RESEARCH ARTICLE – VÝZKUMNÝ ČLÁNEK

Settlement and temporal dynamics during the LBK and post-LBK transition: A study of the loessic corridor from the Rhineland to Hesbaye (Germany, the Netherlands, Belgium)

Sídelní a časová dynamika během LBK a post-LBK přechodu: Studie spražového koridoru od Porýní po Hesbaye (Německo, Nizozemsko, Belgie)

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This study examines the settlement dynamics of Linearbandkeramik (LBK) and post-LBK communities across the loessic corridor spanning the Rhineland, Limburg, and Hesbaye (Germany, the Netherlands, Belgium). By applying Bayesian chronological modelling to radiocarbon dates and regional ceramic typochronologies, we reassess the timing and tempo of LBK expansion, population growth, and the subsequent post-LBK transition. Two alternative models are presented to accommodate the challenges posed by sparse datasets: one prioritising the existing typochronological frameworks, the other emphasising the currently available radiocarbon dates. Our results reveal a rapid initial increase in LBK settlement densities, followed by a phase of intensification linked to enclosure construction during the mid-51st century BC, and a heterogeneous post-LBK transition marked by regional variability in continuity and abandonment. These findings contribute to broader debates on the expansion, social dynamics, and environmental interactions of early farming communities in Northwestern Europe. Moreover, they highlight the potential of, and need for, renewed engagement with absolute dating.

Neolithic – Linearbandkeramik (LBK) – post-LBK – Northwestern Europe – Bayesian chronological modelling – settlement dynamics

Tato studie se zabývá sídelní dynamikou komunit kultury s lineární keramikou (LBK) a post-LBK období ve spražovém koridoru zahrnujícím Porýní, Limburg a Hesbaye (Německo, Nizozemsko a Belgie). Pomocí bayesovského chronologického modelování radiokarbonových dat a regionálních keramických typochronologií nově posuzujeme načasování a tempo expanze LBK, populačního růstu a následného přechodu k post-LBK období. S ohledem na obtíže vyplývající z omezeného množství dat představujeme dva alternativní modely: první upřednostňuje existující typochronologické rámce, zatímco druhý klade důraz na aktuálně dostupná radiokarbonová data. Výsledky ukazují rychlý počáteční nárůst hustoty osídlení LBK, po němž následovala fáze intenzifikace spojená s výstavbou ohrazení v polovině 51. století př. n. l. Přechod k post-LBK období byl heterogenní a vyznačoval se regionálními rozdíly v kontinuitě a opouštění sídel. Tato zjištění přispívají k širší diskusi o expanzi, sociální dynamice a interakcích raně zemědělských komunit se životním prostředím v severozápadní Evropě. Zároveň poukazují na potenciál absolutního datování i na potřebu věnovat mu znovu větší pozornost.

neolit – kultura s lineární keramikou (LBK) – post-LBK – severozápadní Evropa – bayesovské chronologické modelování – sídelní dynamika

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Introduction

The settlement dynamics of Linearbandkeramik (LBK) communities feature prominently in narratives about long-term patterns in human societies. The evolution of settlement and population densities during the LBK and post-LBK transition has been considered in light of human mobility (*Hofmann 2016*; *2020*; *Furholt 2018*), climate change (*Gronenborn 2010*; *Gronenborn et al. 2014*), kinship systems (*Van der Velde 2016*), social cohesion (*Gronenborn et al. 2020*), inter- and intra-community conflict (*Kondor et al. 2024*), and the appearance of novel technologies (*Shennan et al. 2013*). A persistent challenge in these studies is combining data from various national and regional research traditions. Specifically, combining regional LBK chronologies (e.g., *Modderman 1970*; *Lüning 2005*; *Blouet et al. 2013*; *Van der Velde 2016*) into an overarching chronology which can be used to analyse settlement dynamics across larger areas.

Here, we apply Bayesian chronological modelling (*Bronk Ramsey 1995*; *2009a*) to shed new light on settlement dynamics during the LBK and post-LBK period in the Rhineland (or Jülich-Zülpicher Börde, Germany), Limburg (the Netherlands) and Hesbaye (Belgium; see *Fig. 1*). These three areas form a continuous geological and ecological zone, fragmented by modern national borders (*Lehmkuhl et al. 2021*; *Denis et al. in press*). Moreover, they form a critical corridor within the LBK distribution, connecting LBK communities in Central Europe to those further west. During the post-LBK period, this area was a boundary zone between multiple post-LBK communities: Großgartach (GG), Rössen (RÖ), and Blicquy/Villeneuve-Saint-Germain (BVSG), as well as Swifterbant (SWB) communities with strong ties to Late Mesolithic groups (see *Fig. 1*). This paper is a complement to the contribution by *Denis et al.* (*in press*) which looks at the trajectories of these communities in the same area.

We start by reviewing the current understanding of settlement dynamics of early farming communities in the Rhineland, Limburg, and Hesbaye. In all three regions, the population densities of these communities are thought to increase rapidly after their initial arrival, followed by a minor decline and then a resurgence, before a rapid fall (*Zimmermann et al. 2007*; *Bosquet – Fock 2025*). In Hesbaye, LBK was continuous with BVSG occupation (*Hauzeur – Jadin 2025*; *Denis et al. 2024*). By contrast, early farming communities disappeared altogether from the Rhineland and Limburg between the end of the LBK and the arrival of GG and RÖ communities, respectively (*Zimmermann et al. 2007*). In a broader framework, SWB communities with strong ties to Mesolithic populations co-existed with and persisted after LBK communities in the Netherlands (*Amkreutz 2013*; *Olalde et al. 2026*).

We present a comprehensive survey of radiocarbon dates associated with LBK and post-LBK groups in the Rhineland, Hesbaye, and Limburg. The dataset is sparse (cf. *Denaire et al. 2017*, 1132) and mostly composed of radiocarbon dates on charred cereals which pose a relatively high risk of intrusive or residual dates (cf. *Bayliss et al. 2011*, 40–41). Therefore, we explore two alternative Bayesian chronological models: one in which the overarching chronology from *Blouet et al.* (*2021*) has interpretative priority, and another in which the radiocarbon dates have interpretative priority. In both cases, the models present tantalising evidence for a rapid growth of LBK communities after their first arrival, a phase of intensification during the middle 51st century BC which is tied to the construction of enclosures, and a heterogeneous, local dynamic during the post-LBK transition with various degrees of overlap with post-LBK communities.

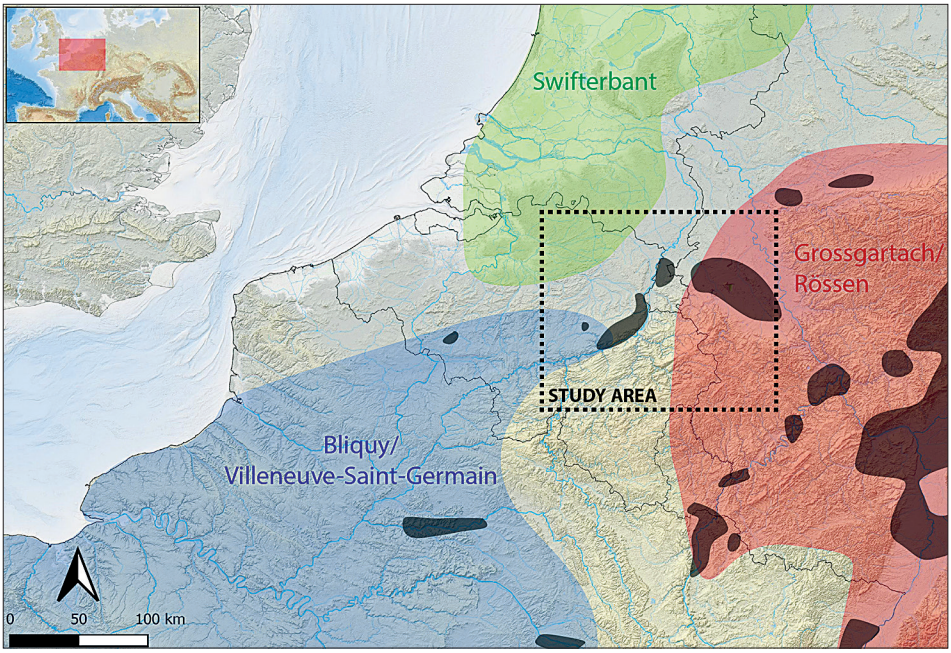


Fig. 1. Map of the study area with the approximate distribution of the archaeological phenomena discussed in the text. Black – Linearbandkeramik (LBK); blue – Blicquy/Villeneuve-Saint-Germain (BVSG); red – Grossgartach (GG) and Rössen (RÖ); green – Swifterbant (SWB).

While these results offer exciting new insights into the LBK and post-LBK transition in Limburg, the Rhineland, and Hesbaye, we underline the challenges posed by sparse radiocarbon datasets. Thus, in the spirit of a *status quaestionis* for LBK and post-LBK research in this area, we call for renewed absolute dating of LBK and post-LBK contexts to illuminate the temporal dynamics of the earliest farming communities in northwestern Europe.

(Post-)LBK settlement dynamics: *Status quaestionis*

To date, studies of settlement dynamics among early farming communities in the Netherlands, western Germany, and Belgium have relied primarily on ceramic typochronology. In the Netherlands, the typochronology proposed by *Modderman* (*1970*) continues to be in use for this purpose, despite more recently proposed alternatives (*Van der Velde 1979*; *2016*; *Van Wijk – Amkreutz 2022*). *Blouet et al.* (*2021*) have recently established a typochronology for the LBK in Hesbaye. The LBK typochronology for the Rhineland was originally established by *Stehli* (*1973*) but has been continuously updated since (see *Kerig et al. 2010*). The *modus operandi* in all three regions is to attribute (houses in) settlements to subphases within the respective typochronology based on the decorated pottery found in features associated with these domestic contexts. The final tally of houses per subphase forms the basis for further inferences about settlement dynamics and population densities (e.g., *Hofmann 2016*).

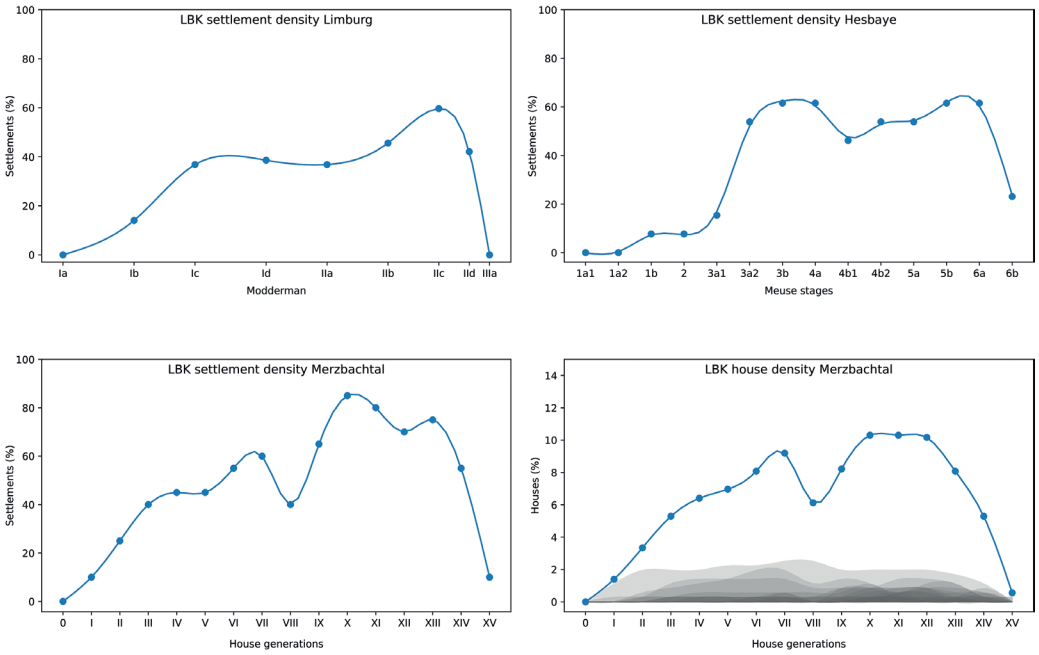


Fig. 2. Settlement densities for LBK communities in Limburg (A; n=57), Hesbaye (B; n=13), the Merzbachtal, Rhineland (C; n=20), and the density of LBK houses in the Merzbachtal, Rhineland (D; n=359) per phase in the respective regional typochronology. Developments in the Merzbachtal are representative of the broader developments in the Rhineland. The grey scale indicates the number of contemporaneous houses at the various settlements (data for settlement and house densities in the Merzbachtal courtesy of A. Zimmermann; points are relative frequencies and the interpolation line was made with a smoothing B-spline using SciPy, see *Virtanen et al. 2020*).

The Rhineland (Germany)

The Rhineland, more precisely the Jülich-Zülpicher Börde, stands out as one of the most thoroughly investigated areas for LBK and post-LBK settlement dynamics. This is thanks to the contributions of research groups at Cologne University, the intensive excavations in the lignite mining area (most famously in the Merzbachtal), and the excavations and landscape surveys in the wider region. For our overview of settlement dynamics in this area, we use the settlement sequence reconstructed for the Merzbachtal on the basis of the *Hofplatzmodell* (*Boelicke 1982*; *Zimmermann 2012*), which subdivides the LBK period into 16 house generations (HG, labelled HG I–HG XVI). Subsequent studies have shown that this sequence is representative of broader developments in the Jülich-Zülpicher Börde.

At present, the starting date for LBK occupation in the Rhineland falls in the late 54th century BC (HG I) and would be followed by a rapid rise in the number of houses until HG VI (c. 5175–5150 BC), a small dip around HG VII (c. 5150–5125 BC), followed by another increase and peak in occupation during HG XI (5050–5025 BC), and then a steep decline (see *Fig. 2*: C–D). Occupation of the Rhineland area would then cease for a century (*Zimmermann et al. 2007*, 34) before the arrival of new farming communities during the Middle GG phase (4900–4850 BC; *Spatz 1996*; *Broich 2021*, 6).

