The beginning of the Neolithic in the central Balkans: knowns and unknowns

Marko Porčić

Department of Archaeology, Faculty of Philosophy, University of Belgrade, RS; mporcic@f.bg.ac.rs

ABSTRACT - *Since 2020 a wealth of new data has been generated on the beginning of the Neolithic in the central Balkans. The picture that has emerged is broadly consistent with the Wave of Advance model, with the first farmers arriving in the region around 6250 BC and expanding gradually towards the north. In this paper, an updated review of the evidence and interpretations is presented, and potentially problematic or ambiguous aspects of the current interpretations of the Neolithic expansion in the Balkans are identified. Alternative hypotheses and means of their testing are also discussed.*

KEY WORDS – *Neolithic; central Balkans; Wave of Advance; first farmers; radiocarbon dating*

Začetek neolitika na osrednjem Balkanu: znano in neznano

IZVLEČEK – *Po letu 2020 je na voljo mnogo novih podatkov o začetku neolitika na osrednjem Balkanu. Nova podoba je na splošno skladna z modelom vala napredovanja, pri čemer so prvi kmetje prispeli v regijo okoli leta 6250 pr. n. št. in se postopoma širili proti severu. V prispevku predstavljamo posodobljen pregled dokazov in interpretacij in potencialno vprašljivih ali dvoumnih vidikov sedanjih interpretacij neolitske ekspanzije na Balkanu. Obravnavane so tudi alternativne hipoteze in načini njihovega preverjanja.*

KLJUČNE BESEDE – *neolitik; osrednji Balkan; val napredovanja; prvi kmetje; radiokarbonsko datiranje*

Introduction

The central Balkans region[1] (Fig. 1) was one of the main corridors for the expansion of the first European farmers from northern Greece. As such, it is an important region for researchers interested in the beginning of the Neolithic in Europe (*e.g., Garašanin 1982; Bailey 2000; Tringham 2000; Whittle* et al. *2002; Tasić 2009;* *Borić 2011; Shennan 2018; Reingruber 2020; Krauß 2023; Vander Linden 2023*). One of the critical aspects of Early Neolithic research has been the establishment of absolute chronology, to determine the arrival time of the first farmers, as well as to test different hypotheses and models about the mechanism, tempo, and

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1 Strictly speaking, the northern boundaries of the Balkan peninsula are demarcated by the rivers Sava and Danube. However, it is important to note that the region of Vojvodina (northern province of the Republic of Serbia) lies immediately to the north of these rivers. In this review, I will include Vojvodina, as well, as it represents a transitional zone between Balkans and Central Europe. Moreover, the Neolithic communities in this area are integral to understanding the expansion process across the central Balkans. The boundaries of the central Balkan region itself are not clearly and unambiguously defined in the literature, but the core of the region consists of western Serbia, central Serbia (Šumadija), southern Serbia and Kosovo. Therefore, the study region in this paper will include these core territories plus Vojvodina.

demographic aspects of the Neolithic expansion. In this region of Europe, the establishment of absolute chronology depends primarily on the number and quality of radiocarbon dates. This number was relatively low in the last quarter of the 20th century. The situation improved in the early 2000s with the study by Alasdair Whittle *et al.* (*2002*), but until recently, the total number of dates for the Early Neolithic in the central Balkans (excluding the Danube Gorges microregion) was less than one hundred (*Porčić* et al. *2016*). In the early 2020s, the ERC-funded BIRTH project, directed by Sofija Stefanović, contributed to the marked increase in the quantity of radiocarbon and bioarchaeological data related to the beginning of the Neolithic in the region (*Porčić* et al. *2016; 2020; 2021a; 2021b; Blagojević* et al. *2017; Jovanović* et al. *2021a; 2021b; Stefanović* et al. *2019; Penezić* et al. *2020; Stojanovski* et al. *2020*).

From this recently published research, a more detailed and complex picture of the Neolithic expansion and demography in the central Balkans emerged (*Porčić* et al. *2020; 2021a; 2021b*). The set of almost 300 new radiocarbon dates enabled the researchers to estimate the timing and speed of the Neolithic expansion across this region (*Porčić* et al. *2020*), as well as to reconstruct population dynamics of the Early Neolithic communities (*Porčić* et al. *2021a*). Computer simulation constrained by the radiocarbon evidence was used to investigate the mode and demographic parameters of the expansion – to estimate the fertility and mortality rates, and population size thresholds of community fission related to migrations (*Porčić et al. 2021b*).

The Wave of Advance model (WoA) (*Ammerman, Cavalli-Sforza 1979; 1984*) coupled with the theory of the Neolithic Demographic Transition (NDT) (*Bocquet-Appel 2008; 2011a; 2011b; 2014; Bocquet-Appel, Bar-Yosef 2008*) was used as the main theoretical framework for modelling and interpretation

of the data. In short, this scenario assumes that the first farming communities gradually spread from the southern Balkans to the central Balkans as a consequence of local population growth. This growth was fueled by an increase in fertility (increased number of children), resulting from a sedentary lifestyle and cereal-oriented subsistence. The expansion of the farmers is seen as a consequence of community fission when certain population thresholds are reached. In our interpretation of the empirical evidence, this threshold was social, related to scalar stress (*Johnson 1982*),rather than ecological (*i.e.* related to environmental carrying capacity) (*Porčić 2021b*).

