

Neolithic and Copper Age settlement dynamics in the Western Carpathian Basin and Eastern Alps

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ABSTRACT – *The paper tackles the spatio-temporal patterns of Neolithic and Copper Age settlement dynamics in the Western Carpathian Basin and Eastern Alps with spatially explicit use of radiocarbon dates. It focuses on the spatial process of spread, movement, aggregation and segregation in the time frame between 8500 and 5000 cal BP. The distribution of Neolithic and Copper Age sites in the study area is clustered and patchy. The first Neolithic settlements appear as isolated islands or enclaves which then slowly expand to fill neighbouring regions. After 6300 cal BP the study area experienced a significant reduction in the extent of settlement systems, associated with the Late Neolithic to Copper Age transition.*

KEY WORDS – *Neolithic; Copper Age; Carpathian Basin; East Alps; settlement patterns; radiocarbon dating; demography; modelling*

Neolitske in bakrenodobne poselitvene dinamike v zahodni Panonski nižini in vzhodnih Alpah

IZVLEČEK – *Članek se posveča prostorsko-časovnim vzorcem neolitske in bakrenodobne poselitve zahodne Panonske nižine in vzhodnih Alp s pomočjo prostorsko eksplicitne rabe radiokarbonskih datumov. Analizira prostorske procese širjenja, gibanja, združevanja in razdruževanja v časovnem loku med 8000 in 5000 pred sedanostjo. Neolitska in bakrenodobna najdišča se pojavljajo v neenakomernih skupkih. Prve neolitske poselitve se pojavijo v obliki izoliranih otokov ali enklav, ki se počasi širijo v okolico. Po 6300 pred sedanostjo lahko zaznamo upad poselitve, ki ga povezujemo s prehodom iz poznega neolitika v bakreno dobo.*

KLJUČNE BESEDE – *neolitik; bakrena doba; Panonska nižina; vzhodne Alpe; poselitveni vzorci; radiokarbonsko datiranje; demografija; modeliranje*

Introduction

What we call the Neolithic is shorthand for several historical processes on different time and spatial scales. Nevertheless, the Neolithic is not just a construct, it is real and has some kind of downward causality on all the historical processes that make it. The historical processes behind the Neolithic are a result of the formation and development of a relatively stable and resilient assemblage of human-material relationships which develops in an increasingly structured, organized and consistent social world

(Robb 2013). The Neolithic assemblage originated in the Near East, where by 9500 cal BP people had domesticated all the major crops and animals. They started to make and use new things, including pottery, figurines, polished stone axes and houses, begun to live in villages and practice new rituals.

What is a proper scale to study the Neolithic? Behind the long-term directionality and near irreversibility of the process is the great local variability seen in

the archaeological record across Europe. On the broad scale, we can see a process of the movement of groups of people and new material assemblage from the southeast towards northwest over a span of several millennia, which resulted in a uniform and coherent thing we call the Neolithic (Robb 2013; 2014).

By about 9000 cal BP this assemblage had spread to south-eastern Europe. The Neolithic assemblage spread rapidly from the Aegean through the Balkans, along the northern coast of the Mediterranean, and across the Northern European Plain. The spread in other areas was slower. There are regions which did not become Neolithic for up to a millennium after their initial contact with farmers.

The spread of the Neolithic assemblage was first estimated to be around 1 kilometre per year, covering the distance between the Levant and Scotland in about 3000 years (Ammerman, Cavali-Sforza 1984). More recent research has refined this picture substantially (e.g., Gkiasta et al. 2004; Bocquet-Appel et al. 2009; Fort 2015). Recent research has also demonstrated that this was not a uniform, 'wave of advance'. Most archaeologically demonstrable movements of people seem to be leap-frog migrations in which small groups leave their community to establish enclave settlements in suitable environments. This is best seen in percolation of the LBK settlements in the river valleys of Central and Western Europe and the spread of Impressa settlements over the Mediterranean.

With the recent development of AMS dating and accumulation of data, it is possible to access the dynamics of spread in much finer temporal and spatial resolutions. A large quantity of AMS radiocarbon data – each individually dating a single event of the end metabolism of an organism – transforms into a new quality, allowing us to glimpse larger spatial and temporal patterns. This radiocarbon 'Big Data' allows us to approach the Neolithic as a set of local historical trajectories, each with its own speed, tempo and rhythm. It enables us to change the narrative of gradually spreading Neolithic assemblage to a series of regional or local responses and actions behind the larger process. In this way, the Neolithic becomes less a uniform process, driven by a single, perhaps evolutionary principle (Shennan 2018), but instead a true historical development. The Neolithic also gains temporal depth. Instead of a narrative of the spread of a formed Neolithic assemblage, we can begin to appreciate the complexity of social proces-

ses and transformations in the established Neolithic societies (Hofmann, Gleser 2019).

The aim of the paper is to approach the process of Neolithic and Copper Age settlement of the Western Carpathian Basin and Eastern Alps based on the available radiocarbon data. It applies spatially explicit use of radiocarbon dates to understand spatiotemporal trends. We are interested in the spatial process of the spread, movement, aggregation and segregation in the time frame between 8500 and 5000 cal BP.

The settlement dynamics proxies that revealed these processes' dynamics are based on the temporal frequencies of radiocarbon-dated archaeological sites, which are represented as summed probability densities (SPDs). The underlying assumption is that the number and distribution of radiocarbon dates in time and space indicate the existence of settlement systems and reflect demography, as more people and more settlements result in more activity and more radiocarbon dates.

This is an explorative study. Its goal and focus are to identify large spatio-temporal patterns in the process of Neolithic settlement in the area around the Eastern Alps and not to test mono-causal explanations for dynamic processes of cultural change. In this way, it is an open-ended study without definite explanations.

Materials, methods and assumptions

The study area covers around 170 000km² and encompasses the western part of the Danube watershed above the Danube – Sava confluence. This includes the western part of the Carpathian basin, Eastern Alps and north-eastern section of the Dinaric Alps.

The study area was divided into grid cells over which we summarized spatial variables. Hexagon cell shapes were chosen as regular hexagons are the closest shape to a circle that can be used in a tessellation. Hexagons have reduced edge effects and have identical neighbouring cells, each sharing one of the six equal length sides. Furthermore, the distance between centres is the same for all the neighbours.

A database of 141 sites with available absolute dates from the Neolithic and Copper Age was compiled for the study area. The observed mean distance between sites is around 11km, while the expected

mean distance is around 20km, indicating the clustered distribution of dated sites. This also dictated the spatial resolution of the study. Grid cell diameter was chosen to be 25km, with each grid cell covering approx. 520km². In this way, the diameter of grid cell is approximately a double mean distance between sites.

The study area is covered with 320 grid cells. Due to the highly clustered distribution, only 77 grid cells are occupied with sites, forming several distinctive clusters. Most of the grid cells are occupied with only one site (43 grid cells, with a median one site per grid and a third quartile of two sites per grid cell), with the densest grid cell occupied by nine sites.