In terms of population density, *Broich* (*2021*, 95) estimates a sharp decline after the disappearance of LBK. Population densities in the Rhineland during the LBK were about 0.6 persons per square kilometre (*Schmidt et al. 2021*, Tab. 3), but fell to 0.01 persons per square kilometre at the beginning of GG occupation. Only during the subsequent RÖ period (4750–4600 BC) would population densities again reach the levels reconstructed for the LBK period. Consequently, current studies suggest a period of significant settlement growth among early farming communities during the LBK period, followed by a strong contraction and an occupation gap during the post-LBK transition.

Enclosures are common at LBK settlements in the Rhineland but only appear during the later stages, from HG XII onward (*Peters – Zimmermann 2017*, 45). These enclosures are commonly interpreted as communal monuments built through cooperation among larger groups of people (*Kerig 2003*). Their function is debated. Originally, enclosures were interpreted as fortifications (e.g., *Buttler – Haberey 1936*, 20; *Höckmann 1975*). However, the size, slope location, multiple entrances, and unclosed ring ditches make these enclosures unlikely to have been fortifications (*Peters 2024*). There is also evidence that the digging and backfilling of ditches was of significance to Early Neolithic societies (*Haack 2014*, 355). As such, an interpretation as socio-ritual gathering places has to be considered (*Whittle 1996*, 174–176; *Kaufmann 1997*; *Meyer – Raetzel-Fabian 2006*). However, the fact that these enclosures emerge in the Rhineland during the later stages of LBK occupation may itself signal a connection to societal stress or violence (*Kondor et al. 2024*). Regardless, the debate about the potential ritual or defensive nature of these enclosures is likely to continue.

Limburg (the Netherlands)

In the Netherlands, LBK settlement dynamics have primarily been studied in relation to landscape zones. Less emphasis was placed on numerical estimates of population densities, which rely on the number of known settlements (see *Fig. 2*: A). The overview of these developments below follows the typochronology from *Modderman* (*1970*), which distinguishes 9 phases: Ia, Ib, Ic, Id, IIa, IIb, IIc, IId, and IIIa.

The initial LBK occupation in Limburg is dated to 5250 BC, or Modderman Ib (*Lanting – Van der Plicht 2000*), and would occur primarily on the middle loess-covered terraces of the Meuse in the Graetheide area and near Maastricht. The initial appearance of LBK communities was followed by a gradual expansion across these terraces between Modderman Ib and Ic (c. 5100–5000 BC) with new settlements appearing preferentially near rivulets and dry valleys. Additionally, LBK settlements emerged in areas less favourable to agriculture during this period. For example, in the floodplains of the Meuse and at more elevated terraces (*Van Wijk 2016*). The number of LBK settlements then dips slightly between Modderman Id and IIa, before rising and peaking again during Modderman IIc. The end of the LBK in Dutch Limburg (around 4950 BC) is marked by a decline in the number of settlements, from 25 known sites during Modderman IIc to 19 in Modderman IId (*Van Wijk in prep.*; see *Fig. 2*: A). The decline of LBK settlements coincides with evidence for the construction of enclosures, such as those at Beek, Kelmond, and Born (*Brounen – Rensink 2007*; *Van de Velde et al. 2009*). By around 4900 BC, LBK settlements appear to have fully disappeared in Limburg and research suggests the area may have been abandoned entirely (*Amkreutz 2016*; *2017*).

Evidence for occupation during the post-LBK period in Limburg is sparse. A RÖ settlement was excavated near Maastricht-Randwijck (*Louwe Kooijmans 1988*). In a broader geographical framework, SWB communities, which have strong ties to Late Mesolithic groups of hunter-gatherers, play a prominent role in the wetland environments of the Netherlands and adjacent parts of Belgium during the Neolithic (*Amkreutz 2013*; *Olalde et al. 2026*). These communities interacted with early farming groups, as evidenced by their integration of domestic animals (as of 4450 BC), crops (as of 4200 BC), as well as artefacts attributed to farming (*Raemaekers et al. 2023*).

Hesbaye (Belgium)

Reconstructions of settlement dynamics during the LBK period and post-LBK period remain challenging for Hesbaye, because only a small fraction of the sites known from this period has been excavated (*Bosquet – Fock 2025*). The LBK settlement at Darion is the only to have been fully excavated; most other sites are only known from surveys. Furthermore, many LBK ceramic assemblages are yet to be classified within the Meuse chronology (*Blouet et al. 2021*). Nevertheless, a preliminary estimate of developments in population densities can be derived from a systematic assessment of the presence or absence of ceramics from specific subphases at these sites (*Bosquet – Fock 2025*; see *Fig. 2*: B).

The typochronology by *Blouet et al.* (*2021*) distinguishes six stages in the LBK occupation of Hesbaye. These phases are labelled ME 1–6 with finer subdivisions indicated by alphanumeric sequences. For example, ME3a1 and ME3a2 refer to the earlier and later parts of the first half of ME3, respectively.

The number of LBK settlements in Hesbaye was initially low during the ME1 and ME2. Then, it rapidly grew during the late ME2 and early ME3 subphases, followed by a brief reduction in settlements during ME4, and then another increase which led to a peak in ME5b. This peak was followed by a rapid decline from ME6a onward, leading to a drastic reduction in settlements by the end of the LBK (see *Fig. 2*: B). During the transition from the Final LBK to the Terminal LBK (ME6a–6b), LBK occupation in Hesbaye was mainly concentrated within villages within enclosures, or in close proximity to such enclosed settlements. This pattern persisted until the disappearance of the LBK from Hesbaye (*Bosquet – Fock 2025*).

The LBK enclosures in Hesbaye are likely defensive in nature, although alternative interpretations cannot be excluded. Crucially, the defensive value of these enclosures does not derive from the discontinuous ditches or simple earthworks but from the palisade associated with these features (*Broes – Bosquet 2007*). The ditches may have hindered movement, but likely result from the construction of these palisades (similar to the extraction pits for loam found beside LBK houses) rather than from a deliberate effort to create a moat. The complex features located at the entrances of the enclosures at Darion and Waremme-Longchamps are a further point in case. Again, a defensive construction is probable but LBK communities may have assigned multiple functions to these features (*Bosquet 1993*; *Bosquet et al. 2007*).

The relation between LBK and post-LBK settlements in Hesbaye remains unclear, because the connection between the ceramic typochronologies for LBK (*Blouet et al. 2021*) and the subsequent BVSG communities (*Constantin 1985*) has not yet been studied. That said, only two BVSG settlements are known from Hesbaye and both are attributed to the

second stage in the BVSG typochronology (*Burnez-Lanotte et al. 1993*; *Jadin 2003*). LBK occupation from the last phase (ME6) in the typochronology from *Blouet et al.* (*2021*) is currently only documented in Hesbaye and remains absent further west in Hainaut. This raises the possibility that LBK occupation lasted longer in Hesbaye while the initial phase of the BVSG may have emerged in Hainaut (*Blouet et al. 2021*). In any case, the continuity of traditions in lithic and ceramic production observed between LBK and BVSG in Hesbaye suggests that these communities were continuous (*Denis et al. 2024*; *in press*), or potentially even partially contemporaneous (*Hauzeur – Jadin 2025*).

Summary

Our overview reveals a shared trend in the settlement dynamics of LBK and post-LBK communities in Limburg, the Rhineland, and Hesbaye (*Fig. 2*). The initial appearance of LBK is characterised by a rapid increase in settlements. This is followed by a slump in settlement densities and then a brief resurgence, before a rapid decrease in settlement densities at the end of the LBK period. The post-LBK period appears discontinuous relative to the LBK period. In the Rhineland, an occupation gap occurs until the arrival of GG communities (*Zimmermann et al. 2007*). Similarly, a settlement hiatus occurs in Limburg after the disappearance of LBK (*Amkreutz 2016*), although Mesolithic populations are continuous. In Hesbaye, no occupation gap occurs but a drastic reduction in settlement densities is evident.

This shared trend is highly suggestive for the development of early farming communities. However, a key question persists: Is this a single trend happening simultaneously across settlement clusters in Limburg, Hesbaye, and the Rhineland, or are these independent local trends which happen asynchronously? To answer this question, an absolute chronological framework is needed to articulate the various typochronologies for the LBK (*Modderman 1970*; *Kerig et al. 2010*; *Zimmermann 2012*; *Blouet et al. 2021*) and post-LBK (*Constantin 1985*; *Spatz 1996*; *Raemaekers 1999*) period in the study area.

Towards an absolute chronological framework

Several studies have attempted to create an overarching chronological framework for the LBK occupation in Hesbaye, Limburg, and the Rhineland. These attempts are often based on ceramic typochronology (e.g., *Stehli 1994*; *Jeunesse 1999*; *Lüning 2005*; *Balkowski – Hartmann 2015*; *Balkowski 2015*; *Blouet et al. 2021*). To our knowledge, no such overarching frameworks have been published for the period following the LBK, since different communities inhabited these areas after the post-LBK transition. However, the chronological framework for the LBK period touches upon the post-LBK transition since it encompasses the end of LBK groups. Therefore, we will focus on an overarching LBK chronology here.

The most recent proposal for an overarching LBK typochronology stems from *Blouet et al.* (*2021*, Tab. 3). It consists of five so-called chronozones, which articulate the regional typochronologies for Limburg, the Rhineland, Hesbaye, the Lorraine, and the Aisne Valley. Each chronozone would capture shared, supraregional patterns. For example, the Rubané ancien corresponds to Modderman I (Limburg), HG I–VIII (the Rhineland) and

ME1 (Hesbaye). The chronozones (listed from oldest to youngest) are: Rubané ancien, Rubané moyen, Rubané récent, Rubané final, and Rubané terminal.

Blouet et al. (*2021*) formulated these chronozones on the basis of the regional LBK typochronology for Hesbaye combined with an earlier LBK typochronology for Lorraine (see *Blouet et al. 2013*). They applied Correspondence Analysis (CA) to the frequencies of decorative motifs on pottery from LBK settlement contexts in Hesbaye. The principal coordinates of these assemblages in the first two dimensions were then plotted in a biplot (see *Blouet et al. 2021*, Fig. 4; Supplementary Data), which served as the basis for the articulation of (supra)regional typochronological trends. Cluster analysis was performed over the biplot to identify stylistic developments, and these developments were anchored in absolute time by looking at the position of assemblages with a known age in the biplot (cf. *Blouet et al. 2021*). This typochronology was then extended to Limburg by incorporating a comparatively small number of ceramic assemblages from Dutch LBK sites, and to the Rhineland by judging the position of assemblages with decorative motifs similar to those found in the Rhineland within the biplot. This resulted in synchronisation of the regional typochronologies for Limburg, Hesbaye, and the Rhineland in the form of chronozones (see *Blouet et al. 2021*, Tab. 3). This overarching synchronisation is the focus of this section.

We agree with *Blouet et al.* (*2021*) that their approach has important advantages in terms of reproducibility and openness. However, a formal evaluation of the chronological information and supraregional trends is desirable because, especially as the geographic scale of the analysis expands, there is a chance that CA captures synchronic variation (e.g., between communities or regions) as well as diachronic variation. Therefore, we advocate the use of Bayesian chronological modelling of radiocarbon dates (*Bronk Ramsey 1995*; *2009a*) associated with ceramic assemblages to evaluate potential chronological trends identified with CA. The power of such a combined methodology has readily been demonstrated by *Denaire et al.* (*2017*; cf. *Whittle 2018*) but not yet been applied in the Rhineland, Limburg, or Hesbaye.

Chronozones and chronological models

We conducted a literature review to gather radiocarbon dates associated with LBK and post-LBK groups in the Netherlands, Hesbaye, and the Rhineland. This review yielded 482 radiocarbon dates (see *Online Supplementary Material 1* for documentation according to the guidelines from *Bayliss 2015*). We then selected a subset of high-quality dates based on two criteria: 1) good association to the dated pottery; and 2) a sample material from a short-lived species with low risk of age offsets. We also excluded any dates for which previous studies suggested a residual or intrusive nature.

The majority of the dates in the high-quality dataset were performed on single-entity, short-lived samples, such as charred seeds (*Jadin 2003*, 573; see *Tab. 1*). *Bayliss et al.* (*2011*, 40–42; cf. *Denaire et al. 2017*, 1081–1082, 1129) argue that radiocarbon dates on articulated skeletal remains are preferable over such samples in this context. This is because charred seeds are mobile and thus present a larger risk of residual or intrusive dates relative to articulated skeletal remains. Unfortunately, no radiocarbon dates on articulated skeletal remains could be found in the study area due to the poor preservation of bones in the decalcified loessic soils. Therefore, radiocarbon dates on short-lived, single entity samples like charred cereals are the best available samples at present.

	Model	Rhineland	Limburg	Hesbaye	All LBK	Rhineland	Limburg	Hesbaye	All post-LBK
Sampled material	**Affiliation**	**LBK**	**LBK**	**LBK**	**Total**	**BI**	**SW**	**BVSG**	**Total**
Absorbed lipids	n	1	3	0	4	0	0	0	0
	%	1.6	4.8	0.0	6.5	0.0	0.0	0.0	0.0
Animal bone	n	0	0	0	0	0	29	0	29
	%	0.0	0.0	0.0	0.0	0.0	25.2	0.0	25.2
Human bone	n	2	4	0	6	2	0	0	2
	%	3.2	6.5	0.0	9.7	1.7	0.0	0.0	1.7
Bone (species indet.)	n	0	0	2	2	0	0	0	0
	%	0.0	0.0	3.2	3.2	0.0	0.0	0.0	0.0
Short-lived charcoal	n	0	0	0	0	0	0	1	1
	%	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.9
Cereal	n	6	3	22	31	0	29	0	29
	%	9.7	4.8	35.5	50.0	0.0	25.2	0.0	25.2
Plant material (other)	n	0	0	1	1	0	15	0	15
	%	0.0	0.0	1.6	1.6	0.0	13.0	0.0	13.0
Seed (other)	n	4	8	6	18	0	37	2	39
	%	6.5	12.9	9.7	29.0	0.0	32.2	1.7	33.9
Total	**n**	**13**	**18**	**31**	**62**	**2**	**110**	**3**	**115**
	%	**21.0**	**29.0**	**50.0**	**100.0**	**1.7**	**95.7**	**2.6**	**100.0**

Tab. 1. Overview of high-quality dataset by sample material, model, and region. Percentages are calculated relative to the total number of radiocarbon dates for the LBK and post-LBK periods.

