Understanding the local dynamics: reconstructing the direction and estimating the local speed of Neolithic expansion in the Central Balkans

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ABSTRACT – This study addresses the dynamics of the Neolithic expansion in the Central Balkans by reconstructing its direction and speed of spread. The Inverse Distance Weighting (IDW) method is applied to the earliest radiocarbon dates from Starčevo culture sites in Serbia. Local speed estimates are derived from the earliest dates within specified spatial bins. The results confirm the assumed south-to-north direction, revealing rapid progression, particularly in the southernmost region. The possibility of pioneering scouting groups was also discussed. The results confirm the arrhythmicity of the Neolithization processes and higher local spread rates while offering new insights into Starčevo culture mobility.

KEY WORDS – Starčevo culture; Early Neolithic; direction of the spread; local speeds; Inverse Distance Weighting method

Introduction

The spread of the Neolithic into Europe: models and dynamics

After arriving in the territory of Greece from southwestern Asia in the 7th millennium BC (Perlès et al. 2013; Özdoğan 2014), the first Neolithic farmers spread to other parts of Europe following two routes. The maritime Mediterranean route led from Greece to the eastern and western Adriatic coasts, southern France, and the Iberian Peninsula. The continental route led from Greece through the Balkans to central, western, and eastern Europe. This process lasted about 3000 years (the Neolithic appeared at the latest in northwestern Europe, a little after 4000 BC) (Price 2000; Bocquet-Appel et al. 2009). In addition to different routes, some studies clearly define different phases of Neolithic expansion from Anatolia, mostly
based on differences in the summed probability distributions of radiocarbon dates from central Anatolia and other regions to which the Neolithic later spread (Brami, Zanotti 2015). According to these authors, the first phase implied the appearance of the Neolithic in central Anatolia, where it remained ‘localized’ for about 2000 years, after which it spread to the area of southwestern Anatolia and the Aegean basin. Around 6600–6500 BC, the Neolithic also appeared in Thessaly and Greek Macedonia, from where it spread further north. After that, around 6000 BC, the Neolithic reached the area of Eastern Thrace, from where it spread arrhythmically (Brami, Zanotti 2015).

Regarding the processes involving the establishment and subsequent expansion of the Neolithic, models explaining them can be built based upon either demic diffusion or cultural diffusion (or, sometimes, their combination) as the primary drivers of the phenomenon. Demic diffusion implies the expansion of populations (and changes in their size), inhabiting new areas and bringing their way of life, while cultural diffusion implies the transfer of ideas and knowledge (related to new technologies, agriculture, animal husbandry, etc.) to indigenous hunter-gatherer communities. When it comes to demographic models of population expansion, the following can be distinguished: the wave of advance model, the so-called leap-frog (or selective) colonization, elite dominance, infiltration, and individual border mobility, to name just some of them (Ammerman, Cavalli-Sforza 1973; 1984; Renfrew 1987; Tringham 2000; Whittle et al. 2002; Richards 2003; Bar-Yosef 2004; Pinhasi et al. 2005; Davison et al. 2007; Bocquet-Appel et al. 2009; Borić, Price 2013).

The wave of advance model (hereafter WoA) was proposed with the aim of explaining the spread of the Neolithic from the southwestern Asia to Europe and its further progress, and soon after it was first proposed it became the basis for much of the subsequent research and interpretation of the Neolithization processes. The model is an upgrade of the hypothesis proposed by Grahame Clark (1965) regarding the spread of the Neolithic from southwestern Asia. This hypothesis, which was based on the map of radiocarbon dates available at that time, suggests that the Neolithic first arrived in Greece and then expanded to the Balkans, eventually spreading further into Europe. The authors who defined the WoA model, archaeologist Albert Ammerman and geneticist Luigi Cavalli-Sforza (1971; 1973), managed to record regularities in the occurrence of radiocarbon dates, which indicated the gradual spread of the Neolithic through Europe. This observed process was explained to be a consequence of colonization, i.e., demic expansion.

In a subsequent paper, the authors reinforced their argument with the results of genetic research (Ammerman, Cavalli-Sforza 1984). More specifically, the combination of the population dynamics model on the one hand and the spatial component on the other represents the basis of this model. The WoA model assumes that Neolithic populations grew following the logistic growth model. More precisely, the model proposes that the primary Neolithic population grew rapidly up to a certain point, after which the growth slowed down, eventually ceasing once the carrying capacity was reached (Ammerman, Cavalli-Sforza 1984; Mooney, Swift 1999; Chamberlain 2006).

