The Dawn of the Mesolithic on the Plains of Poland

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Abstract

In this article we take a fresh look at the population dynamics of the Polish Plain in the transition from the Pleistocene to the Holocene, using Bayesian analysis and modelling of radiocarbon dates, and contrast the results with data from the North German Plain. We argue against simple adaptationalist models and instead see the cultural landscape as a complex patchwork of old forms and the emerging new traits of the early Mesolithic. We argue that the Mesolithic directly follows the Final Palaeolithic on the Polish Plain, without the chronological hiatus of 150–300 years that is often assumed for that region; while, by contrast, the two cultural patterns—Final Palaeolithic and microlith-based Mesolithic—overlapped significantly in time on the adjacent North German Plain.

Keywords Late Palaeolithic · Early Mesolithic · Radiocarbon dating · Pleistocene/Holocene transition · Settlement hiatus · Migration

Introduction

Notwithstanding many years of studies, the mechanism through which hunter-gatherer societies of northern and Central Europe adapted to environmental changes at the transition from the Pleistocene to the Holocene has not yet been satisfactorily described. Clearly, the transition from the Pleistocene to the Holocene is a period of dramatic climate change accompanied by the profound economic and cultural transformation of hunter-gatherer societies worldwide. These changes are particularly visible in the northern portions of America and Europe, where the significant warming of the climate brought about the replacement of tundra by woodlands with

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their associated fauna. In the eyes of many scholars studying this period, the transition from the Palaeolithic to the Mesolithic on the plains of Poland was accompanied by major population changes, as Palaeolithic hunters followed herds of reindeer on their northward migration, thus abandoning the area. Subsequently, and after a hiatus of up to three hundred years, the depopulated plains were thought to have been resettled by hunter-gatherers with Mesolithic cultural traditions. In this paper we challenge this simplistic view and argue that the relationship between the pace of global climatic changes and transformations of society and culture was more complex than usually assumed in simple adaptationist theories.

In focussing on the Final Palaeolithic and early Mesolithic in the central section of the European Plain—in the Polish Plain and the uplands bordering it to the south—we draw the line between the Final Palaeolithic and the Mesolithic not only chronologically, using an approach that takes into consideration climate change, socio-cultural transformation, and genetic data. The use of an inflexible chronological framework—that is, viewing the break between the Pleistocene and Holocene as also constituting the borderline between the Palaeolithic and the Mesolithic—tends to obscure the various changes in the life of hunter-gatherer communities that occurred at the onset of the Holocene. For both the Final Palaeolithic and the earliest stages of the Mesolithic, the genetic data at our disposal is too sparse to serve as a basis for a hypothesis addressing the differences between those two periods (Brace et al. 2019; Günther et al. 2018; Sánchez-Quinto et al. 2012). Hence this paper will differentiate between the Final Palaeolithic and Mesolithic using cultural data, especially those related to technology.

The term *Late Palaeolithic* will be used in relation to a period beginning with the exploitation of the European Plains by hunters and gatherers of the Hamburgian, c. 13,600–12,800 cal BC (13,000–12,500 BP). This period covers also later traditions of the Arch-backed Point Complex (Federmesser) and the Tanged Point Complex (Brommian, Ahrensburgian and Swiderian). The term *Final Palaeolithic* refers to the very end of the Palaeolithic and is used for the sites from c. 10,500 cal BC and younger, mostly Ahrensburgian and Swiderian ones, continued with the so-called Long Blade Industries or the Epi-Ahrensburgian. The people of those cultures centred their economy on late glacial fauna (mostly reindeer), although at the onset of the Holocene they also resorted to woodland-dwelling animals. Their hunting implements consisted mainly of tanged points and backed pieces (late Federmesser), while their organic-material tools included Lyngby axes and harpoons—whether uniserially or biserially barbed—made from reindeer antler. The large numbers of geometric microliths among excavated weapons, mainly triangles and truncated pieces, and of various points and harpoons made from antlers or bone from deer and other woodland fauna, is characteristic of the Mesolithic. Elk antler mattocks are yet another implement characteristic of the onset of the Mesolithic in NW Europe.

The transition from the Palaeolithic way of life to a life in the Early Holocene woodlands of the plains where Poland lies today has been the subject of lively debate for many years. The underlying cause—a warming post-glacial climate and the related ecosystem response—has always been clear, but the speed of socio-cultural and technological changes, and the mechanisms driving them, continue to be open to various interpretations. A few years ago these issues were addressed in

detail in subject literature by Polish researchers specialising in this area (Kabaciński 2016; Kabaciński and Sobkowiak-Tabaka 2010; Kobusiewicz 1999; Schild 1996a, 2001; Sobkowiak-Tabaka 2011, 2016). The same transition has also been the subject of intense debate in the context of the North German Plain, that is, the westernmost segment of the Central European Plain (the western and northwestern sections of the Plain: Brinch Petersen 2009; Conneller et al. 2016; Crombé et al. 2009; Gramsch 1973; Groß 2014; Møller Hansen and Buck Pedersen 2006; Rozoy 1978; Sørensen et al. 2018; Street et al. 2001; Tolkendorf et al. 2009; Terberger 2004, 2006; Weber et al. 2011; Zander 2016).

Polish scientific literature on the subject traditionally held that the transition from the Palaeolithic to the Mesolithic in Poland was related to large-scale human migrations (Galiński 1997, 2002; Ginter 1973; Kabaciński 2016; Kabaciński and Sobkowiak-Tabaka 2010; Kobusiewicz 1999; Kozłowski 2001; Kozłowski and Kaczanowski 2003; Kozłowski and Kozłowski 1975, 1977; Kozłowski 1969, 1972; Schild 1996a, 1996b, 2001; Sobkowiak-Tabaka 2011, 2016; Więckowska 1975). Such a perspective envisioned that Final Palaeolithic hunters—particularly communities representing the Swiderian—left the Polish plains and neighbouring uplands and moved north in the wake of migrating herds of reindeer. Such a process, according to the chronology developed through radiocarbon dating and palynological data, happened at the onset of the Preboreal. Reindeer hunters were replaced by an inflow of hunter-gatherers from the West—and possibly South—who represented Mesolithic cultural traditions and were already adapted to a woodland habitat. Many researchers place the arrival of these hunters some 150–300 years after the envisioned exodus of the Final Palaeolithic population (Kabaciński 2016; Kozłowski 2001; Schild 1996a, 1996b; Sobkowiak-Tabaka 2016). Hence a population hiatus was envisaged for the area today occupied by Poland.

In recent years, the growing number of radiocarbon dates and new techniques of sample preparation, along with the use of accelerator mass spectrometry (AMS) and statistical modelling of dates have all contributed to a more robust foundation on which to base discussions of the chronology of change (Blockley et al. 2004; Bronk Ramsey 1995, 2009a, 2009b; Bronk Ramsey et al. 2006, 2010). Attempts at identification of the pace of development of early Mesolithic settlements in other parts of Europe have resulted in interesting findings which provide a mathematical and statistical foundation for chronological hypotheses (Conneller et al. 2016). It is now possible to treat dates provided by radiocarbon analysis as mathematical data with a certain probability distribution. Previously these had been analysed and treated like dates of historical events, and although in the best circumstances their analysis was conducted by the clustering of radiocarbon dates with a single linkage method (Schild 1996b, Figs 3, 4), one should keep in mind that in the 1990s calibration techniques were very unreliable. We intend to use statistical modelling—which allows for more precise definition of time brackets of studied events—for a more detailed description of the phenomena behind those dates. Chronological models produced in this way will serve as the basis for examination of the mechanisms and pace of cultural changes in the Polish Plain at the transition from the Final Palaeolithic to the Mesolithic. We will supplement our efforts with modelling of radiocarbon dates from the Pleistocene–Holocene transition from the North German Plain, in order to

examine cultural and population changes from a broader perspective. When discussing the social phenomena accompanying such changes, particular attention will be paid to the issue of possible human migrations—such population movements being extensively used in previous interpretations of cultural changes in the Polish Plain during the transition from the Pleistocene to the Holocene. The dates presented in the text are calibrated radiocarbon date estimates given in the standard cal BC form at 95.4% (2 Sigma) range, with uncalibrated radiocarbon ages given as BP in brackets. The calibration of radiocarbon measurements was made using the programme OxCal, version 4.3 (Bronk Ramsey 2009a; Bronk Ramsey and Lee 2013) with a ^{14}C age calibration curve IntCal 13 (Reimer et al. 2013). The *BC* dates in *italic* present the chronology based on the Bayesian modelling of (calibrated) date estimates.

Study Area

The area covered by this study lies at the junction of two large physico-geographical regions, the North European and East European Plains (Kondracki 1998; Solon et al. 2018). Most of the evaluated material comes from the former, with only a few sites from northeastern Poland (Dudka, Łajty, Morąg, Krutynia River) being located in the Masurian Lakeland, a part of the Eastern Baltic–Belarus Lowland and thus included in the East European Plain. The subject area is bordered from the south by uplands and low mountain ranges, the Sudeten and Carpathians, with only a small section of the latter—the Tatra Mountains—exceeding 2000 metres above sea level (masl). The Polish Plain drains to the Baltic through two main river systems—the Vistula and Oder—and through some smaller river systems, for example the Łyna, a tributary of the Pregoła River and the Pomeranian rivers, for example the Rega, Parsęta, and Wieprza, that empty directly into the Baltic.

The relief of the Polish Plain was in large part shaped during Pleistocene glaciations, the latest of which, the Weichselian, at its peak covered northern and north-western Poland (Fig. 1). A post-glacial landscape consists of a rolling plain with lines of terminal moraines as well as other features associated with glaciations: outwash plains, drumlins and eskers. Some moraines exceed 300 masl; Wieżyca, the highest point of the North European Plain, has an absolute height of 328.7 masl, and stands some 270 m above the surrounding terrain. At the end of the Pleistocene the Polish Plain was subject to extensive aeolic accumulation processes, in some places forming entire dune fields (Kozarski et al. 1969; Nowaczyk 1986; Zeeberg 1998). One of the largest such fields is found in western Poland, between the Warta and Noteć Rivers, with some of the dunes having a relative height of 20–40 m (Pilarczyk 1958, 1976). The underlying tectonic structure, with an inclination towards the northwest, produces asymmetric river basins, this being particularly visible in the case of the major rivers running south to north, namely the Vistula and Oder, whose right-bank tributaries significantly outnumber left-bank ones. The areas covered by the latest glaciations contain many lakes of different size (up to 113.8 km²) and

Fig. 1 Final Palaeolithic and early Mesolithic sites with radiocarbon dates in the North German and Polish Plain, and the Eifel. 1—Bedburg-Königshoven 2, 3—Bolków 1; 4, 5—Bützsee-Altfricksack; 6, 7—Całowanie 3; 8—Chwalim 1; 9—Dudka 1; 10—Duvensee 1; 11—Duvensee 11; 12—Duvensee 2; 13—Duvensee 6; 14—Duvensee 8; 15—Duvensee 9; 16—Friesack 27a; 17—Friesack 4; 18—Grabek 11; 19—Greden-Schencking sandpit; 20—Groß Lieskow; 21—Haverbeck; 22—Hohen Viecheln; 23—Kartstein; 24—Kochlew 1; 25—Kopanica 29; 26—Krutynia river; 27—Łajty 1; 28—Łęg Ręczniński; 29—Łykowe 1; 30—Mokracz; 31—Mönchengladbach-Geneicken; 32—Morag; 33—Murowana Goślina; 34—Nahe LA 11; 35—Paderborn-Sande; 36—Potsdam-Schlatt; 37—Smolno Wielkie 2; 38—Stellmoor; 39—Tanowo 3; 40—Unseburg; 41—Wehldorf 7; 42—Werl-Büderich; 43—Wojnowo 2; 44—Wojnowo 4; 45—Wojnowo a; 46—Wustermark 22

depth (up to 106 m), which in many epochs have attracted human settlement to their banks.

The North European Plain is part of the lowlands running longitudinally from the Urals to the Atlantic. It has no real natural borders setting it off from the lowlands to east or west. For instance, the Oder River, used as the western limit of the Polish Plain, is not much of a natural barrier. The German sites included in this study are mostly located on the North European Plain, the exception being Kartstein in the Eifel. There are no major natural obstacles to the migration of fauna and flora, or to the westward movement of air masses—maritime, from the Atlantic, and inland, or continental, from Russia. Neither does the lay of the land hinder the movement of human groups, from West to East or South to North. At the close of the Pleistocene the mountain ranges to the south of the Polish Plain, the Sudeten and Carpathians, did not constitute any sort of impassable barrier, as a result both of their unimpressive elevation and of numerous passes and gaps

(Burdukiewicz 1999, p. 49; Burdukiewicz and Bronowiecki 1999, pp. 176–179; Rydlewski and Valde-Vowak 1979, pp. 5–6, 31–32).

Cultural Background

We shall not discuss in detail the cultural landscape of Central Europe in 10,500–9000 cal BC, but only provide a short summary of the cultural traditions then in existence. At the end of the Pleistocene, this area was inhabited by hunter-gatherer communities of the Tanged Point Complex, whose way of life was largely dependent upon reindeer herds. Two cultures are identified, the Ahrensburgian in the West and the Swiderian in the East, and these differ in the types of tanged points used—Ahrensburgian or Swiderian, the latter with a flat retouch of a tang or a base on a ventral side. Such tools were made from blades knapped off mainly from double platform cores with opposite platforms. A few researchers admit the possible existence of a distinct Ahrensburgian–Swiderian cultural unit in what is now western Poland, which used the two types of tanged points (i.e. both the Ahrensburgian and Swiderian) in parallel (Kobusiewicz 2004). It is also probable that in the Final Palaeolithic there were some groups of the Federmesser tradition in the North European Plain (Sobkowiak-Tabaka 2011).

