Journal of Anthropological Archaeology 64 (2021) 101348

Contents lists available at ScienceDirect

Journal of Anthropological Archaeology

journal homepage: www.elsevier.com/locate/jaa

Population collapse or human resilience in response to the 9.3 and 8.2 ka cooling events: A multi-proxy analysis of Mesolithic occupation in the Scheldt basin (Belgium)

Elliot Van Maldegem [a,*], Hans Vandendriessche [a], Jeroen Verhegge [a], Joris Sergant [a], Erwin Meylemans [b], Yves Perdaen [c], Florian Lauryssen [d], Erik Smolders [d], Philippe Crombé [a]

[a] Prehistory Research Unit, Department of Archaeology, Ghent University, Sint-Pietersnieuwstraat 35, 9000 Ghent, Belgium
[b] Flanders Heritage Agency, Havenlaan 88 bus 5, 1000 Brussel, Belgium
[c] BAAC Vlaanderen, Hendekenstraat 49, 9968 Bassevelde, Belgium
[d] Division of Soil and Water Management, Department of Earth and Environmental Sciences, KU Leuven, Kasteelpark Arenberg 20 bus 2459, 3001 Leuven, Belgium

ARTICLE INFO

Keywords:
Summed Probability Distributions
Climate events
Mesolithic
Prehistoric demography
Hunter-gatherer mobility
NW-Europe

ABSTRACT

This paper explores the impact of environmental, e.g. sea level rise, and climatic events, e.g. abrupt cooling events, on Mesolithic populations (ca. 11,350 to 6600 cal BP) living in the western Scheldt basin of Belgium and Northern France. The Mesolithic in this study-area has been extensively studied during the last few decades, leading to an extensive database of radiocarbon dates (n = 418), sites (n = 157) and excavated loci (n = 145). A multi-proxy analysis of this database reveals important changes both chronologically and geographically, which are interpreted in terms of population dynamics and changing mobility and land-use. The results suggest a population peak and high residential mobility in the Early Mesolithic, followed by a population shift and increased intra-basin mobility in the Middle Mesolithic, possibly triggered by the rapid inundation of the North Sea basin. The situation during the Late Mesolithic remains less clear but a possible reduction in the mobility seems likely. Currently there is little evidence supporting a causal link between these diachronic changes in human behavior and the 9.3 and 8.2 ka cooling events. Most of the observed changes seem more in response to long-term climatic and environmental changes during the Early and Middle Holocene, hinting at considerable resilience.

1. Introduction

In recent years, several studies have dealt with the possible impact of two important, short but abrupt cooling events, known as the 9.3 ka and 8.2 ka cal BP events on Mesolithic hunter-gatherer populations. In the northwest Atlantic regions, these climatic events led to colder, drier and windier conditions which prevailed for 70–160 years (Allan et al., 2018; Alley and Agustsdottir, 2005; Alley et al., 1997; Rasmussen et al., 2014; Thomas et al., 2007). In particular, the 8.2 ka event has been explicitly or tentatively linked to various cultural and demographic changes (e.g. Berger and Guilaine, 2009; Budja, 2007; Crombé, 2019a; Migowski et al., 2006; Riede, 2009; Staubwasser and Weiss, 2006; Weninger et al., 2006).

However, existing theories conflict concerning the impact of these climatic events in northwest Atlantic Europe. On the one hand, Wicks and Mithen (2014), and Waddington and Wicks (2017) claim a significant reduction in the Mesolithic population of northern Britain synchronic with the 8.2 and to a lesser extent to the 9.3 ka event (the latter only affecting the NE of Britain). On the other hand, Griffiths and Robinson (2018) advocate human resilience and adaptation to changing environment in response to the 8.2 ka event along the Atlantic coast of northwest Europe. Curiously, the conclusions in all three studies rely on series of radiocarbon dates exclusively and only differ in the way these dates are processed. In the first two studies, individual ^{14}C-dates are aggregated to sum probability distributions (SPDs) alongside a quantification of activity events, while the third study employs Bayesian statistical modelling of ^{14}C-dates of key sites.

Over the last decade, the use of SPDs to reconstruct prehistoric population dynamics has become widespread (e.g. Bevan et al., 2017; Crema et al., 2016; Edinborough et al., 2017; McLaughlin, 2019; Peros

* Corresponding author.
E-mail address: Elliot.VanMaldegem@Ugent.be (E. Van Maldegem).

https://doi.org/10.1016/j.jaa.2021.101348
Received 7 April 2021; Received in revised form 28 June 2021;
Available online 19 August 2021

et al., 2010; Riede, 2009; Shennan et al., 2013). The method employs "dates as data" (Rick, 1987) and assumes that the population was higher if more radiocarbon dates are available for a specific time-period. In other words, the peaks and troughs in the SPDs are interpreted as population increases and decreases respectively. However, many scholars have criticized this method or pointed out potential sources of bias (e.g. Ballenger and Mabry, 2011; Bamforth and Grund, 2012; Bayliss et al., 2007; Contreras and Meadows, 2014; Crombé and Robinson, 2014; Culleton, 2008; Freeman et al., 2018; Steele, 2010; Surovell and Brantingham, 2007; Torfing, 2015b; Williams, 2012). Despite numerous refinements in response to these critiques (cf. Contreras and Meadows, 2014; Hinz, 2020; Timpson et al., 2015 versus Torfing, 2015a, b), the method remains controversial, particularly when it is used as a single population proxy.

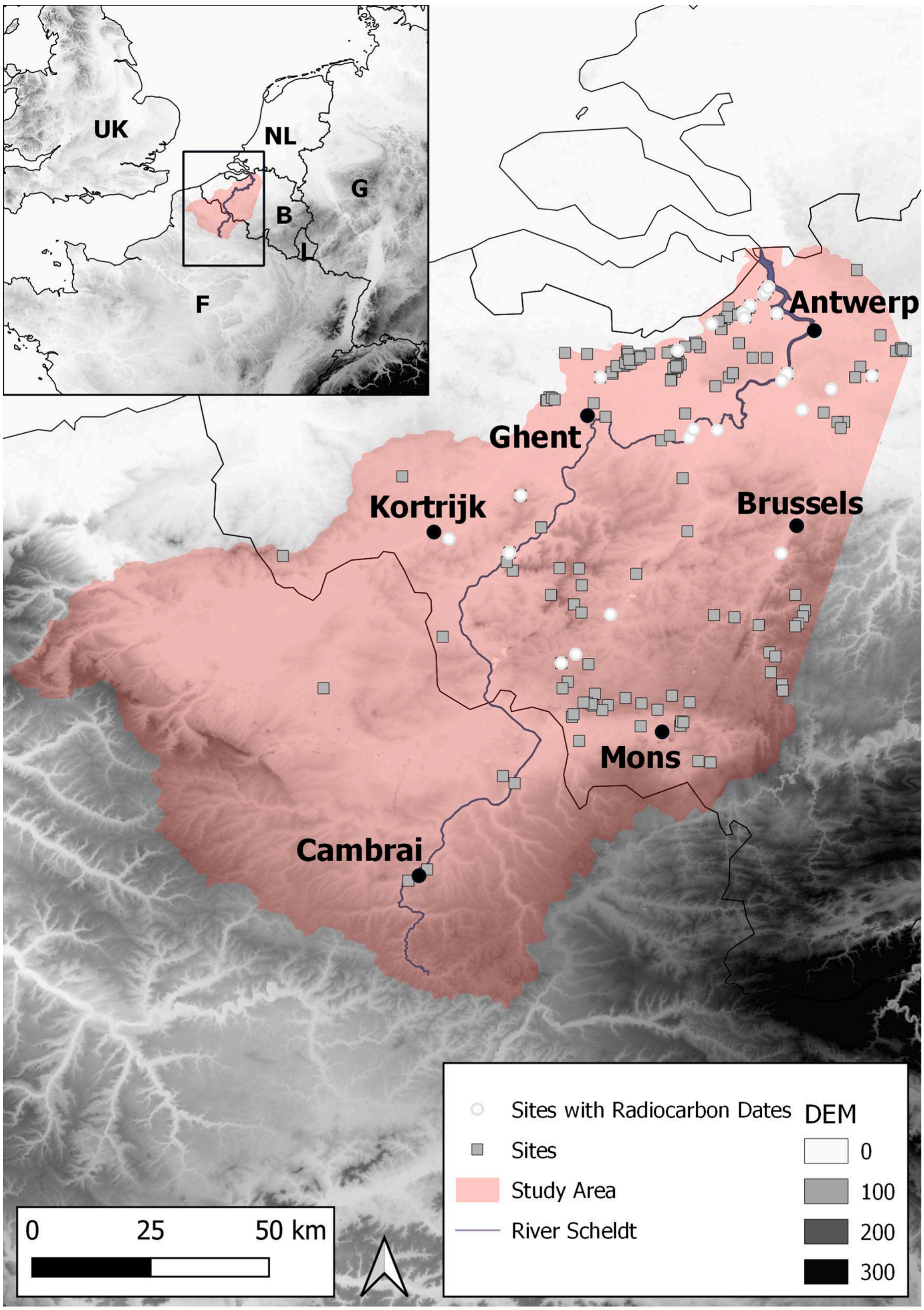

Fig. 1. Study area (red) and spatial distribution of Mesolithic Sites (squares) and Mesolithic sites with radiocarbon dates (circles) (DEM © European Union, Copernicus Land Monitoring Service 2021, European Environment Agency (EEA)). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

None of the beforementioned studies employ multiple proxies to reconstruct former population densities, thereby making the conclusions less solid. As stated by many scholars (e.g. Crema and Kobayashi, 2020; Palmisano et al., 2017; Williams, 2012), it is highly questionable whether changes in population can be traced solely on the basis of the radiocarbon record, because this record is potentially biased by several factors such as interregional and intersite differences in site-taphonomy, research foci, sample selection and excavation methods (Crombé and Robinson, 2014). These problems increase as the study-area gets larger (e.g. national or supranational level), incorporating many different regions with region-specific problems and limitations. In this sense, smaller regions are more homogeneous in terms of environmental evolution and research traditions, yet they include a smaller number of radiocarbon dates. According to Williams (2012), and Michczynska and Pazdur (2004), a minimum of 200 to 500 dates is required to ensure statistically reliable outcomes with SPDs. Such a number is generally difficult to attain on a regional level, especially if the dataset is assessed critically before modelling. In the studies of NW and NE Britain by Wicks and Mithen (2014) and Waddington and Wicks (2017), respectively 137 dates from 32 sites and 163 dates from 37 sites were collated, which is well below this critical limit. In such cases substantiation through additional proxies is essential and such studies have started to appear recently (for example Crema and Kobayashi, 2020; Crombé and Robinson, 2014; Downey et al., 2014; Feeser et al., 2019; Palmisano et al., 2017; Robinson et al., 2020). Despite a lack of precision (although for example see Crema and Kobayashi, 2020), other proxies, such as site count still provide substantiation and allow a more critical appraisal of the SPD peaks and troughs.

In this paper, we present the results of such a multi-proxy approach in the western Scheldt basin of NW Belgium. In the last three decades, intensive Mesolithic research has provided a substantial record (see infra) in this region, which possibly offers an additional perspective on the impact of climatic events on the Mesolithic population of the North Sea basin area.

2. The Scheldt basin

The western Scheldt basin, covering ca. 15,200 km^2 in Belgium and Northern France, is situated at the western limit of the coversand plain of NW Europe and of the central-European loess belt. In the north, the landscape of the lower Scheldt basin (downstream of Ghent, Belgium) is characterized as a lowland dune environment. The topography in the southern upper Scheldt basin is more pronounced with hills reaching up to 165 m a.s.l. and is intersected by relatively deep river and brook valleys.

This study focuses on the western part of the Scheldt basin (Fig. 1), including the valleys of the River Scheldt and its tributaries the Lys, Dendre, Rupel and Kale/Durme. In comparison to the eastern part of the Scheldt basin, corresponding to the Campine area and Hageland area, the western Scheldt basin is economically more dynamic. Different infrastructural activities, such as the development of the Antwerp and Ghent harbors (dock construction, transport means, etc.) and associated nature compensation areas, extensive sand extractions and river management plans (building of dikes, locks, etc.) along the Scheldt have led to numerous large-scale surveys and excavation projects. In many of these projects Mesolithic sites have been investigated resulting in an extensive dataset, unique within the southern North Sea basin. Altogether 49 sites (30 upper Scheldt area, 19 lower Scheldt area) have been excavated. The largest projects, such as Oudenaarde “Donk” (Lombaert et al., 2007; Parent et al., 1986–1987), Verrebroek “Dok” (Crombé, 2005), Doel “Deurganckdok” (Crombé, 2005; Noens, 2013; Van Herzeele et al., 2011), Beveren “Logistiek Park Waasland West” (Perdaen et al., 2017), Bazel (Crombé et al., 2020; Meylemans et al., 2016) and Kerkhove “Stuw” (Vandendriessche et al., 2019), were conducted in wetlands, such as (embanked) river- and estuarine floodplains providing high-quality information. In contrast, excavations of dryland sites have generally been smaller-scaled and yielded more fragmented information due to post-depositional perturbations such as (deep) ploughing and erosion.

The region is large enough to provide an adequate number of sites and radiocarbon dates, whilst still being small enough to maintain ecological, climatological and taphonomic coherence. Wicks and Mithen (2014) have pointed out that larger regions could mask inter-regional differences in population dynamics, as well as potentially exacerbating research or sampling bias. In contrast to other study-areas, Mesolithic research in the western Scheldt basin is not or only very slightly biased by choices made by individual researchers or institutes, which is important for the current study. Moreover, excavations are entirely conditioned by the infrastructural works and no selections have been made according to the age or scientific importance of individual sites. In fact, any threatened Mesolithic site was excavated as extensively as possible. This means that the database collated during the last three decades represents a random selection of Mesolithic sites that have been excavated. In addition, a similar excavation method is applied to most of these sites, i.e. systematic wet sieving through 2 mm meshes of soil excavated in a contiguous ¼ m^2 grid (see Crombé, 2005). As a result, the gathered data is perfectly comparable on an intersite level. This also holds for the selection of radiocarbon samples, which followed the guidelines proposed by Crombé et al. (Crombé et al., 2013) in all excavations.