We selected all radiocarbon dates from the high-quality dataset which could be associated with a single chronozone. In practice, each radiocarbon date in the high-quality dataset has an association with a ceramic assemblage dated within a regional typochronology. These typochronological dates can be converted into chronozones using the synchronisation table from *Blouet et al.* (*2021*, Tab. 3) and then incorporated in a Bayesian chronological model (see *Online Supplementary Material 1*: Model 1) which evaluates this typochronology. As an additional check, we also modelled the regional LBK typochronologies for Limburg (*Modderman 1970*), Hesbaye (*Blouet et al. 2013*), and the Rhineland (*Stehli 1973*; *Zimmermann 2012*) separately with only those radiocarbon dates which are a) from said region, and b) associated with pottery assemblages dated with these typochronologies (see *Online Supplementary Material 1*: Models 2–4).

All Bayesian chronological models presented here were coded in the OxCal v4.4.4 software (*Bronk Ramsey 2021*) using the IntCal20 calibration curve (*Reimer et al. 2020*). The structure of Models 1–4 largely follows that of the Bayesian chronological models in *Denaire et al.* (*2017*) for the LBK typochronology in Alsace. The model contains a single sequence with a phase for each chronozone. A trapezoid boundary (*Lee – Bronk Ramsey 2012*) was placed at the start and end of the sequence, as well as between each phase within the sequence. The advantage of a trapezoid boundary is that it does not assume changes to be instantaneous, which is often preferable for cultural phenomena (*Lee – Bronk Ramsey 2012*; cf. *Denaire et al. 2017*, 1104). The radiocarbon dates in the high-quality dataset were

placed into the phase for the corresponding chronozone or regional phase. Multiple dates from independent samples in the same feature were combined using the Combine function, since they are independent samples.

The outcomes of these models point to a paradox. OxCal returns poor agreement indices (A_{model} = 7.4%; $A_{overall}$ = 6.4%; see *Online Supplementary Material 1*) for the Bayesian chronological model of the overarching typochronology. This indicates a poor fit between multiple radiocarbon dates and the model structure (cf. *Bronk Ramsey 1995*, 428; *2009a*, 357). In practice, each chronozone features dates with calibrated ranges which are too old or too young relative to the other parts of the sequence. Paradoxically, OxCal does return good agreement indices for the Bayesian chronological models of the constituent regional typochronologies. For example, Model 2, which combines the radiocarbon dates and typochronology for Hesbaye, yields a good overall fit between the model and radiocarbon dates (A_{model} = 97.1%) and between the individual dates and model ($A_{overall}$ = 103.2%; see *Online Supplementary Material 1*). Care should be taken due to the sparse data in these models. For example, only five radiocarbon dates made the cut for the Rhineland. However, these outcomes do suggest that the regional typochronologies may be well-supported within the contexts in which they were formulated, but that difficulties ensue when they are extrapolated beyond those confines.

These difficulties may have various causes: an incorrect model structure, plateaus in the calibration curve, or dates which are residual, intrusive, or incorrect. We can test whether the problem lies with the model structure and the shape of the calibration curve by simulating radiocarbon dates (see *Online Supplementary Material 1*: Model 5). The simulated radiocarbon dates are random calendrical dates within the time spans of the chronozones. We obtained these timespans by combining the chronozones in *Blouet et al.* (*2021*) with the dates proposed for the regional typochronologies in France (*Meunier 2013*, Fig. 6) and the Rhineland (*Balkowski 2024*, Fig. 25). The error margin of the simulated dates was set to the average error margin of the radiocarbon dates attributed to that chronozone in the high-quality dataset. We generated one such simulated date for each radiocarbon date in the high-quality dataset and included these in the model with the R_Simulate function (*Bronk Ramsey 1995*). OxCal returns good agreement indices (A_{model} = 67.5%; $A_{overall}$ = 70%) for Model 5 and the proposed start and end dates for the chronozones generally fall within one standard deviation of the estimated start and end boundaries (see *Online Supplementary Material 1*). Therefore, neither the model structure nor the shape of the IntCal20 calibration curve explain the outcomes of Model 1. Instead, the problem likely originates from a mismatch between the radiocarbon dates and the chronozones in the overarching typochronology.

Addressing this mismatch forms a critical decision point in this paper. Roughly speaking, two solutions are possible. The first option is to modify the role of problematic radiocarbon dates in the model or (as a last resort) to reject these dates (cf. *Denaire et al. 2017*). This approach is defensible here given the number of radiocarbon dates on charred seeds which do pose a greater risk of residual or intrusive dates (*Bayliss et al. 2011*, 40–42). However, this solution is far from ideal, given that we have no indications from excavators or previous studies that the radiocarbon dates in the high-quality dataset are problematic (see *Online Supplementary Material 1*). The second option, therefore, is to modify the model structure to accommodate the problematic radiocarbon dates. For example, by releasing the constraint that phases are strictly successive. In essence, this option gives the

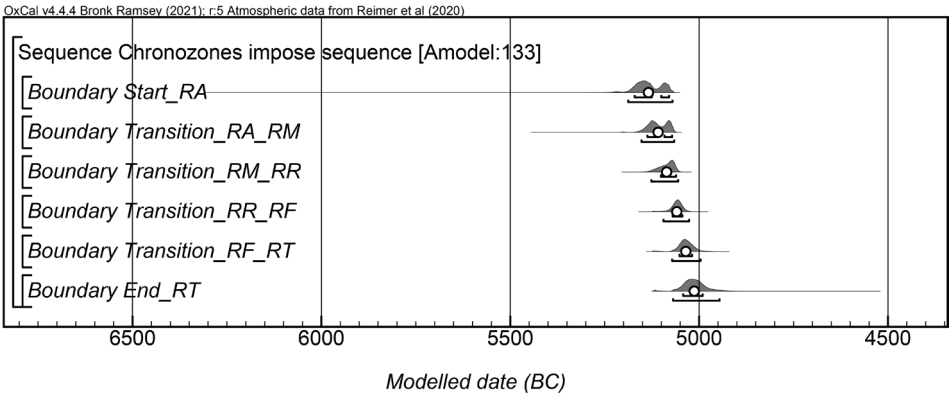


Fig. 3. Overview of posterior distributions for the transitions (normal boundaries) between chronozones from Model 6 (see *Online Supplementary Material 1*). One-sigma and two-sigma confidence intervals and means are indicated. Abbreviations correspond to the chronozones proposed by *Blouet et al.* (*2021*, Tab. 3): RA – Rubané ancien, RM – Rubané moyen, RR – Rubané récent, RF – Rubané final, RT – Rubané terminal.

radiocarbon dates interpretative priority over the overarching typochronology. Given that both approaches come with difficulties and assumptions, we present both solutions as alternative models below.

Option 1: Prioritise the typochronology

Model 6 is built on the assumption that the overarching typochronology from *Blouet et al.* (*2021*) is largely correct and that the aberrant radiocarbon dates in Model 1 are likely residual or intrusive. The structure of this model is identical to that of Model 1, but the role of dates with poor agreement indices in Model 1 has been modified over multiple iterations to maximise the agreement indices and convergence of the model (see *Online Supplementary Material 1*). Initially, all dates with low agreement indices in Model 1 were incorporated with the General Outlier Model from *Bronk Ramsey* (*2009b*). If low agreement indices persisted, the dates were incorporated with the Before or After functions (*Bronk Ramsey 2009a*), or ultimately excluded from the model altogether. The duration of each chronozone was estimated with the Span function (*Bronk Ramsey 2009a*).

The model (*Fig. 3*; *Fig. 4*) estimates that the earliest possible start for the LBK inhabitation of the study area lies between *5176–5082 BC* (68.3% probability) or possibly *5198–5071 BC* (95.4% probability), and the latest possible end date between *5042–4986 BC* (68.3% probability) or possibly *5069–4939 BC* (95.4% probability). The five chronozones are spaced out relatively evenly across this interval and their estimated duration generally falls between *0–30 years* (68.3% probability), or possibly *0–70 years* (95.4% probability). The total duration of the LBK occupation is estimated to lie around *58–176 years* (68.3% probability), or possibly *9–218 years* (95.4% probability). Both the estimated duration of LBK inhabitation and the individual chronozones are shorter than current estimates (see *Lüning 2005*, Fig. 22; *Lanting – Van der Plicht 2000*), although the current estimates fall within two standard deviations of the estimated span (see *Fig. 4*).

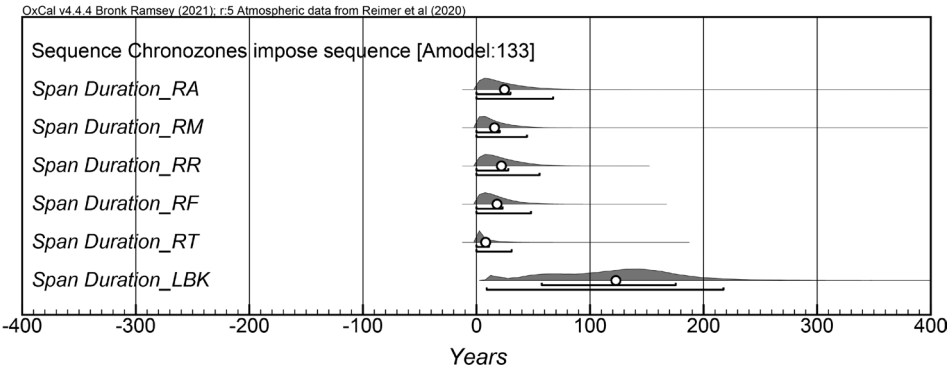


Fig. 4. Estimates for the duration of the chronozones and the LBK from Model 6 (see *Online Supplementary Material 1*). These estimates derive from the Span commands. One-sigma and two-sigma confidence intervals and means are indicated. Distributions cut off at +400 years for convenience. The abbreviations refer to the chronozones defined by *Blouet et al.* (*2021*, Tab. 3): RA – Rubané ancien, RM – Rubané moyen, RR – Rubané récent, RF – Rubané final, RT – Rubané terminal.

The relatively short estimated duration of the LBK inhabitation and chronozones from Model 6 is likely a byproduct of the 'aggressive cleaning' of the radiocarbon dates required to stabilise Model 6. During this process, several of the radiocarbon dates, which are currently accepted as indicators for the earliest and latest possible LBK occupation, had to be treated as outliers or excluded. An example is the radiocarbon date from Uckendorf (*Heinen 2010*; *Balkowski et al. 2016*), which is commonly considered as the start date for LBK occupation in the Rhineland: UtC-13232 (6312±35BP; 5360–5214 cal BC at 95.4% probability). Model 6 estimates a 100% chance that this date is an early outlier, necessitating the application of the General Outlier Model.

Option 2: Prioritise the radiocarbon dates

The alternative to Model 6 is a more flexible model which does not assume that the chronozones are strictly successive but allows for overlap between them. We encoded this possibility in Model 7 (see *Online Supplementary Material 1*). In this model, the internal structures of the phases for each chronozone are identical to those in Model 1. However, the phases are placed into separate sequences, meaning that the chronozones need not be successive. The end and start boundaries of each sequence are inferred with trapezoid boundaries (*Lee – Bronk Ramsey 2012*). The likelihood of these boundaries pre-dating (or post-dating) the boundaries of every other chronozone is estimated with the Order query (*Bronk Ramsey 2009a*).

An important note about Model 7 is that the estimated overlaps are highly dependent on the number and temporal spread of the radiocarbon dates available for each chronozone. This is because OxCal estimates the range of the probability distribution for boundaries based on these two factors (see *Bronk Ramsey 2009a*). The fewer the dates and the wider their spread, the larger the range of the boundary. In practice, this problem is particularly salient for the Rubané terminal, since we found only three radiocarbon dates for this chronozone, which are also relatively far apart in time (see *Online Supplementary Material 1*). Therefore, the outcomes for this chronozone should be ignored.

