore an upscaling procedure was not needed for the agrarian landscape of the Roman

Table 1. Archives Used for Upscaling Population Density for Selected Periods at the Key Area Level

	Settlements			
Time Period	*Basic Variable*	*Critical Variables*	*Necropolis*	*Other*
Before Industrial Revolution, AD 1800			Life expectancy; stationarity of population	Written sources
Merovingian period, AD 530–670			Graves	
Roman Empire, AD 150–200	Villas	Inhabitants of towns		
Iron Age, 600–475 BC	*Altsiedellandschaft*; settlements	Inhabitants; houses per settlement	Uplands and lowlands; graves	
Bandkeramik (Early Neolithic), 5250–5050 BC	Households per square kilometer	Inhabitants; duration of house		

period. In a few cases the number of individuals per villa can be confirmed by a cemetery. The numbers for military personnel are well known. The estimations of the number of people per large town (*municipia*) and village or small town (*vicus*) could be improved in the future by explicit upscaling procedures.

The estimation of the Merovingian period is based on the analysis of necropolises. Because of the excellent archaeological chronology for this period, it is possible to study the effects of nonstationary populations. The data for this time period have to be judged as very good.

The estimations for the time period of AD 1800 are based on a statistical description of the Rhine province (von Restorff 1830). The localization of isolated houses poses a problem for some parts of the area. To keep efforts within limits, we aggregated farms that were not accurately locatable with the next settlement. Another decision to reduce the extraordinary amount of information was to aggregate data for a good half of the working area at the level of the *Kreis* (i.e., an administrative unit with an average area of about 450 km^2).

Estimations of population densities are influenced by various factors. To understand the importance of each one, it is useful to measure the effect of each factor separately. Therefore we varied the specific value of one factor in each comparison while keeping the other variables constant. Only in the last step was it reasonable to consider the combined effect of error propagation as the possible accumulation or compensation of biases. Specific factors are active at the level of large distribution maps, and other factors are active at the level of the key area and its analysis.

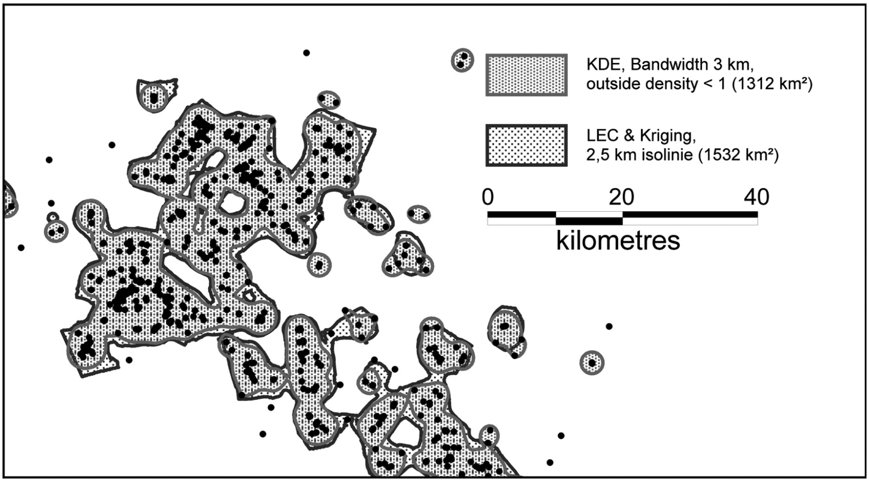

Figure 5. Detail of the Early Neolithic Bandkeramik distribution in the lower Rhine basin comparing isoline computation by kernel density estimation on the one side and by largest empty circle method with kriging on the other side.

Large-Scale Distribution Maps. To upscale information from the level of the key area to larger regions, we need to transform large-scale point distribution maps to area maps with dense site patterns inside an isoline and only a few sites outside. One possible combination of methods has already been described (largest empty circle combined with kriging). Here the method of kernel density estimation is used to control the accuracy of the results achieved so far. In most cases both methods produce areas that are well adapted to the underlying point distribution pattern.

