Populations headed south? The Gravettian from a palaeodemographic point of view

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The Gravettian is known for its technological innovations and artisanal craftwork. At the same time, continued climatic deterioration led to the coldest and driest conditions since the arrival of Homo sapiens sapiens *in Europe. This article examines the palaeodemographic development and provides regionally differentiated estimates for both the densities and the absolute numbers of people. A dramatic population decline characterises the later part of the Gravettian, while the following Last Glacial Maximum experienced consolidation and renewed growth. The results suggest that the abandonment of the northern areas was not a result of migration processes, but of local population extinctions, coinciding with a loss of typological and technological complexity. Extensive networks probably assured the maintenance of a viable population.*

Keywords: Western Europe, Central Europe, Gravettian, palaeodemography, migration/local extinction, cultural complexity, minimum viable population

The protocol for palaeodemographic estimates

The protocol used for our palaeodemographic estimates has been designed and successfully applied for sedentary communities (Zimmermann *et al*. 2004, 2009a & b; Hilpert *et al*. 2008; Wendt *et al*. 2010) and has subsequently been adjusted to account for the idiosyncrasies of mobile societies (Kretschmer 2015; Kretschmer *et al.* 2016; Maier *et al*. 2016).

Using MapInfo pro v.10, point data of the geographic position of individual sites are scaled up into areal data of site density (cf. Schlummer *et al*. 2014). To this end, Thiessen polygons are calculated around each site. Then largest empty circles (LEC) (Preparata & Shamos 1988) are centred on the vertices of the Thiessen polygons with their edges touching the closest three sites (Figure S1). In a second step, the lengths of the circles' radii are taken as a measure of site density and are interpolated using kriging (Haas & Viallix 1976). The interpolated densities are transferred to isolines which comprise areas with the same lower threshold value of site density (cf. Malmer 1962). Eventually, the so-called 'Optimal Isoline' (OI) is identified, which encircles areas with the same minimum threshold value of site-density and thus delimits so-called settlement areas against regions which were used only ephemerally or avoided completely. Settlement areas show a frequent and intensive use over generations (indicated by a high density of sites) and ideally comprise all residential sites and most of the hunting and extraction sites (for different site categories see e.g. Binford 1980). However, activities that took place in their periphery (e.g. in the course of logistical mobility) or during the transition from one settlement area to another (e.g. in the course of residential mobility) may have also left archaeologically visible traces outside the settlement areas. The OI is found using the heuristic criterion of the maximum increase in space enclosed by consecutive isolines, which has proven reliable for this purpose (see Zimmermann *et al*. 2004: 53ff.). The area encircled by the isolines increases with growing distances between the sites. Peaks in the distribution of increasing encircled spaces of successive LEC radii thus mirror changes in site density and thereby help to delimit settlement areas (cf. Fig. S2). Additionally, the OI should encircle as little empty space between sites as possible and ideally enclose about three quarters of all sites in the sample.

Two properties of OIs need to be addressed: bias affection and robustness. Site density is affected by two groups of biases, those slowing down or thinning site detection (e.g. erosion or sediment cover), potentially mimicking a lack of occupation, and those fostering site detection (e.g. intensive research or presence of cavities), potentially overemphasising the importance of a certain settlement area (cf. Kretschmer *et al.* 2016). The first (false negative) bias is particularly important for our protocol, since we assume that there indeed were unsettled areas in the past. A vital question is thus whether the void areas between site-clusters are the result of biases or a reflection of prehistoric settlement patterns. Particularly in areas with high potential for erosion or important sediment cover (e.g. the Pannonian Basin), the status of void areas is considered unclear and thus no estimates are calculated. Regionally differentiated correction curves for taphonomic loss (Surovell *et al*. 2009) would be helpful to cope with this issue. In other areas (e.g. southern Spain, Italy or the Balkan Peninsula) the density of sites is too low to result in an OI. Nevertheless, these areas are not considered unpopulated. Rather, the number of sites is too low to arrive at statistically reliable results and we do not make inferences on the number or density of people in these areas. Only the total absence of reliably typologically assigned or absolutely dated sites in well-researched areas with moderate erosion and sediment cover is interpreted as an absence of people (e.g. central Germany or north-western France). A consequence of taking these void regions within the investigated areas seriously is that our estimates are lower than those produced by approaches which ignore these empty areas as being merely the result of taphonomic processes. Since we assess individually whether void areas are historic or bias-driven, we consider our estimates more reliable and in better accordance with the prehistoric settlement picture.

