SYNCHRONIZING A LATE GLACIAL ABRUPT COOLING EVENT WITH PALEOENVI-RONMENTAL AND POPULATION CHANGES: CASE STUDY OF THE MOERVAART PALEOLAKE AREA (NW BELGIUM)

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ABSTRACT. Sum probability and Bayesian modeling of a substantial series of radiocarbon dates from a former extensive lake area in NW Belgium, known as the Moervaart area, allow important hydrological changes to be synchronized with Greenland Interstadial 1b (or Intra-Allerød Cold Period). It is postulated that the disappearance of nearly all open water systems (Moervaart lake, anastomosing gullies, and dune-slacks) in response to this short but abrupt cooling event was responsible for a nearly total retreat of hunter-gatherers already some centuries before the start of Greenland Stadial 1 (Younger Dryas).

INTRODUCTION

The Moervaart region, situated in the sandy lowland of NW Belgium (Figure 1a–c), is an important area for Late Glacial and Early Holocene geoarchaeological research, as it is one of the rare areas in NW Europe in which high-resolution and high-quality paleoenvironmental data are available in close spatial relationships with prehistoric sites. The region is characterized by a complex and dynamic paleolandscape consisting of four major features (Figure 1d): (1) a massive coversand ridge, named the Great Sand Ridge of Maldegem-Stekene (De Moor and Heyse 1978; Verbruggen et al. 1996; Crombé et al. 2012); (2) a large but shallow freshwater inland paleolake, named the Moervaart Lake, immediately south of the Great Sand Ridge (Heyse 1979, 1983); (3) an anastomosing river system consisting of numerous shallow gullies, connected to the paleolake; and (4) a deep meandering paleochannel, belonging to the Kale (upper course) or Durme (lower course) River, which currently runs through the paleolake area from west to southeast where it joins the River Scheldt.

Within this landscape, numerous prehistoric settlement sites are known from the Final Paleolithic (Federmesser culture) and Mesolithic (Crombé et al. 2011). Evidence of human presence during the colder Younger Dryas, on the other hand, is almost entirely nonexistent in our current state of knowledge (Crombé et al. 2013). A particular feature is the strikingly higher density of Federmesser and Early Mesolithic sites compared to surrounding regions within the coversand area of NW Europe. Site density in the Moervaart area was very high, which led to the formation of almost continuous clusters of sites that formed various site complexes stretching over 10 to 15 km. These site complexes clearly exhibit intensive and recurrent occupation and exploitation of the area by Late Glacial and Early Holocene hunter-gatherers. A shift in settlement locations is apparent, in particular at the transition from the Final Paleolithic to the Early Mesolithic, characterized by changes in the focus of occupations from lake edges to riverbanks.

In order to explain these prehistoric occupation patterns in this particular area, intensive archaeological and paleoenvironmental research has been carried out in the framework of an interdisciplinary research project, conducted between 2008 and 2012. This project included detailed investigations of the paleotopography (Werbrouck et al. 2011; Crombé et al. 2013), paleohydrology (De Smedt et al. 2011, 2012; Zwertvaegher et al. 2013) and paleovegetation (Demiddele et al., unpublished data; Gelorini et al., unpublished data), combined with extensive radiocarbon dating. The present study focuses on the ¹⁴C evidence in an attempt to reconstruct the genesis and evolution of the different

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Figure 1 (a) Extent of the European coversand belt. The location of Belgium is indicated with an open square. (b) Schematic map of Belgium, showing some of the major rivers and the Pleistocene sedimentation areas in N Belgium. (c) Extent of the coversand area and major geomorphological units in NW Belgium. The study area of Sandy Flanders is indicated with an open square. (d) Simplified geomorphological map of Sandy Flanders (after Crombé et al. 2011).

paleolandscape features. Particular attention in this study will be given to possible climate-induced environmental changes that might have impacted the hunter-gatherer occupancy of this former lake area at the transition from the Pleistocene to the Holocene.

