Quaternary Science Reviews 312 (2023) 108170

Contents lists available at ScienceDirect

Quaternary Science Reviews

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

Drowning landscapes revisited. Correlating peatland expansion, human habitation trends and vegetation dynamics in the Northwest European mainland

Roy van Beek [a], [*], Cindy Quik [b], Marjolein van der Linden [c]

[a] Soil Geography and Landscape Group/Cultural Geography Group, Wageningen University, PO Box 47, 6700 AA, Wageningen, the Netherlands
[b] Soil Geography and Landscape Group, Wageningen University, the Netherlands
[c] BIAX Consult, Zaandam, the Netherlands

ARTICLE INFO

Article history:
Received 29 March 2023
Received in revised form
1 June 2023
Accepted 2 June 2023
Available online 9 June 2023

Handling EditorClaudio Latorre

Keywords:
Holocene
Palaeogeography
Peatlands
Vegetation dynamics
Landscape archaeology
Western europe

ABSTRACT

In the course of the Holocene large parts of the Northwest European mainland became overgrown with peat, only a fraction of which has survived to the present day. The diachronic relations between peatland expansion, human habitation trends and vegetation dynamics are poorly understood. Gaining detailed insights in the interrelations between these processes is essential to enhance interpretations of archaeological data on different spatial and temporal scales and to inform cultural heritage management and nature conservation and restoration. To achieve this goal it is key to develop interdisciplinary research designs in which the timing, pace and character of the relevant processes are analysed integrally. In this paper we present a study of the northern Dutch Fochteloërveen area, which is one of the largest and best preserved bog remnants of the Northwest European mainland. We integrate a recently published model on peatland initiation and lateral expansion with an inventory of extant archaeological data and new high-resolution palaeobotanical analyses (plant macro remains and pollen), which produces insights into the dynamic landscape history of this 'drowning' area in hitherto unparalleled detail. Two characteristic phases in the landscape history of the study area (the Late Mesolithic and Middle Roman period) are visualised by means of evidence-based artist impressions. The methodology and results of the study offer inspiration and important material for comparison for similar landscapes across the Northwest European mainland.

1. Introduction

Large parts of the Northwest European mainland were once covered with peat (e.g. Casparie, 1993; Vos et al., 2020). Peatlands are defined here as areas where 30 cm of peat or more naturally accumulated (cf. Quik, 2023, 4). In many non-coastal areas the maximum peatland expansion is thought to have been reached in the Middle Ages, when large-scale reclamations for agriculture and peat extraction were initiated (e.g. Van Beek et al., 2015). Tanneberger et al. (2017) provide an overview map and analysis of surviving peatlands in the present-day European landscape, demonstrating an especially high density in the Northwest European mainland. The vast former expansion of peatlands becomes even more clear from the fact that the current remnants only represent a fraction (often no more than 5–10%) of their original distribution (Joosten and Couwenberg, 2001). The expansion of peatlands in the course of the Holocene had a major impact on prehistoric and early historic human habitation development. Previously habitable landscapes were overgrown with peat (a process sometimes referred to as 'drowning' (e.g. Fokkens, 1998). The expanding peatlands greatly influenced the accessibility of certain areas and the possibilities to travel across. This, amongst others, led to the construction of numerous wooden trackways in peatlands since Neolithic times (e.g. Casparie, 1987). However, expansion of these wetlands did not just limit or hamper human behaviour. They also provided opportunities for hunting, food gathering and peat extraction, and were focal areas for ritual activity from the Neolithic onwards (e.g. Bradley, 2017).

The exact relations between peatland expansion, human habitation trends and vegetation dynamics are poorly understood (Van

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* Corresponding author.
E-mail address: Roy.vanbeek@wur.nl (R. van Beek).

https://doi.org/10.1016/j.quascirev.2023.108170

Beek, 2015; Van Beek et al., 2015). This not only applies to the Northwest European mainland, which is the focal area of this study, but also to many other parts of Europe (e.g. Chapman et al., 2019). To arrive at a detailed understanding of the interrelations between palaeo-environmental developments and human habitation patterns, it is key to develop interdisciplinary research designs in which the timing, pace and character of the relevant processes are analysed integrally. Due to a variety of reasons, including the large-scale disappearance of peatlands (and as such the available study archives) and the prevalence of mono-disciplinary research into these environments (see section 2), such studies are rare. The aim of this paper is to make a contribution to fill in this research gap. This is operationalised by an interdisciplinary study of the northern Dutch Fochteloërveen area. This relatively well-preserved peatland is one of the largest raised bog remnants of the Northwest European mainland. The study area, including both bog remnants and adjacent mineral soils, has yielded a wealth of archaeological information in the past. Radiocarbon dating evidence and detailed information on peatland initiation and lateral development are available from two recent studies (Quik et al., 2022, 2023). In addition, the area offers suitable conditions to collect high-quality palaeo-botanical data for the analysis of vegetation dynamics.

The main research questions are:

- how is the initiation and lateral expansion of the Fochteloërveen peatland related to human habitation patterns through time and space?
- how did the vegetation of the Fochteloërveen area and surrounding mineral soils develop over time, both on local and regional scales, and how are these patterns related to peatland expansion and human landscape impact?

The emphasis of the study is on the period between the Mesolithic and the Early Middle Ages (c. 8000 BCE – 1000 CE). The Late Palaeolithic (c. 15,000–8000 BCE) is included in the archaeological part of the analysis as well. This is the first phase for which significant archaeological data are available, which provide insights into human use of the study area before the start of significant peat growth. The period from the High Middle Ages onwards (after c. 1000 CE), in which reclamations of parts of the Fochteloërveen were initiated (Gerding, 1995, 146–154), is outside the scope of the research. We build on two recent studies that provide detailed radiocarbon dating evidence and a model of peatland initiation and lateral development for the Fochteloërveen area (Quik et al., 2022, 2023). Our methods include an inventory of extant archaeological data and high-resolution palaeobotanical analyses (plant macro remains and pollen) of three selected cores. All information is combined through interdisciplinary analyses and two important phases in the landscape history of the study area are visualised by means of evidence-based artist impressions. The study produces insights into the dynamic landscape history of the study area in hitherto unparalleled detail, and offers valuable material for comparison with similar landscapes in other parts of the Northwest European mainland. Furthermore, the research design may provide inspiration for future research into the landscape history of peatlands in general.

2. Research background

Peatlands are important research subjects in a variety of scientific disciplines, including earth sciences, hydrology, (palaeo)ecology and (palaeo)climatology. In the last decade they have increasingly gained attention because of their important function as carbon stocks, in relation to human-induced climate change (e.g. Yu, 2012; Loisel et al., 2014; Gallego-Sala et al., 2018; Harenda et al., 2018). Peatlands also provide excellent conditions for interdisciplinary research into human-landscape interactions, on a variety of spatial and chronological scales (e.g. Van Beek, 2015; Chapman et al., 2019; Chapman et al., 2019; Gearey and Chapman, 2022). In the present study, the main emphasis is on the 'landscape' or 'macro' scale of analysis (cf. Chapman et al., 2019). This implies that we aim to study the development 0f peatlands in their wider geographical setting, including the adjacent mineral soils. This approach is most suitable to study human-landscape interactions on long time scales (e.g. Van de Noort and O'Sullivan, 2006; Chapman et al., 2019; Van Beek et al., 2015, 2019).