Independent from bias affection is the topic of robustness. The explicitly density-based approach (cf. Bocquet-Appel & Demars 2000; Bocquet-Appel *et al*. 2005) renders our method fairly robust with regard to the discovery of new sites, as has been demonstrated by Wendt *et al*. (2010: 307ff.; see also Zimmermann *et al*. 2009a: 13), regardless of the extent to which the different regions in the investigated area are affected by biases. This is because for the large-scale density pattern to change significantly, many new sites have to be discovered in areas which are currently empty of sites. This is, however, particularly unlikely in well-researched areas such as Western and Central Europe, since new sites are usually discovered in the vicinity of already known sites of the same age (e.g. Rozoy 1988; Bocquet-Appel *et al*. 2005; Holzkämper *et al*. 2014). For examples of the Gravettian compare distribution maps in Otte 1981; Kozłowski 2015; and this paper. For other examples compare e.g. Hahn 1977; Rozoy 1988; Straus *et al*. 2000; Bocquet-Appel *et al*. 2005; Banks *et al*. 2009; Kretschmer 2015; Schmidt 2015). This distinguishes our protocol from other current approaches that rely on counts or frequency distributions of certain features, such as sites, tools, or radiocarbon dates as proxy data for their estimates (e.g. Mellars & French 2011; Shennan *et al*. 2013; French & Collins 2015). Due to the underlying structure of their data, these approaches are rather sensitive to missing values or newly discovered evidence. In contrast, the overall picture of settled and unsettled areas, as used in our approach, can be expected to change much less and thus, with regards to site distribution, our results can be expected to be rather robust.

Complementary to and independent of the identification of settlement areas, we use information on raw material catchments to estimate the number of regional groups per settlement area. Catchments are inferred by drawing polygons that connect a site with its sources of raw material. However, the quality and abundance of the available information on raw material acquisition is rather heterogeneous. Moreover, in regions with ubiquitously available erratics, such as the northern European Plain, an identification of raw material sources is impossible. To avoid the exclusion of regions with insufficient information, we transfer data from neighbouring settlement areas. The basic expectation is that—given the well-founded assumption of an embedded raw material procurement (Binford 1979: 259;

Floss 1994: 325)—similar environmental conditions lead to similar subsistence, mobility and thus catchment patterns (Binford 2001). For all results (Tables 1 & 2) it is indicated whether raw material data has been transferred. For the Gravettian, data on raw material procurement could be obtained for 100 assemblages (P1 = 75, P2 = 25). Again using the criterion of the maximum increase of space, we separate smaller and larger catchments. The smaller (P1 = 29, P2 = 12) are thought to represent daily activities (including foraging trips) within the homerange of a basecamp, whereas the lager (P1 = 46, P2 = 13) are thought to represent seasonal activities and are thus a more suitable indicator for regional groups. We correlate these regional groups with Binford's 'GROUP2' units, i.e. people living together during the most aggregated phase of annual fission and fusion cycles (Binford 2001: 117). There are conflicting views on the use of ethnographic data in archaeological research and the pros and cons have been debated intensively (e.g. Binford 1972, 1980, 1982, 1983, 2001; Clarke 1972; Wobst 1978; Gamble 1986; Kelly 1995; van Reybrouck 2000; Wiermann 2000). Since the use of ethnographic data allows for estimating absolute numbers and densities instead of giving only relative statements of population dynamics, we have deemed it a permissible source of information for the purpose of our research (see also Bocquet-Appel & Demars 2000; Bocquet-Appel *et al*. 2005). To arrive at an estimate for the number of persons in a GROUP2 unit, we selected 16 non-mounted hunter-gatherer communities described by Binford (2001) living at high latitudes in steppe environments and having their subsistence based on at least 60 per cent terrestrial animals. The median number of people was found to be 43 (for details on selection criteria and selected cases see Kretschmer 2015).