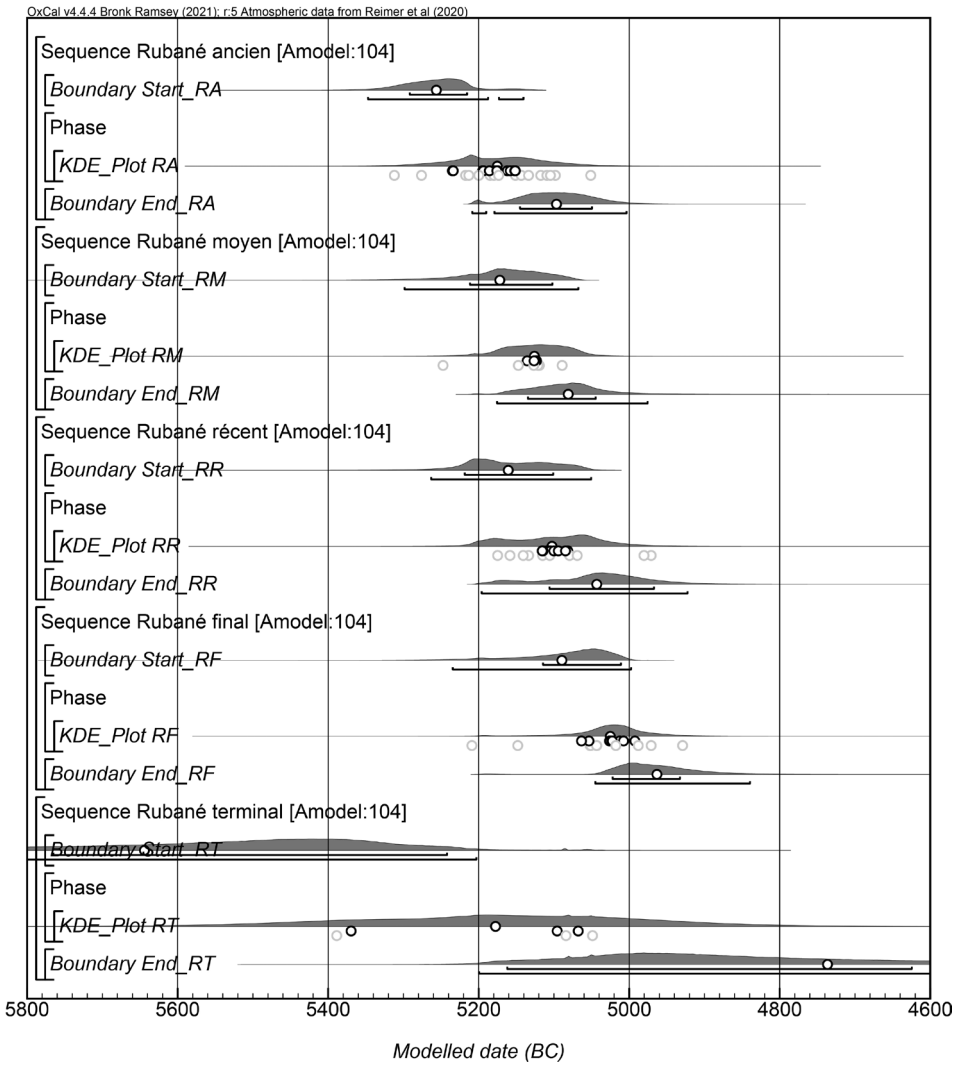


Fig. 5. Overview of Model 7. The vertical brackets and OxCal verbs define the model structure. The one-sigma and two-sigma confidence intervals of the posterior distributions are shown. The plot cuts off at 5800 BC and 4600 BC, since the start and end boundaries for the Rubané terminal have poor convergence and are too broad to be informative (see *Online Supplementary Material 1*). Only the normal boundaries are shown (see *Online Supplementary Material 1* for the trapezium boundaries). Abbreviations for chronozones proposed by *Blouet et al.* (*2021*, Tab. 3): RA – Rubané ancien; RM – Rubané moyen; RR – Rubané récent; RF – Rubané final; RT – Rubané terminal.

The outcomes of Model 7 (*Tab. 2*; *Fig. 5*) illustrate the causes for the poor agreement indices in Model 1, whilst also retaining the outline of the overarching typochronology from *Blouet et al.* (*2021*). For example, the model indicates that the Rubané ancien is likely to start before all other chronozones (with the exception of the Rubané terminal, but see above). However, the end of the Rubané ancien most likely occurs after the start of

	Start RA	End RA	Start RM	End RM	Start RR	End RR	Start RF	End RF	Start RT	End RT
Start RA	0	1	0.880	0.996	0.913	0.995	0.965	0.999	0.052	0.996
End RA	0	0	0.160	0.575	0.205	0.739	0.591	0.972	0.007	0.910
Start RM	0.120	0.840	0	1	0.532	0.915	0.840	0.993	0.022	0.968
End RM	0.004	0.425	0	0	0.153	0.690	0.529	0.949	0.005	0.892
Start RR	0.087	0.795	0.468	0.847	0	1	0.811	0.993	0.016	0.961
End RR	0.005	0.261	0.085	0.310	0	0	0.316	0.832	0.003	0.832
Start RF	0.035	0.410	0.160	0.471	0.190	0.684	0	1	0.009	0.896
End RF	0.001	0.028	0.007	0.051	0.007	0.168	0	0	<0.001	0.705
Start RT	0.948	0.994	0.978	0.995	0.984	0.997	0.991	>0.999	0	1
End RT	0.004	0.090	0.032	0.108	0.039	0.168	0.104	0.295	0	0

Tab. 2. Outcomes of the Order query in Model 7. The cell values are the likelihood that the boundary in the row head predates the boundary in the column head. Abbreviations for chronozones according to *Blouet et al.* (*2021*): RA – Rubané ancien; RM – Rubané moyen; RR – Rubané récent; RF – Rubané final; RT – Rubané terminal. The start boundary and end boundary for the Rubané terminal should be ignored because of the low convergence in Model 7 (see *Online Supplementary Material 1*).

the Rubané moyen, Rubané récent, and potentially the Rubané final. In other words, even though the material associated with the Rubané ancien has the potential to be some of the oldest LBK material, it may also be contemporary with the other chronozones. Similarly, the outcomes of Model 7 suggest that the Rubané moyen, récent, and final are likely to overlap, although the end of the Rubané final is again likely to occur later than the ends of all other chronozones. Based on these radiocarbon dates, overlaps between the chronozones defined by *Blouet et al.* (*2021*) are therefore likely.

With reference to Models 2–5, the outcomes of Model 7 imply that even though certain stylistic traits can be rendered as a chronological sequence in one region, these traits are likely to appear at, and persist for, different times across these regions. As such, overlaps between sequences occur from a supra-regional perspective.

A brief reflection

We present two alternative Bayesian chronological models for the overarching LBK chronology in Hesbaye, Limburg, and the Rhineland. Both alternative models are defensible given the currently available radiocarbon dates but formalise different assumptions about the relation between radiocarbon dates and typochronology. Model 6 prioritises the structure derived from the typochronology in *Blouet et al.* (*2021*), whereas Model 7 prioritises the radiocarbon dates over this structure.

These two Bayesian chronological models pose a fresh challenge for understanding settlement dynamics during the LBK and post-LBK period. If one accepts Model 6, the trends in settlement density discussed above (see *Fig. 2*) remain largely unchanged but their duration shortens, in particular for early chronozones. While interesting, no further analysis of settlement dynamics is thus required here. Instead, we will focus on a scenario in which Model 7 is accepted. In this scenario, the number of houses or settlements per

chronozone can no longer be used to reconstruct settlement dynamics across all three regions because of the overlap between chronozones. Consequently, the challenge becomes to reconstruct settlement dynamics during the LBK and post-LBK directly from the radiocarbon dates.

(Post-)LBK settlement dynamics from the perspective of absolute dates

Radiocarbon dates have previously been used as direct proxies for developments in population densities through statistical analysis of summed probability distributions (*Shennan et al. 2013*). However, this method is prone to artefacts caused by sample bias and the shape of the calibration curve (*Bronk Ramsey 2017*). Therefore, we rely on direct Bayesian chronological modelling of LBK and post-LBK settlements in Hesbaye, the Rhineland, and Limburg. These models are used to infer the start and end dates of LBK occupation in these areas, as well as potential subphases and settlement gaps during the post-LBK transition.

General model outline

The Bayesian chronological models for LBK settlements in the Rhineland (Model 8), Limburg (Model 9), and Hesbaye (Model 10) are structured as follows. Each model contains a separate sequence for LBK and post-LBK communities to avoid assumptions about their chronological relations (*Bronk Ramsey 2009a*). The boundaries of these sequences are inferred with the trapezoid model (*Lee – Bronk Ramsey 2012*). The Order query is applied to infer the likelihood of overlap between the LBK and post-LBK communities, and the Difference query to estimate the duration of this overlap based on the earliest start date for the post-LBK and the latest end date for the LBK (see details in *Online Supplementary Material 1*).

Within each sequence, the radiocarbon dates from the high-quality dataset are grouped into phases for each settlement, and within these phases by feature. The Combine function is used if multiple independent dates are available for the same feature (*Bayliss 2015*). If available, radiocarbon dates outside the high-quality dataset were incorporated as *terminus post quem* for features or sites, given that these dates were often performed on unidentified charcoal which may feature an age offset due to the old wood-effect (cf. *Bayliss et al. 2011*). Outlier models for charcoal, cremations and general outliers were applied if appropriate (*Bronk Ramsey 2009b*; *Rose et al. 2020*). For some settlements, previous studies suggest multiple phases (e.g., *Bosquet – Golitko 2012*). These settlements were modelled as sequences with (sub)phases if this improved the agreement indices of the model and individual dates.

The Bayesian chronological model for SWB settlements in Model 9 is an exception to the above structure. Swifterbant sites often feature settlement deposits which accumulated over longer periods and are continuous with Mesolithic and later Neolithic occupation (e.g., *Teetaert 2020*, 86 on Bazel-Sluis). Detailed studies of site stratigraphy combined with high-precision radiocarbon dating and Bayesian chronological modelling can provide high-resolution chronologies for these settlements (e.g., *Dreshaj et al. 2023a*; *2023b*), but

such analyses are beyond the scope of this paper. Hence, all radiocarbon dates associated with SWB have been modelled as a single phase within a sequence which contains all relevant radiocarbon dates (see *Online Supplementary Material 1*). This phase is summarised with the KDE_plot function (*Bronk Ramsey 2017*).

Three observations about settlement dynamics during the LBK period and post-LBK transition in the Rhineland (Model 8; *Fig. 6*), Limburg (Model 9; *Fig. 7*), and Hesbaye (Model 10; *Fig. 8*) stand out from these models.

Start date for LBK occupation

The earliest appearance of LBK communities in the study area is in the Rhineland. The models estimate that the earliest possible arrival of LBK communities falls between *5460–5310 BC* (68.3% probability), possibly *5550–5224 BC* (95.4% probability; see *Online Supplementary Material 1*). Crucially, the model does not point to a single, oldest settlement but to multiple early settlements (Lamersdorf-Inden, Langweiler 2, 8, 9, Niederkassel-Uckendorf; see *Fig. 6*; *Online Supplementary Material 1*).

The starting dates for LBK in Hesbaye and Limburg are likely later than those in the Rhineland (see *Fig. 7*; *Fig. 8*; *Online Supplementary Material 1*). For Limburg, the models suggest the earliest appearance of LBK communities around *5171–5091 BC* (68.3% probability), possibly *5218–5066 BC* (95.4% probability). The earliest appearance of LBK in Hesbaye is estimated at *5193–5087 BC* (68.3% probability), possibly *5284–5069 BC* (95.4% probability). Strikingly, these starting dates for Limburg and Hesbaye coincide. A simultaneous start of LBK settlement in the Rhineland, Limburg, and Hesbaye is also still possible within the two-sigma ranges, but unlikely. Again, no single settlement takes the crown for being the earliest in Limburg or Hesbaye. Instead, all settlements with associated radiocarbon dates feature starting dates consistent with the initial arrival of LBK communities.

Potential pioneer dynamics

Previous studies of LBK settlements in Hesbaye have argued that some LBK settlements feature a pioneer phase and a main phase (*Bosquet et al. 2008*; *Lodewijckx 2009*; *Bosquet – Golitko 2012*). The pioneer phase would be an initial phase with a small number of houses which is followed by a main phase with multiple houses and in some cases the construction of enclosures. These dynamics are difficult to gauge with the currently available radiocarbon dates because researchers often preferentially dated the earliest houses but rarely undertook systematic dating of all houses at a settlement (see *Online Supplementary Material 1*). Nevertheless, the outcomes of Models 8–10 do hint at such pioneer dynamics.

Specifically, several settlements in Hesbaye (i.e. Darion, Oleye, Remicourt, and Fexhe) appear to have both an older ‘pioneer’ phase and a ‘main’ phase. Radiocarbon dates associated with enclosures and houses in enclosures tend to fall in this main phase (cf. *Bosquet – Golitko 2012*, 95). In fact, we found that the only stable model structure for Hesbaye was to separate the pioneer and main phases at LBK settlements (see *Online Supplementary Material 1*). Other LBK settlements in Hesbaye (e.g., Liège-Place Saint Lambert, Waremme, and Vaux-et-Borset) only appear to be occupied during the pioneer phase (cf. *Lodewijckx*

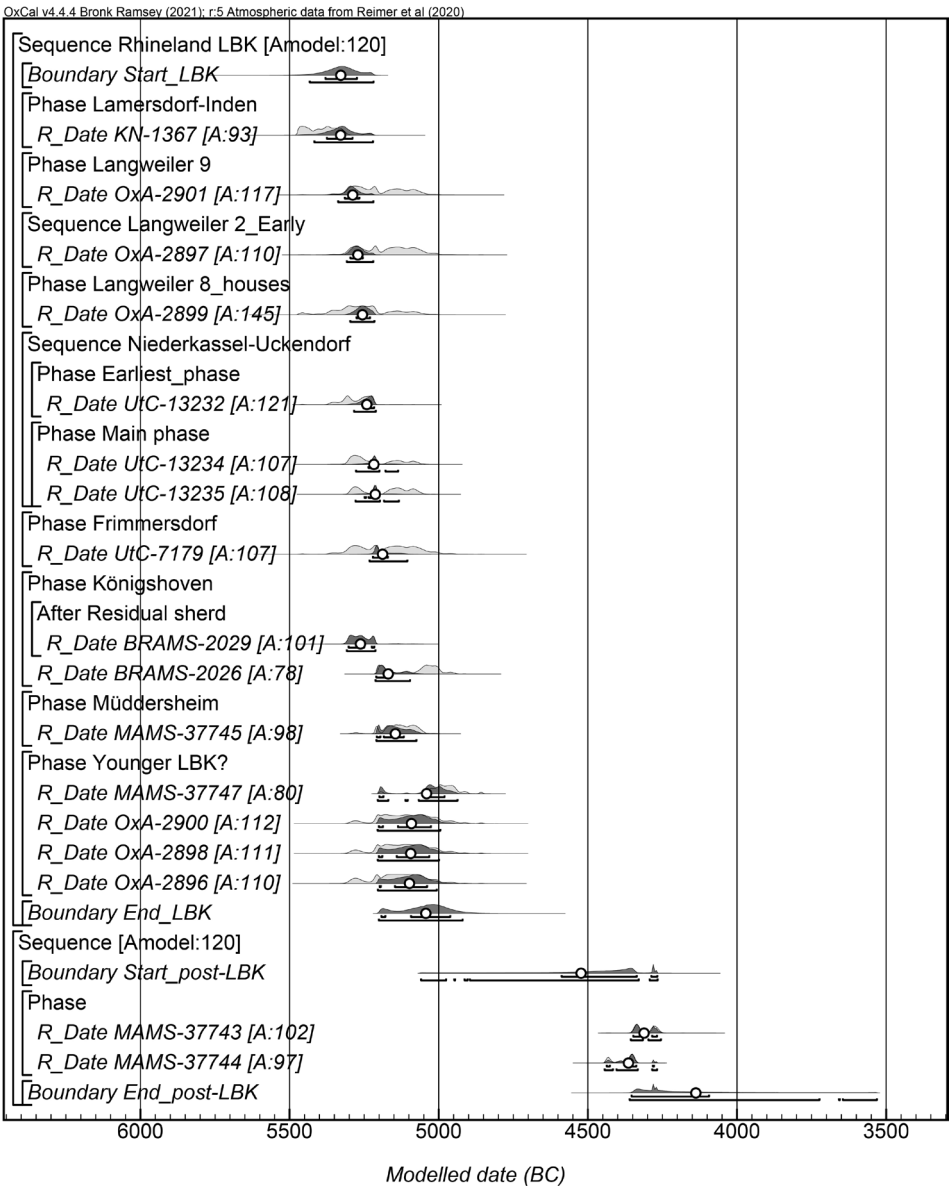


Fig. 6. Overview of Model 8 for the LBK and post-LBK period in the Rhineland. The one-sigma and two-sigma confidence intervals of the posterior distributions are shown. For convenience, only the normal boundaries are shown. Convergence for the post-LBK is low due to the complex model structure and sparse radiocarbon dates (see *Online Supplementary Material 1*). These distributions are shown here for completeness but should not be considered.