Current thought holds that the end of the Pleistocene in the North European Plain brought about the appearance of human groups with a modified toolset, termed Epi-Ahrensburgian, whereas in northern France and southern England we now note characteristic inventories with long blades (Long Blade Industries) knapped from double platform cores with opposite platforms (Barton 1998; Brinch Petersen 2009; Galiński 2018; Gob 1991; Johansen and Stapert 2000; Sørensen et al. 2018; Weber et al. 2011; Zander 2016). Epi-Ahrensburgian inventories from the Netherlands, northern Germany, Denmark, and Sweden as well as northwestern Poland all share the feature of including microlithic forms, mostly small Zonhoven points, as well as no—or very few—tanged points. These late finds are not dated in a reliable manner, with only northern French assemblages—termed Belloisien—and those from southern England being radiocarbon dated to 9700–9400 cal BC; the finds from northwestern Poland are dated to 9600–9300 cal BC, or maybe even later. Such dates give rise to the theory that at the onset of the Preboreal various areas of the European Plain were home to cultural traditions rooted in the Final Palaeolithic.

The beginnings of the Mesolithic in the Polish Plains are linked with the appearance in archaeological inventories of numerous microliths in the form of truncated and backed points, triangles and crescents. These forms dominate toolkits and are chiefly used as arrowhead elements, with bows gaining in popularity in the Holocene woodland environment (Rozoy 1989). Such assemblages from southern Scandinavia are termed the Maglemosian, with the name *Duvensee complex* applied to North European Plain finds; whereas in Poland the accepted term is the *Duvensee-Komornica Complex* or the *Komornician* (Brinch Petersen 2009; Kabaciński 2016; Kobusiewicz 1999; Kozłowski 1989; Terberger 2004, 2006). Today the oldest Maglemosian finds are dated to 9600–9500 cal BC (Jessen et al. 2015), that is, to the

very dawn of the Preboreal, although other early Mesolithic sites from the North European Plain are slightly younger.

Materials and Methods

Studies of the chronology of the Final Palaeolithic and early Mesolithic in the North European Plain are affected by the specific conditions influencing deposition. The last global-scale sedimentation event in this area had been the formation of dunes, the last phase of which took place in the Younger Dryas. However, the settlement processes pertinent to this study are of a younger age and occurred later. Hence most Final Palaeolithic and Mesolithic sites dating from the Pleistocene–Holocene transition are found in sandy sediment, in the same level. Such conditions are not favourable to the preservation of organic matter that could be radiocarbon dated. Sites with clear stratigraphical relationships and rich in organic finds are few and far between, and mostly come from the banks of bodies of water subjected to eutrophication during the Holocene. Layers with organic remains allowing environmental studies and radiocarbon dating are usually located at a camp's periphery, at the shoreline of the body of water alongside which the camp was established, or in shallow water.

Other important sources are single finds of bone and antler artefacts of forms typical for the Final Palaeolithic and early Mesolithic. Their dating provides important pointers as to the duration—or point of emergence—of artefacts characteristic of the Final Palaeolithic and early Mesolithic, such as Lyngby axes or specific types of harpoons. Nevertheless, one should keep in mind that such single finds need to be approached with caution, as some forms may have been in existence for longer periods, from the Late Palaeolithic up to the early Mesolithic (Cziesla and Pettitt 2003).

Unworked reindeer antlers may serve as supplementary material for dating purposes. The presence of such antlers implies the existence of a local population of reindeer—a species highly characteristic of the Pleistocene in the Polish Plain. Whereas artefacts made from reindeer antlers might have been imported from the north, it is very unlikely that unworked antlers had been subject to such exchange. Hence the latest finds of such unworked antlers mark the end of the last herds of reindeer in this part of Europe. Naturally this does not preclude imports of antlers or antler artefacts during later phases of the Mesolithic, a good example of which is the recent find of the baton at Gołębiewo, central Poland (Osipowicz et al. 2017).

Our analysis is based upon radiocarbon dating from Final Palaeolithic and Mesolithic sites from the plains of Poland. The dataset consists of dates in the bracket 10,550–8250 cal BC (10,500–9000 BP) (Tables 1, 2, 3, 4). The southernmost sites included in the analysis are Łykowe and Kochlew from the Pyszna and Nieciecz interfluvium—an area where the southern Polish Plain abuts the Wieluń upland (Majchrowska and Popińska 2018, Fig. 4). As already mentioned, this study also uses—as auxiliary material—radiocarbon dates from this period from sites located in present-day Germany, mostly from the North German Plain, with some dates from the Eiffel (Kartstein) as well (Tables 5, 6, 7, 8). We should point out that some dates from the relevant time brackets were excluded from the analysis: those from stratified sites which are evidently inconsistent with the surrounding stratigraphy

Table 1 Radiocarbon dates from the Final Palaeolithic sites of the Polish Plain

No.	Site	Region	Radiocarbon age BP	Sample code	Calibrated date BC (2σ)	Sample	Context	References
1	Bolków 1, concentration 1	Pomerania	10,280 ± 40	MKL-1875	10,430–10,400 (1.7%) 10,290–10,260 (2.5%) 10,230–9880 (91.2%)	Charcoal	Pit no. 2	Galiński 2015a, 11
2	Bolków 1, concentration PF/2011, layer 7/6	Pomerania	9910 ± 50	MKL-3349	9650–9600 (5.2%) 9550–9480 (5.2%) 9460–9270 (85%)	Birch wood	Settlement concentration	Galiński 2018, Table 1
3	Bolków 1, concentration PF/2011, layer 6	Pomerania	9680 ± 50	MKL-3351	9270–9120 (62.7%) 9080–9050 (1.7%) 9020–8840 (31%)	Birch wood	Settlement concentration	Galiński 2018, Table 1
4	Całowanie 3	Mazovia	10,455 ± 90	GrN-5409	10,680–10,100	Charcoal	Shore zone of island	Schild 2014, Table II
5	Całowanie 3	Mazovia	10,140 ± 80	Gd-1648	10,130–9450	Charcoal	Shore zone of island	Schild 2014, Table II
6	Całowanie 3	Mazovia	10,030 ± 120	Gd-2147	10,060–9290	Burned twig	Shore zone of island	Schild 2014, Table II
7	Całowanie 3	Mazovia	9935 ± 110	GrN-5254	9980–9940 (1.0%) 9880–9230 (94.4%)	Charcoal	Shore zone of island	Schild 2014, Table II
8	Całowanie 3	Mazovia	9750 ± 80	Gd-1662	9370–9110 (74.3%) 9080–9040 (2.0%) 9020–8840 (19.0%)	Charred twig	Shore zone of island	Schild 2014, Table II
9	Całowanie 3	Mazovia	9700 ± 80	Gd-1717	9300–9100 (55.1%) 9090–8830 (40.3%)	Charred twig	Shore zone of island	Schild 2014, Table II
10	Grabek 11	Central Poland	10,430 ± 90	Lod-939	10,630–10,060	Peat	Connected with Swiderian settlement	Plaza et al. 2015, Table 2

Table 1 (continued)

No.	Site	Region	Radiocarbon age BP	Sample code	Calibrated date BC (2σ)	Sample	Context	References
11	Kochlew 1	Great Poland	10,320 ± 220	Lod-142	10,720–9440 (94.8%) 9430–9410 (0.6%)	Charcoal	Fireplace (structure V)	Cyrek 1996
12	Kochlew 1	Great Poland	10,260 ± 210	Lod-143	10,630–9340	Peat	Connected with Swiderian settlement	Cyrek 1996
13	Kopаница 29	Great Poland	10,470 ± 60	Poz-76625	10,620–10,170	Charcoal	Near campsite	Schild 2016, Table 1
14	Krutynia River	Masuria	10,045 ± 40	AAR-26646	9810–9440 (92.3%) 9430–9400 (3.1%)	Lyngby axe of reindeer antler	Stray find	Philippsen et al. 2019, Table 1
15	Łęg Ręczyński	Central Poland	10,270 ± 220	Lod-328	10,670–9340	Peat	Connected with Swiderian settlement	Plaza et al. 2015, Table 2
16	Łykowe 1	Great Poland	10,380 ± 220	Lodz-148	10,760–9640 (90.7%) 9620–9460 (4.7%)	Charcoal	Next to Late Palaeolithic artefacts	Cyrek 1996
17	Mokracz	Central Poland	10,260 ± 210	Lod-280	10,630–9330	Charcoal	Settlement layer	Plaza et al. 2015, Table 2
18	Morag	Masuria	9840 ± 45	AAR-26647	9380–9240	Lyngby axe of reindeer antler	Stray find	Philippsen et al. 2019, Table 1
19	Murowana Goślina	Great Poland	9890 ± 50	Poz-15118	9650–9610 (2.4%) 9520–9500 (1.4%) 9460–9250 (91.6%)	Lyngby axe of reindeer antler	Stray find	Goslar et al. 2006, 7
20	Wojnowo 2, WKT 1/88	Lubusz Land	9880 ± 170	Gd-2976	10,050–9110 (86.3%) 9090–8830 (9.1%)	Charred wood	Peat bog near campsite	Kobusiewicz and Bower 2016, 228; Schild 2016, Table 1

Table 1 (continued)

No.	Site	Region	Radiocarbon age BP	Sample code	Calibrated date BC (2 σ)	Sample	Context	References
21	Wojnowo 2, WKT I/88	Lubusz Land	10,130 ± 120	Gd-2975	10,280–10,270 (0.3%) 10,210–9310 (95.1%)	Charred wood	Peat bog near campsite	Kobusiewicz and Bower 2016, 228; Schild 2016, Table I
22	Wojnowo 2, WKT I/86	Lubusz Land	10,260 ± 100	Gd-5045	10,560–10,560 (0.2%) 10,470–9660 (94.9%) 9570–9560 (0.3%)	Charcoal	Peat bog near campsite	Kobusiewicz and Bower 2016, 228; Schild 2016, Table I
23	Wojnowo 2, WKT I/88	Lubusz Land	10,340 ± 130	Gd-6096	10,630–9750 (94.7%) 9720–9690 (0.7%)	Charcoal	Peat bog near campsite	Kobusiewicz and Bower 2016, 228; Schild 2016, Table I
24	Wojnowo 4, WTIII/11	Lubusz Land	10,000 ± 60	Poz-43873	9800–9780 (1.4%) 9780–9310 (94.0%)	Charcoal	Peat bog near campsite	Kobusiewicz et al. 2016, 279; Schild 2016, Table I
25	Wojnowo a	Lubusz Land	10,410 ± 50	Poz-66522	10,580–10,520 (6.7%) 10,490–10,120 (88.7%)	Charcoal	Flint concentration 179	Kobusiewicz 2016, 179
26	Wojnowo a	Lubusz Land	10,400 ± 50	Poz-66524	10,570–10,520 (4.4%) 10,480–10,110 (91.0%)	Charcoal	Flint concentration 179	Kobusiewicz 2016, 179
27	Wojnowo a	Lubusz Land	10,310 ± 50	Poz-66521	10,440–10,000 (93.9%) 9920–9900 (1.5%)	Charcoal	Flint concentration 179	Kobusiewicz 2016, 179

Table 1 (continued)

No.	Site	Region	Radiocarbon age BP	Sample code	Calibrated date BC (2σ)	Sample	Context	References
28	Wojnowo a	Lubusz Land	10,250 ± 50	Poz-66523	10,420–10,410 (0.2%) 10,280–10,260 (0.7%) 10,220–9810 (94.5%)	Charcoal	Flint concentration	Kobusiewicz 2016, 179
29	Wojnowo a	Lubusz Land	10,210 ± 50	Poz-66525	10,170–9800 (94.5%) 9790–9770 (0.9%)	Charcoal	Flint concentration	Kobusiewicz 2016, 179

Table 2 Methods of radiocarbon analysis of samples from the Final Palaeolithic sites in the Polish Plain

Dates Sites	Radiocarbon dates without AMS	AMS radiocarbon dates	Number
Stratified sites	15	2	17
Flint concentrations in sandy areas	4	5	9
Stray antler/bone artefacts	—	3	3
Number	19	10	29

and are either too old or too young to be in sequence with the layers they were found in. This is the express reason for rejecting the date from Level V of the site at Całowanie (Gd-5202). Also excluded are dates going beyond 8250 cal BC from layers termed *Sedimentkomplex* III at Friesack 4, as these are evidently not related with the pioneer stage of settlement, but rather with an already well-established population (Gramsch 2016, Table 1).

The dataset used for our analysis consists of 160 radiocarbon dates (Tables 1, 2, 3, 4, 5, 6, 7, 8), of which 55 come from Poland and 105 from Germany. Our research identified 29 Final Palaeolithic dates from Poland, originating from 14 sites spread across the Polish Plain (Fig. 1; Tables 1, 2). Twenty-six dates were produced by seven early Mesolithic sites (Fig. 2; Tables 3, 4). Of greatest value for the study are dates from stratified sites, where the samples were taken from clearly defined layers containing settlement structures in the form of flint artefact concentrations. The most relevant finds are those from the site of Całowanie (on an ancient island in the valley of the Vistula) where the site contains stratigraphically arranged remains of Late and Final Palaeolithic, and Mesolithic settlement. Radiocarbon dating of finds from shoreline layers is just as valuable. Of greatest importance are the artefacts from Bolków, site 1, in northwestern Poland (Pomerania), where the habitation from both relevant periods was recorded. A smaller number of dates comes from charcoal and bones found inside flint artefact concentrations in sandy areas, with only three dates coming from reindeer antler items—Lyngby axes. Ten AMS dates (over one-third of the total) are currently available for the Final Palaeolithic, with only five Mesolithic dates derived in this manner. Other radiocarbon dates were produced using older laboratory protocols and their standard deviations are quite significant—most of them in the range 80–320 radiocarbon years; age ranges based upon these dates are consequently quite broad. Note that the attribution of the two oldest dates from Dudka 1 (Nos. 19 and 20 in Table 3) is open to debate; as these contain few flint artefacts the question is—are these dates related to layers associated with early Mesolithic or Final Palaeolithic settlement (Fiedorczuk 1995; Gumiński 1995)? We followed the opinion of Witold Gumiński and consider that it is more likely that the above finds are associated with the early Mesolithic.

