JOURNAL OF QUATERNARY SCIENCE (2017) ISSN 0267-8179. DOI: 10.1002/jqs.2962

JQS Journal of Quaternary Science QRA Quaternary Research Association

Abrupt cooling events during the Early Holocene and their potential impact on the environment and human behaviour along the southern North Sea basin (NW Europe)

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Received 29 September 2016; Revised 23 February 2017; Accepted 23 April 2017

ABSTRACT: In this paper the potential impact of the 9.3k cal a BP cooling event on the environment and human occupation in the Rhine–Meuse–Scheldt region of NW Europe is investigated. Although various environmental (decreased fluvial activity, increased wildfires and changing vegetation) and cultural changes (lithic technology, raw material circulation, decreasing site density) can be identified in the (late) Boreal, a serious problem of equifinality remains. Lacking a high-resolution chronology for these events, it is still difficult to separate the impact of gradual from punctuated climatic changes. However, at present it seems that (some) environmental and cultural changes were already ongoing before the 9.3k cal a BP event but were accelerated by the latter. To gain a better understanding of these processes, it is necessary to take a holistic, multidisciplinary approach towards the Early Holocene in the southern North Sea basin. Copyright © 2017 John Wiley & Sons, Ltd.

KEYWORDS: 9.3k cal a BP event; Early Holocene; Mesolithic hunter-gatherers; palaeoenvironment; southern North Sea basin.

Introduction

Recent high-resolution investigations of Greenland ice cores (Rasmussen *et al.*, 2014) and marine records (Bond *et al.*, 1997) have proven the existence of several short-lived yet abrupt cooling events during the Holocene. During the Early Holocene at least three such events occurred: the Preboreal oscillation or PBO (Björck *et al.*, 1997), the 9.3k cal a BP (Yu *et al.*, 2010) and the 8.2k cal a BP events (Alley *et al.*, 1997; Alley and Ágústsdóttir, 2005). In general terms these events are characterized by a mean temperature decline of between 1 and 2 °C and a duration of between 100 and 150 years.

From an environmental and archaeological perspective, much attention has been given to the study of the PBO (Hoek, 1997; Bos *et al.*, 2006, 2007) and 8.2k cal a BP events (Gronenborn, 2009; Manninen and Tallavaara, 2011; Wicks and Mithen, 2014). Conversely, the 9.3k cal a BP event, dated between 9300 and 9190 cal a BP, has received little attention from archaeologists; a paper by Robinson *et al.* (2013a) constitutes a rare exception. In the latter, the relationship between the emergence of a new 'culture' or techno-complex – the Rhine–Meuse–Scheldt (RMS) 'culture' – at the start of the Middle Mesolithic in the southern North Sea basin and this particular cooling event has been investigated through a critical analysis of the radiocarbon evidence. Although Robinson *et al.* could demonstrate the contemporaneity of both events, the impact of the short climatic event on the contemporaneous landscape and its human occupation remained unclear. Progress is hampered by the lack of published palaeoenvironmental and archaeological research conducted at an appropriately detailed scale (i.e. decadal-to-centennial), resulting in a problem of equifinality. At present, it is difficult to separate the impact of gradual from punctuated climatic and environmental changes on human societies during the Early Holocene. This paper will investigate the problem in detail, concluding with some proposals for future research into the study of climate–ecosystem–human response at the onset of the Holocene. The entire RMS area will be considered, although the principal focus will fall on the Scheldt basin, situated in the western part of the study area.

Study area

The present paper focuses on the area in which the RMS 'culture' occurs (Fig. 1). The study encompasses an area of ca. 150 000 km^2 and lies between the Seine in the south, the North Sea in the west, the Rhine/Meuse/IJssel basin in the north and the Rhine/Moselle in the east. Geographically, the study area (hereafter RMS area) includes parts of northern France, Belgium, the southern Netherlands, Luxemburg and western Germany. Several river basins are included in this vast area: the northern part of the Seine basin, with the Aisne and the Marne tributaries; the Scheldt basin, to which belong the Somme and Scheldt rivers, plus their tributaries (respectively the Selle and Avre, and the Lys, Kale/Durme and Dijle); the Meuse basin and its tributaries (e.g. the Samber, Ourthe, Niers, Roer); and the lower Rhine basin. Topographically, the RMS region evolves from a chalky/loamy upland in the south(east) to a lowland coversand plain in the north(west). Altitudes during the Early Holocene ranged from ca. 700 m above to 15 m below the present sea level.

The palaeoevironmental evidence

Decreasing groundwater table

During the Early Holocene, fluvial discharge in the meandering rivers of the RMS region decreased dramatically compared to that in the Lateglacial. This was probably a direct result of increased temperatures and denser vegetation, which stimulated evapotranspiration and reduced the sediment supply. From the Preboreal (ca. 11 700–10 700 cal a BP[1]) onwards, river channels started to fill with organic to peaty sediments, resulting in shallow and narrow streams with

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[1] All radiocarbon dates in this paper are calibrated according to Reimer *et al.* (2013), using OxCal 4.2 (Bronk Ramsey, 2016).

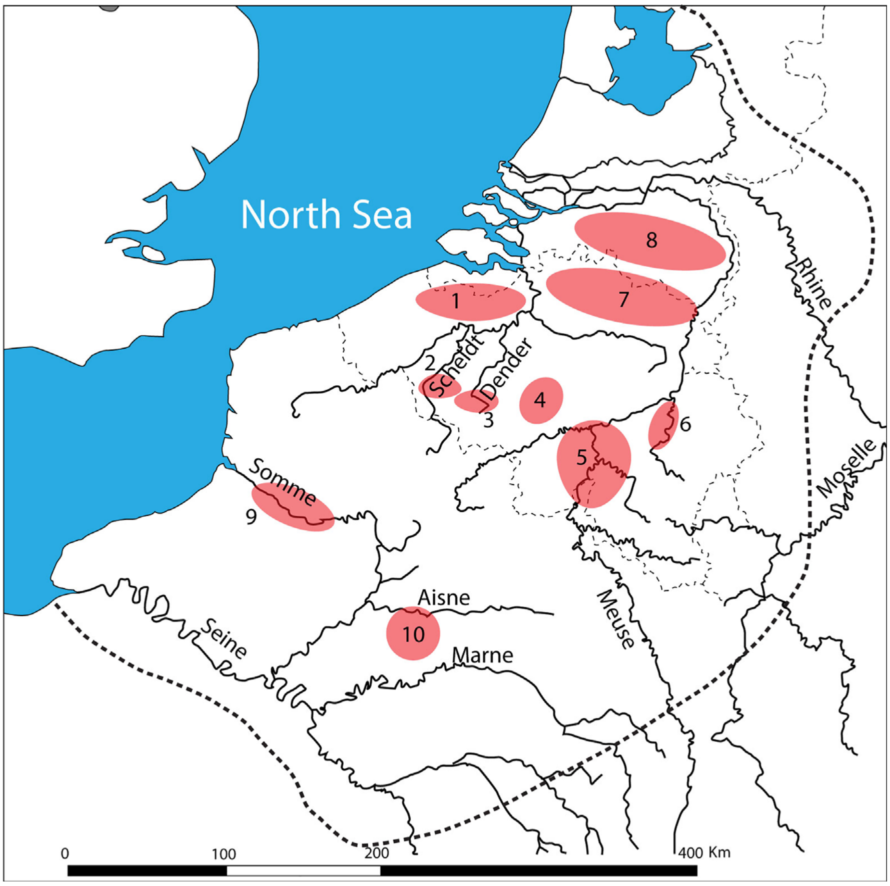

Figure 1. The RMS region with indication of the microregions mentioned in the text: 1, Lower Scheldt basin (Sandy Flanders); 2, Upper Scheldt basin; 3, Upper Dendre basin; 4, Southwest Brabant; 5, Middle Meuse basin; 6, Ourthe basin; 7, Belgian Campine; 8, Dutch Campine; 9, Somme basin; 10, Aisne basin.

slow-running or locally stagnant water. In numerous pollen sequences, a shift is noted from predominantly aquatic to more riparian vegetation, expressed by an increasing occurrence of Cyperaceae, *Phragmites*, *Sparganium*, *Typha* or *Equisetum* (Bos *et al.*, 2007; Storme *et al.*, 2017). The shift is interpreted as a local evolution towards shallower water depths.