Finally, the site database is supplemented with information from decades of intensive field-walking in several core-areas, resulting in numerous mapped Mesolithic surface-sites. Most of these surface-sites have been studied in detail within the framework of different inventory projects (Crombé, 1998; Van Assche, 2005; Van de Konijnenburg, 1980; Van der Haegen et al., 1999; Van Vlaenderen et al., 2006), allowing to include these in the present study. In sum, the Mesolithic dataset gathered the last few decades within the western Scheldt basin provides an excellent basis for a multi-proxy analysis of population dynamics.

3. Materials and methods

3.1. Radiocarbon dates

3.1.1. Selection

Within this study, SPDs will be used as one of three proxies for reconstructing Mesolithic demography and mobility within the western Scheldt basin. The collated ^{14}C database is estimated to have limited preservation bias (Rick, 1987) thanks to uniform sampling strategies (cf. supra) and owing to few intersite differences in the preservation of datable organic materials. Despite clear taphonomic differences between the excavated dryland and wetland sites (cf. 2), there is hardly any difference in the conservation of organic datable material. Except for two sites (Kerkhove and Bazel), only burnt plant (hazelnut shells, seeds and fruit remains, charcoal) and animal remains (calcined bone) are preserved, resulting in a focus on these samples for radiocarbon dating. In addition, sample selection is applied rather uniformly on the different sites, trying to obtain at least one date for each artefact cluster by focusing on samples retrieved from latent surface-hearths (Crombé et al., 2013; Sergant et al., 2006). Multiple dating is generally restricted to large artefact concentrations and complex palimpsest sites, such as the site of Bazel (Crombé et al., 2019a).

Altogether 418 radiocarbon dates ($\Delta T = 51{,}7$), ranging between 11,350 and 5000 cal BP from 30 sites, have been compiled for the study area (Supplementary Materials 1, 7). Only dates attributable to the prepottery Mesolithic will be discussed in this paper. However, dates from Mesolithic/Neolithic transitional contexts, characterized by the appearance of pottery and the first domesticated species (Crombé et al., 2020), were included in the modelling to mitigate edge-effects, as these could distort possible interpretation of the resulting SPD. All dates were collected from published or online databases such as the Radiocarbon

Laboratories of the Royal Institute for Cultural Heritage in Brussels (http://c14.kikirpa.be/ and http://radiocarbon.kikirpa.be/) or Louvain-la-Neuve (Gilot, 1997), archaeological excavation reports, and personal communication.

Before modelling, a critical selection of these dates was performed following the guidelines of Crombé et al. (2013) and Crombé (2016) and using a scoring system based on Pettitt et al. (2003). This scoring system provides a simple, yet objective, basis for selecting or discarding radiocarbon dates. A score of one to three was given in four categories: dating material, context, dating method and precision. This implies that modelling is done only on samples with a small inbuilt age, such as charred seed and fruit remains (mainly hazelnut shells), bone collagen, and charcoal. Due to limited age-control, dates on calcined bone were omitted, because recent research has pointed out that these dates can be affected by carbon exchange from the fire fuel (Crombé et al., 2021; Huls et al., 2010; Snoeck et al., 2014; Van Strydonck et al., 2010). Samples of charcoal clearly associated with lithic scatters or surface-hearths, the latter being very rare, were preferred. Dates on samples within features that could not directly be attributed to anthropogenic activities such as alleged "hearth-pits" (Crombé et al., 2015), peat covering layers, tree-throws, etc., were also eliminated. Twice the weight was given to material and context to ensure that the resulting SPD reflects human activity as accurately as possible. Legacy dates with large standard deviations (>100 years), were avoided as this spreads out possible signals and makes it more difficult to detect and interpret demographic events (Contreras and Meadows, 2014; Hinz, 2020). Lastly AMS on single entity samples was preferred over AMS dating of bulk samples or conventional radiocarbon dating, the latter is primarily inherent to old excavations. Applying this scoring system, the maximum score a date could receive was 18. It was decided that a score of 15 or more was sufficient to be included. Finally, 302 radiocarbon dates ($\Delta T = 44{,}8$) from 22 sites could be selected for modelling, the vast majority of which (60.60%) were conducted on charred hazelnut shells (table 1).

3.1.2. Modelling

A summed probability distribution of radiocarbon dates was created using the rCarbon v.1.4.1 package (Crema and Bevan, 2020) within the RStudio v.4.0.2 environment (RStudio Team, 2020). The dates were calibrated using the IntCal20 calibration curve (Reimer et al., 2020). Unnormalized distributions of calibrated dates were used to construct the SPD in order to avoid artificial peaks caused by steep portions of the radiocarbon calibration curve, as proposed by Weninger et al. (2015). Binning was used to correct for possible overrepresentation of sites that have been subjected to extensive dating programs, or over-sampling according to Shennan et al. (2013) and Timpson et al. (2014). The probabilities of dates with mean values within "n" uncalibrated years of each other (specified by "h" within rCarbon) were summed and then divided by the number of dates within the artificial site phase using the binPrep function in rCarbon (Crema and Bevan, 2020). The resulting probability distribution or bin is then used in the overall SPD along with the other site phases. An h-value of 100 years was used after comparing h-values from 0 to 1000 in 100 year increments with the binsense function in rCarbon (Supplementary Materials 2). Short bins of 100 years were used as to not overly mask sites with multiple occupation periods. Therefore, the SPD reflects site phases through time instead of single dates through time (Robinson et al., 2020). This resulted in 106 bins or artificial site phases. The automatic binning procedure was preferred over manually assigning dates to site phases because this is not possible on Mesolithic sites within the study area, being mainly characterized as un-stratified open-air sites and palimpsests (Bailey, 2007; Crombé and Robinson, 2014). Neither did we opt for the defining of activity events, following Wicks and Mithen (2014) and Waddington and Wicks (2017). The method involves combining dates from single sites, assigning the date of the event to the median of the 95% calibrated range and placing them in appropriate time-steps. This method aims at correcting over-dating of individual sites, yet it might favor discontinuously over (seasonally) continuously occupied sites, as the former will generate more activity events. This would mask too much variation within the dataset. Although dates were collected up to 5000 cal BP to limit edge effects, the SPD (Fig. 2) only displays dates between 11,350 and 6700 cal BP. The latter corresponds to the start of the Mesolithic-Neolithic transition. It was decided not to correct for taphonomic effects (Surovell and Brantingham, 2007; Surovell et al., 2009) as time-dependent taphonomic loss is not assumed for the study region (Williams, 2012). A 200 year running mean was applied to the SPD to smooth out spurious wiggles caused by the calibration process after comparing running means between 50 and 200 years (Supplementary Materials 2).

Both Monte-Carlo simulation methods (MC Method), proposed by Shennan et al. (2013) and improved by Timpson et al. (2014), and Kernel Density Estimations (Bronk Ramsey, 2017; Feeser et al., 2019; McLaughlin, 2019) account for problems with sampling error and calibration artifacts, and aid with the separation of signal and noise (Hinz, 2020). We have chosen to work with a MC Method over the KDE method, because the latter smooths out the distribution more. Using the MC Method, a SPD is compared with a theoretical null model, for example an exponential or a linear model and "n" dates are sampled proportional to the shape of the theoretical null model, the "n" being the amount of samples or bins. These are back-calibrated, assigned a random error, recalibrated and a SPD is constructed. This process is repeated as long as desired, often several hundreds or thousands of times, thereby creating a critical envelope to which the original SPD can be compared. In this study, a logistic model was fitted for this analysis using the modelTest function (e.g. Lawrence et al., 2021). The null model assumes a steady increase, after which it reaches a stable level reflecting the carrying capacity of the environment. The model was run 5000 times ($p = 0.0028$).

The upper Scheldt river area only has 33 radiocarbon dates from 4 sites, this in stark contrast with the lower Scheldt river area which has 269 radiocarbon dates from 18 sites. Because of the low density of radiocarbon dates in the upper Scheldt river only one SPD for the entire Scheldt basin was generated (for examples of regional SPDs and comparisons see Crema et al., 2016 or Palmisano et al., 2017; Palmisano et al., 2021).

The script for the radiocarbon analyses is included in the supplementary materials (Supplementary Materials 8).

Finally, the SPD was divided into 3 sub-phases matching the typo-chronological site phases (cf. 2.2) to facilitate comparison with the site density.

Table 1
Number of radiocarbon dates per dating material and Mesolithic substage: Early Mesolithic (EM), Middle Mesolithic (MM), Late Mesolithic (LM) and Mesolithic-Neolithic transitional contexts.

Dating Material	EM	MM	LM	Transitional contexts	Total	%
Charred hazelnut shell	131	16	7	29	183	60.60
Bone collagen	3		4	33	40	13.25
Cereal grains				25	25	8.28
Charcoal	7	5		11	23	7.62
Antler	5	2		7	14	4.64
Seeds				8	8	2.65
Moss temper				4	4	1.32
Wood				3	3	0.99
Plant remains				2	2	0.66
Total	146	23	11	122	302	100

3.2. Site counts

Similar to the interpretation of radiocarbon dates, it can be assumed that temporal variations in the number of Mesolithic sites within a particular region mirror changes in population density to a certain

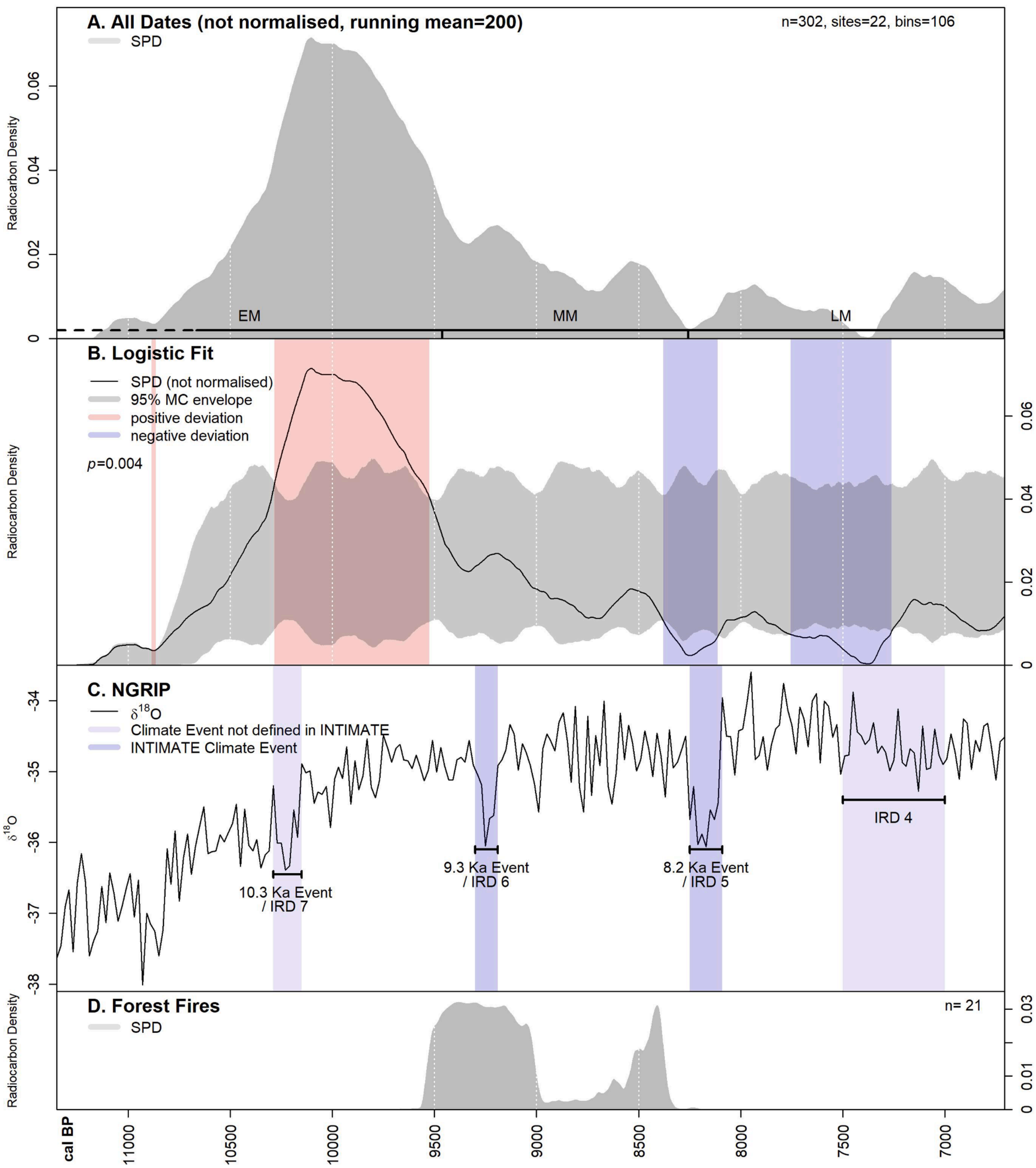

Fig. 2. a) Summed Probability Distribution (SPD) (Not normalized, running mean = 50), b) not normalized SDP (black line) with fitted logistic null model (95% confidence interval). Red blocks denote positive deviations from the logistic null model (larger growth than expected) and blue block denote negative deviations (smaller growth than expected), c) NGRIP climate curve with dark blue blocks indicating climate events defined by INTIMATE and light blue blocks indicating climate events (IRD) defined by Bond et al. (1997), d) SPD indicating forest fire occurrence. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

extent. The advantage of this second proxy is that, compared to radiocarbon dates, it is much less affected by biasing factors, such as taphonomy, sample quality, sampling strategy, etc. (Crombé and Robinson, 2014). Furthermore, it allows for the inclusion of Mesolithic sites without radiocarbon dates and/or no contextual information, such as surface-sites. The latter represent the vast majority of sites within and beyond the study-area. On the other hand, these sites only provide a coarse chronological framework for population reconstructions, as dating is mainly based on lithic typology and/or technology.