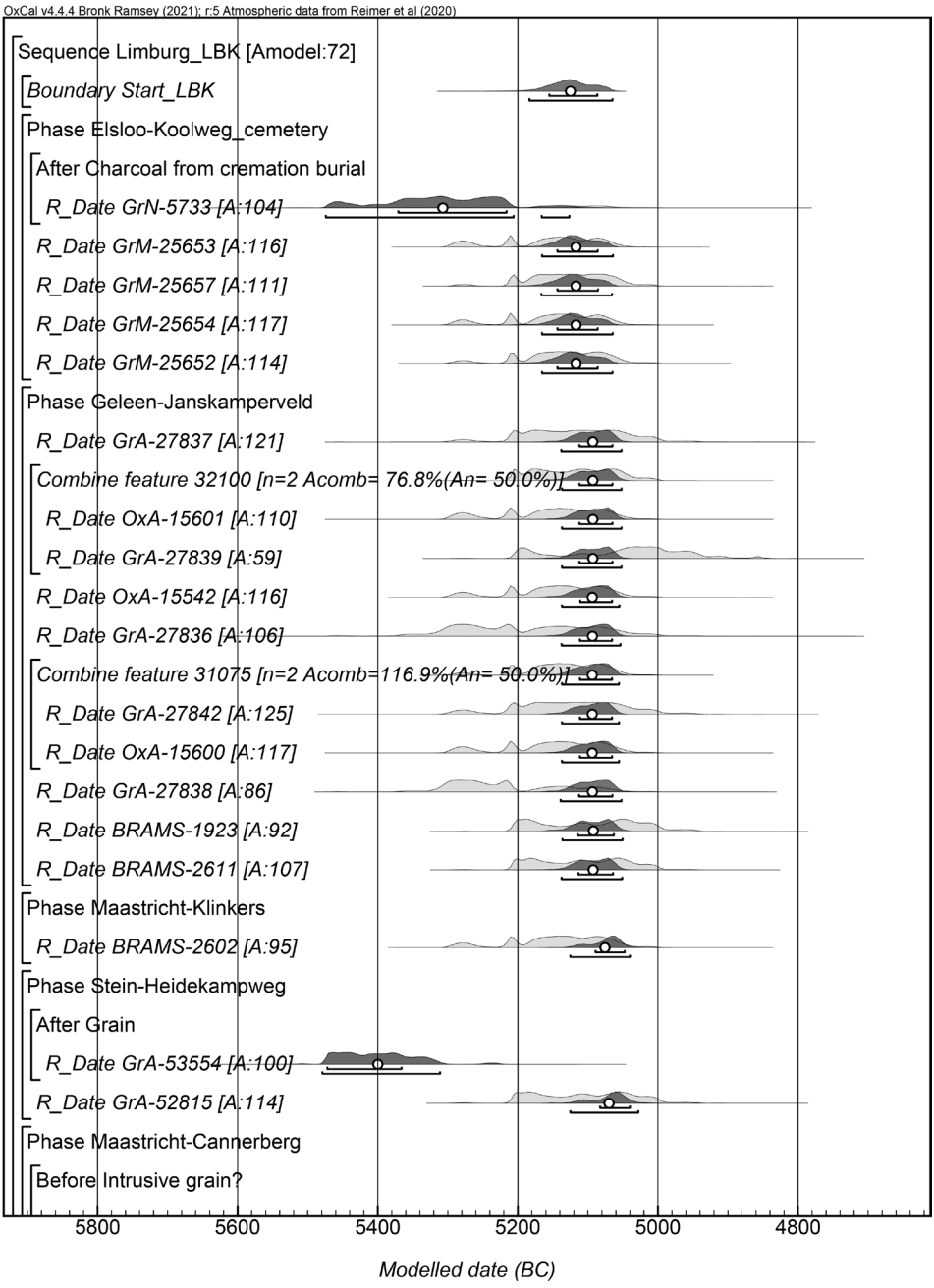


Fig. 7A. Overview of Model 9 for the LBK and post-LBK period in Limburg. For convenience, only the normal boundaries are shown (see *Online Supplementary Material 1*).

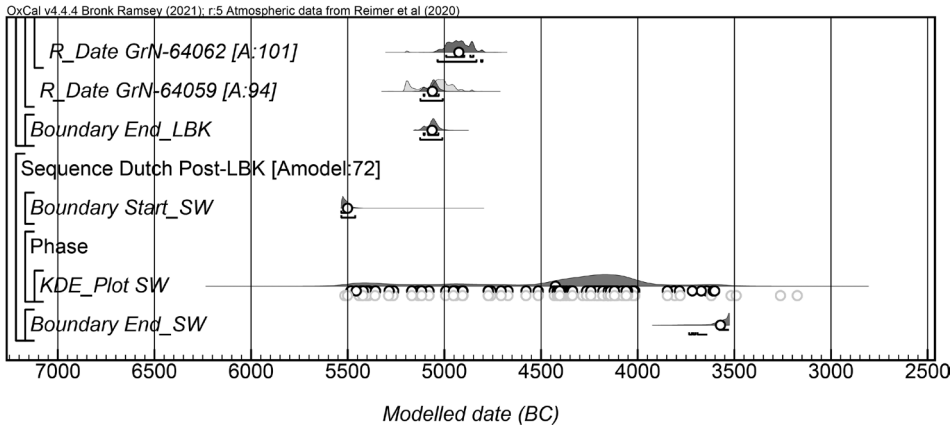


Fig. 7B. Overview of Model 9 for the LBK and post-LBK period in Limburg – continued. For convenience, only the normal boundaries are shown (see *Online Supplementary Material 1*).

2009, 44). Model 10 returns an estimate for the transition between the pioneer and main phase around *5071–5037 BC* (68.3% probability), possibly *5037–5090 BC* (95.4% probability; *Fig. 8*; *Online Supplementary Material 1*).

The currently available radiocarbon dates for LBK settlements in Limburg provide no indication of a similar pioneer and main phase (see *Online Supplementary Material 1*). However, the Bayesian chronological model for the Rhineland does hint at a similar dynamic. The majority of the settlements can be modelled as a single phase, but several dates from Langweiler 2 (specifically those associated with the enclosure), Langweiler 8 (another site with an enclosure), and Müddersheim stand out as relatively young compared to the other radiocarbon dates (see *Fig. 6*; *Online Supplementary Material 1*). The modelled ranges of these dates fall within c. 5200–5000 BC, which is broadly contemporaneous with the main phase in Hesbaye (see *Fig. 8*; *Online Supplementary Material 1*). These dates are also contemporaneous with the dendrochronological dating for the wells at Arnoldsweiler-Ellebach, Kückhoven, and Merzenich-Morschenich (*Balkowski 2024*). Unfortunately, the currently available radiocarbon dates for LBK settlements in the Rhineland do not allow for a more detailed assessment. Regardless, the association of these dates with enclosures and the contemporaneity with the developments in Hesbaye is of interest.

End dates of LBK occupation and relation to post-LBK

The Bayesian chronological models allow us to obtain formal estimates for the end dates of LBK occupation across the study area and to compare these with the start dates for post-LBK communities in these same areas.

For Limburg, the outcomes of Model 9 suggest that the latest LBK occupation likely falls around *5107–5013 BC* (68.3% probability), possibly *5125–4974 BC* (95.4% probability). The duration of the end boundary is relatively short: *0–38 years* (68.3% probability) or possibly *0–109 years* (95.4% probability; see *Fig. 7*; *Online Supplementary Material 1*). However, radiocarbon dates for the youngest LBK occupation in Limburg are sparse. Hence, the radiocarbon date from Maastricht-Cannerberg (GrN-64062 6035±40BP;

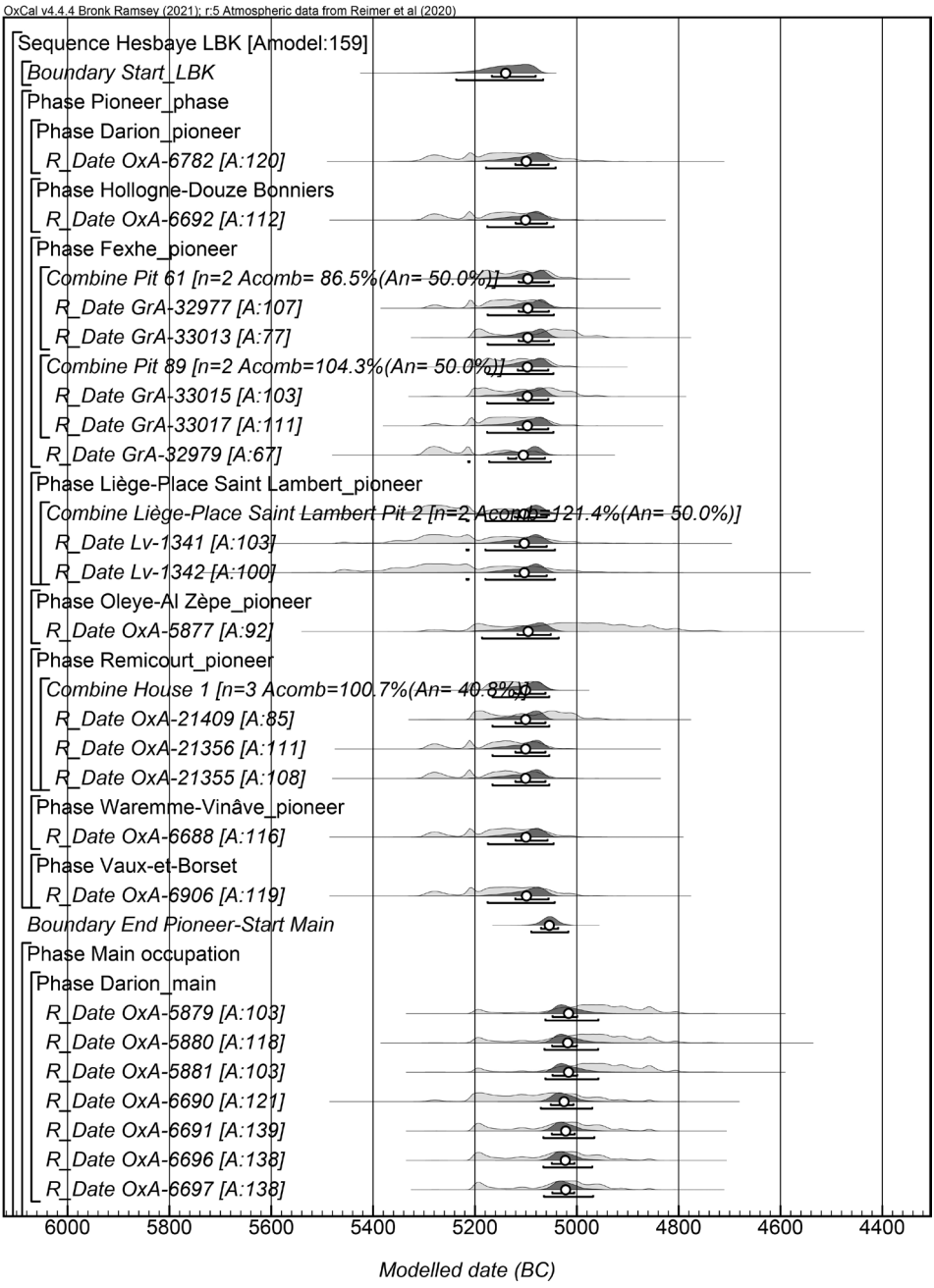


Fig. 8A. Overview of Model 10 for LBK and post-LBK settlements in Hesbaye. For convenience, only normal boundaries are shown (see *Online Supplementary Material 1*). The horizontal brackets are the one-sigma and two-sigma confidence intervals of the posterior distributions.