The 'landscape' scale of analysis requires an interdisciplinary research approach that combines archaeology with palaeogeography and palaeo-ecology. Even though such studies are relatively rare, some inspiring – yet methodologically highly diverse-examples are available. Cases of landscape scale research in which multiple archaeological sites are analysed in their palaeo-environmental setting are the southern German Federsee region (e.g. Liese-Kleiber, 1993), the Irish Lisheen area (Gowen et al. 2005) and Hatfield and Thorne Moors in the United Kingdom (Chapman et al., 2019). Zooming out further, well-known large-scale wetland projects include the British regions of the Somerset Levels and Moors (Coles and Coles, 1986; Brunning, 2013) and Fenlands (e.g. Coles and Hall, 1997; Pryor, 2020). With regard to our study area and its surroundings, some research has been done on the relation between lateral peatland expansion and human habitation patterns in the northern Netherlands (Groenendijk, 2003; Fokkens, 1998; Waterbolk, 2007) and northern Germany (Pantzer, 1986; Behre, 2005; Nösler, 2017). These studies mainly depart from an archaeological perspective and emphasize that encroaching bogs were a key factor determining the structure and development of settlement territories. In most cases archaeological data are compared to existing palaeo-environmental evidence, without collecting new high-resolution field data. Exceptions are the projects investigating well-preserved prehistoric landscapes in the Northern German Stade (Pantzer, 1986; Nösler, 2017) and Ahlen-Falkenberger Moor areas (e.g. Behrens et al., 2019).

The above-mentioned studies clearly demonstrate the potential of integrated research designs. Nevertheless, three persistent challenges and research gaps can still be defined for the Northwest European mainland. Firstly, the process of lateral peat expansion is understudied. This specifically applies to non-coastal peatlands. This may be explained by the scarcity of peatlands with intact extent that survived reclamations and the associated rarity of dating evidence on peat inception (especially on large spatial scales). Quik et al. (2023) provide a basic overview of previous research approaches in this field (for a recent addition, see Sevink et al., 2022). Gaining insights into the mechanisms behind lateral peat expansion, and unravelling the timing and pace of this process (e.g. gradual or accelerating/slowing down in specific phases), is essential to contextualise and interpret changes in human behaviour over long time scales. A second research deficit is that large-scale inventories of archaeological sites in peatland environments are rare. Moreover, the quality of the available archaeological data often is not optimal because many finds were done in the distant past during reclamation activities, and professional archaeological excavations have been very limited in many areas. Thirdly, the high potential of palaeobotanical data to enhance long-term reconstructions of dynamic peatland environments (e.g. Aaby, 1986) is not fully exploited yet. This specifically applies to identifying the timing, intensity and character of human landscape impact over time, and the correlation of observed trends with archaeological evidence. The latter is also vital in disentangling natural and human-induced vegetation changes. Increased openness, for example, may either result from human vegetation clearance (e.g. Behre, 1988) or peat expansion (e.g. Casparie, 1972).

The innovative elements of the current study are in the integral analysis of long-term trends in peatland palaeogeography, palaeoecology and human habitations patterns, incorporating high-resolution datasets from each of these disciplines and 'translating' the produced data in evidence-based artist impressions.

3. Materials and methods

3.1. Chronology and nomenclature

In this paper we present our data using a combination of an archaeological chronological division (with dates indicated in BCE – CE) and palaeobotanical data ordered according to the 'classical' biostratigraphical pollen zones, which is commonly used in Northwest European palaeobotanical studies. Peatland expansion trends are indicated in cal y BP, which are correlated (in text and illustrations) with the archaeological periodisation and pollen zones. Compared to the new formal stratigraphical subdivision of the Holocene (Walker et al., 2019), our work is mainly positioned in the Northgrippian (8200–4200 cal y BP) and Meghalayan (8200 cal y BP – present) Stages. The latter terms are not used in following parts of the paper. In the description of pollen samples (section 4.3) we provide median calibrated radiocarbon ages. These are based on the age-depth model published by Quik et al. (2022, Fig. 7). The elevation of analysed samples is recorded in metres O.D., i.e. relative to Dutch Ordnance Datum (+NAP), which is roughly equal to mean sea level.

3.2. Study area (cf. Quik et al., 2022, 2023)

The northern Dutch Fochteloërveen peatland (c. 2500 ha) is one of the largest bog remnants of the Northwest European mainland (Fig. 1). It may be considered representative for many (non-coastal peatlands) in this region because of the widespread distribution of its mineral substrate and characteristic climatic conditions. As will become apparent the Fochteloërveen formed through coalescence of multiple smaller mires, resulting in a composite peatland that can best be described as a plateau raised bog (Moen, 1985; Charman, 2002; Quik et al., 2023).

During the Saalian (MIS (Marine Isotope Stage) 6) the northern Netherlands were covered by a continental ice sheet. This led to the deposition of glacial till (Rappol, 1987; Van den Berg and Beets, 1987; TNO-GSN, 2021a) and formation of the Drenthe Plateau or till plateau (Ter Wee, 1972; Bosch, 1990). Aeolian cover sands were deposited over large parts of Northwest Europe (the European Sand Belt) during the Weichselian (MIS 4–2; Koster, 1988, 2005). The thickness of cover sands on the Drenthe Plateau varies between 0,5 and 2 m (Ter Wee, 1979; TNO-GSN, 2021b). The Fochteloërveen is situated near the western margin of the Drenthe Plateau and is part of three catchments, which drain into the rivers Drentsche Aa (northeast), Peizerdiep (north) and Kuinder or Tjonger (west). From 18th century historical sources it can be derived that peat thickness at Fochteloërveen locally exceeded 7 m (Douwes and Straathof, 2019, 133–134). Industrial-scale peat exploitation for turf production started in the 17th century (Gerding, 1995, 142–154; Douwes and Straathof, 2019, 134–136), even though peat was probably already extracted centuries before by individual farmers (by means of so-called 'farmers cuttings'). Peat reclamations lasted until the 1970s. As a result, the current Natura 2000 area (Provincie Drenthe, 2016) contains the last remnants of an originally far larger peatland. Buckwheat cultivation, which was at its height in the late 18th and 19th century (Douwes and Straathof, 2019, 136–137), in some areas has affected the uppermost peat layers. Peat thickness currently varies between 20 and 225 cm (Quik et al., 2022). Current average day temperatures are 5.6 °C in January and 15.9 °C in July, whereas average annual rainfall is 809 mm (KNMI, 2021).

Our study follows a nested approach, using three spatial scales (Fig. 2):

(1) the overall study area, which is central in the archaeological inventory (section 3.3) and has a size of 20 × 16 km;
(2) the Fochteloërveen peat remnant, with a size of 2500 ha, which takes a central position in the larger area of scale (1), and for which radiocarbon dating evidence and a model of peatland initiation and lateral development are available from recent work (Quik et al., 2022, 2023) (section 3.4);
(3) three selected cores in different parts of this peat remnant, which form the basis of the palaeobotanical analysis (section 3.5). These do not only provide information on vegetation developments on a local level, but also on spatial scales (2) and (1).

