Population and Settlement Dynamics from the Gravettian to the Magdalenian

Andreas Maier

Friedrich-Alexander-Universität Erlangen-Nürnberg
Institut für Ur- und Frühgeschichte
Kochstraße 4/18
91054 Erlangen, Germany
and.maier@fau.de

Abstract: *Demographic parameters, such as the number and density of people in a region during a given time, are important factors for the understanding of social and cultural evolution, since they have influence, for instance, on innovation dynamics, or the vulnerability and resilience of societies. This paper presents the Cologne protocol for paleodemographic estimates and outlines the development of population and settlement dynamics from the Gravettian to the Magdalenian. A severe demographic crisis is found to have taken place during the Late Gravettian, when regional populations in northern latitudes and Central Europe broke down, probably as a consequence of the deteriorating environmental circumstances. A concomitant disturbance of long-distance communication probably led to a more localized structure of the social network, which together with the low number of people probably triggered not only the emergence of regional idiosyncrasies, but may have also fostered a loss in cultural complexity. A population reconsolidation is observed already during the Last Glacial Maximum which changed over into population growth during the Magdalenian, during which the resettlement of Central Europe took place. Two possible scenarios – a uni- and a bidirectional resettlement – are discussed against the background of the archaeological record.*
Keywords: *Gravettian, Last Glacial Maximum, Magdalenian, paleodemography, resettlement of Central Europe*

Populations- und Siedlungsdynamiken vom Gravettien bis zum Magdalénien

Zusammenfassung: Demographische Parameter, wie die Anzahl und Bevölkerungsdichte der Menschen in einer Region während einer bestimmten Zeit, sind wichtige Faktoren zum Verständnis sozialer und kulturelle Evolution, da sie beispielsweise Einfluss auf Innovationsdynamiken oder die Vulnerabilität und Resilienz von Gesellschaften haben. In diesem Aufsatz wird das Kölner Protokoll für paläodemographische Schätzungen vorgestellt, welches zunächst für sesshafte Gesellschaften entwickelt und später auf die Bedürfnisse mobiler Jäger-Sammler angepasst wurde. Anschließend wird die Entwicklung der Populations- und Siedlungsdynamik vom Gravettien zum Magdalénien umrissen. Während im frühen Gravettien ein weitreichendes Kommunikationsnetzwerk bestand und Funde wie der Obłazowa-Bumerang oder gebrannte Tonfiguren und Schnur-Abdrücke aus Pavlov I und Dolní Věstonice eine Phase technologischer Innovationen anzeigen, zeichnet sich für das späte Gravettien eine ernste demographische Krise ab, während der Regionalpopulationen in nördlichen Breiten und in Mitteleuropa zusammenbrachen, wahrscheinlich in Folge der sich stetig verschlechternden ökologischen Rahmenbedingungen. Eine damit einhergehende Störung der Fernkommunikation führte wahrscheinlich zu einer stärkeren räumlichen Beschränkung der sozialen Netzwerke, was, zusammen mit der geringen Anzahl an Personen, nicht nur möglicherweise die Entstehung regionaler Idiosynkrasien auslöste, sondern vielleicht auch einen Verlust an technologisch-kultureller Komplexität beförderte. Ein Wiedererstarken der Population kann bereits für das Letzte Glaziale Maximum beobachtet werden, das in ein Populationswachstum während des Magdalénien überging, in Zuge dessen die Wiederbesiedlung Mitteleuropas erfolgte. Zwei mögliche Szenarien – eine uni- und eine bidirektionale Wiederbesiedlung – werden vor dem Hintergrund des archäologischen Befundes diskutiert.
Schlagwörter: Gravettien, Letztes Glaziales Maximum, Magdalénien, Paläodemographie, Wiederbesiedlung Mitteleuropas

Introduction

Many aspects of cultural development, such as innovation dynamics (Shennan 2001; Richerson et al. 2009), cultural evolution and complexity (Vaesen 2012), subsistence strategies (Shennan 2009), or vulnerability and resilience of societies (Widlok et al. 2012) seem to be strongly linked to one major factor: demography. Thoughts about the relation between the development of human societies and demographic factors date back to antiquity and can be traced through the Middle Ages and Early Modern Age. At the end of the 18th century, Thomas R. Malthus (1798) took a decidedly pessimistic view in stating that "the power of population is indefinitely greater than the power in the earth to produce subsistence for man." This idea influenced Charles Darwin, who wrote in his autobiography (Darwin 1887, 83): "In October 1838 […] I happened to read […] 'Malthus on Population' and being well prepared to appreciate the struggle for existence […] it at once struck me that under these circumstances favourable variations would tend to be preserved, and unfavourable ones to be destroyed. The results of this would be the formation of a new species. Here then I had at last got a theory by which to work". During the 20th century, Ester Boserup controverted Malthus' view and is often cited as having said that "the power of ingenuity would always outmatch that of demand."

These prominent examples should suffice to highlight the importance of demography for social and cultural evolution. In order to discuss the initially mentioned points also for prehistory, it is necessary to develop means which allow for inferences about the demographic development from the archaeological record. Today exist a number of approaches, which can be roughly divided into two groups: 1) methods giving *relative* estimates about population increase and decline, and 2) methods giving *absolute* estimates about the number and density of people in a given area at a certain time. Examples of the former are inferences about a tenfold increase in population from Neanderthals to anatomically modern humans in Western Europe based on site and artifact counts as well as the spatial extent of sites (Mellars and French 2011; see Dogandžić and McPherron 2013 for detailed critique); the demographic development during the Upper Paleolithic in southwestern France based on similar proxies (French 2015); or boom-bust cycles during the mid-Holocene in Europe based on radiocarbon dates (Shennan et al. 2013). While being certainly valuable contributions to the topic, these approaches rather fall short when it comes to answering questions about minimal viable populations, or carrying capacity of landscapes and economic systems – in short, whenever the actual size of a population matters. Here, estimates about the actual numbers of people are indispensable. For the Upper Paleolithic, Bocquet-Appel and Demars (2000) and Bocquet-Appel et al. (2005) provided such estimates based on growth-rates calculated from site densities per period and area as well as ethnographic data. Many arguments have been brought forward in favor of and against the use of ethnographic data in Paleolithic research (e.g., van Reybrouck 2000; Binford 2001). Without going into detail, it should suffice to say that ethnographic data appear inevitable for absolute paleodemographic estimates and are considered a permissible source of information, provided that the data have been subject to thorough verification of sources.

In the following, the protocol for the presented demographic estimates will be explained in brief and the results will be presented for the Gravettian, the Last Glacial Maximum (LGM), and the Magdalenian. Subsequently, these results will be compared

with those by Bocquet-Appel et al. (2005), and consequences for the interpretation of the cultural development and settlement dynamics will be discussed.

Material and Methods

The estimates given below are based on databases compiled during extensive surveys of the literature (for the Gravettian: Maier and Zimmermann 2016; for the LGM: Maier and Zimmermann 2015; for the Magdalenian: Kretschmer 2015; Maier 2015).

The Cologne protocol for demographic estimates has initially been developed for sedentary societies (Zimmermann et al. 2005, 2009a, b; Hilpert et al. 2008; Wendt et al. 2012) and subsequently adapted to mobile hunter-gatherers (Kretschmer 2015). In brief, it is based on two areal values and ethnographic data (Fig. 1). The first areal value is the size of so-called settlement areas. These settlement areas are thought to represent core areas of hunter-gatherer activities, which can be delimited against those areas of only infrequent and ephemeral use or completely unexploited areas. The basic assumption for well-researched areas, such as Western or Central Europe, is that gaps in the distribution of sites have to be taken seriously, because they mirror to a certain extent prehistoric reality in contrast to being merely a result of insufficient research intensity or taphonomic processes (cf. Bocquet-Appel et al. 2005; Maier et al. 2016). For regions where information about site distribution is too sparse or must be considered unreliable, such as the Pannonian Basin, which – due to extensive sediment cover – cannot be assessed, no estimates are calculated. Delimiting settlement areas against their periphery is done based on site density. Using site density, in contrast to number of sites used in many other approaches, has the advantage that the method is fairly robust against missing values (sites not recorded in the database or yet undetected). Site density is measured using Largest Empty Circles (LEC; Preparata and Shamos 1988). To do so, all sites are plotted on a map and Thiessen polygons are calculated around them. Then, LEC are constructed, which center on the polygon's vertices and whose contours traverse the closest three sites around each vertex. The LECs radii (small in dense site clusters, large in scattered site distributions) then serve as a measure of site density of the observed distribution. The density values thus obtained are subsequently interpolated using kriging (Haas and Viallix 1976), resulting in continuous density values for the entire map section, which are then transformed into isolines comprising areas of equal site densities (cf. Malmer 1962). Eventually, one isoline is selected which is deemed optimal in describing the extent of the settlement areas in the study area. This so-called Optimal Isoline (OI) is selected using heuristic measures, such as the maximum increase of space (Zimmermann et al. 2005, 53f.) or the inclusion of more than 75% of the sites while circumscribing the delimited site clusters as tightly as possible. All areas encircled by the Optimal Isoline are then considered to represent settlement areas.

