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A Hierarchical Model of Scale Levels for Estimations of Population Densities

Abstract: Understanding historical processes in large areas can prove to be a difficult task, especially since it is impossible to excavate or survey these in their entirety. In this paper, a method is presented by which small scale data can be transformed into a larger scale incorporating a rural landscape. The theoretical model is described and explained with a practical example in which the population density at the time of the Linear Pottery Culture is estimated. After the analysis of key areas, settlement areas in the Rhineland are defined on the basis of archaeological sites. Through upscaling, a population density of 0.42 inhabitants per square kilometre is calculated.

Introduction

The Institute for Prehistoric Archaeology in Cologne is part of "RhineLucifs", a project examining human impact on fluvial systems since the beginnings of agriculture. The main task of the archaeological project within the research group is to determine the amount of open farmland during specific time periods. This has influenced other processes such as erosion as well as sediment accumulation, and is therefore important when determining the scale of human impact. Until now, the focus of the archaeological project within the research group has centred upon the analysis of population density, which, it is considered, is a key variable that provides access to both prehistoric economic and social relations.

These methods are presented here including their main features and practical applications. For further reading, please refer to the papers "Überlegungen zu Prinzipien einer Landschaftsarchäologie" (ZIMMERMANN ET AL. 2004) or "Landscape Archaeology" (ZIMMERMANN / WENDT / FRANK IN PRESS).

The Theoretical Model

At the centre of our approach lies a hierarchical model, summarised in *Fig. 1* which shows the data required, the methods used, and the results obtained. The main concept comprised the controlled transfer of data between different scale levels. It should be noted, however, that the applied methods are certainly not the most important factors of the approach. Instead, it is the consistent logic of the line of argumentation connecting the levels which is essential for the transformation of data. The aim of this work is the creation of a cartographical representation of so called "settlement areas" which can be used in multiple ways, e.g. to upscale population densities deduced from key areas. Further applications can be applied to the analysis of soil suitability, landscape use or habitat shifts.

A schematic representation visualises the scale levels and the steps required to upscale or downscale data. On the right hand side of the model, archaeological scale levels and the sources providing the required information are found. On the left hand side, the methods and results obtained are listed. The triangle in the centre symbolises the steps of knowledge which can be achieved at each level. Through upscaling, generalised data is transferred from a lower to a higher level. Downscaling is applied to knowledge, concerning e.g. migrations, which affect special regions of limited extension.

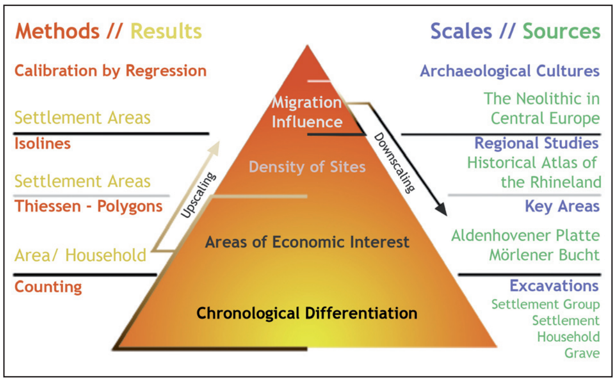

Fig. 1. Hierarchical model of scale levels (ZIMMERMANN ET AL. 2004, Abb. 1, modified).

Practical Example: The Linear Pottery Culture in the Rhineland

On the lowest scale, the level of excavation, houses or graves can be found, dated, and counted. The next level of so called key areas is an intermediate scale between excavations and larger scale distribution maps. These can range in size from some tens up to a few hundred square kilometres. In these areas, the knowledge of archaeological remains is assumed to be nearly complete, since they are characterised by the best observation density available. Therefore, the space available per household or person can be estimated.

The Linear Pottery (Linearbandkeramik: LBK) settlements situated on the Aldenhovener Platte (Zimmermann et al. 2004, 49ff.) and in the Mörlener Bucht (Schade 2004) are examples of such key areas. The Aldenhovener Platte is a small region of ca. 150 km² located in the lignite area between Cologne and Aachen. Due to extensive opencast mining, the archaeological remains in this area are known extensively. Hence, the LBK sites situated here have been excavated completely or were recorded using such methods that the number of contemporaneous households can be estimated in a reliable way. The Mörlener Bucht is subject to intensive surveys, due to being part of a project focusing on Early Neolithic settlement sites in this area.