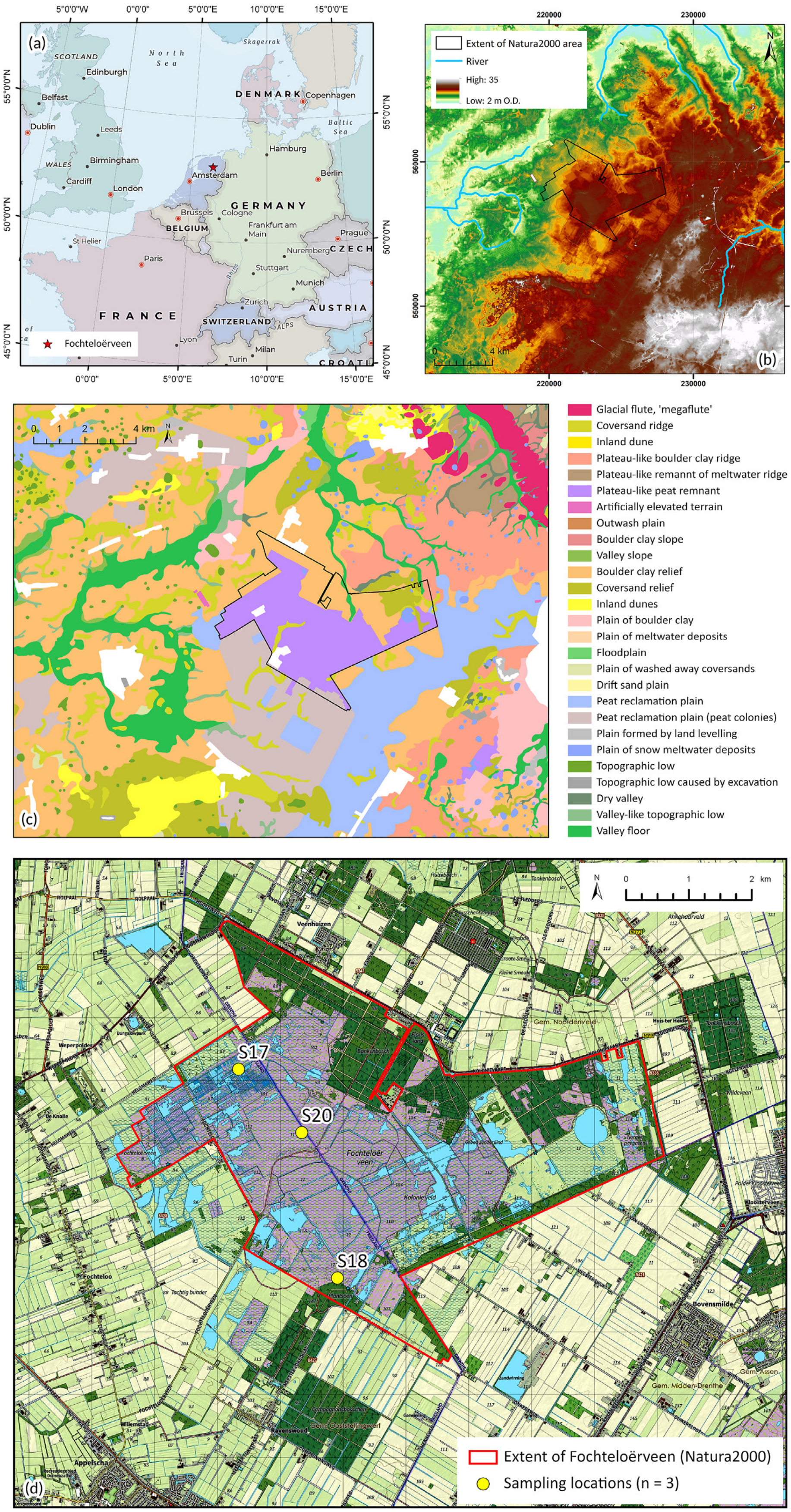
To summarize, the peatland palaeogeographical data are based on previous research (section 3.4), whereas the archaeological inventory (section 3.3), palaeobotanical analysis (section 3.5), data integration (section 3.6) and artist impressions (section 3.7) are the novel contributions of this study. The wider implications of the study, on the geographical scale of the northwest European mainland, are considered in the discussion.

3.3. Human habitation trends

The Fochteloërveen peat remnant and its wider surroundings have been investigated intensively, mainly by amateur archaeologists (often in the form of field surveys) but also by professionals (generally small-scale rescue excavations). Therefore a relatively large number of archaeological sites is known from the study area, ranging from chance finds of single artefacts to excavated settlement sites. We created an inventory of archaeological sites for the study area (spatial scale 1), including the peat remnants, reclaimed parts of the peatland and the adjacent mineral soils. The results are presented in appendix A. Used sources include the national Dutch archaeological repository Archis III (archis.cultureelerfgoed.nl) and a wide variety of published literature. The latter consists of scientific books and papers, reports of contract-based research and so-called 'grey literature'. All sites were recorded in a database, registering all available information on find circumstances, site character and find materials. Based on major societal transformations we present the results in four chronological sections, which are called 'hunter-gatherers' (Late Palaeolithic & Mesolithic; 15,000–5000 BCE), 'early farmers' (Neolithic & Early Bronze Age; 5000–1800 BCE), 'advanced farmers' (1800-19 BCE) and 'early historical communities' (19 BCE – 1000 CE). This division mainly serves to signal and describe large-scale trends, as in reality the transitions between these phases will have been gradual rather than abrupt (the date 19 BCE reflects the first Roman military presence in the Netherlands; Kemmers, 2006). For each period a site distribution map is provided (Figs. 3–6).

3.4. Peatland initiation and lateral expansion

The data on peatland initiation and lateral expansion incorporated in this paper have recently been published by Quik et al. (2023). For a detailed description of the applied methodology we refer to that publication, whereas we suffice with a concise summary here. The focus of the palaeogeographical research was on peat initiation (prior to the formation of a peat layer with a


(a)
Fochteloërveen
North Sea
DENMARK
GERMANY
BELGIUM
FRANCE
SWITZERLAND
AUSTRIA
Amsterdam
(b)
Extent of Natura2000 area
River
High: 35
Low: 2 m O.D.
0 4 km
220000
230000
560000
550000
(c)
0 1 2 4 km
Glacial flute, 'megaflute'
Coversand ridge
Inland dune
Plateau-like boulder clay ridge
Plateau-like remannt of meltwater ridge
Plateau-like peat remnant
Artificially elevated terrain
Outwash plain
Boulder clay slope
Valley slope
Boulder clay relief
Coversand relief
Inland dunes
Plain of boulder clay
Plain of meltwater deposits
Floodplain
Plain of washed away coversands
Drift sand plain
Peat reclamation plain
Peat reclamation plain (peat colonies)
Plain formed by land levelling
Plain of snow meltwater deposits
Topographic low
Topographic low caused by excavation
Dry valley
Valley-like topographic low
Valley floor
(d)
0 1 2 km
S17
S20
S18
Extent of Fochteloërveen (Natura2000)
Sampling locations (n = 3)