The second areal value is derived from raw material polygons. Raw material polygons are constructed using information about the acquisition patterns of lithic raw materials. Taking the known sources of lithic materials present at a certain site, the catchment of the lithic acquisition area is determined by drawing a polygon whose edges correspond with the raw material sources and, in cases where raw material was not acquired from all directions, the site itself. Given the well-founded assumption of embedded procurement of lithic raw materials (cf. Binford 1979, 259), these polygons are thought to represent
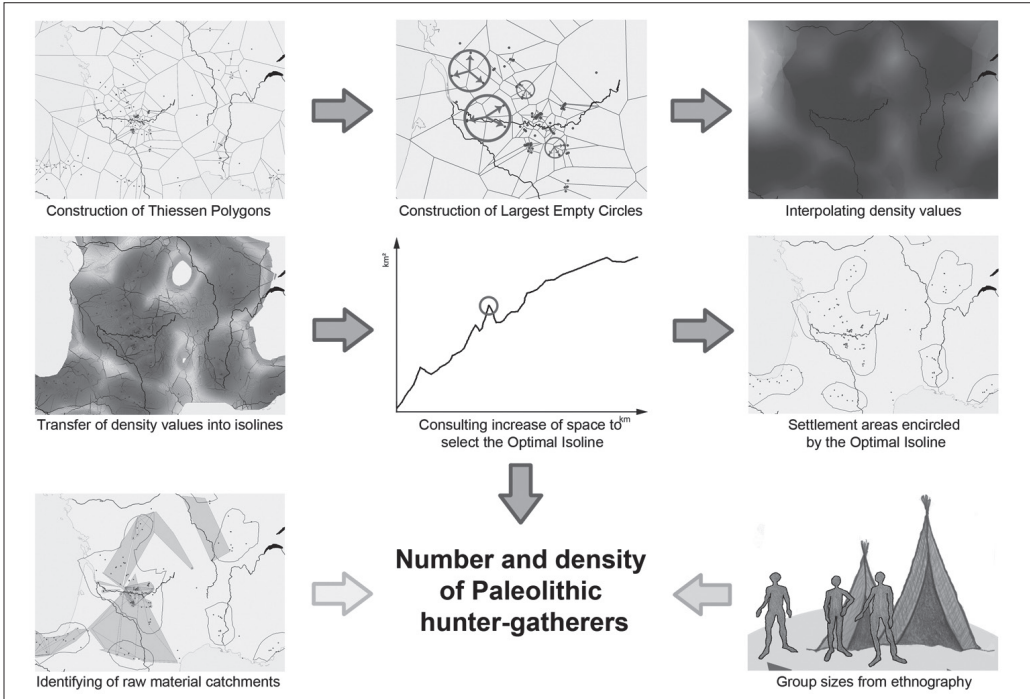
Fig. 1: Overview of the different steps used in the Cologne protocol to estimate the number and density of Paleolithic hunter-gatherers (from Maier and Zimmermann 2017).

minimum estimates for the catchment area of their respective sites. Under the assumption of non-overlapping territories during the Upper Paleolithic (resources are clustered and predictable; cf. Kelly 1995, 161 ff.) it is expected that small raw material polygons are indicative of a larger number of groups exploiting the same region, whereas large polygons indicate few groups. For the estimates, the medium as well as the 1st and 3rd quartile (for estimation range) are calculated, taking into account all available polygons of sites within a certain settlement area.

The basic (uniformitarian) assumption for the incorporation of ethnographic data is that under similar climatic conditions, hunter-gatherer societies will develop similar subsistence strategies and sizes of social organizational units. With reference to the Upper Paleolithic record, 16 non-mounted hunter-gatherer societies from wintery cold steppe environments with a subsistence based on $\geq 50\%$ terrestrial animals, $\leq 30\%$ fishing, and $\leq 30\%$ gathering of plants have been selected and checked for information on group sizes. Since the spatial signals from raw material polygons are thought to be rather in accordance with groups during their most aggregated phase in a fission-fusion cycle, these values were chosen for further use (see Kretschmer 2015 for more information). The median value of people in an aggregated group has been found to be 43. This number is thus used in the subsequent calculations. It has to be kept in mind that most ethnographic observations were recorded when the hunter-gatherer groups under study had already been marginalized by expanding settlers. Therefore, the likewise available

(derived) information on people per km² (as used, e.g., by Bocquet-Appel et al. 2005), are avoided and only direct counts of people per group are considered, because this data is deemed more reliable.

The estimates are then calculated as follows. To estimate the number of groups (1) within a settlement area, the area encircled by the corresponding OI is divided by the median as well as the 1st and 3rd quartile of the area covered by the raw material polygons of that settlement area. This results in a median as well as a minimum and maximum estimate of the number of groups within a settlement area. Population size (2) is calculated by multiplying the number of groups with the group size (here: 43). To calculate population densities within a settlement area (called local population density) or within a map section (called global population density) the population size is divided by the km² either within the OI (3) or of the map section (4).

$$\text{n groups} = \frac{km^2 \text{ within settlement areas (Optimal Isoline)}}{\text{Quartile (Q1;Q2; Q3) of raw material polygons}} \tag{1}$$

$$\text{population size} = \text{n groups} \times \text{group size (43)} \tag{2}$$

$$\text{population density within settlement area} = \frac{\text{population size}}{km^2 \text{ within settlement areas (Optimal Isoline)}} \tag{3}$$

$$\text{population density within settlement area} = \frac{\text{population size}}{km^2 \text{ within map section}} \tag{4}$$