Radiocarbon dating from Poland is analysed alongside results of analysis from Final Palaeolithic and Mesolithic sites from northern Germany (Tables 5, 6, 7, 8). Our article takes into consideration 31 Final Palaeolithic dates from seven sites, and

Table 3 Radiocarbon dates from the early Mesolithic sites of the Polish Plain

No.	Site	Region	Radiocarbon age BP	Sample code	Calibrated date BC (2σ)	Sample	Context	References
1	Bolków 1, layer 5	Pomerania	9480 ± 50	MKL-3350	9120–9000 (21.4%) 8920–8890 (3.1%) 8880–8630 (70.9%)	?	Refuse area	Galinski 2018, Table 1
2	Bolków 1, layer 5	Pomerania	9420 ± 90	MKL-3352	9140–8970 (13.9%) 8940–8460 (81.5%)	?	Refuse area	Galinski 2018, 23
3	Bolków 1, layer 5	Pomerania	9320 ± 40	MKL-1877	8710–8460	Animal bone	Layer in concentration 'S'	Galinski 2014, 85
4	Bolków 1, layer 5/6	Pomerania	9110 ± 50	Gd-3428	8460–8250	Charcoal	Layer in concentration 'E'	Galinski 2014, 85
5	Bolków 1, layer 5/6	Pomerania	9030 ± 50	Poz-55826	8320–8190 (88.9%) 8110–8090 (1.5%) 8080–8060 (0.7%) 8040–7990 (4.2%)	Animal bone	Layer in concentration 'E'	Galinski 2014, 85
6	Całowanie 3	Mazovia	9510 ± 70	CAMS-20867	9150–8640	Charred <i>Polygonum</i> tuber	Shore zone of island	Schild 2014, Table II
7	Całowanie 3	Mazovia	9410 ± 110	Gd-2734	9140–8420 (93.3%) 8410–8390 (0.7%) 8380–8350 (1.4%)	Charred twig	Shore zone of island	Schild 2014, Table II
8	Całowanie 3	Mazovia	9390 ± 70	CAMS-20870	9110–9080 (1.4%) 9050–9020 (1.2%) 8840–8450 (92.8%)	Charred <i>Polygonum</i> tuber	Shore zone of island	Schild 2014, Table II
9	Całowanie 3	Mazovia	9380 ± 80	Gd-1721	9120–9080 (1.8%) 9060–9020 (1.6%) 8840–8420 (89.8%) 8410–8350 (2.3%)	Charred twig	Shore zone of island	Schild 2014, Table II
10	Całowanie 3	Mazovia	9370 ± 60	Gd-1719	8800–8470	Charred twig	Shore zone of island	Schild 2014, Table II
11	Całowanie 3	Mazovia	9350 ± 100	Gd-2198	9120–9080 (1.7%) 9060–9020 (1.6%) 8840–8300 (92.1%)	Charred twig	Shore zone of island	Schild 2014, Table II

Table 3 (continued)

No.	Site	Region	Radiocarbon age BP	Sample code	Calibrated date BC (2 σ)	Sample	Context	References
12	Całowanie 3	Mazovia	9250 ± 55	GrN-5251	8620–8320	Charcoal	Shore zone of island	Schild 2014, Table II
13	Całowanie 3	Mazovia	9200 ± 75	GrN-5442	8610–8290	Charcoal	Shore zone of island	Schild 2014, Table II
14	Całowanie 3	Mazovia	9080 ± 100	Gd-2149	8570–8160 (81.7%) 8150–7970 (13.7%)	Charred twig	Shore zone of island	Schild 2014, Table II
15	Całowanie 3	Mazovia	9030 ± 50	Gd-3041	8320–8190 (88.9%) 8110–8090 (1.5%) 8080–8060 (0.7%) 8040–7990 (4.2%)	Charred twig	Shore zone of island	Schild 2014, Table II
16	Chwalim 1, Bed 2, base	Lubusz Land	9565 ± 90	Gd-1164	9230–8710 (94.9%) 8670–8660 (0.5%)	Charcoal	Short settlement layer	Kobusiewicz and Kabaciński, 1993, Table 55
17	Chwalim 1, Bed 2, top	Lubusz Land	9500 ± 75	Bln-1766	9150–8630	Charcoal	Short settlement layer	Kobusiewicz and Kabaciński, 1993, Table 55
18	Chwalim 1, Bed 2, top	Lubusz Land	9385 ± 75	Gd-1165	9120–9070 (1.7%) 9060–9020 (1.5%) 8840–8430 (91.6%) 8370–8350 (0.6%)	Wood	Short settlement layer	Kobusiewicz and Kabaciński, 1993, Table 55
19	Dudka 1, cut I	Masuria	9710 ± 150	Gd-4305	9660–9580 (2.0%) 9550–8700 (92.6%) 8680–8650 (0.8%)	Charcoal	Bank zone of lake	Gumiński 1995, Table I; Fiedorczuk 1995, Table 2; 56
20	Dudka 1, cut I	Masuria	9610 ± 70	Gd-3310	9230–8790	Charcoal	Littoral of lake	Gumiński 1995, Table I; Fiedorczuk 1995, Table 2; 56
21	Dudka 1, cut I	Masuria	9130 ± 130	Gd-6698	8710–8670 (1.5%) 8660–8160 (84.6%) 8150–7970 (9.3%)	Charcoal	Bank zone of lake	Gumiński 1995, Table I; Fiedorczuk 1995, Table 2; 57

Table 3 (continued)

No.	Site	Region	Radiocarbon age BP	Sample code	Calibrated date BC (2 σ)	Sample	Context	References
22	Łajty 1	Masuria	9420 ± 100	Gd-8027	9150–8450 (95.2%) 8360–8360 (0.2%)	?	Cultural layer	Sulgostowska 1996, 300
23	Łajty 1	Masuria	9240 ± 320	Gd-4584	9320–7600	?	Cultural layer	Sulgostowska 1996, 300
24	Łajty 1	Masuria	9150 ± 200	Gd-4588	9120–9010 (2.5%) 8920–8900 (0.4%) 8860–7750 (92.5%)	?	Cultural layer	Sulgostowska 1996, 300
25	Smolno Wielkie 2	Lubusz Land	9580 ± 40	Poz-58470	9172–9169 (0.3%) 9160–8790 (95.1%)	Charcoal	Peat bog	Schild 2016, Table I
26	Tanowo 3	Pomerania	9150 ± 55	Poz-1378	8540–8510 (5.1%) 8490–8270 (90.3%)	Bone	Concentration in cut XVIII/1001–02	Galiński 2015b, 18

Table 4 Methods of radiocarbon analysis of samples from the early Mesolithic sites in the Polish Plain

Dates Sites	Radiocarbon dates without AMS	AMS radiocarbon dates	Number
Stratified sites	21	4	25
Flint concentrations in sandy areas	—	1	1
Stray antler/bone artefacts	—	—	—
Number	21	5	26

74 dates from 17 early Mesolithic sites. As concerns the Final Palaeolithic dates, a major portion—20, or 64.5%—comes from Kartstein and Stellmoor. Most of these radiocarbon dates (with the exception of two from Kartstein) were calculated in the 1980s, at laboratories in Köln and Copenhagen, without AMS, with standard deviation up to 45–105 years. Their results are being questioned due to their wide spread, which suggests a very prolonged final phase of the Ahrensburgian, extending into the early Holocene (Street et al. 2001; Weber et al. 2011), which is inconsistent with the model of rapid cultural changes in the early Holocene brought about by rapid climatic and environmental changes. Hence only Younger Dryas dates from these sites are accurate (Weber et al. 2011, pp. 291–292). One should note, however, that no scientific criticism of these dates has previously been made. At the same time, the two dates obtained by the Oxford ORAU laboratory for bones from Stellmoor are from the early Holocene. It is worth adding that the late—i.e. early Holocene—dates for Kartstein were obtained independently at different laboratories—at Copenhagen and Köln. To accommodate the reservations mentioned above, we used dates from these two sites but we ran two modelling variants—one including Kartstein and Stellmoor dates, and the other without. The radiocarbon date for the butchery site at Potsdam-Schlaatz was usually quoted in the context of early Mesolithic settlement, even though the flint artefacts found alongside an aurochs skeleton were regarded as not representative and thus not useful in identifying the culture of the hunters who had brought down this animal (Gramsch 1987). Nevertheless, blades from this context (Gramsch 1987, Fig. 1: 2–4, 6) bear evident characteristics of Final Palaeolithic flint working: significant length and breadth plus negatives of double platform flaking on the upper side. This led us to assign this site to the category of Final Palaeolithic settlements. Other dates come from settlement horizons of archaeological sites, from refuse layers on a camp's periphery (Wustermark), and from—typical for this period—Havel harpoons.

Of the 74 Mesolithic dates, 38 radiocarbon dates come from the refuse layers of early Mesolithic camps at Friesack (sites no. 4 and 27a) and Hohen Viecheln; 16 come from remains associated with settlement along an ancient lake shoreline near Duvensee (Schleswig-Holstein); and seven come from settlement layers of the Bedburg-Königshaven site. Three dates were obtained from the skeleton of a 50–55-year-old woman from a grave at Unseburg; one date comes from a killing site. Other radiocarbon dates (9) come from charcoal from settlement structures

Table 5 Radiocarbon dates from the Final Palaeolithic sites of the North German Plain and the Eifel

No.	Site	Region	Radiocarbon age BP	Sample name	Calibrated date BC (2σ)	Sample	Context	References
1	Bütsee-Altfriesack	Brandenburg	10,480 ± 75	OxA-8742	10,670–10,150	Harpoon Havel type 12B	Stray find	Cziesla and Pettitt 2003, 24
2	Bütsee-Altfriesack	Brandenburg	10,020 ± 60	OxA-8841	9820–9320	Harpoon Havel type 12B	Stray find	Cziesla and Pettitt 2003, 24
3	Groß Lieskow	Lusatia	10,420 ± 100	LZ-1353	10,660–10,030	Charcoal	Destroyed fire-place (?)	Bittmann and Pasda 1999, Tab. 1
4	Groß Lieskow	Lusatia	9780 ± 75	LZ-1345	9440–9120 (88.0%) 9000–8920 (6.3%) 8890–8860 (1.0%)	Charcoal	Destroyed fire-place (?)	Bittmann and Pasda 1999, Tab. 1
5	Kartstein abri	Eifel	10,220 ± 100	OxA-9031	10,440–9650 (91.5%) 9610–9530 (2.9%) 9490–9460 (1.0%)	Reindeer femur	Settlement layer	Bronk Ramsey et al. 2002, 30–31
6	Kartstein abri	Eifel	10,090 ± 100	KN-4023	10,080–9330	<i>Lagopus lagopus</i> bone	Settlement layer	Street et al. 1994, Table 1
7	Kartstein abri	Eifel	10,030 ± 60	KN-4254A	9850–9320	Reindeer bone	Settlement layer	Weber et al. 2011, Table 1
8	Kartstein abri	Eifel	10,000 ± 50	KN-4252	9760–9320	Reindeer bone	Settlement layer	Weber et al. 2011, Table 1
9	Kartstein abri	Eifel	9995 ± 65	OxA-9032	9760–9710 (4.0%) 9700–9290 (91.4%)	<i>Lagopus lagopus</i> tarsometatarsus	Settlement layer	Bronk Ramsey et al. 2002, 30–31
10	Kartstein abri	Eifel	9900 ± 45	KN-4254B	9650–9610 (2.0%) 9520–9500 (0.8%) 9460–9260 (92.5%)	Reindeer bone	Settlement layer	Weber et al. 2011, Table 1

Table 5 (continued)

No.	Site	Region	Radiocarbon age BP	Sample name	Calibrated date BC (2σ)	Sample	Context	References
11	Kartstein abri	Eifel	9685 ± 50	KN-4254C	9270–9120 (66.0%) 9070–9060 (1.3%) 9010–8910 (22.4%) 8910–8840 (5.8%)	Reindeer bone	Settlement layer	Weber et al. 2011, Table 1
12	Kartstein abri	Eifel	9550 ± 90	KN-4072	9230–8700 (93.7%) 8680–8650 (1.7%)	Reindeer bone	Settlement layer	Street et al. 1994, Table 1
13	Kartstein abri	Eifel	9530 ± 90	KN-4073	9210–8690 (91.2%) 8690–8640 (4.2%)	Reindeer bone	Settlement layer	Street et al. 1994, Table 1
14	Nähe LA 11	Schleswig-Holstein	10,172 ± 45	K1A-23370	10,100–9750 (92.9%) 9720–9690 (2.5%)	Reindeer bone/antler	Settlement horizon	Weber et al. 2011, Table 1
15	Nähe LA 11	Schleswig-Holstein	10,142 ± 49	K1A-23371	10,090–9650 (92.9%) 9580–9550 (1.9%) 9480–9460 (0.6%)	Reindeer bone/antler	Settlement horizon	Weber et al. 2011, Table 1
16	Potsdam-Schlaatz	Brandenburg	9936 ± 40	K1A-5665	9650–9600 (6.7%) 9550–9480 (6.5%) 9460–9290 (82.2%)	Rib of <i>Bos primigenius</i>	Butchery site	Benecke et al. 2002, Table 1
17	Stellmoor	Schleswig-Holstein	10,160 ± 90	KN-2222	10,200–9440 (94.9%) 9430–9410 (0.5%)	Bone	Kettle hole	Weber et al. 2011, Table 1

Table 5 (continued)