At this resolution, we assume that each grid cell represents the area of a regional settlement system (Kowalewski 2016) or settlement cluster (Parkinson 2002.397–398). A regional settlement system is defined here as interacting interdependent groups of people. It contains several (or several tens of) settlements and communities, tied manly with an exchange of various kinds into “regionally-integrated social networks” (Parkinson 2002.395)

A database of 815 radiocarbon dates from Neolithic and Copper Age contexts between around 8000 and 5000 cal BP was compiled for all sites in the study area. Neolithic and Copper Age contexts were defined on their material assemblage (presence of houses, pottery, domestic animals, and plants); pragmatically this means that they were already assigned to one of the regional Neolithic or Copper Age cultures (LBK, Starčevo, Lengyel, *etc.*) by the authors of the original publications. In order to uphold the quality of the database, all problematic dates (dates that seem too early or too late for a given context) and dates with standard deviations greater than 100 years were discarded, resulting in 750 dates being used in the analysis (see Appendix at <http://dx.doi.org/10.4312/dp.46.16>).

The settlement proxies used in the study are based on the temporal frequencies of radiocarbon-dated archaeological sites, which are represented as summed probability densities (SPDs). This proxy assumes that the temporal frequencies of dates in a given site indicate relative human population size and density of occupation at the site. The SPDs are mainly used

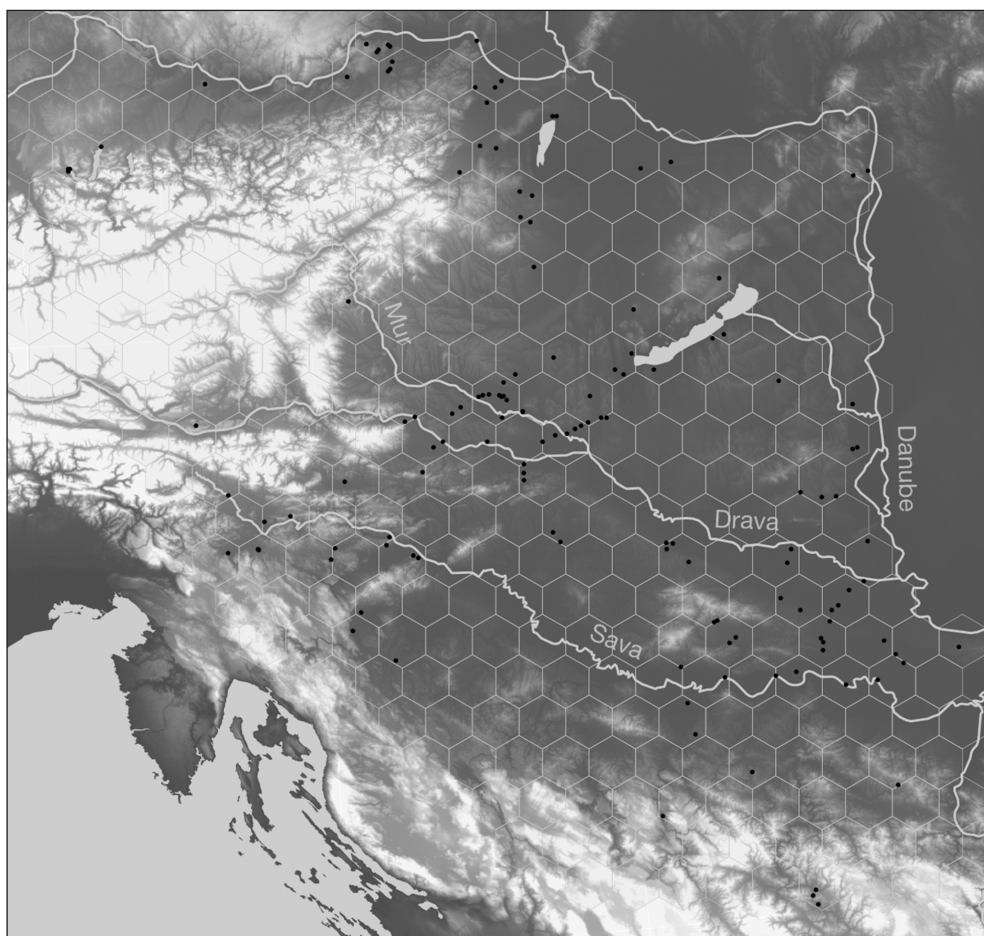


Fig. 1. Study area with sites and grid used in the study.

in demographic studies, while here they are used in a slightly more general way as indicators of grid cell occupation and therefore the existence of regional settlement system in a grid cell.

There are several potential issues associated with the use of summed probability densities, which are summarized by Alan N. Williams (2012), mainly being problems of sample size, intra-site sampling, taphonomic loss and calibration effects.

Two fundamental assumptions of the method are that the radiocarbon dates used in these analyses are associated with occupation events; and that the number of dates from a region represents the occupation events in the region. The first assumption is based on the logic of the selection of archaeological samples for dating. The second assumption is not necessarily true, as radiocarbon samples are not collected randomly between and within sites, and the process is heavily biased by sampling intensity and history of research. The collection of radiocarbon dates is always driven by specific research interests, and consequently the number of dates coming from

different phases on the same site may often be a consequence of the research questions being asked.

However, this bias is to some degree offset by aggregation of data. The working assumption of summed probability analysis is that a sufficiently large regional sample of radiocarbon dates will counteract any problems at the site level, and that multiple small non-systematic samples from a large assemblage of sites constitute a quasi-random sample of regional trends in occupation (Williams 2012:580).

In order to address this bias, the radiocarbon dates are binned (or aggregated) within grid cells. Radiocarbon dates are first binned into grid cell phases and then sorted in decreasing order within each grid cell phase (Shennan et al. 2013; Timpson et al. 2014). The dates within a given grid cell phase were further subdivided into bins if the difference between two adjacent dates was greater 200 radiocarbon years. The dates are first calibrated and summed within bins, with a bin sum normalized to the area of 1, and the resulting bin sums are then summed and normalized to produce the final SPD curve for a