The general goal at this level is to deduce the mean density of households (or burial grounds in other time periods) per square kilometre. The demand of space for one household is calculated with the help of Thiessen-Polygons (or voronoi tessellation). The nodes of these polygons are the points of maximal distance between sites; with the polygons representing the maximal area of economic interest *(Fig. 2)*. Originally, the use of voronoi-tessellation to define "territories" of sites found its way into archaeological studies via "New Geography", and was adopted by "New Archaeology", notably by David Clarke in the 1960s (Clarke 1968). At present, other methods are used to define site territories, most notably "cost surface modelling" which considers social and geographic features (Wheatley / Gillings 2002, 148ff.). Nevertheless, these factors are of minor interest for the method presented here. Currently, the mean density of households per square kilometre is of importance, while the actual size of the area exploited by one single household is of less importance. The

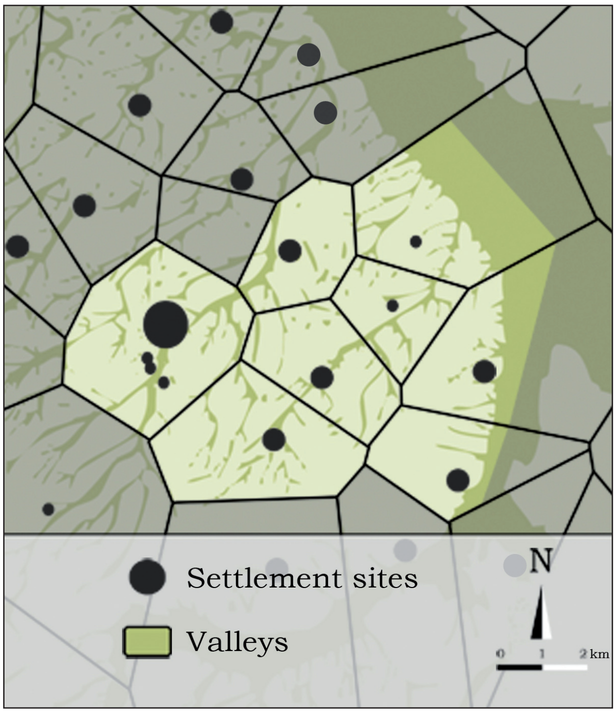

Fig. 2. Aldenhovener Platte with settlement sites and enclosing Thiessen-Polygons (Zimmermann 2002, Abb. 1, modified).

use of Thiessen-Polygons also means that we can eliminate margin areas where border effects might distort results.

In the mid-51st century BC there were 58 households with a total of 55 km² of economic area on the Aldenhovener Platte, correlating with an average of 1.04 households per square kilometre. These results are also supported by surveys conducted in the Mörlener Bucht, where a density of 0.8 households per square kilometre is suggested. Accordingly, an average value of 1 household / km² is transferred to the next level, i.e. the scale level of the regional study.