Results

The distribution of sites and settlement areas as well as the corresponding raw material polygons are shown in Fig. 2. For the demographic estimates, the Gravettian has been subdivided into two equally long periods, an older (P1, 33,000-29,000 calBP) and a younger one (P2, 29,000-25,000 calBP). For P1, the estimated number of people living in Western and Central Europe ranges between 1700 and 3700 with a median of 2800 and the largest number of people (ca. 800) living in the settlement area of southwestern France. The population density ranges within the settlement areas from 2.7 to 0.3 persons per 100 km² (median often around 1.4) and within the entire investigated area (ca. 2 million km²) between 0.18 and 0.08 persons per 100 km² (median around 0.14). For P2, a sharp decline is observable in the whole investigated area and estimates range between 1500 and 700 people with a median value of 1000 for the entire investigated area (Fig. 3). The largest number of people within a settlement area can still be found in southwestern France, but the numbers have dropped to about 300 people. In Great Britain, Belgium and Germany, the number of estimated persons drops to 0. The population density drops within the settlement areas from 1.9 to 0.5 persons per 100 km² (median around 0.8) and 0.08 to 0.03 persons per 100 km² (median 0.05) for the entire investigated area. For more details on the subdivision and regionally differentiated results see Maier and Zimmermann (2017).
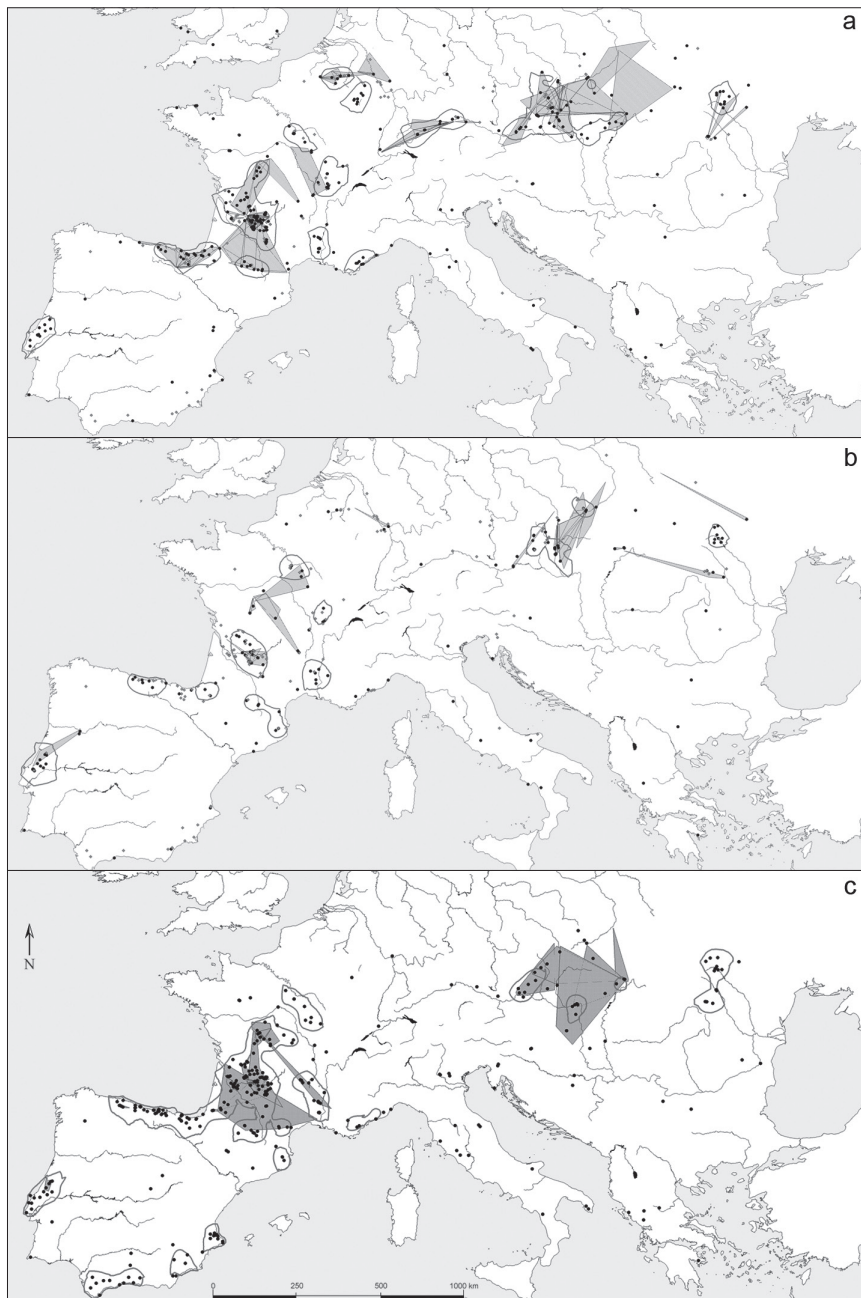
Fig. 2: *Development of settlement dynamics during the Early Gravettian (a), Late Gravettian (b), and Last Glacial Maximum (c). Black dots: sites attributed radiometrically or typologically to a period; grey squares: sites lacking chronological attribution (excluded from calculations); grey polygons: raw material catchments; grey lines (Optimal Isolines) indicate settlement areas (after Maier et al. 2016; Maier and Zimmermann 2017). Maps and calculations in MapInfo Professional v.10.*

The estimates for the Last Glacial Maximum (ca. 25,000-20,000 calBP) range between 1300 and 6300 people with a median value of about 3100 and density values range between 2.3 and 0.5 persons per 100 km² (median 1.4) within the settlement areas and 0.5 to 0.1 persons per 100 km² (median 0.2) for the entire investigated area of 1.2 million km². During the LGM, southwestern France and northern Spain are comprised within a single OI. In this settlement area of about 135,000 km², an estimated number of 1900 people with a density of 1.4 persons per 100 km² have been living, by far the highest values in the whole investigated area (for more details see Maier et al. 2016).

Numbers for the Magdalenian are taken from Kretschmer (2015) and range between 4900 and 10700 persons in total, with a median value of 7700, while the density ranges between 1.6 and 3.6 persons per 100 km² (median of 2.6) within the settlement areas and between 0.2 and 0.5 persons per 100 km² (median of 0.3) within the map section (2.3 million km²).
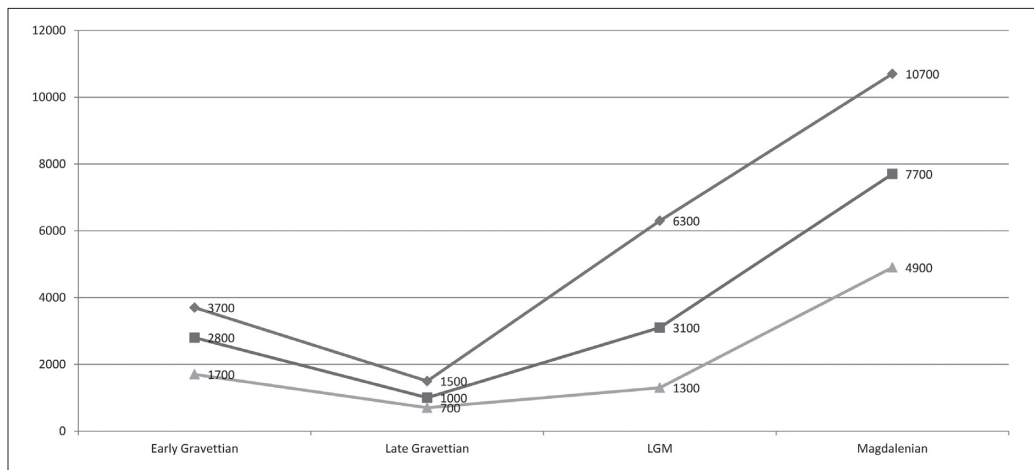

Fig. 3: Estimated total number of people (y-axis) for Western and Central Europe during the Early and Late Gravettian (data from Maier and Zimmermann 2017), Last Glacial Maximum (data from Maier et al. 2016), and Magdalenian (data from Kretschmer 2015).

Discussion

The only studies giving comparable absolute estimates for both the total number and density of people for the Upper Paleolithic in Europe are those by Bocquet-Appel and Demars (2000) and Bocquet-Appel et al. (2005). Both studies gave comparable results, although the former estimated higher densities and more people (if the median estimates of the latter are taken for comparison). These differences are mainly due to divergences in the conception of the area occupied by hunter-gatherers. Generally speaking, Bocquet-Appel et al. (2005) gave more importance to the unoccupied areas. In comparison to the presented estimates, a similar offset can be observed. For the Gravettian and the LGM, the estimates by Bocquet-Appel et al. (2005) for the lower quartile and median are in good accordance, whereas for the Magdalenian only the lower quartile is still in the range of the results of this study. The values for the upper quartile, however, exceed the presented estimates roughly by the factor 7. This discrepancy is mainly

due to the fact that while accounting for fluctuations in site-distributions on a large scale, medium-scale patterns of site clusters and empty areas are largely ignored. This becomes particularly evident with regard to the Magdalenian, where the entire area of Western and western Central Europe is considered a continuous territory. With regard to the presented results this leads to a clear over-estimate of the prehistoric situation. The lower population values are thus deemed more reliable.

