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Research paper

Modelling distribution of archaeological settlement evidence based on heterogeneous spatial and temporal data

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A R T I C L E I N F O

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A B S T R A C T

We analyse variations in prehistoric agricultural settlement behaviour both in space and time to detect main turning points and shifts in settlement patterns in Bohemia, western Czech Republic. We propose a theoretical framework to address our research question and a new evidence density estimation (EDE) method combining and extending existing approaches to produce probabilistic maps and temporal frequency distribution (TFD) curves. This method takes into account heterogeneous spatial and temporal accuracy of archaeological data, and it models settlement structure where respective sites have a specific area and a given interval of duration. We determined minimal sampling densities of archaeological data enabling the method to predict prehistoric settlement at a statistically significant level. The EDE method is universally applicable for all datasets with sampling densities of more than 0.05 archaeological actions per km^2 for chrono-typologically dated evidence and 0.035 actions per km^2 for radiocarbon or similar dates. The results show that changes in spatial extent, density and clustering of settlement activities occur repeatedly throughout the whole agricultural prehistory and shed new light on settlement behaviour of past populations.

1. Introduction

Human activities are in constant interaction with the environment and leave accumulated traces in it contributing to the formation of a landscape. Anthropogenic influence depends primarily on population and land use. One of the ways to examine its extent and intensity is an investigation of past human settlement activities using archaeological data. The aim of this study is to analyse variations in prehistoric agricultural settlement behaviour both in space and time in order to detect main turning points and shifts in settlement patterns. These can be investigated using quantitative methods producing probabilistic maps and temporal frequency distribution (TFD) curves. Our focus area is the present day Bohemia, western Czech Republic for which a centralised repository of archaeological evidence exists in the form of the Archaeological Database of Bohemia. Further studies can examine the underlying causes of the observed patterns. Probabilistic maps quantifying the intensity of human activities may also serve as a base for various environmental models, such as pollen-based quantitative vegetation reconstructions, palaeoclimate modelling and palaeodemographic estimations.

2. Background

Several studies have proposed methods for quantification of past human activity, and have chosen two major approaches to inferring demographic information from archaeological data. The more conservative approach, which we also assume in this study, is to interpret the presence of archaeological features as evidence of human activity, without explicitly linking it to population levels (Grove, 2011: 1013, Armit et al., 2013: 433, Kuneš et al., 2015: 16–17, Kuna, 2015: 75). Another approach, promoted by studies citing the work of Rick (1987) or follow-up works, is to use archaeological evidence as a direct proxy for population size, i.e. to treat fluctuations in evidence of human activity as synonymous with evidence of population dynamics (Gamble et al., 2005: 197, Shennan and Edinborough, 2007: 1340, Collard et al., 2010: 867, Tallavaara et al., 2010: 251, Hinz et al., 2012: 3330, Shennan et al., 2013: 2, Crombé and Robinson, 2014: 558, Lechterbeck et al., 2014: 1300, Timpson et al., 2014: 550, French and Collins, 2015: 122). Despite

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these conceptual differences, all aforementioned studies employ some kind of quantitative method to analyse the temporal and/or spatial frequency distribution of archaeological evidence. The temporal distribution curve or spatial distribution map is then interpreted as a measure of intensity of human activity or population levels.

The existing methods differ depending on the nature of data being used. In the first broad category are methods that work with scientifically dated evidence (radiocarbon, dendro dates age and other) where dates are represented by a normal probability distribution (NPD) specified by a mean and a standard deviation. Methods in the second category work with chrono-typological dating transformed into a time interval with uniform probability distribution (UPD) by assigning calendar dates to its beginning and end based on external evidence. Furthermore it is important if and how the methods handle the spatial aspect of the data points and whether they address the uncertainties caused by variations in archaeological feature visibility, sampling intensity and accuracy. We will provide a brief overview of existing methods from each category. In the following sections we propose a theoretical framework to address our research question and a new method which combines and extends the existing approaches.

The most widely used method of quantifying NPD-dated evidence is the summation of calibrated date probability distributions (SCDPD). It produces TFD curves, first used by Rick (1987) to reveal patterns of human occupation in the preceramic period in Perú. In his opinion "the number of dates is related to the magnitude of occupation. Date records are not true random samples but with sufficient numbers of dates from fairly large regions, numerous sites, and investigators, the general trends of prehistoric occupation should be evident" (Rick, 1987: 58). The idea was further used and developed by multiple studies concerned mostly with palaeodemography (for overview see Brown, 2015; Hinz et al., 2012; Williams, 2012). A similar method using univariate kernel density estimation (KDE) on temporal data and bivariate KDE on spatial data has been proposed by Grove (2011). Both methods rely upon the fact that NPD dates represent probabilistic distributions rather than fixed points in time and their statistical combination produces a more accurate reconstruction of past human activity than traditional methods of spatial and temporal statistics which assume the direct contemporaneity of sites with similarly dated evidence (Grove, 2011: 1012–1013).