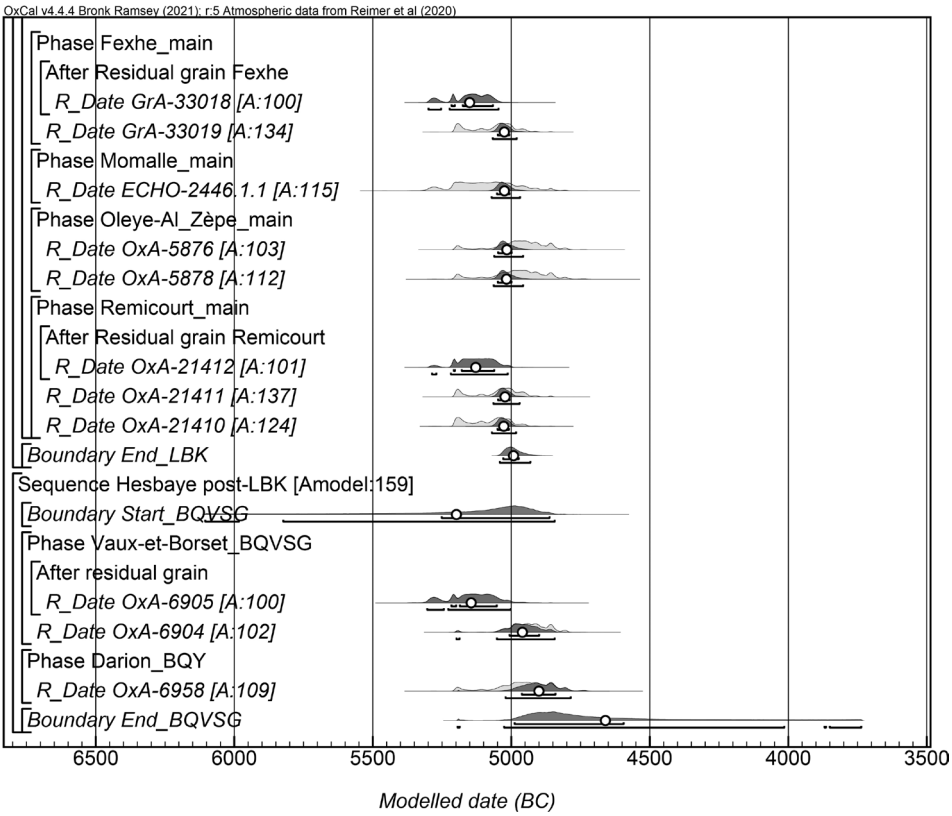


Fig. 8B. Overview of Model 10 for LBK and post-LBK settlements in Hesbaye – continued. For convenience, only normal boundaries are shown (see *Online Supplementary Material 1*). The horizontal brackets are the one-sigma and two-sigma confidence intervals of the posterior distributions.

5036–4835 cal BC at 95.4% probability), which is currently accepted as the best indicator for the end date of LBK occupation in Limburg is an outlier in Model 9 and had to be treated as a *terminus ante quem* for LBK settlement at Maastricht-Cannerberg. We may therefore expect future studies of LBK settlements in Limburg to change these outcomes. Model 9 also indicates that the emergence of SWB communities in the Netherlands and Belgium predates the arrival of LBK communities. The estimate for the earliest appearance of SWB communities is *5542–5504 BC* (68.3% probability), possibly *5578–5473 BC* (95.4% probability). This start date is consistent with those obtained by other studies, but note that the integration of domesticated plants and animals by SWB communities likely occurs after the disappearance of LBK (see *Menne – Brünner 2021*; *Dreshaj et al. 2022*; *2023a*; *2023b*; *Raemaekers et al. 2023*). As a result of this early start date for SWB communities, the likelihood of overlap between LBK and SWB communities approaches 100%. The duration of this overlap is estimated between *426–515 years* (68.3% probability), possibly *378–570 years* (95.4% probability; see *Fig. 7*; *Online Supplementary Material 1*). This estimate fits well with available evidence for continuity of Late Mesolithic populations in the Dutch wetlands (*Amkreutz 2013*; *Olalde et al. 2026*).

The estimated end date of LBK communities in Hesbaye is likely after that in Limburg (see *Fig. 8*; *Online Supplementary Material 1*). Model 10 estimates that the last occurrence for LBK settlements was between *5024–4952 BC* (68.3% probability), or possibly *5040–4896 BC* (95.4% probability). The duration of the end boundary is estimated to be *0–42 years* (68.3% probability) or *0–110 years* (95.4% probability). Unfortunately, few radiocarbon dates are available for the subsequent BVSG communities in Hesbaye (see *Online Supplementary Material 1*), resulting in a broad estimate for their earliest appearance: *5377–4879 BC* (68.3% probability), possibly *6224–4848 BC* (95.4% probability). In turn, this broad estimate causes the likelihood of overlap to approach 100%. The estimated duration for this overlap also varies significantly: anything from a 106-year occupation gap to a 415-year overlap between LBK and BVSG is possible at the 68.3% probability level (*-125–1251 years* at 95.4% probability; see *Online Supplementary Material 1*).

The Bayesian chronological model for the Rhineland estimates a latest appearance of LBK between *5186–4871 BC* (68.3% probability), possibly *5199–4782 BC* (95.4% probability; see *Fig. 6*; *Online Supplementary Material 1*). The estimated duration of the end boundary is longer than those in Limburg or Hesbaye: between *0–212 years* (68.3% probability) or possibly *0–393 years* (95.4% probability). This may imply a comparatively slow process. Unfortunately, Model 8 returns a low convergence for the post-LBK groups (see *Online Supplementary Material 1*), likely due to the small number of available radiocarbon dates (n=2). In fact, the high-quality dataset contains no radiocarbon dates for GG communities which are held to follow LBK communities in the Rhineland (see *Online Supplementary Material 1*, cf. *Denaire et al. 2017*, 1132). Therefore, no conclusions about potential settlement gaps in this region can be drawn based on Model 8.

Discussion

We present two Bayesian chronological models for the overarching chronology of LBK occupation in Limburg, Hesbaye, and the Rhineland. These models represent different points of departure for an absolute chronology: Model 6 prioritises the pre-existing overarching ceramic typochronology, whereas Model 7 relies primarily on the available radiocarbon dates to draw conclusions about chronological patterns.

Both models are defensible with the current state of research. On the one hand, a turn to radiocarbon-based chronology is warranted given the long-standing difficulties in combining the regional typochronologies from Hesbaye, Limburg, and the Rhineland. In a broader framework, studies have also shown that ceramic styles which were traditionally held to be chronological markers are longer-lived than previously thought and partially contemporaneous (*Jakucs et al. 2016*; *Trampota – Květina 2020*; *Furholt et al. 2020*; *Oberc et al. 2022*; *Masclans et al. 2025*; *Pilař et al. 2026*). On the other hand, the radiocarbon evidence is far from perfect. The shift in sample materials from charcoal to short-lived, single-entity samples (primarily charred cereals and seeds) has delivered a significant improvement in data quality over the past two decades (*Jadin 2003*) but the risk of residual and intrusive dates remains high (*Bayliss et al. 2011*, 40–42; cf. *Gronenborn et al. 2014*, 79). Neither model is, therefore, perfect.

Collapsing these alternative models into one will be a key challenge for archaeological investigations of the LBK and post-LBK transition in the study area. We are optimistic

that such a merger is possible even with current methods (cf. *Whittle 2018*). As shown through a simulation in Model 5, a relatively small set of radiocarbon dates with a precision towards the lower margin of those typically seen in modern AMS dates would already suffice to substantiate the overarching typochronology from *Blouet et al.* (*2021*). In addition, emerging methods such as AMS dating of organic temper (*Teetaert et al. 2020*) and compound-specific radiocarbon dating of absorbed lipids (*Casanova et al. 2020*) can extend the spectrum of datable materials. Therefore, we call for a renewed engagement with absolute dating for the LBK and post-LBK transition in the Netherlands, Hesbaye, and the Rhineland.

In a broader framework, our Bayesian chronological models shed new light on the spread, settlement dynamics, and end of LBK societies. The results of Models 8–10 suggest that the expansion of LBK communities may not be gradual but episodic. The earliest appearance of LBK communities in the Rhineland most likely occurred during the last decade of the 54th century BC. This is roughly contemporaneous with the estimates for the appearance of LBK communities in Lower Alsace (see *Denaire et al. 2017*, 1104). However, a gap of at least one century then occurs until the most likely first appearance of LBK settlements in Limburg and Hesbaye during the 52nd century BC. Again, the appearance of LBK communities in Hesbaye and Limburg may be contemporaneous. Therefore, the expansion of LBK communities may be episodic with pauses of several generations between rapid expansion events into adjacent regions. This further illustrates the arrhythmic nature of the Neolithic expansion (e.g., *Dubouloz et al. 2017*; *Hamon – Manen 2021*).

The outcomes of the Bayesian chronological models also indicate that the initial appearance of LBK may have been followed by a rapid increase in settlement densities. Model 6 suggests a contraction of the initial phases of the LBK across all three regions is likely, implying that the peaks observed in current studies may be steeper. This is also corroborated by Models 8–10, which show that the dating ranges of multiple LBK settlements likely coincide with the earliest appearance of LBK communities (cf. *Balkowski et al. 2016*). Given that we are much more likely to detect settlements from a potential peak in the occupation than from a sparse oldest phase, the fact that the age of multiple settlements approaches the earliest possible arrival date for LBK communities suggests a boom in settlements may have followed shortly after the initial arrival of these communities (cf. *Balkowski et al. 2016*). A similar, rapid increase in population densities has also been detected in Alsace (*Denaire et al. 2017*).

The combination of an episodic expansion process and a rapid increase in settlement densities shortly after initial arrival also sheds light on the social dynamics of the LBK expansion (*Hofmann 2016*; *2020*; *Furholt 2018*). The rapid increase in population densities may be too rapid to be caused by autochthonous population growth alone (cf. *Masclans et al. 2025*). Instead, we may envision LBK expansion as a two-stage process as proposed by *Bosquet – Golitko* (*2012*). During the first ‘pioneer’ phase, subcommunities migrate from settled areas, in which population densities are rising, and form small settlements in new areas. News about these new settlements spread back to core areas, attracting further migration and leading to rapid settlement expansion during a ‘main phase’ with a high diversity among settlement communities (cf. *Jakucs et al. 2016*; *Masclans et al. 2025*). In turn, these conditions may trigger new outward migration events.

The environmental impact of the rapid increase in LBK settlement densities is corroborated by palynological profiles from Kleine Gete (*Bakels 1992*; *Lodewijckx 2009*, 33–35),

Sittard (*Bakels 2021*), and Linnich-Broich (*Kalis 1988*). *Bakels* (*2021*, 170–171) argues that all three palynological profiles show an opening up of forests after the arrival of LBK communities, potentially due to logging and gathering of young branches as fodder for cattle. Forest recovery sets in after the end of the LBK period. A similar impact has been reconstructed on the basis of charcoal found at LBK settlements in Hesbaye (*Salavert et al. 2014*).

The Bayesian chronological models also show that a change occurred in LBK settlement after the initial peak. Around the middle of the 51st century BC, the construction of enclosures in Hesbaye and the Rhineland most likely began. This is contemporaneous with the digging of wells at LBK settlements in the Rhineland (*Balkowski 2024*, Fig. 25) and the most likely end date of the LBK settlement cluster in Limburg. In addition, it may coincide with the end of LBK occupation in Alsace (*Denaire et al. 2017*, 1130). Several studies have suggested that a decrease in rainfall during this period may have adversely affected LBK societies in the study area (*Bocquet-Appel et al. 2015*; *Gronenborn et al. 2014*, but see *Shennan et al. 2013*). However, it is also clear that LBK communities in the Rhineland and Hesbaye persisted throughout this period.

The Bayesian chronological models also shed new light on the timing and tempo of the post-LBK transition in the study area. The most likely scenario given the current data is that the LBK settlements in Limburg disappeared within a couple of decades during the middle of the 51st century BC, although radiocarbon dates for the latest phases are still sparse. We found no suitable dates for subsequent RÖ inhabitation in the Netherlands, but Model 9 does show that SWB societies with ties to older Mesolithic populations persisted throughout the LBK and post-LBK period (see *Fig. 7*; *Amkreutz 2013*; *Olalde et al. 2026*). LBK settlements in adjacent Hesbaye and Rhineland were likely longer-lived, potentially persisting until the first decades of the 50th century BC (see *Fig. 6*; *Fig. 8*). Unfortunately, radiocarbon dates from post-LBK groups in both areas are sparse. Based on the available radiocarbon dates from the Rhineland, no conclusions can be drawn about a potential settlement gap between LBK and post-LBK communities (see *Fig. 6*). In Hesbaye, both an occupation gap and a long overlap between LBK and BVSG are possible based on the currently available radiocarbon dates (see *Fig. 8*).

This heterogeneity in the timing and tempo of the post-LBK transition is not consistent with a single process affecting all these communities simultaneously, but suggests that the dynamic of the post-LBK transition may have been tied to local circumstances. These local variations may have structured circulation networks during the post-LBK transition, as stronger connectivity is apparent in regions where archaeological evidence points to continuous settlement (see *Denis et al. in press*).

Conclusion

We shed light on LBK settlement dynamics and the post-LBK transition in Hesbaye, Limburg, and the Rhineland through Bayesian chronological modelling. The outcomes of this study further highlight the potential of absolute dating and Bayesian chronological modelling for this period. However, we emphasise that these results are preliminary and in part grounded in sparse data. We have focused on the most likely scenarios throughout this paper, but the one-sigma and especially two-sigma confidence intervals leave the door

open to many alternative interpretations. Therefore, we hope that these results will inspire renewed interest in absolute dating of archaeological material from this period and contribute to greater attention for chronometric hygiene and new high-precision radiocarbon dating methods. Even with current absolute dating methods and analyses, an overview of LBK settlement dynamics with a resolution of decades is firmly within reach.

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References

Amkreutz, L. 2013: Persistent Traditions: A Long-Term Perspective on Communities in the Process of Neolithisation in the Lower Rhine Area (5500–2500 cal BC). Leiden: Sidestone Press.