In two cases not further regarded in this paper, method-induced differences regarding the space included in isolines accounted for only about 1%. Only the Early Neolithic (Bandkeramik) and the Roman period in the Rhineland are discussed here [point patterns from the GAR: Richter (1997) and Cüppers and Rüger (1985)]. These cases were selected because, on the one hand, the differences between both methods arrived at maximal values and because, on the other hand, they represent examples with a low (Bandkeramik) as well as a high ratio of intensively used land (Roman times). The largest difference resulting from the application of these two methods was observed in the Bandkeramik case. The combination of the largest empty circle and kriging procedures produces a settlement area encompassing 1,532 km^2 (2.5 km isoline). Using kernel density estimation (bandwidth 3 km, outside density less than 1), the settlement area encloses only 1,312 km^2 (Figure 5). Consequently, the population density decreases from 0.6 P/km^2 to 0.52 P/km^2 (P/km^2 is defined as persons per square kilometer), which

Table 2. Maximal Range of Differences Between Estimations of Population Density for Specific Variables Expressed as Percentages in Relation to Mean Estimation

Scale Level		*Linearband-keramik*	*Roman Period*	*Hunsrück-Eifel Culture*	*Merovingian Period*
Large-scale distribution map	Calculation method of isoline	−12.2	+0.8		
	Increase of archaeological knowledge in 10 years	+16.3	+2.5		
	Combination of method and increase of knowledge	+4.1	+3.3		
Key area	Settlement: People/household	35.2	49.2		
	Necropolis				
	Life expectancy			18.2	
	Stationarity				+25.0

is 12% smaller compared with the result using the kriging approach (Table 2). For the Roman period a difference of 0.11 P/km^2 resulting from the use of different methods was observed (0.8% in Table 2). Deviations in population density up to this margin have to be expected through the use of different methods for the computation of isolines (of course differences might be smaller). It is impossible to predict whether future application of improved methods will produce an increase or a decrease in the size of settlement areas.

Another critical value concerning the validity of isolines is the increase in space they enclose that is caused by newly detected sites. For the Rhineland some updated data sets reflect the increase of knowledge during 10 years of work by the cultural resource management program (we are thankful to be allowed to use these data sets). In some cases, not commented on further here, concerning map areas smaller than 10,000 km^2, an increase in settlement area of 3–6% was observed for different periods, for calculations based on graves as well as on settlements. Once more the difference is largest for the Bandkeramik (in this case for the lower Rhine basin with 18,740 km^2). The increase in space reaches +16.3%. The difference of area is approximately the same as the one resulting from the comparison of methods in the preceding section. Therefore today we would estimate 0.10 P/km^2 more than 10 years ago. In the future, we should expect a general increase in settlement areas caused by these influences. A maximal increase could be expected at the magnitude observed for the Bandkeramik.

It cannot be predicted whether or not the effects of different factors accumulate in every case; for example, in the Bandkeramik case the decrease in settlement area by method is nearly balanced by the increase of knowledge in 10 years. However, it is the general magnitude of possible changes based either on method or state of knowledge that is important. Some other factors, such as cell size for interpolation and the algorithm used to construct Thiessen polygons, were controlled by the same procedure. The results were smaller deviations than the ones discussed here.

Reviewing these results, we see that variability resulting from factors that influence estimations of population density at the level of large-scale distribution maps are quite small compared with factors relevant at the level of the key area.

Key Area. At the key area level factors have to be distinguished according to the archaeological systematics of archives. For settlements the number of people per household (P/HH) is a variable of most importance. As an example, until recently, 6 people per household had been assumed for the Bandkeramik, based on assumptions from research history. According to a new master's thesis (Schiesberg 2007), a correspondence between size classes of houses and a simulation of family structure was detected. If the argument holds true, a range of 7–10 people per house has to be considered. In fact, for most periods of prehistory the commonly used assumptions are about 5 people for smaller houses and up to 10 people for larger houses. However, ethnographic examples show the cultural variability of this value. Therefore archaeological observations concerning the number of burials connected with specific houses are enormously important pieces of information for each possible case. By chance, two small Bandkeramik settlements were excavated by our institute, where seemingly all people (with the exception of small children) were buried in a necropolis in the neighborhood. The analysis of these sites supports the figures proposed by Schiesberg [preliminary report by Mischka (2004)]. Therefore an average number of 8.5 inhabitants is now used for the Bandkeramik longhouses (however, it must be pointed out that in numerical simulation experiments exceptional Bandkeramik household compositions occurred with more than 20 people). The actual outcome is 0.6 ± 0.1 P/km^2. The absolute difference between a calculation of population density based on either 7 P/HH or 10 P/HH amounts to 0.2 P/km^2. This maximal difference between 0.5 and 0.7 P/km^2 corresponds to 35.2% of the mean value of 0.6 P/km^2 (after rounding).