According to the radiocarbon and palynological evidence, this process of aggradation occurred rather rapidly; near the end of the Boreal (ca. 10 700–8800/8600 cal a BP) most channels were already reduced to less than half of their original depth (Fig. 2). In some basins, e.g. the Scheldt (Fig. 3), this process had already started in the Late Allerød or start of the Younger Dryas with the deposition of gyttja at the base of the meandering channels (Kiden, 1991; Meylemans *et al.*, 2013; Crombé *et al.*, 2014; Storme *et al.*, 2017). In other basins of the RMS area, including the Somme (Antoine *et al.*, 2000, 2012) and the Meuse/Rhine (Vandenberghe *et al.*, 1994; van Huissteden and Kasse, 2001; Kasse *et al.*, 2005), the Lateglacial fluvial system consisted of a multichannel or braided river developed during the Younger Dryas. It was replaced by a meandering channel system in the transition from the Younger Dryas to the Preboreal. However, this new channel system also silted up rapidly with organic to peaty sediments to a point that by the end of the Boreal only shallow water was running through them. From the Atlantic onwards, peat started to grow in most basins even outside the river beds, covering the deepest parts of the Lateglacial floodplain and turning them into marshy areas (= paludification process). This was partly caused by increased precipitation and the rise in sea level, as the North Sea was largely inundated by that time (Kiden, 1991). It therefore seems that in the course of the Preboreal and Boreal rivers in the entire RMS area experienced a rapid and considerable lowering of their water levels.

Examining in more detail the organic infill of these abandoned river channels, one can observe in several, mostly smaller and medium-sized, valleys a temporal decrease or even a halt of peat growth during the Boreal. In most soil sequences the major part of the peat belongs to the Preboreal, while the Boreal is often only partially or limitedly represented (Bohncke and Hoek, 2007; Bos *et al.*, 2007). In several tributaries of the Scheldt and the Meuse (Table 1) a sedimentary hiatus in peat growth is reported, which started between ca. 10 700 and 10 200 cal a BP (first half of Boreal) and lasted until the Atlantic (ca. 9000/8500 cal a BP at its earliest). In some instances, Preboreal peat is covered immediately by Atlantic peat, clearly indicating a drastic lowering of the ground water table in the course of the (late) Boreal. In principal and deeper river channels, such as the Scheldt, sedimentation appears to have been less affected, as peat continued to grow (Storme *et al.*, 2017). However, here, too, a change in the hydrology can be observed. At Kerkhove in the Upper Scheldt, for example, a lithological change from organic alluvial sediments deposited in stagnant water conditions to peat occurred around the middle of the Boreal (Sergant *et al.*, 2016).

Increased forest fires

Several studies focusing on the presence of microcharcoal in pollen slides have proven the repeated occurrence of forest fires during the Preboreal (Bos *et al.*, 2006; Storme *et al.*, 2017; Woelders *et al.*, 2016). Unfortunately, due to delayed peat growth in the area and the lack of similar research, it could not until recently be determined whether

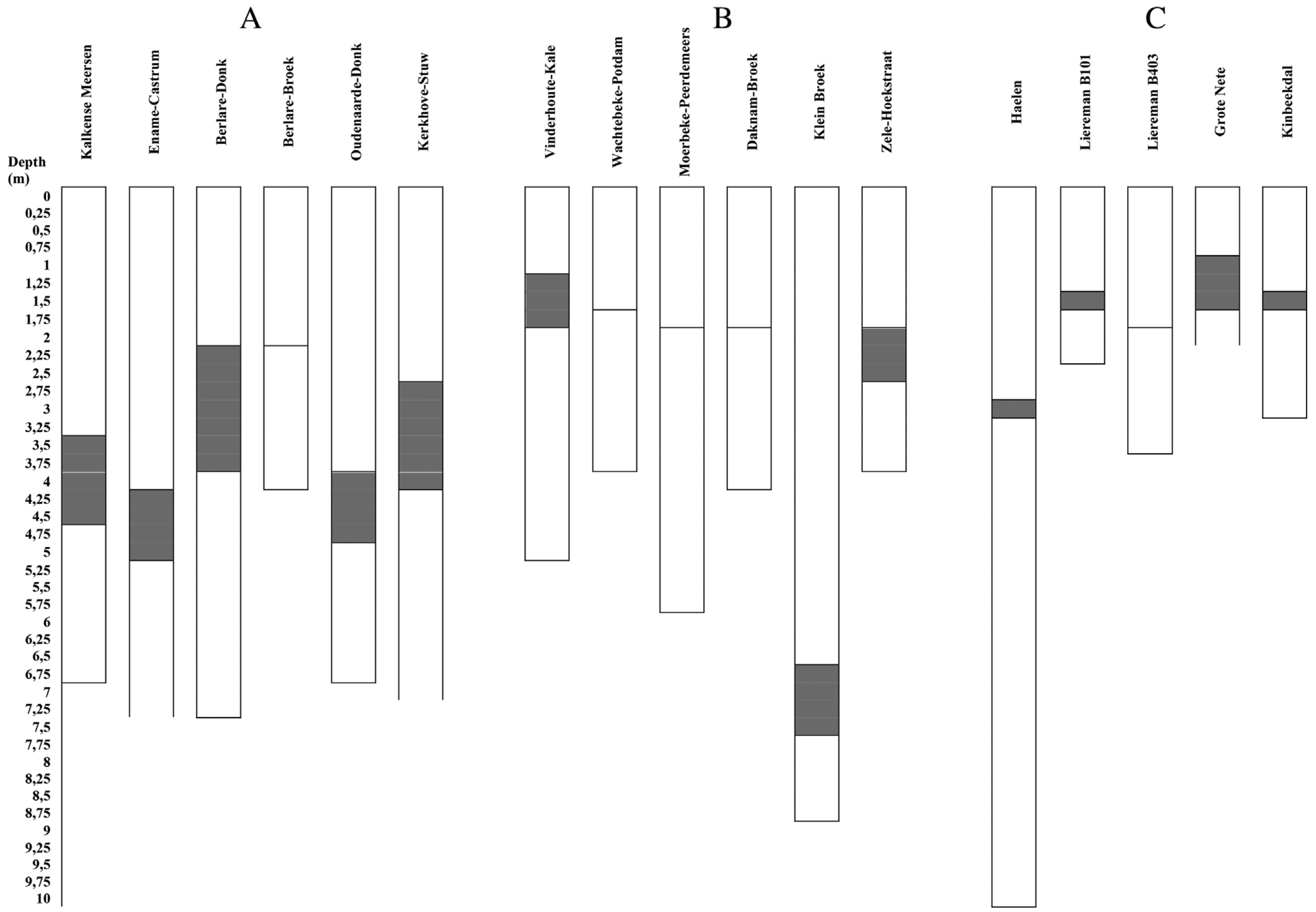

Figure 2. Schematic representation of the Boreal infilling (grey colour) of abandoned river channels in the RMS region. (A) Scheldt river; (B) Kale/Durme river; (C) Meuse and tributaries.

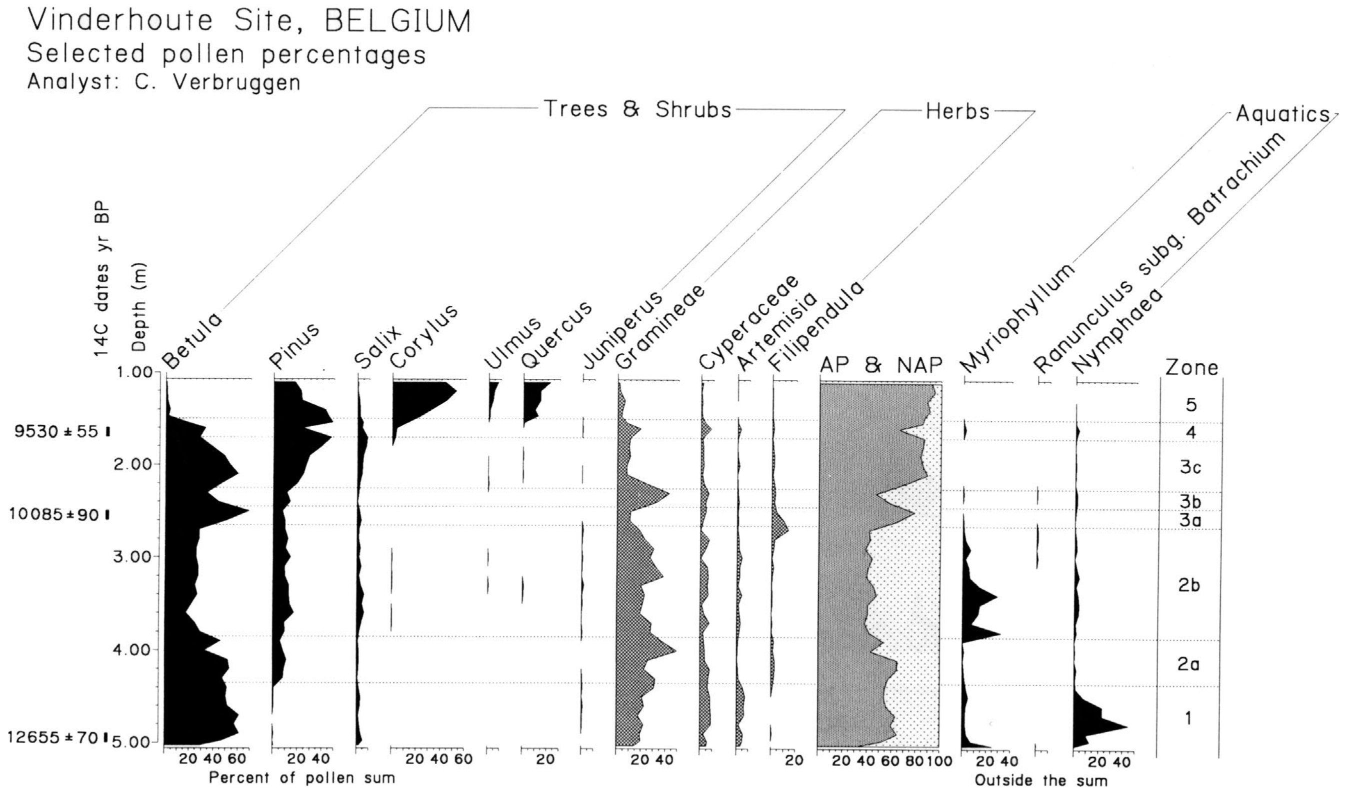

Figure 3. Lateglacial–Early Holocene pollen diagram of an abandoned river channel in the Kale/Durme valley at Vinderhoute (from Verbruggen *et al.*, 1996).