The spatial component of the model refers to the movement of people, i.e. the settlement of suitable uninhabited space in the immediate vicinity. Once these spaces are inhabited within the immediate surroundings, there is continued advancement of the ‘wave’, i.e. further movement of people. The rate of Neolithic expansion, estimated by regression analysis, is ~ 1km per year (Ammerman, Cavalli-Sforza 1984). Criticisms of the model point out its inability to encompass the complexity of the Neolithization processes. This limitation is also evident in the occurrence of several rapid expansions in specific regions, followed by subsequent periods of stagnation. That is, some authors point out that models based on linear regression, such as WoA, conceal strong regional variations by averaging them, although they are good for explaining comprehensive patterns and the direction of Neolithic expansion at the continental level (Brami, Zanotti 2015). In this context, other modes of Neolithic spread are insufficiently included, primarily the diffusion of cultural influences, especially in areas with confirmed indigenous hunter-gatherer populations. The use of genetic maps for Europe, which served the authors as confirmation of the proposed model, has since been repeatedly criticized. This criticism stems from the fact that the maps do not contain chronological data, so they cannot be unequivocally linked to a specific period. Nevertheless, most research (Gkiasta et al. 2003; Bocquet-Appel et al. 2009; Fort 2012, and others) indicates that the WoA model provides a strong
explanation of the Neolithization process at the continental level. Furthermore, recent estimates of Neolithic spread speed on a continental scale align closely with the values projected by the WoA model (~1km/yr) (Gkiasta et al. 2003; Pinhasi et al. 2005).

**The rate of the Neolithic spread: previous studies**

Numerous studies of the spatio-temporal patterns of the spread of the Neolithic in different parts of Europe indicate that these processes were not uniform and that they depended on many factors (geo-ecological, climatic, or cultural) specific to individual regions. More recent studies that considered the influence of climatic factors, biomes, and various geographical features in different regions indicate high variability between regions and at different time intervals (Davidson et al. 2006; Bocquet-Appel et al. 2009; 2012; Lemmen, Wirtz 2014; Silva, Steele 2014; Silva et al. 2014; Weninger et al. 2014; Orton et al. 2016; Fort, Paretra 2020). These studies are based on various statistical modelling techniques and often use radiocarbon dates as one of the parameters. It has already been mentioned that, according to the WoA model, the estimated speed of Neolithic expansion is about 1km per year (Ammerman, Cavalli-Sforza 1984). This speed varied in different periods and in different areas, and new studies have yielded estimated speeds of the spread that range from ~0.03 to as much as 29.475km per year, depending on the region (Pinhasi et al. 2005; Bocquet-Appel et al. 2012; Silva, Vander Linden 2017; Fort, Paretra 2020). For this reason, the concept based on the assumption of a constant rate of spread cannot a priori be applied to any region. Nevertheless, if the process of the expansion of the Neolithic way of life is observed at the continental level (the whole of Europe), it could be characterized as slow and gradual.

Another study compared the estimated rate of Neolithic spread, which was obtained by interpolating radiocarbon dates from various European and southwestern Asian Neolithic sites, with rates predicted by several different models: demic, cultural, and their combination (Fort 2015). The results indicated that different regions exhibited different dynamics of Neolithic spread, but also different strategies for adopting the new lifeways. Genetic research indicates that cultural diffusion played the most prominent role in certain regions, including northern Europe, the Alps, and the area west of the Black Sea (Fort 2015, 5 and cited references). On the other hand, demic diffusion was dominant in the Balkans and Central Europe (Gkiasta et al. 2003; Fort 2015). When considering a blend of demic and cultural diffusion influences, the range of estimated speeds allowed for the more precise determination of cultural diffusion’s contribution to the Neolithic spread in specific regions (Fort 2015.5). Spatial interpolation methods that included radiocarbon dates from Neolithic sites have been used in various studies to estimate not only the speed but also the direction(s) of Neolithic spread on the continental scale and at the level of individual regions (e.g., Pinhasi et al. 2005; Bocquet-Appel et al. 2009; Brami, Zanotti 2015). Another important piece of research on the Neolithic of Europe, with a focus on individual regions, involved the reconstruction of the direction and rate of the Neolithic expansion using the geostatistical method of interpolation (kriging) (Bocquet-Appel et al. 2009). An important segment of the research is the inclusion of potential ecological barriers that could have influenced the direction and speed of the Neolithic expansion. Moreover, the estimates of the population density of individual areas enabled a better interpretation of the results obtained by spatial interpolation. In this case, different zones of expansion were defined, as well as centres of stagnation and further expansion. Among other things, the results indicate the non-linearity of the Neolithic expansion into (and through) Europe and define it as a process characterized by phases of expansion and stagnation (Bocquet-Appel et al. 2009). This arrhythmicity of the process is also indicated by other studies (Gkiasta et al. 2003; Pinhasi et al. 2005; Brami, Zanotti 2015; Porčić et al. 2020). In the study conducted by Marina Gkiasta et al. (2003), they employed a regression analysis that utilized the earliest dates from Late Mesolithic and Early Neolithic European sites, along with distances from the chosen centre of Neolithization (in this case, Jericho). This study aimed to test the Neolithization patterns proposed by the WoA model. The estimated mean speed of Neolithic expansion was ~1.3km/year, which is close to the originally estimated values within the WoA model (Gkiasta et al. 2003.51). The initial spread of the Neolithic from the presumed centre followed a northwestern path, but regional deviations in different parts of Europe are also observed on isochron maps (Gkiasta et al. 2003). An extensive investigation of the spatio-temporal patterns of Neolithic expansion, using radiocarbon dates from over 700 sites in Europe, southwestern Asia, and Anatolia, as well as the distances from 35 possible Neolithic centres, also yielded significant results (Pinhasi et
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The Early Neolithic of the Central Balkans