In this paper, I will first make an updated review of the available evidence, and then I will critically reflect on the current interpretation. In the research published with my colleagues, a version of the WoA model was established as the interpretation of the
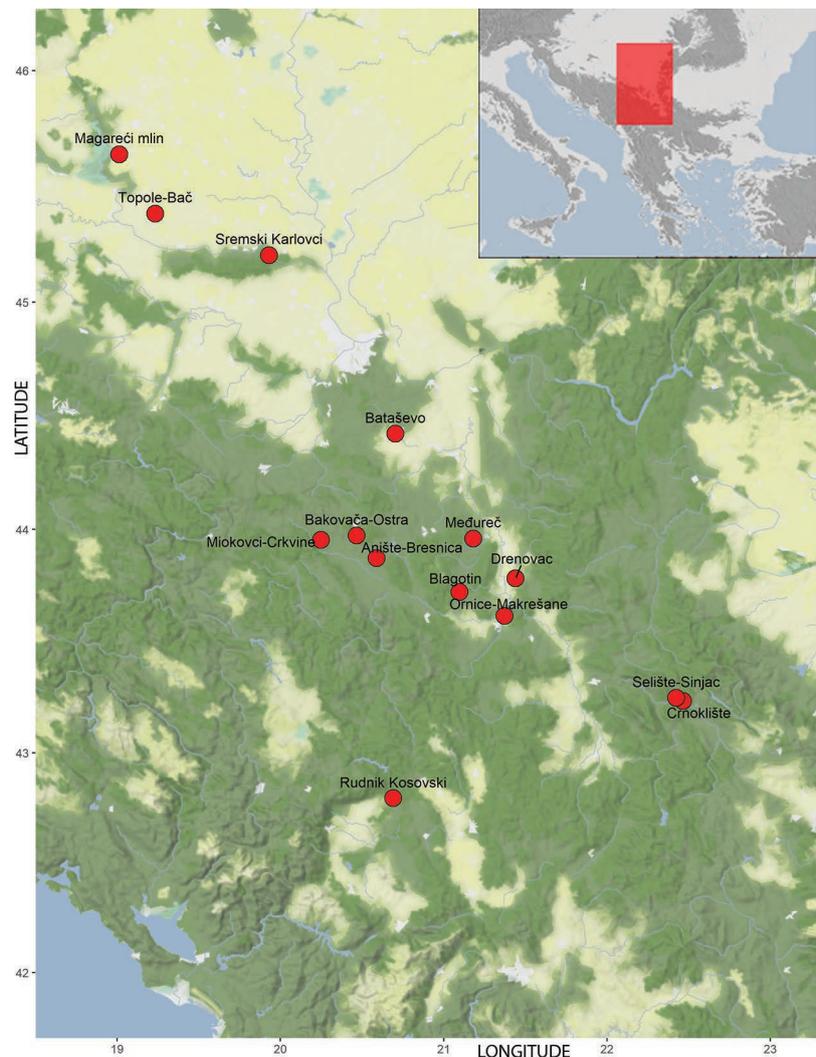

Fig. 1. The study region (see footnote 1 in the main text for the definition of the study region) and the sites mentioned in the text.

data – I will refer to it as the standard interpretation or the standard model. However, in this text, I wish to address the potentially problematic or ambiguous aspects of this interpretation. The evidence is such that, although it does support the standard model, it leaves room for alternative hypotheses and models, as suggested by Marko Porčić *et al.* (*2021b*). In other words, the available data does not fully constrain our models of the Neolithic expansion in the central Balkans. So, even though I consider the standard interpretation based on the WoA model as the currently best explanation (as I will argue in more detail below), it is still necessary to formulate and discuss alternative hypotheses and means of their testing.

The main questions regarding the beginning of the Neolithic that I will address in this paper are:
• When did the Neolithic begin in the central Balkans – when did the first farmers settle in this region?
• What was the tempo and mode of the expansion?
• What drove the expansion?
• How did population size change during the Early Neolithic?

What we (think that we) know: "*the standard interpretation*"

Porčić *et al.* (*2020*) suggested that the first Neolithic populations reached southern parts of the central Balkans, *i.e.* northern parts of North Macedonia and southern parts of Serbia, between 6250 and 6200 BC. The reconstructed speed of the expansion front was around 1.5–2km/year (*Porčić* et al. *2020*). The general gradient of the expansion follows the south-north axis of the major river valleys of South and Great Morava (*Porčić* et al. *2020*). Therefore, the observed spatio-temporal pattern is broadly consistent with the WoA model.

The method of summed probability distributions of calibrated radiocarbon dates (SPD) was used to reconstruct the population dynamics of the first farmers in this region (Fig. 2). The SPD demographic proxy curve suggests a rapid increase in population after the arrival of the first farmers, and the population rapidly increased between 6200 and 6000 (*Porčić* et al. *2021a*). However, the SPD curve suddenly goes down after 6050–6000 BC, suggesting a population crash. The minimum is reached around 5800 BC, after which the SPD proxy starts to increase again, reaching a second peak around 5650 BC. After this second peak, the SPD curve suggests a population crash (or a lack

of dates, in more neutral terms) between around 5500 and around 5300 BC, a phenomenon which is related to the start of the Late Neolithic in the region, which is discussed elsewhere (*Porčić 2020*).

The estimated growth rates, also based on the frequency of radiocarbon dates, are high. Porčić *et al.* (*2021a*) used the Approximate Bayesian Computation method to estimate population growth rate. The results suggest a growth rate of 2.36% (95% credible in-
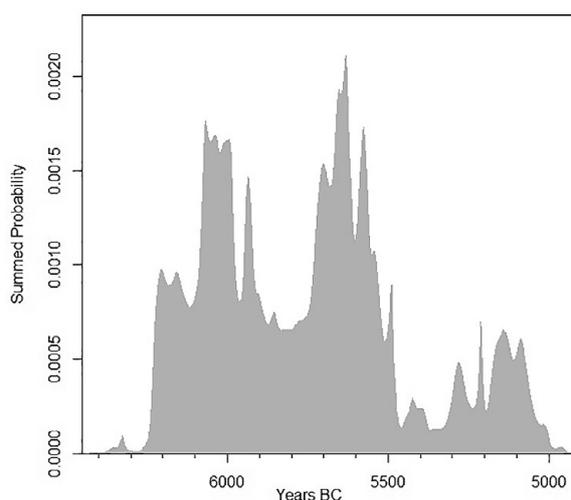

Fig. 2. Summed probability distribution demographic proxy curve based on all Neolithic radiocarbon dates from the central Balkans (after Porčić *et al.* 2021.Fig. 2, panel c*).*

terval 0.9–3.97%). Tamara Blagojević *et al.* (*2024*) used hierarchical Bayesian modeling (*Crema, Shoda 2021*) to estimate growth rates and the resulting estimates are even higher – 3.25% (95% credible interval 0.96–5.97%).