Table 1. Chronology of the hiatus in the peat growth within several river channels of the RMS region.

Location	Start hiatus	End hiatus	Reference
Scheldt basin			
Vinderhoute-Kale	ca. 9100 BP (ca. 10 500 cal a BP)	Subboreal	Verbruggen *et al.* (1996)
Zeeland-Kreekkrak	9080 ± 60 BP (10 430–10 150 cal a BP)	Atlantic	Bos *et al.* (2005)
Berlare-Donk	2nd half Boreal	6280 ± 70 BP (7420–6990 cal a BP)	Verbruggen (1971)
Meuse/Rhine basin			
Mildert-Tungelroyse Beekvallei	9070 ± 60 BP (10 420–10 150 cal a BP)	Atlantic	Woelders *et al.* (2016)
Zutphen	9430 ± 50 BP (10 800–10 500 cal a BP)	Atlantic	Bos *et al.* (2006)
Oud-Turnhout Liereman	9261 ± 47 BP (10 570–10 270 cal a BP)	Atlantic	Unpublished data (F. Verbruggen)
Grote Nete	10 270 ± 50 BP (12 400–11 800 cal a BP)	7720 ± 60 BP (8600–8400 cal a BP)	Verbruggen (2016) (BIAXiaal)

forest fires also occurred during the Boreal. However, in a recent study based on an analysis of over 400 radiocarbon dates from burned ant hills (Crombé, 2016), an abrupt and steep increase of wildfires has been demonstrated in the northern part of the RMS area. Occurring in the late Boreal, more precisely between ca. 9500/9300 and ca. 8600/8400 cal a BP, these fires have been tentatively linked to the colder and drier conditions caused by the 9.3k cal a BP event (cf. Discussion). At present, it is not known whether the loamy upland part of the RMS area was also affected by these wildfires. However, a recent study by Dreibrodt *et al.* (2010) in eastern Germany, situated just outside the RMS region, also points to repeated forest fires associated with several Early Holocene climatic oscillations, including the 9.3k cal a BP event. It could be demonstrated that these fires triggered slope instability that ultimately led to soil erosion. Similar, although preliminary, observations have been reported from Kerkhove, in the uplands of the Scheldt valley (Sergant *et al.*, 2016).

Changing vegetation

Compared to the Preboreal (Verbruggen *et al.*, 1996; Hoek and Bohncke, 2002; Bos *et al.*, 2006, 2007) and Mid-Holocene (Deforce, 2011), there is a considerable lack of well-dated, high-resolution (1–5 cm) multi-proxy palaeoenvironmental studies focusing on the Boreal. Hence, the available palynological evidence does not generally allow the detection of decadal-to-centennial vegetational changes which may have occurred in response to the 9.3k cal a BP event. Most Boreal pollen sequences from river valleys within the RMS area (Fig. 3) are dominated by pine and hazel (*Corylus*), showing a gradual decrease of pine (from ca. 60/80 to <20%) and an increase of hazel (from ca. 10 to 30/40%) towards the transition with the Atlantic (Verbruggen *et al.*, 1996; Storme *et al.*, 2017). The same period witnessed a growth in the instances of oak (*Quercus*), willow (*Salix*) and elm (*Ulmus*).

However, two studied Boreal sequences from a deep palaeochannel at Berlare ‘Donk’ and ‘Broek’ (Fig. 4) in the Lower Scheldt floodplain provide a different picture (Verbruggen, 1971, Verbruggen *et al.*, 1996). In both ca. 2-m-long sequences an abrupt shift in the pine/hazel ratio occurs shortly after 8730 ± 70 ^{14}C a BP or 10 150–9500 cal a BP. Before this date, hazel predominates with a maximum of up to 65%, while pine gradually decreases to ca. 15%, afterwards, the ratio changes as pine rapidly increases to a maximum of ca. 75%, while hazel drops to almost 10%. This radical change has been connected by Verbruggen to a transition from a moist to a drier phase within the late Boreal.

Changing fauna/hunting strategies?

Little is currently known about changes in the composition of wild game during the Early Holocene within the RMS area, due mainly to the generally poor preservation of unburned animal bones, which are usually only found in river floodplains and caves or rock-shelters. In addition, the small size and highly fragmented nature of most Mesolithic faunal assemblages severely inhibits species determination, a situation that is compounded by the relative dearth of assemblage studies that make it to publication.

Despite these limitations, it has been demonstrated that wild boar (*Sus scrofa scrofa*) was by far the most important human prey animal during the first half of the Boreal (Fig. 5). Before that, during the Preboreal, it seems that hunting focused mainly on red deer (*Cervus elaphus*) or auroch (*Bos primigenius*), although this tentative surmise is still based on too few (published) data. The focus on wild boar hunting is generally explained by the increased availability of the species, due to their very high reproduction rate and forest expansion (Bridault, 1997). Early Boreal hunters seemingly targeted mostly groups of females with subadults younger than 2 years (Bridault, 1997; Leduc *et al.*, 2013).

Awaiting the publication of two recently excavated Middle Mesolithic sites (Kerkhove and Remilly-les-Pothées), it is already clear that wild boar continued to be the chief prey during the second half of the Boreal, although other species, such as red deer, may have increased in importance.

The archaeological evidence

Lithic technology

By far the most important characteristic of the RMS ‘culture’ is the sudden appearance of a new microlithic type, the invasively or flat retouched microlith (Gendel, 1984; Gob, 1985; Heinen, 2006), which is usually accompanied by small backed bladelets (Fig. 6). In contrast to the armature types of the Early Mesolithic, which were manufactured by means of steep, unidirectional retouching of a bladelet side(s) or end(s), the new microliths were made by a flat retouch, partially

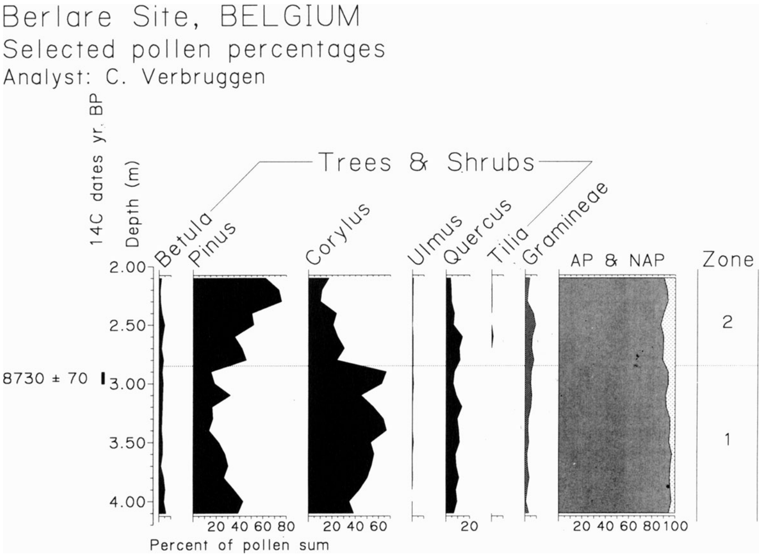

Figure 4. Pollen diagram of an abandoned river channel in the Lower Scheldt valley at Berlare 'Broek' (Verbruggen *et al.*, 1996).

bifacially and most probably by means of the pressure technique. The result of this technological change was the production of very thin and, thus, fragile armatures. Morphologically three to four different sub-types can be defined, including mistletoe points (*feuilles de gui*), triangles and points with rounded or oblique base (leaf-shaped microliths) (Fig. 6).

Despite the lack of a detailed geographical analysis, the existence of some interregional differences within the distribution of these different subtypes is clear (Figs 1 and 7). Although all subtypes occur randomly within the entire RMS region, some types are clearly dominant within specific basins. As such, the absolute predominance of mistletoe points in the Somme (ca. 90%) and, to a lesser extent, in the adjacent Aisne (ca. 75%) and Middle Meuse basins (ca. 66%) cannot be denied. However, triangles with surface retouch clearly dominate in the coversand area of the southern Netherlands, while points with rounded and/or oblique bases are the most frequently occurring types in the Upper Scheldt and Upper Dender basins. The latter are also well represented together with mistletoe points in the Lower Scheldt basin (Sandy Flanders) and the adjacent Belgian Campine.