Another factor important for the estimations regarding the number of houses in a settlement is the average period a house was used. For the Bandkeramik in the Rhineland, a chronology connecting ceramic ornamentation, settlement structure, and ^{14}C dates by archaeological wiggle matching suggests that about 25 years seem to be a good estimation for average life expectancy of a house (Stehli 1989). Assuming an average use period of 50 years per house would increase population density by 0.5 P/km^2. Both the variables "use period" and "numbers of persons per house" are hotly debated topics for the Bandkeramik period.

For necropolises, life expectancy and nonstationarity are the most important problems. In the Iron Age Hunsrück-Eifel culture, for example, a lower life expectancy at birth of 25 years and an upper life expectancy of 30 years were considered. The resulting change of population size of 18.2% corresponds to an absolute difference of 0.8 P/km^2 [for the Merovingian period a mean life expectancy of 35.9 years is used, according to a recent compilation of 52 necropolises with 12,525 individuals (F. Siegmund, unpublished data, 2009)].

The isolation of a time period with a tolerable stationary population is possibly best in the Merovingian period. For this time the chronological resolution is extremely good. The first typical burials are rare during the 5th century AD; the number per year reaches a maximum in the 6th and the first half of the 7th century and decreases again afterward (Siegmund 1998: 495–515, list 3). Considering only the time period with the maximal density of graves increases the population density by 25%, to 1 P/km^2.

It seems that necropolis-based estimations are more accurate than settlement-based estimations. The number of dead reflects the number of living persons better than the number of households because of the uncertainty of the number of inhabitants per household. Therefore observations of a necropolis belonging to specific households are of enormous importance for calibrating the number of people per household. However, graves are passed down only for specific periods to an extent that estimations of population size are possible. At the scale level of large distribution maps, estimations seem to be more accurate for times with a high population density, such as the Roman period, than for periods with low densities. However, it is nearly impossible to distinguish differences of a few tenths of the number of people per square kilometer in the summarizing graphs because they illustrate the case of low absolute densities.

Results and Discussion

Dynamics of Settlement Cycles: The Early Neolithic Bandkeramik. Estimations of population density derived from archaeological data mostly concern the climax of cultural cycles with optimal archaeological knowledge. Typically, uncertainty is larger at the beginning and at the end of such cycles. In the middle phase of the Bandkeramik in the lower Rhine basin, a long time of stable maximal population density existed between approximately 5250 and 5050 BC. In the preceding 50 years the number of households quickly increased; in the century after the long phase of stability the number of households slowly decreased.

It is clear that the development in the lower Rhine basin is not representative of all other areas of the Bandkeramik in terms of absolute dates. The development from the oldest Bandkeramik in southern Germany to the following Flomborn phase between 5300 and 5200 BC is a different process from the new formation of a Neolithic way of life that occurred at 5300 BC in the lower Rhine basin. Likewise, the hiatus between the Bandkeramik and the following middle Neolithic of Grossgartach type suggests another type of transition that is different from the continuous development from the Bandkeramik to the succeeding Stichbandkeramik in the Elbe-Saale region and Bohemia, for example. Therefore scaling approaches based on the absolute dates from the Rhineland will fail. However, we