Computer simulation based on the modified WoA model was used to infer the demographic parameters (fertility, mortality and the settlement fission threshold) of the expanding Neolithic populations (*Porčić* et al. *2021b*). The results of the simulation suggest that fertility rates must have been very high, with an estimated total fertility rate of around 10 children, which is at the very upper end of the ethnographically and historically recorded spectrum (*Wood 1990; Bentley* et al. *1993a; 1993b*). The simulation also suggests that fission thresholds for settlements must have been relatively low due to scalar stress – when a settlement population size reached 30–60 people, part of the community would migrate somewhere else, thus contributing to the expansion of the Neolithic population front.

Updating the arrival time and expansion speed estimates

Arrival time revisited

The question of when the Neolithic in the central Balkans started is yet another instance of a general problem of determining the temporal beginnings of phenomena in archaeology (*Perreault 2011; Lipo* et al. *2021*). The problem is twofold: what is the target event in question (*e.g.,* is it the date when the first, wandering farmer set foot in the central Balkan area, or the date when the first settlement was established?) and how can we know that we genuinely have the earliest date for the target event, given the fragmentary nature of the archaeological record and the incompleteness of archaeological research? The first part of the question can be defined with relative clarity – we are interested in the date of establishment of the earliest Neolithic settlement in the central Balkans. But estimating this date is a serious methodological challenge (*Perreault 2011; Lipo* et al. *2021; Crema* et al. *2022*). We can be almost certain that we will not have the exact date for our target event, for at least two reasons:

❶ The probability that the actual earliest site was archaeologically discovered and investigated is low.
❷ Even if the earliest site is found and excavated, the probability that the earliest context (*i.e.* the first built dwelling) is identified is also low, as the sites are rarely excavated in their totality.

The samples, which were collected for the BIRTH project, were chosen randomly. There was no effort to identify the earliest context. This is so because the dates were primarily collected for the application of SPD method of demographic inference, which ideally requires a random sample of datable material. Therefore, we can be almost certain that none of the dates come from the earliest contexts at a given site.

For this reason, Porčić *et al*. (*2020*) made an educated guess that the actual arrival time (*i.e.* the establishment of the first Neolithic settlement) in the central Balkans (in southern Serbia and Kosovo), was earlier than the 6200 BC date suggested by the radiocarbon dates. But there are three problems with this 6250–6200 BC estimate:

❶ The dates were originally calibrated with the Intcal13 curve (*Reimer* et al. *2013*), which yielded slightly older dates in this period than the current Intcal2020 curve (*Reimer* et al. *2020*).

❷ The oldest date on a cattle bone from Miokovci site is potentially problematic, as the precise zooarchaeological determination of the bone fragment is not possible and the site from which the sample comes is in the central area of the central Balkans rather than the south (*Blagojević 2023*). It was identified as *Bos* sp. (*Porčić* et al. *2020; 2021a*), meaning that it is not certain if this bone belonged to a domesticated (*Bos taurus*) or wild cattle (*Bos primigenius*). If the latter is the case, it could potentially be a residual sample, but it could also be authentically Neolithic given that *Bos primigenius* is found, although in low frequencies, in the Early Neolithic faunal assemblages in this region (*Vuković 2021*). However, it is mostly problematic from the perspective of the WoA model as the Miokovci date is too early for this part of Serbia. So, excluding it only on this ground would be circular reasoning, if we wish to use the dates to test the WoA model. The inclusion or exclusion of this individual date does not make a significant difference to any of the results, so I decided to keep it for analysis in this paper, as there is no evidence beyond reasonable doubt to exclude it.

❸ The bulk of calibrated probability distribution for the oldest samples, especially the one from the site of Rudnik Kosovski, which is the second oldest date after the sample from Miokovci, is between 6200 and 6100 BC.

Therefore, there is a need to update and critically review the results related to the arrival time of the Neolithic. I recalibrated the oldest dates from Miokovci and Rudnik Kosovski with the Intcal20 curve (*Reimer* et al. *2020*) in OxCal 4.4 (*Bronk Ramsey 2001*). The resulting distributions are shown in Figure 3. Although the means of calibrated distributions suggest dates closer to 6200 BC, a significant part of the calibrated probability distribution is between 6200 and 6100 BC. So, we know that the date of the target event is earlier than the earliest dated event, but we do not know what is the difference, and more importantly, we do not know what is the precise date of the dated event – is it closer to 6200 or 6100 BC?

To go beyond an educated guess and offer a more formal estimate of the arrival time, I will use the optimal linear estimation (OLE) method advocated by Alastair Key *et al*. (*2021*), implemented in the sExtinct package for R (*Clements 2013*) and suitable for estimating the full range of archaeological phenomena – *i.e.* the beginnings and endings. The OLE method estimates the first or the last occurrence of an archaeo-
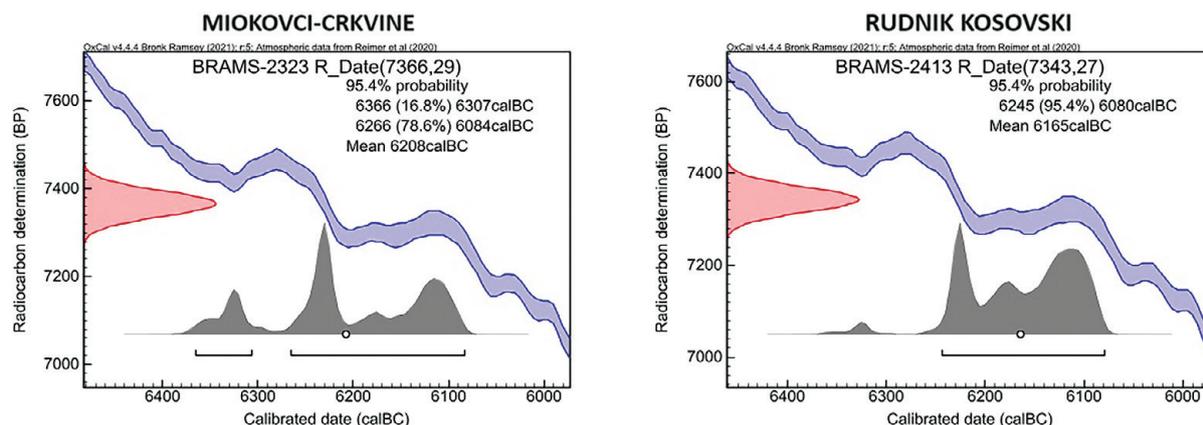
Fig. 3. The earliest Neolithic radiocarbon dates from the central Balkans.