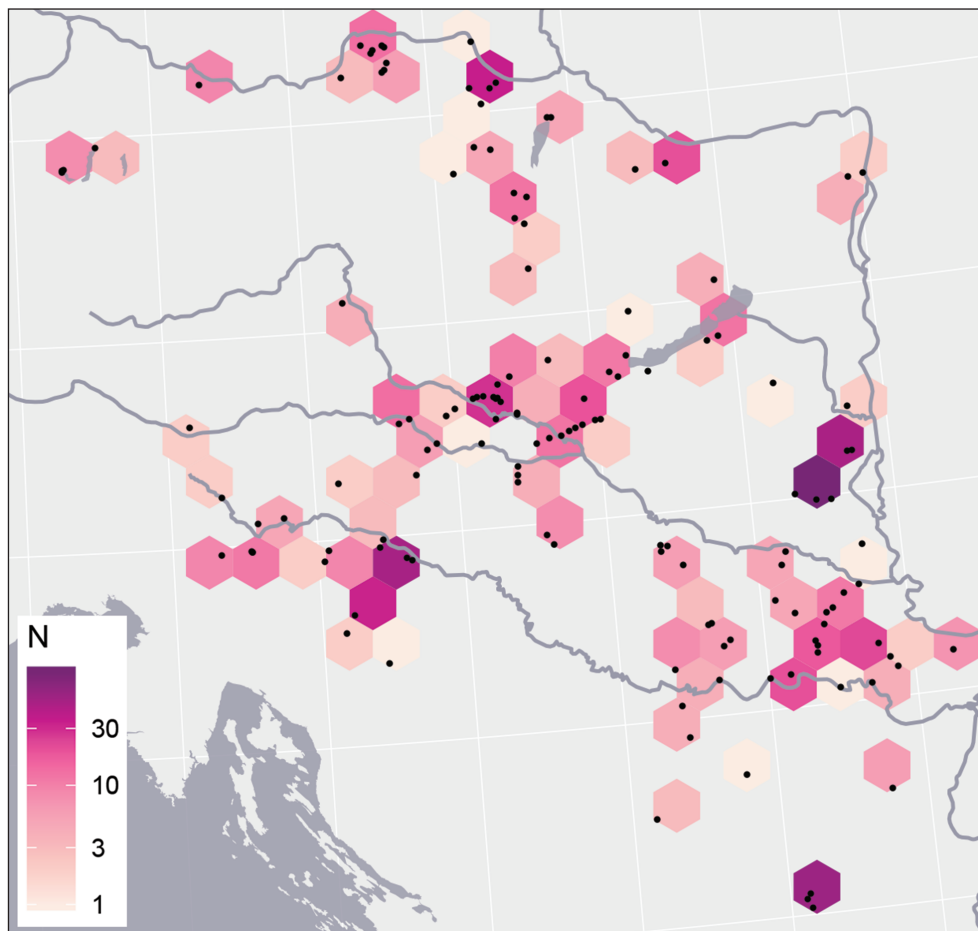


Fig. 2. A number of radiocarbon dates per grid cell. Values are log₁₀ scaled.

grid cell. This procedure controls for research bias when it comes to the frequency of samples per site or site phase, but it does not control for the bias stemming from the different regional histories of research.

All analysis was performed in an R statistical environment (*R Core Team 2018*), using the *rcarbon* package for radiocarbon calibration (using the IntCal13 radiocarbon curve; *Reimer et al. 2013*) and SPD analysis (*Bevan 2018*) and *sp* package for spatial analysis (*Bivand et al. 2013*).

For each grid cell, a normalized summed calibrated radiocarbon probability distribution was calculated. The number of radiocarbon dates varies from one per grid cell (9 grid cells) to 88 radiocarbon dates per grid cell with a median value of four dates per grid and third quartile at eleven dates per grid cell.

The ranges were calculated on the basis of the highest probability density and are the shortest ranges that include 95% of the probability in the probability density function.

The lower 95% range endpoint date was taken as the start of the Neolithic at a particular grid cell. This was then used to estimate the spread of the Neolithic across the study area using kriging interpolation (see *Brami, Zanotti 2015*).

Kriging is a two-stage geostatistical method which begins with analysis of the gathered data to establish the predictability of values from place to place. This results in a graph known as a semivariogram which models the difference between a value at one location and the value at another location according to the distance and direction between them (*Chilés, Delfiner 2012:147–150*). Based upon these, it estimates values at those locations which have not been sampled. The technique uses a weighted average of neighbouring samples to estimate the unknown value at a given location. Weights are optimised using the semivariogram model, the location of the samples and all the relevant inter-relationships between known and unknown values. The technique can also assess the uncertainty of the predictions.

Kriging data in our study consists of grid cell centroids with the date for a beginning of the Neolithic occupation, calculated using the procedure described above. Grid cells with only one radiocarbon date were excluded from the interpolation. The result of

kriging is an interpolated surface with values for the earliest estimated date of Neolithic settlement with a spatial resolution of 12.5km.

This data was used to compute the direction and speed of the spread of the Neolithic. The aspect and slope for 12.5km large grid cell were computed on a smoothed surface. The slope in this study is defined as the rate of change between adjacent cells, expressed as the time to traverse from each cell to its neighbours, while aspect is defined as the direction of maximum slope from each cell to each of its neighbours. Slope and aspect were visualized as a vector field, with the size of each vector indicating the speed and direction of spread.

SPDs were also used for crude demographic estimation, which is the most common use of summed calibrated radiocarbon probability distributions. In most of the palaeodemographic sites in studies, SPDs are summed together to an empirical SPD that is treated as a proxy for demographic dynamics. Therefore, it is a number of sites and extents of activity at a particular site that provide a proxy for demographic growth. Empirical SPDs are compared to theoretical growth curves to test the statistical significance of the empirical SPD curve (*Shennan 2009; Porčić et al. 2016; Blagojević et al. 2017*).

In this study the normalized SPDs for each grid cell are summed together. SPDs were thus aggregated or binned over grid cells. This approach offsets bias in the selection of regional research histories. Thus, a grid cell with one site has the same weight as a grid cell with many sites, as we assume that the difference in a number of sites is a direct result of sampling bias. The assumption is that each grid cell (and therefore local settlement system) has the same maximum population (which is of course not necessarily true). In this way, SPDs provide only a dynamic component, an indication of a change in settlement intensity over the grid cell, while the number of grid cells provides the main proxy into overall demographic dynamics.

Although this is an explorative study, we compared the empirical SPD curve against the theoretical null model of population growth. The null model assumes that the underlying population was stationary. Statistically significant positive local deviations from the null model (peaks) occur between 6860 and 6180 cal BP, while significant negative local deviations (dips) appear at 8000–7630 cal BP, 5880–5730 cal BP, 5450–5390 cal BP and 5350–5260 cal BP.

We also compared the empirical SPD curve for the study area with the SPD created from the subset of dates from the SE Alps area. The idea was to evaluate regional variations in settlement trends (see *Timpson et al. 2015; Crema et al. 2016*), and to test whether differences between curves are statistically significant, possibly indicating different settlement trends in the SE Alps area. We found significant positive local deviations (higher settlement intensity in the SE Alps area) at 6390–5940 cal BP, 5880–5780 cal BP and 5600–5390 cal BP and significant negative local deviation (lower settlement intensity in SE Alps) at 7810–6850 cal BP.

Another similar, even simpler graph is the number of grid cells occupied at a particular time. This estimate gives the extent of the settlement system and can provide insight into the spatial dynamics in terms of the expansion and contraction of regional settlement systems. It was constructed by counting grid cells where there is an indication of occupation (with 95% probability) for every century, and summarized in a graph.