At present, the true meaning of these interregional differences remains unknown but they could be related to chronological, cultural/ethnic and/or functional (seasonal) differences. The few reliable radiocarbon dates from the initial phase (before ca. 9000 cal a BP) indicate that all four subtypes were already in existence from the very beginning of the Middle Mesolithic (Table 2). However, these early dates do not allow us to conclude that northern France was the cradle of the RMS techno-complex, as suggested by Heinen (2006). For this, many more radiocarbon dates from chronologically secure archaeological contexts are needed.

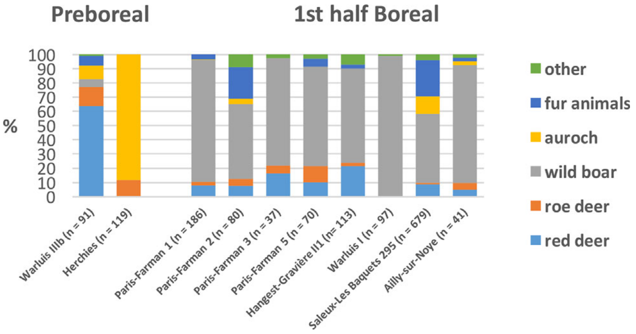

Figure 5. Composition of mammal species (expressed in NISP) found on Early Mesolithic sites in different river valleys of northern France (data from Bignon-Lau *et al.*, 2010; Coutard *et al.*, 2010; Ducrocq, 2001; Ducrocq *et al.*, 2014, Ducrocq *et al.*, 2016; Leduc *et al.*, 2013).

According to Ducrocq (2001), the introduction of the first invasively retouched points was possibly preceded by a (short?) phase in which small backed bladelets dominated alongside points with retouched base and, to a lesser extent, scalene triangles (sites of Kruishoutem, and Chausée-Tirancourt fosse 1 and 3; Table 2). The latter two are characteristic of the latest Early Mesolithic assemblages attributed to the Chinru assemblage-type (Crombé *et al.*, 2009). These older microlith types survived beyond the introduction of the first invasively retouched microliths (Table 2), indicating that the appearance of the latter was probably not triggered by functional needs (cf Discussion). It would seem that, at least at the start of the Middle Mesolithic, two types of arrow shafts with small backed bladelets inserted as barbs were in use simultaneously: one type has a point with retouched base as its tip, a legacy from the Early Mesolithic; the other is tipped with one of the invasively retouched microliths.

Whether this radical change in microlithic implements also involved a change in the knapping techniques and methods remains unclear. There are no clear morphological differences between bladelets from the Early and Middle Mesolithic, as both present the main characteristics of the Coincy knapping style. However, while this does not necessarily exclude technological differences, it can only be determined by means of detailed technological analyses the type of which have so far only been applied to Early Mesolithic assemblages (Ketterer, 1997; Ducrocq, 2001; Perdaen *et al.*, 2008). Such studies have highlighted the preferential use of the soft stone hammer technique for the *plein débitage*.

Raw material procurement

The start of the Middle Mesolithic coincides with a marked change in the procurement and use of two quartzite types – Wommersom quartzite (WSQ) and Tienen quartzite (TQ) –

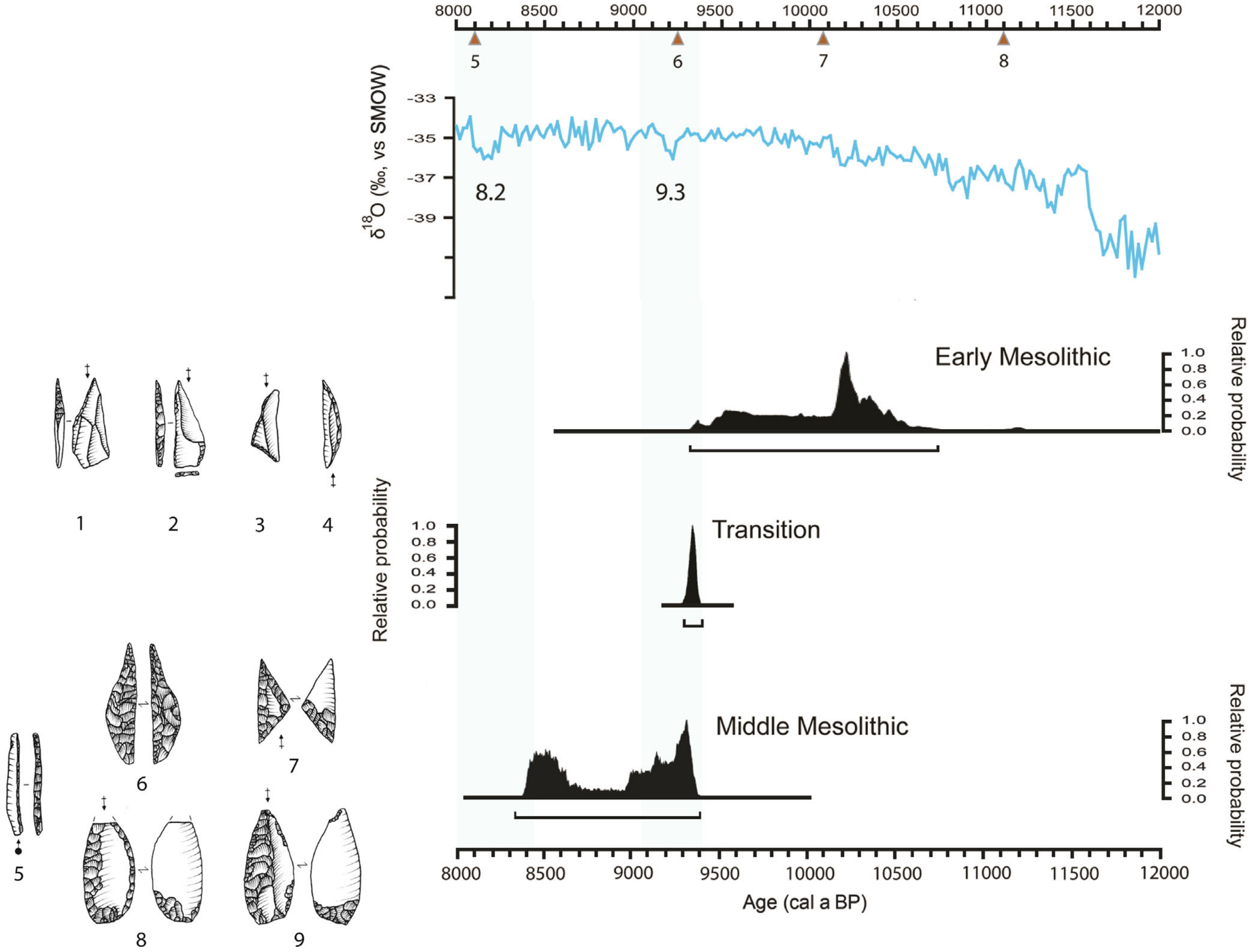

Figure 6. Radiocarbon chronology (sum probabilities) for the Early and Middle Mesolithic in the RMS area in relation to the ice-rafted debris events and the NGRIP ice core record. Chronozones of the 9.3 and 8.2k cal a BP cooling events are shaded. Left: the main microlith types for the Early (1, point with unretouched base; 2, point with retouched base: 3, triangle; 4, crescent) and Middle Mesolithic (5, small backed bladelet; 6, mistletoe point; 7, triangle with invasive retouch; 8, point with rounded base; 9, point with oblique base) (adapted from Robinson *et al.*, 2013a, fig. 3).

within the RMS. Both quartzites originate from the same outcropping area and geological formation (Upper Landian), situated in the centre of Belgium (Blomme *et al.*, 2012; Cnudde *et al.*, 2013), and have from the very beginning of the Mesolithic been distributed within an area of at least 50 000 km^2, covering the entire northern part of the RMS area (Gendel, 1982, 1984; Perdaen *et al.*, 2009) (Fig. 8). However, most instances were orientated towards the coversand region north of the outcrop, while only small amounts of quartzites were transported south to the loamy upland. Furthermore, the Meuse clearly acted as a border, both to the east and to the north, beyond which quartzite artefacts are seldom found, mostly as (semi-)finished tools. Both quartzites were preferably used for the production of blade(let)s and microliths (Gendel, 1982, 1984; Coppens, 2015).