Although the largest and best preserved sites were investigated through excavations (n = 49), a greater number (n = 108) were discovered by (amateur) fieldwalking (Crombé et al., 2011). Firstly, the Mesolithic sites (n = 157)(Supplementary Materials 3, 7) were attributed to the Mesolithic sub-phases, i.e. Early, Middle and Late Mesolithic as defined in earlier studies (Crombé et al., 2009b; Ducrocq, 2001, 2009; Robinson et al., 2013). This attribution relied on typological and technological criteria of the lithic assemblages such as guide-fossils (e.g. microliths, Montbani blades, etc.) and general knapping characteristics (regular versus irregular knapping). Secondly, the site counts per subphase were converted into estimates per 100 calendar years to account for the different duration of each subphase (Crombé et al., 2011).

The duration of the sub-phases within the study area was determined by constructing a Bayesian chronological model of the typo-technological sequence of the subphases using OxCal (v4.4) (Bronk Ramsey, 2009a) with the intcal20 calibration curve (Reimer et al., 2020). Additional dates from surrounding countries (northern France and southern Netherlands) were included in this duration analysis (Crombé, 2019b). This inclusion enabled modeling the Middle and Late Mesolithic sub-phases because sufficient secure dates from these sub-phases were lacking within the study area (Table 1). The selection criteria were similar to the SPD date selection (focus on short-lived materials, clear association to human activity, etc.). A total of 263 dates were selected, divided over the Early (n = 183), Middle (n = 21), Late Mesolithic (n = 18) and Mesolithic/Neolithic transitional contexts (n = 41). The latter were included to more effectively model the end of the Late Mesolithic. For the start of the Early Mesolithic period a trapezoidal model was used (Lee and Bronk Ramsey, 2012) as a gradual transformation and a slow introduction and adoption of Early Mesolithic lithic technologies was hypothesized. The remaining sub-phases were treated as non-overlapping uniformly distributed phases. Outliers were not omitted from the model, but were marked as such as defined in Bronk Ramsey (Bronk Ramsey, 2009b).

The obtained Bayesian model (Amodel = 74.4)(Supplementary Materials 4) allowed us to define the start and end date of each Mesolithic stage (table 2). To assess the possible bias caused by the predominance of dated carbonized hazelnut shells (cf. 2.1.1), a species that did not occur in the study area before ca. 10,600 cal BP (Crombé et al., 2014; Storme et al., 2017), a second model (Amodel = 87) (Supplementary Materials 5) was created including four dates on animal bone from so-called Initial Mesolithic assemblages on the northern French sites of Amiens - Renancourt and Warluis (Ducrocq, 2019). This shifted the eventual start of the Early Mesolithic period back six centuries. These two models will be referred to as late starting EM and early starting EM respectively. Probably, the real start of the Mesolithic is situated in between both starting dates, similar to other NW European study-areas (Grimm et al., 2020; Plonka et al., 2020). Because of the limited number of radiocarbon dates within the Middle Mesolithic and Late Mesolithic period, the OxCal boundary (Lee and Bronk Ramsey, 2012), the period during which a transition between two sub-phases occurs, is relatively wide. Fortunately, due to the comparatively high number of Early Mesolithic and Mesolithic-Neolithic transitional phase dates, the other boundaries are more narrow.

3.3. Artefact loci: Counts and size

Since each Mesolithic site counts just once within a specific Mesolithic stage in the site count analysis above (see 3.2), intersite differences in occupation duration and re-use are not taken into account. In order to deal with this, a similar quantitative analysis has been conducted on the level of lithic artefact concentrations (called loci), representing individual dwelling and/or activity areas within a settlement (Supplementary Materials 6). We assume that each locus represents a separate occupation event of a site, but realize that this is probably not always the case. Artefact refitting on sites beyond the study-area (cf. Séara, 2013; Séara et al., 2002) strongly suggests that different loci within a site can be synchronic. Unfortunately, similar extensive intrasite refit data is lacking for the western Scheldt basin, except for the site of Kerkhove (Vandendriessche, 2021). Here, a combination of radiocarbon dating and refitting revealed two to maximum three contemporaneous clusters during the Early as well as Middle Mesolithic. Therefore, it can be reasonably assumed that contemporaneity of loci also applies to other sites, independent of the assigned Mesolithic subphase. Even if contemporaneous, we believe that artefact loci counts and size analysis form interesting additional proxies to compare with the results of the radiocarbon and site modelling.

All loci were linked to one of the Mesolithic subphases based on tool-typology and/or radiocarbon dates, followed by a conversion of the number of loci per 100 years. Clusters which clearly represent cumulative palimpsests (definition according to Bailey, 2007) of two or more subphases were counted for each subphase separately. In addition to the locus counts, the size of each cluster, corresponding to the surface (m^2) occupied by the lithic remains, was determined as far as this was possible. This approach was only applicable to excavated sites, since the spatial information of surface sites is too limited due to post-depositional factors such as ploughing and erosion. It starts from the basic assumption that there might exist a positive correlation between the size of a locus and the population group occupying it (Downey et al., 2014; Ortman et al., 2014). However, possible biases need to be considered, e.g. frequent re-use of the same locus, leading to denser and larger accumulations of waste, but also possible differences in boundary definition. The latter, however, is probably negligible within the Scheldt basin as excavations were conducted by a limited number of researchers, applying roughly the same methodology for delineating the borders of artefact loci (Crombé et al., 2006; Crombé et al., 2013). All loci with clear proof of cumulative palimpsest were eliminated from the size analysis to reduce the influence of re-used loci.

3.4. Artefact loci: Artefact density and tool frequency

Similar to the size of the loci, the mean artefact density and number of lithic tools can provide information on the group size and occupation duration and possible diachronic changes therein. Mean artefact density is expressed in number of lithic artefacts (including the fraction < 1 cm) per 1 m^2, while the quantification of the lithic tools only takes into account retouched tools. Numerous microwear studies demonstrate that unretouched flakes and blades also display microscopic wear traces and are therefore also considerable as tools. However, since microwear data is not available for all excavated loci within the study area (Cordemans et al., 2001; Crombé and Beugnier, 2013; Guéret, 2013, 2017), this study only quantifies retouched tools.

Table 2
Calculation of the duration of each Mesolithic subphase (cal BP) within the western Scheldt basin, based on the median Baysesian models of available radiocarbon evidence.

Sub-Phase	Early Start	Late Start
Start EM	11460–11264	10911–10621
Boundary EM-MM	9490–9416	9490–9416
Boundary MM-LM	8400–8064	8400–8064
Boundary LM-LM/EN	6856–6605	6856–6605

4. Results

4.1. Summed probability distribution

The results of the SPD analysis are shown in Fig. 2. After an initial slow start, a substantial peak encompasses most of the Early Mesolithic. A significant positive deviation from the null model is dated between ca. 10,280 and 9540 cal BP.

The Middle Mesolithic is characterized by a markedly lower density of radiocarbon dates. Several small troughs are visible between 9400 and 9300 cal BP and between 8700 and 8600 cal BP, although these do not significantly depart from the null model. A significant negative deviation only appears between ca. 8370 and 8115 cal BP, which corresponds with the transition from the Middle to the Late Mesolithic.

Finally, the overall decrease in radiocarbon date density continues into the Late Mesolithic. Two periods of significant negative deviations from the null model are present: a short deviation between ca. 7700 and 7680 cal BP and a second larger deviation between ca. 7500 and 7250 cal BP, the probability density in the latter dropping to 0 for the majority of the deviation.

The pattern of a large peak in the Early Mesolithic (>9500/9000 cal BP) followed by a sharp decrease and very low densities in the subsequent phases is also visible in the individual SPDs of some more extensively dated sites in the study area (Fig. 3), namely Verrebroek "Dok 1" (Crombé, 2005), Verrebroek "LPWW" (Perdaen et al., 2017), Deurganckdok "Zone J/L, M" (Noens, 2013; Van Herzeele et al., 2011), Kerkhove (Vandendriessche et al., 2019) and Bazel (Crombé et al., 2020; Meylemans et al., 2016). The site of Verrebroek "Aven Ackers" is an exception (Crombé et al., 2009a), as one of few sites yielding numerous Middle Mesolithic dates.

4.2. Site counts

Considering the entire western Scheldt basin, the evolution of the site frequency is characterized by a sharp decrease towards the younger Mesolithic phases (Fig. 4). Depending on the selected starting date model for the Early Mesolithic, the decrease starts during either the Middle Mesolithic (late start date) or the Late Mesolithic (early start date). However, as few sites in the Scheldt basin pre-date 10,700 cal BP, the late start model seems more realistic.

Looking at the upper and lower Scheldt (Fig. 4c & 4d) separately, a different trend emerges. Independent of the start date of the Early Mesolithic, the number of sites declines considerably in the Middle Mesolithic and drops slightly further in the Late Mesolithic along the

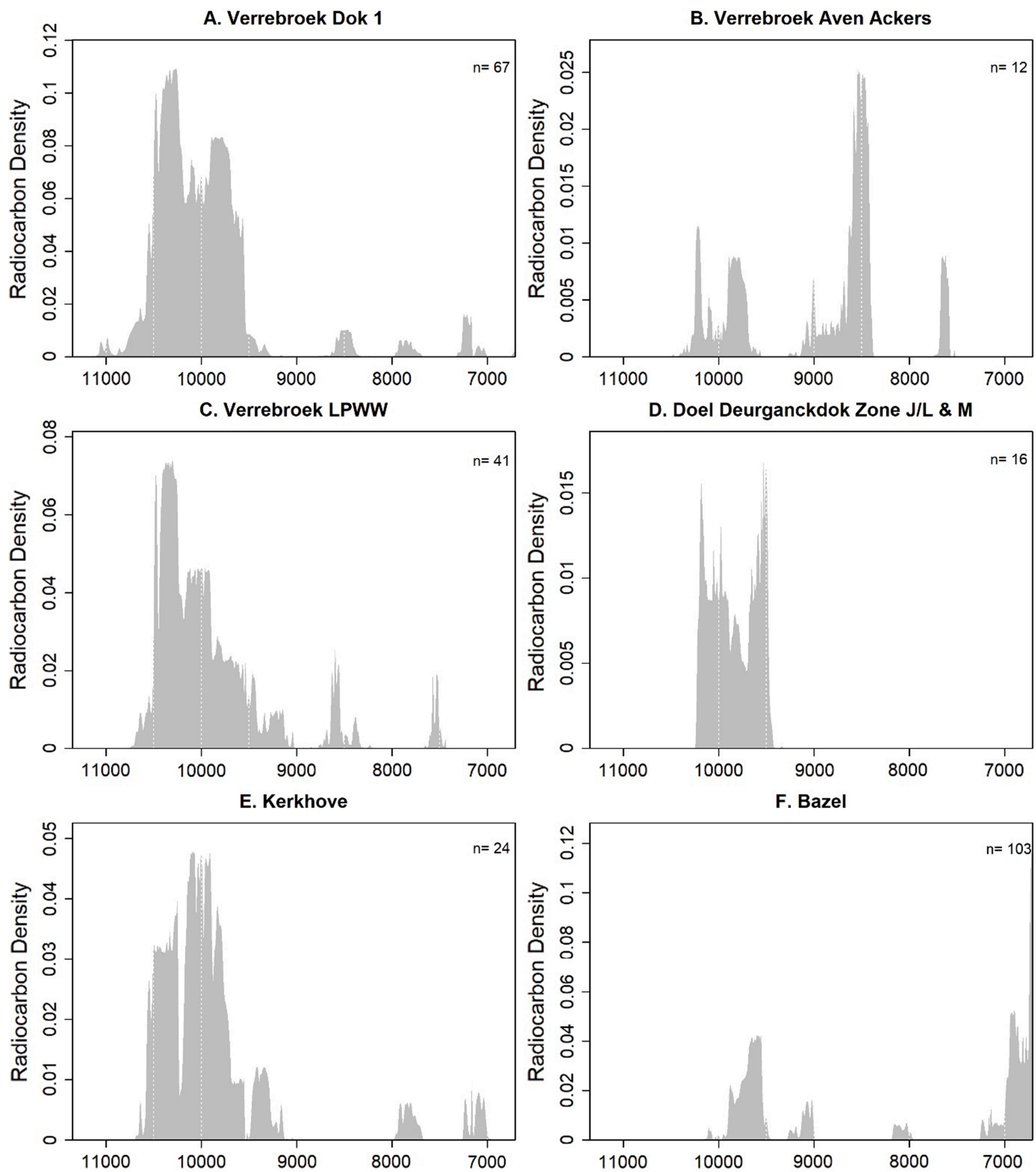

Fig. 3. Summed Probability Distributions (SPDs) of extensively excavated and dated sites in the Scheldt basin.