Results

The patchy distribution of occupied grid cells reflects the uneven density of Neolithic sites in the study area (Figs. 2–3). Grid cells are agglomerated into several contiguous clusters, two in Slavonia, a large one stretching across the SE Alps, across Western and Central Transdanubia, and a third in the Vienna basin. There are also some curious gaps, an especially large one in the Alps, but also smaller gaps in the middle reach of the Sava (Posavina) and Drava rivers (Podravina), parts of Southern and Central Transdanubia and Styrian basin.

This is probably a result of research bias, as most of the new dates are from recent research, especially in relation to the Slovenian and Hungarian motorway construction programme. However, it also reflects a deeper pattern, as Neolithic sites seem to avoid hilly and mountainous terrain.

When we plot each grid cell with the dates of earliest occupation (Fig. 3) it can be noted that the ear-

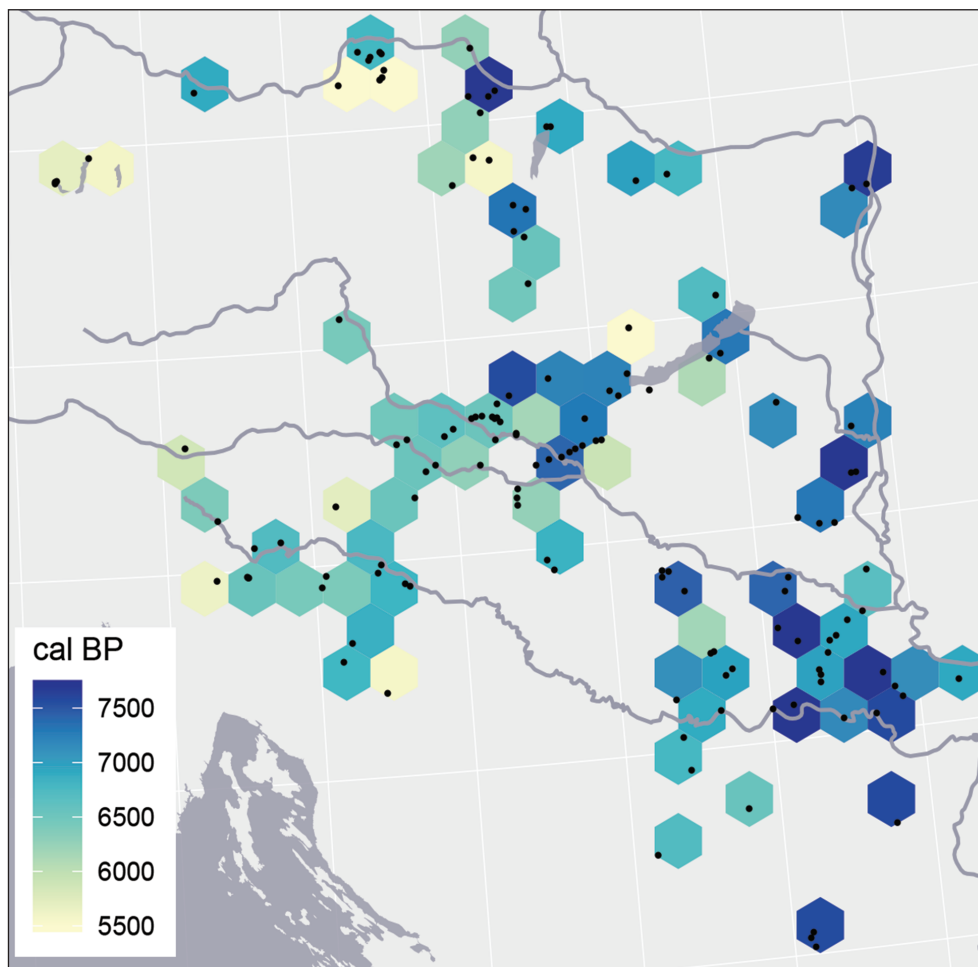


Fig. 3. The earliest appearance of the Neolithic settlement in a grid cell.

liest grid cells are concentrated in the SE edge of the study area (mainly Slavonia around 8000 cal BP), but isolated grids cells with very early dates are spread all over the study area. It seems that within 500 years after the first appearance of the Neolithic in Slavonia, Neolithic sites can be found all over the study area, except the Alps. Thus we have the earliest appearance of Neolithic settlements after 8040 cal BP in Slavonia (Sopot: *Krznarić Škrivanko 2011*), then after 7830 cal BP in the Vienna basin (Brunn am Gebirge: *Stadler, Kotova 2010*), after 7780 cal BP in the Budapest area, and after 7590 cal BP in western Transdanubia, at the edge of the SE Alps (Szentgyörgy-Pityerdomb: *Bánffy 2004*). There seem to be two possible corridors of expansion from the Slavonian core area, one along the Danube and the other on along Drava River and then along the eastern edge of the Alps.

The first Neolithic thus appears as isolated islands or enclaves of Neolithic settlements which then slowly expand to fill neighbouring regions. However, there are some areas, especially the SE Alps west of the Mur River, which are consistently settled much later than their neighbours.

The spatio-temporal pattern of the 2000-year long process of the formation of Neolithic settlement systems in the study area is clearly visible on the map of the estimated age of the arrival of the Neolithic (Fig. 4).

The core area for the spread of the Neolithic is that between the Sava and Drava. From the origin in Slavonia, the Neolithic expands in two prongs, one along the Danube and the other along the Drava, Mur and eastern foothills of the Alps. This expansion is in the form of several very early enclaves with a much earlier appearance of the Neolithic than the surrounding areas, such as those enclaves along the Danube, Vienna basin and Western Transdanubia. Those enclaves are limited one or two grid cells, and might in some cases reflect the research bias. What we see is a very crude remnant of a string of small communities stretching along expansion corridors.

There are also some backwater areas with much later Neolithic occupation. The most prominent being the area of the Alps and the smaller area around Balaton lake. While those small backwater areas are most probably the result of research bias, the Alps area