Calculations are carried out as follows:

To account for uncertainties, we use the first, second and third quartile of the area of raw material catchments to estimate a minimum, median and maximum number of regional groups per settlement area. The logical connection between these two areas is established by the fact that the same people that were living within the settlement areas also produced the catchment pattern. Following Kelly (1995: 161ff.) we do not expect more than one regional group exploiting the same area, given the presumably aggregated and predictable resource distribution at that time. Thus we assume non-overlapping catchments within the settlement areas. Consequently, the size of the catchments is supposed to be smaller if many regional groups shared a settlement area than would be the case if only a few groups lived together. Therefore, we divide the area inside the OI by the area of the raw material catchments according to

$$N_{gmin} = \frac{A_{OI}}{A_{Q3}} \qquad N_{gmed} = \frac{A_{OI}}{A_{med}} \qquad N_{gmax} = \frac{A_{OI}}{A_{Q1}} \qquad (1)$$

Here, N_g is the number of groups ($_{gmin}$ = minimum, $_{gmed}$ = medium, and $_{gmax}$ = maximum estimate), A_{OI} the area enclosed by an OI, and A_{Q3}, A_{med}, and A_{Q1} the minimum, median, and maximum areas of raw material catchments. To calculate minimum, median and maximum estimates of population size Po, the number of groups is multiplied by this median value L found during the analysis of ethnographic data (43 persons).

$$Po_{min} = N_{gmin}.L \qquad Po_{med} = N_{gmed}.L \qquad Po_{max} = N_{gmax}.L \qquad (2)$$

Minimum, median and maximum estimates for two population densities are then calculated as follows:

$$D_{smin} = \frac{Po_{min}}{A_{OI}} \qquad D_{smed} = \frac{Po_{med}}{A_{OI}} \qquad D_{smax} = \frac{Po_{max}}{A_{OI}} \qquad (3)$$

where D_s is the population density in a settlement area ($_{min}$ = minimum, $_{med}$ = medium, and $_{max}$ = maximum estimate). The areas encircled by OIs can either be considered individually, or—if raw material catchments link two or more settlement areas—collectively. Another possibility is to consider the averaged population density of a map section, D_m, including areas enclosed by OIs and the empty zones between OIs.

$$D_{mmin} = \frac{Po_{min}}{A_m} \qquad D_{mmed} = \frac{Po_{med}}{A_m} \qquad D_{mmax} = \frac{Po_{max}}{A_m} \qquad (4)$$

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Table S1. Overview of the number of assemblages used in this study and their radiometric and typological attribution to the earlier (P1) and later (P2) Gravettian.

Assemblages in study	**n**	**%**
Temporally attributable	510	77.98
Not temporally attributable	144	22.02
Total	654	100.00

Temporally attributable	**P 1**	**%**	**P 2**	**%**	**Total**	**%**
Rediometrically	146	66.66	73	33.33	219	100.00
Typologically	201	69.42	90	30.58	291	100.00
Total	347	68.24	163	31.76	510	100.00

Table S2. Radiocarbon dates from the earlier to later Gravettian transition used in Figure 2.