The appearance of the Neolithic in the territory of the Central Balkans (in this paper, the term ‘Central Balkans’ refers to the territory of modern-day Serbia, and both these terms will be used throughout the paper) is defined as the Starčevo culture, which, according to the traditional definition, was part of the wider cultural complex Starčevo-Körös-Criş. Geographically, this heterogeneous complex included the territory of the Danube region, the right bank of the Danube (Starčevo culture), the Tisza valley in the Great Hungarian Plain (Körös culture), and Transylvania (Criş culture), i.e. the area of modern Serbia, northern, eastern, and central Bosnia, eastern and northern Croatia, Romania, and southeastern Hungary (Garašanin 1979; 1982; Bailey 2000; Tasić 2009; Mester, Rácz 2010) (Fig. 1). In an even broader sense, the Early Neolithic cultures of the region include Amzabe-govo-Vršnik in North Macedonia as well as Karanovo in Bulgaria.

The beginning of the Starčevo culture is conventionally dated to around 6200 cal BC, based on the earliest dates from the Blagotin site as well as the first appearance of Starčevo ceramics in Mesolithic contexts at Danube Gorges sites (Garašanin, Radovanović 2001; Whittle et al. 2002; Borić 2009; 2011). The youngest absolute dates indicate that Starčevo culture lasted until around 5300 cal BC. The latest dates slightly moved the beginning of the Starčevo culture to about 6250 cal BC. The earliest date comes from the Early Neolithic site of Miokovci-Crkvine (BRAMS-2324 7361±28, 6357–6083 cal BC 95.4% CI), located in western Serbia (Porčić et al. 2020). However, this result should be interpreted with caution, due to the fact that it is a single specimen that could not be identified to the level of species but only to the genus level (Bos sp.). The bone was discovered at the bottom of the pit, and the possibility that these are residual remains of aurochs should not be dismissed.

There are several periodizations that define different phases within the Starčevo culture (Milojčić 1950; Arandelović-Garašanin 1954; Dimitrijević 1974; Garašanin 1979; Srejović 1971; Tasić 2009, to name a few), among which some clearly distinguish the Early and Middle Neolithic, with sub-phases (Tasić 1997; 2009). However, given that these periodizations are primarily based on changes in pottery, for the purposes of this work it was decided to avoid more detailed divisions within the Starčevo culture. Therefore, for the entire duration of the Starčevo culture (that is, the period from the earliest Neolithic appearance until the appearance of the Vinče culture) the term ‘Early Neolithic’ will be used.

Early Neolithic inhabitants of these areas built their settlements on river terraces, slopes near springs or streams, and mild elevations above marshes (Garašanin 1979; Bailey 2000). Architectural features interpreted as habitats appear in the form of semi-buried (semi-pit dwellings), buried (pit dwellings), and above-ground objects, with the first two types of objects being significantly more common (Bogdanović 1988; Greenfield, Drašovean 1994). Based on the available data, the size of the settlements in most cases did not exceed 5ha, and the absence of horizontal stratigraphy on most of them indicates that they were short-lived. In addition to the estimated settlement sizes, other indicators indirectly point to their possible short-term duration, i.e. the pronounced mobility of the Starčevo culture communities. For example, the lack of vertical stratigraphy (which would indicate the longevity of the settlement) as well as the types of architectural features, which do not indicate a major architectural investment (Garašanin 1979; Bailey 2000.)
The application of geostatistical methods in archaeology

Data and method

The application of geostatistical interpolation methods in archaeology

The application of geostatistical methods in archaeology represents an important analytical tool that enables a better understanding of various phenomena within spatio-temporal frames. Geostatistics represents a set of different methods and analyses that define spatial variations and enable spatial predictions and simulations. In other words, geostatistics combines procedures for the analysis and evaluation of spatially dependent variables and is based on the principle of spatial interdependence, which implies that phenomena that are spatially closer will share more common characteristics than phenomena that are more distant (Trangmar et al. 1986; Lloyd, Atkinson 2004). That is, spatially closer locations are also interdependent in a statistical sense, which is an important property of spatial data and justifies the use of interpolation in analyses (Olivier, Webster 1990).