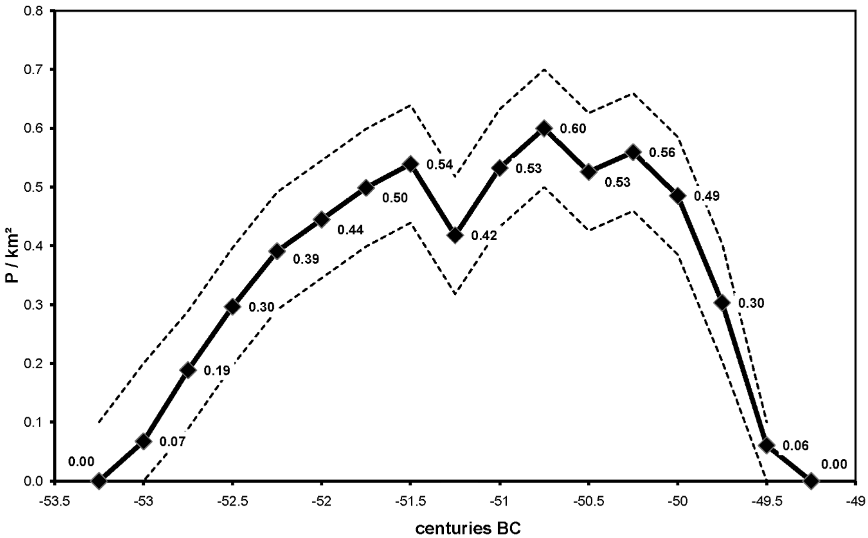

Figure 6. Population densities of the Early Neolithic Bandkeramik in the lower Rhine basin (solid line) according to the number of excavated and dated houses (dotted line is the postulated error margin). The maximal density of 0.6 P/km^2 in the first half of the 51st century BC is obtained by the upscaling procedure described in the text. The other estimations are interpolated linearly on the basis of 0.6 P/km^2 according to the number of excavated and dated houses. Forty-four houses correspond to this estimation. For the maximal estimation of 0.6 P/km^2, an error of ±0.1 P/km^2 was obtained. This error is schematically transferred to all other periods of the Bandkeramik.

could consider these approaches if the magnitudes of population size are typical for cyclical developments during the Neolithic. Of course the remaining substantial uncertainties would have to be considered in generalizations of this kind.

Considering the number of excavated and dated houses could be a simple technique for approximating the different population densities during the Bandkeramik settlement cycle in the lower Rhine basin (Figure 6) [for references, compare Zimmermann et al. (2005: 16–20)]. Considering an error margin of ±0.1 P/km^2 visualizes the margin of possible solutions.

The other possibility would be to argue individually for different periods concerning size of settlement area and number of inhabitants per household. For example, the number of people per household could have been larger during times of increasing population density than during times of decreasing density at the end of the Bandkeramik.

In the Merovingian period there seems to be a cycle regarding the variable number of graves per year. In this case, however, this pseudocycle is not related to fluctuations in population size. At the end of this period, inhumation in an outdated pagan way with weapons and ornaments became uncommon because the

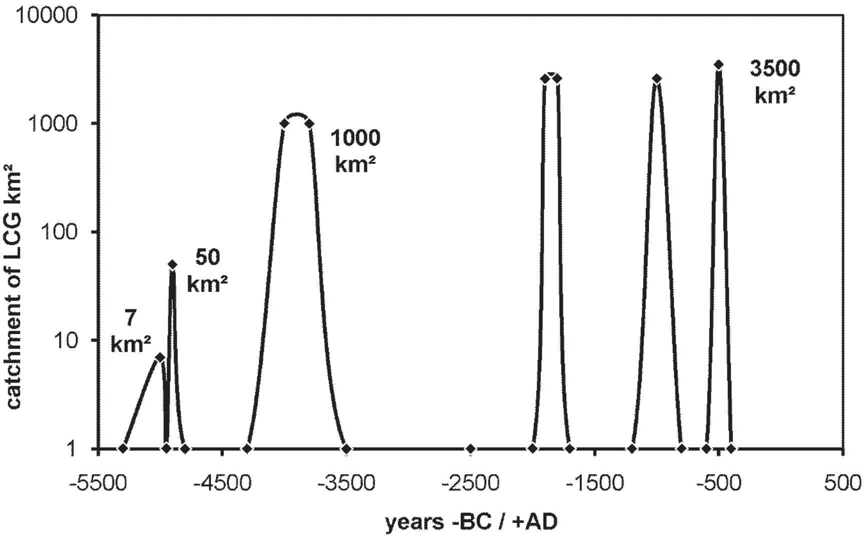

Figure 7. Size of the catchment areas of the largest consciously and collectively cooperating groups in central Europe (LCG). *y*-axis scale is square kilometers logarithmically scaled; the *x*-axis gives the different time periods. Values for labeled peaks are derived from the intersection of Thiessen polygons and settlement areas; other peaks are estimated from the size of the Thiessen polygons alone. No proposition is presented for group size between the peaks.

dead began to be interred without grave goods in the neighborhood of the church. This behavior changes the archaeological dating possibilities of the dead to the worst case. In this respect, cycles of household frequencies seem to better reflect fluctuations in population densities compared to necropolises.