Set	Site	P	Lab.-Nr.	Date	Std	R	Set	Site	P	Lab.-Nr.	Date	Std	R
Set 1: Noaillian and Rayssian							****	Gargas	2	Ly-3409	26 480	420	2
*	Grotte du Renne	V	L-340	11 400	250	1	****	Carane 3	1.3	GifA-100404	26 490	390	2
*	Abri Lespaux	2	Ly-3307	17 450	780	1	****	Flageolet	VI	OxA-579	26 500	900	1
**	Chamvres		Lv-1974	17 890	280	1	****	Abri Pataud	4	OxA-167	26 500	980	1
*	Grotte du Renne	V	Ly-2126	20 150	500	1	**	Gargas	Pp	GifA-92369	26 860	460	2
*	Abri Pataud	3-4	OxA-580	20 400	600	1	****	Abri Pataud	4	OxA-169	26 900	1000	1
****	Abri Facteur	11	GSY-69	21 180	1500	1	1	Gargas	2	Ly-3408	26 910	130	2
****	Laraux	3	Ly-1739	21 530	910	1	****	Abri Pataud	4	GrN-4280	27 060	370	1
****	Flageolet	V	Ly-2721	22 520	500	1	****	Verpillière		GrA-45450	27 700	320	4
****	Flageolet	IV	Ly-2186	22 950	500	1	1	Verpillière		GrA-44701	27 900	170	4
**	Camalhot		Gif-2942	22 980	330	1	****	Enlène	5	GifA-97306	27 980	350	1
**	Chamvres		Ly-9094	23 170	230	1	1	Tarté	c1c	Ly-2105	28 410	150	2
****	Flageolet	IV	OxA-596	23 250	500	1	****	Verpillière		GrA-45482	28 900	440	4
**	Camalhot		GRA-14939	23 380	150	1	Set 2: Pavlovian						
1	Gargas	2	Ly-3400	23 590	100	2	***	DV I	mp	Ly-1999	19 640	540	6
**	Carane 3	1.2	GifA-99245	23 710	270	1	***	DV II	h	CU-748	21 920	743/ 734	6
****	Ferrassie	B7	OxA-401	23 800	530	1	***	DV I	mp	Ly-1303	22 250	570	6
****	Abri Facteur	10	OxA-584	24 210	500	1	***	DV II	md	CU-715	22 368	749	6

**	Camalhot		GRA-14938	24 220	260	1	***	DV II	h	ISGS-1899	22 630	420	6
1	Bilancino	og	Beta-93272	24 220	100	3	***	DV II	h	CU-747	23 799	870	6
****	Flageolet	VI	Ly-2722	24 280	500	1	***	DV II	h	ISGS-1616	24 000	900	6
****	Abri Facteur	10	OxA-585	24 400	600	1	2	DV II	h	GrN-1103	24 470	190	6
****	Enlène	5	Gif-6656	24 600	350	1	***	DV II	h	ISGS-1617	24 970	920	6
****	Abri Facteur	10	OxA-586	24 690	600	1	2	Pavlov I		GrN-1325	25 020	150	6
****	Abri Facteur	10	OxA-583	24 720	600	1	****	Předmostí II	b4	OxA-5971	25 040	320	6
**	Peyrugues	22	Gif-7998	24 800	500	1	****	Boršice		GrN-11454	25 040	300	6
1	Bilancino	og	Beta-93271	24 970	110	3	****	Jarošov II		GrN-9613	25 110	240	6
****	Le Raysse	4	Ly-2782	25 000	660	1	2	Pavlov I		GrN-22304	25 160	170	6
1	Gargas	2	Ly-3404	25 030	110	2	****	Milovice	fG	GrN-14824	25 220	280	6
**	Gargas		Ly-1625	25 050	170	2	2	Pavlov I		GrA-192	25 530	110	6
1	Gargas	2	Ly-3406	25 230	110	2	****	DV II	16	GrN-15276	25 570	280	6
1	Bilancino	og	Beta-106549	25 410	150	3	****	DV II	h	GrN-15277	25 740	210	6
****	Abri Facteur	10	OxA-594	25 450	650	1	****	Jarošov II		GrN-9604	25 780	250	6
****	Abri Pataud	3-4	OxA-687	25 500	700	1	****	DV I		GrN-6857	25 790	320	6
1	Gargas	2	Ly-3401	25 520	110	2	2	DV I	mp	GrN-1286	25 820	170	6
****	Abri Facteur	10	OxA-595	25 630	650	1	****	Pavlov I		GrN-22305	25 840	290	6
1	Gargas	2	Ly-3405	25 700	120	2	****	DV IIa	tA	GrN-15134	25 870	370	6
****	Flageolet	V	OxA-447	25 700	700	1	****	DV IIa	tD	GrN-15147	25 890	370	6
1	Gargas	2	Ly-3403	25 920	130	2	****	DV II	up	GrN-18189	25 950	630/	6