Numerous studies of the Neolithic spread from southwestern Asia to and through Europe used geostatistical interpolation methods to reconstruct the spatio-temporal dynamics of these processes. The most common method used is kriging (e.g., Pinhasi et al. 2005; Bocquet-Appel et al. 2009; Brami, Zanotti 2015; Fort 2015; Vander Linden, Silva 2021). This is based on the principle of spatial autocorrelation, whereby the values of parameters in an environment where they are unknown are evaluated based on the known values of certain parameters in space (Trangmar et al. 1986; Wackernagel 2003).

Given the above, the application of geostatistical methods can be considered an important tool in the reconstruction of the spatial and temporal patterns of past human communities, including the process of Neolithization. Nevertheless, one of the crucial requirements for the effective application of a specific method such as kriging is a substantial sample size, distributed relatively evenly across a large area. Past research, focused on reconstructing the speed of Neolithic expansion in the Central Balkans has predominantly relied on regression analyses. These analyses consider parameters like the estimated time of Neolithic arrival (earliest dates) and the distance from the presumed expansion centre in northern Greece (Porčić et al. 2020). The disadvantage of this approach is reflected in the averaging of the estimated propagation speeds over a wider geographical area.

An attempt to apply kriging for the purposes of this research revealed noise in the data, most likely caused by the sample size as well as the uneven distribution of points (that is, Early Neolithic sites) in space. For this reason, it was decided to apply the so-
called Inverse Distance Weighting method (abbreviated as IDW). This method is suitable for effectively reconstructing the spread of the Neolithic in a small area with a limited sample size.

The application of the Inverse Distance Weighting method (IDW) in assessing the direction of the Neolithic spread through the Central Balkans

The IDW method is one of the simplest and, next to kriging, the most widely used spatial interpolation methods. It combines the concept of spatial proximity with a gradual change in trend in the area of interest. It is based on the same assumption on which all geostatistical interpolation methods rest – that points in space that are closer to each other are more similar than those that are more distant. Based on the known values of the parameters that are investigated at one location, the values of those parameters are predicted at nearby locations for which the data is lacking. If the points are closer, their local influence will be greater, and therefore their weight will be higher, while the weight will decrease as a function of the distance from the starting point (Wackernagel 2003; Mitasova 2005; Babak, Deutsch 2008; Gräler et al. 2016; Vasić 2017).

The simplicity of this method enables its application in different types of research as well as on many dimensions, and the estimations and predictions it provides are robust. Moreover, numerous comparative studies have shown that it often gives better results than kriging (Babak, Deutsch 2008 and cited references). In this paper, the IDW method will be used for the spatial interpolation of the earliest dates from Starčevo sites on the territory of Serbia, with the aim of testing the hypothesis about the south-to-north spread of the Neolithic (Whittle et al. 2002). Indirectly, the results of this analysis will also indicate the tempo of expansion by making it possible to visually highlight areas where the Neolithic arrived earlier or later than the assumed time for a given area.

The database for the application of the IDW method consists of georeferenced earliest dates, falling within the range of approximately 6250 to 6000 cal BC, from the Starčevo sites in Serbia (a database with all radiocarbon dates can be found in Blagojević 2022. 186, Prilog 2). To establish the spatial context of the study, a grid was generated within the QGIS software (QGIS.org 2021) encompassing the territory of Serbia. This grid divided the area into squares measuring 30 x 30km each (Fig. 2a and 2b). For each of the squares, the site with the earliest radiocarbon date, not younger than 6000 cal BC (more precisely, those sites with median values of the earliest dates lying in the range of around 6250 to around 6000 cal BC), was chosen. If there was more than one site within the square, the one with the older date was chosen. The medians of the calibrated values of the radiocarbon dates were compared for sites located in adjacent squares. In cases where the difference between the medians was more than 200 years, the site with a younger date was excluded from the analysis. Testing the difference between dates from adjacent squares was performed in the OxCal program, v. 4.4 (https://c14.arch.ox.ac.uk/oxcal/OxCal.html). The final database consists of the earliest dates with a total of 21 Starčevo sites from the territory of Serbia, including two sites from the Danube Gorges (Lepenski Vir and Ajman) (Tab. 1, see below). Two analyses were performed: the first one with all the dates included and the second one with the two oldest dates from the sites of Miokovci-Crkvine and Blagotin omitted. The date from Miokovci can be considered potentially unreliable due to its unclear provenience, while the date from Blagotin has values that significantly depart (~200 years) from all other earliest Starčevo culture sites. Therefore, it was decided to check in what way those two early dates from the region of central Serbia affected the results and what potential interpretations they could point out.