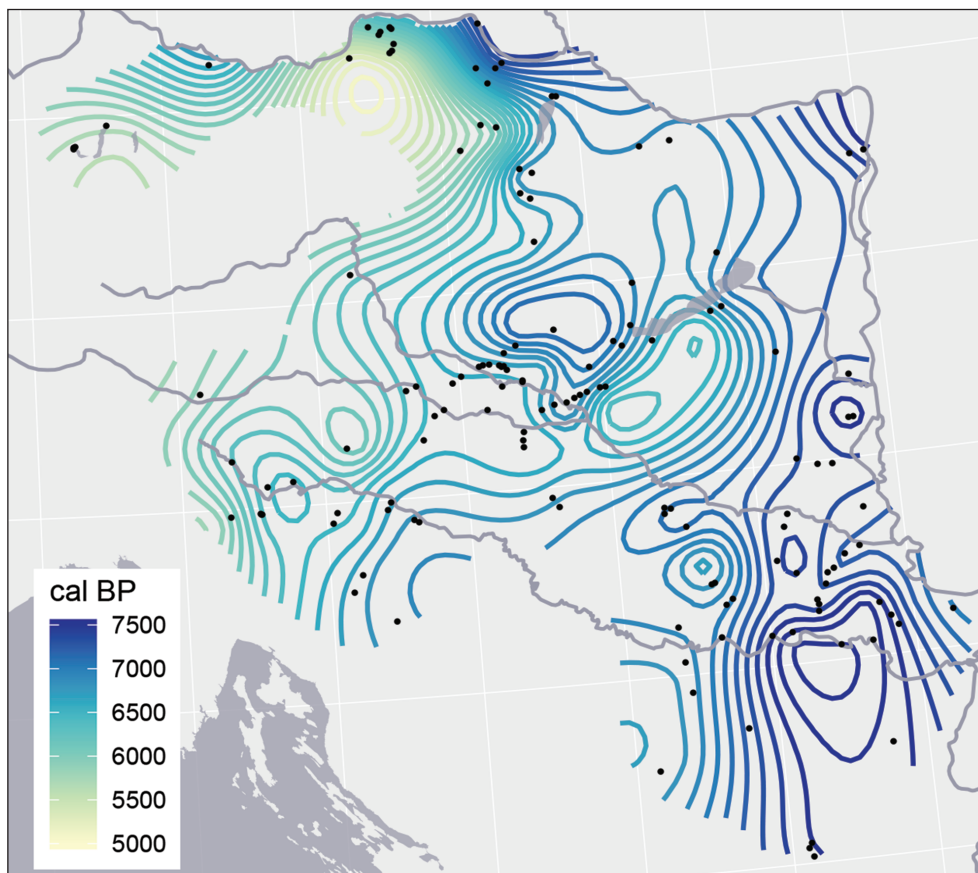


Fig. 4. Isochrone map of the estimated age of the beginning of the Neolithic, result of a kriging interpolation. The contour interval is 100 years.

does not seem to be an artefact. A large number of dates from the SE Alps indicate the relatively late arrival of the Neolithic with rapid expansion along river valleys.

Dense isochrones indicate the existence of a stationary border, most prominently on the edges of Carpathian Basin and the Alps, along the lower course of the Mur river, where the Neolithic expansion toward the west halted for almost 500 years with a stationary border, and more than 1000 years with a stationary border on the western edge of the Vienna basin toward the Alps.

The distance and shape between isochrones encode the rhythm, tempo and direction of the process, which can more clearly be visualized as a vector field (Fig. 5). The overall speed of the process seems to be quite rapid. The study area was crossed in a direction from SE to NW in around 200 years, as the 370km distance between Sopot in Slavonia and Brunn am Gebirge in the Vienna basin was covered in a span of around 210 years, which gives an average speed of Neolithic expansion of about 1.7km per year. Thus is a speed of enclave colonization over the study area

that reflects the high mobility of early Neolithic communities.

The local speed of expansion was estimated to be from 0.025 to around 5km per year, with the median speed around 0.15km per year. The local speeds estimated in this study indicate other processes, a relatively slow expansion around core regions and enclaves that filled the landscape.

The estimated speed of expansion is the highest in the areas of no data, such as the Alps and middle reach of the Sava, where it slows down when encounters Alpine foothills, once it reaches the area where we have more data. This points to significant gaps in the data.

The general direction of expansion is mostly from the core areas and enclaves toward surrounding regions. Even so, it looks that the main direction of spread is from SE to NE.

Although the spatial resolution is quite low, it seems that the main corridors of expansion are the river valleys of Danube, Drava, and the Sava.

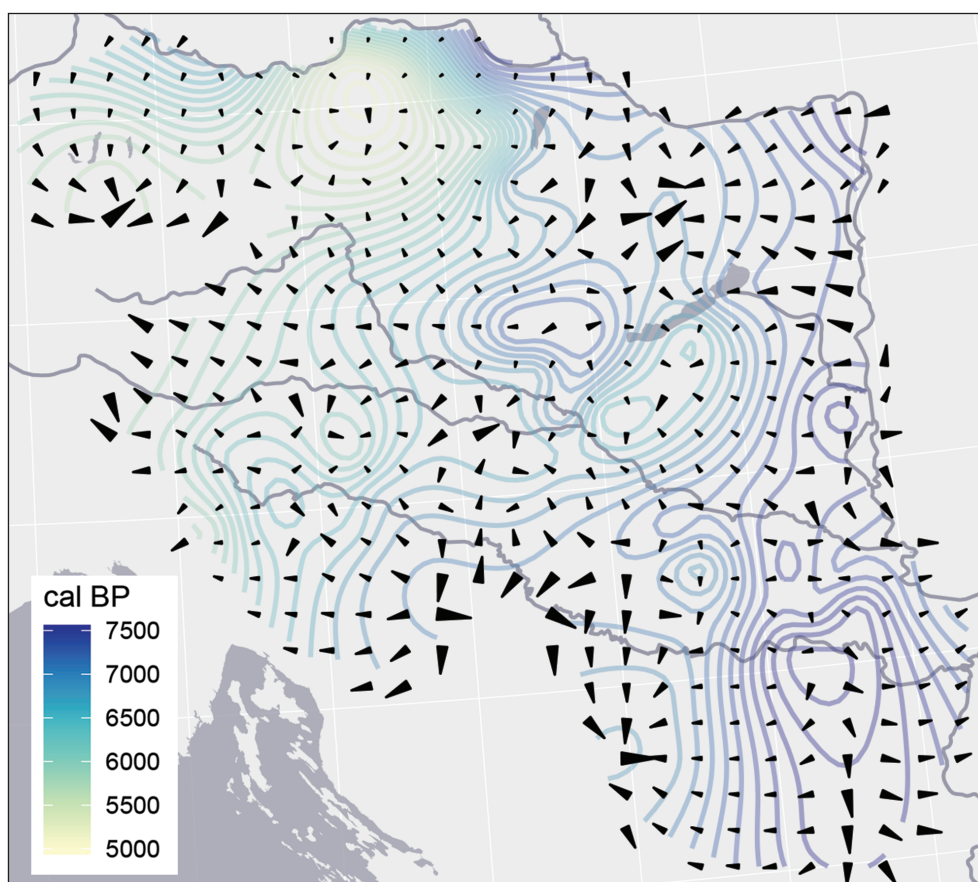


Fig. 5. Direction and speed of the spread of the Neolithic, based on the estimated age of the beginning of the Neolithic (Fig. 4) visualized as a vector field.

Expansion along the Mur and Drava Rivers slows down until an over 500-year long standstill of the stationary border when settlements reach the foothills of the Alps. However, after the border was breached it expands very rapidly into the hilly fringe of SE Alps. This expansion happens at roughly the same time as the expansion of the Neolithic along the Sava River into the SE Alps, and might be a part of the same process.