												580	
1	Verpillière		GrA-44702	26 010	120	4	****	Pavlov I		GIN-104	26 000	350	6
****	Abri Pataud	3-4	OxA-166	26 100	900	1	2	DV II	md	GrN-14830	26 100	100	6
****	Flageolet	VII	Ly-2723	26 150	600	1	****	DV III	u.2	GrN-22307	26 160	770	6
1	Gargas	2	Ly-3402	26 260	130	2	****	Pavlov I		GrN-20391	26 170	450	6
****	Abri Pataud	4	OxA-374	26 300	900	1	****	DV IIa	tA	GrN-15132	26 190	390	6
1	Gargas	2	Ly-3410	26 380	120	2	****	Jarošov II		GrN-15137	26 220	390	6
****	CdMina	VII	Ua-3587	26 470	520	5	****	Předmostí Ib	c	GrN-6852	26 320	240	6

Set	Site	P	Lab.-Nr.	Date	Std	R	Set	Site	P	Lab.-Nr.	Date	Std	R
2	Jarošov II		GrN-17191	26 340	180	6	4	Kůlna	6a	GrN-5774	21 260	140	6
2	DV II		GrN-21123	26 390	190	6	4	Pod Hradem	E	GrN-1734	21 500	100	6
***	DV II	h	ISGS-1744	26 390	270	6	4	Kůlna	6	GrN-6800	21 630	150	6
****	Pavlov I		GrN-22303	26 400	310	6	4	Kůlna	6	GrN-5773	21 750	140	6
2	DV I	h	GrN-10524	26 430	190	6	****	Milovice	md	GrN-14835	22 100	1100	6
****	Pavlov I		KN-1286?	26 580	460	6	4	DV I		OxA-8292	22 840	200	6
****	Pavlov I		GrN-1272	26 620	230	6	****	Milovice		ISGS-1690	22 900	490	6
****	Pavlov I		GrN-19539	26 650	230	6	4	Kůlna	6	GrN-6853	22 990	170	6
****	Pavlov I		GrN-4812	26 730	250	6	4	Petřkovice Ia		GrA-891	23 370	160	6
****	Předmostí Ib	c	GrN-6801	26 870	250	6	****	Brno II		OxA-8293	23 680	200	6
2	Jarošov II		GrN-17087	26 950	200	6	****	DV III	h	GrN-20392	24 560	660/	6

Set 3: Laugerian/Protomagdalenian						
*	Abri Pataud	3	GrN-1864	18 470	280	1
*	Flageolet		Ly-2185	18 610	440	1
****	Le Blot	39	Ly-565	21 500	700	1
3	Abri Pataud	3	GrN-1892	21 540	160	1
****	Le Blot	39	Ly-564	21 700	1200	1
****	Abri Pataud	3	OxA-599	21 740	450	1
****	P.Brosses		OxA-179	22 200	600	1
3	Le Blot	42	GRA-17217	22 210	150	1
****	P.Brosses		OxA-180	22 500	600	1
3	Abri Pataud	3	GrN-4506	22 780	140	1
3	Abri Pataud	3	GrN-4721	23 010	170	1
****	Abri Pataud	3	OxA-163	23 180	670	1
****	Abri Pataud	3	OxA-164	24 250	750	1
****	Abri Pataud	3	OxA-165	24 440	740	1
****	Abri Pataud	3	OxA-686	24 500	600	1
****	Flageolet		OxA-448	24 600	700	1
3	Le Blot	39	GRA-17336	24 640	120	1
Set 4: Willendorf-Kostenkian						
					610	
****	Pod Hradem	E	GrN-1981	26 830	300	6
Set 5: Shouldered points in Moldova						
5	Molodova V	7	GrA-9443	21 070	150	7
5	Molodova V	7	GrA-23801	21 150	80	8
5	Molodova V	7	GrA-9455	23 000	170	7
****	Molodova V	7	Mo-11	23 000	800	7
5	MMG	4a	GrA-14671	23 290	100	8
****	MMG	5a	GrN-20438	23 390	280	7
****	MMG	5a	GrN-15805	23 490	280	7
****	MMG	4b	OxA-1779	23 650	400	7
5	Molodova V	7	GrA-22909	23 650	140	8
****	Molodova V	7	GIN-10	23 700	320	7
****	MMG	5a	GrN-14034	23 830	330	7
5	MMG	4a	GrA-1353	23 850	100	7
****	MMG	4b	GX-9422	24 620	810	7
****	MMG	5a	OxA-1780	24 650	450	7
****	Molodova V	7	GrA-9564	25 130	220/ 200	7
****	Molodova V	7	GrA-9457	25 170	210	7
****	Molodova V	7	GrA-9456[a]	25 280	210	7