Nevertheless, in most periods of prehistory cultural cycles overlay the long-term trend of a slow increase in population density. Beginning with the Neolithic these cycles lasted between a few hundred years and a millennium.

Size of Consciously Collectively Acting Group. Enclosure camps are an important feature of the Neolithic. Although the function of the specific construction can be debated, it is generally agreed that the camps represents the common effort of a group larger than a household.

The maximal space available per settlement (or group of settlements) can be approximated for the Bandkeramik of the Aldenhovener Platte using Thiessen polygons. The areas that the Thiessen polygons enclose range from 5 km^2 to 13 km^2. In Figure 7 a mean size of 7 km^2 is used. The inhabitants of these small agglomerations of settlements acted together as a group to build the enclosure camps. Buildings within distances less than 1.5 km were used one after the other. In fact, very short use periods between approximately half a dozen years and

25 years seem to correspond best with the integrated chronological analysis of ceramic ornaments and the archaeological wiggle matching of ^{14}C dates [for absolute chronology, see Stehli (1989); for the specific enclosure camps considered, see Lüning and Stehli (1994, beilage 6, phases XIII to XV)].

In the following Middle Neolithic period [4950–4600 BC; chronology according to Lüning (1996)], the catchments of circular enclosures in lower Bavaria show remarkably regular distances (Petrasch 1990) and they cover areas of about 50 km^2, measured by intersection of Thiessen polygons with the isoline contouring of the settlement areas [data of site locations according to Preuss (1998)]. Petrasch argues that all buildings are more or less contemporaneous according to ^{14}C dates. The circular enclosures of lower Austria confirm these observations (Trnka 1991). For the Austrian data, buildings within a distance of less than 1.5 km are aggregated because they are expected to have been used in succession (according to the high resolution chronology of the Bandkeramik in the Aldenhovener Platte). The catchment areas of the remaining enclosures increase from 16 km^2 (for Wetzleinsdorf) to 84 km^2 (for Porrau) and affirm the observations from lower Bavaria. According to ^{14}C dates, not all the areas have to be necessarily contemporaneous (Stadler et al. 2006). That would increase the size of their specific catchment areas; buildings not yet found by the systematic surveys of our Austrian colleagues would decrease the space available.

The same analysis for the subsequent Michelsberg period (4300–3500 BC) results in values of another magnitude. It is possible to assess the relationships between enclosure camps quite well in the lower and middle Rhine basins. Here again the buildings succeeding each other chronologically are aggregated around one central coordinate because it is assumed that it was the same group of people erecting these monuments. For the Michelsberg period the space of Thiessen polygons per enclosure (enclosed by the isoline of the Michelsberg settlement areas) is increased by a factor of 10 compared with the Early Neolithic (ca. 1,000 km^2). Regarding the size of the building in Urmitz (Boelicke 1977) (the length of two ditches and a palisade each amounts to more than 2 km), a group size has to be expected that corresponds to chiefdoms better than to tribal societies. However, until now there have been no indications by, for example, pollen diagrams that population density in the time of Michelsberg culture was substantially larger compared to the Early Neolithic.

For the Hallstatt time, an isoline of dense tumulus distribution exists in southern Germany (Müller-Scheessel 2007, Abb. 10). The territories of the princely sites of Heuneburg, Ipf, and Hoher Asperg in the middle of the first millennium BC measure about 3,500 km^2 each when delimited by the Thiessen polygons first presented by H. Härke (1979). The catchment areas of Urnfield hill forts (Jockenhövel 1974) and the convex hull around the early Bronze Age princely tombs of Aunjetitz in central Germany (Leubingen, Helmsdorf, etc.; Otto 1955) include areas of approximately 6,500 km^2. Isolines of settlement areas are still missing for these periods on an appropriate scale. Therefore it is possible to argue only that the size of Thiessen polygons has to be reduced by a factor 2 or 3 to approximate the parts of the landscape that were intensively used, as observed in other cases. Following this line of argument for the early Bronze Age and the Urnfield culture, catchment areas of perhaps 2,500 km^2 are to be expected. In this perspective, group size in Hallstatt times seems to be a factor of 3 larger than in the Michelsberg period, although both societies are classified as chiefdoms using the social scale of neoevolutionists.

It is not reasonable to interpret the increasing catchment areas and therefore also the increasing size of groups that acted collectively as a linear evolutionary development from the Neolithic to the Iron Age. The examples from the early Bronze and Iron Ages are historical cases with suspicious rich grave goods. Therefore it is to be expected that between these maxima of social inequality, cyclical processes of devolution occurred.

