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Population and forest dynamics during the Central European Eneolithic (4500-2000 BC)

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Abstract

The population boom-and-bust during the European Neolithic (7000-2000 BC) has been the subject of lively discussion for the past decade. Most of the research on this topic was carried out with help of summed radiocarbon probability distributions. We aim to reconstruct population dynamics within the catchment of a medium sized lake on the basis of information on the presence of all known past human activities. We calculated a human activity model based on Monte Carlo simulations. The model showed the lowest level of human activity between 4000 and 3000 BC. For a better understanding of long-term socio-environmental dynamics, we also used the results of a pollen-based quantitative vegetation model, as well as a local macrophysical climate model. The beginning of the decline of archaeologically visible human activities corresponds with climatic changes and an increase in secondary forest taxa probably indicating more extensive land-use. In addition, important social and technological innovations, such as the introduction of the ard, wheel, animal traction and metallurgy, as well as changes in social hierarchy characterizing the same period.

Keywords

Population dynamics; Neolithic; Eneolithic; Secondary woodland; REVEALS; Macrophysical climate model

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1 Introduction

Archaeology commonly tries to conduct research on diverse characteristics of past societies, such as political institutions, social identities, communication intensity within or between these societies, hierarchical or non-hierarchical organizational structures, subsistence strategies etc. All aspects of human societies are closely connected to the size of social units and to population density. Research on population dynamics was accelerated by the wide use of databases for storing archaeological data from excavations, and especially for radiocarbon dates on national or continental scales.

There are several approaches to the reconstruction of past population dynamics. J. Müller (2013) in his exhaustive literature review divided them into two groups according to the results produced. The first group provides absolute demographic values, usually in form of population densities (persons/km^2), the latter one relative demographic values. Absolute population sizes and densities are commonly related to some environmental proxy (e. g. carrying capacity), ethnographical or archaeological data (e. g. Hassan 1981; Zimmermann et al. 2005). Concerning relative demographic values, aDNA samples have often been used to reveal population dynamics (e.g. Fehren-Schmitz 2012). Demographic research can benefit also from palaeoanthropology, as demonstrated for Mesolithic and Neolithic cemeteries (cf. Bocquet-Appel 2002). The past decade brought the massive use of summed radiocarbon probability distributions as a proxy for relative demographic developments (e.g. Collard et al. 2010; Hinz et al. 2012; Shennan et al. 2013; Whitehouse et al. 2014; Timpson et al. 2014), although some aspects (such as the regional coverage of ^{14}C dates or changes in mobility and subsistence strategies of past societies) of this method are still subject to lively and critical discussions (Crombé and Robinson 2014; Contreas and Meadows 2014; Williams 2012; Torfing 2015).

One of the major increases in European populations is often connected with the Mesolithic–Neolithic transition. The adoption of agriculture in the Neolithic meant major changes in the life-styles of past societies including not only to subsistence strategies but also to social structures (Price 1995) and population dynamics. The process of neolithization occurred at different times in different European regions ranging from the first half of the 7th millennium BC (Balkan peninsula) to 4000 BC (northern part of Central Europe, Jutland, Scandinavia, Great Britain, Ireland). However, a few centuries after the adoption of agriculture a massive drop in the archaeological record – represented mainly by the summed radiocarbon probability distributions (Hinz et al. 2012; Whitehouse et al. 2014; Müller 2013; Timpson et al. 2014; Torfing 2015) – is registered in many regions. For the same period, environmental archaeological and palaeoecological studies indicated less intensified land-use (Whitehouse and Smith 2010; Lechterbeck et al. 2014; Lechterbeck et al. 2014). The most striking feature of this alleged population decline, which usually ended with the beginning of the Early Bronze Age, is that it happened simultaneously with several social and technological innovations that affected human populations for many centuries. The highly innovative character of these societies, which for example started to use the ard and wheel and invested much energy into building large monuments (hillforts, causewayed enclosures or long barrows), appears to be in contradiction with the image of unstable and declining societies suffering from famines or epidemic events.

This paradoxical situation leads us to our main questions: Is it possible to directly connect the intensity of the archaeological record with population dynamics? Are there some alternative scenarios? Why are population decline and several social and technological innovations recorded at the same time? Was the alleged population decline also connected with changes in land-use or the abandonment of landscapes?

To answer these questions we first discuss the significance of the regional archaeological record for the reconstruction of population dynamics during the Neolithic, Eneolithic and Early Bronze Age. Secondly, we employ several independent datasets (vegetation and climate models) to evaluate the relationship between population dynamics, subsistence strategies, vegetation cover and other environmental conditions.

2 Materials and Methods

2.1 Archaeological data and human activity model

The study area was defined as a circle with a diameter of 25 km around Lake Vracov in the southeastern part of the Czech Republic (Fig 1). Intensive palaeoecological research at the site (Svobodová 1997; Kuneš at al. 2015) allowed for the multi-proxy comparison of diverse types of data. We collected all unpublished archaeological data from excavation reports stored in the archive of the Institute of Archaeology of the Czech Academy of Sciences, Brno. We also used published short reports by the Institute of Archaeological Heritage, Brno, and topographical summaries of known archaeological sites and finds (for a full list of literary sources, see Kolář et al. 2016). Archaeological components were used as the basic analytical unit. Archaeological components are defined as spatially continuous sets of finds delineated by their function (e.g. burial, residential) and chronological position (e.g. Neolithic, Linearbandkeramik culture). For example, an archaeological component could be a settlement assigned to Linearbandkeramik (LBK), or a graveyard of the Early Bronze Age Únětice culture. The number of finds in one component played no role (for further details see Kolář et al. 2016).