DESCRIPTION OF THE PALEOLANDSCAPE

In the Moervaart study area, numerous sandy ridges occur that are believed to have been formed during the final Pleniglacial and Late Glacial by eolian sedimentation (Heyse 1983). By far the most important one is the massive dune complex known as the Great Sand Ridge of Maldegem-Stekene (Figure 1d). Starting at the present-day North Sea coast, it extends west to east over a distance of ~80 km. Its width varies locally between 1 to 3 km and its height is generally >5 m above the surrounding topography. According to earlier studies (Heyse 1979, 1983), this feature was created by dominant northern winds providing the dune with a gentle northern slope and a steep southern slope. Recent investigations revealed that it is built up of thick coversand deposits alternating with thin (from a few cm to ~0.25/0.30 m) organic to peaty layers, the latter representing the remains of former temporary dune slacks and ponds (Crombé et al. 2012; Bos et al. 2013).

The Moervaart depression comprises the remains of one of many hundreds of shallow freshwater paleolakes in Sandy Flanders that are dated to the Late Glacial. These paleolakes are all situated along the southern steep slope of the Great Sand Ridge of Maldegem-Stekene (Figure 1d), suggesting that the latter is partially responsible for their formation. It is currently believed that these freshwater paleolakes came into existence while the Great Sand Ridge was forming and blocking the previously open northern exit route for surface waters (De Moor and Heyse 1978; Verbruggen et al. 1996). The paleolakes formed as surface water and groundwater accumulated in local closed depressions, filling the lakes with very calcareous gyttja sediments. Initially, such local lakes would be a few hundred meters in diameter, with some evolving into larger paleolakes covering several km². The Moervaart paleolake (Figure 2), situated ~1 m above present sea level, was by far the largest within NW Bel-



Figure 2 General map showing the rough limits of the Moervaart paleolake in which an anastomosing and meandering channel system were detected. North of the lake runs the Great Sand Ridge of Maldegem-Stekene.

gium, covering a maximum surface of $\sim 25 \text{ km}^2$. It developed within an asymmetric depression with a steep northern slope and gently sloping southern edge, the deepest part being situated in the center along the northern lakeside. Based on evidence from different aquatic proxies, such as aquatic pollen, macrophytes, chironomids, and diatoms, the maximum water depth is estimated at ~ 3 to 4 m; this was reached during the Allerød (Crombé et al. 2013). Recent drillings and excavations in the deepest part of the lake revealed a soil sequence of maximum ~ 2 m thick consisting of alternating (humic) calcareous gyttja (lake marls; layers D-F and J-L) and relatively thin strongly organic layers (layers C, G, I) (Figure 3). These lacustrine sediments are covered by a peat layer (layer M), which unfortunately is only locally preserved as a result of peat cutting and ploughing.





Figure 3 Top: photograph of the trench through the Moervaart paleolake sediments at the location "Suikerfabriek" (photo UGent, 2009). Trench details 1 and 2: Lithostratigraphy of the Moervaart paleolake sequence at two locations in the trench. Ap: plough layer; L-J upper lake marl; I-G: middle organic layer; F-D: lower lake marl; C: lower organic layer; B: Pleniglacial sand.

In the western part of the Moervaart paleolake, a complex network of narrow (\sim 15–20 m wide) and shallow (on average \sim 1.5–2.5 m deep) gullies was detected, which most likely coexisted as a small anastomosing network (De Smedt et al. 2012; Crombé et al. 2013) (Figure 2). The anastomosing gullies appear to have been flowing from the west and recharging the freshwater lake in the east. There is no evidence that they formed a major drainage element, and the negligible slope on which the gullies were active suggests that the flow may have been very slow or even stagnant as they drained into the receding lake.

Fieldwork also revealed that the northernmost part of the gully complex consists of a much larger, single meandering river channel (Figure 2). The channel measures between 30 and 50 m wide and reaches a depth of 4 to 6 m. The infilling consists of fine to broadly laminated brown to gray-colored sediment units, with a wide range of grain sizes (from sand to clay), organic matter (plant remains), and calcareous material (bivalves). This meandering deeper channel could be mapped from west to east, first running parallel with the northern paleolake edge and then halfway across the Moervaart paleolake changing its direction towards the south-southeast, inducing localized deep erosion of the lake sediments. Further east, the paleochannel connects to the current Durme Valley and joins the River Scheldt near Temse.