logical phenomenon based on the *n* first or last observations. In this case, I used the 10 earliest dates from Kosovo, South and West Morava river valleys (Tab. 1). As radiocarbon dates are not simple point estimates of calendar ages, the OLE earliest date estimate is not going to be a single estimate but a distribution of estimates based on the Monte Carlo sampling from the calibrated distributions of these particular 10 dates (method and R code adapted from *Porčić* et al. *2020*). In short, the computer will sample 10 000 potential realizations of the calendar years for each radiocarbon date from its corresponding calibrated distribution. For each set of the sampled calendar dates, an OLE estimate is calculated. Based on the latest radiocarbon evidence from the site of Vlaho in North Macedonia, the first farmers reached the southern part of this country around 6300 BC (*Naumov* et al. *2023*). As it is reasonable to assume that the Neolithic arrived earlier in North Macedonia than Serbia, I limit the potential OLE estimates only to the dates which are younger than 6324 BC, which is the mean value of the calibrated distribution of the oldest radiocarbon date from Vlaho.

The results of the Monte Carlo OLE estimation are shown in Figure 4. The mean of estimated mean earliest dates for the beginning of the Neolithic is 6250 BC (with a standard deviation of 25 years)[2], in line with an informal estimate proposed by Porčić *et al.* (*2020*). However, it should be emphasized that the OLE estimate is based on an empirical generalization and a generic statistical model, rather than the underlying population dynamics model and its parameters, which in reality govern the probabilities of discovering the earliest sites and the earliest datable items from a site, and thus these results should be considered as tentative. The matter can only be resolved with new dates, sampled specifically for Bayesian modeling.

Expansion speed revisited
To revise the estimate of the expansion speed, I used the earliest dates from sites grouped in 50km wide bins (Tab. 2) – binning is performed relative to the distance of a site from the Early Neolithic site of Mavropigi in Greece (see *Porčić* et al. *2020* for a detailed explanation of the spatial bins). In other words, I only use the earliest dates from each successive 50km wide (in the

Site	Date label	¹⁴C Age	Error	Mean	95% Confidence Interval	Reference for the ¹⁴C date
Rudnik Kosovski	BRAMS-2413	7343	27	6165	6245-6080	*Porčić* et al. *2020; 2021*
Crnoklište	BRAMS-2290	7293	29	6153	6225-6076	*Porčić* et al. *2020; 2021*
Selište Sinjac	BRAMS-2303	7300	30	6154	6226-6078	*Porčić* et al. *2020; 2021*
Ornice-Makrešane	BRAMS-2223	7335	31	6162	6241-6079	*Porčić* et al. *2020; 2021*
Blagotin	OxA-8609	7270	50	6141	6231-6029	*Whittle* et al. *2002*
Drenovac	BRAMS-2244	7309	28	6155	6227-6082	*Porčić* et al. *2020; 2021*
Anište Bresnica	BRAMS-2331	7306	28	6154	6226-6081	*Porčić* et al. *2020; 2021*
Međureč	BRAMS-2251	7316	29	6156	6230-6081	*Porčić* et al. *2020; 2021*
Bakovača Ostra	BRAMS-2329	7299	27	6154	6225-6078	*Porčić* et al. *2020; 2021*
Miokovci Crkvine	BRAMS-2323	7366	29	6208	6366-6084	*Porčić* et al. *2020; 2021*

Tab. 1. 10 earliest dates used for the OLE estimation of the arrival time of the first farmers to the central Balkans region. Dates calibrated in OxCal with Intcal20.

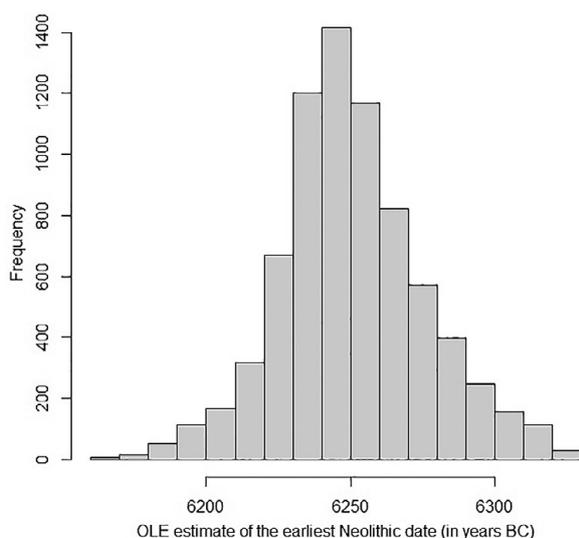2 Each OLE estimate has its confidence intervals. I only presented the distribution of mean estimates here.

Fig. 4. Distribution of the Neolithic arrival time estimates based on the OLE method implemented with Monte Carlo sampling of the calendar dates from probability distributions of calibrated radiocarbon dates.

south-north direction) microregion from the central Balkans as an approximation of the arrival of the Neolithic population front at that particular latitude. In addition to the dates used in Porčić *et al.* (*2020*), I also include the oldest date from North Macedonia, from the site of Vlaho (*Naumov* et al. *2023*). I use the Monte Carlo method of estimation, with two regression techniques – ordinary least squares (OLS) and reduced major axis regression (RMA) (for a detailed description of the method and dedicated R code, see *Porčić* et al. *2020*).

The results suggest that the average expansion speed was around 1.6km/ or 2km/year, depending on the regression technique (Tab. 3, Fig. 5). When the means of calibrated dates, as point estimates of front arrival dates, are plotted against the distance from Mavropigi,

we can see that even though a linear model gives a relatively good fit (mean Pearson's correlation coefficient value is 0.8 with standard deviation of 0.1), there seems to be a difference in the expansion speeds between the regions of Kosovo, southern and central Serbia on one side, and northern Serbia (Vojvodina) on the other (Fig. 6). The slope is lower in the former case, suggesting a higher speed[3] of expansion, and lower in the latter, suggesting a lower speed of expansion once the Sava and Danube are crossed. This is in line with the local speed estimates made by Blagojević (*2023*).