Estimating the local speeds of the Neolithic expansion in the Central Balkans

Most of the studies in which the speed of Neolithic expansion has been estimated emphasize the high variability of these values in smaller, local areas. These studies indicate that larger deviations in local speeds can often be expected compared to those estimated at the continental level (Pinhasi et al. 2005; Bocquet-Appel et al. 2012; Silva, Vander Linden 2017; Fort, Pareta 2020). This paper will assess the local speed of the Early Neolithic spread on the territory of Serbia. In contrast to other studies based on regression analyses, in which the variables were the time of the Neolithic arrival to a certain territory and the distance from the centre of expansion, this paper will focus on local processes, that is, on the rate of the Neolithic expansion from the moment when these populations arrived in this area.

In order to estimate the local speed, the following parameters were used: (1) distances between spatial
groups in the south-to-north direction, each formed at intervals of 50km, as assumed to be the maximum migration distance in the WoA model, based on the ethnographic data as discussed in Ammerman and Cavalli-Sforza (1984.78); and (2), a measure of the central tendency of the oldest dates (median or, alternatively, mean, in cases of pairs of sites with identical median values), serving as the estimated beginning of life in the settlements. From the mentioned spatial groups, one site with the oldest date was singled out (Tab. 2). Unlike in the case of the IDW interpolation, when calculating the estimations of the local speeds a date from the site of Blagotin was not included since it significantly deviates chronologically from other sites. Its date is around 150 years older than the Crkvine-Miokovci date and approximately 200 years older than dates from other sites. The distance between sites, represented by the difference between spatial groups (50km each), was divided by their difference in medians or means for each pair. Using this approach, individual estimates of the speed of Neolithic expansion among spatial groups were obtained, following the south-north direction. Finally, the calculated average of all obtained quotients provided an estimation of the average local speed of Neolithic expansion across the territory of Serbia.

It is well known that radiocarbon dates do not represent absolute values (i.e. calendar years), but rather ranges of values within particular confidence intervals (68% or 95%, most often). Therefore, the estimations of the speeds of the spread based on central tendency measurements represent approximate estimations. In other words, these estimations do not take into account the full uncertainty of the radiocarbon dates, and this is the greatest weakness of this approach. However, central tendency measurements (the mean and median, in this case) are usually used in this type of analysis because they provide valuable insights into the central value of a dataset. These measures help us summarize and understand the data’s distribution, which is essential for making estimations and drawing general conclusions. The mean is especially useful in analysing this type of data, such as radiocarbon dates, since it is a robust measure not affected by extreme values or outliers. Considering this, the approach used in this study does give us a useful insight into the general pattern of the spread rates on a small scale.

Fig. 2. Square grid with Early Neolithic sites included in the IDW analysis: a all sites; b a selected section of the map that shows the layout of squares within the grid in more detail.
Results

The reconstruction of the direction of Neolithic expansion

Figure 3 shows the results of spatial interpolation based on the earliest radiocarbon dates, using the IDW method. Figure 3a shows the results with all the dates included, while Figure 3b shows the results with the two oldest dates (from the sites of Miokovci-Crkvine and Blagotin) omitted. Intervals of 50 (Fig. 3.a) and 20 (Fig. 3.b) years each, which were calculated based on the median values of the oldest dates from the Early Neolithic sites, are shown through a colour palette. Each shade corresponds to one interval, so darker shades represent older dates and lighter shades represent younger dates (that is, intervals). This approach allows for tracking the spatio-temporal trend in the establishment of the earliest Early Neolithic settlements within the territory of Serbia. In the broadest sense, this trend aligns with the assumed south-to-north direction (Whittle et al. 2002). When the two oldest dates from the sites of Miokovci-Crkvine and Blagotin are included in the IDW interpolation, the results appear to be ‘biased’ towards these values, while all other, younger sites, seem to be smoothed out across the entire territory. On the other hand, when these dates are omitted from the analysis, more subtle differences between different sites and defined regions can be observed. The southern region stands out more clearly as the oldest one. In this case, zones with older or younger sites than expected for a given region could also be observed with greater clarity.