In examining the distribution of both quartzite types separately, an interesting pattern emerges (Figs 9 and 10). During the Early Mesolithic, both quartzites were used simultaneously, albeit in different areas. TQ was almost exclusively distributed to the north-west of the outcropping area, towards the west bank of the Lower Scheldt River, called Sandy Flanders (Crombé, 1998). There it was used principally for the manufacturing of points with retouched base and triangles (Coppens, 2015). Radiocarbon evidence also demonstrates that the use of TQ in Sandy Flanders gradually increased in the course of the Early Mesolithic, the highest proportions of TQ being found in association with the ‘Chinru’ assemblage-type, dated between ca. 10 135 and 9335 cal a BP (Crombé *et al.*, 2009; Fig. 11). At the same time, WSQ was chiefly distributed to the north, in the direction of the Belgian and Dutch Campine, where it served as raw material for the production of crescents and points with retouched bases (Coppens, 2015; Figs 9 and 10), interpreted, respectively, as arrow barbs and tips. Therefore, during the Early Mesolithic the Lower Scheldt River constituted a limit between two distribution networks, possibly related to two different (regional) groups of hunter-gatherers.

Remarkably, at the onset of the Middle Mesolithic, TQ went almost entirely out of use in the west (Fig. 9). It was replaced with WSQ, conforming to the pattern observed in the remaining parts of the northern RMS area until the very end of the Mesolithic. At the same time, WSQ is used more intensively than before (Fig. 10). In his 1984 study, Peter Gendel noted that during the Middle Mesolithic, WSQ was distributed in larger quantities (up to 30%) further away from the outcrop, as far as 70–80 km. Although his observation was based on two sites only, Bladel and Oirschot V, it has since been confirmed by more recent data (Coppens, 2015) (Figs 8 and 10). Interestingly, these sites are all situated north of the outcrop in the Dutch and Belgian Campine (Fig. 8). It

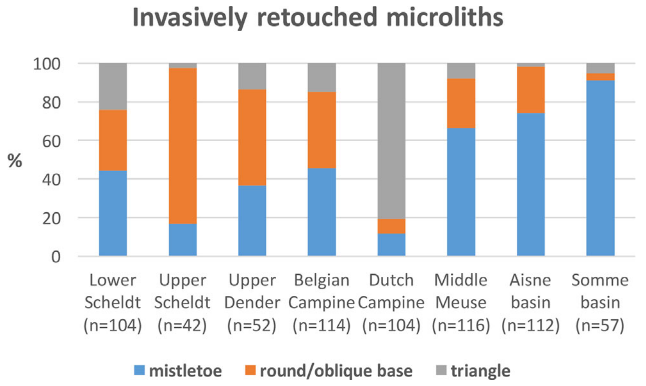

Figure 7. Interregional comparison of invasively retouched microlith subtypes within different subregions of the RMS area.

can be observed from Fig. 9 that WSQ in the Campine was used at least twice (ca. 37%) as much for the production of invasively retouched points compared to Sandy Flanders (ca. 16%); the difference is even greater among the small backed bladelets (ca. 28% versus ca. 3%). This trend persists during the Late Mesolithic among the trapezes (ca. 32% versus 8%) (Robinson *et al*., 2013a, 2013b).

Site density

Within the RMS area, a few regions exist for which detailed information about the Mesolithic occupation is available, thanks to long-term fieldwork. An analysis of the number of sites during the different stages of the Mesolithic reveals some interesting patterns, which might reflect changes in land use. A recurrent pattern is the marked reduction in sites during the transition from the Early to Middle Mesolithic, a trend which persists into the Late Mesolithic. Based on published information, this reduction was attested in the Lower Scheldt basin (Crombé *et al*., 2011), Southwest Brabant, and the Ourthe and Somme valleys (Fig. 12). In most of these areas the number of sites during the Middle Mesolithic drops to little more than half, or, even more spectacularly, to a third (South Brabant) or a fifth (Ourthe), of the number known for the Early Mesolithic. Exceptionally, in the Upper Scheldt basin the pattern is reversed and Middle Mesolithic sites outnumber Early Mesolithic ones (Fig. 12). So far the Upper Scheldt is an anomaly, but there is reason to believe it also applies to other, still less well-documented areas of the RMS (e.g. the Dutch Campine region of North Brabant and Limburg).

Discussion

The environmental changes

From the evidence presented, it is clear that the RMS region experienced a series of important environmental changes during the Early Holocene, and in particular during the (late) Boreal. There was obviously much less water running through the rivers and brooks compared to the Lateglacial, the pine forests were affected by repeated wildfires and, locally, hazel grew less densely. The question which arises is one of the equifinality of these changes: are these the result of gradual processes or are they, instead, related to punctuated event(s), such as the 9.3k cal a BP cooling event. This question can only be addressed if there is high enough chronological resolution in data relevant to these changes. At present, this is unfortunately not the case for the RMS region, but it is nevertheless possible to formulate some hypotheses which demand further testing.

The decrease of the fluvial discharge and related colmation of the meandering river channels could well be the result of a gradual lowering of the ground water table, caused by increasing temperatures and vegetation from the Preboreal onwards. The growth of dense pine forests in the course of the Boreal might have been the ultimate trigger for the drying out of rivers and delayed peat growth. It is commonly known that coniferous trees retain larger quantities of ground water than deciduous trees, principally because the former are evergreens. However, the possibility that the 9.3k cal a BP event also played a role is not dismissed. Although the palynological and radiocarbon evidence does not permit a close correlation, there is increasing evidence that the 9.3k cal a BP climatic event led to regionally variable hydrological and vegetation responses in the North Atlantic region (Magny *et al*., 2003; Litt *et al*., 2009). The area above 50°N, to which the RMS region belongs, would have had drier conditions compared to the mid European zone, which became wetter.

A somewhat comparable hydrological change occurred in the RMS area in response to an earlier short and abrupt cooling event during the Lateglacial. Recent research (Crombé *et al*., 2013, 2014; Bos *et al*., 2017) has convincingly demonstrated the link between the desiccation of numerous shallow freshwater lakes and ponds and the Intra Allerød Cold Period or GI-1b, which occurred near the end of the Allerød between ca. 13 260 and 13 050 cal a BP (Rasmussen *et al*., 2014). In addition, this event probably also triggered the start of the sedimentation of the Lateglacial river channels with calcareous gyttja, at least in the Scheldt basin (Crombé and Robinson, 2017). Therefore, it is not unlikely that the 9.3k cal a BP event accelerated the lowering of ground water levels in the RMS area, a process which was initiated by the increased evapotranspiration.

A comparison with the Lateglacial is also informative in the search for an explanation for the increased wildfires during the late Boreal. An important question relates to the reason why these forest fires increased only from ca. 9500/9300 cal a BP and not earlier, despite the fact that pines already dominated the landscape during the final Preboreal and very beginning of the Boreal. Pines are well known to be vulnerable to lightning, in contrast to deciduous trees, such as oak and alder. Pine is the tree with the greatest fire risk within the Eurasian woody taxa today (Dreibrodt *et al*., 2010). A possible explanation for the 'delayed' wildfires is that the deterioration of the climate during the 9.3k cal a BP event led to an increased death rate among pines, which resulted in a readily combustible environment (Crombé, 2016). A comparable situation occurred during the final Allerød, when NW Europe was also largely dominated by pines. The overall presence of pine charcoal fragments in Usselo soils, dated between 13 200/13 100 and 12 700/12 600 cal a BP, is generally linked to the climate deterioration towards the Younger Dryas (and/or GI-1b), which increased the likelihood of drought and severe frost damage, making pines much more prone to burning (Kaiser *et al*., 2009).

While some doubt remains, it cannot be fully excluded that the accelerated lowering of the ground water table during the Early Holocene caused the dying of numerous pine trees rather than, or in combination with, the decreasing temperatures. In this respect, the radical decrease of hazel and the connected increase of pine in the pollen record of Berlare is also relevant. According to Verbruggen (1971), the abrupt change suggests a drier phase which started shortly after 10 150–9500 cal a BP. This coincides approximately with the timing of the 9.3k cal a BP event, although more detailed data are needed to prove any causality. However, a similar temporal increase of pine connected to a marked decrease of

Table 2. Typological composition of the armatures found in the Middle Mesolithic lithic assemblages of the RMS, dated to prior to ca. 8000 ^{14}C a BP (ca. 9000 cal a BP).