Regional studies deal with larger areas, ranging from a few hundred up to several tens of thousands of square kilometres. This means that the "Historical Atlas of the Rhineland" (GAR) from 1997 with the scale of 1:500,000 used in our study borders on the upper limits of this level. Data from the lower lying level is up-scaled in order to calculate population densities. This is achieved by the transformation of point data, i.e. site distribution, from the GAR into isolines enclosing "settlement areas". These areas differ in size, but have the same lower threshold value of site-density. Thus, they are assumed to have featured the same density of households in past times. The isolines are calculated with the help of the construction of the "largest empty circle" (LEC) between archaeological sites (Preparata / Shamos 1988, 256ff., 207). In the scale level of key areas, Thiessen-Polygons enclosed the maximal area of economic interest. At this level of regional studies, this cannot be true, since it is not feasible that the data record is complete. Instead, we work with the nodes of the polygons that are situated in the middle of the LEC. These are the points of maximal distance to its nearest three surrounding sites. The higher the value is, the lower the density. The value of the distance is transferred to the nodes, which are used in the next step to build an interpolated grid. In this latter step, Kriging is used (Haas / Viallix 1976), a geostatistical method based on the assumption that "all things are related, but nearby things are more related than distant things" (Tobler 1970). As such, it uses "a variable to weight the contribution of surrounding known values based on their distance from the unsampled location to predict a new value" (Conolly / Lake 2006, 98). In other words, Kriging predicts values for unmeasured points based on their distance and direction from known points. By using Thiessen-Polygons for the analysis of large-scale maps, one avoids making assumptions, with regard to, for example, prehistoric travel conditions. In fact, factors such as the latter are probably better studied within the frame of small-scale examinations. To what extent the results of cost surface analysis, as calculated on a large scale, is related to the results achieved on a small scale, will also make for an interesting area of study in the future.

Based on the distance between find spots, the resulting grid is used to construct isolines. One of these lines has to be identified as the area for which up-scaling information seems reasonable. This region is enclosed by what is termed the "optimal isoline", which defines the settlement area. Different statistical properties can be described for each isoline, e.g. the number of sites it contains *(Tab. 1)*. In our approach, we use the increase of area it encloses, since this criterion seems the most reliable. An isoline is identified as optimal when a clear maximum becomes visible in the sequence of consecutive isolines. This statistical criterion is solely a heuristic measure used to obtain reasonable and reliable regions suitable for upscaling population densities. In many cases, the archaeological maximum is not a global one. Other maxima can circumscribe regions with much larger distances between sites which might correspond to specific types of landscapes or cultural borders (Zimmermann et al. 2004, 53ff.).

Isolines for the LBK in the Rhineland					
		Sites		area per isoline	
km	**no. of areas**	*no.*	*percentage*	*area*	*increase/ km*
2.5	19	104	50%	553.3	
					874.884
3	17	127	60%	990.8	
					1132.38
3.5	13	144	69%	1557.0	
					1407.68
4	10	157	75%	2260.8	
					1249.32
4.5	7	173	82%	2885.5	
					1065.54
5	8	184	88%	3418.2	
					1045.26
5.5	8	188	90%	3940.9	
					1077.12
6	7	192	91%	4479.4	
					911.62
6.5	7	193	92%	4935.2	
					879.72
7	6	194	92%	5375.1	
					850.84
7.5	8	197	94%	5800.5	
					875.54
8	7	198	94%	6238.3	
					814.94
8.5	7	198	94%	6645.8	
					900.2
9	7	198	94%	7095.9	
					931.02
9.5	7	200	95%	7561.4	
					905.32
10	8	200	95%	8014.0	
		210			

Tab. 1. Statistical properties of the LBK-isolines for the GAR with 210 sites (Zimmermann et al. 2004, Tab.1, modified).

For the LBK, an increase in the local maximum of enclosed area can be observed at the 4 km line. In principle, this means the isoline encloses areas in which sites lie closer together than 8 km, but no areas where distances between them exceed this value. Within a range of a minimal distance of some hundred metres to the maximum distance of 8 km to each other, the site density within the enclosed areas may differ. However, we assume that the mean density in the 51st century BC would have been the same in the different areas, therefore the transfer value of one household per km^2 is a plausible average for all enclosed areas.

In the next step, the features of the key area are up-scaled up to the settlement area. The value of one household per square kilometre is transferred to the 2261 km^2 enclosed by the isoline. Accordingly, 2261 households existed in the settlement area *(Fig. 3)*. It is evident that not all sites are located within an optimal isoline. In our study, this is the case with a total of 53 sites. Of these, only a small number might develop into groups of settlements by increased intense archaeological observation. The majority, however, are probably isolated settlements or special purpose camps, and are therefore of minor interest for demographic analysis. Nevertheless, they are added to the number of households already calculated. Following observations from the Aldenhovener Platte, an average of 7.25 households are assumed to have existed in each of these settlement groups. Consequently, a total of 2645 households would have existed in the 51st century BC in the whole area covered by the Historical Atlas. Following Lüning (Lüning 1988), and assuming 6 persons per household, a population density of 0.42 inhabitants / km² for the Rhineland is suggested.