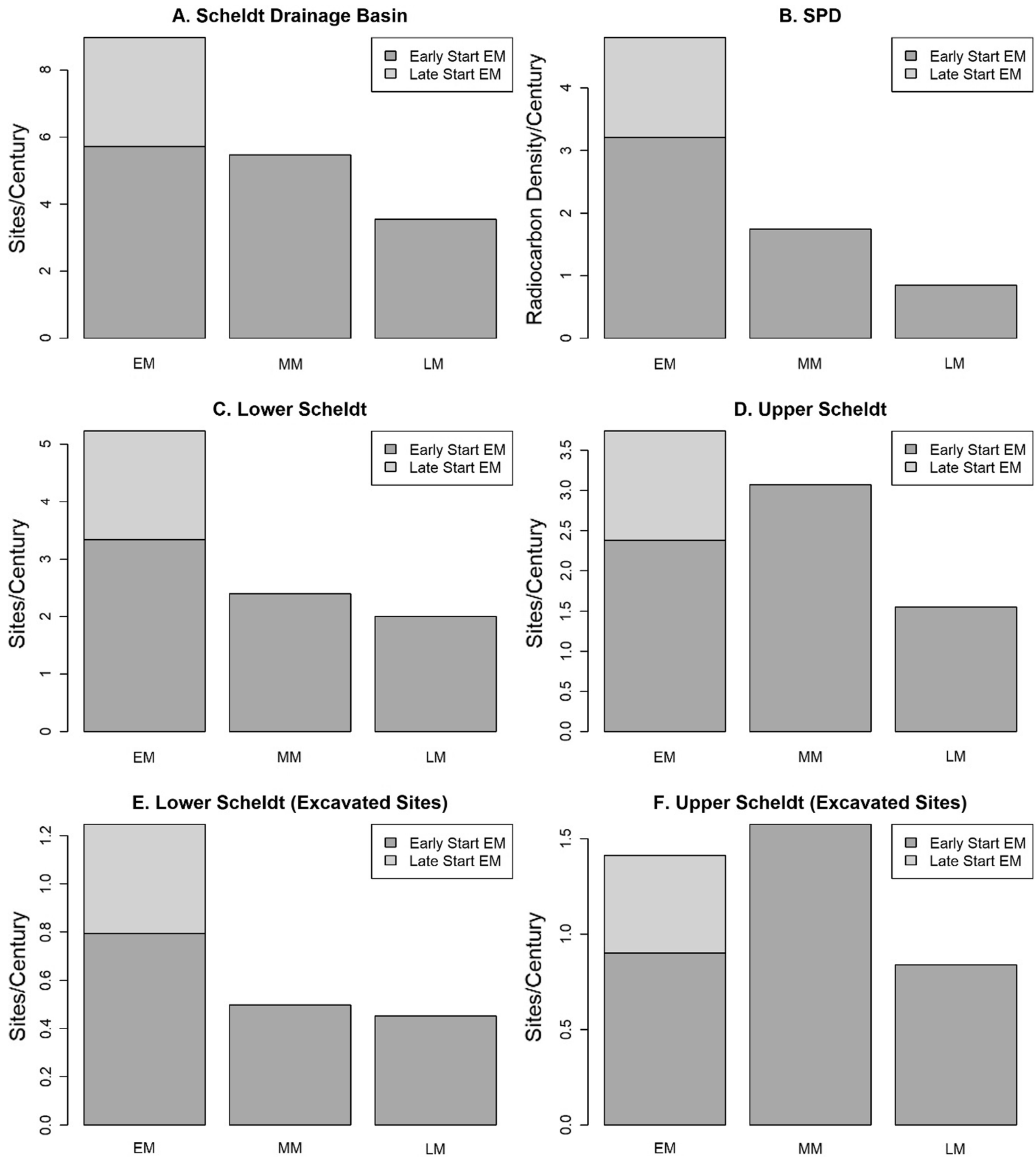

Fig. 4. (A, C-F) Chronological distribution of site counts per (sub-)region (corrected for duration of sub-phase) and (B) Scheldt Drainage Basin SPD (divided into the 3 sub-phases for easier comparison).

lower Scheldt basin. On the other hand, the Middle Mesolithic is characterized by a substantial increase (late start date) or stabilization (early start date) followed by a marked decline in the Late Mesolithic in the upper Scheldt. This implies different hunter-gatherer site dynamics during the Middle Mesolithic in both sub-regions.

4.3. Artefact loci: Counts and size

The dataset only allows us to investigate these proxies within the lower Scheldt basin, as excavations in the upper Scheldt basin are still too scarce to yield statistically relevant data. A chi-square test showed significant differences between observed and expected loci counts in the three subphases ($X^2(2,\ n = 145) = 161.72,\ p < 0.01$). All differ significantly from the expected values (48.3). The amount of excavated loci in the lower Scheldt (Fig. 5a; table 3) mirrors the trend observed in the site counts and radiocarbon dates, i.e. a significant decrease from the Middle Mesolithic onwards. Concerning the size of the loci (Fig. 5b), a Kruskal-Wallis test shows a significant difference between the three subphases ($H(2) = 6.187$, p-value = 0.045), yet a Wilcox post hoc test to test pairwise comparisons using the Benjamin-Hochberg method to adjust p-values reveals no significant differences (EM-MM p-value = 0.14; EM-LM p-value = 0.14 and MM-LM p-value = 0.15). The decrease is more pronounced when a late start to the Early Mesolithic is considered. An early start to the Early Mesolithic changes the trend slightly to a small increase in mean locus size in the Middle Mesolithic followed by a decrease in the Late Mesolithic. Due to the limited data for the Late

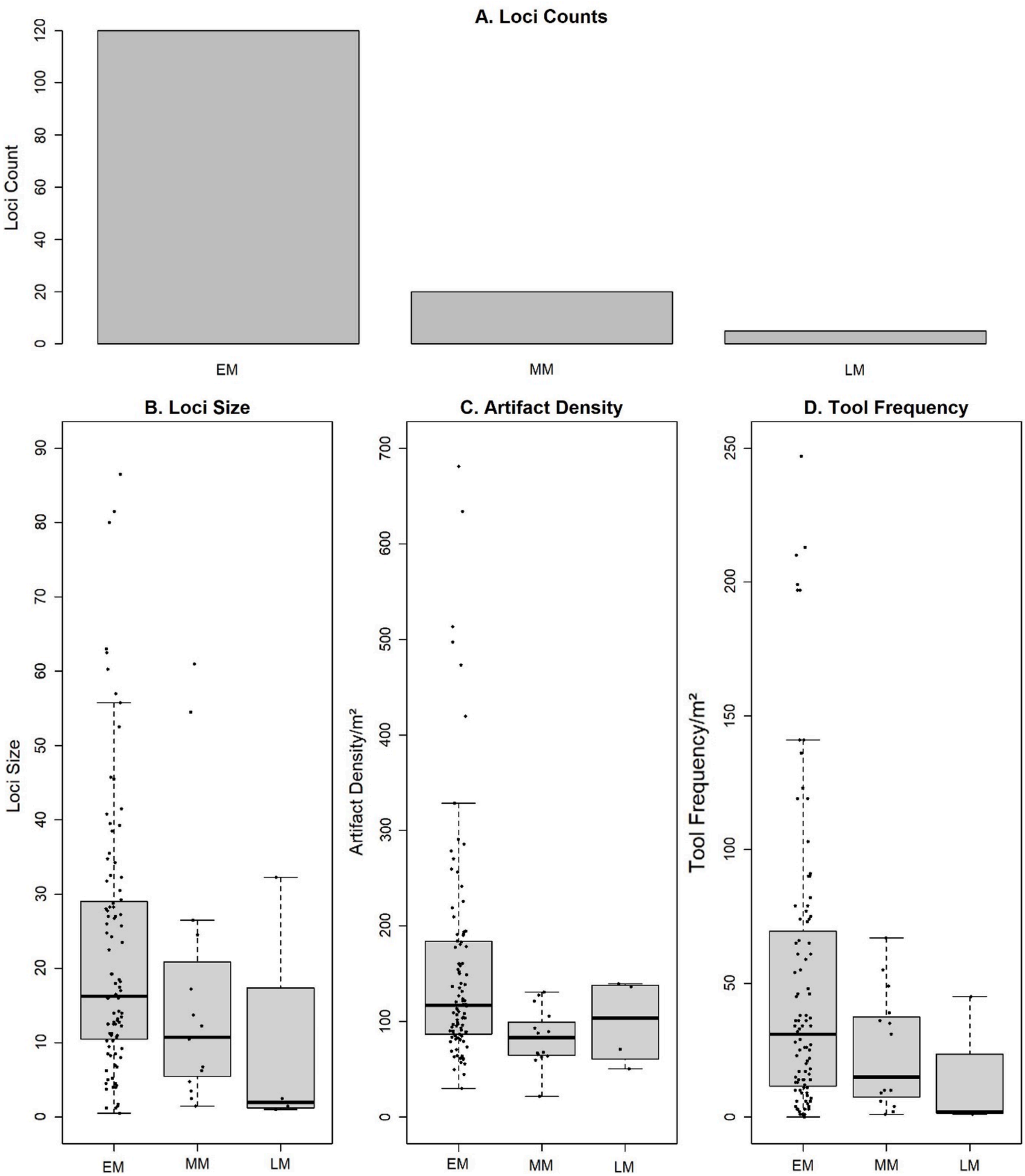

Fig. 5. Artifact loci: a) Loci counts per sub-phase, b) spread of loci sizes per sub-phase, c) spread of artifact density (/m^2) per sub-phase, d) spread of tool frequency per sub-phase.

Mesolithic, these results are not robust, yet they suggest a further, substantial decrease in both loci counts and size (table 4).

4.4. Artefact loci: Artefact density and tool frequency

The artifact density per m^2 and the tool frequency in the lower Scheldt basin (Fig. 5c&d) display a similar declining trend. A Kruskal-Wallis test shows a significant difference between the artifact densities in the three subphases ($H(2) = 10.408$, p-value < 0.01). A Wilcox post hoc test to test pairwise comparisons using the Benjamin-Hochberg method to adjust p-values reveals a significant difference between EM and MM (p-value < 0.01). Between EM and LM (p-value $= 0.44$), and MM and LM (p-value $= 0.45$) no significant differences could be detected. During the Middle Mesolithic the mean artefact density per m^2 is halved compared to the Early Mesolithic (Table 4). This also holds for the mean tool frequency (Table 4), although a Kruskal-Wallis test shows

Table 3
Overview of all Mesolithic sites (excavated + surface-sites) and loci per subphase and the conversion to counts relative to subphase duration (bold).

	Subphase	EM	MM	LM
Total study area	Absolute site count	108	66	55
	Number of sites/ Century	**5.72 (Early Start EM)/ 8.97 (Late Start)**	**5.47**	**3.55**
Upper Scheldt Basin	Absolute site count	46	37	24
	Number of sites/ Century	**2.38 (Early Start)/ 3.74 (Late Start)**	**3.07**	**1.55**
Lower Scheldt Basin	Absolute site count	64	29	31
	Number of sites/ Century	**3.34 (Early Start)/ 5.23 (Late Start)**	**2.40**	**2**
	Absolute loci count	120	20	5
	Relative loci count (/century)	**6.36 (Early Start)/ 9.97 (Late Start)**	**1.66**	**0.32**

Table 4
Overview of the loci count, mean loci size, mean artifact density and mean tool frequency per subphase within the lower Scheldt basin.

Subphase	EM	MM	LM
Number of loci	120	20	5
Mean Size	22.48	17.08	9.31
Mean artefact density/m^2	155.95	83.13	99.41
Mean tool frequency	49.74	24.60	12.00

no significant differences between the tool frequencies in the three subphases ($H(2) = 4.527$, p-value = 0.104). Unfortunately, no conclusions can be drawn with respect to the Late Mesolithic due to too few data.

5. Discussion

5.1. Potential biases

To facilitate the comparison of the summed probability evidence and the site and loci density, the probabilities for the years within the three sub-phases were summed, thereby creating a SPD consisting of only three blocks (Fig. 4b). This sacrifices the greater chronological precision of the SPD for ease of comparison between the different proxies. Also included are $\delta^{18}O$ concentrations from the NGRIP ice core synchronized to the GICC05 chronology (Rasmussen et al., 2006; Rasmussen et al., 2014; Vinther et al., 2006) and the four Early Holocene cooling events, 10.3 ka /IRD7, 9.3 ka/IRD 6, 8.2 ka/IRD 5 and IRD 4 (Fig. 2c) (Bond et al., 2001; Bond et al., 1997).

Contrary to the upper Scheldt basin, the lower Scheldt area represents the best case for a multi-proxy comparison, given the substantial number of radiocarbon dates and excavated sites. In the latter area, the three proxies (^{14}C, site and loci counts) display the same trend, starting with a major peak in the Early Mesolithic followed by a substantial decrease in the Middle phase to end with very low densities in the Late Mesolithic. However, it should be investigated to what extent this trend could be affected by biasing factors before interpreting this pattern. First of all, site frequencies can be biased to a certain level by taphonomy, as they are largely based on data from surface sites. The latter are predominantly composed of dryland sites which are easier to detect during field-walking or other surveys. An earlier study (Crombé et al., 2011) pointed out that Middle and Late Mesolithic sites tend to be located more frequently on lower locations, such as river floodplains, which are much less accessible for field-walking. Hence, sites from the latter two subphases might be somewhat underrepresented in the site counts. In order to take this potential problem into account, a model only including excavated sites has been produced for both the lower and upper Scheldt (Fig. 4e & 4f). As (salvage) excavations have been performed randomly within both dryland and wetland contexts (cf. supra), there is reason to believe that this model is less biased towards specific environmental and taphonomic contexts. The obtained model largely confirms the above chronological pattern, demonstrating that the overall site trend is not unduly biased. This is further supported by the data on the frequency of excavated artefact loci, which also displays a marked declining trend towards the Middle and Late Mesolithic.