	Early Mesolithic microlith types				Middle Mesolithic microlith types				Late Mesolithic microlith types
					Invasively retouched microliths			Other types	
	Points with unretouched base	Points with retouched base	Crescents	Triangles	Mistletoe points	Points with rounded/oblique base	Triangles with surface retouch	Small backed bladelets	Trapezes
Chaussée-Tirancourt fosse 1 (8460 ± 70 BP; 8360 ± 90 BP) (9550–9300 cal a BP; 9540–9120 cal a BP)		+						+	
Chaussée-Tirancourt fosse 3 (8180 ± 70 BP; 9400–8990 cal a BP)	1	+						+	
Kruishoutem-Kerkakkers (8270 ± 80; 9450–9030 cal a BP)	2	15	1					31	1
Hangest-Gravière III 2 (8290 ± 70 BP; 9470–9080 cal a BP)	2			4	9	1		5	
Chaussée-Tirancourt 1bs (ca. 8400–7800 BP; ca. 9500–8500 cal a BP)	27	66	18	5	37	1		584	2
Belloy-le-Plaisance (8240 ± 100 BP; 9470–9000 cal a BP)		+		+	+				
Saleux- La Vierge Catherine niv. sup (8210 ± 110 BP; 9500–8750 cal a BP).		3		1	1		2	37	
Oirschot V-site 21 (8320 ± 40 BP; 9470–9140 cal a BP)					1	2		2	

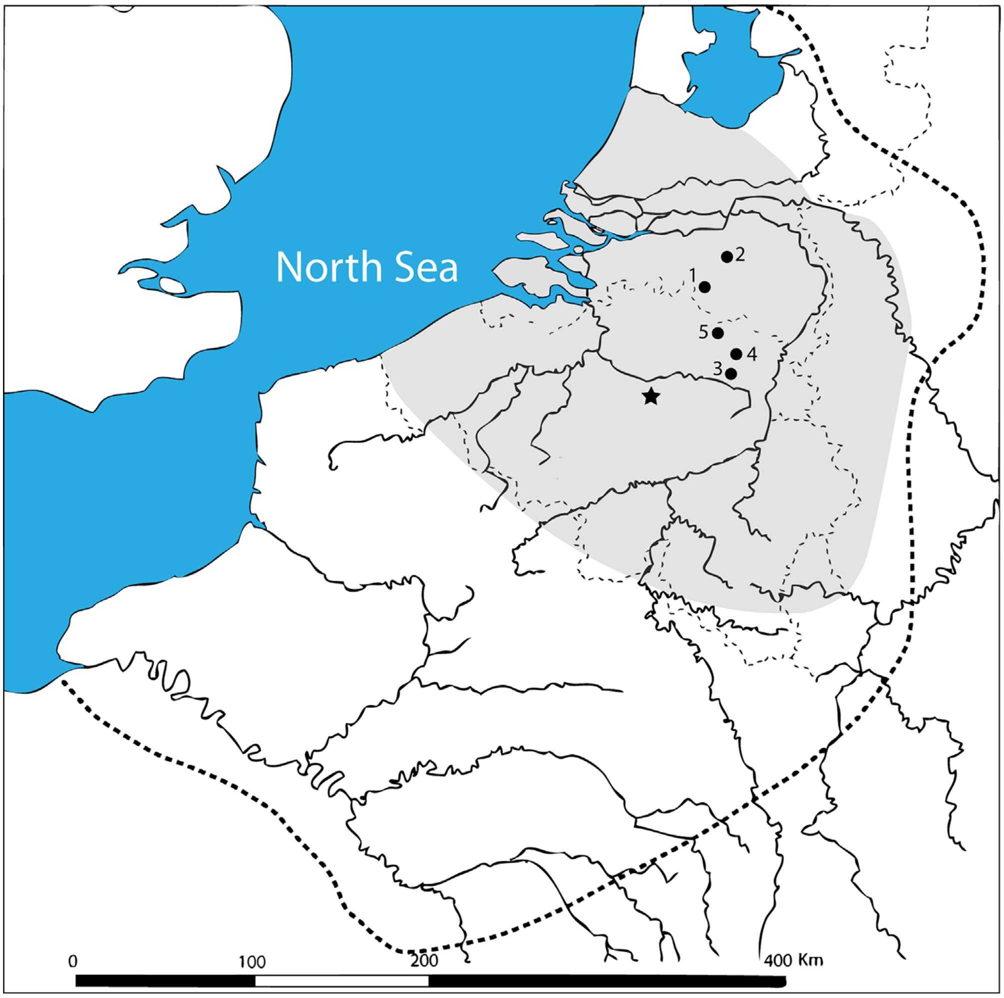

Figure 8. Map showing the maximum distribution of WSQ and TQ within the RMS region. Indicated are the outcrop area (star) and Middle Mesolithic sites with >20% of WSQ. Key: 1, Bladel; 2, Oirschot V; 3, Zonhoven; 4, Helchteren; 5, Lommel.

temperate thermophilous tree taxa, such as hazel, oak, alder and elm, has been attested in response to the 8.2k cal a BP event, for instance in southern Scandinavia (Seppä *et al.*, 2007; Hede *et al.*, 2010), western Ireland (Ghilardi and O'Connell, 2013) and central Europe (Tinner and Lotter, 2001). The similarities between the two cooling events increase the possibility that the pine increase at Berlare was a response to the 9.3k cal a BP event. This remains, however, to be verified by means of future high-resolution studies of similar Boreal peat sequences.

Archaeological changes

The same question of equifinality should be addressed to the observed changes in hunting equipment, raw material circulation and site distribution during the Middle Mesolithic of the late Boreal. To what extent are these changes a response to shifting environmental conditions and, in particular, the 9.3k cal a BP event, or just the result of long-term functional, economic and social evolutions?

Social territorial boundaries

It has already been argued that the abrupt introduction of invasively retouched microliths at the start of the Middle Mesolithic cannot, in all probability, be explained as resulting from a need to improve the hunting equipment. The continued use of old microlith types, in particular of points with retouched base, next to the small backed bladelets in the oldest assemblages supports this assumption. Furthermore, there is little reason to assume that arrow shafts mounted with mistletoe or leaf-shaped microliths were more efficient compared to the Early Mesolithic ones. On the contrary, the flat and bifacial retouch of the former probably made these armatures thinner and, hence, less resistant and more fragile on impact than the older types. Functionally, therefore, these new microliths had no obvious advantage. From this it can be assumed that they were developed for other reasons, such as symbolic or cultural reasons. Based on their restricted geographical distribution, it has been suggested (Gendel, 1984; Heinen, 2006) that they were used as emblematic markers for symbolizing social group affiliation and social territorial boundaries of a late Boreal population living between the Seine and the Rhine. Ethnographically, the use of 'style' to visualize group affiliation, next to other mechanisms (e.g. overt defence, endogamy, place-names and interregional ceremonies) is well documented (Newell *et al.*, 1990; Andrews, 1994; Kelly, 1995). Furthermore, the observation that the Seine continued to serve as a border during the Late Mesolithic, as indicated by the different lateralization of trapezes south and north of the Seine, fully supports the idea of social boundaries (Gendel, 1984; Löhr, 1994). The question, however, remains as to which level of group organization is symbolized by means of these invasively retouched microliths. Based on ethnographic data from hunter-gatherers living in a forested environment with stable, evenly spaced resources (Houtsma *et al.*, 1996, p. 58), the surface of ca. 150 000 km^2 encompassed by the microliths' distribution might correspond to the territory of a (small) language family or (large) dialectic tribe. Compared to (sub)recent dialectic tribes in North America that have

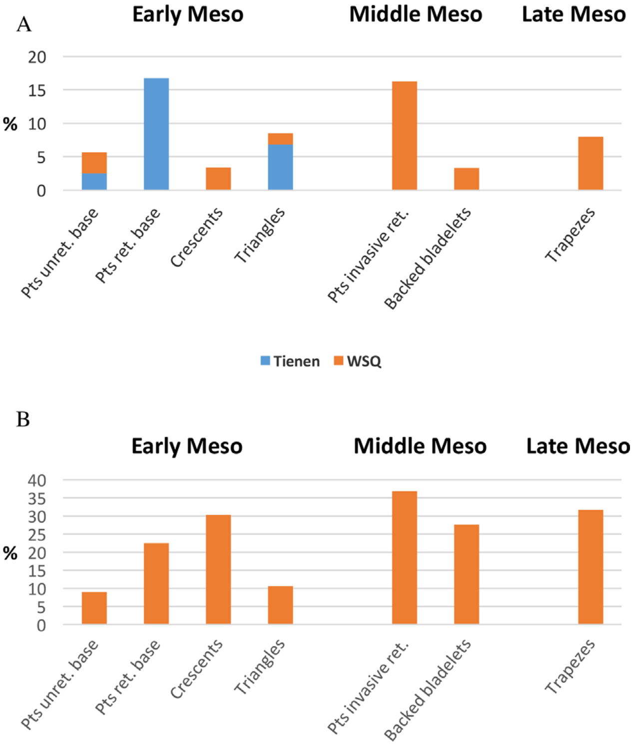

Figure 9. Frequency of microliths manufactured in WSQ and TQ in two adjacent areas within the coversand lowland of Belgium. (A) Sandy Flanders (Lower Scheldt basin); (B) Campine.

been recorded as occupying a territory of ca. 60 000 km^2 on average, the RMS area appears far too large. However, a few dialectic tribes have been known to occupy territories up to 200 000/250 000 km^2, such as the Tutchone, Slavey and Kesyehot'ine Chipewyan (Houtsma *et al.*, 1996).