Based on the analysed data we can identify at least two processes behind the pattern. The first is the establishment of enclaves which happened in the first 500 years and then spread relatively slowly from there. In some areas, especially on the western fringe of the Carpathian Basin, we can observe the formation of a stationary border for almost 500 to 1000 years, followed by quick spread into the Alpine foothills.

The general SPD curve constructed from the SPD curves for each grid cell thus reflects the settlement and demographic dynamics in the study area (Fig. 6). The curve shows a rapid increase from 8000 to 7500 cal BP with another push after 7000 cal BP when the curve reaches a peak at around 6300 cal BP. After 6500 and especially after 6000 there is a pronounced dip in the curve, with small increase and local peak just before 5500 cal BP followed by a slow decrease until the end of time frame. Main peak and dips are statistically significant.

This curve might overrepresent the earliest dates due to the research bias, as research strategy is usually focused mainly on the oldest and the earliest dates and contexts. Nevertheless, the SPD curve reflects some trends, the most interesting being the rapid decline after 6300 cal BP. The fast rise and peak are consistent with the Neolithic demographic transition model (*Bocquet-Appel 2011*), which postulates fast growth at the border, followed by a drop a few centuries later. The same pattern is found in other regions all over Europe (*Shennan et al. 2013*).

More interesting are regional differences in the process.

The curve for the SE Alps rises rapidly just after 7000 cal BP. Most of the growth in the study area between 7000 and 6300 cal BP can be attributed to the expansion and growth in the SE Alps area in this period. There is also proportionally less decline than elsewhere after 6300 cal BP, where especially after 6000 cal BP the SE Alps contribute most of the value to the overall curve. Those differences from the study area are statistically significant

Another estimate shows the number of occupied grid cells at 100-year intervals (Fig. 6). This is a similar although simplified estimate of the extent of Neolithic settlement in the study area. The curve shows a steady increase in the number of occupied grid cells starts around 8000 cal BP and reaches a peak around 6500 cal BP. After 6300 cal BP, beginning of the Copper Age in the study area, the curve experiences fast decline with some fluctuations after 6000 cal BP. Overall it seems that the extent of the Copper Age settlement systems is approximately half that of the maximum extent of Neolithic settlement around 6500 cal BP in the study area.

In contrast to the study area, the SE Alps experiences different dynamics. Fast expansion into the SE Alps starts just after 7000 cal BP and reaches a peak at around 6500 cal BP, like the curve for the overall study area. It looks as if the main contribution to the overall extent of settlement after 7000 cal BP can be attributed to the expansion into the SE Alps. When, after 6500 cal BP the curve experiences a notable and rapid drop, the reduction in the SE Alps is

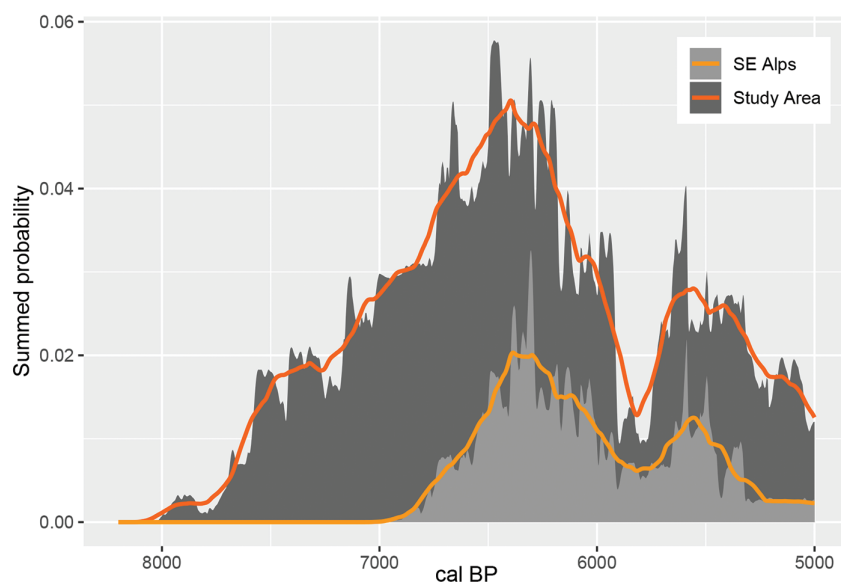


Fig. 6. SPD curve based on the Neolithic dates from the study area (dark) and a subset of dates from the SE Alps (light) and 200-year rolling means (oranges).

not as significant as in the overall study area. After the drop stabilises at around 6000 cal BP, the SE Alpine area contributes a large number of grid cells to the overall study area, as up to half of the grid cells in the study come from the area of the SE Alps.

This might be exacerbated by the research bias, as this is the period of the appearance of Neolithic in Slovenia, where a lot of dating effort was focused. The Late Neolithic has received much less focus elsewhere. However, even considering this research bias, the area of the SE Alps experiences different dynamics than the rest of the study area.

The spatial pattern of this process is clearly shown in a sequence of settled grid cell maps at 500-year intervals (Fig. 7). Neolithic settlement starts as sparse isolated grid cells in Slavonia, along the Danube, Bosnia and at the eastern edge of the Alps. Between 7000 and 6500 cal BP we can observe a process of expansion around already established grid cells. The first clusters of grid cells are formed in Slavonia, in the area between the Sava and Drava and at the eastern edge of the Alps, between the rivers Balaton and Mur.

The time slice between 7000 and 6500 cal BP is marked by expansion into the SE Alps, with a further process of expansion in other areas. This is also the period where we can observe the abandonment of the first grid cells. This process continues after 6000 cal BP, with continuous expansion into the SE Alps and extensive abandonment of grid cells in the lower reaches of the Sava, Drava and Danube. The general decline in the settled grid cell density continues toward 5000 cal BP.

Discussion

Alasdair Whittle in his discussion of long-term and large-scale processes suggests three interweaved processes behind the formation of European Neolithic settlement patterns. There is the first phase of primary agricultural colonization, followed by the second phase of internal infilling and continued ex-

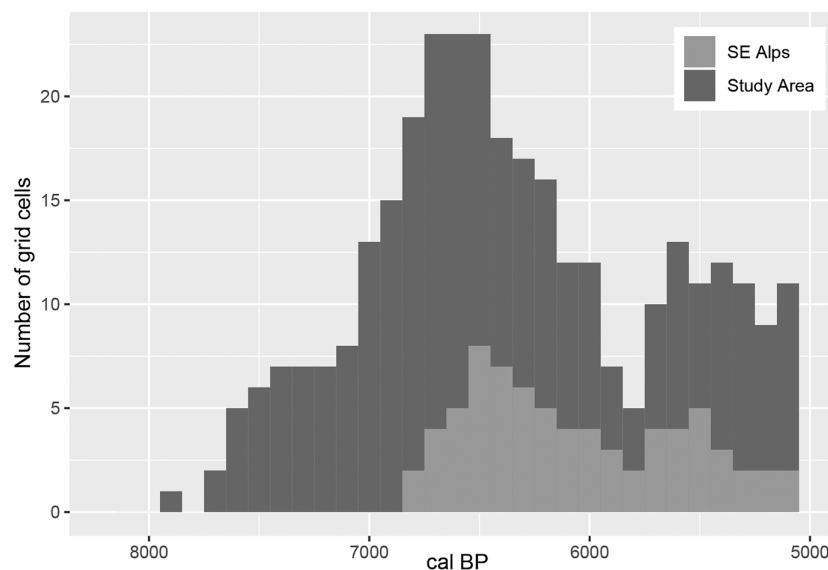


Fig. 7. Number of occupied grid cells by century from the study area (dark) and SE Alps (light).

ternal expansion, followed in turn by the final phase of 'packing' (Whittle 1987:34).