Similarly, the reliability of the SPD of the Scheldt basin needs to be investigated. For example, it is questioned whether the pronounced peak of Early Mesolithic radiocarbon dates is not influenced by the strong focus on charred hazelnut shells as dating material (ca. 60% of all dates). The palynological evidence from the Scheldt basin (Storme et al., 2017) indicates that hazel (*Corylus avellana*), which first appeared around ca. 10,600 cal BP, declined markedly around 8600 cal BP at the latest, which implies that hazelnuts must have been less available towards the end of the Middle Mesolithic and during the Late Mesolithic. This is corroborated by a decreased occurrence of charred hazelnut shells on sites from the latter two subphases, strongly reducing the possibility of radiocarbon dating these sites. This is best illustrated by the wetland sites of Verrebroek "LPWW" (Perdaen et al., 2017) and Kerkhove "Stuw" (Vandendriessche et al., 2019). These two sites yielded artefact loci typologically attributed to the Early (resp. 41 and 9), Middle (resp.14 and 3) and Late Mesolithic (resp. 3 and 1). However, only the Early Mesolithic loci could be extensively radiocarbon dated (resp. 33 and 21 dates), whereas hardly any dates could be obtained for the Middle and Late Mesolithic loci (resp. 2 and 0 dates) (Fig. 3). So, clearly the SPD of the lower Scheldt basin is biased to a certain degree, however, probably not to that extent to question the declining trend of the distribution, since the latter is also confirmed by the other proxies. However, it warns us against interpreting every detail of the SPD but rather argues in favor of focusing on the general trends, i.e. the deviations from the null model, assuming logistic growth. For the site counts, this bias is somewhat alleviated through the use of both a late and an early start to the Early Mesolithic, the latter also including several dates on animal bones.

5.2. Demography versus mobility

The SPD of the (lower) Scheldt is very similar to the ones obtained in other NW European study-areas, in particular in northwest (Wicks and Mithen, 2014) and northeast Britain (Waddington and Wicks, 2017). Although these are also largely based on hazelnut dates (respectively ca. 41% and 57%), both display the same declining trend throughout the Mesolithic. Particularly the SPD from northeast Britain resembles the lower Scheldt SPD: it also starts with a major peak between ca. 10,000 and 9350 cal BP, followed by very low densities afterwards, with almost zero density around 8600 cal BP and between ca. 7600 and 7200 cal BP, and very low densities between 8200 and 7900 cal BP. Following the principles of "dates as data" Waddington and Wicks (2017) interpret this declining trend as reflecting major changes in the population density of northeast Britain, more specifically as a strong indication of a significant population collapse. Below we will investigate whether this demographic model is also valid for the (lower) Scheldt basin.

5.2.1. Early Mesolithic

Following a demographic interpretation, the major peak during the Early Mesolithic in all proxies, in particular between ca. 10,280 and 9540 cal BP as indicated by a positive deviation from the null model in the SPD, might point to a substantial increase of the population in the Scheldt basin at the start of the Mesolithic in addition to the assumed logistic growth. This might be a logical consequence of Early Holocene warming, creating an environment more suitable for human exploitation following a period of extreme coldness and sparse occupation during the Younger Dryas (Crombé, 2019a). However, since the radiocarbon dates start to increase not before ca. 10,700 cal BP, which is almost a millennium later than the start of Holocene warming, other factors must have played a role. It is, for example, striking that the positive deviation in the SPD of the Scheldt basin immediately follows the 10.3 ka cooling event (Bjorck et al., 2001), also known as the IRD 7 event (Bond et al., 1997; Bond et al., 1999) or Erdalen event (Dahl et al., 2002), dated between ca. 10,300 and 10,100 cal BP. The precise impact of this punctuated climatic event on the ecosystem in the southern North Sea area remains unclear due to a lack of high-resolution palaeoecological analyses (Crombé, 2018), yet in western Scandinavia it corresponded to a marked increase of winter precipitation (mainly snow) and a major advance of glaciers (Bakke et al., 2005; Dahl et al., 2002), while conversely in the Jura mountains lake levels were lower pointing to lower precipitation (Magny, 1999). So perhaps population growth "boosted" once this cold event ended and Holocene climate became more stable and temperate. Another environmental change which might have impacted the Early Mesolithic population of the Scheldt basin is the rapidly drowning North Sea basin which could have triggered the movement of hunter-gatherer groups from (north)west to (south)east resulting in increased population densities in the adjacent regions (Crombé, 2019b). According to a recent modelling (Sturt et al., 2013) approximately 50,000 km^2 of the North Sea basin was drowned between 11,000 and 9500 cal BP, which ethnographically corresponds to the territory of an entire dialect tribe living in a forested environment.

However, it is questionable whether this pronounced Early Mesolithic peak should be interpreted in terms of population growth alone. Similar peaks in site counts and/or radiocarbon dates during the Early Mesolithic have also been attested in areas that were potentially differently affected by cooling events and located further away from the drowning North Sea basin, such as southern Germany (Jochim, 2006; Jochim, 2008) and France (Berger et al., 2019; Gkiasta et al., 2003). There, this peak is often interpreted as an indication of higher residential mobility during the initial stages of the Mesolithic. High residential mobility has also been suggested on the basis of intense microwear studies on several sites within the Scheldt basin (Crombé and Beugnier, 2013; Guéret, 2013, 2017; Vandendriessche et al., 2019). The combination of shortly used tools (with weakly developed wear traces), partial *chaînes opératoires* e.g. in the processing of hides, and the limited intersite typological and functional variability all point in the direction of relatively briefly occupied camp-sites of similar functionality and seasonality. According to several ethnographic analogies (cf. Houtsma et al., 1996; Kelly, 1983; Kelly, 1995) this pattern is typical of hunter-gatherers living in densely forested environments in which resources were sparse and unpredictably distributed (i.e. using a forager type subsistence strategy according to Binford, 1980). Lithic raw material procurement strategies also seem in agreement with this interpretation as they are almost entirely focused on the exploitation of local outcrops (cf. 5.2.2).

5.2.2. Middle Mesolithic

Based on the broad synchronicity of the troughs in the radiocarbon data with the 9.3 and 8.2 ka cooling events, Waddington and Wicks (2017) conclude that in northeast Britain there might be a causal link between Mesolithic population decline and these climatic changes, augmented by the Storegga megaslide tsunami occurring around 8100 ± 100 cal BP (Weninger et al., 2008). However, within the SPD of the (lower) Scheldt the 9.3 ka event, dated between 9300 and 9190 cal BP (Rasmussen et al., 2014), does not correspond with a significant negative trough in the SPD, even if the period following this climatic event, the Middle Mesolithic, generally displays a drastic reduction in radiocarbon dates, site counts and loci. Comparing the trends for the upper and lower Scheldt separately though, a reverse trend is visible for the upper Scheldt, with a substantial increase of sites in the Middle Mesolithic. These intra-basin differences might point to a population shift during the Middle Mesolithic, from the lowland to the upland and/or an extension of the yearly territory. This is supported by the loci proxies from the lower Scheldt basin, which demonstrate a marked decrease in mean size as well as in artefact and tool frequencies compared to the Early Mesolithic (Fig. 5). This might hint at even shorter occupations and thus a further increase of the residential mobility. Unfortunately the scarcity of loci data from the upper Scheldt does not allow us to investigate eventual changes in mobility in the uplands. However, studies of raw material procurement and circulation (Crombé, 2018; Crombé et al., 2011; Fiers et al., 2019; Vandendriessche et al., 2019) have revealed marked changes from the Early to Middle Mesolithic in the Scheldt basin. Early Mesolithic raw material procurement in both the lower and upper Scheldt is characterized by the almost exclusive use of local flint types, originating from a radius of ca. 20–30 km around the sites (Fig. 6). One exception is Tienen quartzite, outcropping in the center of Belgium just beyond the borders of the Scheldt basin. Remarkably, this exotic raw material was used rather intensively in the lower Scheldt basin, while it was hardly distributed in the upper Scheldt (Crombé, 2018; Vandendriessche et al., 2019). This probably indicates the existence of two distinct group territories along the Scheldt basin during the Early Mesolithic. From the Middle Mesolithic raw material use changed as there is increasing evidence of circulation of particular flint types, such as Ghlin flint, between the upper and lower Scheldt. In addition the use of Tienen quartzite stopped abruptly; instead Wommersom quartzite, originating from the same outcropping area, was increasingly imported in both the lower and upper Scheldt basin (Crombé, 2018; Perdaen et al., 2009). All this seems to support the idea of increasing intra-basin mobility and/or exchange and larger territories within the Scheldt basin from the Middle Mesolithic onwards.

Following this reasoning, possible causes for this shift need to be explored. Continued rapid sea level rise, resulting in another ca. 50,000 km^2 of flooded territory (Sturt et al., 2013), and related population displacement ultimately might have culminated in a population stress in the lower Scheldt basin. This in its turn might have forced groups to move to more inland areas further away from the North Sea, such as the upper Scheldt. Earlier studies (Crombé, 2018, 2019b; Robinson et al., 2013) have identified other responses around the same period, such as a radical change in microlith design and technology with the development of invasively retouched armatures, e.g. mistletoe and leaf-shaped microliths. Rather than interpreting these microlith changes as functional adaptations of the hunting gear they are considered as a possible expression of social boundary defense by means of symbolic tools in response to changing environment. In addition differential environmental evolutions may have been at the base of the shift to the uplands of the Scheldt basin, such as the occurrence of forest wildfires. According to the available information from burnt ant-nests (Crombé, 2016; Crombé et al., 2015), a major peak in forest fires would have occurred in the sandy lowland of the lower Scheldt basin between ca. 9600 cal BP and 8500 cal BP, corresponding to the Middle Mesolithic (Fig. 2d). This has been tentatively linked to the 9.3 ka cooling event in combination with the predominance of pine (*Pinus sylvestris*), a tree species with a very high fire risk. The limited data on microcharcoal from the upper Scheldt basin (Crombé et al., 2019b; Storme et al., 2017) point to an earlier peak of forest fires, situated between ca. 11,200 and 9600 cal BP, so mainly during the Early Mesolithic. This difference in the timing of wildfires might be connected to an earlier transition from coniferous to deciduous forest vegetation in the upper Scheldt basin, although much more fine-grained pollen data is needed to verify this assumption. So, it could be hypothesized that, besides sea level rise, repeated and devastating forest fires, which strongly affected human resources (wild game and plants, drinking water, etc.), were responsible for the intra-basin movement during the Middle Mesolithic. A similar population shift might have occurred at the same time in northern Britain. Comparing the SPDs from eastern and western Scotland, the main peak of dates shifts from ca. 10,000–9000 cal BP in the former to ca. 9000–8000 cal BP in the latter. Here, this shift also coincides with a major peak in wildfires around the timing of the 9.3 ka event (Tsakiridou et al., 2020), although it is not clear whether these fires affected the eastern and western side of Scotland differently.

5.2.3. Late Mesolithic

Statistically the two troughs in the SPD of the Scheldt basin combined, cover half of the total duration of the Late Mesolithic, i.e. 755 cal years. Between these two troughs the density of radiocarbon dates

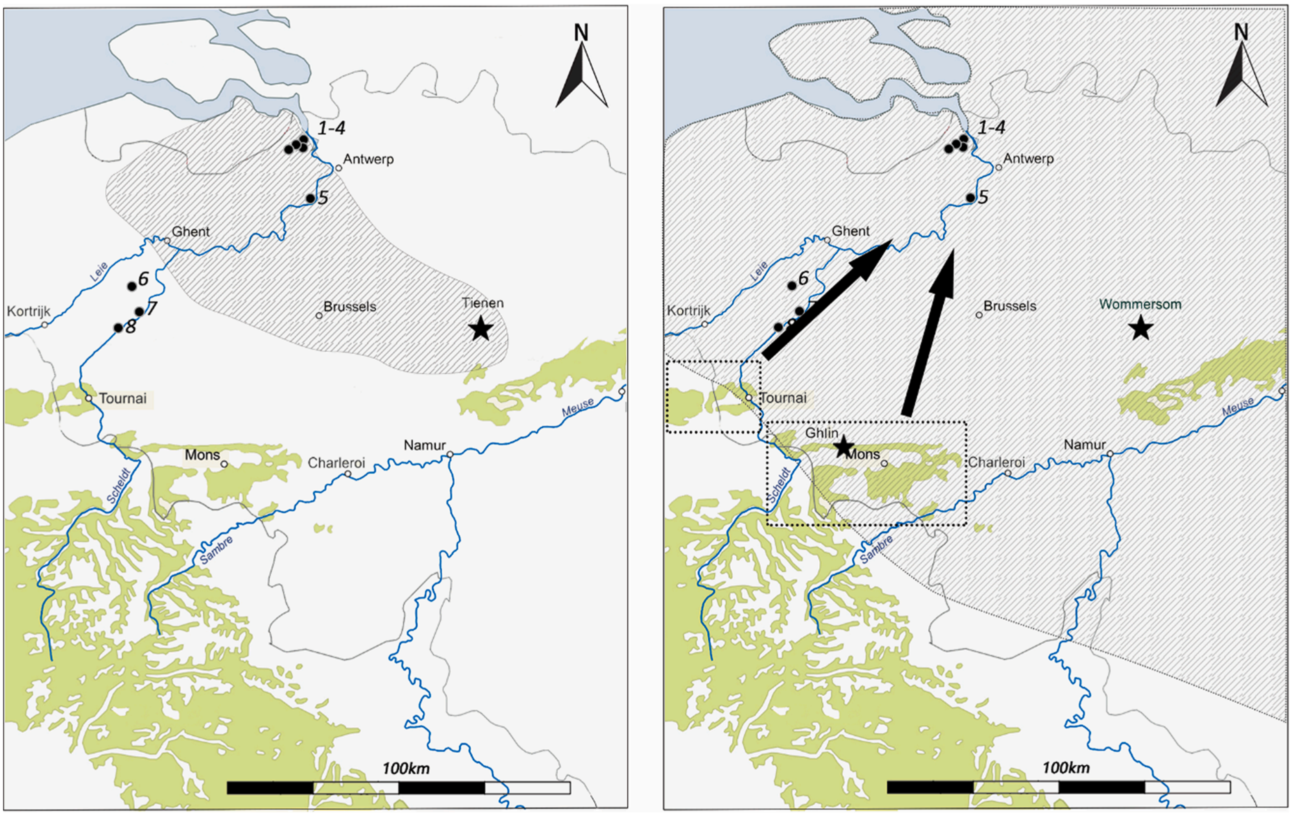

Fig. 6. Distribution of flint and quartzite types. Cretaceous outcrops (green), the outcrop location of Tienen and Wommersom Quartzites (star) and excavated sites mentioned in the text: 1–4: Doel-Deurganckdok, Verrebroek-Dok 1, Verrebroek- Aven Ackers and Verrebroek - Logistiek Park Waasland; 5. Bazel; 6. Kruishoutem - Kerkakkers; 7. Oudenaarde - Donk; 8. Kerkhove. Left: Early Mesolithic - Distribution area of Tienen quartzite (hatched area), based on Perdaen et al., 2009; Right: Late Mesolithic - Distribution area of Wommersom Quartzite (hatched area) and movement of flint raw materials from the Tournaisis and Mons basin areas (frames) to the lower Scheldt (modified after Fiers et al. 2019). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