****	Petřkovice Ia	GrN-19540	20 790	270	6
****	Milovice	ISGS-1691	21 200	1100	6

****	MMG	5a	GrN-12635	27 150	750	7

* Date too old/young; ** Attribution unclear; *** old measurements; **** standard deviation > 200. Sites: DV = Dolní Věstonice; MMG = Mitoc-Malu Galben; Camalhot = Tuto de Camalhot; CdMina =Cueto de la Mina; P.Brosses= Pente-des-Brosses. P = Provenence (Layer or Feature): og = on gravels; Pp = Panneau peint; mp = middle part; mammoth deposit; h = hearth; b =burial; ba = base; f = feature; t = trench; up = upper part; c = cemetery; z = zone. R = References: 1: Klaric 2008; 2: Foucher & San Juan-Foucher 2008; 3: Aranguren & Revedin 2001; 4: Floss *et al*. 2013; 5: Bradtmöller 2014; 6: Jöris & Weninger 2004; 7: Noiret 2009; 8: Haesaerts *et al*. 2003. [a]: Lab.-Nr. in Haesaerts *et al*. 2003: GrA-9458. Please note that this list contains only a selection of relevant measurements for the separation of our data in two chronological units, which are typologically identifiable. Therefore it contains only those dates which are rather young for the Pavlovian, the Noaillian, and the Rayssian and rather old for the Laugerian, Protomagdalenian, Willendorf-Kostenkian, and assemblages from Molodova with shouldered points. As can be seen in Figure 2, there seems to be a shift in typological composition of assemblages in Eastern and Western Europe at around 29 000 cal BP.