As suggested by Gendel (1982, 1984), the distribution of WSQ (and TQ) might also be interpreted socially, as a supplementary means of symbolizing group affiliation and boundaries. Such an interpretation is supported by the fact that during the Middle Mesolithic this raw material was preferentially used to make invasively retouched microliths (Fig. 9). Consequently, both microlith morphology and raw material may have been combined to symbolize group affiliation. However, the distribution pattern of WSQ is much more restricted (ca. 50.000 km^2), covering only the northern part of the distribution area of invasively retouched points (Fig. 8). According to Gendel (1982, 1984), this is due to the comparative abundance of flint sources in northern France and/or the existence of two or more discrete or overlapping annual territories within the context of a larger maximum band. It seems, however, more likely that the distribution of WSQ corresponds to the territory of a dialectic tribe, as part of a bigger language family covering the entire RMS area (cf supra). A second dialectic tribe from the same language family would have occupied the southern part of the RMS area, corresponding largely to northern France, and may have used another mechanism or emblemic marker(s) to define its borders.

Increased territoriality

A much more important question relates to the reason why hunter-gatherers in the RMS region needed to symbolize their social boundaries precisely at the start of the Middle Mesolithic. Ethnographically, the symbolization of group boundaries has often been connected with increased territoriality, meaning the exclusive use of resources or exploitation of an area (Andrews, 1994, p. 82; Kelly, 1995), and preventing neighbouring group members from gaining access to these resources. Territoriality more frequently occurs in environments containing critical food resources that are predictable in time and space and are dense or abundant, such as coastal regions. The reason is that the resources are worth defending and are crucial for the survival of the group. Conversely, in environments with sparse, dispersed and unpredictable resources, like Boreal or taiga forests, the costs to defend the often extensive boundaries would exceed the benefits gained, and hence territoriality evolves less frequently. There are no indications that the Middle Mesolithic environment provided dense and predictable resources, as observed in the ethnographic record; on the contrary, the many environmental changes probably made the environment less suitable for hunter-gatherers, as resources such as water, game and wild fruits were largely affected by drought, coldness and wildfires.

However, in the ethnographic record social-boundary defence is sometimes also attested in environments lacking dense and abundant resources. In such contexts resource competition and stress, caused by increasing population density and/or a reduction of the carrying capacity of the environment, are the main reasons for defending a resource or an area as it is worth the potential benefit (Gendel, 1984; Kelly, 1995). As argued by Cohen (1977), resource scarcity will often motivate greater defence of the group territory and a gradual breakdown of the system of open population-flux. It is thus perfectly conceivable that the reduced availability of hydrological resources and plant material at the onset of the Middle

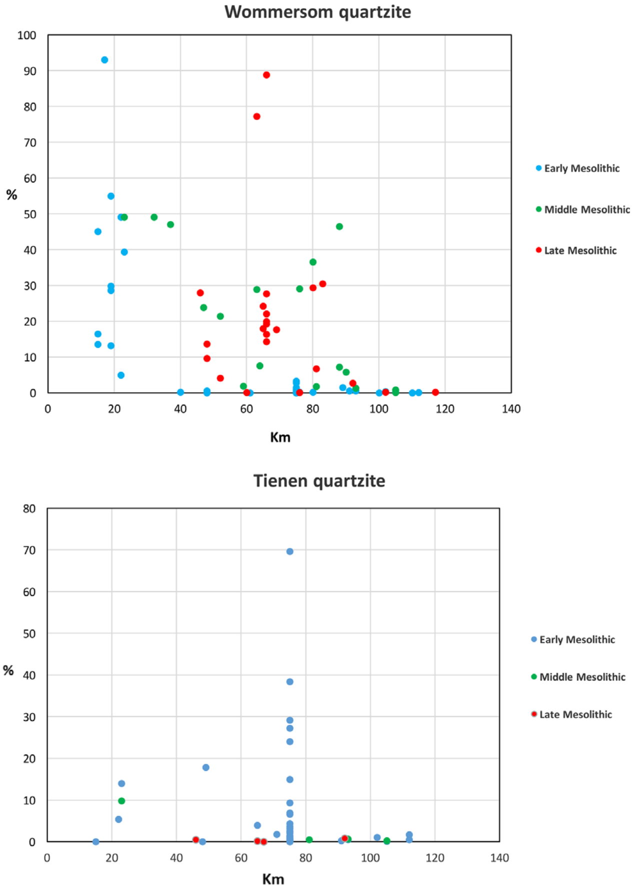

Figure 10. Frequency of WSQ and TQ on Mesolithic sites plotted against the distance from the outcrop.

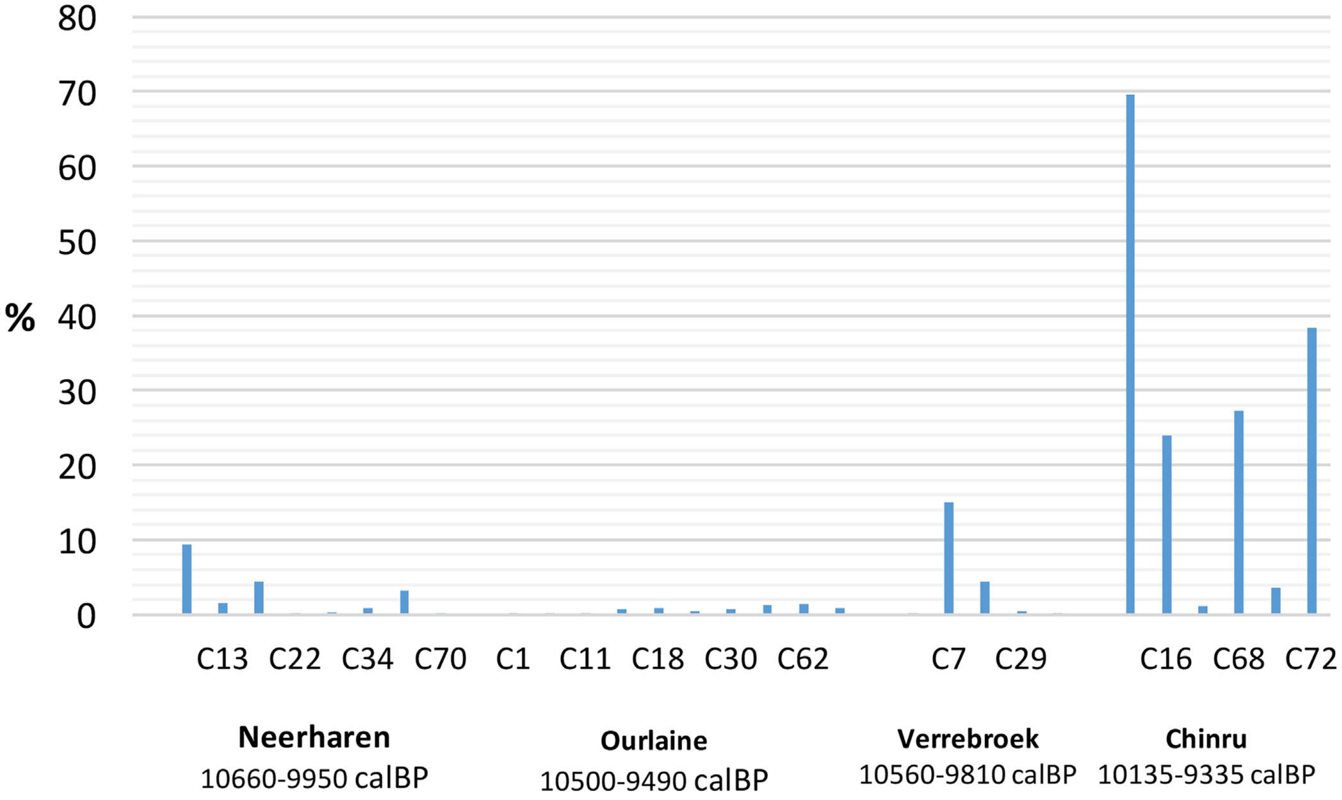

Figure 11. Frequency of TQ in Sandy Flanders (Lower Scheldt basin) within different Early Mesolithic assemblage-types.

Mesolithic led to a stress situation, which required hunter-gatherers to invest in social-boundary defence by means of symbolized tools, such as invasively retouched microliths. This process may have started already in the course of the Early Mesolithic, as indicated by the differential use of TQ and WSQ to the west and east of the Lower Scheldt River (Fig. 9). The trigger might have been the rapid drowning of the adjacent North Sea basin, another major environmental event during the Early Holocene. Recent finds of Mesolithic artefacts (antler and bone tools) and human remains retrieved from the North Sea floor prove that this formerly dry basin of ca. 250 000 km^2 was indeed occupied and exploited by hunter-gatherer-fishers (van der Plicht *et al.*, 2016). However, sea levels rapidly rose until ca. 7500 cal a BP, with an average of 1.5 m per century, and reached the level of ca. 10 m below actual sea level (Jelgersma, 1979; van der Plassche, 1982). This led to a major reduction of habitation area which, in its turn, triggered a gradual yet sustained displacement of hunters in search of new hunting and occupation grounds, especially throughout the Preboreal and large parts of the Boreal. Movements in an eastern direction towards the 'continent' imply intrusions into others' territories and the exploitation of resources already claimed by other groups. This might have led to increased competition in an environment with low resource density, which is the ideal context for social-boundary defence (Kelly, 1995). As competition further increased when resources were affected by drought and burning in response to the 9.3k cal a BP event, social-boundary defence was intensified by the development of symbolized tools, the invasively retouched microliths, and increased use and intra-group exchange of WSQ. Clearly, the main exploitation of WSQ was still in the hands of the regional group occupying the Dutch and Belgian Campine, as most of this raw material was still transported to the north of the outcrop (Fig. 8). Whether the neighbouring groups obtained their WSQ through direct procurement or exchange with the Campine group remains unclear. The reason why the use of TQ abruptly stopped from the Middle Mesolithic onwards also needs to be elucidated. It might be for purely practical reasons because, compared to WSQ, TQ is much coarser and tougher to knap, especially when applying the pressure technique. It is indeed questionable whether this raw material is appropriate for the production of invasively retouched microliths. The same holds for the production of regular and standardized blade(let)s during the Late Mesolithic.