Cracks in the interpretative edifice

In this section, I will focus on some of the results of previous research which leave room for doubt regarding the 'standard interpretation', *i.e.* the WoA model (see also the discussion in *Porčić* et al. *2021b*):

• The estimated fertility rate of around 10 children per woman is possible, but suspiciously high, as it is at the very upper end of the ethnographically recorded spectrum (*cf. Bentley* et al. *1993a; 1993b*).

• The mean estimated population growth rates are also very high, around 2.5–3% (*Porčić* et al. *2021a; Blagojević* et al. *2024*), but the confidence intervals suggest that they may have been even higher, outside the ethnographically and historically recorded range. This would suggest that the model which assumes only local population growth due to increased fertility is not an adequate explanation.

• The estimated expansion speed is higher than the continental average of 1–1.3km (*Ammerman, Cavalli-Sforza 1971; Gkiasta* et al. *2003; Pinhasi* et al. *2005; Bocquet-Appel* et al. *2012; Henderson* et al.

Site	Distance from Mavropigi (km)	Date label	¹⁴C Age	Error	Mean	References
Miokovci-Crkvine	408	BRAMS-2323	7366	29	6208	*Porčić* et al. *2020; 2021*
Rudnik Kosovski	275	BRAMS-2413	7343	27	6165	*Porčić* et al. *2020; 2021*
Ornice-Makrešane	353	BRAMS-2223	7335	31	6162	*Porčić* et al. *2020; 2021*
Bataševo	450	BRAMS-2227	7331	27	6158	*Porčić* et al. *2020; 2021*
Selište Sinjac	316	BRAMS-2303	7300	30	6154	*Porčić* et al. *2020; 2021*
Sremski Karlovci	548	BRAMS-2423	7233	28	6102	*Porčić* et al. *2020; 2021*
Topole Bač	585	OxA-8693	7170	50	6036	*Whittle* et al. *2002*
Magareći mlin	617	Grn-15973	7130	60	5997	*Whittle* et al. *2002*
Vlaho	55	CAN-6151	7460	36	6324	*Naumov* et al. *2023*

Tab. 2. Radiocarbon dates used for the estimation of the Neolithic front expansion speed.

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3 As time is regressed on distance in this case, speed is equal to the reciprocal value of the slope, therefore, lower slopes indicate higher expansion speeds, and vice versa.
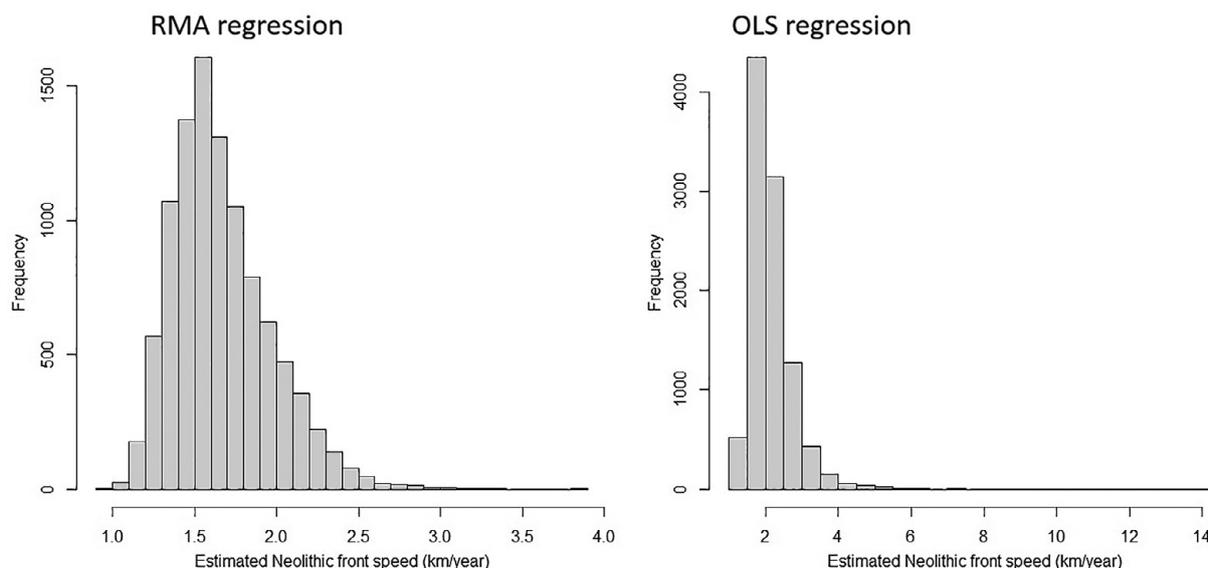
Fig. 5. Distributions of the expansion speed estimates based on the reduced major axis regression (left) and ordinary least squares regression, with Monte Carlo sampling of the calendar dates from probability distributions of calibrated radiocarbon dates.

2014). It is especially high in the area of southern and central Serbia (*Blagojević 2023*). Translated into more neutral terms, there is a very rapid appearance of Neolithic sites in the region.

• The most puzzling result is the abrupt drop of the SPD curve after 6050 BC (Fig. 2). This pattern is difficult to explain and correlate with other phenomena in the archaeological or environmental record.

As I will argue in the last section, none of these observations is sufficient to falsify the standard interpretation, but they open possibilities for alternative interpretations and formulations of alternative models of the beginning of the Neolithic in the central Balkans.

Alternative hypotheses

There are alternative hypotheses that can be formulated to accommodate the data, and in some form they are already present in the literature (*Porčić* et al. *2021b*). In this section, I will present these hypotheses, evaluate them against current evidence and suggest how they can be tested.

The Mesolithic hypothesis
The Mesolithic presence in the central Balkans seemed to be limited to the Danube Gorges area (*Gurova, Bonsall 2014*), but more recent research suggests that Mesolithic populations may have been present in other parts of the region, as well (*Petrović, Starović 2016; Živaljević* et al. *2021*). If there was an underlying Me-

solithic population, then the process of the Neolithic expansion would have been more complex and would have probably involved interactions with the local Mesolithic population, similar to what is documented in the Danube Gorges area between 6200 and 6000 BC (*Borić 2011*).