METHODS AND MATERIALS

Sampling and Dating

All four landscape features have been extensively sampled for ¹⁴C dating, yielding a total of 55 dates (see Appendix, online Supplemental file) divided as follows: the Moervaart paleolake (14 dates), the anastomosing river system (7 dates), the meandering river channel system (24 dates), and the Great Sand Ridge (10 dates). The samples were retrieved from both excavation trenches (Moerbeke "Suikerfabriek," Rieme "Noord," Klein-Sinaai "Boudelo") and mechanical coring. The Moervaart paleolake was sampled at three different locations, all situated in the central and deepest part of the lake. Five different shallow gullies from the anastomosing river system were sampled, while the meandering Kale/Durme paleochannel was studied at six different locations from west (Mendonk) to east (Daknam). Finally, ¹⁴C samples of the Great Sand Ridge were taken from organic (sub) aquatic layers at two different localities (Rieme and Wachtebeke). The sampling strategy consisted of either sampling entire soil sequences in a systematic way or targeted sampling of the base and top of sequences. The latter was mainly applied on the anastomosing gullies and at some sections of the meandering channel. Levels that were chosen for ¹⁴C dating were based on lithological and palynological events, such as the start of peat formation and changes in the AP/NAP ratio and other trends in the pollen curves (Gelorini et al., unpublished data).

In order to minimize the freshwater reservoir effect (Hatté and Jull 2013), accelerator mass spectrometry (AMS) ¹⁴C dating was conducted on small samples exclusively consisting of carefully selected terrestrial and semiaquatic macroremains (fruits and seeds), such as sedge (*Carex* spp.), club-rush remains (*Schoenoplectus lacustris*), birch (*Betula* spp.), gypsywort (*Lycopus europaeus*), among others (Appendix). Sample selection was done by Hanneke Bos from ADC ArcheoProjecten (Amersfoort, the Netherlands). The selection of terrestrial macroremains proved particularly difficult in the Moervaart paleolake and anastomosing gullies, as terrestrial remains in these lacustrine sediments are generally insufficiently present and/or in a bad state of preservation. As a result, several selected soil samples could not be used for ¹⁴C dating, which was particularly problematic for the upper gyttja sediments of the Moervaart paleolake (top 0.25 m of layer L) and the anastomosing gullies. Dating of the upper infilling of the deep meandering channel also turned out to be problematic due to modern peat extraction, which reached as deep as ~1.5 m. In addition, the low density of

terrestrial macroremains did not allow us to perform ¹⁴C dating on samples consisting of one single species. According to recent insights (Turney et al. 2000; Hatté and Jull 2013; Howard et al. 2013) samples of "fragile" macrofossils, such as *Betula* seeds or *Salix* leaves, are to be preferred for dating lacustrine and riverine deposits as these are less resistant to transport and hence provide a date that is in accordance with the deposition of the layer. As these macroremains are not sufficiently abundant within the analyzed soil sequences, we were forced to date composite samples, including plant remains from different terrestrial species.

All samples within the mentioned 2008–2012 research project were prepared using the conventional ABA (acid base acid) method. They were combusted, transformed into graphite (Van Strydonck and van der Borg 1990–1991), and AMS dated. KIA samples were measured in Kiel (Nadeau et al. 1998), and RICH samples in the Royal Institute for Cultural Heritage (Brussels) by means of a MICADAS. A few ¹⁴C samples were prepared and AMS dated in the Beta laboratory, Miami, Florida,USA (Appendix). Calibration was done according to the IntCal09 curve (Reimer et al. 2009).

Modeling

Sum probability calculations were performed using CALIB software (Stuiver and Reimer 1993) for each landscape feature separately (Figure 4). Dates KIA-18759 and KIA-47015 (Appendix) have not been included in the modeling because of their aberrant results. The former deviates considerably from the relative dating based on pollen data (Allerød; Gelorini et al., unpublished data), while the latter date might be contaminated due to peat cutting in the top of the channel infilling. This, however, needs to be further verified by means of additional ¹⁴C dating in the near future. Date KIA-46190 was also omitted because it provides a start date for peat growth rather than dating the period of activity of the anastomosing gully system.