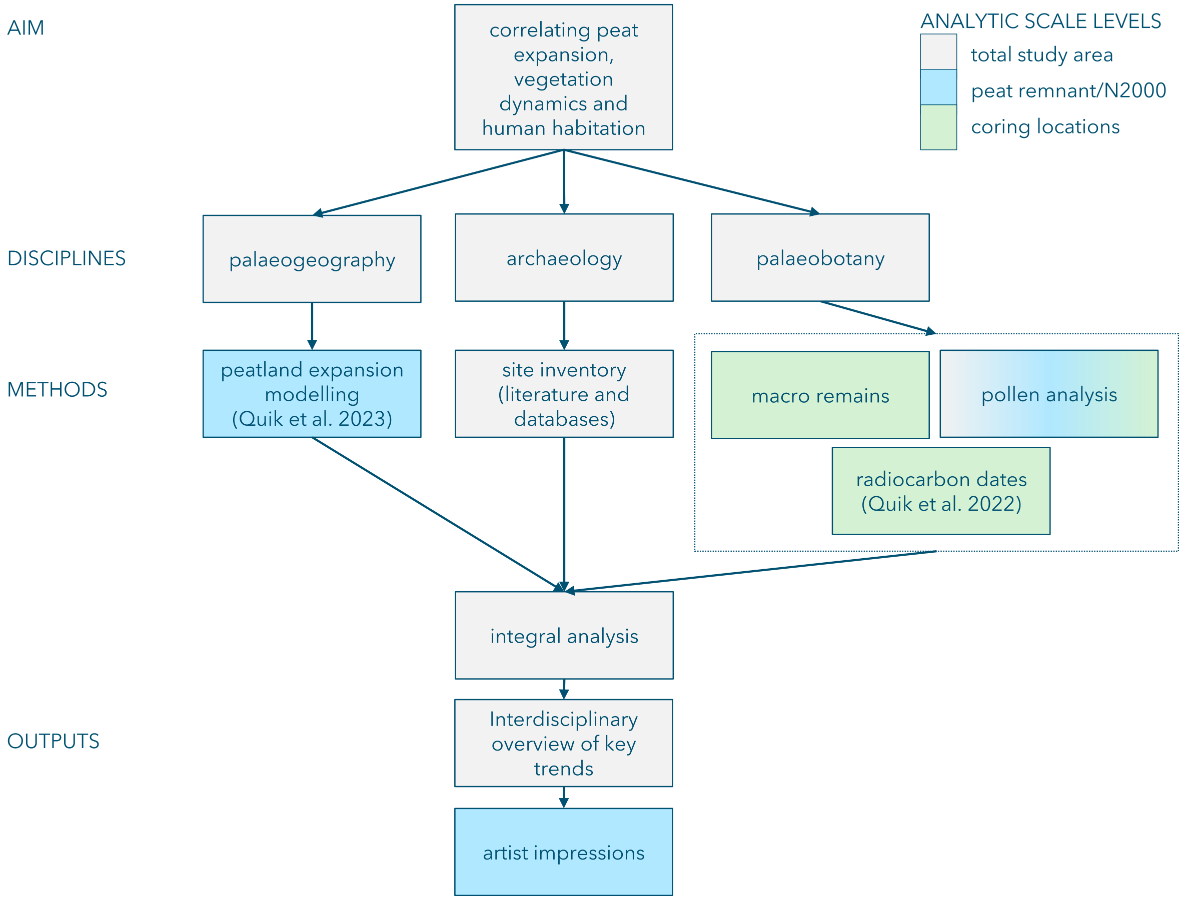


Fig. 2. Interdisciplinary workflow (1.5 or 2-column image, color in print and online).

thickness of ≥30 cm), both in time (initiation at one or more nuclei) and space (lateral expansion). The fieldwork underlying the analysis consisted of spatially distributed transects of gouge corings with elevation gradients in the (compaction-free) mineral deposits underlying the organic deposits (93 corings in total). An extensive set of basal peat radiocarbon dates was obtained, which formed the basis for further modelling steps. With *basal peat* we refer to the stratigraphical level that reflects peat initiation, which is defined as the lowermost level from a peat core that contains ≥40% organic material (for a detailed discussion on this topic, based on earlier work in Fochteloërveen, see Quik et al., 2022).

To reconstruct peat initiation ages for non-sampled sites, a digital soil mapping approach was applied in which a covariate map (explanatory variable) was converted to a map of the variable of interest (peat initiation age) based on a statistical relationship. Using linear regression in R, significant relationships were found between peat initiation age and two covariates: (1) the total thickness of organic deposits and (2) a constructed variable based on elevation of the mineral surface and hydraulic head. The latter reflects groundwater-fed wetness that results from position within the large-scale geomorphology of high topographic plains and incised valleys. By means of the linear models, prediction maps of peat initiation age were created using the R 'raster' package. Standard deviation maps were obtained from the limits of the prediction interval of the regressions.

Both maps reflect fairly similar trends over time, with slight differences in the exact timing of lateral expansion. In this paper we have chosen to work with the prediction map based on the thickness of organic deposits, as this is probably least affected by the drainage of areas bordering the Natura 2000 area (see also Quik et al., 2023).

3.5. Vegetation dynamics

Three peat cores, named S17, S18 and S20, were selected for palaeobotanical analysis (Fig. 1; Table 1). A range of levels from these cores was studied by Quik et al. (2022), yielding detailed information on organic matter content, plant macro remains, and an extensive series of radiocarbon dates. 23 samples from the same cores were selected for palynological research. They were treated following the standard method of Erdtman for pollen preparation (Erdtman, 1960, with modifications by Konert, 2002) and analysed at BIAX Consult (Zaandam, The Netherlands). All samples were scanned to establish their preservation, pollen richness and pollen variety, which led to a general impression of vegetation changes. Based on these preliminary results and available radiocarbon dating evidence 14 levels were selected for further analysis (8 from S17, 3 from S20 and 3 from S18). The combined data form a pollen record of which the chronology ranges from the Boreal (Early Mesolithic) to Subatlantic (Roman period, possibly including the initial stage of the Early Middle Ages).

The pollen analysis was performed using compound light

Fig. 1. Study area. (a) Location within Europe (ESRI, 2022); (b) digital elevation model (version AHN 3; www.ahn.maps.arcgis.com) of the Fochteloërveen remnant within the wider study area; (c) geomorphology (www.pdok.nl); (d) topography (www.opentopo.nl) including paleobotanical sampling locations. (2-column image, color in print and online).