Shifting population

But how should theories of increased territoriality and evidence for decreasing site density during the Middle Mesolithic, as attested in several core areas of the RMS region, be integrated? In earlier papers on the Lower Scheldt area (Sandy Flanders), this reduction has been tentatively linked to a decreased mobility from the Middle Mesolithic onwards, possibly induced by greater reliance on fishing and/or a gradual closing of the forests due to the arrival (late Boreal) and subsequent dominance (Atlantic) of deciduous trees (Crombé *et al.*, 2011). The latter would have led to more clustered resources, as plants and animals shifted towards the forest edges situated along river floodplains. It is believed that this explanation is still valid for the late and final stages of the Mesolithic, when occupation concentrates in the river and lacustrine wetlands (Crombé *et al.*, 2015). However, the late Boreal landscape was still largely dominated by pine forests, which were still rather open as indicated by the (very) high frequencies of hazel in most pollen records. Furthermore, it is questionable whether fishing could increase in importance at a time when rivers were running almost dry. Alternatively, fishing might have become easier as the water became shallower. Yet, there is little supporting evidence for increased fishing during the Middle Mesolithic. A recent literature survey (Slabbinck, 2016) has demonstrated that fish remains are

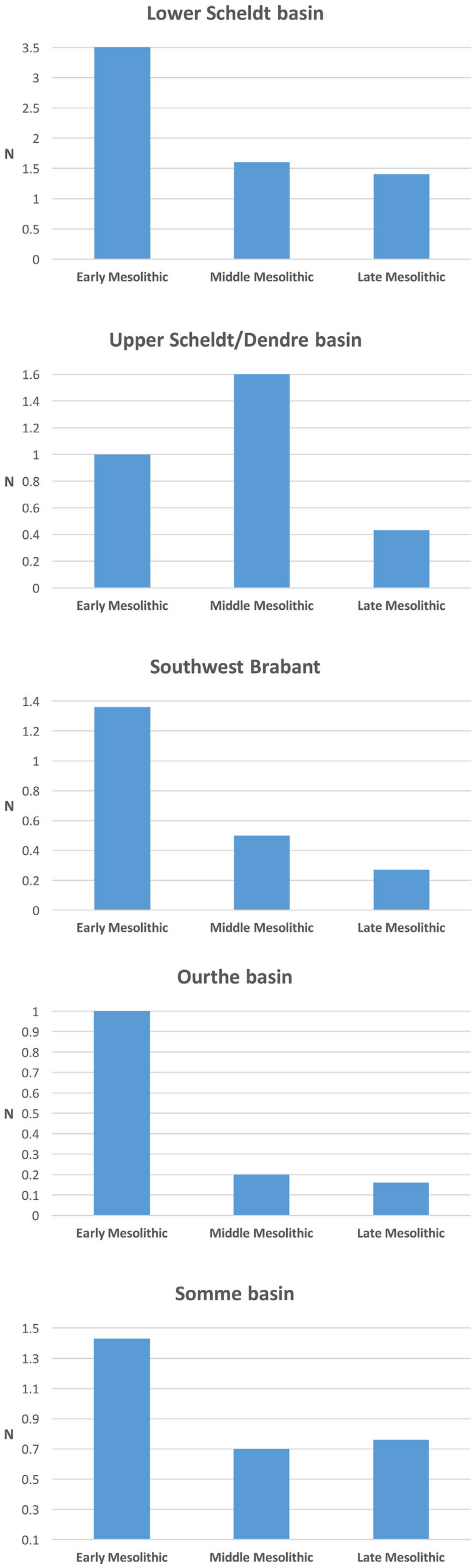

Figure 12. Evolution of the number of sites in several core-areas of the RMS region. The data are expressed in mean number of sites per 100 calendar years for each stage.

hardly ever present on Early and Middle Mesolithic sites within the RMS region, although sites are generally situated along river banks. This changed markedly near the end of the Middle Mesolithic and the transition to the Late Mesolithic, when the first sites with substantial numbers of fish bones (mainly cyprinids, pike, perch) appear, for instance at Almere-Hout Zwaanpad (Niekus *et al.*, 2012), Rotterdam-Yangtzehaven (Zeiler *et al.*, 2014) and Noyen-sur-Seine (Dauphin, 1989).

In addition, reduced mobility does not explain why site density during the Middle Mesolithic increased or remained stable in particular areas, such as the Upper Scheldt basin. A possible explanation for this inter-regional difference in site density might be found in population shift and movement. Rather than interpreting site reduction as a reflection of decreased mobility it might be seen as a result of decreased exploitation of particular areas, at least during the late Boreal. It is perfectly reasonable to assume that the environmental changes of the (late) Boreal made certain regions less attractive for hunter-gatherers. The reduced availability of water, in particular away from the main rivers (Scheldt, Meuse, Rhine), probably limited the survival not only of people but also of wild game in the dry interior. Prolonged settling was probably only possible along the main rivers and/or in the upland loamy regions of the RMS area.

A shift to the uplands, for example of the Upper Scheldt basin, is a possibility, given the marked increase of sites in this region. The appearance of small amounts of flint typical of the Upper Scheldt, such as Ghlin-flint, on Middle Mesolithic sites in the Lower Scheldt basin already indicates circulation of raw materials between both regions, which was non-existent during the Early Mesolithic (Crombé *et al.*, 2011). Moreover, in adjacent upland regions, such as the Hageland, a similar shift from river valleys to hilltops has been attested during the late Boreal (Vanmontfort, 2008). Perhaps the loamy uplands were less affected by the environmental changes compared to the sandy lowlands, allowing hunter-gatherers to temporarily move to these higher grounds. The presence of numerous freshwater springs might have been an important reason to move to the uplands. In addition there are indications that during the Boreal in the uplands the number of pines was already greatly reduced in favour of oak and elm, which might have limited the risk of wildfires. Therefore, differences in the climatic threshold of vegetation and hydrology between neighbouring regions might be the reason for the assumed population shifts in the (late) Boreal. Interestingly, these hunter-gatherers moving from the sandy lowlands apparently preferred to settle on small outcrops of (Tertiary) sands, which constituted ‘islands’ within the loamy uplands. Perhaps these represented small natural openings in the dense deciduous forests or were just familiar soils for hunter-gatherers coming from the sandy lowlands.

Conclusions

Despite the fact that a definite correlation with the 9.3k cal a BP event is still not ascertained, it is clear from the analysis above that Early Holocene hunter-gatherers along the southern North Sea basin were confronted with a series of environmental changes which had considerable impact on their subsistence. The available data, although still not precise enough, illustrate that the Early Holocene was not as stable as generally assumed. The strong reduction in freshwater and rising sea levels were definitely major environmental changes that impacted the lifeways of both humans and animals. To fully understand the relationship between climate and environmental changes, and human responses there is a need for a more holistic approach: one that combines high-resolution multi-proxy investigations of soil sequences with in-depth archaeological analyses of lithic assemblages (both technology and typology), raw materials and site distribution within the different river valleys of the RMS region.

One of the major challenges will be the establishment of strict synchronicity between the observed climatic, environmental and archaeological events. Even if these events can be successfully dated by means of series of radiocarbon dates conducted on reliable samples, the 'tuning' of these different proxy archives will be neither simple nor straightforward (Blaauw, 2012), especially when investigating the effects of short-lived events, such as the 9.3k cal a BP event, which only lasted between 100 and 150 years. As Baillie (1991) argues, the inherent uncertainties of radiocarbon dates may 'smear' these decadal events over longer periods, making them completely invisible. This, however, can be partially resolved by applying a more statistical analysis of the radiocarbon evidence using age–depth modelling, such as ^{14}C wiggle-matching or Bayesian modelling (Blaauw, 2012).

Acknowledgements. I thank João Cascalheira and Nuno Bicho for inviting me to present this paper at the SAA congress in Orlando, as well as two anonymous reviewers for their much appreciated comments. I am also very grateful to Russell Palmer for all text and language corrections.

Abbreviations. PBO, Preboreal oscillation; RMS, Rhine–Meuse–Scheldt; TQ, Tienen quartzite; WSQ, Wommersom quartzite.

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