This density is much smaller than in earlier estimations (Zimmermann 1996). Therefore, doubts are raised as to the validity of the earlier hypothesis that land was always used to its maximum carrying capacity. Taking into consideration only archaeological sites, the much lower values presented here have been calculated. It is questionable whether land was really used most effectively in all time periods, as this would imply that population density was high enough to do so (Zimmermann / Wendt / Frank in press).

Alternative Approaches

In the future, our research aims to improve the methods within the model presented here. One possible amelioration might be reached in the choice of the optimal isoline. It would be desirable to find an approach which is independent of the class width (see above). Furthermore, other means to define settlement areas have been proposed. A promising alternative might be found in Kernel Density Estimations (KDE) (Herzog in press). In the set of methods presented here, the isolines were constructed using LEC and Kriging interpolation, ergo the distances between sites were used to deduce settlement areas. KDE is based upon point densities; to obtain a KDE a symmetrical three-dimensional "bump" is centred at each single data point. For each point on the plane the sum of the relevant bump heights is calculated (Beardah / Baxter 1996). To obtain area-data, these KDE's are interpolated with a simple bilinear function (Herzog in press). However, this approach is somewhat problematic with respect to the determination of its parameters. The bandwidth of the "bumps" has to be defined, as it is crucial to the results obtained. Finally, an optimal isoline has to be chosen in a similar manner to the method presented above. To solve these problems and to find a solution that applies to all time periods is the task of future research.

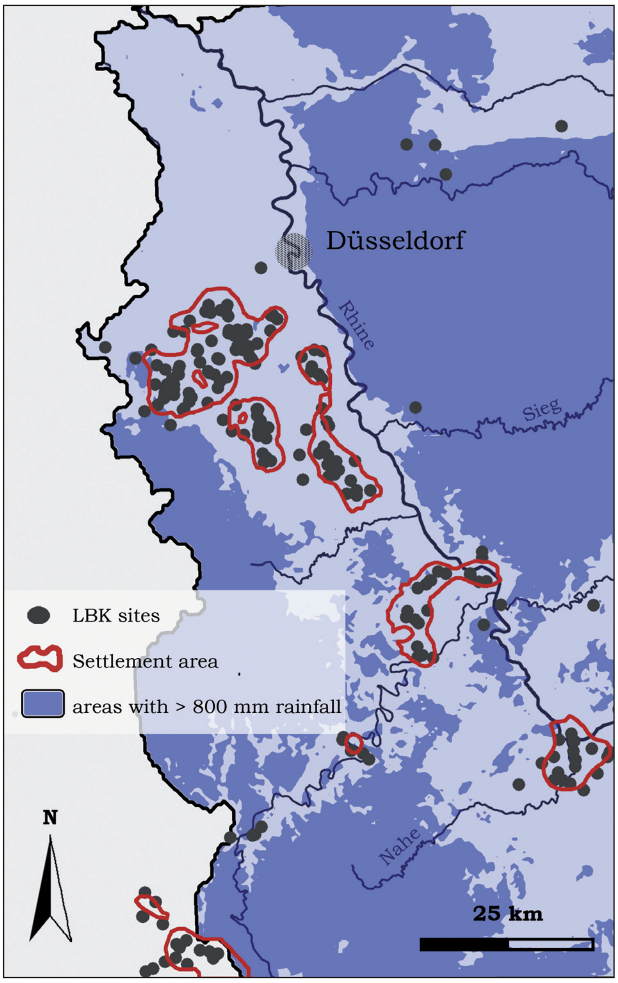

Fig. 3. Map with LBK-settlements and calculated settlement areas; data according to GAR (Richter et al. 1997, Map 1, Alt- und Mittelneolithikum) and the German meteorological service (Deutscher Wetterdienst 2006).