Amkreutz, L. 2016: It's better to burn out than to fade away: A comparative perspective on the diversity in LBK endings in the Rhine-Meuse region. In: L. Amkreutz – F. Haack – D. Hofmann – I. van Wijk (eds.), Something out of the ordinary? Interpreting diversity in the Early Neolithic Linearbandkeramik and beyond. Newcastle upon Tyne: Cambridge Scholars Publishing, 357–397.

Amkreutz, L. 2017: A world ends: The demise of the northwestern Bandkeramik. Analecta Praehistorica Leidensia: Excerpta Archaeologica Leidensia II, 47, 19–35.

Bakels, C. C. 1992: The botanical shadow of two early Neolithic settlements in Belgium: Carbonized seeds and disturbances in the pollen record. Review of Palaeobotany and Palynology 73, 1–19.

Bakels, C. C. 2021: De vegetatiegeschiedenis van Sittard aan de hand van een pollendiagram. Natuurhistorisch Maandblad 110(7), 165–172.

Balkowski, N. 2015: From Merzbachtal to the Graetheide? Mobility at the end of the Linear Pottery Culture. In: S. Scharl – B. Gehlen (eds.), Mobility in Prehistoric Sedentary Societies: Papers of the CRC 806 Workshop in Cologne 26–27 June 2015. Kölner Studien zur Prähistorischen Archäologie 8. Rahden: Verlag Marie Leidorf, 119–128.

Balkowski, N. 2024: Chronologie und Siedlungsstruktur des Fundplatzes. In: N. Balkowski – R. Peters (eds.), Der bandkeramische Fundplatz Arnoldsweiler-Ellebach (Band 1). Rheinische Ausgrabungen 85/1. Bonn: LVR-Amt für Bodendenkmalpflege im Rheinland, 43–135.

Balkowski, N. – Classen, E. – Peters, R. 2016: The older LBK site of Niederkassel-Uckendorf revisited. In: T. Kerig – K. Nowak – G. Roth (eds.), Alles was zählt...: Festschrift für Andreas Zimmermann. Bonn: Rudolf Habelt, 79–92.

Balkowski, N. – Hartmann, S. 2015: Vom Merzbachtal in die Graetheide? Die Synchronisation der niederländischen Bandkeramik mit der Aldenhovener Platte am Beispiel der Siedlung und des Gräberfeldes von Elsloo. Archäologische Informationen 38, 531–542. https://doi.org/10.11588/ai.2015.1.26233

Bayliss, A. 2015: Quality in Bayesian chronological models in archaeology. World Archaeology 47, 677–700. https://doi.org/10.1080/00438243.2015.1067640

Bayliss, A. – van der Plicht, J. – Bronk Ramsey, C. – McCormac, G. – Healy, F. – Whittle, A. 2011: Towards generational time-scales: the quantitative interpretation of archaeological chronologies. In: A. Whittle – F. Healy – A. Bayliss (eds.), Gathering time: Dating the Early Neolithic enclosure of Southern Britain and Ireland. Oxford: Oxbow Books, 17–59.

Blouet, V. – Bosquet, D. – Constantin, C. – Fock, H. – Ilett, M. – Jadin, I. – Klag, T. – Petitdidier, M.-P. – Thomashausen, L. 2021: Le Rubané en Belgique: nouvelle chronologie céramique et synchronisation avec les régions voisines. Bulletin de la Société préhistorique française 118, 277–322.

Blouet, V. – Klag, T. – Petitdidier, M.-P. – Thomashausen, L. 2013: Le Néolithique ancien en Lorraine: Inventaire des sites et planches céramique. Mémoire 55. Paris: La Société Préhistorique Française.

Bocquet-Appel, J.-P. – Dubouloz, J. – Moussa, R. – Berger, J.-F. et al. 2015: Multi-agent Modelling of the Trajectory of the LBK Neolithic. In: F. Giligny – F. Djindjian – L. Costa –P. Moscati – S. Robert (eds.), CAA2014: 21st Century Archaeology: Concepts, methods and tools. Proceedings of the 42nd Annual Conference on Computer Applications and Quantitative Methods in Archaeology, Oxford: Archaeopress, 611–622.

Boelicke, U. 1982: Gruben und Häuser: Untersuchungen zur Struktur bandkeramischer Hofplätze. In: B. Chropovský – J. Pavúk (eds.), Siedlungen der Kultur mit Linearkeramik in Europa. Internationales Kolloquium Nové Vozokany 17.–20. November 1981. Nitra: Archäologisches Institut der Slowakischen Akademie der Wissenschaften, 17–28.

Bosquet, D. 1993: Essai de reconstitution des dispositifs d'entrées de deux villages fortifiés du Rubané de Hesbaye. Notae Praehistoricae 12, 123–130.

Bosquet, D. – Fock, H. 2025: Rise and fall: Settlement dynamics of LBK groups in the Middle Belgium loess belt (5150–4950 cal. BC) based on the new Meuse ceramic chronology. Journal of Archaeological Science: Reports 61, 104940. https://doi.org/10.1016/j.jasrep.2024.104940

Bosquet, D. – Goffioul, C. – Preud'homme, D. 2007: Les enceintes rubanées de Belgique: apport des fouilles récentes. In: O. Agogué – D. Leroy D. – C. Verjux (dir.), Camps, enceintes et structures d'habitat néolithiques en France septentrionale, Actes du 24 ème Colloque Interrégional sur le Néolithique, Orléans 19–21 novembre 1999, Revue archéologique du Centre de la France, (27ème supplément), 5–20.

Bosquet, D. – Golitko, M. 2012: Highlighting and characterising the pioneer phase of the Hesbayen Linear Pottery Culture (Liège province, Belgium). In: R. Smolnik – S. Wolfram – H. Stäuble (eds.), Siedlungsstruktur und Kulturwandel in der Bandkeramik: Beiträge der internationalen Tagung 'Neue Fragen zur Bandkeramik oder alles beim Alten?!'; Leipzig, 23 bis 24. September 2010. Arbeits- und Forschungsberichte zur sächsischen Bodendenkmalpflege 25. Dresden: Landesamt für Archäologie, 91–106.

Bosquet, D. – Golitko, M. – Salavert, A. – Beugnier, V. – Fanchon, D. – Jadin, I. – Martin, F. – Quick, R. 2008: Une phase pionnière à l'origine du peuplement rubané de la Hesbaye liégeoise (Belgique). Mémoires de la Société préhistorique française 44, 301–315.

Broes, F. – Bosquet, D. 2007: Fabrication d'outils de terrassier et creusement des fossés rubanés : de la théorie à la pratique. Notae Praehistoricae 27, 131–149.

Broich, M. 2021: Die Landwirtschaft im Mittelneolithikum: Demografie, Ökonomie, Umwelt. Cologne: University of Cologne. Unpublished PhD thesis.

Bronk Ramsey, C. 1995: Radiocarbon calibration and analysis of stratigraphy: The OxCal program. Radiocarbon 37, 425–430. https://doi.org/10.1017/S0033822200030903

Bronk Ramsey, C. 2009a: Bayesian analysis of radiocarbon dates. Radiocarbon 51, 337–360. https://doi.org/10.1017/S0033822200033865

Bronk Ramsey, C. 2009b: Dealing with outliers and offsets in radiocarbon dating. Radiocarbon 51, 1023–1045. https://doi.org/10.1017/S0033822200034093

Bronk Ramsey, C. 2017: Methods for summarizing radiocarbon datasets. Radiocarbon 59, 1809–1833. https://doi.org/10.1017/RDC.2017.108

Bronk Ramsey, C. 2021: OxCal v4.4.4.

Brounen, F. – Rensink, E. 2007: Kelmond-Beekerveld, Amersfoort: Rijksdienst voor Archeologie, Cultuurlandschap en Monumenten (RAM 153).

Burnez-Lanotte, L. – Caspar, J.-P. – Constantin, C. 1993: Introduction. In: J.-P. Caspar – C. Constantin – A. Hauzeur – L. Burnez-Lanotte (eds.), Nouveaux éléments dans le groupe du Blicquy en Belgique: le site de Vaux-et-Borset 'Gibour' et 'A la Croix Marie-Jeanne'. Helinium 23. Wetteren: Universa, 67–79.

Buttler, W. – Haberey, W. 1936: Die bandkeramische Ansiedlung bei Köln-Lindenthal. Römisch-Germanische Forschungen 11. Berlin: de Gruyter & Co.

Casanova, E. – Knowles, T. D. J. – Bayliss, A. – Dunne, J. – Barański, M. Z. et al. 2020: Accurate compound-specific 14C dating of archaeological pottery vessels. Nature 580, 506–510. https://doi.org/10.1038/s41586-020-2178-z

Constantin, C. 1985: Fin du Rubané, Céramique du Limbourg et post-Rubané: Le Néolithique le plus Ancien en Basin Parisien et en Hainaut. Oxford: Oxbow Books.

Denaire, A. – Lefranc, P. – Wahl, J. – Bronk Ramsey, C. – Dunbar, E. – Goslar, T. – Bayliss, A. – Beavan, N. – Bickle, P. – Whittle, A. 2017: The Cultural Project: Formal Chronological Modelling of the Early and Middle

Neolithic Sequence in Lower Alsace. Journal of Archaeological Method and Theory 24, 1072–1149. https://doi.org/10.1007/s10816-016-9307-x

Denis, S. – Allard, P. – Amkreutz, L. – Bosquet, D. – Demaraix, I. et al. in press: Reassessing the LBK/post-LBK transition at the northwestern edge of Central Europe: Crossing boundaries with a lithic perspective. Archeologické Rozhledy.

Denis, S. – Deramaix, I. – Jadin, I. – Cagnato, C. – Cayol, N. et al. 2024: Ath « Les Haleurs », deux occupations Rubané et Blicquy/ Villeneuve-Saint-Germain (Néolithique ancien). Mécanismes de transition culturelle par l'étude intégrée des productions. Anthropologica et Praehistorica 135, 7–106. https://doi.org/10.57937/ap.2024.001

Dreshaj, M. – Dee, M. – Brusgaard, N. – Raemaekers, D. – Peeters, H. 2023a: High-resolution Bayesian chronology of the earliest evidence of domesticated animals in the Dutch wetlands (Hardinxveld-Giessendam archaeological sites). PLOS ONE 18, e0280619. https://doi.org/10.1371/journal.pone.0280619

Dreshaj, M. – Dee, M. – Peeters, H. – Raemaekers, D. 2022: Blind dates: Exploring uncertainty in the radiocarbon evidence on the emergence of animal husbandry in the Dutch wetlands. Journal of Archaeological Science: Reports 45, 103589. https://doi.org/10.1016/j.jasrep.2022.103589

Dreshaj, M. – Raemaekers, D. – Dee, M. 2023b: Chronological modeling on a calibration plateau: Implications for the emergence of agriculture in the Dutch wetlands. Radiocarbon 65, 1280–1298. https://doi.org/10.1017/RDC.2023.126

Dubouloz, J. – Bocquet-Apel, J.-P. – Moussa, R. 2017: Modélisation, simulation et scénarios d'expérimentation: La colonisation néolithique de l'Europe tempérée par la culture à Céramique Linéaire (LBK) (5550–4950 avant notre ère). In: N. Manolakakis – N. Schlanger – A. Coudart (eds.), European archaeology: Identities & migrations. Hommages à Jean-Paul Demoule. Leiden: Sidestone Press, 315–339.

Furholt, M. 2018: Translocal communities: Exploring mobility and migration in sedentary societies of the European Neolithic and Early Bronze Age. Prähistorische Zeitschrift 92, 304–321. https://doi.org/10.1515/pz-2017-0024

Furholt, M. – Müller-Scheeßel, N. – Wunderlich, M. – Cheben, I. – Müller, J. 2020: Communality and Discord in an Early Neolithic Settlement Agglomeration: The LBK Site of Vráble, Southwest Slovakia. Cambridge Archaeological Journal 30, 469–489. https://doi.org/10.1017/S0959774320000049

Gronenborn, D. 2010: Climate, crises, and the 'Neolithisation' of Central Europe between IRD-events 6 and 4. In: D. Gronenborn – J. Petrasch (eds.), The spread of the Neolithic to Central Europe: International Symposium, Mainz 24 June–26 June 2005. Mainz: Römisch-Germanisches Zentralmuseum, 61–80.

Gronenborn, D. – Strien, H.-C. – Dietrich, S. – Sirocko, F. 2014: 'Adaptive cycles' and climate fluctuations: a case study from Linear Pottery Culture in western Central Europe. Journal of Archaeological Science 51, 73–83.

Gronenborn, D. – Strien, H.-C. – Wirtz, K. – Turchin, P. – Zielhofer, C. – van Dick, R. 2020: Inherent Collapse? Social dynamics and external forcing in Early Neolithic and modern SW Germany. In: F. Riede – P. D. Sheets (eds.), Going forward by looking back: Archaeological perspectives on socio-ecological crisis, response, and collapse. Oxford: Berghahn Books, 333–366.

Haack, F. 2014: Die frühneolithische Grabenanlage von Herxheim bei Landau: Architektur, Verfüllungsprozesse und Nutzungsdauer. Berlin: Freie Universität Berlin. Unpublished PhD thesis.

Hamon, C. – Manen, C. 2021: The mechanisms of Neolithisation of western Europe: Beyond a South/North approach. Open Archaeology 7, 1, 718–735. https://doi.org/10.1515/opar-2020-0164

Hauzeur, A. – Jadin, I. 2025: Le Néolithique ancien oriental: Deux territoires pour une même culture ou deux cultures pour un même territoire? In: M. Otte (ed.), Les territoires culturels entre Seine et Rhin. De la Préhistoire à l'an 1000. Flémalle: Préhistomuseum, 274–299.

Heinen, M. 2010: Niederkassel-Uckendorf: Eine bandkeramische Pioniersiedlung im Rheinland. In: D. Gronenborn – J. Petrasch (eds.), The Spread of the Neolithic to Central Europe: International Symposium, Mainz 24 June–26 June 2005 (Part 2). Mainz: Verlag des Römisch-Germanischen Zentralmuseums, 517–534.