Probably the most conspicuous result of the presented estimates is the sharp population decline during the Late Gravettian (see above) followed by a reconsolidation during the LGM. A population growth from the Gravettian to the LGM has already been estimated by Bocquet-Appel and Demars (2000) and Bocquet-Appel et al. (2005). In their study, the chronological resolution (the Gravettian was estimated as a whole) did not allow for the detection of the population decline. Relative studies with higher resolution, although for smaller areas such as southwestern France, have likewise postulated a population decline during the Late Gravettian followed by an increase during the LGM (e.g., French 2015). What may seem counter-intuitive at first becomes understandable against the background of the climatic development of that time (Fig. 4). The Gravettian was a period of continuous climatic deterioration. Temperatures, as indicated in the $\delta^{18}O$-values of the Greenland ice-core record (Björck et al. 1998; Rasmussen et al. 2006), were most of the time at the lowest level of the entire Upper Paleolithic. Additionally, the solar insolation (i.e., the solar energy available per m²) declined constantly (Ji et al. 2006),
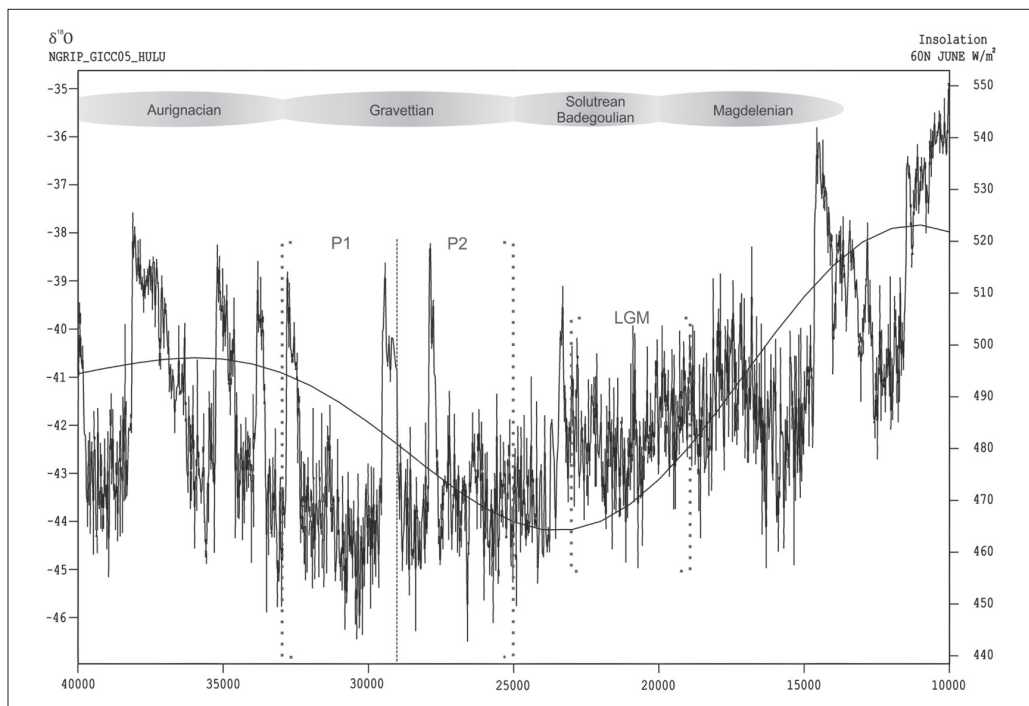
Fig. 4: *The climatic conditions during the Gravettian and the LGM (from Maier and Zimmermann 2017). Temperatures are indicated by the $\delta^{18}O$ curve. Insolation (smooth curve) is given in watts per square meter for 60°N. Time on the x-axis is given as calBP. Data from CalPal 2012 (Weninger et al. 2012).*

probably with pronounced effects on net primary production and, as a consequence, the animal biomass, particularly in northern latitudes. During the LGM (*sensu* Mix et al. 2001), i.e. the period of the maximum extent of the glaciers, temperatures had already risen again to a higher level and were rather constant, while the solar insolation kept increasing. From a climatic point of view, the LGM (often misunderstood as the coldest period) was thus much more favorable than the Late Gravettian.

Another question often connected to the disappearance of hunter-gatherers in the northern latitudes is whether or not they migrated to the south when faced with climatic deterioration. In the case of such migration scenarios, a population increase in the more southern habitats is to be expected. However, the archaeological record does not show any signs of such movements of populations. To the contrary, populations declined everywhere in Europe. This pattern indicates more a breakdown and extinction of the hunter-gatherer communities in the north rather than migration to the south. With regard to the total estimated number of people, it seems even likely that the meta-population in Europe reached a critically low number. It is difficult to find reliable information on the size of a minimal viable population (MVP) for humans. A comprehensive review of this subject (Smith 2014) makes it likely that about 1500 people (770 in the reproductive age) are sufficient to ensure the survival of a population, and it seems that for shorter periods even lower numbers might still be enough to counteract the effects of inbreeding (Hey 2005; Smith 2014; Traill et al. 2010).

While being able to maintain a viable population, it seems that the demographic decline coincided with a disturbance of the long-distance connections within the communication network. A loss of long-distance connections leads to a more localized network structure, within which information travels less efficiently (Bentley and Maschner 2008). A small population, which is disaggregated in many local networks, seems thus to be more prone to degrading effects such as drift (Neiman 1995) and eventually to a loss in cultural complexity (e.g., Richerson et al. 2009; Premo and Kuhn 2010; Roebroeks et al. 2011). For the Gravettian, it is noticeable that almost all the evidence of high technological standards, such as the Obłazowa boomerang (Valde-Nowak et al. 1987) or ceramics, cordage items, and basketry from Pavlov I and Dolní Věstonice (Soffer 2000; Soffer and Adovasio 2004) are related to the Early Gravettian, while the Late Gravettian seems to be rather a phase of impoverishment of the typological and technological spectrum (e.g., Svoboda 2007, 207).

As already stated above, the LGM was – contrary to common perception – a time of population reconsolidation. However, the strong demographic decline during the preceding period and the concomitant population breakdown in the northern latitudes probably led to distortions in the long-distance network structure of that time. As a consequence, two hunter-gatherer communities can be observed during the LGM, located east and west of the Alps, clearly separated spatially by an area of about 1000 km in diameter from where almost no sites are reported. A striking difference between the western and the eastern site cluster is that raw material polygons in the east are much larger than those observed in the west. This may point to a different subsistence pattern and to a different environmental adaption. In order to check for different environmental preferences, the sites are plotted against a climatic model of the LGM. Subsequently, a regression of the observable climatic preferences as indicated by the location of sites for both,