<table>
<thead>
<tr>
<th>Site 1</th>
<th>Lab No., uncalibrated date with standard error, and a reference</th>
<th>Site 2</th>
<th>Median and mean* values of the oldest date (cal BC)</th>
<th>Median and mean* values of the oldest date (cal BC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rudnik Kosovski</td>
<td>BRAMS-2413, 7343±27; Porčić et al. 2021a</td>
<td>6165*</td>
<td>Selište-Sinjac</td>
<td>6154*</td>
</tr>
<tr>
<td>Selište-Sinjac</td>
<td>BRAMS-2303, 7300±30; Porčić et al. 2021a</td>
<td>6154*</td>
<td>Ornince-Makrešane</td>
<td>6162*</td>
</tr>
<tr>
<td>Ornince-Makrešane</td>
<td>BRAMS-2223, 7335±31; Porčić et al. 2021a</td>
<td>6162</td>
<td>Miokovci-Crkvine</td>
<td>6195</td>
</tr>
<tr>
<td>Miokovci-Crkvine</td>
<td>BRAMS-2324, 7361±28; Porčić et al. 2021a</td>
<td>6195</td>
<td>Bataševo</td>
<td>6156</td>
</tr>
<tr>
<td>Bataševo</td>
<td>BRAMS-2227, 7331±27; Porčić et al. 2021a</td>
<td>6156</td>
<td>Sremski Karlović-Sonje Marinković</td>
<td>6078</td>
</tr>
<tr>
<td>Sremski Karlović-Sonje Marinković</td>
<td>BRAMS-2423, 7233±28; Porčić et al. 2021a</td>
<td>6078</td>
<td>Topole-Bač</td>
<td>6034</td>
</tr>
<tr>
<td>Topole-Bač</td>
<td>OxA-8693, 7170±50; Whittle et al. 2002</td>
<td>6034</td>
<td>Magareći mlin (Grn-15973; 7130±60; Whittle et al. 2002)</td>
<td>6003</td>
</tr>
<tr>
<td>Bataševo</td>
<td>BRAMS-2227, 7331±27; Porčić et al. 2021a</td>
<td>6156</td>
<td>Lepenski Vir</td>
<td>6046</td>
</tr>
<tr>
<td>Lepenski Vir</td>
<td>OxA-16005, 7190±45; Borić, Dimitrijević 2009</td>
<td>6046</td>
<td>Ajmana (AA-58322, 7219±51); Borić 2011</td>
<td>6075</td>
</tr>
</tbody>
</table>

Tab. 2. Sites with the oldest dates within defined spatial groups formed at 50km used for the estimation of the local speeds of the spread. Local speeds were calculated for each pair of neighbouring sites by using the measurements of central tendency for the calibrated values (95% CI) of radiocarbon dates. The median of the oldest date was used as the primary measurement of central tendency. In cases where the medians of the oldest dates from neighbouring sites were identical, their means were used. These cases are marked with an asterisk (*) in the table.
Estimates of the rates of Neolithic expansion are given in Table 3. It’s important to note that the results obtained through the application of this method are primarily indicative of the variations among the defined spatial bins (regions). This approach allows us to determine whether, and in which regions, the Neolithic expansion occurred at a faster pace than in other areas within the Central Balkans. When considering sites with very close dates the obtained scores are notably high, indicating a rapid Neolithic spread, characteristic of the southernmost regions of the territory. Other values show limited variation and do not suggest significant changes in tempo. Since the assumed direction of the expansion was south-to-north, in cases where older sites were also northern sites negative values were obtained. When these cases are included, the average estimated speed for the whole territory is 4.57km per year. However, when these cases are excluded, the average estimated speed is 1.61km per year. Both scenarios will be discussed further below.

**Discussion and conclusion**

The results of the IDW interpolation, which included the georeferenced earliest radiocarbon dates from the Starčevo sites (from ~6250 to ~6000 BC), confirmed the previously assumed general direction of the Neolithic spread from south to north (Fig. 3.a and 3.b). Individual zones that, in a certain sense, deviate from the assumed pattern have been singled out. Cases of sites with dates that are younger than the assumed earliest dates for the region could be explained by the degree of research that has been carried out, and this could mostly mean that none of the older sites in the specific region have been discovered or dated yet. However, the presence of sites with significantly older dates is noteworthy. This is the case for the sites of Miokovci-Crkvine and Blagotin, which belong to the region of central Serbia.

According to the reconstructed Neolithic expansion route, these Early Neolithic settlements should be younger than those in southern Serbia. However, the dates from these sites represent the oldest dates from the entire sample of Starčevo radiocarbon dates from the territory of Serbia at the current level of research (Porčić et al. 2021a; Blagojević 2022). The possibility that there are undiscovered settlements in the south that would yield dates of a similar age certainly exists, but that does not account for the early establishment of a settlement in an area that, based on current data, should have been inhabited later. A possible explanation could be the existence of smaller scouting groups that established short-term settlements with the aim of familiarizing themselves with an environment suitable for future settlement. This would represent some version of leap-frog colonization, which has already been assumed in some earlier studies (e.g., Spataro 2010). However, we should not rule out the possibility that, at least in the case of the Miokovci-Crkvine site, we are dealing with a residual specimen, which could have belonged to an aurochs from an earlier period, considering that the dated specimen was determined only at the species level. When the two earliest dates are not included in the analysis, a slightly different dynamic is revealed that emphasizes the chronological difference between regions more but still retains zones with older and younger dates. Therefore, even though these two types of results differ, they both indicate that, although the general direction of the spread followed the south-to-north axis, it can be argued that the process was not linear but rather arrhythmic. This espe-
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of the smaller number of discovered and dated Early Neolithic sites in the south of Serbia.