remains very low, especially with respect to the Early Mesolithic and even the first half of the Middle Mesolithic. This overall low density is also reflected in the extremely low frequency of sites and loci during the Late Mesolithic in both the upper and lower Scheldt valley. Whether this points to a major population decline, remains difficult to assess. Clearly the two troughs do not match with the known climatic deteriorations during the Early and Middle Holocene. The first trough which significantly deviates from the null model, spanning the period of ca. 8370 and 8115 cal BP, starts at least one century earlier than the well-known 8.2 ka event, dated in the GICC05 event stratigraphy between 8250 and 8090 cal BP (Rasmussen et al., 2014). Similarly the second, more extensive trough occurring between ca. 7760 and 7260 cal BP initiates almost 2.5 centuries before the start of a minor cooling episode known from other paleoclimatic records (Bond et al., 2001; Haas et al., 1998; Hou et al., 2019), called the IRD-event 4bis (Magny, 1999) or 5bis (Gronenborn, 2010), between ca. 7500 and 7000 cal BP. It thus seems that the low density of dates, sites and loci is unrelated to these climatic events, although it is not excluded that the latter played a secondary role. In various parts of northern and central Europe the 8.2 ka event seriously impacted the forest vegetation. Generally, an abrupt decrease of thermophilous taxa in favor of cold tolerant taxa is observed. In north (west)ern Europe (Ghilardi and O'Connell, 2013; Hede et al., 2010; Litt et al., 2009; Seppa et al., 2007) hazel, alder, elm, oak, and lime temporarily declined while pine and/or birch increased. Comparable taxa shifts in response to the 8.2 ka event have been noted in central (Tinner and Lotter, 2001) and eastern (Feurdean et al., 2008) Europe, so it may be assumed that the Scheldt basin was also temporarily affected in this way, although concrete pollen evidence is still lacking. The environmental impact of the IRD-event 4bis/5bis on the other hand is much less clear, but it can be assumed to have been much more limited compared to the 8.2 ka event.

Clearly other factors were in play, but currently it remains difficult to define these precisely. Possibly the marked reduction in ^{14}C dates, sites and loci starting from the Middle to Late Mesolithic reflects a gradual adaptation to the long-term gradual vegetation change from pine and hazel-dominated (open) forests in the Boreal to dense and dark mixed deciduous forests in the Atlantic, as documented by multiple pollen records from the Scheldt basin (Crombé et al., 2019b; Meylemans et al., 2013; Storme et al., 2017; Verbruggen et al., 1996). The latter might have led to a reorganization of the natural resources from scattered to more clustered, a process which allowed hunter-gatherers to reduce their mobility (Crombé et al., 2011). Similar decreases in both site and radiocarbon densities following shifting settlement patterns such as nucleation or increased sedentism have also been noted in other regions such as in Italy (Palmisano et al., 2017) and Japan (Crema and Kobayashi, 2020). Unfortunately, these interpretations need further confirmation, as only few Late Mesolithic sites have been excavated so far and faunal remains are completely lacking. The only hint so far is the marked increase of microliths on several Late Mesolithic surface-sites compared to Early and Middle Mesolithic ones (Crombé et al., 2011), which might reflect longer stays and thus reduced mobility, albeit other factors may also have contributed (e.g. changes in hunting gear). Furthermore, lithic raw material analysis seems to confirm the increased contacts between the upper and lower part of the Scheldt basin observed for the Middle Mesolithic (Fig. 6). From now on, high quality upper Turonian flints from the Mons basin and the Tournaisis area are, together with Ghlin flint, more systematically imported to the lower Scheldt sites (Messiaen, 2020). This also holds for the exotic fine-grained

Wommersom quartzite. The longer logistical forays typically undertaken in subsistence economies with reduced residential mobility could have allowed for a more effective exploitation of these more distant outcrop areas or could have benefitted contact/exchange with them. In turn, this increased circulation and use of higher quality raw materials could be related to the shift in knapping technology from irregular bladelet (Coincy) to regular blade (Montbani) technology, the latter demanding better-quality flint. Different trigger(s) might have been responsible for this radical technological shift, such as climate and/or environmental changes, social changes and/or population changes (migrations). Yet, current research within the Scheldt basin does not allow to specify these.

6. Conclusions

The multiproxy evidence presented in this study, albeit difficult to interpret unambiguously, suggests a population growth in combination with high residential mobility during the Early Mesolithic, followed by a population shift and increased intra-basin mobility in the Middle Mesolithic. The situation during the Late Mesolithic is less clear, mainly due to incomplete records, yet the scant evidence seems to point to a reduced mobility. Furthermore the models strongly suggest a link between shifting demographic and mobility trends and rapid sea level rise in combination with long-term climatic and vegetation changes. On the other hand no causal relationship could be demonstrated with the known short but abrupt climate events, such as the 9.3 and 8.2 ka events. As such this study does not support the conclusions of similar research along the North Sea coast, in particular Scotland (Wicks and Mithen, 2014; Waddington and Wicks, 2017), advocating a demographic collapse in response to the 8.2 ka event and to a lesser extend the 9.3 ka event. Our study hints at a greater resilience and ability of hunter-gatherers along the Scheldt basin to cope with the possible effects of these cooling events. In this sense our study is more in line with the observations of Griffiths and Robinson (2018). To further this understanding of the environmental and climatic impact on humans in the western Scheldt basin, more palaeoenvironmental records must be investigated and the radiocarbon and settlement databases must be strengthened, particularly in the upper Scheldt basin, which has been less intensively studied archaeologically.

Our analysis also demonstrates that SPDs for hunter-gatherer societies need not to be interpreted strictly in demographic terms, as is often the case in studies using "dates as data". Peaks and troughs can also be created as a result of mobility and land-use variability, parameters which often are neglected or underestimated. However, this demands a multi-proxy approach combining several archaeological and environmental records, allowing to weight the strengths and weaknesses of the various methods. Ultimately, this should lead to a better understanding of demographic and behavioral dynamics for the Mesolithic period.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors are grateful to two anonymous reviewers for their comments on an earlier version of this manuscript.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jaa.2021.101348.

References

Allan, M., Fagel, N., Van Der Lubbe, H.J.L., Vonhof, H.B., Cheng, H., Lawrence Edwards, R., Verheyden, S., 2018. High-resolution reconstruction of 8.2-ka BP event documented in Père Noël cave, southern Belgium. Journal of Quaternary Science 33, 840–852.

Alley, R.B., Agustsdottir, A.M., 2005. The 8k event: cause and consequences of a major Holocene abrupt climate change. Quaternary Sci Rev 24, 1123–1149.

Alley, R.B., Mayewski, P.A., Sowers, T., Stuiver, M., Taylor, K.C., Clark, P.U., 1997. Holocene climatic instability: A prominent, widespread event 8200 yr ago. Geology 25, 483–486.

Bailey, G., 2007. Time perspectives, palimpsests and the archaeology of time. J Anthropol Archaeol 26, 198–223.

Bakke, J., Dahl, S.O., Nesje, A., 2005. Lateglacial and early Holocene palaeoclimatic reconstruction based on glacier fluctuations and equilibrium-line altitudes at northern Folgefonna, Hardangern western Norway. Journal of Quaternary Science 20, 179–198.

Ballenger, J.A.M., Mabry, J.B., 2011. Temporal frequency distributions of alluvium in the American Southwest: taphonomic, paleohydraulic, and demographic implications. J Archaeol Sci 38, 1314–1325.

Bamforth, D.B., Grund, B., 2012. Radiocarbon calibration curves, summed probability distributions, and early Paleoindian population trends in North America. J Archaeol Sci 39, 1768–1774.

Bayliss, A., Bronk Ramsey, C., van der Plicht, J., Whittle, A., 2007. Bradshaw and Bayes: Towards a timetable for the neolithic. Camb Archaeol J 17, 1–28.

Berger, J.F., Guilaine, J., 2009. The 8200 cal BP abrupt environmental change and the Neolithic transition: A Mediterranean perspective. Quatern Int 200, 31–49.

Berger, J.F., Shennan, S., Woodbridge, J., Palmisano, A., Mazier, A.F., Nuninger, L., Guillon, S., Doyen, E., Begeot, C., Andrieu-Ponel, V., Azuara, J., Bevan, A., Fyfe, R., Roberts, C.N., 2019. Holocene land cover and population dynamics in Southern France. Holocene 29, 776–798.

Bevan, A., Colledge, S., Fuller, D., Fyfe, R., Shennan, S., Stevens, C., 2017. Holocene fluctuations in human population demonstrate repeated links to food production and climate. P Natl Acad Sci USA 114, E10524–E10531.

Binford, L.R., 1980. Willow smoke and dogs' tails: Hunter-gatherer settlement systems and archaeological site formation. Antiquity 45, 4–20.

Bjorck, S., Muscheler, R., Kromer, B., Andresen, C.S., Heinemeier, J., Johnsen, J., Johnsen, S.J., Conley, D., Koc, N., Spurk, M., Veski, S., 2001. High-resolution analyses of an early Holocene climate event may imply decreased solar forcing as an important climate trigger. Geology 29, 1107–1110.

Bond, G., Kromer, B., Beer, J., Muscheler, R., Evans, M.N., Showers, W., Hoffmann, S., Lotti-Bond, R., Hajdas, I., Bonani, G., 2001. Persistent solar influence on north Atlantic climate during the Holocene. Science 294, 2130–2136.

Bond, G., Showers, W., Cheseby, M., Lotti, R., Almasi, P., deMenocal, P., Priore, P., Cullen, H., Hajdas, I., Bonani, G., 1997. A pervasive millennial-scale cycle in North Atlantic Holocene and glacial climates. Science 278, 1257–1266.

Bond, G.C., Showers, W., Elliot, M., Evans, M., Lotti, R., Hajdas, I., Bonani, G., Johnson, S., 1999. The North Atlantic's 1-2 Kyr Climate Rhythm: Relation to Heinrich Events, Dansgaard/Oeschger Cycles and the Little Ice Age. Mechanisms of Global Climate Change at Millennial Time. Scales 35–58.

Bronk Ramsey, C., 2009a. Bayesian Analysis of Radiocarbon Dates. Radiocarbon 51, 337–360.

Bronk Ramsey, C., 2009b. Dealing with Outliers and Offsets in Radiocarbon Dating. Radiocarbon 51, 1023–1045.

Bronk Ramsey, C., 2017. Methods for Summarizing Radiocarbon Datasets. Radiocarbon 59, 1809–1833.

Budja, M., 2007. The 8200 calBP 'Climate Event' and the process of neolithisation in south-eastern Europe. Documenta Praehistorica XXXIV 191–202.

Contreras, D.A., Meadows, J., 2014. Summed radiocarbon calibrations as a population proxy: a critical evaluation using a realistic simulation approach. J Archaeol Sci 52, 591–608.

Cordemans, K., Bats, M., Crombé, P., Meganck, M., 2001. Extensive survey in the Antwerp harbour area; Assessing a buried mesolithic landscape at Verrebroek (East-Flanders, Belgium). Notae Praehistoricae 21, 79–83.

Crema, E., Bevan, A., 2020. Inference from large sets of radiocarbon dates: Software and Methods. Radiocarbon 63 (1), 23–39.

Crema, E.R., Habu, J., Kobayashi, K., Madella, M., 2016. Summed Probability Distribution of C-14 Dates Suggests Regional Divergences in the Population Dynamics of the Jomon Period in Eastern Japan. Plos One 11.

Crema, E.R., Kobayashi, K., 2020. A multi-proxy inference of Jomon population dynamics using bayesian phase models, residential data, and summed probability distribution of C-14 dates. J Archaeol Sci 117.

Crombé, P., 1998. The Mesolithic in northwestern Belgium : recent excavations and surveys. Hedges, Oxford.

Crombé, P., 2005. The last hunter-gatherer-fishermen in Sandy Flanders (NW Belgium): the Verrebroek and Doel excavation projects. Academia press, Gent.

Crombé, P., 2016. Forest fire dynamics during the early and middle Holocene along the southern North Sea basin as shown by charcoal evidence from burnt ant nests. Veg Hist Archaeobot 25, 311–321.

Crombé, P., 2018. Abrupt cooling events during the Early Holocene and their potential impact on the environment and human behaviour along the southern North Sea basin. Journal of Quaternary Science 33, 353–367.

Crombé, P., 2019a. In: Préhistoire de l'Europe du nord-ouest : mobilités, climats et identités culturelles. Volume 2: Paléolithique supérieur ancien, Paléolithique final – Mésolithique, Congrès préhistorique de France, pp. 407–416.