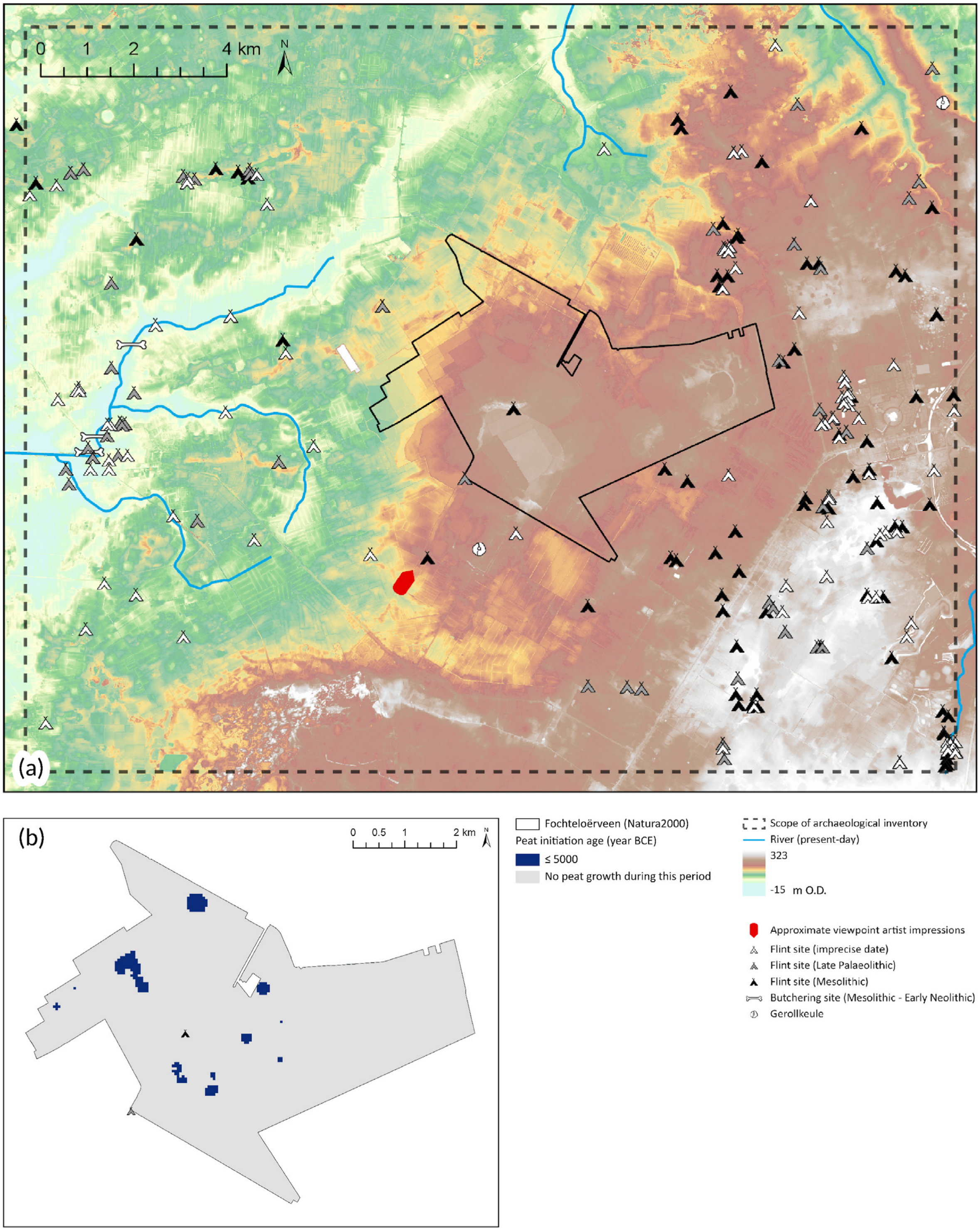


Fig. 3. Archaeological site distribution map for the period between 15,000 and 5000 BCE, plotted on an elevation model (www.ahn.maps.arcgis.com). The inset shows the peat expansion during this period (modified after Quik et al., 2023). 2-Column image, color in print and online).

microscopy with a maximum magnification of 1000×. The pollen grains and spores of mosses, horsetails and ferns and other microfossils (non-pollen palynomorphs such as fungal spores and algal remains) were identified, quantified and ecologically grouped using reference literature (e.g. Punt et al. 1976–2009; Van Geel et al., 1981; Moore et al., 1991; Beug, 2004) and the reference collection of BIAX *Consult*. Pollen percentages were calculated based on a total pollen count of a minimum of 600 pollen and spores of terrestrial plant species. To aid the interpretation the pollen taxa were classified in ecological groups (Weeda et al. 1985–1994). In order to visualise the changes in dryland and wetland vegetation an overview pollen diagram was drawn based on a total pollen sum of all taxa minus *Sphagnum* and *Dryopteris* spores. Finally, the pollen percentages were based on a regional

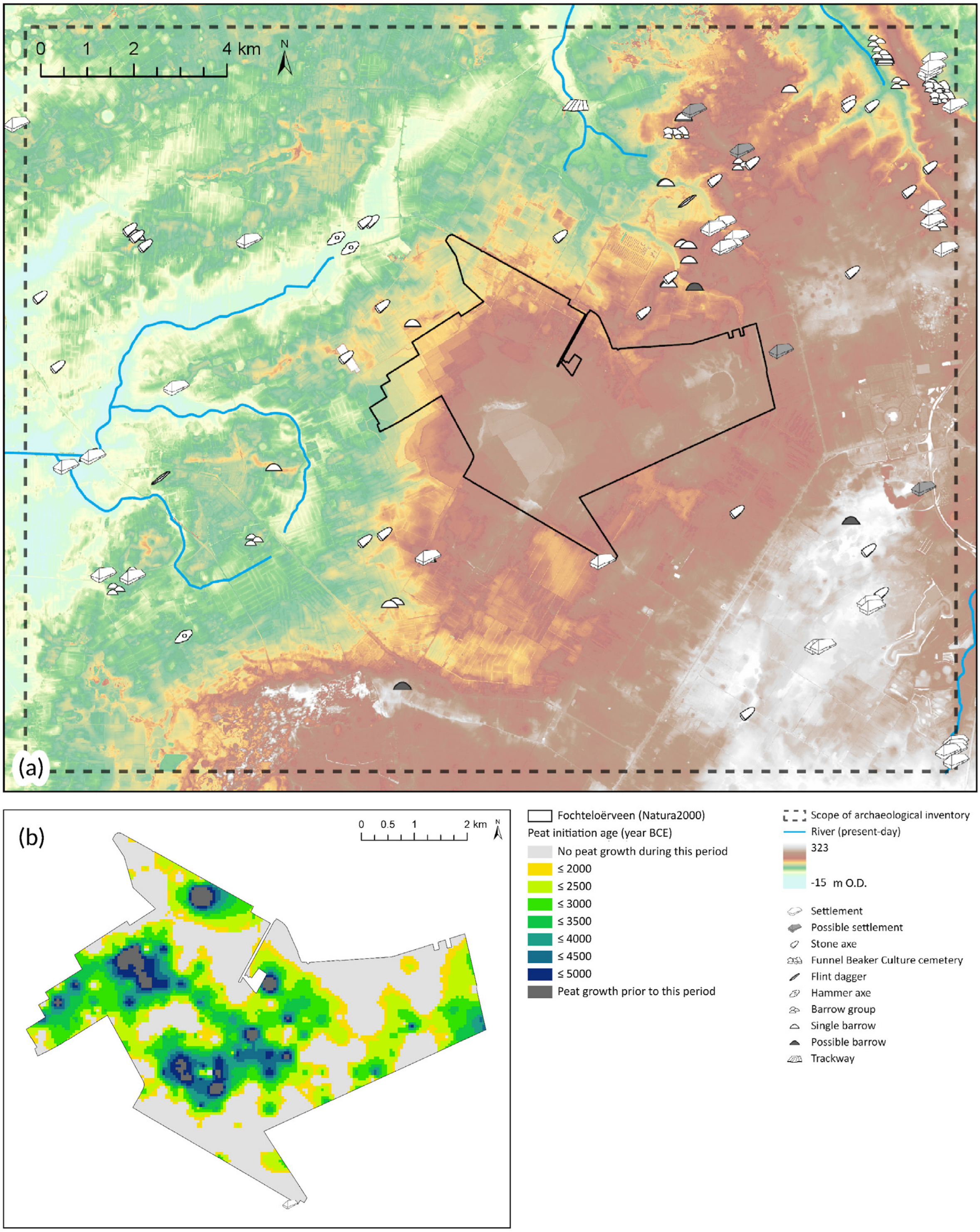


Fig. 4. Archaeological site distribution map for the period between 5000 and 1800 BCE, plotted on an elevation model (www.ahn.maps.arcgis.com). The inset shows the peat expansion during this period (modified after Quik et al., 2023). 2-Column image, color in print and online).

pollen sum (including regional trees from dry soils and *Alnus* and upland herbs including Poaceae and Ericaceae). This method is often used in pollen studies where *Betula* carr was locally present during initial peat formation (cf. Bakker, 2003). The pollen percentages of wetland species, including trees from wet soils and marsh, riparian and mire vegetation, were expressed as percentages based on the regional pollen sum. The same applies to the non-pollen palynomorphs.