the western and the eastern site cluster is calculated (for details see Maier et al. 2016). The results show a surprisingly clear differentiation into two almost mutually exclusive
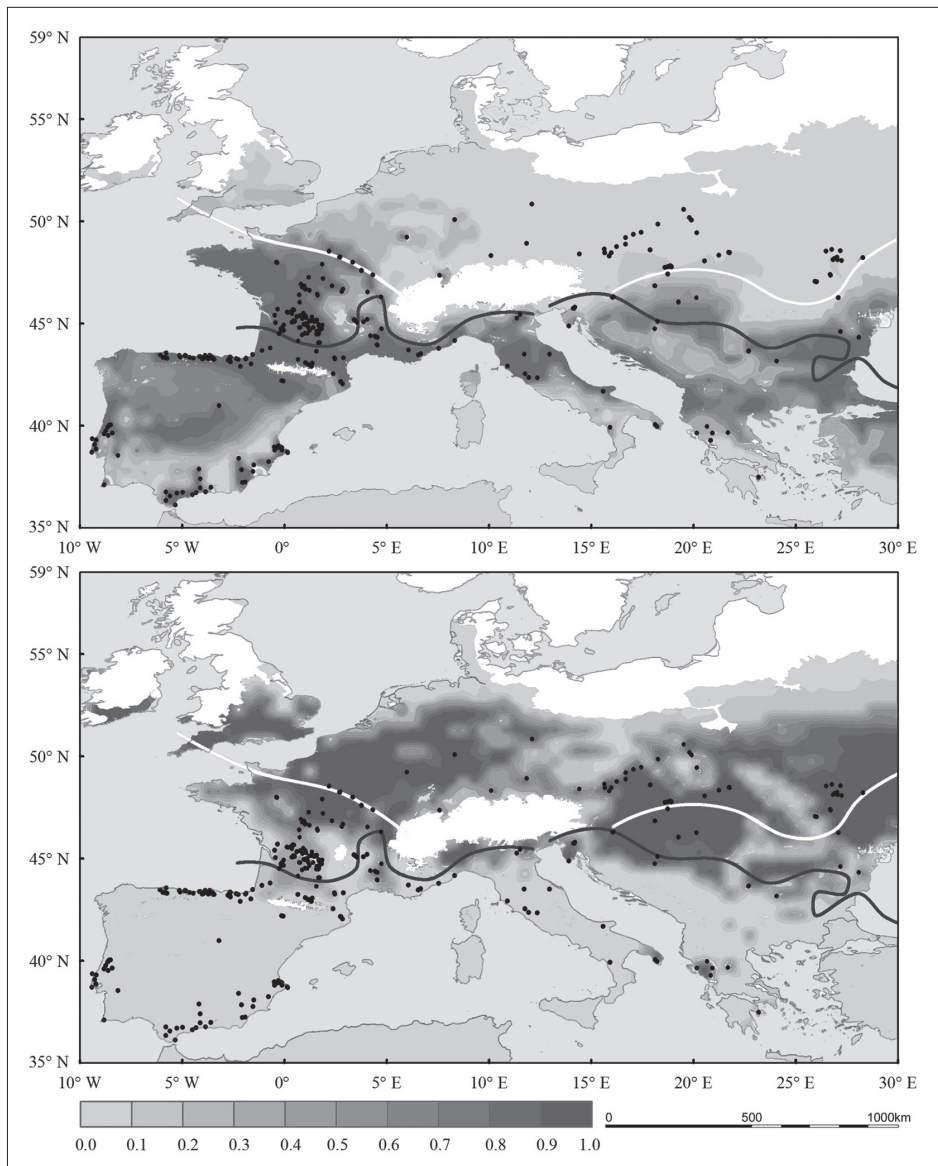
Fig. 5: *Preferred (dark grey) and avoided (light grey) areas of hunter-gatherers in Western (upper part) and Central Europe (lower part) during the Last Glacial Maximum as calculated from modeled temperature, rainfall and elevation values using a regression model from the observed site locations (Maier et al. 2016). The white line indicates the southern border of continuous permafrost (redrawn after Baulin et al. 1992). The dark grey line indicates the northern timberline (redrawn after Grichuk 1992). The white areas mark the extent of glaciers. The map uses the modern shoreline, since it represents the limit of archaeological observations. Maps in ArcGIS 9.*

adaptions (Fig. 5). While the sites in the west show a clear preference for areas south of the permafrost line and an indifference towards the tree-line, the sites in the east are located preferentially north of both the tree line and the permafrost line. It thus seems that hunter-gatherers in the west were adapted to cold-temperate conditions, whereas the community in the east was adapted to open landscapes in (contrary to Banks et al. 2008) colder environments, where larger distances had to be covered in order to fulfill the needs of subsistence.

Whether or not this difference in environmental adaption also coincided with a lack of communication between both groups is a subject of ongoing debate. While the traditional view holds that there was a period without contact between the hunter-gatherer communities in Western and Central Europe lasting for roughly 10,000 years from the end of the Gravettian until the resettlement of Central Europe during the Magdalenian (e.g., Bosinski 1990; Svoboda et al. 1996), there is today continuously accumulating evidence that contact had been re-established much earlier, if it really had ceased at all (e.g., Terberger and Street 2002). Such contact may be indicated by the advent of shouldered points in Western Europe during the Solutrean (Tiffagom 2006) around maybe as early as 25,000 calBP (Cascalheira and Bicho 2015), while this type of point is present in Central Europe since about 29,000 calBP (Svoboda 2007). Strong similarities between Badegoulian assemblages and inventories of the same age from Central Europe, such as Kammern-Grubgraben (Montet-White 1994; Neugebauer-Maresch et al. 2016) likewise indicate contact between both groups. This, in turn, has consequences for the traditional view of the resettlement process of Central Europe during the post-LGM period. Here, textbooks convey the scenario of a unidirectional resettlement process from the Franco-Cantabrian region in the West up the Bug River in the east. However, such a reading of the archaeological record is at odds with several observations of the period in question. In the following, I will thus formulate two expectations of what the archaeological record should or should not look like if a unidirectional expansion had taken place, and compare these expectations with the actual evidence from the archaeological record.

Expectation 1

In case of a unidirectional expansion, the groups at the expanding fringe of the population should maintain close contact with their group of origin, mainly for two reasons. First, the expanding party pushes forward into previously unsettled and therefore unknown regions. Given that these regions became habitable again shortly before, and due to their location at comparatively northern latitudes, even slight changes in the climatic setting might have strong effects on their carrying capacity. These regions thus constitute high-risk environments, and the potential to encounter subsistence problems is great. Second, groups at the fringe of a population need to turn towards its center to find reproductive partners. Eventually this should result in close contact which, in turn, should be visible in the archaeological record as an intensive exchange of concepts and goods, resulting in a rather homogeneous distribution with only gradually shifting trends in quantity and style. Sharp boundaries between regions are therefore not in accordance with the expectation. For the same reasons, complex packages of concepts, which occur in the heartland of the expanding population and are thought to be characteristic of this group, should not occur at sites which are located far away from the presumed front of the expansion.

Lithic raw materials

As explained above, the catchment pattern of the acquisition of lithic raw materials is thought to mirror the area used by hunter-gatherer groups during their daily activities. Under the assumption of non-overlapping territories (see above), overlapping catchments should thus indicate the common exploitation of an area by a single regional group. Looking at the raw material acquisition pattern of the Central European Magdalenian, five regional groups can be identified (Fig. 6a): 1) a Circum-Jurassic Group in Eastern France and Switzerland, 2) a Danube Group between the Randen and Regensburg area, 3) a Meuse-Rhine Group between the Ardennes and the Neuwied Basin, 4) a Vltava-Saale Group in Eastern Germany and Bohemia, and 5) a Polish-Moravian Group in Moravia and southern Poland (for details see Maier 2015). Regionalization in itself neither contradicts nor corroborates the idea of a uni- or bidirectional expansion, since it can occur in both scenarios. However, a comparison of inter-group differences can be quite revealing in this regard.

Mollusk shells

Fossil and sub-recent mollusk shells have been transported over large distances of up to about 800 km as the crow flies. In contrast to lithic raw material, they thus do not mirror regional movements within a group's territory, but indicate large-scale contacts between regional groups. Interestingly, the transport pattern indicates a clear boundary (Fig. 6b). While the three regional groups in the western part (1-3) participate in an intensive exchange network which spans the Atlantic and Mediterranean coast as well as the Paris basin, the two groups in the eastern part have no share in it. Apart from an assemblage of shells found at the site of Kniegrotte and a specimen of *Turritella communis* from Gera Zwötzen (Schafgraben), probably originating from the Mainz tertiary basin and the Atlantic or Mediterranean coast (Höck 2000; Küßner 2009), the acquisition pattern of mollusk shells is restricted to local and regional occurrences. Such a clear boundary is at odds with Expectation 1 and rather speaks in favor of two distinct communication networks.

Typological composition

When the presence or absence of single tool types within regional groups is evaluated, the resulting pattern is indifferent, since all types occur in all groups. When types are mapped according to their percentage values, some trends become visible (cf. Maier 2015). However, these trends do not allow for a clear regional distinction. For an in-depth evaluation, a Linear Discriminate Analysis (LDA: e.g., Legendre and Legendre 2003) has been performed. In brief, a LDA tests an *a priori* assignment of elements (here: the assemblages) to a given set of groups (here: 5 regional groups) against an independent variable (here: the typological composition of the assemblages). The resulting *a posteriori* assignment is then compared with the *a priori* assignment. The closer the *a posteriori* assignment matches the *a priori* assignment, the more credence is lent to the latter. In case of the Central European Magdalenian, 76% of the *a posteriori* assignments match the *a priori* assignment. Given the weak spatial signals arising from a mapping of presence/absence or percentage values, this clear result is rather surprising and strongly

Fig. 6: a) The five regional groups of the Central European Magdalenian as inferred from raw material catchments (grey lines); 1: Circum-Jurassic Group, 2: Danube Group, 3: Meuse-Rhine Group, 4: Vltava-Saale Group, 5: Polish-Moravian Group; b) The five regional groups against the transport pattern of fossil and sub-recent mollusk shells (grey lines); c) Results of the Linear Discriminant Analysis. Numbers indicate the position of the group's centroids and correspond to the numbering of the regional groups; d) distribution of sites attributed to the Magdalenian "à navettes." Maps a-c in MapInfo Professional v.10, Map d in ArcGIS 9, LDA scatter plot in R (R Development Core Team 2011) version 2.13.0. with the function "candisc" of the package "candisc" (Friendly and Fox 2011). Figures after Maier 2017.

supports the assignments of sites to the five regional groups. Even more remarkable is the fact that the typological variation within the three western groups (1-3) is best explained by a single straight line, whereas the variation in the two eastern groups (4 and 5) is best explained by a second line running perpendicular to the former (Fig. 6c; for more details see Maier 2015). This, again, indicates a clear boundary between the western and the eastern regional groups.