The components, divided into behavioural categories (residential and burial components, traces, hoards), were characterized by various degrees of spatial and temporal accuracy. The spatial accuracy range began with exactly located finds and ended with components located only to the parish. The temporal definition of the components also varied from relatively short periods (e.g. Bell Beaker culture: 2500–2150 BC) to long periods for vaguely dated finds (e.g. ’Neolithic-Eneolithic’: 5400–2000 BC for most of the non-diagnostic polished stone tools). Variation in dating accuracy was mainly caused by the sporadic occurrence of radiocarbon dates. For the Neolithic of the eastern Czech Republic we know that ^{14}C based chronologies of inner material cultural evolution show significant differences from traditional typologies (Kuča et al. 2012). We therefore avoided the use of detailed local typo-chronologies based on pottery styles ordered in evolutionary series (for criticism, see e. g. Sørensen 1997; Müller 2004) and benefited from the constancy of time spans of archaeological cultures and periods, corrected with the help of recently collected ^{14}C dates from Central Europe (Barta et al. 2013).

To understand the socio-environmental processes behind the Neolithic, Eneolithic and Early Bronze Age transitions, we calculated a long-term human activity model. The rationale for this approach is in the hypothesis that similar population densities created similar amounts of archaeological record (cf. Rick 1987) and have a similar impact on the surrounding vegetation (e.g. forested and deforested land ratio).

Using all known archaeological evidence from the region, and not only ^{14}C dated components, we decreased the bias caused by research preferences or regional financial possibilities. By quantifying different behavioural categories, we got a precise picture of the character of the archaeological evidence in each time block (cf. Contreras and Meadows 2014; Torfing 2015; Timpson et al. 2015).

We used three different procedures to calculate the human activity model. First, we quantified the uncertainty in the temporal density of components with the help of Monte Carlo simulations. We simulated 1000 potential time-series, where every single archaeological component was assigned according to uniform probability to a random single year within the time span. This procedure enabled us to reveal the temporal dynamics of registered human activity. A cumulative plot of 1000 Monte Carlo simulation runs for each dated component with the initial duration of time blocs set at 500 years was created for our dataset (Fig. 2). Figure 2 also shows the temporal pattern of the envelope for each data category. The thickness of the envelope indicates the temporal uncertainty for each behavioural category and time block.

Second, we calculated parish occupancy likelihood in order to reduce the bias caused by the varying intensity of archaeological research in individual parishes. A parish was considered as occupied in a particular time block and simulation run if at least one archaeological component was attributed to it. Parish occupancy likelihood in a given time block is the proportion of simulation runs in which the parish was considered as occupied. To compare the human activity model with other models, the overall proportion of occupied parishes from the whole was expressed (Fig 3). This number also provided information about the spatial distribution of archaeologically visible human activities. Parish occupancy likelihood was visualized using interpolation (natural neighbour method: Sibson 1981; Watson 1992) in GIS. For the purposes of this study only archaeological evidence clearly indicating repeated human activity was included (for further details see Kolář et al. 2016).

2.2 Palaeovegetation data and model

Past vegetation was reconstructed from a sedimentary pollen record obtained from Lake Vracov. The site, pollen analyses and the dating of the sediment were described elsewhere (Svobodová 1997; Kuneš et al. 2015). Here we used a pollen-based quantitative land-cover reconstruction derived from the REVEALS model (Sugita 2007) to estimate the abundances of 27 pollen-equivalent taxa within the study area for 500-year time blocks during the past 12000 years. All parameter settings of the REVEALS model were described in a previous publication (Kuneš et al. 2015). The reconstructed taxa were grouped into land cover classes (LCC; Behre 1981; Gaillard 2013) to better demonstrate socio-environmental relationships. Because not all pollen taxa could be used for quantitative reconstruction due to missing information on their pollen, additional LCC groups were created from pollen percentages to complement the REVEALS model. The full list of taxa attributed to each LCC is provided in Table 1.

2.3 Climate model

Archaeoclimate modelling or Macrophysical Climate Model (MCM; Bryson 2005) was used to model local palaeoclimatic development. MCM was suitable for our purposes because i) it is locally specific ii) it models the palaeoclimate for 100-year intervals, iii) it does not derive from pollen, insect and similar biotic proxies which could introduce bias into the model, iv) it works with calibrated radiocarbon dates and v) it was successfully applied in archaeology and paleoecology (Riehl et al. 2008, Higgins and McFadden 2009, Jamrichová et al. 2014). Meteorological observations between 1960 and 1990 from the station closest to the study area (Velké Pavlovice) were used to calibrate the local MCM. Mean January (the coldest month) and July (the warmest month) values of temperature, and summer precipitation sums for the period between April and July (crucial for crop cultivation) were compared to archaeological and palaeoecological data from the region in order to explain socio-environmental changes.

3 Results

3.1 Archaeology and human activity model

Altogether 3116 unique archaeological components (from the time range 10.000 BC–1000 AD) have been collected in the study area (Table 2). The classification of the components resulted in 639 residential components (settlements with remains of houses, storage pits etc.), 550 burial components (burial grounds with diverse numbers of buried individuals), 1801 traces (surface finds, surface scatters), 60 hoards (of bronze artefacts, iron artefacts, coins, ceramic vessels etc.) and 66 other activity areas. The temporal uncertainty in archaeological dating gradually decreases from as much as 4200 years in the Mesolithic to 407 years in the Roman Period.