Local and Global Estimations of Population Density. When dealing with estimations of population density, one has to decide whether the number of people is calculated with regard to a limited "local" vicinity or a large "global" environment. According to the method in the LUCIFS framework, a density considering only settlement areas is a local estimation. A density considering also seemingly empty areas between settlement areas is a global estimation. Population densities of farmers and hunter-gatherers can be compared only on a global scale. Therefore seasonal use of specific landscapes without or with only a few archaeological finds is considered only with global estimations. However, there are also arguments to calculate local population densities. For example, concentrations of people influence their environment much more than dispersed people do. Functional relations between a local population's size and its social structure probably will be easier to recognize than global density. Therefore we propose here to differentiate between these two aspects and to examine them both systematically.

For example, population density in the Old and Middle Kingdoms of ancient Egypt seems to be completely incomparable with contemporaneous ancient Mesopotamia (Table 3). According to Whitmore et al. (1990: 29 and 31), density varies at the Euphrates and Tigris between 5 P/km^2 and 11 P/km^2. At the Nile it ranges between 51 P/km^2 and 73 P/km^2. The Egyptian values, though, relate only to the fertile Nile valley itself and are therefore a local value. For Mesopotamia, however, the grassland used as winter pasture is also included in the estimations, which is hence a global measure. In this perspective the Egyptian values are in line with Beloch's (1886) estimation of 80 P/km^2 in Attika during the Classical period in Greece and 57 P/km^2 in the Roman Rhineland as calculated by our project considering only settlement areas and their centers. The population density of Mesopotamia corresponds to the density for Classical Greece in its entirety, to the density of Roman Italy, and to our global density for the Roman Rhineland. Considering these observations, it seems useful to also document the size of reference space besides the density measures themselves, thus allowing a possible recalculation.

Table 3. Mean Densities of Populations Classified as Local and Global

Early States and Civilizations	*State*	*Age*		*Local km²*	*Global km²*	*Percentage of Population in Centers*[a]	*Population Density*		*Reference*
		Beginning	*Ending*				*Local P/km²*	*Global P/km²*	
Inca	Territory		AD 1500		980,000			6.5	Trigger (2003: 106)
Aztecs	City		AD 1500	6,650		30%, max. 50%	180.4		Whitmore et al. (1990: 33)
Central Mayan lowlands	City	AD 700	AD 900	Part of region, 22,715		15–35%, max. 50%	134.2		Whitmore et al. (1990: 35)
Roman Empire, Italy	Territory		AD 165		310,000			27.4	Scheidel (2007: 48)
Roman Empire, European provinces	Territory		AD 165		2,568,000			14.4	Scheidel (2007: 48)
Classical Greece	City		440 BC				(80 in Attika (Beloch 1886)	17.5	Scheidel (2007: 44 and Map 3.1)
Southern Mesopotamia, early Dynastic to old Babylonian	City	2500 BC	1600 BC	(12,000)	55,260 (120,000)	70–80%	(37.5)	7.1	Whitmore et al. (1990: 29); values in parentheses from Trigger (2003)
Egypt									
Roman Empire	Territory		AD 165	30,000			183.3		Scheidel (2007: 48)
New Kingdom	Territory	1320 BC	750 BC	27,300			96.7		Whitmore et al. (1990: 31)
Old and Middle Kingdoms	Territory	2500 BC	1600 BC				61.8		Whitmore et al. (1990: 31)
Rhine-LUCIFS									
AD 1800			AD 1800		26,145	20%		80	For centers, see note (b)
Merovingian period		AD 530	AD 670	9,570.5	60,008			1.0	

Franken	AD 530	AD 670	5,883		8%	6.5		For centers, see note (c)
Sachsen	AD 530	AD 670	3,687.5			0.37 with centers		
Romans, GAR altogether	AD 150	AD 200	9,304	22,848	14%	56.9 without centers	14.4 ± 3.5	For centers, see note (d)
Agrarian population, low density	AD 150	AD 200	7,506	22,848	–	8.3		
Agrarian population, high density	AD 150	AD 200	1,798	22,848	–	14.7		
Iron Age, GAR altogether	600 BC	475 BC	10,528	23,935		4.0	1.8	
Upland	600 BC	250 BC	5,679	14,443		0.8	0.3	
Lowland	700 BC	475 BC	2,243	3,720		2.2	1.4	
Altsiedellandschaft	700 BC	250 BC	2,651	5,772		11.9	5.5	
Bandkeramik, GAR	5250 BC	5050 BC	2,261	37,989	0%	8.5	0.6 ± 0.1	

a. Percentage of population in urban centers according to Trigger (2003).