Supplementary figures

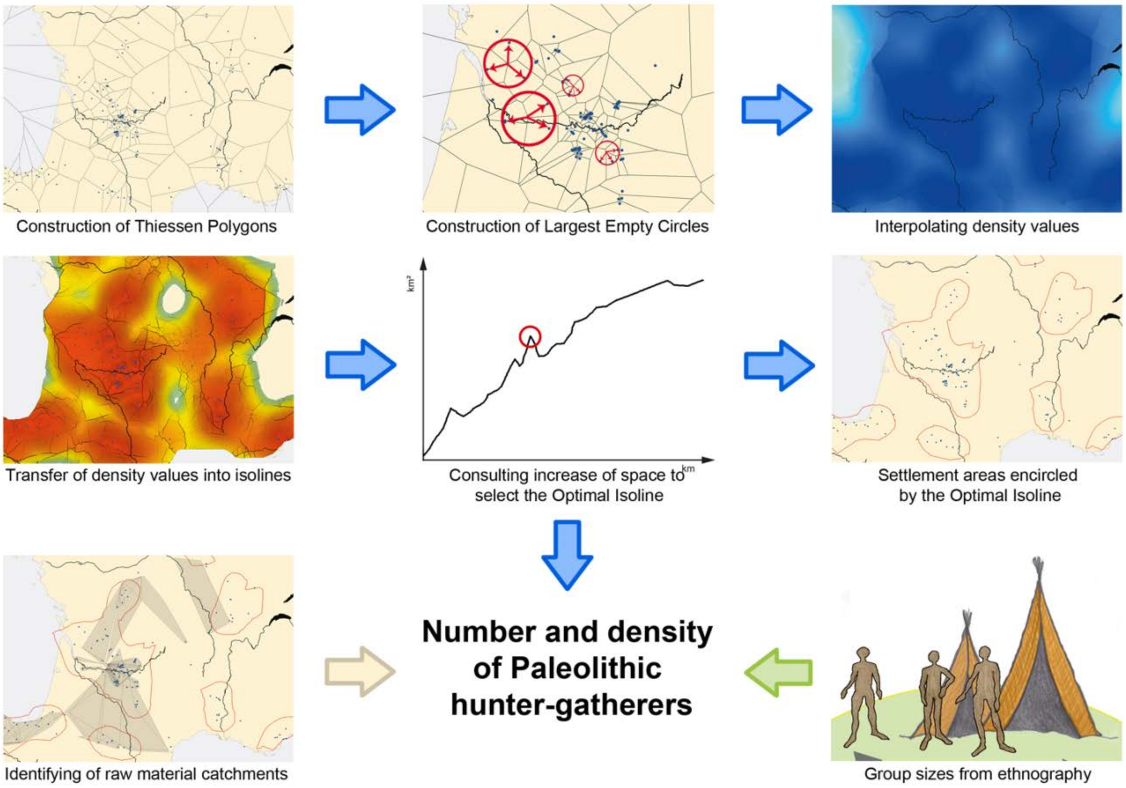

Figure S1. Overview of the different steps used in our protocol to estimate the number and density of Palaeolithic hunter-gatherers.

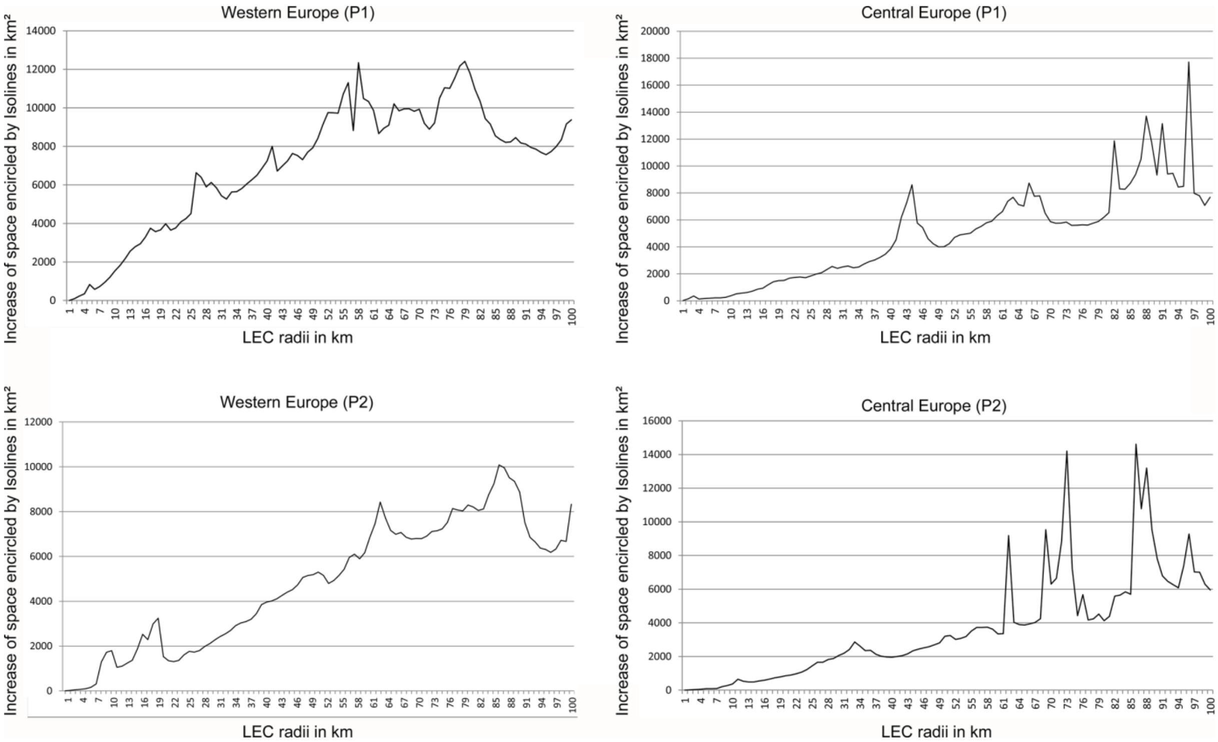

Figure S2. Increase of space encircled by Isolines in km² (y-axis) *in relation to increasing LEC radii in km* (x-axis). *Upper left: P1, Western Europe (OI = 41km); upper right: P1, Central Europe (OI = 44km); lower left: P2, Western Europe (OI = 50km); lower right: P2, Central Europe (OI = 33km).*