No.	Site	Region	Radiocarbon age BP	Sample name	Calibrated date BC (2σ)	Sample	Context	References
18	Stellmoor	Schleswig-Hol- stein	10,140 ± 105	K-4326	10,200–9360 (95.2%) 9350–9340 (0.2%)	Marrow split long bone of reindeer	Kettle hole	Fischer and Tauber 1986, 9
19	Stellmoor	Schleswig-Hol- stein	10,100 ± 100	K-4578	10,100–9340	Marrow split long bone of reindeer	Kettle hole	Fischer and Tauber 1986, 9
20	Stellmoor	Schleswig-Hol- stein	10,080 ± 80	KN-2221	10,050–9370	Bone and antler	Kettle hole	Weber et al. 2011, Table 1
21	Stellmoor	Schleswig-Hol- stein	10,010 ± 105	K-4262	10,010–9920 (5.2%) 9890–9290 (90.2%)	Reindeer antler with skull	Kettle hole	Fischer and Tauber 1986, 9
22	Stellmoor	Schleswig-Hol- stein	10,010 ± 100	K-4325	10,010–9920 (4.4%) 9890–9290 (91.0%)	Bison bone	Kettle hole	Fischer and Tauber 1986, 9; Weber et al. 2011, Table 1
23	Stellmoor	Schleswig-Hol- stein	9990 ± 105	K-4581	10,000–9930 (3.4%) 9890–9270 (92.0%)	Reindeer antler with skull	Kettle hole	Fischer and Tauber 1986, 9
24	Stellmoor	Schleswig-Hol- stein	9980 ± 105	K-4579	9990–9930 (2.5%) 9880–9260 (92.9%)	Reindeer antler	Kettle hole	Fischer and Tauber 1986, 9
25	Stellmoor	Schleswig-Hol- stein	9930 ± 100	K-4323	9850–9840 (0.5%) 9830–9240 (94.9%)	Shed antler of reindeer	Kettle hole	Fischer and Tauber 1986, 9
26	Stellmoor	Schleswig-Hol- stein	9900 ± 105	K-4324	9850–9840 (0.3%) 9830–9190 (95.1%)	Reindeer antler with skull	Kettle hole	Fischer and Tauber 1986, 9

Table 5 (continued)

No.	Site	Region	Radiocarbon age BP	Sample name	Calibrated date BC (2σ)	Sample	Context	References
27	Stellmoor	Schleswig-Holstein	9810 ± 100	K-4580	9670–9120 (86.1%) 9080–9060 (0.6%) 9020–8840 (8.7%)	Reindeer antler with skull	Kettle hole	Fischer and Tauber 1986, 9
28	Wustermark 22	Brandenburg	10,389 ± 57	Bln-5646	10,570–10,520 (4.0%) 10,480–10,080 (91.4%)	Pine wood fragment	Water body shore at a camp	Gramsch and Beran 2010, 100
29	Wustermark 22	Brandenburg	10,370 ± 75	Ua-24701	10,580–10,510 (5.3%) 10,490–10,020 (90.1%)	Fishhook of bone	Water body shore at a camp	Gramsch and Beran 2010, 100
30	Wustermark 22	Brandenburg	10,050 ± 80	Bln-5645	10,010–9920 (5.6%) 9890–9320 (89.8%)	Wood fragment	Water body shore at a camp	Gramsch and Beran 2010, 100
31	Wustermark 22	Brandenburg	10,005 ± 70	Ua-20962	9820–9300	Ornamented elk antler artefact	Water body shore at a camp	Gramsch and Beran 2010, 100

Table 6 Methods of radiocarbon analysis of samples from the Final Palaeolithic sites from the North German Plain and the Eifel

Dates Sites	Radiocarbon dates without AMS	AMS radiocarbon dates	Number
Stratified sites	20	6	26
Flint concentrations in sandy areas	2	–	2
Stray antler/bone artefacts	–	2	2
Butchery site	–	1	1
Number	22	9	31

and from stray finds of Mesolithic tools: points, harpoons and an elk antler mattock. Only 30 dates were obtained using AMS; the remainder were obtained through traditional methods, with standard deviation being 60–170 years. The oldest dates from Bedburg-Königshaven are questioned as they would suggest that the early Mesolithic pre-dated the Holocene warming. On the other hand their large standard deviation (100 years) places them in a broad time span. Two dates from Duvensee 1 (Bokelmann et al. 1982, Table 1—H23/22, H26/23) are from the early days of the Heidelberg laboratory's existence: these dates come with large standard deviations and are usually omitted from tables of dates for the Mesolithic (Weninger et al. 2009, Table 9-6).

A major issue in pinpointing borders of developments during the Pleistocene–Holocene transition is the radiocarbon plateaux found in that period, brought about by a sharp drop in the production of the ^{14}C isotope in the atmosphere as a result of various terrestrial and cosmic phenomena (Kitagawa and van der Plicht 1998). In this period, radiocarbon years are shorter than calendar years. In the relevant timespan, 10,550–8250 cal BC (10,500–9000 BP), the strongest noted plateaux are those for c. 10,350–10,100 cal BC (10,400–10,300 BP), 9550–9350 cal BC (10,000–9900 BP), and 9000–8850 cal BC (9600–9500 BP) (Björck et al. 1998; Bos et al. 2007, p. 1928). For the entire length of the Younger Dryas and early Holocene the difference between radiocarbon years and calendar years may be as much as 1500 years, that is, 10,800–9800 radiocarbon years BP versus 10,800–9250 calendar years cal BC (Kitagawa and van der Plicht 1998, p. 1188). Analysis of the chronology of phenomena during the Pleistocene–Holocene transition becomes more reliable, however, when we use the whole dataset of radiocarbon dating and employ Bayesian statistical procedures, which allow for more objective conclusions, independent of climatostratigraphical data (Lowe et al. 2008).

The analysis of absolute dates was performed using a series of Bayesian models made with OxCal 4.3 software (Bronk Ramsey 2009a), with some analysis also using R v. 3.5.3 software (R Core Team 2019), with a ^{14}C age calibration curve IntCal 13 (Reimer et al. 2013).

The fundamental question of the research was the issue of the chronological relations between Final Palaeolithic and Mesolithic settlement in the Polish Plain.

Table 7 Radiocarbon dates from the early Mesolithic sites of the North German Plain

No.	Site	Region	Radiocarbon age BP	Sample name	Calibrated date BC (2σ)	Sample	Context	References
1	Bedburg-Königshoven	Lower Rhineland	10,670 ± 100	KN-4138	10,800–10,450	Skull of <i>Bos</i> 93/106-2	Settlement layer	Street et al. 1994, Table 1
2	Bedburg-Königshoven	Lower Rhineland	10,290 ± 100	KN-4137	10,570–10,520 (1.8%) 10,480–9760 (93.2%) 9720–9700 (0.4%)	Skull of <i>Bos</i> 96/105-2	Settlement layer	Street et al. 1994, Table 1
3	Bedburg-Königshoven	Lower Rhineland	10,140 ± 100	KN-4139	10,180–9370	Skull of <i>Bos</i> 87/108-2	Settlement layer	Street et al. 1994, Table 1
4	Bedburg-Königshoven	Lower Rhineland	10,020 ± 100	KN-4136	10,010–9920 (5.4%) 9890–9290 (90.0%)	Skull of <i>Bos</i> 96/108-1	Settlement layer	Street et al. 1994, Table 1
5	Bedburg-Königshoven	Lower Rhineland	9780 ± 100	KN-3999	9650–9600 (1.6%) 9530–9490 (1.3%) 9460–8820 (92.5%)	Wood	Settlement layer	Street 1991, Table 24.1
6	Bedburg-Königshoven	Lower Rhineland	9740 ± 100	KN-4135	9400–8800	Skull of <i>Bos</i> 90/108-2	Settlement layer	Street et al. 1994, Table 1
7	Bedburg-Königshoven	Lower Rhineland	9600 ± 100	KN-3998	9260–8720	Wood	Settlement layer	Street 1991, Table 24.1
8	Bütsee-Altfriesack	Brandenburg	10,185 ± 65	OxA-8743	10,190–9660 (94.6%) 9580–9550 (0.8%)	Point of Duvensee type	Stray find	Cziesla and Pettitt 2003, 26
9	Bütsee-Altfriesack	Brandenburg	9505 ± 80	OxA-8726	9170–8630	Point of Duvensee type	Stray find	Cziesla and Pettitt 2003, 26
10	Bütsee-Altfriesack	Brandenburg	9195 ± 65	OxA-8744	8570–8280	Point of Pitzerbe type	Stray find	Cziesla and Pettitt 2003, 26
11	Duvensee 1	Schleswig-Holstein	9200 ± 160	KI-1883.01	9120–9070 (0.9%) 9060–9020 (0.8%) 8840–7960 (93.7%)	Charcoal	?	Bokelmann et al. 1982, Table 1

Table 7 (continued)

No.	Site	Region	Radiocarbon age BP	Sample name	Calibrated date BC (2σ)	Sample	Context	References
12	Duvensee 1	Schleswig-Holstein	9170 ± 120	KI-1883.02	8750–8200 (94.1%) 8110–8090 (0.4%) 8040–8010 (0.9%)	Hazelnut shell	Settlement debris	Bokelmann et al. 1982, Table 1
13	Duvensee 1	Schleswig-Holstein	9095 ± 170	H-431/379	8750–7750	Hazelnut shell	Settlement debris	Bokelmann et al. 1982, Table 1
14	Duvensee 2	Schleswig-Holstein	9420 ± 130	KI-1884.01	9180–8350	Charcoal	?	Bokelmann et al. 1982, Table 1
15	Duvensee 2	Schleswig-Holstein	9280 ± 100	KI-1884.02	8760–8290	Hazelnut shell	Settlement debris	Bokelmann et al. 1982, Table 1
16	Duvensee 6	Schleswig-Holstein	9100 ± 130	KI-1111	8700–8670 (0.8%) 8650–7940 (94.6%)	Hazelnut shell	Settlement debris	Bokelmann et al. 1982, 25, Table 1
17	Duvensee 6	Schleswig-Holstein	9090 ± 130	KI-1113	8690–8680 (0.2%) 8640–7920 (93.7%) 7930–7920 (0.2%) 7900–7840 (1.3%)	Hazelnut shell	Settlement debris	Bokelmann et al. 1982, 25, Table 1
18	Duvensee 8	Schleswig-Holstein	9640 ± 100	KI-1818	9280–8760	Birchbark mat	Settlement floor	Bokelmann et al. 1982, 25, Table 1
19	Duvensee 8	Schleswig-Holstein	9440 ± 130	KI-1885.03	9220–8430 (94.4%) 8401–8396 (0.2%) 8370–8350 (0.8%)	Charcoal	?	Bokelmann et al. 1982, Table 1
20	Duvensee 8	Schleswig-Holstein	9420 ± 130	KI-1885.01	9180–8350	Hazelnut shell	?	Bokelmann et al. 1982, Table 1
21	Duvensee 8	Schleswig-Holstein	9410 ± 110	KI-1819	9140–8420 (93.3%) 8410–8390 (0.7%) 8380–8350 (1.4%)	Birchbark mat	Settlement floor	Bokelmann et al. 1982, 25, Table 1
22	Duvensee 9	Schleswig-Holstein	9600 ± 90	KI-3043	9250–8750	Charcoal	Fireplace	Bokelmann 1991, Table 1

Table 7 (continued)

No.	Site	Region	Radiocarbon age BP	Sample name	Calibrated date BC (2σ)	Sample	Context	References
23	Duvensee 9	Schleswig-Holstein	9590 ± 90	KI-3041	9250–8740	Charcoal	Fireplace	Bokelmann 1991, Table 1
24	Duvensee 9	Schleswig-Holstein	9440 ± 80	KI-3044	9140–8970 (16.5%) 8940–8540 (78.3%) 8510–8490 (0.6%)	Charcoal	Fireplace	Bokelmann 1991, Table 1
25	Duvensee 9	Schleswig-Holstein	9380 ± 80	KI-3042	9120–9080 (1.8%) 9060–9020 (1.6%) 8840–8420 (89.8%) 8410–8350 (2.3%)	Charcoal	Fireplace	Bokelmann 1991, Table 1
26	Duvensee 11	Schleswig-Holstein	9379 ± 35	KIA-17064	8750–8570	Hazelnut shell	Settlement layer	Bokelmann 2012, 372
27	Friesack 4	Brandenburg	9680 ± 70	Bln-3036	9280–9110 (51.2%) 9090–8830 (44.2%)	Charcoal	Water body shore at a camp; Sub-complex I-1	Gramsch 2012, 8
28	Friesack 4	Brandenburg	9670 ± 60	Bln-3026	9270–9110 (50.7%) 9090–8840 (44.7%)	Charcoal	Water body shore at a camp; Sub-complex I-1	Gramsch 2012, 9
29	Friesack 4	Brandenburg	9640 ± 70	Bln-2828	9250–8810	Charcoal	Water body shore at a camp; Sub-complex I-1	Gramsch 2012, 8; 2016, Table I
30	Friesack 4	Brandenburg	9640 ± 70	Bln-3019	9250–8810	Charcoal	Water body shore at a camp; Sub-complex I-3	Gramsch 2012, 9; 2016, Table I
31	Friesack 4	Brandenburg	9640 ± 60	Bln-3020	9250–8830	Charcoal	Water body shore at a camp; Sub-complex I-3	Gramsch 2012, 9; 2016, Table I

Table 7 (continued)