The picture painted here is a bit more intricate. Complex spatio-temporal processes can be decomposed into three basic processes, spread, then movement, and aggregation or segregation (O'Sullivan, Perry 2013). Although the present study observes these processes at a very low spatial and temporal resolution it is still possible to appreciate the complexity and identify the main components. The spread processes include growth, diffusion and percolation, and they all refer to the expansion of a common boundary or fronts of a phenomenon, such as the expansion of a gas into a vacuum, forest fire or spread of animal species in a new environment (O'Sullivan, Perry 2013:133–168). Movement refers to the spread of individual entities, and can be seen as the secession of shifts which relocate an entity (single molecule of gas, fire, or individual animal or human) from one location to another. These walks can be random (as in case of isolated gas molecules) or, more often, influenced by the environment or other entities (O'Sullivan, Perry 2013:97–131). Aggregation and segregation are two facets of the same process, driven by a tendency of similar elements to group together in space or dissimilar elements to separate in space (O'Sullivan, Perry 2013:57–95).

The process of the formation of Neolithic settlement systems in the study area was not a swift, uniform transition that established stable Neolithic settlement system in the course of a few centuries. It was not an even diffusion of Neolithic settlements, filling the

landscape of the study area. Instead, as already argued by Marek Zvelebil (2001.1), it was a complex interaction of several processes with their own dynamics and time depth, which included both movement and contact, combining in a very complex and long historical trajectory, embedded in the existing social and historical conditions. In this sense, the social context of the agricultural transition in the study area had structure and agency. The formation of Neolithic settlement systems in the study area lasted several millennia and included lives over tens of generations. The process was probably experienced more as continuity than one of disjuncture and change (Hofmann, Gleser 2019).

The spread of Neolithic settlements was part of a wider phenomenon, the Neolithisation of Europe. However, the spread of specific material assemblage associated with Neolithic was not uniform. Instead, the edge of the process observed in a study area has a ragged, swirly, pixelated border (Robb 2014.33). The Neolithic material assemblage percolated along different paths, with the establishment of pioneer communities at the front. The discontinuous spread and establishment of enclaves point to the key role of movement and personal and group mobility in the process. Spread involved the movement of small groups or even individuals (see Zvelebil 2001.2A). These movements usually do not have a single origin point, creating a perplexing pattern of “migrations without a homeland” (Robb 2014.658–659). What drives such groups onward is poorly known (but see Hofmann 2016). Movement seems to follow the natural corridors in a landscape, especially river valleys. Here, the Danube, Sava, Drava, and Mur seem to be main lines along which Neolithic communities moved forward. Rapid enclave movements tend to halt when they encounter either different environments (Alpine foothills) or dense forager settlements (possibly Alpine foothills and the Balaton Area; see Bánffy 2006.130–136). The resulting frontiers lasted a long time, and may include the movement of individuals, families or small groups of people across the border.

The third process is the aggregation or segregation of Neolithic settlements, which created a patchy landscape of a structured, organized and consistent Neolithic social world surrounded by untamed, wild landscape. There are two general factors behind the process, one is the environment while the other is demographic and social. Initial enclave colonization targeted specific environmental niches. After the formation of initial or core settlements, a gradual pro-

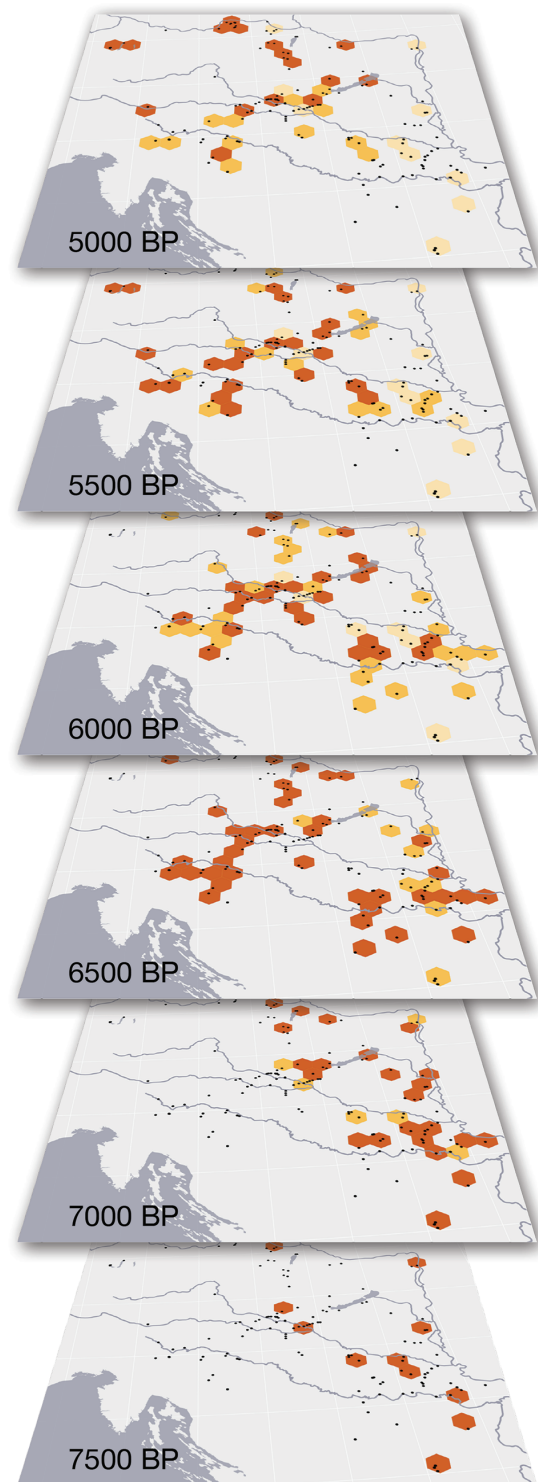


Fig. 8. The extent of Neolithic and Copper Age settlement systems in the study area in 500-year time slices. Dark grid cells indicate occupation while light indicates abandoned grid cells.

cess of aggregation continues as a slow infill of the landscape around initial settlements, creating Siedlungskammern of Neolithic settlements. The movement of people and things between settlements and patches connected them in the social landscape,

prone to shifting patterns of interaction and integration. There are several centripetal and centrifugal forces leading to either integration or fissioning of groups. These changes are reflected in a settlement pattern and may be a driving force behind other processes, such as movement and spread.