The beginning of the Neolithic around 5500 BC means a significant increase in all kinds of archaeological evidence (Fig. 2), especially settlements and traces. Nevertheless, a relatively rapid decrease is observed already before 4000 BC, and between 4000 a 3000 BC our result show the lowest values for all behavioural categories throughout the whole of prehistory and later up to 1000 AD. Depending on the behavioural data category, the archaeological record starts to increase again only after 3000 BC or 2500 BC. For that time the model demonstrates that the burial record becomes highly frequent. Data on graveyards steadily decrease after the Final Eneolithic/Early Bronze Age (2500–2000 BC), and in fact similar levels are reached again only in 500–1000 AD. The temporal structure of traces is similar. The high levels recorded in the Neolithic are not repeated until the second half of the 3rd millennium BC. The archaeological evidence of settlements shows a slightly different pattern. The increase and decrease is present in this case as well, but the increase after 3000 BC is not as rapid as in the case of cemeteries. A gradual rise in settlement activities is shown by the model between 3000 and 1000 BC.

Parish occupancy likelihood (Fig. 3), which should be less biased by culturally specific depositional processes and regional research history, shows very similar results. The number of possible occupied parishes rapidly increases after the start of the Neolithic around 5500 BC. Until 4500 BC the occupied area seems to be relatively stable, but after 4500 BC a significant drop begins, which continues until 3000 BC. In the following time block, a slight rise is visible. This is accelerated after 2500 BC. After this point the parish occupancy likelihood oscillates between 0.6 a 0.4.

Similar temporal dynamics of parish occupancy likelihood can be observed in space (Fig. 4). The beginning of agricultural practices after 5500 BC is connected with larger areas with evidence of human presence. After 4500 BC a decreasing tendency commences, and between 4000 and 3000 BC archaeologically detected human activities are rare. The situation starts to change after 3000 BC and further on after 2500 BC. With emergence of the communities of the Final Eneolithic and Early Bronze Age, the archaeological evidence of human activity is even stronger than at the beginning of the Neolithic.

3.2 REVEALS and climate model

Following the multi-proxy approach, the human activity model was compared to regional vegetation abundances estimated by the REVEALS model. During the period of interest (4500 – 2000 BC) there are no significant changes in the proportion of deforested landscape. Open land was naturally present in the region since the early Holocene probably maintained by climate (Kuneš et al. 2015). However, shifts in tree species composition during the time block 4500-4000 BC do reflect significant changes. Simultaneously with the start of a decrease in archaeologically detected human activities, a significant rise in secondary woodland taxa (*Betula, Corylus avellana*) is observed. Such taxa remained frequent in the following 500-year time-block as well. The middle time-block (3500-3000 BC) is characterized by lower values for secondary woodland and higher values for coniferous woodland. Secondary woodland ratio rises again after 3000 BC, and remains at high levels for 1000 years until the Early Bronze Age, when indicators of arable land and deciduous woodland became more abundant.

It has already been described elsewhere (Kuneš et al. 2015) that in the region of lake Vracov the combination of palynological proxies and the results of MCM demonstrate three main Holocene climatic phases. The first one, which ends at 7500 BC, does not concern Eneolithic socio-environmental dynamics. The second climatic phase (7500-3500 BC) is characterized by relatively stable conditions, although January temperature slowly rises to -3°C. The combination of low summer precipitation and high summer evaporation arguably created very arid conditions during this period of year. In the third phase, starting in 3500 BC, similar temperatures to recent conditions can be observed. Short periods of summer droughts were caused by high but fluctuating precipitation.

4 Discussion

Archaeological evidence is a random collection of material remains of past human activities, which went through formation and taphonomic processes. The amount of available information is biased by several factors. Past depositional behaviour influenced the character of the moveable and immoveable artefacts. Specific archaeological component taphonomy, which is tightly connected to past and recent cultural and natural landscape processes (e.g. land use, erosion and/or accumulation), affects the character and rate of preservation. Survey and excavation intensity is another factor influencing the quality and quantity of available data. Hypothetically, high amounts of archaeological evidence in form of traces could result from specific past behaviour, but also from large scale survey projects.

Our region has under intensive research for decades due to the Early Medieval central hillfort at Mikulčice. Research projects employed many survey campaigns exploring both Early Medieval and prehistoric sites. The results of these projects are regularly published (e.g. Poláček 1999). To avoid geographical and/or period specific bias, data stemming from various research projects led by a range of institutes focusing on all periods were included. The only limiting factor was the absence of excavation reports or publications.

4.1 Population dynamics, depositional behaviour and subsistence strategies

As stated above, the period between 4000 and 2500 BC is characterized by the lowest values of archaeologically detected human activities from the beginning of the Neolithic. Assuming that the archaeological evidence from large areas is basically a random collection of signs of human presence evenly affected by natural formation processes, the most important factor influencing its density is depositional intensity. The common interpretative model for such results would be population fluctuations. The widely accepted assumption of Rick (1987) that the fluctuating amount of radiocarbon dates or archaeological evidence reflects demographic fluctuations was often used in studies on Neolithic population dynamics at both regional and continental levels (e. g. Shennan et al. 2013; Timpson et al. 2014; Whitehouse et al. 2014; Hinz et al. 2012; Woodbridge et al. 2014). Interpreted in the same manner, our human activity model demonstrates strong depopulation in the study region between 4000 and 3000 BC. The local Eneolithic population would start to recover after 3000 BC, and later on after 2500 BC Corded Ware, Bell Beaker and Únětice communities would reach even higher population levels than those during LBK times at the beginning of the Neolithic. Recent results of the aDNA analyses suggest that the increase in archaeological evidence could be related to migration from the Pontic-Caspian steppe (Allentoft et al. 2015; Haak et al. 2015).