The high estimated rates of Neolithic expansion are often attributed to the influence of cultural transmission, specifically interactions with local Mesolithic communities (Fort 2012). While there are isolated cases of radiocarbon dates from certain sites (Magareći Mlin, Grabovac-Durića vinogradi, and Gospodinci-Nove zemlje) that may suggest the potential presence of Mesolithic communities (Življević et al. 2021), confirmation of such communities in the territory of Serbia is still lacking, except for the Danube Gorges area. The model of directional expansion proposed by Joaquim Fort (2020) explains the higher speeds in those cases when the possibility of interaction with the local Mesolithic population is excluded by implying the expansion of communities to areas that are closest to the direction of the advance of the front and in which the population density is low. Among other things, this model allows for the scenario in which people choose to settle in the first available areas they come across. We should also keep in mind the assumed increased mobility of communities in this period, which, among other factors, can lead to faster movement across space, quicker settling of new areas, and rapid abandonment of certain regions. The existence of smaller scouting groups is also a possible part of the Neolithization process in this area, especially if the earliest dates from the sites of Blagotin and Miokovci-Crkvine are considered.

The question of the degree of mobility of the Starčevo communities has been emphasized in numerous studies (Garašanin 1979: Bailey 2000.57; Tringham 2000.25; Greenfield, Jongsm 2008; Greenfield et al. 2014; Porčić et al. 2021a; Blagojević 2022) The estimated local speeds at which the Neolithic spread through the territory of the Central Balkans further contribute to this discussion, but they represent only an indirect indicator. The current level of research has produced a limited set of data and knowledge on this complex issue, where it is important to pay special attention to the study of settlement organization and duration. Future research should focus on these issues through detailed contextual and functional analysis at the level of settlements and individual households.

<table>
<thead>
<tr>
<th>Site 1</th>
<th>Site 2</th>
<th>Estimated speed of the expansion (km/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rudnik Kosovski</td>
<td>Selište-Sinjac</td>
<td>4.55</td>
</tr>
<tr>
<td>Selište-Sinjac</td>
<td>Ornice-Makrešane</td>
<td>-6.25</td>
</tr>
<tr>
<td>Ornice-Makrešane</td>
<td>Miokovi-Crkvine</td>
<td>-1.52</td>
</tr>
<tr>
<td>Miokovi-Crkvine</td>
<td>Bataševi</td>
<td>1.28</td>
</tr>
<tr>
<td>Bataševi</td>
<td>Sremski Karlovići-Sonje Marinković</td>
<td>0.64</td>
</tr>
<tr>
<td>Sremski Karlovići-Sonje Marinković</td>
<td>Topole-Bač</td>
<td>1.14</td>
</tr>
<tr>
<td>Topole-Bač</td>
<td>Magareći mlín</td>
<td>1.61</td>
</tr>
<tr>
<td>Bataševi</td>
<td>Lepenski Vir</td>
<td>0.45</td>
</tr>
<tr>
<td>Lepenski Vir</td>
<td>Ajmane</td>
<td>-1.72</td>
</tr>
</tbody>
</table>

Tab. 3. Estimated local speeds of the Neolithic expansion in the Central Balkans.
Acknowledgements
The author would like to acknowledge the financial support of the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (Grant No. 451-03-47/2023-01/200358), as well as the support of the Antares-Centre of Excellence for Advanced Technologies in Sustainable Agriculture and Food Security, funded by the European Commission, Grant Agreement No. 739570. https://doi.org/10.3030/739570. This study would not have been possible without the support of Dr. Sofija Stefanović (University of Beograd, Faculty of Philosophy), as the PI of the project BIRTH: Births, mothers, and babies: prehistoric fertility in the Balkans between 10 000–5000 BC (2015–2020), and Dr. Marko Porčić (University of Beograd, Faculty of Philosophy), as the supervisor of the author's doctoral dissertation, in which the subject of this study was defined. The author would also like to thank Dr. Aleksandar Sekulic from the Faculty of Civil Engineering, University of Beograd, who helped with the application of the IDW method in the R programming language. Thanks also go to the two reviewers whose comments and suggestions were of great help in finalizing the paper.
The author declares no conflict of interest.