Complex concept packages

Single characteristics of archaeological cultures can occur at distant places without any contact between the producing groups as a result of autochthonous developments, either because of chance or strong physical and functional restrictions, as is the case for lithic tools. However, a contemporaneous occurrence of an entire set of very distinct functional and artistic features exceeds the explanatory power of chance and is very likely the result of a movement of people or communication between groups.

Some sites, roughly dated between 18,500 and 18,000 calBP, can be attributed to the Magdalenian facies called "à navettes" which is characterized by a distinct set of functional and artistic characteristics (Allain et al. 1985). The sites related to this facies are located mainly in France (Fig. 6d). Here, the easternmost site is the Grotte Grappin at Arlay (Cupillard and Welté 2006), located in the French Jura. Further to the east, there is only one site attributed to this facies, Maszycka Cave (Kozłowski et al. 1995). This site is located in the Polish Jura, at a distance of about 1300 km from Grotte Arlay as the crow flies, without any other Magdalenian site whatsoever in between. If this observation is explained within the scenario of a uni-directional expansion, one must assume that a small group of people separated from their group of origin and travelled 1300 km into an unknown and unpopulated area without leaving any signs of their presence until they arrived in the Polish Jura, where they disappeared shortly after. Such an assumption seems highly unlikely. The observed pattern is thus much better explained by assuming two hunter-gatherer populations, one in Western and the other one in Central Europe, who knew of each other's existence and maintained contact through a small number of far-travelling individuals. Since these individuals presumably travelled fast with few short-term stops and with a known destination (rather than entering unknown areas), they did not leave archaeologically detectable traces in the area between both communities, but ensured the mutual exchange of ideas and maybe even objects (see Maier 2017).

Expectation 2

In case of a unidirectional expansion, the respective oldest sites should become gradually younger in the direction of expansion.

Looking at the spatiotemporal gradient of the respective oldest Magdalenian sites from west to east, there is indeed a clear trend from the Franco-Cantabrian region via Eastern France and Switzerland up to the Meuse-Rhine area, the Swabian and Franconian Alb, and Eastern Germany, where Magdalenian hunter-gatherers had arrived at around 16,000 calBP. If only this section of the Magdalenian record is taken into consideration, there seems to be a good fit with the unidirectional scenario. However, further to the east the respective oldest sites become older again. This observation is strongly

at odds with a unidirectional resettlement hypothesis and in much better accord with a bidirectional settlement process (Fig. 7). In this scenario, hunter-gatherers expanded from Franco-Cantabria up to the Meuse-Rhine area as well as the Swabian and Franconian Alb, while a second population expanded over southern Poland, Moravia and Bohemia up to Eastern Germany (for more details see Maier 2015).
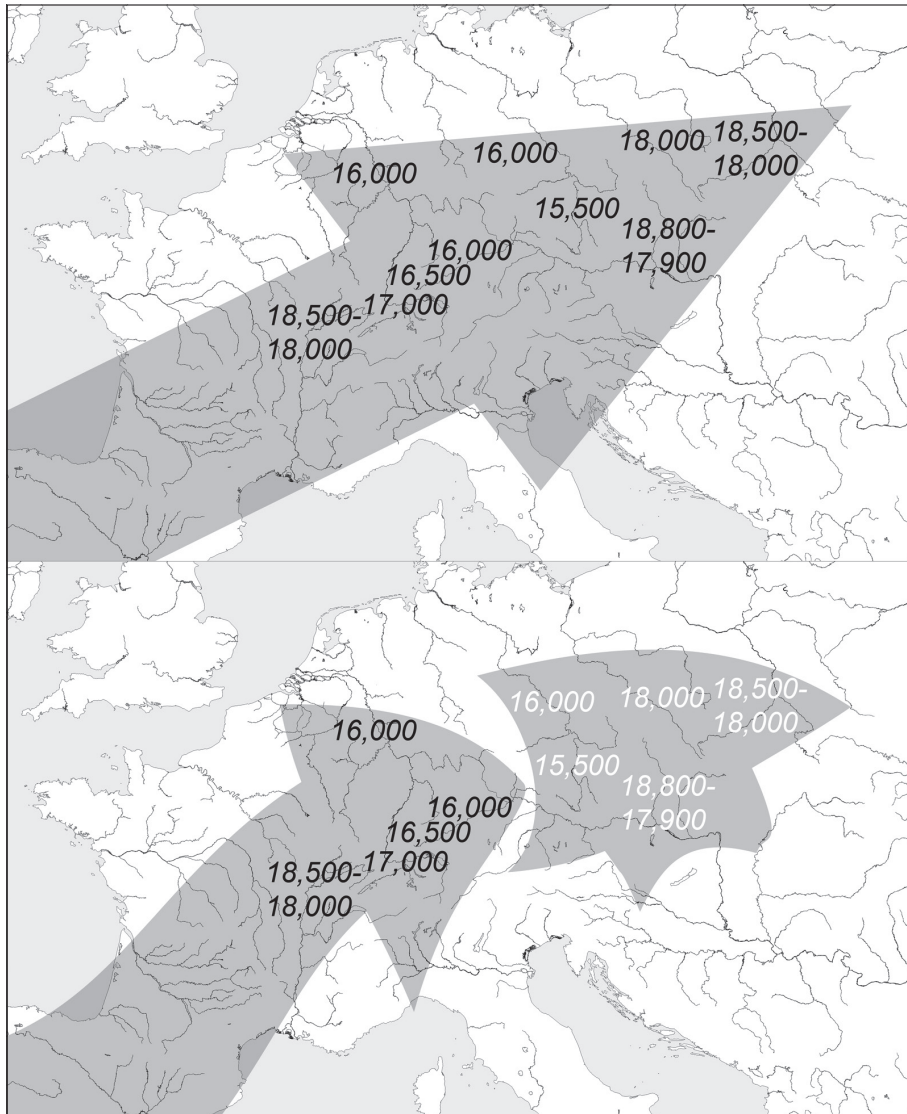
Fig. 7: Two scenarios for the resettlement of Central Europe during the Magdalenian. Numbers indicate the oldest Magdalenian ^{14}C-dates per region, given as calBP. Upper part: uni-directional expansion from the Franco-Cantabrian region up to the Bug River. Lower Part: bidirectional expansion from the Franco-Cantabrian region up to the Meuse-Rhine area and the Swabian and Franconian Alb as well as from Central Europe up to Eastern Germany. Maps in MapInfo Professional v.10.

Eventually, it can be stated that the distribution pattern of mollusk shells as well as a LDA of the typological composition of the assemblages indicate a clear boundary between a western and an eastern supra-regional group. This finding is in sharp contrast to Expectation 1. Moreover, the occurrence of a characteristic set of objects attributable to the Magdalenian "à navettes" in the Polish Jura is much better explained under the assumption of two communicating populations than of a unidirectional expansion. The same accounts for the spatiotemporal pattern of the Magdalenian recolonization, which does not comply with Expectation 2.