Counting of archaeological evidence for a given period (further referred to as "evidence counting") is a commonly used statistic method when dealing with temporal distribution of UPD-dated evidence (as seen in Kuna, 2015). The basic assumption is that the amount of evidence falling into a given period is proportional to the intensity of human activity. The nature of typo-chronological dating can lead to an artificial inflation of frequencies caused by overlapping time intervals. This effect can be alleviated by reducing dating precision to a level where chronological overlapping does not occur and/or excluding data points with broader dating intervals. Another approach is to convert dating intervals into uniform probability distributions by dividing the number of sites falling into the interval by its length (Tallavaara et al., 2010: 254). More sophisticated methods which are dealing with the temporal uncertainty of archaeological dating by probabilistic reasoning and using Monte Carlo simulations have been proposed by Crema et al. (2010) and Kolář et al. (2015). All methods of this family are based on the realization that an archaeologically observed event occurred within an interval defined by the dating which represents the extent of uncertainty.

The empirical way of working with the spatial aspect of archaeological evidence is through distribution maps, where archaeological finds are represented as dots or discrete polygons. For the purpose of predictive modelling or analysis of settlement patterns and strategies, the individual finds are understood as independent points of evidence of past human activity (Neustupný, 1998: 11). Real-world data almost always diverge from this ideal model and bring with them two major sources of uncertainty. The first is the degree of localization accuracy, which can vary from very precise geodetic measurements to a broad assignment of a find to a specific parish. This issue is commonly dealt with by lowering spatial resolution of the data to the lowest acceptable value and discarding points with lower resolution – thus accuracy is increased at the expense of precision (see Kolář et al., 2015). The second source of uncertainty is the fact that a data point does not represent a single find, but a distribution of finds around the recorded coordinates (Grove, 2011: 1014). It becomes an issue when performing analyses at higher spatial resolutions and can be addressed by kernel density estimation (KDE) as proposed by Grove (2011). Another approach is overlaying the examined area by a square grid and recording the presence or absence of evidence in a given square, regardless of its quantity as proposed by Kuna (2015). A third way is using fuzzy logic for spatial analyses (see Lieskovský et al., 2013).

An important source of uncertainty in the reconstruction of past settlement areas is varying archaeological visibility, e.g. the ability to detect archaeological remains of human activities from different archaeological periods, contexts and environments. It is directly proportional to three factors: (i) dating resolution of features from a given period or archaeological culture, (ii) survey strategy and intensity and (iii) feature visibility influenced by cultural behaviour and archaeological transformations in a sense of Neustupný's theory (2007). The first factor is approached by most of the above mentioned methods using probabilistic ways to combine temporal data. The only method where it represents a major bias is the non-probabilistic evidence counting. The second factor is more problematic to approach, since most of the available data on past human activity has been collected over a long period of time by various teams and for various research or heritage protection interests. This leads to a non-standard distribution of the measurements across time and space which makes it impossible to estimate the accuracy of a prediction based on them using standard statistical techniques. To alleviate this problem, it is necessary to find a level of generalization of the data or analytical methods, at which the sampling starts to behave like a uniform distribution. Some studies employ an intuitive approach, suggesting e.g. that "with sufficient numbers of dates from fairly large regions, numerous sites and investigators, the general trends of prehistoric occupation should be evident (Rick, 1987: 58, adopted also by Shennan and Edinborough, 2007: 1340)". Other studies use simulated data with randomly applied errors to estimate the statistical significance of departures in the resulting TFD curves from a null model (Shennan et al., 2013: 6 and subsequent studies). The third factor – variable feature visibility – is the most difficult to handle while its elimination is crucial for acceptance/rejection of the "dates-as-data" hypothesis postulated by Rick (1987).

The major causes of variations in feature visibility are cultural behaviour and archaeological transformations, part of which is taphonomic bias. Taphonomic bias implies that "the longer something is in existence, the more chances it has to be removed from the archaeological record by taphonomic processes such as erosion and weathering thereby causing over-representation of recent events relative to older events (Surovell et al., 2009: 1715)". This may be true especially for the Palaeolithic and/or for the specific environs like caves or alluvia in which the geological and sedimentological processes are driven by different principles than in ordinary "open" landscape. In contrast to the Pleistocene the character of erosion and weathering in the younger part of the