The alternative explanation of the decline of archaeological evidence is a change in behavioural patterns. This could include ways of building dwellings, waste management, subsistence strategies or mobility. Such a change can result in a lower possibility of detecting human activities in the archaeological record alongside a relatively stable population. Using this interpretative model, two major changes in depositional behaviour in Central European Eneolithic societies would have happened. Between 4000 and 3000 BC their daily activities would have become less evident, and later on after 2500 BC daily practices would have changed again leaving behind more visible traces in the archaeological evidence. Lower archaeological visibility is traditionally interpreted as characteristic for communities with higher mobility incorporated into their subsistence strategies. Typical examples are Mesolithic hunters and gatherers. Agricultural and hunting and gathering communities are known to have lived side by side during the Neolithic in other Central

European regions (Furmanek et al. 2013; Bollongino et al. 2013), thus this theoretical model could be one of the possible explanations also for our region (cf. Pavlů 2012).

The beginning of the decline of archaeologically detected human activities in the study region is connected with higher reliance on wild resources. Whereas the LBK communities from the first centuries of the Neolithic show higher reliance on domestic animals (Dreslerová 2006; Clason 1970), the archaeozoological evidence from sites of the Lengyel culture shows changes in hunting practices. Good quality samples from the large Lengyel sites of Těšetice and Roztoky contain more than 40% wild animals. During the subsequent centuries of the Early Eneolithic, the importance of hunting decreased, but later on during the Middle Eneolithic it increased again. At sites with large archaeozoological datasets (Cimburk, Kutná Hora – Denemark, Palliardiho Hradisko u Vysočan) the proportion of wild animals exceeds 50% (Kyselý 2012).

In the same period, we observe the beginning of intentional barley (*Hordeum vulgare*) cultivation indicated by the appearance of rich finds. This became more important later on during the Early Bronze Age (Dreslerová – Kočár 2013). Bearing in mind the results of the climatic model, i.e. that this period was characterized by arid summers, we can hypothesize that the higher importance of hunting and the slight change of crops may have been part of an adaptation process. Climatic conditions around 4000 BC could have various consequences for human communities: extinction, migration out of the region or a change of life-style and subsistence strategy. In all possible cases, these communities disappeared from the archaeological evidence.

Similar temporal dynamics of behavioural patterns (sometimes also connected with population decline) from the same period (4000-3000 BC) were observed in several European regions. In neighbouring Bohemia, changes in arable farming and settlement behaviour around 3500 BC were recorded (Dreslerová 2012). For Funnel Beaker (Trichterbecher) communities in north-central Europe, Hinz et al. (2012) associated the decline in the archaeological record between 3400 and 3100 BC with social changes. In south-eastern Europe, the end of Chalcolithic tell-based agriculture and the transition to more scattered upland settlements economically based on pastoralism was most likely related to rapid climate change between 4200 and 3000 BC in the form of seasonal cool periods in winter and spring (Weninger – Harper 2015). Due to a rise in the water table, climatic instability and increasing climatic regionalism, transformations of settlement and economic systems in Ireland were observed between 3600 and 3000 BC. According to Whitehouse et al. (2014) the lower level of archaeologically registered human activity was caused by population decline or a change in depositional processes. Similar climatic changes around 3400 BC caused significant modifications of agricultural systems in Great Britain. Whereas in England people incorporated higher mobility and a more frequent use of wild sources, Scottish mainland communities adapted to this change with higher reliance on barley, which is more stress tolerant (Stevens and Fuller 2012; 2015; for criticism see Bishop 2015a; 2015b). Great Britain probably went through a major population decline (Woodbridge et al. 2014; Shennan et al. 2013). Climate played a crucial role also in the pile dwellings in the Alpine region. Here, subsistence during cold and wet periods, which are not favourable for cereals, was based more on wild resources (Schibler and Jacomet 2010). In the case of hunters and gatherers in Fennoscandinavia in the same time period, we see strong correlations between population dynamics and climatic or climate-derived environmental factors. Population increase was connected with higher biomass productivity of lacustrine and marine environments between 4500 and 3500 BC, whereas the subsequent decline between 3500 BC and 0 occurred together with cooling temperatures and an increased ratio of coniferous forests, which provided less animal biomass (Tallavaara and Seppä 2011).

4.2 Vegetation and land-use changes

As demonstrated above, population dynamics in other European regions was probably significantly intertwined with subsistence strategies, thus our model of vegetation cover provides relevant information for understanding population dynamics. From our previous research it needs to be stressed that some of the wider landscape around Lake Vracov (ca. 20%) had a naturally open character in the form of grasslands (Fig 3, for details see Kuneš et al. 2015). These open habitats probably provided enough space for human communities and their activities up to 1000 AD, when significant deforestation started. However, significant changes in forest composition can be observed. One of the possible explanations of the higher representation of the secondary woodland species in the 4th millennium BC could be linked to the persistence of pine-dominated forests until 3000 BC and the possibility of the natural coexistence of hazel and birch within these forests. Such vegetation pattern could be supported also by drier climate (Kuneš et al. 2015).

Nevertheless, there is also an alternative explanation. It is evident that the strong decline of archaeological evidence after 4000 BC is accompanied by a strong increase of secondary woodland taxa (*Betula*, *Corylus avellana*). The increased occurrence of birch and hazel may have started already around 4500 BC as indicated by extension clearings (spread of ruderals *Artemisia*, *Chenopodiacea* and *Urtica*). Both *Betula* and *Corylus avellana* can indicate early forest successional stages. They are able to occupy abandoned fields for a few decades before they are outcompeted by late successional temperate climax forests. Such a vegetation scenario would be likely in case of a rapid population decline connected with massive landscape abandonment. But the REVEALS model shows something different. Natural succession was halted and only the first stages are observed. Secondary forests were abundant for a millennium between 4500 and 3500 BC. This could indicate constant management by local communities. Hazel had an important role in prehistoric societies; it served not only as a source of food, but also as a building and craftsmanship material. In some European regions it was coppiced already in the Mesolithic and Neolithic (Gardner 2002; Dufraisse 2008; Klooß 2014). Birch was used for manufacturing tar and bark containers (e. g. Koschik 2004; Fleckinger 2002; de Capitani et al. 2002), but so far there is no evidence for purposeful management in early prehistory. Keeping in mind the possibility of population decline caused by limited food availability (depletion of fields or climatic deteriorations in general), the increase in the secondary forests could indicate innovations in land-use.