Crombé, P., 2019b. Mesolithic projectile variability along the southern North Sea basin (NW Europe): Hunter-gatherer responses to repeated climate change at the beginning of the Holocene. Plos One 14.
Crombé, P., Aluwe, K., Boudin, M., Snoeck, C., Messiaen, L., Teetaert, D., 2020. New evidence on the earliest domesticated animals and possible small-scale husbandry in Atlantic NW Europe. Sci Rep-Uk 10.
Crombé, P., Beugnier, V., 2013. La fonction des industries en silex et les modalités d'occupation des territoires au Mésolithique. Le cas des zones sableuses du nord-ouest de la Belgique et des Pays-Bas (8700–5400 cal. BC). L'anthropologie 117, 172–194.
Crombé, P., Boudin, M., Van Strydonck, M., 2021. Can calcined bones be used to date Final Palaeolithic and Mesolithic open-air sites? A case-study from the Scheldt basin (NW Belgium). J Archaeol Sci 131, 105411.
Crombé, P., Deeben, J., Van Strydonck, M., 2014. Hunting in a changing environment: the transition from the Younger Dryas to the (Pre)boreal in Belgium and the southern Netherlands. In: Michel, S., Naudinot, N. (Eds.), Actes du XXVIIe Congrès Préhistorique de France, Transitions, Ruptures et Continuité durant la Préhistoire. Paris (Congrès préhistorique de France), Bordeaux-Lez Eyzies, pp. 583–604.
Crombé, P., Langohr, R., Louwagie, G., 2015. Mesolithic hearth-pits: fact or fantasy? A reassessment based on the evidence from the sites of Doel and Verrebroek (Belgium). J Archaeol Sci 61, 158–171.
Crombé, P., Messiaen, L., Teetaert, D., Sergant, J., Meylemans, E., Perdaen, Y., Verhegge, J., 2019a. Bioturbation and the formation of latent stratigraphies on prehistoric sites. Two case studies from the Belgian-Dutch coversand area. In: Déak, J., Ampe, C., Mikkelsen, J.H. (Eds.), Soils as records of past and present. Raakvlak, Brugge, pp. 99–112.
Crombé, P., Perdaen, Y., Sergant, J., 2006. Extensive artefact concentrations: single occupations or palimpsests?: the evidence from the Early Mesolithic site of Verrebroek "Dok" (Belgium). In: Kind, C.-.-J. (Ed.), Materialhefte zur Archäologie in Baden-Württemberg. Konrad Theiss, Stuttgart, pp. 237–243.
Crombé, P., Robinson, E., 2014. C-14 dates as demographic proxies in Neolithisation models of northwestern Europe: a critical assessment using Belgium and northeast France as a case-study. J Archaeol Sci 52, 558–566.
Crombé, P., Robinson, E., Van Strydonck, M., Boudin, M., 2013. Radiocarbon Dating of Mesolithic Open-Air Sites in the Coversand Area of the North-West European Plain: Problems and Prospects. Archaeometry 55, 545–562.
Crombé, P., Sergant, J., Lombaert, L., Van Strydonck, M., Boudin, M., 2009. The Mesolithic and Neolithic site of Verrebroek - Aven Ackers (East Flanders, Belgium): the radiocarbon evidence. Notae Praehistoricae 29, 15–21.
Crombé, P., Sergant, J., Robinson, E., De Reu, J., 2011. Hunter-gatherer responses to environmental change during the Pleistocene-Holocene transition in the southern North Sea basin: Final Palaeolithic-Final Mesolithic land use in northwest Belgium. J Anthropol Archaeol 30, 454–471.
Crombé, P., Storme, A., Cruz, F., Allemeersch, L., Vandendriessche, H., Deforce, K., Mikkelsen, J., Aluwe, K., Boudin, M., Sergant, J., 2019b. Early Holocene slope erosion in the Scheldt basin (Belgium): Naturally and/or human induced? Geomorphology 337, 79–93.
Crombé, P., van Strydonck, M., Boudin, M., 2009b. Towards a Refinement of the Absolute (Typo)Chronology for the Early Mesolithic in the Coversand Area of Northern Belgium and The Southern Netherlands, in: P. Crombé, M.V.S., J. Sergant, M. Boudin, & M. Bats (Eds.), (Ed.), Chronology and Evolution within the Mesolithic of North-West Europe: Proceedings of an International Meeting. Cambridge Scholars Publishing, Newcastle, pp. 95-112.
Culleton, B.J., 2008. Crude demographic proxy reveals nothing about Paleoindian population. P Natl Acad Sci USA 105, E111-E111.
Dahl, S.O., Nesje, A., Lie, O., Fjordheim, K., Matthews, J.A., 2002. Timing, equilibrium-line altitudes and climatic implications of two early-Holocene glacier readvances during the Erdalen Event at Jostedalsbreen, western Norway. Holocene 12, 17–25.
Downey, S.S., Bocaege, E., Kerig, T., Edinborough, K., Shennan, S., 2014. The Neolithic Demographic Transition in Europe: Correlation with Juvenility Index Supports Interpretation of the Summed Calibrated Radiocarbon Date Probability Distribution (SCDPD) as a Valid Demographic Proxy. Plos One 9.
Ducrocq, T., 2001. Le Mésolithique du bassin de la Somme. Insertion dans un cadre morpho-stratigraphique, environnemental et chronoculturel. Publications du CERP 7.
Ducrocq, T., 2009. Chronology and Evolution within the Mesolithic of North-West Europe. In: Crombé, P., Van Strydonck, M., Sergant, J., Boudin, M., Bats, M. (Eds.), Élements de chronologie absolue du Mésolithique dans le Nord de la France. Cambridge scholar publishing, Cambridge, pp. 95–112.
Ducrocq, T., 2019. Mésolithique initial et Mésolithique ancien en France septentrionale à Warluis (Oise), in: Montoya, C., Fagnart, J.P., Locht, J.L. (Eds.), Préhistoire de l'Europe du nord-ouest : mobilités, climats et identités culturelles. Volume 2 : Paléolithique supérieur ancien, Paléolithique final – Mésolithique, Congrès préhistorique de France. Compte Rendu de la 28ème session, Amiens 2016. Société Préhistorique Française, Paris, pp. 333-348.
Edinborough, K., Porcic, M., Martindale, A., Brown, T.J., Supernant, K., Ames, K.M., 2017. Radiocarbon test for demographic events in written and oral history. P Natl Acad Sci USA 114, 12436–12441.
Feeser, I., Dörfler, W., Kneisel, J., Hinz, M., Dreibrodt, S., 2019. Human impact and population dynamics in the Neolithic and Bronze Age: Multi-proxy evidence from north-western Central Europe. Holocene 29, 1596–1606.
Feurdean, A., Klotz, S., Mosbrugger, V., Wohlfarth, B., 2008. Pollen-based quantitative reconstructions of Holocene climate variability in NW Romania. Palaeogeogr Palaeocl 260, 494–504.
Fiers, G., Halbrucker, E., De Kock, T., Laforce, B., Vandendriessche, H., Messiaen, L., Vincze, L., Crombé, P., Cnudde, V., 2019. Preliminary characterization of flint raw material used on prehistoric sites in NW Belgium. Geoarchaeology 34, 400–412.
Freeman, J., Byers, D.A., Robinson, E., Kelly, R.L., 2018. Culture Process and the Interpretation of Radiocarbon Data. Radiocarbon 60, 453–467.
Ghilardi, B., O'Connell, M., 2013. Early Holocene vegetation and climate dynamics with particular reference to the 8.2 ka event: pollen and macrofossil evidence from a small lake in western Ireland. Veg Hist Archaeobot 22, 99–114.
Gilot, E., 1997. Index général des dates Lv, Laboratoire du Carbone 14 de Louvain/ Louvain-la-Neuve. s.n, Liège.
Gkiasta, M., Russell, T., Shennan, S., Steele, J., 2003. Neolithic transition in Europe: The radiocarbon record revisited. Antiquity 77, 45–62.
Griffiths, S., Robinson, E., 2018. The 8.2 ka BP Holocene climate change event and human population resilience in northwest Atlantic Europe. Quatern Int 465, 251–257.
Grimm, S.B., Groß, D., Gerken, K., Weber, M.-J., 2020. On the onset of the Early Mesolithic on the North German Plain. In: Zander, A., Gehlen, B. (Eds.), From the Early Preboreal to the Subboreal period - Current Mesolithic research in Europe. Studies in honour of Bernhard Gramsch. Mesolithic edition, Welt und Erde, Loogh, pp. 11–33.
Gronenborn, D., 2010. Climate, Crises, and the »neolithisation« of Central europe between ird-events 6 and 4. The Spread of the Neolithic to Central Europe. Römisch-Germanisches Zentralmuseum, Forschungsinstitut für Vor- und Frühgeschichte, Mainz, pp. 61–80.
Guéret, C., 2013. Identité et variabilité de l'outillage lithique du Premier Mésolithique en Belgique et dans le Nord de la France : Les apports de l'approche fonctionnelle. In: Valentin, B., Souffi, B., Ducrocq, T., Fagnart, J.-P., Séara, F., Verjux, C. (Eds.), Palethnographie du Mésolithique. Recherches sur les habitats de plein air entre Loire et Neckar, Actes de la table-ronde internationale de Paris, 26 et 27 novembre 2010. Société Préhistorique Française, Paris, pp. 147–167.
Guéret, C., 2017. Retoucher, pour quoi faire ! Réflexions fonctionnelle et méthodologique sur la place occupée par l'outillage brut dans l'économie du premier Mésolithique en Europe du Nord-Ouest. Bulletin de la Société préhistorique française 114, 339–372.
Haas, J.N., Richoz, I., Tinner, W., Wick, L., 1998. Synchronous Holocene climatic oscillations recorded on the Swiss Plateau and at timberline in the Alps. Holocene 8, 301–309.
Hede, M.U., Rasmussen, P., Noe-Nygaard, N., Clarke, A.L., Vinebrooke, R.D., Olsen, J., 2010. Multiproxy evidence for terrestrial and aquatic ecosystem responses during the 8.2 ka cold event as recorded at Hojby So. Denmark. Quaternary Res 73, 485–496.
Hinz, M., 2020. Sensitivity of Radiocarbon Sum Calibration. Journal of Computer Applications in Archaeology 3, 238–252.
Hou, M., Wu, W., Cohen, D.J., Zhou, Y., Zeng, Z., Huang, H., Zheng, H., Ge, Q., 2019. Evidence for a widespread climatic anomaly at around 7.5–7.0 cal ka BP. Climate of the Past Discussions.
Houtsma, P., Kramer, E., Newell, R., Smit, J.L., 1996. The Late Palaeolithic Habitation of Haule V: From Excavation Report to the Reconstruction of Federmesser Settlement Systems and Land-Use. Koninklijke Van Gorcum, Assen.
Huls, C.M., Erlenkeuser, H., Nadeau, M.J., Grootes, P.M., Andersen, N., 2010. Experimental Study on the Origin of Cremated Bone Apatite Carbon. Radiocarbon 52, 587–599.
Jochim, M., 2006. Regional perspectives on Early Mesolithic land use in southwestern Germany. J Anthropol Archaeol 25, 204–212.
Jochim, M.A., 2008. The Mesolithic of the Upper Danube and Upper Rhine. In: Bailey, G., Spikins, P. (Eds.), Mesolithic Europe. Cambridge University Press, New York, pp. 203–220.
Kelly, R.L., 1983. Hunter-Gatherer Mobility Strategies. J Anthropol Res 39, 277–306.
Kelly, R.L., 1995. The Foraging Spectrum. Diversity in Hunter-Gatherer Lifeways. Smithsonian Institution Press, Washington and London.
Lawrence, D., Palmisano, A., De Gruchy, M.W., 2021. Collapse and continuity: A multi-proxy reconstruction of settlement organization and population trajectories in the Northern Fertile Crescent during the 4.2kya Rapid Climate Change event. Plos One 16.
Lee, S., Bronk Ramsey, C., 2012. Development and Application of the Trapezoidal Model for Archaeological Chronologies. Radiocarbon 54, 107–122.
Litt, T., Scholzel, C., Kuhl, N., Brauer, A., 2009. Vegetation and climate history in the Westeifel Volcanic Field (Germany) during the past 11 000 years based on annually laminated lacustrine maar sediments. Boreas 38, 679–690.
Lombaert, L., Noens, G., Ameels, V., 2007. Een mesolithische vindplaats te Oudenaarde-Donk: een ruimtelijke, typologische en technische analyse. Notae Praehistoricae 27, 89–99.
Magny, M., 1999. Lake-level fluctuations in the Jura and french subalpine ranges associated with ice-rafting events in the northatlantic and variations in the polar atmospheric circulation. Quaternaire 10, 61–64.
McLaughlin, T.R., 2019. On Applications of Space-Time Modelling with Open-Source C-14 Age Calibration. J Archaeol Method Th 26, 479–501.
Messiaen, L., 2020. Lithics in contact: the neolithization process in the Lower-Scheldt basin (mid-6th to mid-4th millennium BC) from a lithic perspective. Universiteit Gent, Faculteit Letteren en Wijsbegeerte.
Meylemans, E., Bogemans, E., Storme, A., Perdaen, Y., Verdurmen, I., Deforce, K., 2013. Lateglacial and Holocene fluvial dynamics in the Lower Scheldt basin (N-Belgium) and their impact on the presence, detection and preservation potential of the archaeological record. Quatern Int 308, 148–161.
Meylemans, E., Perdaen, Y., Sergant, J., Bastiaens, J., Crombé, P., Debruyne, S., Deforce, K., Du Rang, E., Ervynck, A., Lentacker, A., Storme, A., Van Neer, W., 2016.