Höckmann, O. 1975: Wehranlagen der jüngeren Steinzeit. In: Ausgrabungen in Deutschland: Gefördert von der Deutschen Forschungsgemeinschaft 1950–1975 (Band 1). Mainz: Verlag des Römisch-Germanischen Zentralmuseums, 278–296.

Hofmann, D. 2016: Keep on walking: The role of migration in Linearbandkeramik life. Documenta Praehistorica 43, 235–252.

Hofmann, D. 2020: Not going anywhere? Migration as a social practice in the early Neolithic Linearbandkeramik. Quaternary International 560–561, 228–239. https://doi.org/10.1016/j.quaint.2020.04.002

Jadin, I. 2003: Trois petits tours et puis s'en vont... La fin de la présence danubienne en Moyenne Belgique. 2nd ed. ERAUL 109. Liège. https://popups.lib.uliege.be/3041-5527/index.php?id=2735

Jakucs, J. – Bánffy, E. – Oross, K. – Voicsek, V. – Bronk Ramsey, C. et al. 2016: Between the Vinča and Linearbandkeramik Worlds: The Diversity of Practices and Identities in the 54th–53rd Centuries cal BC in Southwest Hungary and Beyond. Journal of World Prehistory 29, 267–336. https://doi.org/10.1007/s10963-016-9096-x

Jeunesse, C. 1999: La synchronisation des séquences culturelles des bassins du Rhin, de la Meuse et de la Seine et la chronologie du Bassin parisien au Néolithique ancien et moyen (5200–4500 av. J. C.). Bulletin de la Société Préhistorique Luxembourgeoise 20–21, 337–392.

Kalis, A. 1988: Zur Umwelt des frühneolithischen Menschen: Ein Beitrag der Pollenanalyse. In: H. Küster – U. Körber-Grohne (eds.), Der prähistorische Mensch und seine Umwelt. Forschungen und Berichte zur Vor- und Frühgeschichte in Baden-Württemberg 31. Stuttgart: Konrad Theiss Verlag, 125–137.

Kaufmann, D. 1997: Zur Funktion linienbandkeramischer Erdwerke. In: K. Schmotz (ed.), Vorträge des 15. Niederbayerischen Archäologentages. Rahden: Marie Leidorf, 41–87.

Kerig, T. 2003: Von Gräbern und Stämmen: Zur Interpretation bandkeramischer Erdwerke. In: U. Veit – T. L. Kienlin – C. Kümmel – S. Schmidt (eds.), Spuren und Botschaften: Interpretationen materieller Kultur. Münster: Waxmann, 225–244.

Kerig, T. – Krahn, C. – Münch, U. – Nockemann, G. – Strien, H.-C. 2010: Bandkeramik online: Merkmalskatalog zur Aufnahme verzierter Keramik. Available at: https://www.archaeologie-stiftung.de/de/wissenschaft/bandkeramik_online/bandkeramik_online_1.html [accessed 15-03-2026].

Kondor, D. – Bennett, J. S. – Gronenborn, D. – Turchin, P. 2024: Landscape of fear: indirect effects of conflict can account for large-scale population declines in non-state societies. Journal of The Royal Society Interface 21, 217. https://doi.org/10.1098/rsif.2024.0210

Lanting, J. N. – van der Plicht, J. 2000: De C14-chronologie van de Nederlandse pre- en protohistorie III: Neolithicum. Palaeohistoria 41(2), 1–110.

Lee, S. – Ramsey, C. B. 2012: Development and Application of the Trapezoidal Model for Archaeological Chronologies. Radiocarbon 54, 107–122. https://doi.org/10.2458/azu_js_rc.v54i1.12397

Lehmkuhl, F. – Nett, J. J. – Pötter, S. – Schulte, P. – Sprafke, T. et al. 2021: Loess landscapes of Europe – Mapping, geomorphology, and zonal differentiation. Earth-Science Reviews 215, 103496. https://doi.org/10.1016/j.earscirev.2020.103496

Lodewijckx, M. 2009: Frontier settlements of the LBK in central Belgium. In: D. Hofmann – P. Bickle (eds.), Creating communities: New advances in Central European Neolithic research. Oxford: Oxbow Books, 32–49.

Louwe Kooijmans, L. P. 1988: Een Rössen-nederzetting te Maastricht-Randwijck. Notae Praehistoricae 8, 67–71.

Lüning, J. 2005: Bandkeramische Hofplätze und die absolute Chronologie der Bandkeramik. In: J. Lüning – C. Frirdich – A. Zimmermann (eds.), Die Bandkeramik im 21. Jahrhundert. Symposium in der Abtei Brauweiler bei Köln vom 16. 9.–19. 9. 2002. Rahden: Marie Leidorf, 49–74.

Masclans, A. – Tóth, P. – Tvrdý, Z. – Hamilton, D. – Bickle, P. – Díaz-Zorita Bonilla, M. – Morell-Rovira, B. 2025: Funerary Practices Among Central European First Farmers in the Light of New Radiocarbon Dates: The Case of Southern Moravia/Western Slovakia. Journal of World Prehistory 38, 13. https://doi.org/10.1007/s10963-025-09201-8

Menne, J. – Brunner, M. 2021: Transition from Swifterbant to Funnelbeaker: A Bayesian Chronological Model. Open Archaeology 7, 1235–1243. https://doi.org/10.1515/opar-2020-0191

Meunier, K. 2013: Chronologie de la céramique rubanée dans le Sud-Est du Bassin parisien. Bulletin de la Société préhistorique française 110, 447–462.

Meyer, M. – Raetzel-Fabian, D. 2006: Neolithische Grabenwerke in Mitteleuropa: Ein Überblick. Journal of Neolithic Archaeology 8. https://doi.org/10.12766/jna.2006.20

Modderman, P. 1970: Linearbandkeramik aus Elsloo und Stein. Analecta Praehistorica Leidensia 3. Leiden: Leiden University.

Oberc, T. – Czekaj-Zastawny, A. – Rauba-Bukowska, A. 2022: Radiocarbon dating for the Linear Pottery Culture from the territory of Poland: research problems. In: M. Grygiel – P. Obst (eds.), Walking among ancient trees. Łódź: Fundacja Badań Archeologicznych, 183–212.

Olalde, I. – Altena, E. – Bourgeois, Q. – Fokkens, H. – Amkreutz, L. et al. 2026: Lasting Lower Rhine–Meuse forager ancestry shaped Bell Beaker expansion. Nature 652, 938–946. https://doi.org/10.1038/s41586-026-10111-8

Peters, R. 2024: Grabenanlage. In: N. Balkowski – R. Peters (eds.), Der bandkeramische Fundplatz Arnoldsweiler-Ellebach (Band 1). Rheinische Ausgrabungen 85/1. Bonn: LVR-Amt für Bodendenkmalpflege im Rheinland, 292–310.

Peters, R. – Zimmermann, A. 2017: Resilience and Cyclicity: Towards a macrohistory of the Central European Neolithic. Quaternary International 446, 43–53.

Pilař, D. – Daněček, D. – Květina, P. 2026: What does the Šárka stage mean? And did it ever actually exist? Documenta Praehistorica 53, 2–18. https://doi.org/10.4312/dp.53.3

Raemaekers, D. C. – Brusgaard, N. Ø. – Dreshaj, M. – Erven, J. – Dee, M. W. – Peeters, H. M. 2023: Going against the grain? The transition to farming in the Dutch wetlands re-examined (5000–4000 BCE). In: D. Groß – M. Rothstein (eds.), Changing identity in a changing world. Leiden: Sidestone Press, 225–233.

Raemaekers, D. C. M. 1999: The articulation of a 'New Neolithic'; The meaning of the Swifterbant Culture for the process of neolithisation in the western part of the North European Plain (4900–3400 BC). Leiden: Leiden University.

Reimer, P. J. – Austin, W. E. N. – Bard, E. – Bayliss, A. – Blackwell, P. G. et al. 2020: The IntCal20 northern hemisphere radiocarbon age calibration curve (0–55 cal kBP). Radiocarbon 62, 725–757. https://doi.org/10.1017/RDC.2020.41

Rose, H. A. – Meadows, J. – Henriksen, M. B. 2020: Bayesian Modeling of Wood-Age Offsets in Cremated Bone. Radiocarbon 62, 379–401. https://doi.org/10.1017/RDC.2020.3

Salavert, A. – Bosquet, D. – Damblon, F. 2014: Natural woodland composition and vegetation dynamic during the Linearbandkeramik in north-western Europe (central Belgium, 5200–5000 b.c.). Journal of Archaeological Science 51, 84–93. https://doi.org/10.1016/j.jas.2012.10.017

Schmidt, I. – Hilpert, J. – Kretschmer, I. – Peters, R. – Broich, M. – Schiesberg, S. – Vogels, O. – Wendt, K. P. – Zimmermann, A. – Maier, A. 2021: Approaching prehistoric demography: proxies, scales and scope of the Cologne Protocol in European contexts. Philosophical Transactions of the Royal Society B: Biological Sciences 376, 1816. https://doi.org/10.1098/rstb.2019.0714

Shennan, S. – Downey, S. S. – Timpson, A. – Edinborough, K. – Colledge, S. – Kerig, T. – Manning, K. – Thomas, M. G. 2013: Regional population collapse followed initial agriculture booms in mid-Holocene Europe. Nature Communications 4, 2486. https://doi.org/10.1038/ncomms3486

Spatz, H. 1996: Beiträge zum Kulturenkomplex Hinkelstein – Großgartach – Rössen: Der keramische Fundstoff des Mittelneolithikums aus dem mittleren Neckarland und seine zeitliche Gliederung, Stuttgart: Konrad Theiss.

Stehli, P. 1973: Keramik. In: J.-P. Farruggia – R. Kuper – J. Lüning – P. Stehli (eds.), Die bandkeramische Siedlungsplatz Langweiler 2, Gemeinde Aldenhoven, Kreis Düren. Rheinische Ausgrabungen 13. Bonn: Rheinland Verlag, 57–100.

Stehli, P. 1994: Chronologie der Bandkeramik im Merzbachtal. In: J. Lüning – P. Stehli (eds.), Die Bandkeramik im Merzbachtal auf der Aldenhovener Platte, Köln: Rheinland Verlag, 79–191.

Teetaert, D. 2020: Routes of Technology: Pottery Production and Mobility during the Mesolithic-Neolithic Transition in the Scheldt River Valley. Gent: Universiteit Gent. Unpublished PhD thesis.

Teetaert, D. – Boudin, M. – Goemaere, E. – Crombé, P. 2020: Reliability of AMS 14C dates of moss temper preserved in Neolithic pottery from the Scheldt river valley (Belgium). Radiocarbon 62, 1667–1678. https://doi.org/10.1017/RDC.2019.148

Trampota, F. – Květina, P. 2020: How do they fit together? A case study of Neolithic pottery typology and radiocarbon chronology. Archeologické Rozhledy 72, 163–193. https://doi.org/10.35686/AR.2020.6

van de Velde, P. 1979: On Bandkeramik Social Structure: An analysis of pot decoration and hut distributions from the Central European Neolithic Communities of Elsloo and Hienheim. Analecta Praehistorica Leidensia 12, 1–242.

van der Velde, P. 2016: It's the lineage, stupid! The rise and fall of the northwestern Linearbandkeramik. In: T. Kerig – K. Nowak – G. Roth (eds.), Alles was zählt: Festschrift für Andreas Zimmermann. Bonn: Rudolf Habelt, 233–246.

van de Velde, P. – Lohof, E. – Wyns, S. 2009: A LBK Earthwork at Beek (Prov. Limburg) – le modèle rosheimois– in the Netherlands. Archäologisches Korrespondenzblatt 39, 455–470.

Virtanen, P. – Gommers, R. – Oliphant, T. E. – Haberland, M. – Reddy, T. et al. 2020: SciPy 1.0: Fundamental algorithms for scientific computing in Python. Nature Methods 17, 261–272. https://doi.org/10.1038/s41592-019-0686-2

Whittle, A. 1996: Europe in the Neolithic: The creation of new worlds. Cambridge: Cambridge University Press.

Whittle, A. 2018: The Times of Their Lives: Hunting History in the Archaeology of Neolithic Europe. Oxford: Oxbow Books.

van Wijk, I. 2016: The Linear Bandkeramik Settlement. In: I. van Wijk (ed.), Settlement dynamics on the Cannerberg: Archaeological research of the Bandkeramik and Iron Age settlements. Archol Report 300. Leiden: Archol, 91–140.

van Wijk, I. in prep.: Footsteps of the First Farmers: A Socio-Landscape Approach to the First Agricultural Communities in Dutch Limburg (5250–4950 BC). Leiden: Leiden University. Unpublished PhD thesis.

van Wijk, I. M. – Amkreutz, L. W. S. W (eds.) 2022: Elsloo-Koolweg Revisited: Science-based perspectives on the burials and grave goods of the Linear Bandkeramik burial ground of Elsloo-Koolweg. Nederlandse Archeologische Rapporten 76. Amersfoort: Cultural Heritage Agency of the Netherlands, 99–114.

Zimmermann, A. 2012: Das Hofplatzmodell: Entwicklung, Probleme, Perspektiven. In: R. Smolnik (ed.), Siedlungsstruktur und Kulturwandel in der Bandkeramik: Beiträge der internationalen Tagung „Neue Fragen zur Bandkeramik oder alles beim Alten?!", Leipzig, 23 bis 24. September 2010. Dresden: Universität Leipzig – Landesamt für Archäologie, Dresden, 11–19.

Zimmermann, A. – Meuers-Balke, J. – Kalis, A. 2007: Das Neolithikum im Rheinland: Die Ausbreitung des Neolithickums und das Verhältnis der frühen Bauern zu den spätmesolithischen Sammlerinnen und Jägern. Bonner Jahrbücher 205, 1–63.

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