No.	Site	Region	Radiocarbon age BP	Sample name	Calibrated date BC (2σ)	Sample	Context	References
32	Friesack 4	Brandenburg	9630 ± 100	Bln-2756	9270–8760	Charcoal	Water body shore at a camp; Sub-complex I-1	Gramsch 2012, 8; 2016, Table I
33	Friesack 4	Brandenburg	9580 ± 60	Bln-3001	9200–8780	Charcoal	Water body shore at a camp; Sub-complex I-2	Gramsch 2012, 9; 2016, Table I
34	Friesack 4	Brandenburg	9580 ± 100	Bln-2761	9250–8710 (94.8%) 8670–8660 (0.6%)	Charcoal	Water body shore at a camp; Sub-complex I-1	Gramsch 2012, 8; 2016, Table I
35	Friesack 4	Brandenburg	9490 ± 100	Bln-2753	9200–8570	Charcoal	Water body shore at a camp; Sub-complex I-3	Gramsch 2012, 9; 2016, Table I
36	Friesack 4	Brandenburg	9450 ± 65	Bln-1914	9120–9000 (14.1%) 8920–8570 (81.3%)	Charcoal	Water body shore at a camp; Sub-complex I-3	Gramsch 2012, 9; 2016, Table I
37	Friesack 4	Brandenburg	9420 ± 100	Bln-2760	9150–8450 (95.2%) 8360–8360 (0.2%)	Charcoal	Water body shore at a camp; Sub-complex II-1	Gramsch 2012, 9
38	Friesack 4	Brandenburg	9420 ± 80	Bln-3705	9130–9000 (10.8%) 8930–8470 (84.6%)	Charcoal	Water body shore at a camp; Sub-complex II-2	Gramsch 2012, 9
39	Friesack 4	Brandenburg	9400 ± 70	Bln-3018	9120–9070 (2.1%) 9060–9010 (1.9%) 8850–8460 (91.4%)	Charcoal	Water body shore at a camp; Sub-complex II-1	Gramsch 2012, 9
40	Friesack 27a	Brandenburg	9775 ± 45	KIA-46296	9310–9190	Bone (<i>Equus ferus</i>)	Water body shore at a camp; Layer Complex I	Groß 2014, Fig. 2

Table 7 (continued)

No.	Site	Region	Radiocarbon age BP	Sample name	Calibrated date BC (2σ)	Sample	Context	References
41	Friesack 27a	Brandenburg	9680 ± 35	KIA-46733	9260–9120 (77.6%) 9000–8920 (17.4%) 8880–8880 (0.4%)	Bone (<i>Castor fiber</i>)	Water body shore at a camp; Layer Complex 1	Groß 2014, Fig. 2
42	Friesack 27a	Brandenburg	9645 ± 65	KIA-46734	9250–8820	Bone (<i>Bos primigenius</i>)	Water body shore at a camp; Layer Complex 1	Groß 2014, Fig. 2
43	Friesack 27a	Brandenburg	9610 ± 33	KIA-46297	9210–9100 (23.9%) 9090–8830 (71.5%)	Bone (<i>Capreolus capreolus</i>)	Water body shore at a camp; Layer Complex 1	Groß 2014, Fig. 2
44	Friesack 27a	Brandenburg	9545 ± 50	KN-5848	9150–8750	Wood, charcoal (<i>Pinus</i>)	Water body shore at a camp; Layer Complex 1	Groß 2014, Fig. 2
45	Friesack 27a	Brandenburg	9400 ± 60	KN-5846	9110–9090 (0.6%) 8840–8540 (93.2%) 8510–8480 (1.6%)	Bark	Water body shore at a camp; Layer Complex 1	Groß 2014, Fig. 2
46	Friesack 27a	Brandenburg	9940 ± 60	KN-5844	9740–9730 (0.6%) 9670–9280 (94.8%)	Charcoal (<i>Pinus</i>)	Water body shore at a camp; Layer Complex 2	Groß 2014, Fig. 2
47	Friesack 27a	Brandenburg	9530 ± 55	KN-5845 (?)	9150–8720	Charcoal (<i>Pinus</i>)	Water body shore at a camp; Layer Complex 2	Groß 2014, Fig. 2
48	Friesack 27a	Brandenburg	9458 ± 64	KN-5845	9130–9000 (16.7%) 8920–8560 (77.9%) 8590–8570 (0.8%)	Wood (<i>Pinus</i>)	Water body shore at a camp; Layer Complex 2	Groß 2014, Fig. 2
49	Friesack 27a	Brandenburg	9400 ± 70	Bln-3215	9120–9070 (2.1%) 9060–9010 (1.9%) 8850–8460 (91.4%)	Peat	Water body shore at a camp; Layer Complex 2	Groß 2014, Fig. 2

Table 7 (continued)

No.	Site	Region	Radiocarbon age BP	Sample name	Calibrated date BC (2σ)	Sample	Context	References
50	Friesack 27a	Brandenburg	9565 ± 40	KIA-46298	9150–8790	Bone (<i>Sus scrofa</i>)	Water body shore at a camp; Layer Complex 3	Groß 2014, Fig. 2
51	Friesack 27a	Brandenburg	9531 ± 33	KIA-49735	9130–9000 (45.9%) 8930–8750 (49.5%)	Bone (<i>Capreolus capreolus</i>)	Water body shore at a camp; Layer Complex 3	Groß 2014, Fig. 2
52	Friesack 27a	Brandenburg	9480 ± 60	KN-5843	9130–8980 (24.7%) 8930–8620 (70.7%)	Charcoal (<i>Salix</i>)	Water body shore at a camp; Layer Complex 3	Groß 2014, Fig. 2
53	Greven-Schencking sandpit	Westphalia	9402 ± 32	MAMS-18465	8780–8610	Bone point with small barbs	Stray find	Baales et al. 2015, 457
54	Haverbeck	Lower Rhinland	9505 ± 40	GrA-38367	9130–9000 (33.7%) 8930–8710 (60.9%) 8670–8660 (0.8%)	Charcoal	Shallow pit	Tolksdorf et al. 2009, Table 1
55	Haverbeck	Lower Rhineland	9425 ± 105	Hv-23306	9160–8440 (94.9%) 8370–8350 (0.5%)	Charcoal	Shallow pit	Tolksdorf et al. 2009, Table 1
56	Hohen Viecheln I	Mecklenburg	9608 ± 44	RICH-22176	9210–8820	Antler tine, production waste (ID15314)	Gytija (refuse area)	Groß et al. 2019, Table 8
57	Hohen Viecheln I	Mecklenburg	9518 ± 46	KIA-51074	9140–8970 (40.7%) 8940–8710 (54.7%)	Antler frontlet (ID 15863)	Basal sand (refuse area?)	Groß et al. 2019, Table 8
58	Hohen Viecheln I	Mecklenburg	9349 ± 35	KIA-51093	8730–8540 (93.5%) 8510–8490 (1.9%)	Antler axe (ID 13843)	Brushwood layer (refuse area)	Groß et al. 2019, Table 8
59	Hohen Viecheln I	Mecklenburg	9309 ± 51	KIA-51086	8710–8420 (90.6%) 8410–8390 (1.5%) 8380–8350 (3.3%)	Axe head (ID 15324)	Above gytija (refuse area)	Groß et al. 2019, Table 8

Table 7 (continued)

No.	Site	Region	Radiocarbon age BP	Sample name	Calibrated date BC (2 σ)	Sample	Context	References
60	Hohen Viecheln I	Mecklenburg	9278 $\pm$ 44	RICH-22650	8630–8350	Point of Duvensee type (ID 14926)	Peat (refuse area)	Groß et al. 2019, Table 8
61	Hohen Viecheln I	Mecklenburg	9205 $\pm$ 43	KIA-51087	8550–8500 (12.4%) 8500–8300 (83%)	Simple bone point (ID 15610)	Peat (refuse area)	Groß et al. 2019, Table 8
62	Hohen Viecheln I	Mecklenburg	9055 $\pm$ 44	RICH-22172	8330–8220	Simple bone point (ID 15610)	Peat (refuse area)	Groß et al. 2019, Table 8
63	Hohen Viecheln I	Mecklenburg	9180 $\pm$ 40	KIA-35740	8540–8510 (4.7%) 8490–8290 (90.7%)	Wild horse bone	Layer a	Groß et al. 2019, Table 8
64	Hohen Viecheln I	Mecklenburg	9109 $\pm$ 49	RICH-22640	8460–8250	Point of Duvensee type (ID 13743)	Peat (refuse area)	Groß et al. 2019, Table 8
65	Hohen Viecheln I	Mecklenburg	9064 $\pm$ 43	RICH-22175	8330–8230	Artefact fragment (ID 15325)	Gyttja or above gyttja (refuse area)	Groß et al. 2019, Table 8
66	Hohen Viecheln I	Mecklenburg	9043 $\pm$ 42	KIA-51090	8310–8220	Simple bone point (ID 13692)	Below upper peat (refuse area)	Groß et al. 2019, Table 8
67	Hohen Viecheln I	Mecklenburg	9015 $\pm$ 43	RICH-22646	8300–8200 (89.4%) 8110–8090 (1.4%) 8070–8070 (0.4%) 8040–8000 (4.2%)	Point of Pritzerbe type (ID 16090)	Sand	Groß et al. 2019, Table 8
68	Mönchengladbach-Geneiken	Rhineland	9246 $\pm$ 48	COL-2616	8610–8320	Aurochs bone	Killing site	Heinen 2014, 302
69	Paderborn-Sande	Westphalia	9591 $\pm$ 30	MAMS-14119	9160–8810	Elk antler mattock-head	Stray find	Baales et al. 2015, 457
70	Unseburg	Saxony-Anhalt	9420 $\pm$ 45	OxA-29230	8810–8600 (92.4%) 8590–8570 (1.2%)	Rib fragment	Grave of 50–55-year-old woman	Grünberg 2016, 240, Fig. 2

Table 7 (continued)

No.	Site	Region	Radiocarbon age BP	Sample name	Calibrated date BC (2σ)	Sample	Context	References
71	Unseburg	Saxony-Anhalt	9410 ± 45	OxA-31094	8800–8570	Rib fragment	Grave of 50–55-year-old woman	Grünberg 2016, 240, Fig. 2
72	Unseburg	Saxony-Anhalt	9375 ± 40	OxA-31095	8760–8560	Rib fragment	Grave of 50–55-year-old woman	Grünberg 2016, 240, Fig. 2
73	Wehldorf 7	Schleswig-Holstein	9430 ± 60	K1A-4645	9120–9070 (3.4%) 9060–9010 (3.1%) 8910–8900 (0.3%) 8850–8560 (88.5%)	?	?	Galinski 2015c, 49
74	Werl-Büderich	Westphalia	9923 ± 33	MAMS-15941	9640–9630 (0.6%) 9622–9618 (0.2%) 9460–9290 (94.6%)	Charcoal	Fireplace at the flint concentration	Baales et al. 2015, 456

Assuming continuity inside each phase, there are three possible combinations of their mutual relationship (Bronk Ramsey 2009a):

- sequential—the phases succeed one another, with possibility of hiatus between them;
- contiguous—the phases directly succeed one another, with no interruption;
- overlapping—the order of the phases is unknown, or one phase begins before the other ends.

To attempt to answer the above questions, we proceeded as follows. First, three models were designed—each with two phases (groups of dates) associated with the Final Palaeolithic and the Mesolithic. Codes of all processed models and their results are included in Electronic Supplementary Material 1. Each model represented one of the three possible combinations outlined above. These were the null hypothesis; the results of model processing led to either their acceptance or rejection. Each model was run twice, first as an outlier analysis to reject dates not fitting the statistical model (Bronk Ramsey 2009b). The same parameters were used in analysis of all three hypotheses. The parameter used for the whole model was `Outlier_Model("General",T(5),U(0,4),"t")`, for every analysed date the assumption was that the probability of it being an outlier was 0.05. The second run was identical, but with the dataset purged of previously identified outliers. The results of all models were evaluated for 2 sigma (95.4%), with all values rounded to the nearest 10.

The Boundary Between the Final Palaeolithic and Mesolithic in Light of Radiocarbon Dating

The Polish Plain

In the sequential model the null hypothesis was that of two discrete phases in human settlement, with a hiatus between Final Palaeolithic and Mesolithic communities. The modelling included the start and end boundaries for the phases, as well as the length of the gap between them.

The first stage—outlier analysis—revealed the need to eliminate date MKL-3349 from Bolków 1. After its removal from the dataset the model was run again. The query *interval* (i.e. the length of the hiatus) produced a range of 0–310 years. This result, with 0 as the value of one of the boundaries, makes it imperative that the hypothesis of a hiatus between the phases should be rejected.

The above analysis eliminated the hypothesis of a hiatus between the two settlement phases but did not resolve the issue of possible overlap. Thus the next, overlapping model was designed with the assumption that the phases might overlap. Hence the model now included the query *order*, which would calculate the relative sequence of modelled events.

Here again outlier analysis pointed out the need to eliminate date MKL-3349, and after its removal the model was run again. The model demonstrated high consistency

Table 8 Methods of radiocarbon analysis of samples from the early Mesolithic sites in the North German Plain

Dates Sites	Radiocarbon dates without AMS	AMS radiocarbon dates	Number
Graves	–	3	3
Stratified sites	43	18	61
Flint concentrations in sandy areas	1	3	4
Stray antler/bone artefacts	–	5	5
Killing site	–	1	1
Number	44	30	74

(c. 118% for indexes A_{model} and A_{overall}), in spite of one of the dates (Bolków, site 1—MKL-3351) generating Index A below the required level (53%). The result of the *Order* query, visualised using *prob_phases_rel*.r script (Alberti 2016) points to the probability of the phases' overlap being relatively low (11%, i.e. with 89% probability of their being separated)—hence the overlapping hypothesis should be rejected (Figs. 2, 3). This model also identified the points at which Final Palaeolithic settlement ended (between 9290 BC and 9030 BC) and the Mesolithic began (between 9230 BC and 8860 BC).

The two procedures described above allowed the elimination of the hypothesis of there being either a hiatus or an overlap between Final Palaeolithic and Mesolithic settlement. The third stage of modelling, that is the contiguous model, aimed at confirmation or rejection of the hypothesis of a 'smooth' passage between the two: the modelling aimed at identification of the period when one phase transitioned into the other.

Yet again outlier analysis led to the elimination of date MKL-3349 from the dataset. When run without it, the model revealed a high level of consistency, thus supporting its high statistical accuracy. The modelling generated the value of the boundary function—that is, the time range during which the Final Palaeolithic 'transitioned' into the Mesolithic—placing it between 9260 BC and 8980 BC (Fig. 2). Some difference in the chronology of the Early Mesolithic may be discerned between the western and eastern areas of the Polish Plain (Fig. 4). Separate modelling of boundary dates for the onset of the early Mesolithic for these two areas (using the *overlapping* model) produced the result that in the west of the Polish Plain the Mesolithic began between 9410 BC and 8860 BC, and in the eastern part—between 9230 BC and 8760 BC. Hence it seems reasonable to assume that the transition to the Mesolithic way of life in the west of present-day Poland happened at least several decades earlier.