The Mesolithic hypothesis assumes that most of the earliest Neolithic sites, dated to a period before 6050 BC, are not outposts of the migrating farmers of the Anatolian/Aegean origin, but seasonal settlements of the local (semi)mobile hunter-gatherers which became archaeologically visible as they adopted the Neolithic material culture (pottery), as well as domesticated plants and animals by a process of cultural diffusion. The true arrival of the farmers, *i.e.* the demic diffusion, and their subsequent demographic growth (which would in this scenario correspond to the second peak of the SPD curve around 6250 BC in Fig. 2) would occur only after 6050 BC in this scenario.

This hypothesis has several merits (pros):
❶ It would explain an unusually high estimated speed of expansion in southern and central Serbia. If the actual farmers arrived in the south of Serbia around

	Mean expansion speed estimate (km/year)	Standard deviation of the estimate
RMA	1.66	0.30
OLS	2.14	0.59

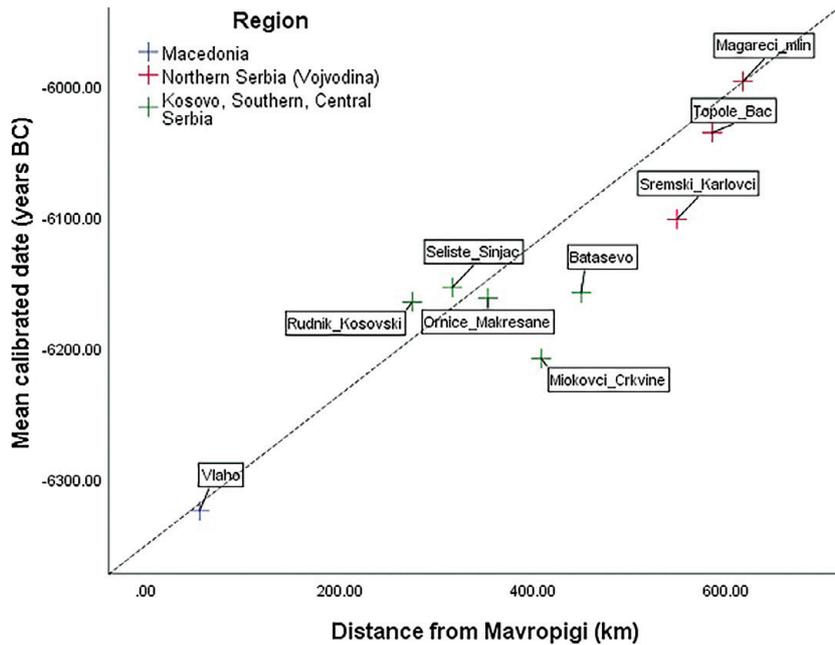*Tab. 3. Summary of the Monte Carlo expansion speed estimates.*

Fig. 6. Plot of the means of the calibrated distributions of the earliest radiocarbon dates against distance from the Mavropigi site in Greece. The dashed line represents an ordinary least squares regression line with distance from Mavropigi as the independent variable, and the mean of distribution of calibrated radiocarbon date as the dependent variable.

Early Neolithic sites in the central Balkans are flat sites with little or no vertical stratification of habitation horizons. For these reasons, many scholars share the view that these sites represent the remains of short-lived settlements, frequently relocated with high residential mobility (*Bailey 2000.58; Tringham 2000; Greenfield, Jongsma 2006; Greenfield et al. 2014; Klindžić, Hršak 2014; Greenfield, Lawson 2020*).

❸ Most importantly, this hypothesis would explain the drop of the SPD proxy curve. If the first farmers came in greater numbers only after 6000 BC, replaced the local hunter-gatherers, and started to live in sedentary settlements, the number of sites and datable material would decrease between 6000 and 5800 BC, only to rise again as the Neolithic population in the central Balkans started to grow as suggested by the second peak of the SPD curve and predicted by the NDT theory.

6250 BC, it would have taken around 200 years for them to reach central Serbia and Šumadija if their speed of expansion was equal to the continental average.

❷ It would explain differences in architecture and settlement layout between the settlements in the southern and northern parts of the central Balkans. In contrast to the Neolithic in North Macedonia and southern parts of Serbia, where Neolithic settlements consisted of solidly built wattle-and-daub houses with rectangular plans (*Gimbutas 1976; Horejs et al. 2022; Naumov et al. 2023*), as in the Neolithic sites in Thessaly and Greek Macedonia[4] (*Perlès 2001*), the Neolithic settlements in the north (central Balkans and the Pannonian plain) consisted mostly of pit-houses (*e.g., Bogdanović 1988; Minichreiter 1992; 2007; Greenfield, Drasovean 1994; Greenfield, Jongsma 2006; Marić 2013; Greenfield et al. 2014; Oross et al. 2016*), and in rare cases, lightly built above ground houses (*e.g., Bogdanović 1988; Minichreiter 2010*). This low investment in dwelling architecture would be consistent with the less sedentary and more mobile lifestyle (*McGuire, Schiffer 1983; Binford 1990*).

However, there are also arguments against the Mesolithic hypothesis (cons):

❶ Individuals with genotypes indicating Anatolian descent are already present in the Danube Gorges before 6000 BC. According to the recent paleogenetic study by Maxime Brami *et al.* (*2022*), the mean calibrated date for the oldest individual (the adult male from grave 18) buried at Lepenski Vir with admixed Aegean/Anatolian and Mesolithic ancestry is 6099 BC (95% CI: 6230–5984 BC). This means that demic diffusion did take place earlier, in accord with the standard model, but on the other hand, these pre-6000 BC contacts could be limited to individual interactions, not an advancement of the Neolithic expansion front.

❷ Individuals who are found in pre-6050 BC contexts are usually buried in a flexed position (*Jovanović* et al.

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4 It should be noted that pit-houses are dominant at the earliest Neolithic sites in Greece, such as Mavropigi, Paliambela and Revenia (*Karamitrou-Mentessidi* et al. *2013; Tsartsidou, Kotsakis 2020; Maniatis, Adaktylou 2021*), but after around 6400 BC above ground houses are built more often, and became the norm on tell sites.