The dynamics of the Neolithic spread and the movement of individuals and small groups were determined to an extent by social processes in already settled regions. This is especially pronounced in the case of the secondary expansion of Neolithic settlement systems into the SE Alps.

Around 6700 cal BP there is a pronounced change in the settlement systems in the Balkans with the appearance of stratified tell sites, large nucleated settlements and large cemetery grounds (Hofmann, Gleser 2019.24–29). In the study area, this process is very well documented with the dynamics in Alsónyék-Bátaszék in south-west Hungary, where the settlement that formed in the Starčevo phase experiences sudden large-scale expansion around 6800 cal BP with the erection of settlement with 122 houses and cemetery with around 2300 graves. It is just one of several substantial Lengyel culture sites in the neighbourhood which include both cemeteries and settlements. Alsónyék-Bátaszék became a large aggregation of people, with a population that suddenly increased almost fifty-fold. This aggregation stayed in place for only one generation, followed by an equally fast dispersal (Osztás et al. 2012; 2013; 2016).

This process coincides with the Neolithic expansion into the SE Alps, especially the area of modern Slovenia, which started after 7000 BP. It is marked by a relatively fast expansion along the Sava River, establishment of settlements in the river valleys and plains. This is followed by the expansion along Drava and Mur river valleys into the Alps. This process of expansion into the Alpine river valleys continues for almost 500 years. The same pattern of breach of long-standing frontiers is also visible elsewhere in the study area.

A resurgence of Mesolithic ancestry in the Late Neolithic has already been noted all over Europe, although in some places this process was limited. Genetic signatures associated with European hunter-gatherers (mitochondrial U-haplotypes) reappear in central Europe during the 7th and 6th millennium BP (Haak et al. 2015; Bollongino 2013; Fu et al. 2016; Lipson et al. 2017). The possible origins of this resurgence are currently not yet clear, however, it

might be associated with the expansion of Neolithic communities into previously marginal areas, new contacts with Mesolithic hunter-gatherer communities that could have been accompanied by increased genetic exchange with more central areas.

On the other hand, it seems that by around 6600 cal BP, tell and nucleated sites which previously characterized most of the Carpathian Basin were suddenly abandoned. The transition from Late Neolithic to Copper Age is marked by a change from nucleated to a dispersed settlement pattern. In the whole Carpathian Basin previously nucleated sites were replaced by smaller, flat settlements, largely characterized by shallow single-layer occupation deposits, along with a change from intramural burials to large extramural cemeteries (Parkinson 2002.391–394; Borić 2015.157). This seems to be a wider process that occurred almost simultaneously over the study area.

This process of segregation can be detected all over the study area. Initial Neolithic settlements in Lahinja river valley and Krupsko polje in Bela Krajina, Slovenia targeted fertile soils and were established soon after 7000 cal BP. In the mid-6th millennium BP there is an expansion from core areas into the drier Karst hinterland, with new sites that were occupied less intensively and for shorter periods and the formation of enclosed upland sites (Budja 1995; Mason 1995). However, initial settlements, such as Moverna vas, were not abandoned.

The pattern of smaller dispersed settlements in the Early Copper Age, despite possible research biases regarding the visibility of small dispersed sites, could suggest a drop in population levels, even if the number of individual sites increases. However, the demographic decline did not affect all areas equally, but is much more pronounced in core areas of Slavonia, while newly settled areas peripheral areas seem to experience much less severe declines.

Attempts to explain these discontinuities by simple boom-boost cycles of population dynamics (caused by climate change which affected subsistence practices, ultimately lowering reproductive success; Shennan 2009; 2013; 2018) seem overly simplistic and theoretically impoverished. If the Neolithic was a historical process (in contrast to an evolutionary episode) the explanations must take into account the nature of social interaction and the way it is stabilized by the use of durable material resources and symbols. Material resources fix the way individuals

interact, behave and move, and dictate new skills, habits and actions. They impose new physical techniques, training and disciplines, making individuals become productive members of a specific assemblage.

The spatial segregation processes that mark the transition from Late Neolithic to Copper are obviously connected to increased residential mobility, as reflected in the dispersed settlement pattern and occupation of new areas with newly founded settlements. It is difficult to identify the mechanisms behind the centrifugal forces which caused the segregation of previously dependent and closely-knit communities at a larger regional level (*Borić 2015.189–193*).

It might be the result of a restructuring of a Neolithic assemblage which becomes destabilized with the introduction of new components such as copper metallurgy and the growing importance of domestic cattle and pastoral economy (*Orton 2012*). After all, assemblages are precarious composite entities that just about hold together because all their parts happen to be in the right places, doing the right things to achieve this. Adding and swapping new elements in an assemblage can cause non-linear transitions to occur (*DeLanda 2006.10–11*).

Conclusion

The paper approached large spatio-temporal trends in the formation and change of regional settlement systems in the Western part of the Carpathian Basin area around the Eastern Alps in the Neolithic and Copper Age. We were interested in the spatial processes of spread, movement, aggregation and segregation in the time frame between 8500 and 5000 cal BP.

The distribution of Neolithic and Copper Age sites in the study area is clustered and patchy. The first Neo-

lithic thus appears as isolated islands or enclaves of Neolithic settlements which then slowly expand to fill neighbouring regions.

The core area for the spread of the Neolithic is that between the Sava and Drava. From the origin in Slavonia, the Neolithic expands in two prongs, one along the Danube and the other along the Drava, Mur and eastern foothills of the Alps. This expansion is in the form of several enclaves with much earlier appearance of the Neolithic than surrounding areas, such as ones along the Danube, Vienna basin and Western Transdanubia.

There are also some backwater areas with much later Neolithic settlement. The most prominent being the area of the Eastern Alps. We identified the existence of stationary borders, most prominently on the edges of Carpathian basin and the Alps, along the lower course of the Mur River, where the Neolithic expansion toward the west halted for almost 500 years.

However, once the border was breached it expands very rapidly into the hilly fringe of SE Alps. Fast expansion into SE Alps starts just after 7000 cal BP and reaches a peak at around 6500 cal BP, which is also the period of the maximum extent of Neolithic settlement systems in the study area.

After 6300 cal BP study area experiences a significant reduction in the extent of settlement systems, associated with the Late Neolithic to Copper Age transition. This was a significant decrease in the extent of settlements system, but not all areas were affected to the same extent.

Appendix is available at
<http://dx.doi.org/10.4312/dp.46.16>

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