The analysis described above allows us to reject the hypothesis of there being either a hiatus or overlap between Final Palaeolithic and Mesolithic settlement on the plains of Poland. The existing dating points to the veracity of the hypothesis that there was a smooth transition between the two phases, with this event taking

Fig. 2 The model of the Palaeolithic/Mesolithic boundary in the light of modelling radiocarbon dates from the Polish Plain

place some time between *9260 BC and 8980 BC* (Supplementary Material 2). For this reason we would describe such a model as the replacement model.

The North German Plain

The result of the same analysis for data from Germany was different. Here again three possible variants were modelled, and each model run twice—the first run to eliminate outliers from the dataset. Further outlier analysis led to the exclusion of dates from Bützsee-Altfrisesack (OxA-8742, OxA-8743) and Bedburg-Königshoven (KN-4139, KN-4138, KN-4137, KN-4136) from further calculations (Fig. 5). The subsequent modelling of the three relationship variants determined that the most probable outcome for this area was the two phases overlapping.

The modelling results run for Germany point to the Final Palaeolithic and Mesolithic there overlapping as the end of the Final Palaeolithic takes place between *9210 BC and 8900 BC*, while the Mesolithic begins somewhere between *9400 BC and 9300 BC* (Supplementary Material 2). Compared with the Polish Plains, in Germany the end of Final Palaeolithic settlement happened at the same time as in Poland, but Mesolithic related settlement appeared some 200 years earlier. For this reason we would describe such a model as the coexistence model.

Fig. 3 The posterior probabilities of modelling Palaeolithic/Mesolithic boundary in the Polish Plain and in the North German Plain and the Eifel

Discussion

The Pleistocene–Holocene Transition and Cultural Change

Prevailing scientific opinion on the end of the Final Palaeolithic and the emergence of the early Mesolithic in the Polish Plain is that this process was significantly shaped by human migrations. This assumption has its roots in the first half of the 20th century, and survived the emergence of radiocarbon dating. It was in large part influenced by early stylistic studies of flint artefacts, focusing on their typology and not on the technology of their manufacture. The first works on the genesis of the Mesolithic—which are today of purely historical interest—pointed out the similarities between Mesolithic artefacts from Poland and those of the western European Tardenoisian (Kostrzewski 1939; Zotz 1934); accordingly their appearance in Poland was linked with an influx of human populations from the west of the continent. This view was rejected by Polish scholars in the mid-twentieth century (Schild and Więckowska 1961).

The discussion on the end of Final Palaeolithic and the dawn of the early Mesolithic on the plains of Poland is still dominated by the migration theory, a hypothesis which in general terms holds that Swiderian people moved to northeastern Europe while a portion of Ahrensburgian hunters moved to Scandinavia (Galiński 1997; 2002; Ginter 1973; Kabaciński 2016; Kabaciński and Sobkowiak-Tabaka 2010; Kobusiewicz 1999; J. K. Kozłowski 2001; Kozłowski and Kaczanowski 2003; Kozłowski and Kozłowski 1975, 1977; S. K. Kozłowski 1969; 1972; Schild 1996a, 1996b, 2001; Sobkowiak-Tabaka 2011, 2016; Więckowska 1975). Some researchers interpret radiocarbon dates from Polish sites as indicating a hiatus between Final Palaeolithic and early Mesolithic settlement (Kabaciński 2016; Schild 1996a, 1996b, 2001) where, after a period of some 150–300 years, during which the Polish Plain was a depopulated desert, it was resettled by an inflow of Mesolithic people. Romuald Schild sees evidence for migrations and a settlement hiatus in the collapse

Fig. 4 The model of the Palaeolithic/Mesolithic boundary in the eastern and western area of the Polish Plain

of chocolate flint exploitation in the early Mesolithic; in the scant signs of early Mesolithic settlement around the red pigment mine at Rydno; and in the severance of Final Palaeolithic exchange networks, whose existence is indicated by wide distribution of both commodities. In his opinion, this would point to the Mesolithic population being unaware of these resources, *eo ipso* being distinct from Swiderian communities. Most researchers consider dates from early Mesolithic sites from eastern Germany to pre-date those from Poland, thus hinting at Mesolithic ideas coming to Poland from that direction; nevertheless, there is a group championing the idea that inflow from the South trumped that from the West. T. Galiński (1992, p. 160) is more reserved in his views, as he considers the cultural transformation at the transition from Pleistocene to Holocene to have been a complex process: changes inside Final Palaeolithic cultures took place in parallel to the immigration of groups bearing ‘Mesolithic culture’. In the opinion of S. K. Kozłowski and T. Galiński, the Mesolithic in Polish lands, besides a component characteristic of the Ahrensburgian (cf. Kozłowski 1972, p. 222), includes artefacts suggesting the possibility of immigration from the Carpathian Basin of people representing Epi-Gravettian, Epi-Tardigravettian and/or Epi-Magdalenian traditions (Kozłowski 1989, p. 136; Galiński 2002, p. 350). For J. K. Kozłowski (2001, p. 117) the development of the Mesolithic in today’s Poland was too rapid to be explicable with reference to adaptation, hence Mesolithic communities must have come to the Polish Plain from the West during the Preboreal. However, in his opinion it was possible that in western Poland the traditions of the Arch-backed Point Complex lived on, with these communities giving rise to the early Mesolithic culture (Kozłowski and Kaczanowski 2003, p. 101). M. Kobusiewicz (1999, p. 117) also allows for the possibility of the emergence of the Mesolithic in northwestern Poland to be partly autochthonous in origin, with a contribution of immigrants from the West.

Many authors point out that in various parts of Poland there are Final Palaeolithic assemblages from the early Preboreal. According to S. K. Kozłowski (1969), in northeastern Poland one may discern a Preboreal phase of the Swiderian which did not, however, extend to the west of the Vistula. In such a case one may presume that Swiderian reindeer hunters would also be present in today’s Latvia and Estonia (Zagorska 2006).

The few existing radiocarbon dates for northern Germany and the Rhineland do not provide a clear picture as to the boundary between the Palaeolithic and Mesolithic. According to many German scientists, the cultural Final Palaeolithic/Mesolithic division closely follows the climatostratigraphical boundary between the Pleistocene and Holocene, that is, the onset of the Holocene and of the Mesolithic are as good as synonymous, with radiocarbon dating showing that Final Palaeolithic cultures survived into the Preboreal being erroneous (Street et al. 2001, p. 393). The theory of migration of Final Palaeolithic hunters is considered to apply to the North German Plain as well (Groß 2014; Terberger 2004, 2006), with an imprecisely-defined segment of Ahrensburgian hunters leaving this area and heading North in pursuit of reindeer herds, although such communities are presumed to still be present in situ in the early phases of the Preboreal (Groß 2014, p. 220; Terberger 2004, p. 44). However, the analysis of radiocarbon dates supports the thesis that for the vast expanses of the European Plain and neighbouring uplands, no uniform process—or

Fig. 5 The model of the Palaeolithic/Mesolithic boundary in the light of modelling radio-carbon dates from the North German Plain and the Eifel

model—of changes existed, that it was more a patchwork of many local models of the disappearance of old and emergence of new cultural trends. The dynamics of such changes are affected not only by local environmental conditions, but also by complex cultural and social relationships. The most recent literature on the subject appears to be dominated by the view that the transition from the Final Palaeolithic to the Mesolithic in the North European Plain was a complex process, involving the existence of human groups following different cultural traditions (Groß 2014; Sørensen et al. 2018; Zander 2016). Here D. Groß (2014, p. 219) draws upon earlier migration theories, according to which Ahrensburgian reindeer hunters followed that species north, while the forerunners of the Mesolithic—most probably from the Federmesser milieu—slowly drifted northward, following the Preboreal succession of woodlands.

The transition from the Final Palaeolithic to the Mesolithic in southern Scandinavia also is the subject of lively debate. According to E. Brinch Petersen (2009), currently available data points to the Maglemosian beginning with the onset of the Holocene, there being no reason to assume the existence of the Ahrensburgian during the Preboreal. However, not all researchers agree with this opinion as, in spite of the lack of radiocarbon dates from early Preboreal Final Palaeolithic sites, one might assume that the transition was not purely linear, that is, that the Ahrensburgian was immediately followed by the Maglemosian (Sørensen et al. 2018, p. 328). There are many pointers to the early Maglemosian in present-day Denmark and southern Sweden being accompanied by other communities, with, for example, Long Blade Industries or the Epi-Ahrensburgian (Nørregård VI, Årup context 1). It is possible that this variety was related to different biotopes and landscape types (e.g. Jutland vs. Sealand), and the various human groups ‘were mobile in relation to seasons and game’ (Sørensen et al. 2018, p. 328).

We find an equally complex situation in Westphalia where, as in other parts of Europe, during the transition from the Pleistocene to the Holocene one may note the coexistence of various cultural traditions, including Long Blade Industries known from the northwest of the continent (Baales et al. 2015; Zander 2016). In the Heek-Nienborg archaeological site long blades are accompanied by finds of tools typical for the Final Palaeolithic and Mesolithic: Zonhoven points, a double truncation, a Komornica point and an isosceles triangle (Zander 2016). Sadly, no radiocarbon dating was possible for this site. Inventories from northwestern France containing long blades and microliths were found at Buhat and Alizay, with the latter settlement being dated to c. 9700–9000 cal BC.

The analysis of radiocarbon dating results does not allow for the rejection of the thesis that Final Palaeolithic and Mesolithic settlement in the Polish Plains were not separated—as presumed to date—by a hiatus; however, the modelling of radiocarbon dates points to the two phases of human habitation directly following one another. The probability that for some time the two cultures existed side by side, that is, overlapped, is very low. This model fits the way the Mesolithic developed in the Polish Plains. One cannot rule out population movements, but these could not have been mass migrations involving larger numbers of people. The Final Palaeolithic cultural model was still around at the onset of the Preboreal.

We now turn to the overlap between the Final Palaeolithic and the dawn of the Mesolithic in the North German Plain. As already mentioned, the overlap model is generated by the large number of Final Palaeolithic dates from Stellmoor and Kartstein. If these were to be eliminated—as suggested by some German researchers—this would drastically reduce the number of radiocarbon dates from Final Palaeolithic sites, and in such a scenario the probability of overlap becomes very low. According to German scientists who hold that view (Street et al. 2001), these dates should be rejected as their connection to the Final Palaeolithic is doubtful. Similar doubts may be extended towards a series of early dates from Mesolithic sites at Bedburg-Königshoven and Bützsee-Altfrisesack. Two additional models were developed so as to examine the impact of the questioned dates (Fig. 6): the first excluded dates from the aforementioned Mesolithic sites (Fig. 6b), the second additionally excluded dates from the listed Palaeolithic sites (Fig. 6c). In both cases the result of the modelling is affected by the diminished number of dates for both phases, in effect producing greatly extended boundaries for the end of the Final Palaeolithic—and indirectly lowering the accuracy of statistical conclusions based upon those models. Irrespective of that fact, both models confirm the previous conclusion that the two phases overlapped. The sole difference concerns the probable timing of the demise of Final Palaeolithic settlement: when all dates are included in the dataset (Fig. 6a, b) this could have happened between 9210 BC and 8900 BC, whereas when the dates from Stellmoor and Kartstein are excluded, the boundary is moved up by some 200 years, to a period lasting from 9430 BC to 8810 BC. In either case there should be a period of at least two hundred years during which both cultural traditions existed side-by-side in the North German Plain.

It is worth pointing out that the modelling makes Mesolithic sites from Poland younger than the oldest German sites, a result consistent with R. Schild's calculations (1996b, 2001). However, on closer inspection of the differences in dating we note that the onset of the Mesolithic in the west of Poland is dated similarly to its emergence in the German Plains, with the difference in chronology being between the appearance of the Mesolithic in the western and eastern halves of Poland. However, other data make it difficult to assume that this time lag reflects the pace of West to East migration of Mesolithic communities. Date modelling has shown that there was no hiatus between Final Palaeolithic and Mesolithic settlement. At present it is difficult to interpret this difference in timing—it could be related to the existence of a more continental type of climate in the eastern reaches of Poland. A role could have been played by the cooling of the climate in the early Preboreal period, which in eastern Poland began c. 9150 cal BC and lasted for some 60–160 years (de Klerk et al. 2007); the cooling might possibly have been more acute than in western Poland, thus delaying the spread of the Mesolithic way of life.

In our opinion the issues of possible hiatus and migration should be addressed separately and with consideration of environmental, cultural and societal factors. Below we examine the onset of the Mesolithic in Poland from different points of view: in the first section we look early Holocene environmental changes and their pace; in the second section we ponder the message communicated by lithics and artefacts of symbolic culture; and in the third section we cover the social aspects of the beginnings of the Mesolithic, with special focus on hunter-gatherer migrations.

Environment

The transition from the Pleistocene to the Holocene in the Polish Plain involves profound changes in the natural environment. From the perspective of local communities, the most significant change was the warming of the climate and the resultant appearance of woodlands and associated fauna, accompanying the intensive melting of dead ice, which created inland expanses of water. Although reliable environmental data for climate change accompanying the early Holocene in Central and northern Europe exist, the pace and extent of the changes are subject to debate. For example at Lundby in Sealand dense woodland appears only at c. 9300 cal BC, replacing open woodland with extensive grassland areas (Jessen et al. 2015). In Pomerania (near Rusinowo) the woodlands from the early Preboreal are also relatively open, with remains of vegetation typical of the late Pleistocene: *Artemisia*, *Chenopodiaceae* or *Rumex* (Malkiewicz 2017). On the other hand, in western Pomerania (Germany) we note a rapid succession of birch–pine woodland, although with the presence of relicts of Younger Dryas flora (de Klerk 2004)—sadly we do not have enough data at our disposal as to define how open these woodlands were. The prevailing view is that during the Preboreal the climate of the mountain and piedmont zones was quite harsh, with the early Holocene warming reaching those areas of southern Poland with a certain delay (Baranowska and Malkiewicz 2003; Starkel et al. 2013). On the other hand, environmental data from studies around Lake Gościąg in central Poland point to relatively rapid environmental changes in the early Preboreal, involving rapid succession of thermophilic trees and plants (Ralska-Jasiewiczowa et al. 2003). In western Europe during the Preboreal, we note cooler and drier swings in climate which delayed the expansion of birch forests and which favoured the development of grassland communities (Bos et al. 2007; Hoek, Bos 2007). The most notable of such swings—known variously as the Piottino oscillation (Switzerland), the Friesland oscillation (Denmark), or the Rammelbeek phase (Netherlands)—is the so-called Preboreal oscillation (PBO), whose onset from profiles from the Netherlands is dated to c. 9480–9400 cal BC. It also transpires that local conditions may have affected environmental changes in the Preboreal, leading to local variations in biotopes. This phase is also visible in the profiles from Poland (De Klerk et al. 2007).