The tree species composition observed between 4500 and 3500 BC could be the result of extensive land use. Farming experiments showed that swidden (or extensive slash-and-burn agriculture) cultivation with short arable and long fallow phases can produce large fallow areas with different stages of reforestation by successional forest species (Rösch et al. 2008; Schier et al. 2013). Among the advantages of swidden cultivation, which includes the burning of branches and shoots, are the suppression of weeds, raised concentrations of nutrients, raised soil surface in spring enabling the faster growth of seeds, good yields on poor soils and thus lower risk of total farming failure. Importantly, the area affected (in the form of fallows or reforesting plots) is 16 to 20 times larger than in regular cultivation (Schier et al. 2013; Ehrmann et al. 2014). Because of its spatial requirements, this type of agriculture can be performed only under unlimited access to forests. Such access can be result from population decline and subsequent lower population density. Earlier research showed that the intensive garden cultivation with fixed plots was the most probable method of agriculture in the earlier Neolithic (mainly LBK) in Central Europe (Bogaard 2004). However, swidden, as a risk avoiding farming practice, could be appealing especially in less safe general conditions during the later Neolithic and Eneolithic.

The adaptation to less favourable climatic conditions that resulted in large secondary forest areas could involve also other practices. The opponents of the swidden model suggest deliberate burning of woodland for creating pastures for domestic and wild animals. Evidence from animal dung from Alpine lake dwellings shows high amounts of micro-charcoal, and seeds, pollen and other plant parts of woodland taxa. This implies grazing by domestic animals on burnt woodland surfaces (Jacomet et al. 2016).

4.3 Technological and social innovations

Considering the possibility of transition from intensive to extensive land-use, it is interesting that this agricultural innovation emerged here during a hypothetical population decline. Moreover, the alleged population decline coincided with other innovations. The innovative character of the society in the study period is, in our opinion, in contradiction to the common image of societies being in decline. We would rather suggest a more complicated scenario, in which various social groups reacted to the new environmental conditions differently, according to their current state (cf. Gronenborn et al. 2014).

From the point of view of landscape management, the most important innovation was the introduction of the ard in ca. 3500 BC. Modern ethnographic observations demonstrated that this technological innovation could increase the cultivated land or enable the cultivation of plots with heavier soils. Among the negative effects are thinning of the humus cover and increased erosion. Through the differentiation of agricultural work and the higher importance of land, the adoption of ploughing probably increased social inequality (Halstead 2014; Mischka 2014; Ebersbach 2002; Fokkens 1986). The Funnel Beaker communities, which first used this technology, also constructed fortified hillforts and burial mounds in Central Europe. This could reflect changes in land ownership patterns (Bourgeois 2013), and definitely shows their ability to mobilize and organize larger groups of people for building monumental architecture.

Among innovations with lesser agricultural significance, one can enumerate copper metallurgy and the wheel. The first copper artefacts in the region are known from the Lengyel culture communities (from around 4000 BC). Later on, during the Funnel Beaker culture, local metallurgical production developed (Dobeš 2013). There is an ongoing debate whether copper production had an impact on emerging social hierarchies (e.g. Klassen et al. 2012; Krause 2003) or it was incorporated into Neolithic social structures without such influence (Kienlin 2014). In any case, metallurgical production had its own dynamics. The registered human activity decline is partly contemporary with the loss of production of heavy metal artefacts, and the increase in human activity after 3000 BC is marked by the re-emergence of metallurgy connected with the Corded Ware and Bell Beaker cultures (Kienlin 2014).

Animal traction, which was crucial for ploughing, could also be useful in the use of carts emerging in Central Europe probably around 3500 BC in the Funnel Beaker and Baden contexts (Mischka 2011; Bakker et al. 1999). During the Eneolithic, cattle were significant not only because of their power. In some Central European regions, there is evidence of increased economic exploitation, larger and demographically sustainable herds owned by one community and significant impact on the vegetation after 3500 BC (Ebersbach 2002; Dörfler 2008). Through grazing in forests, large herds of cattle could increase the ratio of light demanding hazel and birch (Diers et al. 2014). Intensive mixed farming, closely integrating small-scale cultivation and small-scale herding, which was proposed for the Neolithic (especially LBK) by Bogaard (2004; 2005), could be undermined through larger herds during the Eneolithic. Hypothetically, secondary forests could provide areas not only for the grazing of livestock, but also for the gathering of branches and shoots, later burnt on fields for fertilizing them. Mischka (2014) pointed out the possible high significance of cattle in changing woodland management especially at the end of the Eneolithic. According to her, this brings us back to the reconsideration of Andrew Sherrat's (1981) social model of two economically different groups (plough agriculturalists vs. pastoralist) and Madsens and Jensens (1982) model of different activities practiced by the same social groups.

5 Conclusions

South-eastern Moravia shares a similar pattern in the archaeological record with several other European regions. The beginning of the Neolithic shortly after 5500 BC entailed a boom in the archaeological record and probably also in population levels. By contrast, the beginning of the Eneolithic around 4000 BC was accompanied by rapid decline. After 3000 BC a slight increase commenced, which accelerated after 2500 BC. Our human activity model shows the lowest archaeologically detected human activities between 4000 and 3000 BC. The same period is characterized by an increase in secondary forest taxa (*Betula, Corylus avellana*). This could indicate the importance of extensive land-use in adaptation processes during climatic changes. The same time period is characterized by several social and technological innovations (ard, wheel, animal traction, metallurgy), which could also be part of adaptation processes, but could also play another, independent role within socio-environmental relationships.