The detailed results of all the analyses are provided in the supplementary material, including the pollen scans (appendix B), macro remains (C) and pollen counts and percentages (D and E). Three pollen diagrams are presented in the text (Figs. 7–9).

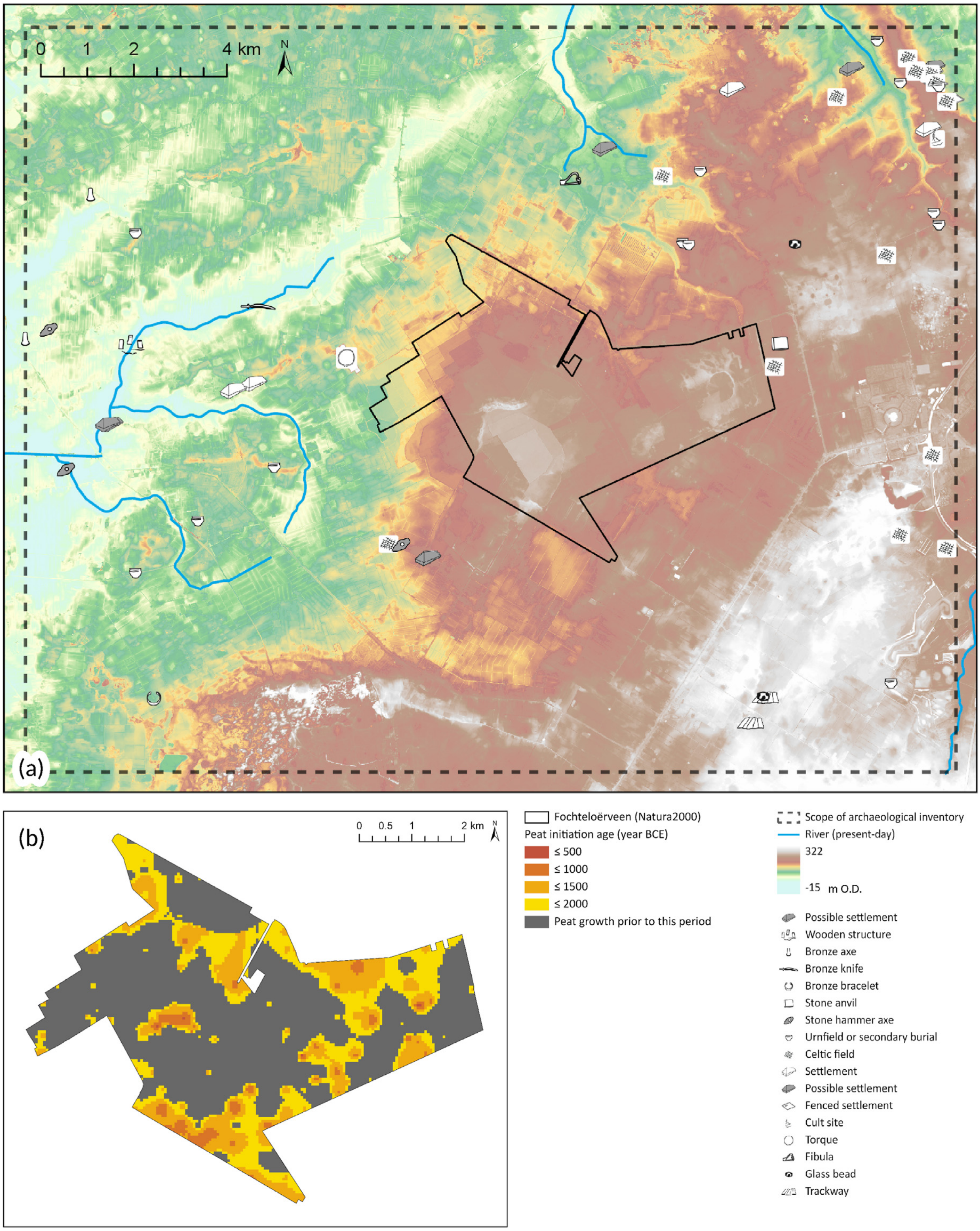


Fig. 5. Archaeological site distribution map for the period between 1800 and 19 BCE, plotted on an elevation model (www.ahn.maps.arcgis.com). The inset shows the peat expansion during this period (modified after Quik et al., 2023). 2-Column image, color in print and online).

3.6. Interdisciplinary analysis

The most important chronological and spatial trends in human habitation, peatland initiation and lateral expansion and vegetation development are described in detail in separate sections (4.1–4.3). In order to facilitate interdisciplinary data integration the modelled peat expansion for the Fochteloërveen peat remnant (spatial scale 2) is included in the four archaeological distribution maps (Figs. 3–6, spatial scale 1). Subsequently the most important trends signalled in all three disciplines are integrated and discussed (section 5.1). In this part of the analysis we maintain a simplified ‘archaeological’ subdivision in four phases (cf. Van Beek, 2009,