Bayesian modeling was conducted in OxCal v 4.2.3 (Bronk Ramsey 1995, 2009). The central aim of Bayesian modeling was to refine the timing of the drying up of the paleolake and the incision and infilling of the meandering channel. For this reason, and also because of the lack of sufficient dates per sequence (Appendix), dates were excluded from the anastomosing gullies and dune slack sequences. Only the best sequences were incorporated from both the paleolake and channel contexts, which provided ¹⁴C dates over the total depth and were located from the central, most vital area of the transition zone between paleolake and channel. The informative prior for the model was provided by the geomorphological information yielded by the multiple geophysical analyses, as well as the deposition order of the dates. The model was therefore constructed using the *Sequence, Boundary, Phase*, and *Order* commands. A *Sequence* assumes that all of the events within a group are ordered,

whereas a *Phase* assumes there is no internal order. While most models of sedimentary sequences would use either the *P_sequence* or *U_sequence* models (Bronk Ramsey 2008), as just stated, our objective in this modeling procedure was the combination of multiple sequences from the paleolake and channel phases in order to focus on the *Boundary* of the paleolake-channel transition. The model sets up the general *Sequence* of the Moervaart system, in which this transitional *Boundary* lies between two contiguous phases (*Phase* Paleolake and *Phase* Channel) (Figure 5). These were set up as two separate phases because the two sequences that were included within them overlapped and were therefore not taken to be in order. The *Phase* Paleolake included the Moerbeke "Suikerfabriek" *Sequence* (4 dates) and the Moerbeke "Dambrug" *Sequence* (6 dates). The *Phase* Channel included the Wachtebeke "Penen" *Sequence* (4 dates) and the Moerbeke and the Moerbeke "Peerdemeers" *Sequence* (6 dates).



Agreement indices in OxCal facilitate the quantitative identification of problematic dates within the sequence, which might be intrusive or residual and thus need to be removed from the model (Bronk Ramsey 1995, 2009). OxCal determines a threshold of more than 60% as being close to the 5% confidence interval of a chi-squared test (Bronk Ramsey 1995:428). This showed that two

dates from the Moerbeke "Dambrug" sequence were highly problematic, and inclusion of either of these results at the appropriate point in the sequence resulted in an unsatisfactory overall index of agreement ($A_{model} < 60$; Bronk Ramsey 1995, 2009). These two dates, KIA-18758 (12,435 ± 53 BP) and KIA-18759 (8425 ± 55 BP) (Appendix), were clearly out of place in the sequence and needed to be removed in order for the model to run successfully. Both dates were taken from the top of layer J at depths of 105–95 cm, and therefore indicate possible contamination. Explaining these deviating dates is difficult since the first date is much older while the second one much younger with respect to the pollen dating (Allerød). The former could point to a freshwater reservoir effect but since only terrestrial macroremains have been used for ¹⁴C dating this is not a valid explanation. The too-young date on the other hand might result from admixture with intrusive plant material. The other paleolake sequence (Moerbeke "Suikerfabriek") and both of the channel phase sequences did not yield any problematic dates. Lastly, the *Order* function in OxCal enabled us to incorporate the date ranges of start of both the GI-1a and GI-1b climate events (Blockley et al. 2012) and interrogate their relative order against the *Boundary* paleolake-channel transition.

RESULTS

Sum Probability Modeling

The sum probability curves (Table 1, Figure 4) suggest that the Moervaart paleolake, the western anastomosing gully system, and the dune-slacks on the Great Sand Ridge were broadly active simultaneously. Their infilling started at the transition from the GI-2a (Oldest Dryas) to the GI-1e (Bølling) or early in the GI-1e, between ~14,850 and 14,500 cal BP, and continued during the main part of the Allerød (GI-1c). The youngest dune-slack dates are situated around 13,350/13,300 cal BP (Crombé et al. 2012), indicating they already dried out several decades before the end of Allerød, dated ~12,900 cal BP (Blockley et al. 2012). Due to the aforementioned sampling problems, the end of the sedimentation in the paleolake and anastomosing gullies is currently less precisely dated. However, the youngest dates from both hydrological systems demonstrate their final stage most likely is situated shortly after ~13,250/13,150 cal BP. In addition, ¹⁴C date KIA-46190 (Appendix) from the basis of a peat layer, which covers the lacustrine sediments in one of the shallow gullies (gully 6), proves the anastomosing river system stopped functioning as a discharge system before ~13,150 and ~12,846 BP, i.e. before the start of GS-1 (Younger Dryas). Furthermore, the basal dates of the deep meandering channel indicate an initial incision prior to ~13,150 cal BP. Since this channel locally cuts through the paleolake lacustrine sediments, it can be concluded that the lake already vanished or at least decreased in size and depth prior to the channel incision in the final stage of the Allerød.