Food availability played a crucial role in population dynamics during prehistory. When farming yields declined, Eneolithic societies reacted in diverse ways. For some, it was possible to change their agricultural and pastoralist practices. Other communities could alter their subsistence strategies towards mobile life-styles relying more on wild resources, thus we register them only sparsely in archaeology. Still others migrated or might have died out.

Apart from population density, subsistence strategies and behavior clearly influence the amount and character of the archaeological evidence. For Central Europe, there was probably not a uniform model of dealing with critical situations.

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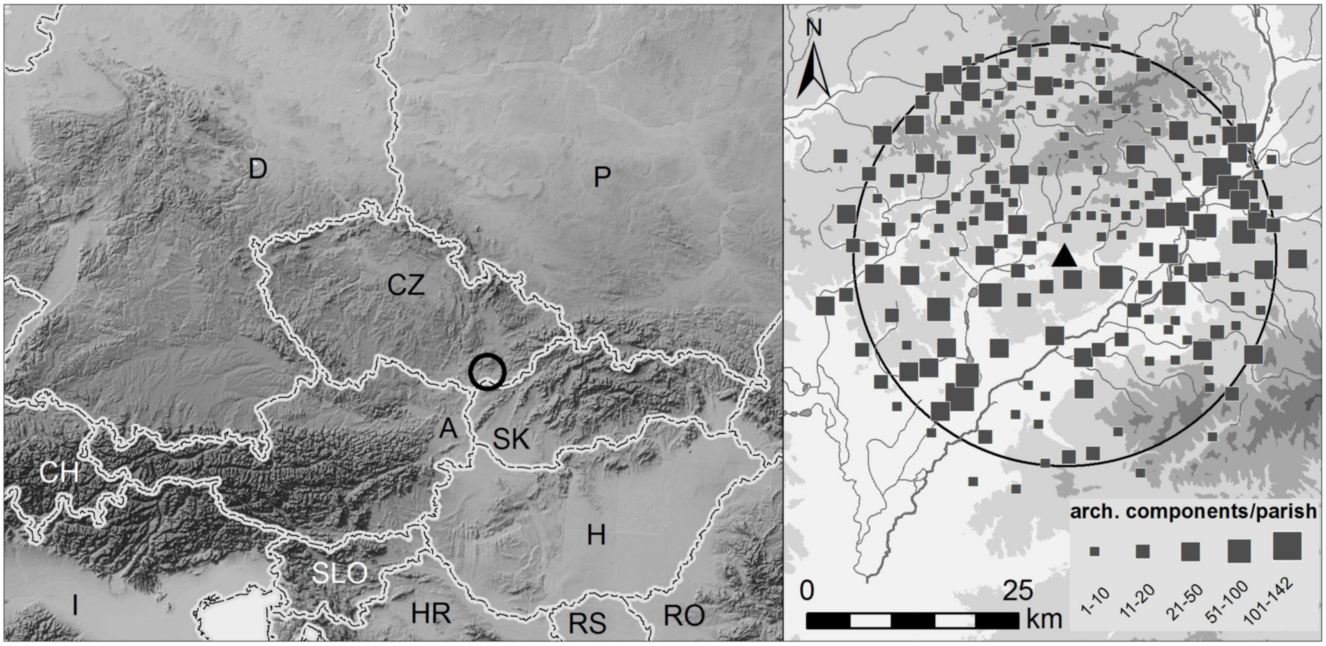

Fig. 1.
The study region around the former Lake Vracov, the 25 km buffer zone and the number of archaeological components per civil parish.