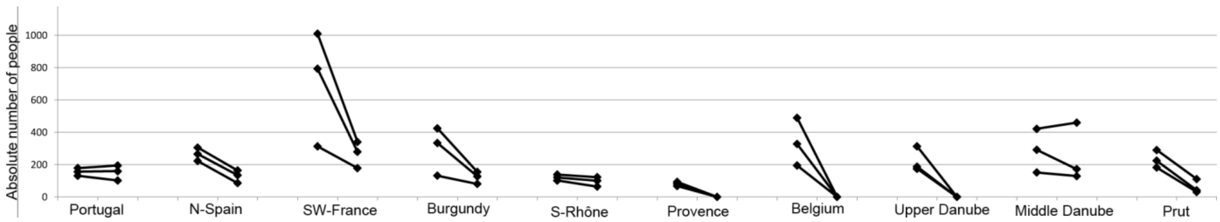

Figure S3. Population development from P1 to P2 in different regions. Estimates are given according to the 1st, 2nd, and 3rd quartile of raw material catchments (cf. Tables 1 and 2).

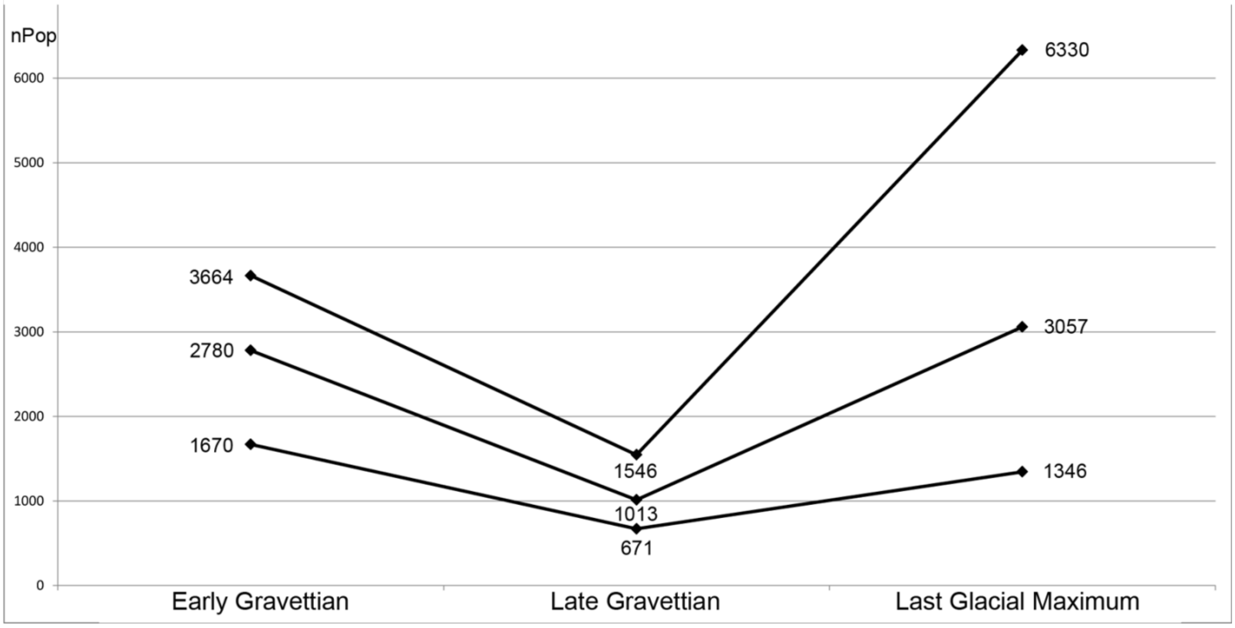

Figure S4. Palaeodemographic development from the Early Gravettian to the Last Glacial Maximum. Numbers give the median estimates of absolute numbers of people in the investigated area (cf. Tables 1 and 2).