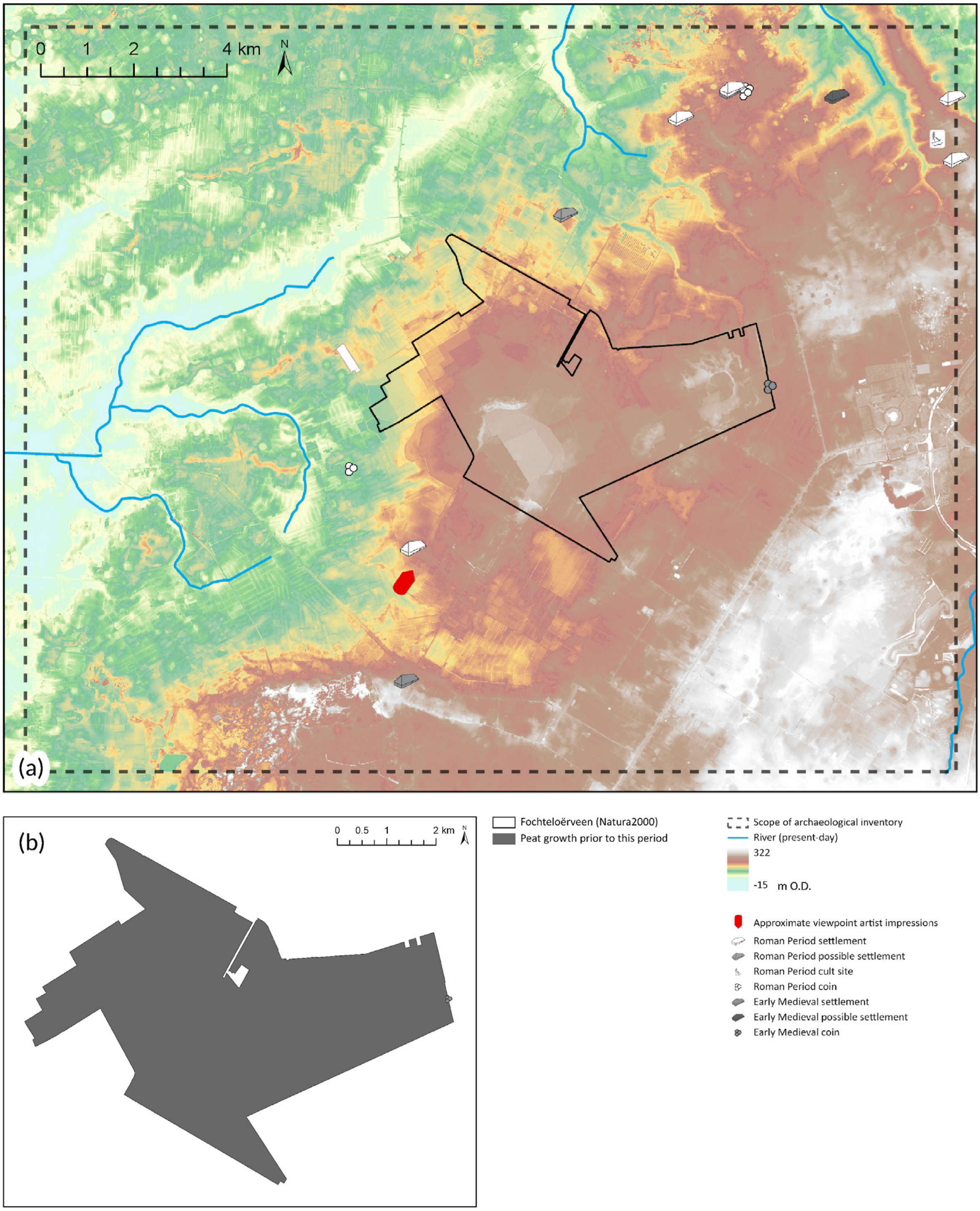


Fig. 6. Archaeological site distribution map for the period between 19 BCE and 1000 CE, plotted on an elevation model (www.ahn.maps.arcgis.com). The inset shows the peat expansion during this period (modified after Quik et al., 2023). 2-Column image, color in print and online).

360–380), the boundaries of which are mainly based on changes in human subsistence economy and land-use: (1) ‘hunter-gatherers’ (c. 15,000–5000 BCE), (2) ‘early farmers’ (c. 5000–1800 BCE), ‘advanced farmers’ (1800–19 BCE) and ‘early historical societies’ (19 BCE – 1000 CE). We produce a schematical image in which the most important changes in all disciplines are combined, which helps to investigate potential cause-and-effects (Fig. 10).

3.7. *Artist impressions*

Based on the integrated interdisciplinary analysis of the collected data (section 3.6), two artist impressions were made that reflect the character of the landscape in the Late Mesolithic (c. 6000 BCE) and Middle Roman period (c. 200 CE). These two phases were chosen because they, after data integration, proved to represent key phases in the dynamic landscape history of the study area. The

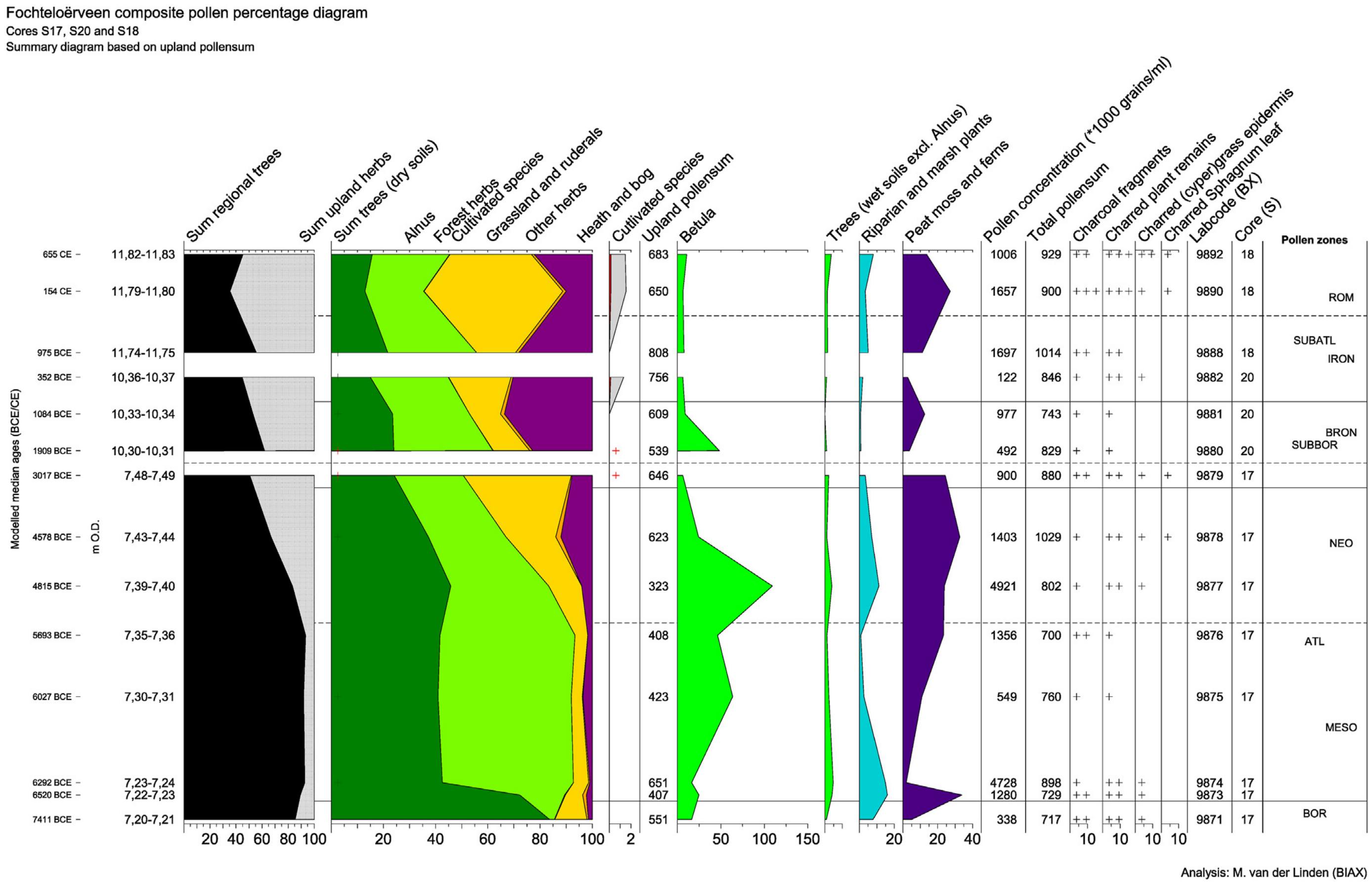


Fig. 7. Summary pollen diagram based on the total pollen sum minus *Sphagnum* and *Dryopteris*.2-column image, color in print and online).

Table 1
Characteristics of the investigated palaeobotanical samples from the peat cores S17, S18 and S20.