Nevertheless, already in 9550 cal BC at Lundby we note deposits of elk bones, with the oldest Mesolithic artefact—unheard of in the Final Palaeolithic—an elk antler mattock being dated at c. 9840 cal BC ($10,127 \pm 33$ BP, AAR-15630) (Jessen et al. 2015, Table 2; Fig. 8a). This is evidence that the beginnings of Mesolithic-style cultures appear at the very start of the Holocene, even if elsewhere in southern Scandinavia and western Europe their chronology may be younger.

And finally we have numerous pointers to some populations of Central European reindeer surviving the end of the Pleistocene and thriving in the woodland habitats of the early and middle Preboreal. This is evidenced not only by radiocarbon-dated reindeer remains from Stellmoor and Kartstein (Table 5)—as the reliability of these is questioned—but also, possibly, by antlers from Chmielewo in northeastern Poland, which are dated to 9870–9380 cal BC with 94.5% probability, that is, to the Late Younger Dryas or early Preboreal (Gizejewski et al. 2004). The presence of

Fig. 6 Reanalysis of the model of the Palaeolithic/Mesolithic boundary in the light of modelling radio- ▶ carbon dates from the North German Plain and the Eifel. **a** All dates concerned; **b** without the dates from Bedburg-Königshoven and Büttzsee-Altfrisesack; **c** without the dates from Bedburg-Königshoven, Büttzsee-Altfrisesack, Stellmoor and Kartstein

reindeer in western Europe at the onset of the Holocene is additionally confirmed by dates of bones from a specimen found at Rottenburg-Siebenlinden, namely 8570–8020 cal BC (9110 ± 80 BP, ETH-8265) and 8560–8310 cal BC (9225 ± 35 BP, GrA-39961), plus dates from southwestern England and Denmark (Drucker et al. 2011). Using radiocarbon dating on three Lyngby axes from Great Poland and northeastern Poland also produced dates from the early Preboreal. It does not seem likely that such objects would have been imported by Mesolithic hunters; we believe that these belong to the last reindeer hunters who, at the onset of the Holocene, continued to hunt a local reindeer population.

Summarizing the points made above, we may affirm that the environmental conditions of the early Preboreal favoured gradual cultural changes, in the wake of environmental change. For several hundred years the woodlands brought into existence by climatic warming were of quite an open character, with relatively numerous grassland communities typical of Late Pleistocene conditions. Hence such conditions were favourable for the continued existence of residual populations of reindeer.

Ornamented Artefacts and Lithics

In the Late and Final Palaeolithic the geometrical style of representation spreads across the broad expanses of northern Europe. From the onset of the Allerød, artefacts sporting patterns of densely engraved, parallel zigzag lines arranged in groups separated by unornamented surface become popular in this area (Płonka et al. 2011; Płonka and Kowalski 2017; Vang Petersen 2015). This decorative style may be encountered on a broad range of objects, such as: a stone plate, a horse mandible, a ceremonial object from elk antler, an antler rod, a red deer antler shaft, an amber elk figurine, and harpoons. Most of these artefacts, with the exception of harpoons, do not show any evidence of usewear, hence we may assume that they were primarily of symbolic importance in the life of Late and Final Palaeolithic hunter-gatherers. In the case of the ceremonial object from elk antler from Rusinowo, we determined that the rich geometrical ornamentation and anthropomorphic representation were the product of the combined labour of a group of people, and had most probably been conducted over a longer period (Diakowski and Płonka 2017). The depiction, an image of a woman with spread legs and emphasised vulva, was made in geometrical style conforming to the rest of the ornamentation (Fig. 7a). Polishing of the surface and the zigzag lines of the ornament points to the object's long-term use, up to the moment of its abandonment.

Ornamentation styles used by Late and Final Palaeolithic hunters are continued in the Maglemosian art from northwestern and Central Europe. The pattern of densely engraved zigzag lines and anthropomorphic representations in the geometrical style,

with human depictions composed of strokes are found on objects made from bone, antler and amber. Such finds come from various areas of early Mesolithic settlement: today's Denmark, northern Germany, England and northwestern Poland. There are striking stylistic similarities in anthropomorphic representation between the Late Palaeolithic artefact from Rusinowo and the bone fragment from Bolków, site 1 (Fig. 7a, b), the latter being found in the layers of an early Mesolithic site related to the complex of northwestern Mesolithic cultures (Galiński 2014, Fig. 13b). The distance between those two sites is 85 km in a straight line, while their ages are dated some 1900–2300 years apart. The simplest explanation for this would be a continuation of human settlement, and of the same cultural tradition, gradually changing over time. If we were to assume the migration and hiatus model, then Final Palaeolithic hunters would have to migrate to an area where the northwestern Mesolithic cultures milieu emerged, and then move back and resettle Pomerania again.

While the custom of decorating hunting weapons with simple geometric patterns is almost unheard of in the northwestern province of Mesolithic art, it is a highly characteristic feature of the Mesolithic in the eastern area of the Baltic Sea Basin and northeastern Europe (Płonka 2003). It is difficult to explain in simple terms how this borrowing came to be; it is not necessarily connected to human migration but might be connected to local traditions related to the Final Palaeolithic. The distribution of chocolate flint among Swiderian communities shows that single items regularly reached up to 300–400 km away from their outcrop of origin (Sulgostowska 1997a, 2005, 2008). A single site, Salaspils Laukskola near Riga, provides evidence for the existence of a distribution network reaching up to 600 km from the outcrop. Radiocarbon dates of biserially barbed harpoon heads found at Lake Lubanas in Latvia place them at the transition from the Pleistocene to the Holocene, or Late Preboreal, that is, 9760–9210 cal BC (Meadows et al. 2014; see also Ukkonen et al. 2006), thus confirming the continuation of Final Palaeolithic cultural forms in this area into the early Holocene.

An often-used argument in support of the theory of the emigration of Swiderian hunters to northeastern Europe is the lack of continuity between lithics forms used by this people and early Mesolithic flint working (Kozłowski and Kozłowski 1977; Kozłowski 1972; Więckowska 1975). Still, some authors note that in some Swiderian assemblages from central and eastern Poland we find forms of truncated and backed points which could be deemed to be the precursors of Mesolithic microliths. At some Final Palaeolithic sites, particularly in those in the middle Vistula basin, we find small truncations (Burdukiewicz 2011, p. 307). Here Więckowska (1975, p. 419) draws attention to Rydno II/59, while in this context Galiński (2002, pp. 340–341) mentions artefacts from Level VI, Trench V at Całowanie and inventories from Grochale Górne, which include, for example, Zonhoven points. The inventory from Krajkowo 1 (near Poznań) published not so long ago lists microliths and finds representative of the flint working style of the late Tanged Point Complex—the Ahrensburgian and Swiderian (Dmochowski and Dziewanowski 2008). Forms of this type (microlithic truncated points) are already known from older stages of the Younger Dryas, as evidenced by the inventory of Level V at Całowanie, Trench XI (Schild 1975, pp. 278–279), where a whole group of microliths of this type was found. Although this inventory is viewed as atypical, one must say that

Fig. 7 Late Palaeolithic and early Mesolithic art from NW Poland (Pomerania). **a** Rusinowo; **b** Bolków 1

the manufacture of microlithic tools did not exceed the capability or skill of people representing Swiderian traditions. The tradition of microlith use is also visible at the Younger Dryas Swiderian campsite at Witów, central Poland. Besides classical Swiderian points, the Witów site also produced finds of microlithic truncated and Zonhoven points (Schild 1975, p. 282). Microlithic truncated points, including those of the Zonhoven type, are also known from other Swiderian sites (Schild 1975, p. 289).

A short time ago materials concerning concentration PF/2011 at Bolków, site 1, in Pomerania were published; this concentration displays many features characteristic for Final Palaeolithic sites of the Epi-Ahrensburgian type (Galiński 2018). In this assemblage blanks were usually knapped from double platform cores with opposite platforms. The list of tools includes three tanged points—two

Ahrensburgian and one Swiderian; two arch-backed points; and various forms of truncated points, including the Zonhoven type (Galiński 2018, Fig. 7). This site dates to the early and middle Preboreal (Table 1, Nos. 2 and 3).

To summarise the points made above, Swiderian hunters should not be perceived as incapable of modernisation of their hunting weapons. Microlithic forms have been present in the Swiderian assemblages from their inception—this is also true in the Ahrensburgian and Federmesser groups, as well as in Final Palaeolithic Epi-Ahrensburgian sites. Archaeological data from across the North European Plain show an increasing number of finds of microliths, truncated and backed points at sites from the end of the Younger Dryas and early Preboreal. One may assume that such forms were originally part of projectile points, and thus their presence would be linked with the spread of a new type of hunting weapon. Hence it transpires that in this case we are dealing with arrowheads—with the bow gaining immensely in importance at the end of the Pleistocene (Fischer 1989; Rozoy 1978, 1989; Serwatka 2018). Besides the point itself, mounted at the end of the shaft, the arrowhead also includes barbs—truncated and back points, most probably mounted in pairs to the sides of the shaft. Arrows with microlith barbs could have caused more severe wounds to the animal—their sharp edges cutting blood vessels, nerves and tendons, with devastating effects on an organism's vital parts, rendering them inactive. The spread of this invention was helped by the expansion of the birch, a tree type providing an inexhaustible supply of pitch used as adhesive to fix the microliths to the shaft. The use of pitch is confirmed by Mesolithic sites from northwestern Europe (Aveling and Heron 1999; Rozoy 1989; Sulgostowska 1997b). The changes in arrowhead design, just like any other effective weapons-related innovation, rapidly spread among communities of the European Plains.

It is difficult for us to explain the popularity of this innovation in hunting weapon design; everything points to many different factors being at play here, with environmental changes being just one. It could be linked to changes in perceptions of a weapon's effectiveness, as mentioned by Peter Bleed (1986, p. 739) who, in his seminal paper on weapon designs, wrote that besides being effective, a weapon must also 'meet social expectations'. Here effectiveness is understood as maximization of damage to the target, as caused by an arrow with a barbed head, assuming that the hunter aimed at the chest, that is, a large target containing various vital organs, damage to which caused the animal's death (Fischer 1989; Guthrie 2005, pp. 240–241). The second microlith on the side of the famous arrow from Loshult in southern Sweden is not a barb but a lateral cutting edge (Rozoy 1989, p. 18). Adding such cutting edges to arrows prevented them from slipping out of the wound. If the animal was not killed on the spot and bolted, it would keep on snagging the shaft against tree branches, weakening itself even further. However, although in a wooded environment an escaping animal is indeed more likely to hit an arrow protruding from its body against a branch and thus cause further damage to itself, it is difficult to decide whether this was a consideration in the popularization of this new weapon. Such a simple correlation should probably be ruled out, especially as microliths make their first appearance in the Younger Dryas, in almost treeless tundra conditions.

Social Circumstances and Migration

As already mentioned, one of the arguments used in support of the theory that Polish lands were abandoned at the close of the Pleistocene, with a hiatus between the departure of the previous population and the arrival of Mesolithic settlers, is the demise of chocolate flint mining and the collapse of its distribution network, as well as the scant traces of settlement around the ochre mine in Rydno (Schild 1996a, 1996b, 2001). In this context it should be noted that explaining mechanisms of cultural change using coarse-grained archaeological evidence is a difficult and thankless task. Such changes are the outcome of a mix of circumstances, of factors difficult to identify and combine into some sort of structure, especially as only a negligible percentage of such factors leaves traces in the archaeological record. One example of difficult-to-interpret cultural behaviour is the model of exchange of shells and fossils which lasted in southwestern Germany from the Magdalenian to the Mesolithic (Eriksen 2002). We note the inflow of shell imports during the Magdalenian and in the Mesolithic—yet in the Final Palaeolithic such imports dwindle to almost nil, for no known reason, with no evidence of any change to the resident population. The very same mechanism might apply to early Mesolithic dwellers ceasing to extract ochre at Rydno. In exactly the same way as with flint, acquisition efforts may have been redirected into use of local ochre sources. Additionally, at Rydno there are signs of Komornica-culture settlement from the early Mesolithic—however, a large part of the site was destroyed before it was excavated (Schild et al. 2011, pp. 47, 331–344). The termination of exploitation of the chocolate flint outcrop by early Mesolithic dwellers may have been driven by technological considerations—the needs of early Mesolithic hunters-gatherers being fully met by surface-gathered erratic, chocolate or Jurassic flint. We find examples of use of erratic chocolate flint in the Final Palaeolithic/early Mesolithic at the aforementioned site no. 1 Krajkowo near Poznań. This flint may have come from a secondary source which could not, however, have been far removed from the original outcrops (Dmochowski and Dziewanowski 2008, p. 408). As an aside here, we should mention that pioneer communities do not seem to have had difficulty in finding essential stone resources: flint for tools and pigments. Magdalenian immigrants to southern Poland may serve as an example of this, as they quickly found their way around the available Late Pleistocene resources and exploited various local outcrops of flint and pigment (Kozłowski and Sachse-Kozłowska 1995). Therefore, even if Mesolithic communities were newcomers to this area they doubtlessly would have identified locally available resources. The trade networks for flint and pigments from the Late and Final Palaeolithic could not function as efficiently as previously due to changed conditions in the dense woodlands of the temperate zone. Furthermore, this was a period when we note the rise of local social relations as reflected in the diversification of stone inventories and art motifs (Kozłowski 2009; Kozłowski and Kozłowski 1975; Płonka 2003; Stoczkowski 1987). Hence the simple explanation could be that mined flint and ochre were simply not attractive enough to become trade items, with other prestige objects being of greater relevance.