b. Towns in Germany according to Berry (1990); for the Prussian Rhineland the same result is obtained considering only towns that had received a town charter. Estimations from the LUCIFS project.

c. Only Köln, with presumably 5,000 inhabitants, and Trier, with 2,500 people, are classified as centers for the Merovingian period. Estimations from the LUCIFS project.

d. For Roman times, Xanten, Köln, Bonn, and Trier (with perhaps 65,250 inhabitants) are classified as centers; however, this value also includes military personnel (26,100 people). Estimations from the LUCIFS project.

The variability of ecological conditions suitable for the farming system of each period is related to the local versus global estimations of the dimension. As mentioned, a much larger variety of landscapes in central Europe was suitable for farming in the Iron Age compared to the Stone Age because of progress in techniques. However, Iron Age population density in the uplands and lowlands was considerably smaller than in loess areas. In the loess areas, the number of people was not much smaller than the Roman agrarian population, whereas in the uplands and lowlands the density was of a magnitude comparable to the Stone Age one in *Altsiedellandschaften*. Therefore differences in population density between different ecological zones are to be expected. We consider for each individual historical case whether these differences are related to the center or periphery dimension. In interaction with cultural cycles these differences characterize the dynamics of prehistoric population densities.

The regional differentiated population densities of the LUCIFS project were calculated independently of each other (Figure 8, bars indicated by arrows). Unlike the estimations compiled from the literature, they are derived using a standardized method and they are all concerned with the same region in the Rhineland. The sizes of the target regions differ according to the archives used and are of a magnitude between 23,000 km^2 and 38,000 km^2. The outcome seems plausible when comparing the results diachronically.

The result for AD 1800 with 80 P/km^2 for the Rhineland is substantially larger than the value for Germany in its entirety for the same time with 50 P/km^2, according to the *Atlas of World Population History* (McEvedy and Jones 1978: 67–72). This difference is probably related to the larger population density in western central Europe compared to western and eastern Europe in general.

All estimations for earlier times presented here are less than the values found in the literature, with the value for Roman times a meaningful exception. As we said in the beginning, estimations for specific prehistoric periods are usually presented only for situations with exceptional observation densities and preservation conditions. Values for ecologically less suitable regions are underrepresented or are missing. It is symptomatic that the result for the loess regions in the Iron Age corresponds to published values. However, the weighted mean considering also the uplands and lowlands is much lower.

Another more general difference between conventional estimations and the values derived for the Rhineland is the method applied. In our standardized approach, upscaling is carried out only in regions with archaeological finds. The competing approach is to transfer information from key areas to whole regions that are seemingly ecologically suitable. In the Bandkeramik example of the Rothbach, it was shown that in fact empty areas existed. However, it is still open to discussion how many other empty areas are due to erosion, missing archaeological observations, or difficult visibility of specific archaeological features and recognizability of finds. It is assumed that in many estimations in the literature, the investigators tried to overcome this problem by adding a certain amount of land presumed to be used in the past. These individual decisions pose a problem