	2.50%	25% (Q1)	75% (Q3)	97.50%
Moervaart paleolake	14,806 cal BP	14,171 cal BP	13,456 cal BP	13,245 cal BP
Anastomosing gullies	14,848 cal BP	14,119 cal BP	13,767 cal BP	13,163 cal BP
Great Sand Ridge	14,474 cal BP	13,963 cal BP	13,506 cal BP	13,336 cal BP
Meandering channel	13,144 cal BP	12,523 cal BP	10,897 cal BP	8910 cal BP

Table 1 Sum probability and interquartile range of the four paleolandscape features within the Moervaart study area.

From the above, it can be concluded that important hydrological changes occurred in the Moervaart area within the timespan of ~13,300/13,250 until 13,150/13,100 cal BP, i.e. during the final stage of the Allerød and clearly before the onset of the GS-1. A general drop in the groundwater level led to a considerable lowering of the water levels in the Moervaart lake and surrounding gullies and ponds,

most likely turning them either completely dry (dune-slacks) or into swamps with peat growth (lake and shallow gullies). Unfortunately, based on the summed probability calculation, it cannot be determined whether the incision of the meandering paleochannel occurred simultaneously or shortly after this drainage event. Further precision on this can be obtained by means of a Bayesian approach.

Bayesian Modeling

The model (Figure 5) returned a high agreement index ($A_{model} = 113.4$; $A_{overall}$: 112.9). As discussed, Bayesian modeling was undertaken in order to combine different sequences and define the boundary between the two contiguous phases of the paleolake and channel. The *Boundary* is an undated event that is postulated from the dates within the phase (Bronk Ramsey 2001). It therefore indicates the uncertainty of the date of the transitional event between the lake and channel phases. This boundary was modeled between 13,370 and 12,920 cal BP (Table 2). This boundary lies within the ranges of both the GI-1b and GI-1a events, which had start dates of 13,261 and 13,049 cal BP, respectively (Blockley et al. 2012). Results of the *Order* function in the model indicated a probability of 0.797 that the transition paleolake-channel occurred *after* the start of GI-1b and a probability of 0.8141 that the transition occurred *before* the start of GI-1a. These results thus suggest with rather high probability that the boundary of the paleolake-channel transition occurred before GI-1a, and is therefore most likely to be in direct response to GI-1b.

Table 2 Modeled boundary range for the start and end of the Moervaart paleolake and meandering channel using Bayesian analysis.

	Boundary modeled cal BP		
	Start	End	
Moervaart paleolake			
Moerbeke "Suikerfabriek"	14,722–13,998	13,757-13,181	
Moerbeke "Dambrug"	14,866–14,123	13,432-13,103	
Meandering channel			
Wachtebeke "Penen"	13,255-12,789	11,266-10,658	
Moerbeke "Peerdemeersen"	13,107–12,491	11,616–10,793	
Transition paleolake-meandering channel	13,367	12,921	