Migration as a factor explaining cultural change at a time of dramatic environmental changes requires separate investigation. It is noteworthy that none of the

quoted texts suggesting the depopulation of Polish lands in the Late Pleistocene provides a definition of *migration*, with this term being differently understood in studies of ecology or biology, geography, genetics, history or other sciences (Anthony 1990; Burmeister 2000; Clark 1994); neither has there been any discussion of the models and pace of migration movements, nor debate about the theoretical aspects of how migrations might be reflected in the archaeological record. This is in spite of the view expressed by David Anthony that using archaeological data to prove human migration is rather foolhardy (Anthony 1990, p. 95). Furthermore, in the archaeology of the Palaeolithic the use of migrations as an explanation of *anything* is frowned upon, due to the low population density of that period (Clark 1994). In the opinion of Graham Clark (1994, pp. 305–307) the terms *migration* and *diffusion* are more pertinent for the historical period, and using them as an explanation in the archaeology of the Palaeolithic is inappropriate. Such a position is, naturally, too extreme and reflects processual archaeology's dislike of using these phenomena in interpretation of cultural processes (Burmeister 2000).

According to Anthony, the most appropriate approach towards the issue of migration starts by defining its nature. In his opinion 'migration can be understood as a behaviour that is typically performed by defined subgroups (often kin-recruited) with specific goals, targeted on known destinations and likely to use familiar routes' (Anthony 1990, pp. 895–896). He identifies the main drivers as negative factors at the point of origin (*push*) and positive factors at the destination (*pull*)—although such an approach is criticized as being inflexible and ahistorical (Burmeister 2000). Although *push* factors are mostly economic in nature, religious, cultural or social (oppression) considerations are also possible. As concerns Younger Dryas inhabitants of the Polish Plain, the negative factor would have been the extinction or migration of cold-adapted Pleistocene species, reindeer in particular. However, the change in fauna was not as drastic as previously thought, with reindeer surviving into the oldest phases of the Preboreal and coexisting with woodland species. Hence environmental conditions allowed for gradual adaptation to the new situation, without the need to assume significant changes to the human population. Naturally, it cannot be ruled out that some communities gradually moved northwards following the new geographic range of reindeer, yet it is difficult to view this as an organised migration in the sense defined above.

In our opinion it would be best to look at the likelihood of human migration through a model showing its pace (dynamics) in relation to the predictability of the environment. The predictability may be defined as 'the degree to which a correct forecast [or prediction] of a system's state can be made either qualitatively or quantitatively' (Mihailović et al. 2016, p. 266). The assumption is that predictability of environment is high when the climate is stable and is lowered in conditions of rapid climate change. Such modelling looks at four extreme scenarios (Fig. 8):

1. high predictability and low rate of migration—a situation typical of stable environmental conditions and stable social relations; these are individuals and families, driven by personal considerations, who leave the group (Gamble 1998);
2. high predictability and high rate of migration—this scenario happens when migration is driven by non-economic factors: social, religious or cultural. In our opinion

the migration of the Magdalenian population from southwest to Central Europe is an example of this model (Jochim et al. 1999; Svoboda et al. 1996). As the area of origin had stable environmental conditions, one may assume that the outbound migration was brought about by other than economic factors—probably an increase in population leading to problems with social organisation (Płonka 2012);

3. low predictability and low rate of migration—this occurs during times of rapid climate change; strong social cohesion will cushion the impact of change (Whallon 2006); archaeological data points to the existence of such strong social bonds in the Swiderian and Ahrensburgian in the Polish plains, as evidenced by trade networks for the exchange of raw materials (Sulgostowska 1997a, 2005, 2008);
4. low predictability and high rate of migration—this is when rapid environmental changes are accompanied by high migration rates; this is found in conditions of weak social ties and highly specialized cultures. To date this model has been used to explain the cultural changes in the Polish Plain at the Palaeolithic–Mesolithic transition.

Of course, there are many intermediate scenarios between these extreme examples which are, however, difficult to identify using coarse-grained archaeological evidence. Nevertheless, the existing archaeological record provides the largest quantity of supporting evidence for scenario no. 3. People from the Final Palaeolithic living in the Younger Dryas formed well-organized communities connected by a strong network of mutual relations. It is therefore unlikely that environmental changes would have triggered a migration, especially as some elements of the new environment, for instance, elk, were already known in Central Europe during the Younger Dryas (Płonka et al. 2011), whereas reindeer was still present in Polish lands in the Preboreal. It should also be noted that there are no signs whatsoever of human migration in the Central European Plain at the break of Allerød and Younger Dryas, a time of dramatic change in climate.

It may therefore be assumed that any human movements affecting the Polish Plain at the transition from Pleistocene to Holocene were not particularly dramatic in scope. In our view it would be better to explain such movements using the term *dispersal*—which, unlike *migration*, means expansion, but not as focused along a specific axis—and the category *familiar area*. ‘A familiar area is the entire area known to a species, although not all parts of it will be known to individuals or would be regularly exploited by any single group or individual. The familiar area can be many times greater than a species’ home range’ (Clark 1994, pp. 313–314). A clear example of such familiarity is the above-mentioned site of Salaspils Laukskola near Riga, some 600 km away from the outcrop of chocolate flint which provided the raw material for a large part of the inventory.

To add an anthropological dimension we searched—using the tag *migration*—the e-HRAF database for hunter-gatherer communities of the arctic and sub-arctic areas of North America and Asia. Naturally enough the term *migration* is used in explaining the mechanisms through which various areas of the Arctic and Far North were settled. Nevertheless, such processes behind human movements may involve quite distant times and are thus similar to our subject area—and in some

Predictability	High	Stable environment Low exchange of personnel among groups	Stable environment Migration due to social and/or religious reasons
	Low	Environmental change Strong social ties – minimal migration	Environmental change Migration
		Low	High
		Tempo of migration	

Fig. 8 Model presenting a tempo of migration vs. the predictability of the environment

cases migrations are questioned, specifically in relation to the Nenets, part of the Cree or Ojibwa. There are instances where a migration has partly moved into the realm of legend, becoming a Great Journey, a part of a tribe's religious life and the axis of its ideology, for example among the Ojibwa, where tradition holds that they abandoned their previous grounds near the mouth of the Saint Lawrence river and moved to the Great Lakes area (Bishop 1974; Greenberg and Morrison 1982).

Of greater interest is information about the reactions of various hunter-gatherer communities to the disappearance of their traditional prey—the reindeer. Sadly such scenarios are not well represented in the database. The Copper Inuit from Victoria Island in northern Canada had a problem when, after 1925, the spring and summer migrations of reindeer ceased (Damas 1972, pp. 17, 19). Different Inuit communities reacted in different ways. Some sought replacement for reindeer through hunting for seals or fishing either in the west of the island, around Prince Albert Sound, or on the eastern coast—around Wellington Bay and Cambridge Bay. However, some hunters, particularly from the eastern part of island, moved to the mainland, for instance to the Kent Peninsula, to continue their hunting for reindeer, still occasionally encountered in that area.

Another account concerns the Naskapi (Innu) who, up to the early 20th century, sustained themselves with hunting forest reindeer around House Lake (Naskapi: *Mushuan Nipi*), in northeastern Canada. Around 1916, reindeer changed their migration routes, which caused a famine threatening the existence of the Naskapi (Henriksen 1973). This led the Naskapi to move to the coast and seek succour at Hudson Bay Company outposts. This disaster was brought about by the total dependence of the Naskapi on reindeer. They did not know how to hunt for sea animals, as previously they had visited the coast solely to trade. Tellingly they did not look for the reindeer's new migration routes to their northwest—probably their material culture was so tailored to their woodland habitat that they decided against hunting reindeer in the tundra, a treeless landscape totally alien to them (Tanner 1944, pp. 677–678).

The situations described above, in spite of having happened in the period of globalization where people with traditional lifestyles live alongside complex Western societies, nevertheless shed light on the cultural mechanisms behind human migration and dispersion. The most salient conclusion seems to be that decisions—regardless of cultural and social motives—are most dependent upon the role of the ‘staple prey’—in this case reindeer—in the affected population’s diet and material culture. The Copper Inuit switched to different prey or partly employed periodical dispersion to adapt to their new situation. The Naskapi chose to migrate—albeit making use of an opportunity provided by the new, globalised world—to the trade outposts of white settlers. Now looking at the Polish and Central European Plain in the early Preboreal we see that it still harboured herds of reindeer—probably well adapted to the prevailing conditions of a woodland landscape with broad expanses of open terrain.

To sum up this theoretical examination of the process of human migration and review of the anthropological data, we must admit that the data do not point to migrations being common among hunter-gatherer populations; the movements of such communities are usually better described with the term *dispersal*. It is doubtful that Final Palaeolithic communities of the Polish Plain, bound together by strong social bonds, would not have been capable of adapting to new environmental conditions. Analysis of the chronology of the Pleistocene–Holocene transition suggests that change in that period is best described as a gradual process, allowing for parallel existence of the old, Final Palaeolithic and new, Mesolithic ways of life.

Conclusion

The available data—results of statistical modelling of radiocarbon dating, and data concerning the natural environment, symbolic culture and flint artefacts, and the information on hunter-gatherer social life—give grounds to question the theory that Polish lands were depopulated during the final stages of the Pleistocene or onset of the Holocene, and then repopulated by an inflow of Mesolithic settlers after a settlement hiatus. The analysed dates tend to point to Final Palaeolithic and Mesolithic settlement not being separated in chronological terms. The results of our research support what we term here the ‘replacement model’, and convince us that in the Polish Plain the Mesolithic directly succeeded the Final Palaeolithic some time between 9260 and 8980 BC, with a very low probability of overlap between the Final Palaeolithic and Mesolithic settlement (11%). It is difficult to use existing data to theorise the earlier emergence of the Mesolithic in Germany and western Poland. However, in light of the presented data it is difficult to advance the view that it was related to a gradual eastward migration of Mesolithic hunters, as there is no evidence for a mass exodus to the north by the Final Palaeolithic population.

A slightly different model, the ‘coexistence model’, regarding the disappearance of Final Palaeolithic traditions and the emergence of a new way of life may be assumed to apply to the North German Plain. Here we can argue that the two cultural patterns coexisted alongside one another for some two hundred years: there the Palaeolithic terminates between 9210 and 8900 BC, while the Mesolithic begins

somewhere between 9400 and 9300 BC. Here the modelling of radiocarbon dating points to an overlap between Final Palaeolithic and Mesolithic settlement, where even the elimination of earliest Mesolithic dates from Bützsee-Altfrisesack, Bedburg-Königshoven and the latest Final Palaeolithic dates from Stellmoor or Kartstein does not fundamentally alter the results of the modelling; this change merely lowers the probability of the conclusion.

In eastern Poland the Mesolithic began slightly later than in western Poland or Germany, possibly due to climate factors at the onset of the Preboreal period. Data from radiocarbon dating point to there being neither mass migrations nor a settlement hiatus. Environmental data, flint artefact forms and symbolic culture all confirm that human communities inhabiting the European Plain developed local cultural forms typical of the Mesolithic. Anthropological studies also add weight to the argument that a mass migration of Palaeolithic and Mesolithic hunter-gatherers was not very likely.

Although the corpus of analysed dates is rather limited, considering that they cover some two thousand years, it is nevertheless possible to theorise on the social phenomena behind the presented models of changes occurring in the Polish and North German Plains at the Palaeolithic–Mesolithic transition. The replacement model assumes a relatively rapid disappearance of cultural forms typical of the Final Palaeolithic and the emergence of Mesolithic forms. It is difficult to pinpoint the causes of this turn of events. However, one may theorise that it could stem from the presence of strong social bonds, from the rapid exchange of information between various human groups, with such an information exchange being accompanied by the dispersion to the northeast of those who preferred the traditional way of life. However, this never took on the character of a mass migration, but was rather a relocation inside a well-known landscape. It is likely that the coexistence model reflects a different set of social circumstances. Here we would have a highly diverse cultural landscape, where different niches are inhabited by different human groups—some cultivating old traditions, others following a new way of life. The existence of social interaction between these distinct communities may be surmised from the appearance of new flintworking techniques, as evidenced by, for example, Epi-Ahrensburgian assemblages. The question remains whether it is possible to interpret the models resulting from Bayesian analysis of existing radiocarbon dates. It seems that we still do not possess enough radiocarbon dates to allow for more precise analysis of transition-period processes in a regional perspective.

In light of the above analysis, the hypothesised settlement hiatus between the Final Palaeolithic and early Mesolithic, and mass early Holocene immigration into the Polish Plain appears to be rather unlikely. Such a theory is contradicted not only by the results of radiocarbon dating modelling, but also by data concerning the state of transformation of the habitat, artefacts from various materials, and remains of symbolic culture. The migration and hiatus theory is further undermined by results of analysis of anthropological materials concerning migrations of hunter-gatherer communities. During the Younger Dryas and at the beginning of the Preboreal the broad expanses of the North European Plain witness a change in the tool kit—the emergence and growing role of microlithic tools. In the early Preboreal there still exist communities continuing Late Pleistocene traditions. The migration of new

communities of flora and fauna occurred in parallel to the existence of enclaves of grassland communities and fauna typical of the late Pleistocene. We conclude that during the Pleistocene/Holocene transition, the European Plain was host to complicated changes which cannot be explained by a simple linear evolutionary model. The cultural landscape was a patchwork, interweaving old forms with emerging new traits, the latter becoming broadly understood as early Mesolithic traditions.

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Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

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