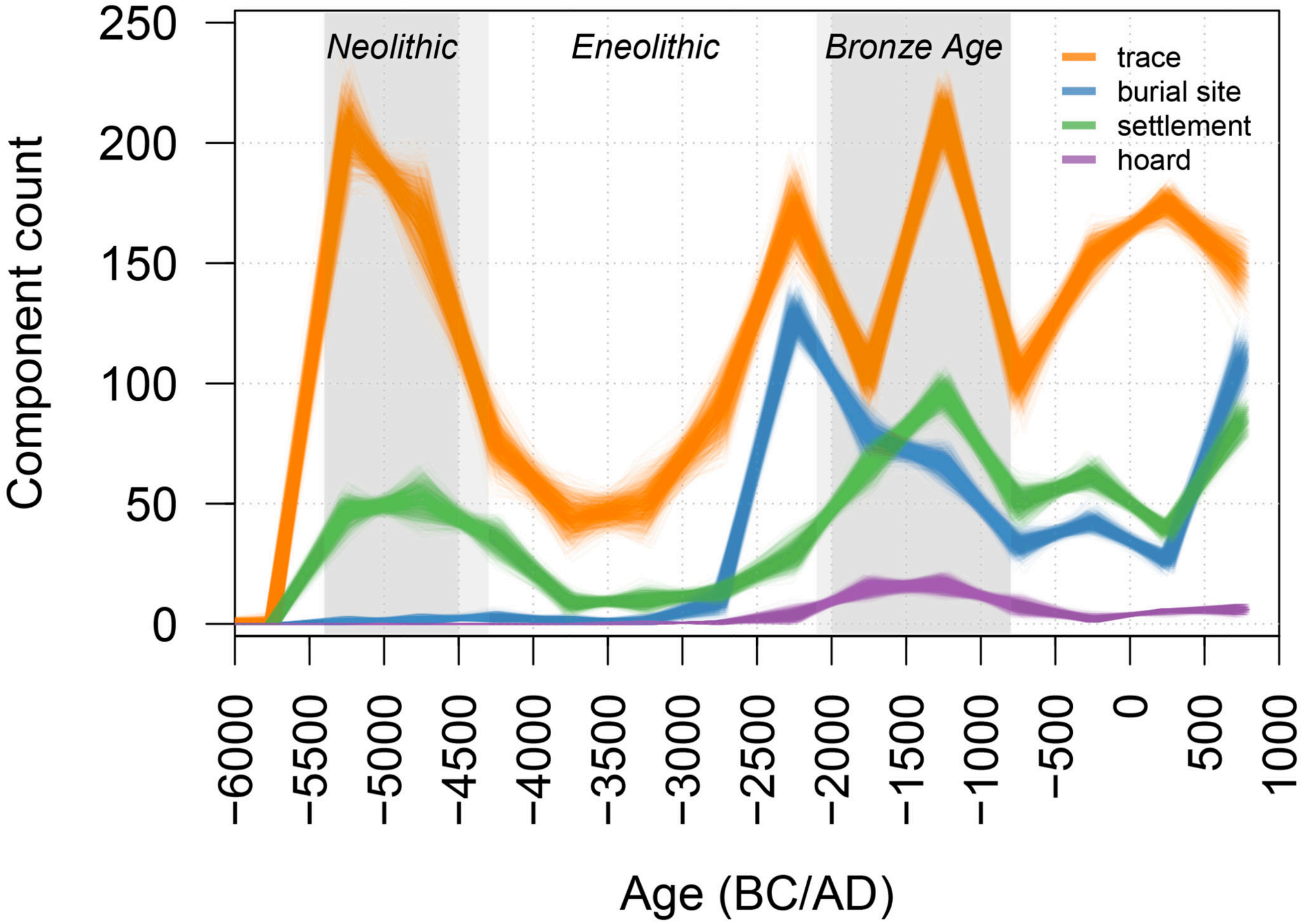

Fig. 2.

Counts of components assigned by Monte Carlo simulation to 500-year time blocks between 6000 and 1000 BC, classified according to the origin of activity. The counts are based on 1000 simulations.

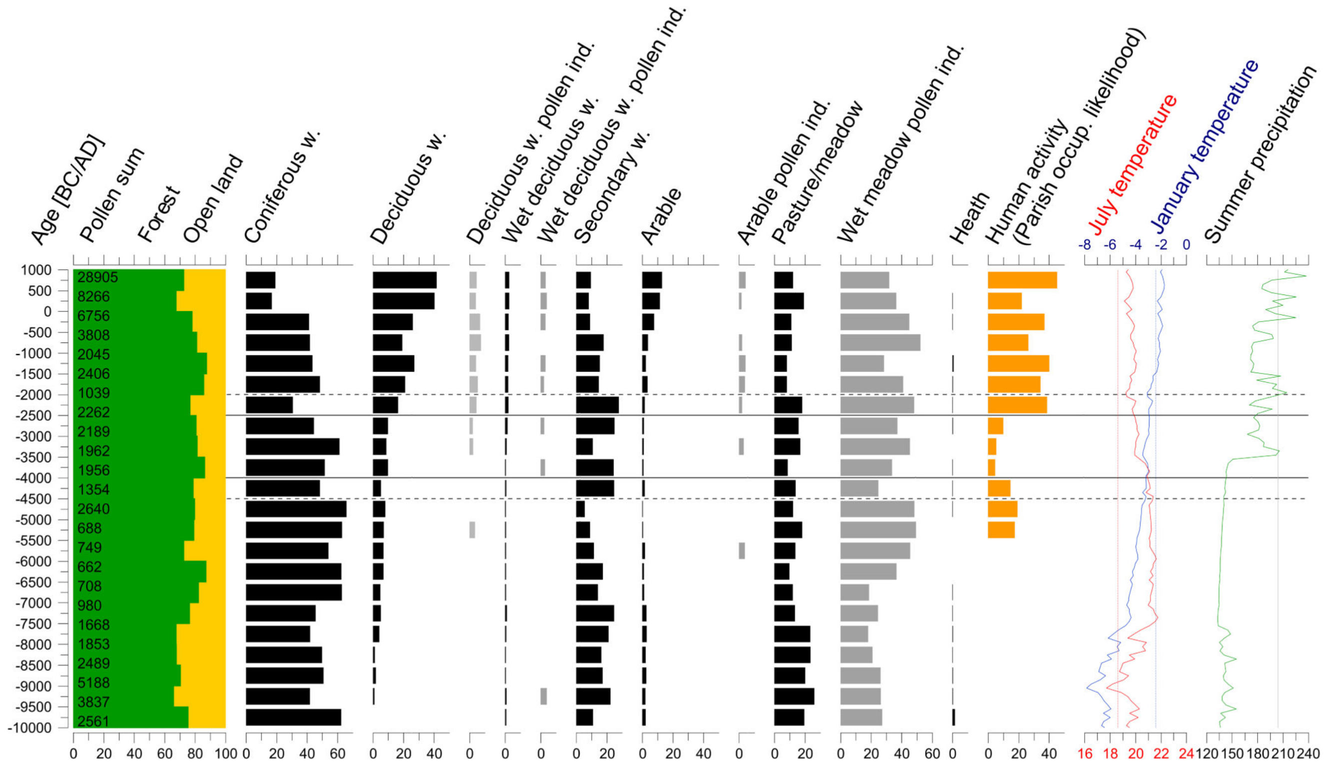

Fig. 3.