DISCUSSION

The available ¹⁴C dates from the Moervaart paleolake area in NW Belgium clearly point to considerable hydrological changes occurring well before GS-1 or the Younger Dryas. These changes include a drastic lowering of the water level in lakes and ponds as well as a transition from an anastomosing to a meandering discharge system. Sum probability as well as Bayesian modeling demonstrate that both these changes were most likely caused by a short but abrupt cooling event, the Intra-Allerød Cold Period IACP or GI-1b as known from the oxygen isotope record of the Greenland ice cores (Blockley et al. 2012) and the Gerzensee Lake record in Switzerland (van Raden et al. 2013). This climatic event, which was most likely triggered by catastrophic freshwater meltwater discharge from the Glacial Lake Iroquois out the Hudson Valley to the North Atlantic Ocean, is dated between ~13,350 and ~13,100 cal BP (Donnelly et al. 2005). This meltwater outburst likely influenced global oceanic thermohaline circulation and heat transport, i.e. by slowing it down. From the literature, it becomes clear that similar temporal lake-level drops, often leading to facies transitions, if not sedimentary hiatuses, have been observed within various smaller Allerød paleolakes within NW Europe, e.g. in the Netherlands (Hoek and Bohncke 2002; Bos et al. 2006), France (Deschodt et al.

2009), northern Germany and Denmark (Usinger 1981). Although these lake-level fluctuations are not always dated precisely, it is clear that they occurred near the end of the Allerød and prior to the start of the Younger Dryas.

The *Order* function in the OxCal model indicates that the start of GI-1b preceded the paleolake-channel transition, and this transition was therefore most likely in response to this climate change event. The close temporal correlation between the channel incision and the abandonment of the anastomosing gullies suggests that these two different elements may record the partly autocyclic reorganization of the local drainage system in response to the recession and ultimate cessation of lacustrine conditions in the Moervaart depression (De Smedt et al. 2012). The anastomosing gullies responded to the falling lake water table by migrating in conjunction with the eastwards-retreating paleoshoreline. As the lake proceeded to dry up, local water flow is interpreted to have reorganized and coalesced into the single channel system, leading to the abandonment of the small gullies as drainage elements. This would have been a direct response to the disappearance of the former lake. The drop of water level reorganized water and sediment transport through the incision of a single channel of greater width, depth, and carrying capacity than the multiple small channels. However, soon after its formation the flow within the meandering river became more tranquil, indicated by ostracod assemblages (Gelorini et al., unpublished data). According to the ¹⁴C evidence, the infilling of this deep channel continued into the Younger Dryas (GI-1) and the (Pre)boreal.

In terms of human occupation, it can be expected that these hydrological changes had a big impact on the lives of contemporaneous hunter-gatherers. As mentioned earlier, the Moervaart area is characterized by a very high incidence of Federmesser culture sites, probably testifying the important ecological value of the lake and its immediate environment, especially during the Allerød. Although none of these sites is actually dated by 14C, due to a lack of reliable dating samples (Crombé et al. 2011), the total absence of Federmesser sites along the meandering channel can be interpreted as a strong but indirect evidence of their dating prior to the incision of this channel. As a matter of fact, all Federmesser sites are located either along the northern edge of the Moervaart lake or on small sandy outcrops along the shallow gullies from the anastomosing system (Figure 6A). None are clearly or exclusively associated with the meandering channel, which was created in response to GI-1b; hence, it may be assumed that Federmesser hunter-gatherers had already left the area. Possibly, the draining of all shallow lakes and ponds in the Moervaart area was responsible for their retreat, as it turned the area into a much less attractive environment for human (and animal) occupation. Due to this hydrological event at the end of the Allerød, Federmesser hunter-gatherers living in seasonally concentrated sites along the northern lakeside were confronted with a sudden reduction of drinking water and probably also wild resources such as game and water plants.

Similar depopulations of specific areas in response to environmental changes have been observed in other parts of Late Glacial NW Europe. In the Thuringian Basin, situated in the uplands of central Germany, a settlement hiatus beginning prior to or at the Laacher See eruption (LSE), dated dendrochronologically to the late spring/early summer of 12,916 cal BP (Baales et al. 2002), was observed by Riede (2008). It is suggested that Federmesser hunter-gatherers that were present in the area during the whole of the Allerød had to shift to other regions since the LSE tephra fallout must have led to an acidification of freshwater resources used by elk and giant deer, the main prey animals of Federmesser hunters in northern Europe. Depopulation at the time of the LSE was also reported by Baales et al. (2001) in the Neuwied Basin of the Middle Rhine Basin, situated even closer to the Laacher See Volcano. Except for the site of Bad Breisig, all Federmesser sites in this area pre-date the LSE; remarkably, the ¹⁴C evidence seems to indicate that Federmesser occupation already ended some 100 to 300 yr before the eruption took place (Baales 2006), as if another event