2021a), which is the typical Neolithic funerary practice of the first farmers in SE Europe. People of Mesolithic origin in the second half of the 6th millennium BC in the Danube Gorges are usually buried in the supine position (*Radovanović 1996*)

❸ The sudden drop of the SPD curve would mean that the curve stops tracking the Mesolithic people with pottery and elements of the Neolithic package which increase their visibility, and starts tracking the Neolithic farmers who are present at first in low numbers. But the question in this case is what happened to the hypothesized Mesolithic population, why would they simply disappear and how?

The Mesolithic hypothesis can be tested primarily with the aDNA data. If this hypothesis is true, then most individuals buried before 6050 BC should be of local Mesolithic, rather than Anatolian/Aegean, descent. It is possible that some of the individuals with pure or mixed Anatolian descent occur in pre-6050 BC contexts, even if the Mesolithic hypothesis is true, but the majority would have to be predominantly local.

Changes in mobility and residence patterns influenced by environmental factors

In a previously published paper (*Porčić* et al. *2021a*), it was proposed that the puzzling decrease of the SPD curve after 6050–6000BC could have been caused by changes in residential mobility of the first farmers rather than drastic changes in population size: "*If the communities prior to 6000 BC were for some reason (*e.g.*, unstable climate due to 8.2 ky event) more mobile than communities afterwards* i.e. *that the average duration of the pre-6000 BC settlements was lower than the average duration of post-6000 BC settlements, then the number of pre-6000 BC sites would be higher than the number of post-6000 BC sites, even if there was no difference in population size.Assuming the random sampling of sites for radiocarbon dating, this would result in a higher number of pre-6000 BC dates relative to the post-6000 BC dates. In terms of the SCPD curve, this might produce a pattern of increase and decrease similar to the one observed. The first peak of the curve would reflect higher mobility in the pre-6000 BC period. After 6000 BC, if the residential mobility was reduced, this would explain the abrupt drop of the SCPD curve. The second episode of growth, after 5800 BC, would represent the growth of population due to the NDT. Therefore, this hypothesis would suggest that we only have one process of population growth as* predicted by the major theories but that it is distorted by the effect of the changes in settlement pattern on the SCPD curve. Instead of observing a monotonically increasing SCPD curve, we would observe a falsepeak around 6000 BC due to these effects.*" (*Porčić* et al. *2021a.Supplementary File 1.21–22*).

In this paper I will present slightly modified version of this hypothesis: the initial expansion of farmers in the central Balkans was accompanied by increased residential mobility as a consequence of the encounter with new environment and/or the consequences of the 8.2 ky event.

The migration to the central Balkans from the southern Balkans was a shift from one climatic regime, Mediterranean and Sub-Mediterranean in the south, to another – Sub-continental and Continental climate in the north (*Ivanova* et al. *2018; Krauß* et al. *2018; de Vareilles* et al. *2022; Vander Linden 2023*). This change in the environment had implications for the farming systems in terms of the exploited plant and animal species and their diversity (*Orton* et al. *2016; Ivanova* et al. *2018; de Vareilles* et al. *2022*). In addition to the environmental shift associated with geography, the expansion of the Neolithic across the central Balkans broadly coincided with the climatic 8.2 ky event (*Budja 2007; Krauß 2023; Vander Linden 2023*). The 8.2 ky event is the Holocene cold climatic event which peaked between approximately 6250BC and 6200 BC and ended before the start of the 6th millennium BC (*Weninger* et al. *2006; Pross* et al. *2009; Flohr* et al. *2016*). It was a period of colder climate broadly comparable to the historically recorded Little Ice Age (*cf. Fagan 2000*).

If the environment of the central Balkans presented new challenges to the first farmers, for intrinsic geographic reasons related to climate, specific conditions related to the 8.2 ky event, or both, it is possible that failure to establish permanent residence in some microregions occurred, with the net result being higher residential mobility. After two centuries, the sociocultural system adapted in such a way that settlements became more permanent, and therefore, less numerous in the archaeological record. This would account for the sudden drop of the SPD proxy at the end of the 7th millennium BC. The increase in the SPD curve from around 5800 BC and around 5600 BC would be due to population growth related to the Neolithic Demographic Transition.

It should be noted that this hypothesis is not in contradiction with the WoA standard model. The main difference lies in the mechanism of expansion. Whereas the WoA model assumes that the expansion occurs primarily because the surplus population diffuses over space, this hypothesis assumes that the Neolithic front is moving primarily due to high residential mobility, which may or may not be related to climate-induced factors.

The arguments in favor of this hypothesis (pros) are as follows:
❶ As both theoretical frameworks (*McGuire, Schiffer 1983*) and empirical data (*Binford 1990*) suggest, more mobile communities have lighter and less durable architecture. Again, this would account for the above-mentioned difference in the Early Neolithic settlement architecture between southern and northern parts of the Balkans, where above-ground rectangular houses dominate in the south, extending approximately to southern parts of Serbia and Kosovo, whereas pit-houses are the dominant architectural form north of this line.

❷ The idea that the first farmers were in exploration mode is consistent with the higher diversity of environments as reflected in the higher altitudinal variance of settlements in the pre-6000 BC period (*Porčić* et al. *2021a.Supplementary file 1*).

The main argument against this hypothesis (con) is that there is no apparent difference in the settlement size, layout and architecture between settlements founded before and after 6000 BC. For example, settlements consisting of pit-houses are present well into the 57th century BC, at sites such as Starčevo, Vinča-Belo Brdo, Jaričište and so on. If there was a shift to a more permanent settlement type, we would expect this to be reflected in the architecture as well. However, it should be emphasized that this absence of apparent evidence may be due more to less extensive (*i.e.* a small percentage of the total site area excavated) and less intensive (no Bayesian modelling of dates, no attempts at pottery seriation, or micromorphological studies) research on most sites. Therefore, a way to test this hypothesis would include several lines of research:

❶ Targeted sampling for radiocarbon dating, specifically for Bayesian modelling to determine, as precisely as possible, the duration and continuity of the settlement occupations before and after ~6000 BC. Even though the number of radiocarbon dates is rather large for the central Balkans, they were mostly sampled for the SPD method, where the sampling design, with random sampling (see *Porčić* et al. *2021a*), is precisely the opposite of the one needed for Bayesian modelling.