Stratigraphic diagram showing regional vegetation abundances estimated by the REVEALS model grouped into land cover classes (black bars), additional pollen proportions not included in REVEALS (grey bars), human activity model, Macrophysical climate model showing mean January and mean July temperatures and summer precipitation and evaporation. The inner solid horizontal lines delimit the time blocks with the lowest level of human activities; the outer ones delimit the time blocks with increased ratios of secondary forest taxa. The pollen sum indicates the amount of pollen counted in each 500-year time window.

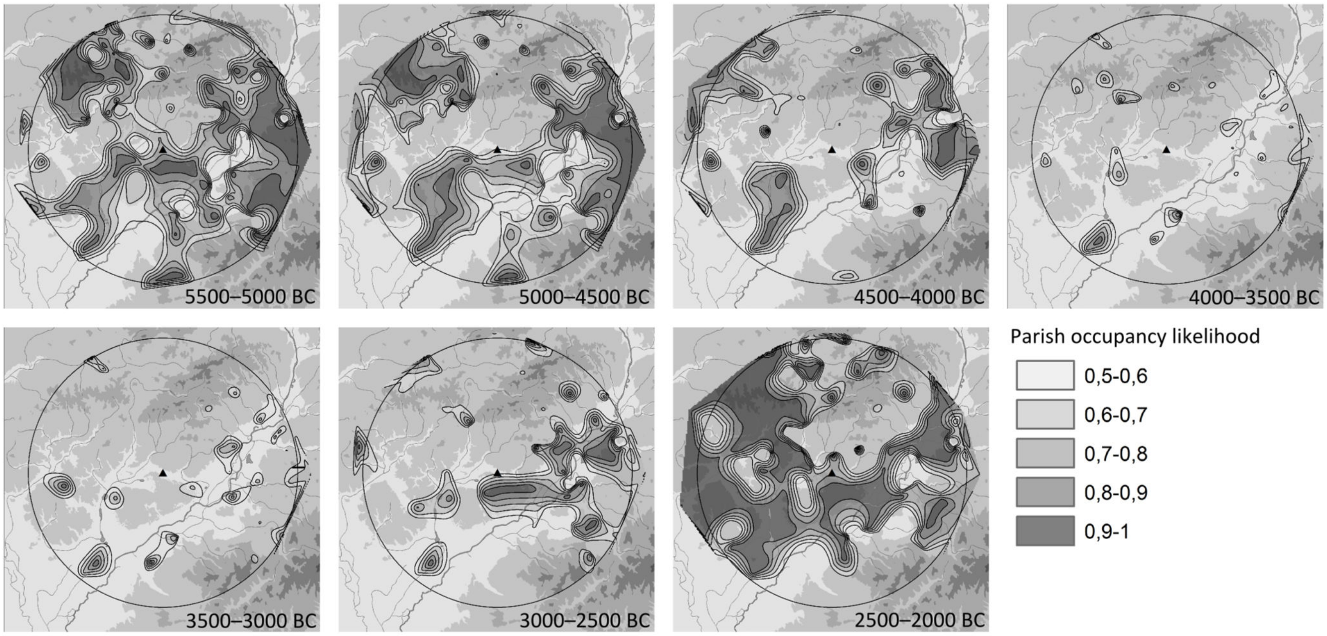

Fig. 4.

Spatial patterns of parish occupancy likelihood in the study region between 5500 and 2000 BC. The raster was interpolated by the natural neighbour method. Parish occupancy likelihoods higher than 0.5 are shown.

Table 1

Taxa list of plants included in the land cover classes (LCC).

REVEALS

Coniferous woodland	**Deciduous woodland**	**Secondary woodland**	**Wet deciduous woodland**	**Arable**	**Pasture/meadow**	**Heath**	**Wet meadows**
Abies	*Carpinus*	*Betula*	*Alnus*	*Artemisia*	*Plantago lanceolata*	*Calluna vulgaris*	*Filipendula*
Juniperus	*Fagus*	*Corylus*	*Salix*	Cerealia-t	*Plantago media*	*Juniperus*	
Picea	*Fraxinus*			Chenopodiaceae	Poaceae		
Pinus	*Quercus*			*Plantago media*	*Ranunculus acris*-type		
	Tilia			*Secale*-t	*Rumex acetosa*-type		
	Ulmus				Rubiaceae		
					Urtica		
					Potentilla-t		

POLLEN INDICATORS

	Deciduous woodland		**Wet deciduous woodland**	**Arable**	**Pasture/meadow**		**Wet meadows**
	Acer		*Frangula alnus*	*Centaurea cyanus*	*Alchemilla/Aphanes*		*Caltha-type*
	Cornus			*Juglans*	*Anthemis-type*		*Polygonum bistorta-type*
				Papaver	*Campanula-type*		
				Plantago major/media	Cruciferae		
				Polygonum persicaria-type	Compositae subfam# Asteroideae		
					Compositae subfam# Cichorioideae		
					Centaurea scabiosa-type		
					Cirsium-type		
					Gentianaceae		
					Helianthemum		
					Sanguisorba officinalis		
					Thalictrum		
					Trifolium-type		
					Urtica dioica-type		
					Succisa		

Table 2

Archaeological record categorized according to activity area and period.

	hoard	burial ground	settlement	trace	other	Sum
Mesolithic	0	0	0	8	0	8
Neolithic	0	4	128	362	3	497
Neolithic / Eneolithic	0	0	1	159	0	160
Eneolithic	1	110	50	257	1	419
Bronze Age	41	188	196	389	15	829
Hallstatt Period	1	21	38	49	4	113
La Tène Period	1	36	49	125	0	211
Roman Period	6	20	40	184	0	250
Migration Period	0	14	3	8	0	25
Early Medieval Period	9	151	125	232	25	542
other	1	6	9	28	18	62
Sum	60	550	639	1801	66	3116