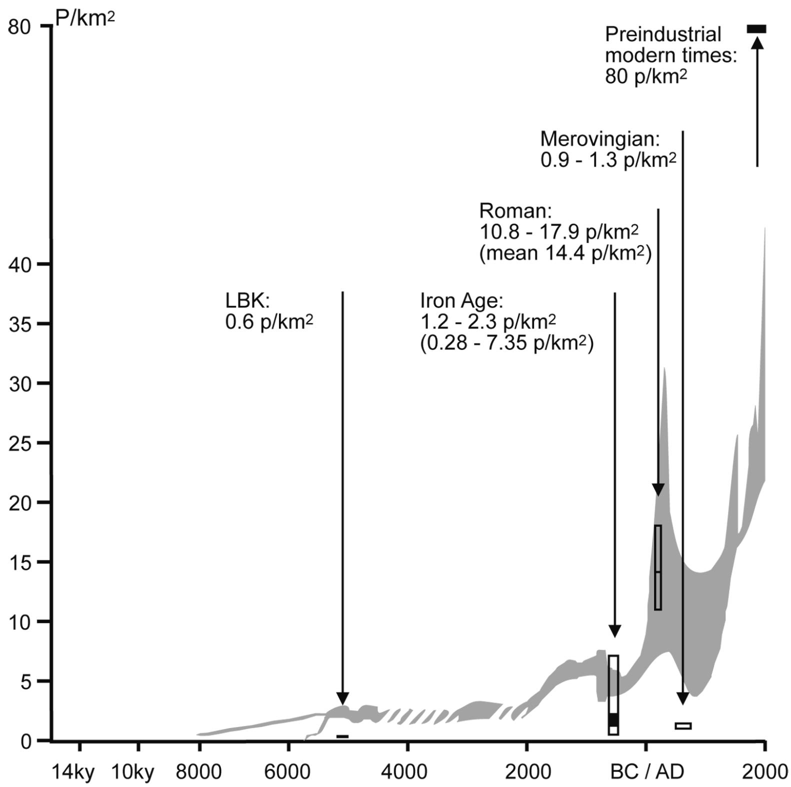

Figure 8. Global population densities in central Europe. Dark shaded areas: Conventional estimations collected from the literature (Zimmermann 1996). Bars indicated by arrows: Estimations for the Rhineland considering variability resulting from ecological conditions based on archaeological distribution maps [from *Geschichtlicher Atlas der Rheinlande* (Cüppers and Rüger 1985; Joachim 1997; Nieveler 2006; Richter 1997)].

for comparability of the results, because it is difficult to say how much of a result is due to archaeological data and how much to an individual decision. For example, the difference in density between the Neolithic and the Iron Age 10 years ago seemed to be markedly smaller than it is today. Perhaps the reason for high estimations of population density during the Merovingian period is based more on comparison with Roman and medieval times and less on the archaeological evidence of the period. For densities based on archaeological distribution maps, future fieldwork will increase the values somewhat. Transferring densities from key areas to regions of seemingly suitable ecological conditions, however, could easily lead to overestimations.

The general trend, however, will not be changed by our new estimations: In all prestate societies low population densities seem to have existed. Improvements in farming techniques had nearly no impact on the population level in central Europe (dairy farming in several settlements during the 5th millennium BC, plow use in the second half of the 4th millennium BC, and even the introduction of greenland pasture and of manuring during the 1st millennium BC had only limited impact on population density).

Conclusions

In this context the estimation of Roman population density is of special importance. The estimation based on archaeological evidence corresponds well with the results based on written sources. This is true for the Rhineland values as well as for Roman Italy, where density is nearly twice as high.

Global population densities for state societies have already been documented at a magnitude of 5 P/km^2 (for Mesopotamia at 2300 and 1600 BC; Whitmore et al. 1990: 29). Therefore low estimations for prestate societies gain credibility.

On the basis of these data, it is not population pressure that causes innovations or cultural change in prestate societies. Malthus claimed population pressure correctly as a problem during the Industrial Revolution with the demographic transition in Europe (Malthus 1970 [1798]). It seems not correct to transfer this line of reasoning to situations of the past with low population densities.

Low population density resulted in long periods of prehistory with a marked situation of instability, resulting in regional population fluctuations and mobility at the level of individuals and at the household level. Migrations of larger groups presuppose an organization at the chiefdom level. Therefore mobility is specific not only for hunter gatherers but also for farmers, who moved in cycles of a few hundred years instead of according to the seasons of the year (Zimmermann et al. 2005).

Possible Topics for Future Developments

The long-term evolutionary perspective with an increase in population density and vertical social differentiation has been well recognized since the 19th century on the regional, continental, and global scales. Less clear are regionally differentiated developments, for example, when comparing the Mediterranean and central Europe during the last three millennia BC. Most difficult to understand are the reasons for regional fluctuations on a small scale (in terms of a few hundred years) during periods of sedentary society. As already mentioned, instability resulting from small population density does not help us to understand which factors were more important than others in a specific historical situation. We see the possibility of coming to a better understanding of such complex developments through (1) reintroduction of systemic analysis, (2) the introduction of the social scale dimension into systemic analysis (household, largest collectively cooperating group, and level of self-organizing processes between groups), and (3) improvement in the methods used for comparisons of cultural cycles.

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