Archeologische opgraving van een midden- mesolithische tot midden neolithische vindplaats te 'Bazel-Sluis 5' (gem. Kruibeke, prov. Oost-Vlaanderen), Onderzoeksrapporten Agentschap Onroerend Erfgoed, Brussel.
Michczynska, D.J., Pazdur, A., 2004. Shape analysis of cumulative probability density function of radiocarbon dates set in the study of climate change in the late glacial and holocene. Radiocarbon 46, 733–744.
Migowski, C., Stein, M., Prasad, S., Negendank, J.F.W., Agnon, A., 2006. Holocene climate variability and cultural evolution in the Near East from the Dead Sea sedimentary record. Quaternary Res 66, 421–431.
Noens, G., 2013. Intrasite analysis of Early Mesolithic sites in Sandy Flanders: The case of Doel-'Deurganckdok J/L', C3. In: Valentin, B., Souffi, B., Ducrocq, T., Fagnart, J.P., Séara, F., Verjux, C. (Eds.), Mesolithic Palethnography, Research on open-air sites between Loire and Neckar, Proceedings from the international round-table meeting, Paris, November 26–27, 2010. Société préhistorique française, Paris, pp. 217–234.
Ortman, S.G., Cabaniss, A.H.F., Sturm, J.O., Bettencourt, L.M.A., 2014. The Pre-History of Urban Scaling. Plos One 9.
Palmisano, A., Bevan, A., Shennan, S., 2017. Comparing archaeological proxies for long-term population patterns: An example from central Italy. J Archaeol Sci 87, 59–72.
Palmisano, A., Lawrence, D., de Gruchy, M.W., Bevan, A., Shennan, S., 2021. Holocene regional population dynamics and climatic trends in the Near East: A first comparison using archaeo-demographic proxies. Quaternary Sci Rev 252.
Parent, J.-P., Van Der Plaetsen, P., Vanmoerkerke, J., 1986-1987. Prehistorische jagers en veetelers aan de donk te Oudenaarde. VOBOV-info 24-25.
Perdaen, Y., Crombé, P., Sergant, J., 2009. The use of quartzite as a chrono-cultural marker in the Mesolithic cultures of the Low Countries, in: Sternke, F., Costa, L.J., Eigeland, L. (Eds.), Non-Flint Raw Material Use in Prehistory: Old Prejudices and New Directions. Proceedings of the XVth Congress of the" Union International de Sciences Pré-et Protohistoriques", Volume 11. Archaeopress, Oxford, pp. 217-224.
Perdaen, Y., De Loecker, D., Opbroek, M., Woltinge, I., 2017. Verder grootschalig archeologisch onderzoek ter hoogte van het Logistiek Park Waasland Fase West (Verrebroek-Beveren, Oost-Vlaanderen, BE). Notae Praehistoricae 37, 45–52.
Peros, M.C., Munoz, S.E., Gajewski, K., Viau, A.E., 2010. Prehistoric demography of North America inferred from radiocarbon data. J Archaeol Sci 37, 656–664.
Pettitt, P.B., Davies, W., Gamble, C.S., Richards, M.B., 2003. Palaeolithic radiocarbon chronology: quantifying our confidence beyond two half-lives. J Archaeol Sci 30, 1685–1693.
Plonka, T., Bobak, D., Szuta, M., 2020. The Dawn of the Mesolithic on the Plains of Poland. J World Prehist 33, 325–383.
Rasmussen, S.O., Andersen, K.K., Svensson, A.M., Steffensen, J.P., Vinther, B.M., Clausen, H.B., Siggaard-Andersen, M.L., Johnsen, S.J., Larsen, L.B., Dahl-Jensen, D., Bigler, M., Rothlisberger, R., Fischer, H., Goto-Azuma, K., Hansson, M.E., Ruth, U., 2006. A new Greenland ice core chronology for the last glacial termination. J Geophys Res-Atmos 111.
Rasmussen, S.O., Bigler, M., Blockley, S.P., Blunier, T., Buchardt, S.L., Clausen, H.B., Cvijanovic, I., Dahl-Jensen, D., Johnsen, S.J., Fischer, H., Gkinis, V., Guillevic, M., Hoek, W.Z., Lowe, J.J., Pedro, J.B., Popp, T., Seierstad, I.K., Steffensen, J.P., Svensson, A.M., Vallelonga, P., Vinther, B.M., Walker, M.J.C., Wheatley, J.J., Winstrup, M., 2014. A stratigraphic framework for abrupt climatic changes during the Last Glacial period based on three synchronized Greenland ice-core records: refining and extending the INTIMATE event stratigraphy. Quaternary Sci Rev 106, 14–28.
Reimer, P.J., Austin, W.E.N., Bard, E., Bayliss, A., Blackwell, P.G., Ramsey, C.B., Butzin, M., Cheng, H., Edwards, R.L., Friedrich, M., Grootes, P.M., Guilderson, T.P., Hajdas, I., Heaton, T.J., Hogg, A.G., Hughen, K.A., Kromer, B., Manning, S.W., Muscheler, R., Palmer, J.G., Pearson, C., van der Plicht, J., Reimer, R.W., Richards, D.A., Scott, E.M., Southon, J.R., Turney, C.S.M., Wacker, L., Adolphi, F., Buntgen, U., Capano, M., Fahrni, S.M., Fogtmann-Schulz, A., Friedrich, R., Kohler, P., Kudsk, S., Miyake, F., Olsen, J., Reinig, F., Sakamoto, M., Sookdeo, A., Talamo, S., 2020. The Intcal20 Northern Hemisphere Radiocarbon Age Calibration Curve (0–55 Cal Kbp). Radiocarbon 62, 725–757.
Rick, J.W., 1987. Dates as Data - an Examination of the Peruvian Preceramic Radiocarbon Record. Am Antiquity 52, 55–73.
Riede, F., 2009. Climate and Demography in Early Prehistory: Using Calibrated C-14 Dates as Population Proxies. Hum Biol 81, 309–337.
Robinson, E., Bocinsky, R.K., Bird, D., Freeman, J., Kelly, R., 2020. Dendrochronological dates confirm a Late Prehistoric population decline in the American Southwest derived from radiocarbon dates. SocArXiv.
Robinson, E., Van Strydonck, M., Gelorini, V., Crombé, P., 2013. Radiocarbon chronology and the correlation of hunter-gatherer sociocultural change with abrupt palaeoclimate change: the Middle Mesolithic in the Rhine-Meuse-Scheldt area of northwest Europe. J Archaeol Sci 40, 755–763.
Séara, F., 2013. Les occupations du premier Mésolithique des Basses Veuves (Pont-sur-Yonne). CNRS éditions/INRAP, Paris.
Séara, F., Rotillon, S., Cupillard, C., 2002. Campements mésolithiques en Bresse jurassienne. Choisey et Ruffey-sur-Seille. Editions de la Maison des Sciences de l'Homme, Paris.
Seppa, H., Birks, H.J.B., Giesecke, T., Hammarlund, D., Alenius, T., Antonsson, K., Bjune, A.E., Heikkila, M., MacDonald, G.M., Ojala, A.E.K., Telford, R.J., Veski, S., 2007. Spatial structure of the 8200 cal yr BP event in northern Europe. Clim Past 3, 225–236.
Sergant, J., Crombé, P., Perdaen, Y., 2006. The 'invisible' hearths: a contribution to the discernment of Mesolithic non-structured surface hearths. J Archaeol Sci 33, 999–1007.
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. Nat Commun 4.
Snoeck, C., Brock, F., Schulting, R.J., 2014. Carbon Exchanges between Bone Apatite and Fuels during Cremation: Impact on Radiocarbon Dates. Radiocarbon 56, 591–602.
Staubwasser, M., Weiss, H., 2006. Holocene climate and cultural evolution in late prehistoric-early historic West Asia - Introduction. Quaternary Res 66, 372–387.
Steele, J., 2010. Radiocarbon dates as data: quantitative strategies for estimating colonization front speeds and event densities. J Archaeol Sci 37, 2017–2030.
Storme, A., Louwye, S., Crombé, P., Deforce, K., 2017. Postglacial evolution of vegetation and environment in the Scheldt Basin (northern Belgium). Veg Hist Archaeobot 26, 293–311.
Sturt, F., Garrow, D., Bradley, S., 2013. New models of North West European Holocene palaeogeography and inundation. J Archaeol Sci 40, 3963–3976.
Surovell, T.A., Brantingham, P.J., 2007. A note on the use of temporal frequency distributions in studies of prehistoric demography. J Archaeol Sci 34, 1868–1877.
Surovell, T.A., Finley, J.B., Smith, G.M., Brantingham, P.J., Kelly, R., 2009. Correcting temporal frequency distributions for taphonomic bias. J Archaeol Sci 36, 1715–1724.
Team, R., 2020. RStudio: Integrated Development for R. RStudio, PBC, Boston, MA.
Thomas, E.R., Wolff, E.W., Mulvaney, R., Steffensen, J.P., Johnsen, S.J., Arrowsmith, C., White, J.W.C., Vaughn, B., Popp, T., 2007. The 8.2 ka event from Greenland ice cores. Quaternary Sci Rev 26, 70–81.
Timpson, A., Colledge, S., Crema, E., Edinborough, K., Kerig, T., Manning, K., Thomas, M.G., Shennan, S., 2014. Reconstructing regional population fluctuations in the European Neolithic using radiocarbon dates: a new case-study using an improved method. J Archaeol Sci 52, 549–557.
Timpson, A., Manning, K., Shennan, S., 2015. Inferential mistakes in population proxies: A response to Torfing's "Neolithic population and summed probability distribution of C-14-dates". J Archaeol Sci 63, 199–202.
Tinner, W., Lotter, A.F., 2001. Central European vegetation response to abrupt climate change at 8.2 ka. Geology 29, 551–554.
Torfing, T., 2015a. Layers of assumptions: A reply to Timpson, Manning, and Shennan. J Archaeol Sci 63, 203–205.
Torfing, T., 2015b. Neolithic population and summed probability distribution of C-14-dates. J Archaeol Sci 63, 193–198.
Tsakiridou, M., Hardiman, M., Grant, M.J., Lincoln, P.C., Cunningham, L., 2020. Evidence of wildfire in the British Isles during the Last Glacial-Interglacial Transition: Revealing spatiotemporal patterns and controls. P Geologist Assoc 131, 562–577.
Van Assche, M., 2005. Aperçu sur le Mésolithique des régions d'Ath et de Mons (Hainaut). Amphora 83, 42–82.
Van de Konijnenburg, R., 1980. Het mesolithicum in Henegouwen en Brabant ten zuiden van de lijn Roosdaal-Brussel-Orp-Jauche. K.U.Leuven, Leuven.
Van der Haegen, G., Crombé, P., Semey, J., 1999. Steentijdvondsten in het Meetjesland (Oost-Vlaanderen, België). Inventaris en geografische analyse, Gent.
Van Herzeele, L., van Strydonck, M., Boudin, M., Crombé, P., 2011. Vroeg-mesolithicum in zone M van het Deurganckdok te Doel (Oost-Vlaanderen, B). Notae Praehistoricae 31, 101–109.
Van Strydonck, M., Boudin, M., De Mulder, G., 2010. The Carbon Origin of Structural Carbonate in Bone Apatite of Cremated Bones. Radiocarbon 52, 578–586.
Van Vlaenderen, L., Sergant, J., De Bock, H., De Meireleir, M., 2006. Steentijdvondsten in de Moervaartdepressie (Oost-Vlaanderen, België). Inventaris en geografische analyse, Gent.
Vandendriessche, H., 2021. Flintknapping in a changing world – The organization of lithic technology during the Lateglacial and Early Holocene in the Belgian Scheldt valley. Unpublished doctoral dissertation. Ghent University.
Vandendriessche, H., Guéret, C., Aluwé, K., Messiaen, L., Cruz, F., Storme, A., Allemeersch, L., Van Neer, W., Sergant, J., Crombé, P., 2019. Deux millénaires d'occupations mésolithiques au bord de l'Escaut à Kerkhove (Belgique): Première approche palethnographique. Bulletin de la Société préhistorique française 116, 283–316.
Verbruggen, C., Denys, L., Kiden, P., 1996. Belgium. In: Berglund, B., Birks, H., Ralska-Jasiewiczowa, M., Wright, H. (Eds.), Palaeoecological events during the last 15,000 years : regional syntheses of palaeoecological studies of lakes and mires in Europe. John Wiley & Sons, Chichester, pp. 453–474.
Vinther, B.M., Clausen, H.B., Johnsen, S.J., Rasmussen, S.O., Andersen, K.K., Buchardt, S. L., Dahl-Jensen, D., Seierstad, I.K., Siggaard-Andersen, M.L., Steffensen, J.P., Svensson, A., Olsen, J., Heinemeier, J., 2006. A synchronized dating of three Greenland ice cores throughout the Holocene. J Geophys Res-Atmos 111.
Waddington, C., Wicks, K., 2017. Resilience or wipe out? Evaluating the convergent impacts of the 8.2 ka event and Storegga tsunami on the Mesolithic of northeast Britain. J Archaeol Sci-Rep 14, 692–714.
Weninger, B., Alram-Stern, E., Bauer, E., Clare, L., Danzeglocke, U., Joris, O., Claudia, K. E., Gary, R.F., Todorova, H., van Andel, T., 2006. Climate forcing due to the 8200 cal yr BP event observed at Early Neolithic sites in the eastern Mediterranean. Quaternary Res 66, 401–420.
Weninger, B., Clare, L., Joris, O., Jung, R., Edinborough, K., 2015. Quantum theory of radiocarbon calibration. World Archaeol 47, 543–566.
Weninger, B., Schulting, R., Bradtmoller, M., Clare, L., Collard, M., Edinborough, K., Hilpert, J., Joris, O., Niekus, M., Rohling, E.J., Wagner, B., 2008. The catastrophic final flooding of Doggerland by the Storegga Slide tsunami. Doc Praehist 35, 1–24.
Wicks, K., Mithen, S., 2014. The impact of the abrupt 8.2 ka cold event on the Mesolithic population of western Scotland: a Bayesian chronological analysis using 'activity events' as a population proxy. J Archaeol Sci 45, 240–269.
Williams, A.N., 2012. The use of summed radiocarbon probability distributions in archaeology: a review of methods. J Archaeol Sci 39, 578–589.