Conclusion

During the Gravettian, hunter-gatherers in Europe experienced a pronounced demographic crisis, in the course of which local populations in the northern latitudes and western Central Europe broke down. The associated disturbances of long-distance connections led to a stronger localization of social networks. Together, both effects probably led to an impoverishment of the technological spectrum and the overall cultural complexity. The thus-impaired communication between hunter-gatherer communities in Western and Central Europe fostered the development of regional idiosyncrasies, which find expression in the many small-scale entities defined in the archaeological literature for the LGM, such as the Badegoulian, the Salpetrian, Arenian, Sagvarian, Kasovian, or Grubgrabian. However, similarities in the technological and typological composition of the assemblages attributed to these entities indicate that contact was re-established already during the LGM or had never ceased completely. The recolonization of Central Europe after the LGM then took place as a bidirectional process. At around 16,000 calBP hunter-gather groups expanding from the west had reached the Meuse-Rhine area as well as the Swabian and Franconian Alb, while groups expanding from the east had reached the rivers of Saale and Weiße Elster. A revitalization of long-distance connections in the European networks eventually led to a decrease of regional idiosyncrasies and greater overall similarity in the assemblages between 16,000 and 14,000 calBP.

Acknowledgments

References

Allain, J., Desbrosse, R., Kozłowski, J. K., Rigaud, A., Jeannet, M., and Leroi-Gourhan, A. 1985: Le Magda-
    lénien à Navettes. Gallia Préhistoire 28, 37–124.
Banks, W. E., d'Errico, F., Peterson, A.T., Vanhaeren, M., Kageyama, M., Sepulchre, P., Ramsteim, G., Jost,
    A., and Lunt, D. 2008: Human ecological niches and ranges during the LGM in Europe derived from an
    application of eco-cultural niche modeling. Journal of Archaeological Science 35, 481–491.

Baulin, V. V., Danilova, N. S., Nechayev, V. P., Péwé, T. L., and Velichko, A. A. 1992: Glaciation and perma-frost – maximum cooling of the last glaciation. In: B. Frenzel, M. Pécsi, and A. A. Velichko (eds.), Atlas of Paleoclimates and Paleoenvironments of the Northern Hemisphere – Late Pleistocene – Holocene. Stuttgart: Gustav Fischer Verlag/Budapest: Geographical Research Institute, 49.

Bentley, R. A. and Maschner, H. D. G. 2008: Complexity Theory. In: R. A. Bentley, H. D. G. Maschner, and C. Chippindale (eds.), Handbook of Archaeological Theories. Lanham, MD: Rowman and Littlefield, 245–270.

Binford, L. R. 1979: Organization and formation processes: looking at curated technologies. Journal of Anthropological Research 35, 255–273.

Binford, L. R. 2001: Constructing Frames of Reference. An Analytical Method for Archaeological Theory Building Using Ethnographic and Environmental Data Sets. Berkeley: University of California Press.

Björck, S., Walker, M. J. C., Cwynar, L. C., Johnsen, S., Knudsen, K.-L., Lowe, J. J., and Wohlfahrt, B. 1998: An event stratigraphy for the Last Termination in the North Atlantic region based on the Greenland ice-core record: a proposal by the INTIMATE group. Journal of Quaternary Science 13, 283–292.

Bocquet-Appel, J.-P. and Demars, P.-Y. 2000: Population kinetics in the Upper Palaeolithic in Western Europe. Journal of Archaeological Science 27, 551–570.

Bocquet-Appel, J.-P., Demars, P.-Y., Noiret, L., and Dobrowsky, D. 2005: Estimates of Upper Palaeolithic meta-population size in Europe from archaeological data. Journal of Archaeological Science 32, 1656-1668.

Bosinski, G. 1990: Homo sapiens. L'histoire des chasseurs du Paléolithique supérieur en Europe (40 000–10 000 avant J.-C.). Paris: éditions errance.

Cascalheira, J. and Bicho, N. 2015: On the Chronological Structure of the Solutrean in Southern Iberia. PLOS ONE 10(9): e0137308.

Cupillard, C. and Welté, A.-C. 2006: Le Magdalénien de la grotte "Grappin" à Arlay (Jura, France): nouveaux regards. L'Anthropologie 110, 624–683.

Darwin, F. (ed.) 1887: The life and letters of Charles Darwin, including an autobiographical chapter. Volume 1. London: John Murray.

Dogandžić, T. and McPherron, S. P. 2013: Demography and the demise of the Neandertals: A comment on 'Tenfold population increase in Western Europe at the Neandertal-to-modern-human transition'. Journal of Human Evolution 64, 311–313.

French, J. C. 2015: The demography of the Upper Palaeolithic hunter–gatherers of Southwestern France: A multi-proxy approach using archaeological data. Journal of Anthropological Archaeology 39, 193–209.

Friendly, M. and Fox, J. 2011: candisc: Generalized canonical discriminant function analysis. R package version 0.5-21. http://CRAN.R-project.org/package=candisc.

Grichuk, V. P. 1992: Main types of vegetation (ecosystems) for the maximum cooling of the Last Glaciation. In: B. Frenzel, M. Pécsi, and A. A. Velichko (eds.), Atlas of Paleoclimates and Paleoenvironments of the Northern Hemisphere – Late Pleistocene – Holocene. Stuttgart: Gustav Fischer Verlag/Budapest: Geographical Research Institute, 123–124.

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

Hey, J. 2005: On the Number of New World Founders: A Population Genetic Portrait of the Peopling of the Americas. PLoS Biology 3(6), 965–975.

Hilpert, J., Wendt, K. P., and Zimmermann, A. 2008: A Hierarchical Model of Scale Levels for Estimations of Population Densities. In: A. Posluschny, K. Lambers, and I. Herzog (eds.), Layers of Perception. Proceedings of the 35th International Conference on Computer Applications and Quantitative Methods in Archaeology (CAA), Berlin, Germany, April 2-6, 2007. Kolloquien zur Vor- und Frühgeschichte 10. Bonn: Dr. Rudolf Habelt, 245–251.

Höck, C. 2000: Das Magdalénien der Kniegrotte. Ein Höhlenfundplatz bei Döbritz, Saale-Orla-Kreis. Stuttgart: Konrad Theiss Verlag.

Ji, J., Balsam, W., Chen, X., Chen, J., Chen, Y., and Wang, H. 2006: Rate of solar insolation change and the glacial/interglacial transition. Geophysical Research Letters 33, L04706.

Kelly, R. L. 1995: The Foraging Spectrum. Diversity in Hunter-Gatherer Lifeways. Washington and London: Smithsonian Institution Press.

Kretschmer, I. 2015: Demographische Untersuchungen zu Bevölkerungsdichten, Mobilität und Landnutzung im späten Jungpaläolithikum. Kölner Studien zur Prähistorischen Archäologie 6. Rahden/Westf.: Verlag Marie Leidorf.

Kozłowski, S. K., Sachse-Kozłowska, E., Marshack, A., Madeyska, T., Kierdorf, H., Lasota-Moskalewska, A., Jakubowski, G., Winiarska-Kabacińska, M., Kapica, Z., and Wierciński, A. 1995: Maszycka Cave, a Magdalenian Site in Southern Poland. Jahrbuch des Römisch-Germanischen Zentralmuseums 40/1993, 115–252.

Küßner, M. 2009: Die späte Altsteinzeit im Einzugsgebiet der Saale. Untersuchungen an ausgewählten Fundstellen. Weimar: Beier & Beran.

Legendre, P. and Legendre, L. F. J. 2003: Numerical Ecology. Amsterdam: Elsevier.

Maier, A. 2015. The Central European Magdalenian. Regional Diversity and Internal Variability. Vertebrate Paleobiology and Paleoanthropology Series. Dordrecht: Springer.

Maier, A. 2017: Expansion or communication? The phenomenon of the Magdalenian à navettes from a Central European point of view. In: C. Bourdier, L. Chehmana, R. Malgarini, and M. Połtowicz-Bobak (eds.), L'essor du Magdalénien. Aspects culturels, symboliques et techniques des faciès à Navettes et à Lussac-Angles. Actes de la séance de la Société Préhistorique Française de Besançon, 17-19 octobre 2013. Paris: Société Préhistorique Française, 175–186.