❷ Micromorphological and geoarchaeological research of sediments to establish how settlements were used, in terms of permanence and continuity of habitation, for settlements before and after ~6000 BC.

❸ Bioarchaeological research using stable isotopes (*e.g.,* strontium, oxygen) to reconstruct the mobility patterns of humans and animals before and after ~6000 BC.

❹ Paleoclimatological research aimed at reconstructing environmental conditions in the central Balkans during the 8.2 ky event. As there are no climate proxies from the central Balkans itself, we can only extrapolate or interpolate climatic and environmental reconstructions from the surrounding proxies. However, we need to have more precise environmental reconstructions in order to evaluate the impact of the 8.2 ky event on early farming with more confidence.

Salvaging the standard model

This section may seem anticlimactic, as many words are spent in this paper criticizing the standard model. However, it seems appropriate to evaluate the ability of the standard model to resist criticism, *i.e.* to explore whether the potential cracks in the interpretative edifice can be patched.

Let us begin with the expansion speed. First of all, 1–1.3km/year is the continental average, and variability is expected and does occur at the regional level (*Bocquet-Appel* et al. *2012; Blagojević 2023*). However, the question persists: why was the expansion speed greater in the central Balkans? Fort's modified WoA model with anisotropic expansion[5] might be an answer (*Fort 2020*). The differences in expansion speed between the mountainous and hilly lands south of Sava and Danube and the Pannonian plain to the north can be explained by a shift from anisotropic

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5 Isotropic expansion refers to the case where all directions are equally probable for the migration, whereas anisotropic expansions refer to the case when one or several directions are preferred over others.

migration in the former region, to isotropic migration in the latter. As the main corridors for the expansion in the rugged terrain were valleys of rivers that flow in thesouth-north direction, this kind of topography channeled the demic diffusion of farmers, making the northern direction more probable than any other, and thus increasing the speed of the expansion. Once the farming front reached the plain, it slowed down as all directions became relatively equally probable for the expansion. This would explain both why the average speed is high (as most of the central Balkan region is mountainous or hilly) and it would also explain the difference in the expansion speed between regions south and north of the Danube and Sava rivers.[6]

When it comes to growth rates, the unusually high growth rate estimates can be explained by sampling bias.Even though the number of radiocarbon-dated sites from different parts of the central Balkans is representative in relation to the number of Early Neolithic sites in different regions of the central Balkans (see *Porčić* et al. *2021a.Supplementary file 1*), the distribution of archaeologically recorded (dated or not) sites between regions may be biased due to modern regional differences in economy and research intensity (*cf. Palmisano* et al. *2021*). It could be argued that, as southern Serbia and Kosovo were among the poorest regions in ex-Yugoslavia, the intensity of research was lower, so the overall number of discovered sites was lower. If we are systematically missing the earliest part of the population growth curve, *i.e.* if we have a spatio-temporally biased sample, then our estimate of the growth rate will also be biased. The dates from the southern parts of the study area contribute most to the SPD demographic proxy curve in the earliest times of Neolithic expansion. As the frequency of these dates will be lower than in reality due to regional sampling bias, the increase of the SPD curve will appear sharper than it is, leading to higher growth rate estimates. This is one possible explanation for the unusually high growth rate estimates reported in Blagojević *et al.* (*2024*).

As new data become available, they seem to fill the blanks which led to doubts about the standard interpretation based on the WoA model. For example, one of the important reasons for the mistrust in the standard interpretation was the lack of reliable pre-6200 BC dates in North Macedonia (see the discussion in *Porčić* et al. *2020*). However, with the discovery and dating of the site of Vlaho (*Naumov* et al. *2023*), located in the southernmost part of North Macedonia, a gap was filled between the oldest dates in Greece, from sites such as Mavropigi, Revenia-Korinos and Paliambela (*Karamitrou-Mentessidi* et al. *2013; Maniatis 2014; Reingruber 2020; Tsartsidou, Kotsakis 2020; Urem-Kotsou, Kotsos 2020; Maniatis, Adaktylou 2021*), and Serbia.

When it comes to the puzzling decrease of the SPD proxy curve after 6050 BC, it can indeed be due to a population decrease. Demographic boom and bust patterns have been observed in almost all parts of Europe in the Neolithic (*Shennan* et al. *2013; Timpson* et al. *2014*), and recent research suggests that violent conflicts, triggered by high population density and competition for resources, might have caused the bust episodes (*Kondor* et al. *2023*). Currently, there is insufficient material (human skeletons or extensively excavated settlements) from the 6000–5800 BC period in the central Balkans to evaluate this hypothesis.

Cultural evolutionary theory suggests that a population decrease should result in the reduced stylistic diversity of the material culture (*Neiman 1995; Rorabaugh 2014*) and a significant change in style after the population bottleneck (*Shennan 2000*). A study by Nenad Tasić (*2009*) suggests that there was a temporal discontinuity of painted pottery styles after ~5800 BC in the central Balkans. This observation is consistent with the demographic interpretation of the SPD curve (*i.e.* a population crash), but it should be tested more rigorously with quantified data on pottery variability, including all pottery types, not just painted pottery, which is scarce.

Conclusion

This paper has summarized the available evidence and critically reflected on the proposed interpretations related to the onset of the Neolithic period in the central Balkans. The data support a version of the WoA model, but there is still room for other hypotheses. These hypotheses are elaborated here and means of their test-

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6 The simulation in Porčić *et al.* (*2021b*) does take the topography into account, so directional expansion is effectively taking place in the simulation, yet it still returns a high total fertility rate. It is possible though that the settlement threshold was in reality much higher than allowed for in our simulations, meaning that farmers were more demanding when it came to choosing their settlement locations than we allowed for. This would increase the speed of expansion without the need to increase the fertility and growth rates.

ing are proposed. The fact that we are still left with uncertainties and questions, despite a large quantity of empirical data amassed in the last decade, highlights how complex the Neolithisation process was. In other words, more research is needed before we reach a full (or adequate) understanding of the historical events and processes which unfolded at the end of the 7th millennium BC in the central Balkans. Fortunately, the road ahead does not seem too long, as all hypotheses and questions discussed in this paper are within the reach of modern archaeological methods.

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