Even though some of the methods and arguments may be exchanged in the future for better ones, it is the logical relations within the model that are crucial. The main aspect of the model presented here is the consistency of the system of methods, which is essential in order to upscale data received on lower scale levels to higher ones. The advantages are apparent. It enables us to develop a fixed methodology to control factors affecting source criticism. This then enables us to conduct diachronic comparisons. Within the set model, we are able to substitute single methods to determine which are most appropriate for the analysis of the broad spectrum of settlement patterns found in different time horizons. Additionally, a controlled approach can also be developed which helps us to integrate processes of culture historical development into the interpretation of large-scale distribution maps.

References

BEARDAH / BAXTER 1996
C. BEARDAH / M. BAXTER, The Archaeological Use of Kernel Density Estimates. Internet Archaeology 1, 1996. http://intarch.ac.uk/journal/issue1/beardah/ [31 Dec 2007].

CLARKE 1968
D. L. CLARKE, Analytical Archaeology (London 1968).

CONOLLY / LAKE 2006
J. CONOLLY / M. LAKE, Geographical Information Systems in Archaeology (Cambridge 2006).

DEUTSCHER WETTERDIENST 2006
Deutscher Wetterdienst, http://www.dwd.de/de/FundE/klima/KLIS/daten/online/nat/index.htm.

HAAS / VIALLIX 1976
A. G. HAAS / J. R. VIALLIX, Krigeage Applied to Geophysics. The Answer to the Problem of Estimates and Contouring. Geophysical Prospecting 24, 1976, 49–69.

HERZOG IN PRESS
I. HERZOG, Testing GIS Methods by Means of Simulation: Detecting and Describing Find Spot Densities. In: Workshop 12, Archäologie und Computer, Kulturelles Erbe und Neue Technologien (Vienna in press).

LÜNING 1988
J. LÜNING, Frühe Bauern in Mitteleuropa im 6. und 5. Jahrtausend v. Chr. Theodor Mommsen-Vorlesung. Jahrbücher RGZM 35, 1988, 27–93.

PREPARATA / SHAMOS 1988
F. P. PREPARATA / I. S. SHAMOS, Computational Geometry: An Introduction (New York 1998).

RICHTER ET AL. 1997
J. RICHTER / E. CLASSEN / A. J. KALIS / J. MEURERS-BALKE, Neolithikum. Geschichtlicher Atlas der Rheinlande Beiheft II/2.1-II/2.2 (Köln 1997).

SCHADE 2004
C. C. J. SCHADE, Die Besiedlungsgeschichte der Bandkeramik in der Mörlener Bucht / Wetterau. Zentralität und Peripherie, Haupt- und Nebenorte, Siedlungsverbände. Universitätforschungen in der Prähistorischen Archäologie 105 (Bonn 2004).

TOBLER 1970
W. R. TOBLER, A Computer Movie Simulating Urban Growth in the Detroit Region. Economic Geography 46, 1970, 234–240.

WHEATLEY / GILLINGS 2002
D. WHEATLEY / M. GILLINGS, Spatial Technology and Archaeology: The Archaeological Applications of GIS (London 2002).

ZIMMERMANN 1996
A. ZIMMERMANN, Zur Bevölkerungsdichte in der Urgeschichte Mitteleuropas. In: I. CAMPEN / J. HAHN / M. UERPMANN (EDS.), Spuren der Jagd: Die Jagd nach Spuren (Tübingen 1996) 49–61.

ZIMMERMANN 2002
A. ZIMMERMANN, Landschaftsarchäologie I: Die Bandkeramik auf der Aldenhovener Platte. Bericht der Römisch-Germanischen Kommission 83, 2002, 17–38.

ZIMMERMANN ET AL. 2004
A. ZIMMERMANN / J. RICHTER / T. FRANK / K. P. WENDT, Landschaftsarchäologie II: Überlegungen zu Prinzipien einer Landschaftsarchäologie. Bericht der Römisch-Germanischen Kommission 85, 2004, 37–95.

ZIMMERMANN / WENDT / FRANK IN PRESS
A. ZIMMERMANN / K. P. WENDT / T. FRANK, Landscape Archaeology.

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