Figure 6 Top: Plot of the maximum extent of the Moervaart depression (area within dashed line) and the distribution of Federmesser sites (dots) along the southern edge of the Great Sand Ridge of Maldegem-Stekene (shaded area) on top of the elevation model (Lidar, AGIV 2001–2004). Bottom: Plot of the maximum extent of the Moervaart depression (area within dashed line) and the distribution of Early Mesolithic sites (dots) along the course of the meandering channel (black line) and the southern edge of the Great Sand Ridge of Maldegem-Stekene (shaded area) on top of the elevation model (Lidar, AGIV 2001–2004).

caused depopulation (the IACP?). Further west, in Belgium and the southern Netherlands, the frequent occurrence of charcoal particles in the Usselo soil, formed during the Allerød, also testifies major environmental events. The weighted mean average of 23 ¹⁴C dates collected from the Usselo soil yields 10,988 \pm 26 BP, which corresponds to the final Allerød (Hoek and Bohncke 2002). The many charcoal particles probably result from forest fires that occurred as many *Pinus* trees died back as a result of changing climate. Unfortunately, the extremely poor chronological resolution of

the Federmesser culture in Belgium (De Bie and Vermeersch 1998) and the Netherlands (Lauwerier and Deeben 2011) does not allow a precise assessment of the impact that these large forest fires had on the contemporaneous hunter-gatherers, but it can be assumed that they considerably altered their way of living.

It therefore becomes clear that Federmesser hunter-gatherers in several parts of NW Europe (N Belgium, S Netherlands, W and central Germany) were faced with dramatic environmental stress situations induced either by climatic fluctuations (cold events) and/or catastrophic environmental events (forest fires, eruptions) already some decades before the onset of the extensive Younger Dryas cold period. During the final stage of the Allerød, i.e. between ~13,300 and 13,000 cal BP, relocation must have happened quite often, probably forcing men to reorganize their territories and social networks. One possible refuge area may have been northern France, where ¹⁴C evidence confirms Federmesser culture to have persisted unit the very end of the Allerød and even into the early stages of the Younger Dryas (Bodu and Valentin 1997; Fagnart and Coudret 2000).

It appears that the drastic decline of human occupation in the Moervaart area persisted throughout the entire Younger Dryas and Preboreal. Except for a few finds of so-called Malaurie points, lithic projectiles typical of (early stage) Younger Dryas cultures in France (Bodu 2000; Valentin 2006), no firm evidence of human activity during this cold oscillation is available (Crombé et al. 2014). Apparently, new cultures of hunter-gatherers regained interest in the area only from the start of the Boreal (~10,700 cal BP), now situating their camp sites preferably along the dry banks of the meandering small river that cuts through the former Moervaart lake (Figure 6B). Occupation shows the same density as during the Allerød, demonstrating that although the Moervaart lake had already vanished long before, the area regained its ecological importance. It seems that the meandering river and its floodplain offered the same conditions as the former lake, perhaps due to the formation of extensive peatlands.

CONCLUSIONS

Based on sound ¹⁴C evidence, a major hydrological event in an extensive lake environment situated in NW Belgium could be linked with a short but abrupt cooling event known as the Intra-Allerød Cold Period (IACP or GI-1b), which happened between ~13,350 and ~13,100 cal BP. This cold event most likely triggered a considerable lowering of the groundwater level that dried up all open water systems, including the large Moervaart paleolake (~25 km²) and surrounding shallow ponds and gullies. This in turn led to a reorganization of the local drainage system, resulting in the formation of a deep meandering channel, which rapidly changed into a tranquil river. In response to these dramatic hydrological changes, it is assumed that contemporaneous hunter-gatherers belonging to the Federmesser technocomplex were forced to leave the lake area prior to the climatic deterioration of the Younger Dryas. The disappearance or at least strongly reduced availability of drinking water for both humans and animals, probably combined with the harsh climatic and environmental conditions of GS-1, must have made this area highly unattractive until the onset of the Boreal.

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