References


### Tab. 1. Early Neolithic sites from the Central Balkans used in the study.

<table>
<thead>
<tr>
<th>Site</th>
<th>Context</th>
<th>Material</th>
<th>Lab No.</th>
<th>Uncal BP</th>
<th>C%</th>
<th>N%</th>
<th>C/N</th>
<th>d13C (IRMS)</th>
<th>d15N (IRMS)</th>
<th>d13C (AMS)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anište-Bresnica</td>
<td>Trench 1, Pit 1</td>
<td>Ovis/Capra, mandible dext.</td>
<td>BRAMS-2331</td>
<td>7306±28</td>
<td>48.3</td>
<td>17.7</td>
<td>3.2</td>
<td>/</td>
<td>/</td>
<td>−21.3</td>
<td>Porčić et al. 2021</td>
</tr>
<tr>
<td>Bakovača-Ostra</td>
<td>Trench 3; e.l. K</td>
<td>Ovis/Capra, scapula dext.</td>
<td>BRAMS-2329</td>
<td>7299±27</td>
<td>45.96</td>
<td>16.83</td>
<td>3.2</td>
<td>/</td>
<td>/</td>
<td>−20.5</td>
<td>Porčić et al. 2021</td>
</tr>
<tr>
<td>Batašev</td>
<td>Trench 1</td>
<td>Bos taurus, radius dext.</td>
<td>BRAMS-2230</td>
<td>7284±28</td>
<td>44.1</td>
<td>16.2</td>
<td>3.2</td>
<td>/</td>
<td>/</td>
<td>−21.3</td>
<td>Porčić et al. 2021</td>
</tr>
<tr>
<td>Blagotin</td>
<td>13/3, base of pit JA2, pit dwelling 7</td>
<td>Red deer antler</td>
<td>OxA-8608</td>
<td>7480±55</td>
<td>/</td>
<td>/</td>
<td>3</td>
<td>−20.6</td>
<td>4.4</td>
<td>/</td>
<td>Whittle et al. 2002</td>
</tr>
<tr>
<td>Crnoškiče</td>
<td>Trench 3 northern extension, Pit 9</td>
<td>Bos taurus, scapula sin.</td>
<td>BRAMS-2290</td>
<td>7293±29</td>
<td>48.4</td>
<td>17.7</td>
<td>3.2</td>
<td>/</td>
<td>/</td>
<td>−21.7</td>
<td>Porčić et al. 2021</td>
</tr>
<tr>
<td>Donja Branjevina</td>
<td>Trench V, 1986-1987, Pit e.l. 6</td>
<td>Animal bone</td>
<td>GrN-15974</td>
<td>7155±50</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>Tasić 1993</td>
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<tr>
<td>Drenovac</td>
<td>Trench 15, sq. 2; in the line with the eastern profile</td>
<td>Large mammal long bone</td>
<td>BRAMS-2244</td>
<td>7309±28</td>
<td>47.06</td>
<td>17.18</td>
<td>3.2</td>
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<td>/</td>
<td>−20.7</td>
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<tr>
<td>Gospodinci-Nove zemlje</td>
<td>Feature 45-emptying</td>
<td>Mammalia, long bone</td>
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<td>45.77</td>
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<td>/</td>
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<tr>
<td>Grivac</td>
<td>Trench B, 1969, level at the relative depth of 2m</td>
<td>Charcoal</td>
<td>Bln-869</td>
<td>7250±100</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>/</td>
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<tr>
<td>Magareči mlin</td>
<td>Semi-pit-house 1, by the hearth</td>
<td>Animal bone</td>
<td>Gm-15973</td>
<td>7130±60</td>
<td>/</td>
<td>/</td>
<td>/</td>
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<td>Whittle et al. 2005</td>
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<tr>
<td>Međureč-Dunjički Šljivar</td>
<td>Trench 1, quadrant 2</td>
<td>Bos taurus, vertebra lumbals</td>
<td>BRAMS-2251</td>
<td>7316±29</td>
<td>42.36</td>
<td>15.52</td>
<td>3.2</td>
<td>/</td>
<td>/</td>
<td>−18.6</td>
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<tr>
<td>Miokovići-Crkvine</td>
<td>Trench 3, bottom of the pit</td>
<td>Bos sp, mandible sin.</td>
<td>BRAMS-2324</td>
<td>7361±28</td>
<td>45.7</td>
<td>16.8</td>
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<tr>
<td>Omice-Makrešane</td>
<td>Trench 1, sq. b5; B-71</td>
<td>Cervus elaphus, radius dext.</td>
<td>BRAMS-2223</td>
<td>7335±31</td>
<td>42.06</td>
<td>15.38</td>
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<td>Perlez-Batka “C”</td>
<td>12/2, Grave 1, Trench 2/1975</td>
<td>Homo, tibia</td>
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<td>15.32</td>
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<td>Seljište-Sinjac</td>
<td>Trench 6, northeastern quarter; 1.3−1.5m; box 13</td>
<td>Bos taurus, Ph III</td>
<td>BRAMS-2303</td>
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<td>46.99</td>
<td>17.18</td>
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<td>Porčić et al. 2021</td>
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<td>Homo, costae</td>
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<td>8.8</td>
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<td>/</td>
<td>−20.4</td>
<td>Porčić et al. 2021</td>
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<td>Burial 122, between Buildings 47 and 47'</td>
<td>Human skull</td>
<td>7190±45</td>
<td>/</td>
<td>/</td>
<td>/</td>
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<td>/</td>
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<td>Ajmana</td>
<td>Burial 7</td>
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<td>7219±51</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>−20</td>
<td>10</td>
<td>/</td>
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