Maier, A. and Zimmermann, A. 2015: CRC806-E1 LGM-sites Database V-20150313. http://dx.doi.org/10.5880/SFB806.12.

Maier, A. and Zimmermann, A. 2016: CRC806-E1 Gravettian-sites database V-20160219. CRC806-database. https://doi.org/10.5880/SFB806.18.

Maier, A. and Zimmermann, A. 2017: Populations headed south? The Gravettian from a palaeodemographic point of view. Antiquity 91, 573–588.

Maier, A., Lehmkuhl, F., Ludwig, P., Melles, M., Schmidt, I., Shao, Y., Zeeden, C., and Zimmermann, A. 2016: Demographic estimates of hunter-gatherers during the Last Glacial Maximum in Europe against the background of palaeoenvironmental data. Quaternary International 425, 49–61.

Malmer, M. P. 1962: Jungneolithische Studien. Bonn: Rudolf Habelt Verlag/Lund: CWK Gleerups Förlag.

Malthus, T. R. 1798: An essay on the principle of population, as it affects the future improvement of society. With remarks on the speculations of Mr. Godwin, M. Condorcet, and other writers. Chapter 1, unpaginated. London: printed for J. Johnson, in St. Paul's church-yard.

Mellars, P. and French, J. C. 2011: Tenfold Population Increase in Western Europe at the Neandertal-to-Modern Human Transition. Science 333, 623–27.

Mix, A. C., Bard, E., and Schneider, R. 2001: Environmental processes of the ice age: land, oceans, glaciers (EPILOG). Quaternary Science Reviews 20, 627–657.

Montet-White, A. 1994: Alternative Interpretations of the Late Upper Paleolithic in Central Europe. Annual Review of Anthropology 23, 483–508.

Neiman, F. D. 1995: Stylistic Variation in Evolutionary Perspective: Inferences from Decorative Diversity and Interassemblage Distance in Illinois Woodland Ceramic Assemblages. American Antiquity 60, 7–36.

Neugebauer-Maresch, C., Einwögerer, T., Richter, J., Maier, A., and Hussain, S. T. 2016: Kammern-Grubgraben. Neue Erkenntnisse zu den Grabungen 1985−1994. Archaeologia Austriaca 100, 225-254.

Premo, L. S. and Kuhn, S. L. 2010: Modeling Effects of Local Extinctions on Culture Change and Diversity in the Paleolithic. PLOS ONE 5, e15582.

Preparata, F. P. and Shamos, M. I. 1988: Computational Geometry. An Introduction. New York: Springer.

R Development Core Team 2011: R: A language and environment for statistical computing. Vienna: the R foundation for statistical computing.

Rasmussen, S. O., Andersen, K. K., Svensson, A. M., Steffensen, J. P., Vinther, B. M., Clausen, H. B., Siggard-Andersen, M.-L., Johnsen, S. J., Larsen, L. B., Dahl-Jensen, D., Bigler, M., Röthlisberger, R., Fischer, H., Goto-Azuma, K., Hansson M. E., and Ruth, U. 2006: A new Greenland ice core chronology for the last glacial termination. Journal of Geophysical Research 111, D06102.

Richerson, P. J., Boyd, R., and Bettinger, R. L. 2009: Cultural Innovations and Demographic Change. Human Biology 81, 211–235.

Roebroeks, W., Hublin, J.-J., and MacDonald, K. 2011: Continuities and Discontinuities in Neandertal presence: A Closer Look at Northwestern Europe. In: N. M. Ashton, S. G. Lewis, and C. B. Stringer (eds.), The Ancient Human Occupation of Britain. Amsterdam: Elsevier, 113–123.

Shennan, S. 2001: Demography and Cultural Innovation: a Model and its Implications for the Emergence of Modern Human Culture. Cambridge Archaeological Journal 11, 5–16.

Shennan, S. 2009: Evolutionary Demography and the Population History of the European Early Neolithic. Human Biology 81, 339–355.

Shennan, S., Downey, S. S., Timpson, A., Edinborough, K., Colledge, S., Kerig, T., Manning, K., and Thomas, M. G. 2013: Regional population collapse followed initial agriculture booms in mid-Holocene Europe. Nature Communications 4: 2486.

Smith, C. M. 2014: Estimation of a genetically viable population for multigenerational interstellar voyaging: Review and data for project Hyperion. Acta Astronautica 97, 16–29.

Soffer, O. 2000: Gravettian technologies in social contexts. In: W. Roebroeks, M. Mussi, J. Svoboda, and K. Fennema (eds.), Hunters of the Golden Age: the Mid Upper Palaeolithic of Eurasia 30,000–20,000 BP. Leiden: University of Leiden, 59–75.

Soffer, O. and Adovasio, J. M. 2004: Textiles and Upper Paleolithic Lives. A Focus on the Perishable and the Invisible. In: J. Svoboda and L. Sedláčková (eds.), The Gravettian along the Danube. Dolní Věstonice Studies 11. Brno: Academy of Sciences of the Czech Republic, 270–282.

Svoboda, J. 2007: The Gravettian on the Middle Danube. Paleo 19, 203–220.

Svoboda, J., Ložek, V., and Vlček, E. 1996: Hunters between East and West. The Paleolithic of Moravia. New York and London: Plenum Press.

Terberger, T. and Street, M. 2002: Hiatus or continuity? New results for the question of pleniglacial settlement in Central Europe. Antiquity 76, 691–698.

Tiffagom, M. 2006: De la Pierre à l'Homme. Essai sur une paléoanthropologie solutréenne. ERAUL 113. Liège: Université de Liège.

Traill, L. W., Brook, B. W., Frankham R. R., and Bradshaw, C. J. A. 2010: Pragmatic population viability targets in a rapidly changing world. Biologist Conservation 143, 28–34.

Vaesen, K. 2012: Cumulative Cultural Evolution and Demography. PLOS ONE 7: e40989.

Valde-Nowak, P., Nadachowski A., and Wolsan, M. 1987: Upper Palaeolithic boomerang made of a mammoth tusk in south Poland. Nature 329, 436–438.

van Reybrouck, D. 2000: Beyond ethnoarchaeology? A critical history on the role of ethnographic analogy in contextual and post-processual archaeology. In: A. Gramsch (ed.), Vergleichen als archäologische Methode. Analogien in den Archäologien. BAR International Series 825. Oxford: Archaeopress, 39–51.

Wendt, K. P., Hilpert, J., and Zimmermann, A. 2012: Landschaftsarchäologie III. Untersuchungen zur Bevölkerungsdichte der vorrömischen Eisenzeit, der Merowingerzeit und der späten vorindustriellen Neuzeit an Mittel- und Niederrhein. With contributions by S. Ickler, H. Nortmann, B. Päffgen, F. Siegmund, and P. Tutlies. Berichte der Römisch-Germanischen Kommission 91/2010, 217–338.

Weninger, B., Jöris, O., and Danzeglocke, U. 2012: CalPal-2007. Cologne radiocarbon calibration and palaeoclimate research package. Available at: http://www.calpal.de/ (access 09 November 2016).

Widlok, T., Aufgebauer, A., Bradtmöller, M., Dikau, R., Hoffmann, T., Kretschmer, I., Panagiotopoulos, K., Pastoors, A., Peters, R., Schäbitz, F., Schlummer, M., Solich, M., Wagner, B., Weniger, G.-C., and Zimmermann, A. 2012: Towards a theoretical framework for analyzing integrated socio-environmental systems. Quaternary International 274, 259–272.

Zimmermann, A., Richter, J., Frank, T., and Wendt, K. P. 2005: Landschaftsarchäologie II – Überlegungen zu Prinzipien einer Landschaftsarchäologie. Berichte der Römisch-Germanischen Kommission 85/2004, 37–95.

Zimmermann, A., Hilpert, J., and Wendt, K. P. 2009a: Estimations of Population Density for Selected Periods Between the Neolithic and AD 1800. Human Biology 81, 357–380.

Zimmermann, A., Wendt, K. P., Frank, T., and Hilpert, J. 2009b: Landscape Archaeology in Central Europe. Proceedings of the Prehistoric Society 75, 1–53.