Core	Sample	Pollen zone	Archaeological period	Median cal. Date (BCE/CE)	Median cal. Date (cal BP)	Radiocarbon age (BP)	M + O.D.	Analysis type
S17	M1	Boreal	Early Mesolithic	7770 BCE	9720		7,17–7,18	scan
S17	M11	Boreal	Early Mesolithic	7411 BCE	9361	8305 ± 30	7,20–7,21	analysis
S17	M12	Boreal	Early Mesolithic	7375 BCE	9325	8400 ± 80	7,21–7,22	scan
S17	M13	Bor/Atlantic	Early/Middle Mesolithic		8470	7680 ± 50	7,22–7,23	analysis
S17	M14	Atlantic	Middle Mesolithic	6789 BCE	8242	7430 ± 100	7,23–7,24	analysis
S17	M6	Atlantic	Late Mesolithic	6028 BCE	7978	7300 ± 80	7,30–7,31	analysis
S17	M15	Atlantic	Mesolithic/Neolithic?		7643	6810 ± 45	7,35–7,36	analysis
S17	M16	Atlantic	Early Neolithic	4817 BCE	6765		7,39–7,40	analysis
S17	M17	Atlantic	Early Neolithic	4310 BCE	6258		7,43–7,44	analysis
S17	M8	Subboreal	Middle Neolithic	3048 BCE	4967	4395 ± 26	7,48–7,49	analysis
S20	M5	Subboreal	Early/Middle Bronze Age	1790 BCE	3859	3561 ± 27	10,30–10,31	analysis
S20	M12	Subboreal	Middle/Late Bronze Age	1100 BCE	3034	2910 ± 30	10,33–10,34	analysis
S20	M8	Subatlantic	Middle Iron Age	326 BCE	2302	2229 ± 22	10,36–10,37	analysis
S20	M10						10,38–10,39	scan
S20	M15						10,40–10,41	scan
S18	M18	Subboreal	Middle Bronze Age	1273 BCE	3223		11,69–11,70	scan
S18	M6	Subboreal					11,71–11,72	scan
S18	M7	Subboreal	Middle Bronze Age	1524 BCE	3474	3276 ± 24	11,72–11,73	scan
S18	M15	transition	Iron Age?		2925		11,74–11,75	analysis
S18	M10	Subatlantic	Middle Roman period	159 CE	1791		11,78–11,79	scan
S18	M11	Subatlantic	Middle Roman period	218 CE	1732	1892 ± 24	11,79–11,80	analysis
S18	M12	Subatlantic	Late Roman period	298 CE	1652		11,80–11,81	scan
S18	M14	Subatlantic	Roman period/Early Middle Ages?		1295		11,82–11,83	analysis

artist impressions were both made for scientific purposes (this paper) and to inform a wider, non-scientific audience on the former character of the area. They are digital 3D renders created by archaeological illustrator Ulco Glimmerveen, using scientific data provided by the authors. A series of earlier drafts were discussed repeatedly by the illustrator and authors, with continuous improvements leading to the end results. To the extent possible we aimed for evidence-based images, informed by elevation data, archaeological, palaeogeographical and palaeobotanical evidence. Both images were made for the exact same spot near the modern-

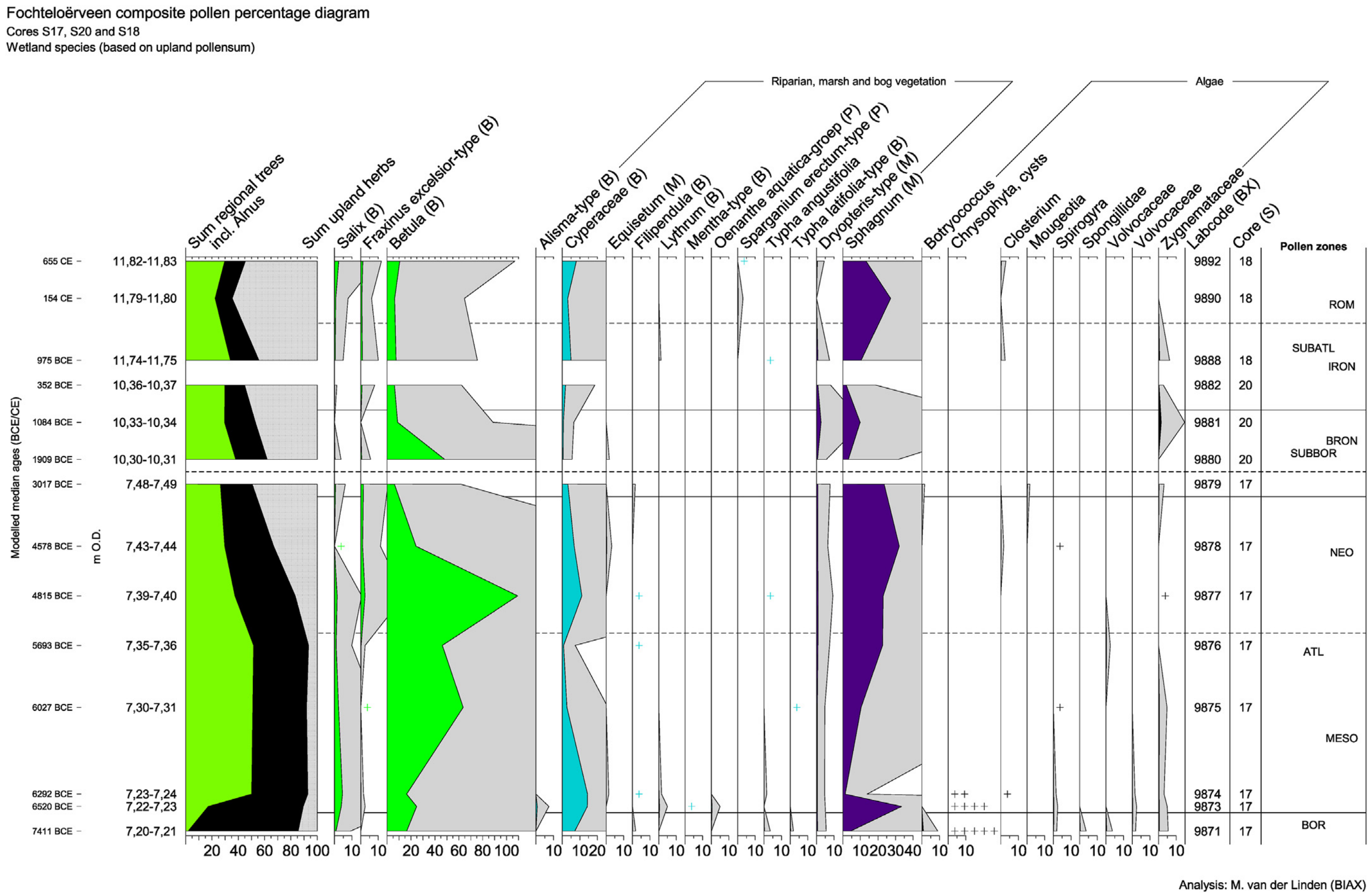


Fig. 8. Pollen diagram of wetland species based on the regional pollen sum (dry trees, *Alnus* and upland herbs excluding *Betula*). 2-Column image, color in print and online).

day village of Fochteloo, using the same angle and overlooking the Fochteloërveen peatland in the same (northeastern) direction (the viewpoints of these two impressions are indicated on Figs. 3 and 6). They are presented in the ‘Integration and discussion’ section.

4. Results

4.1. Human habitation trends

The archaeological analysis has led to an inventory of 371 sites, dating from the period between the Late Palaeolithic and High Middle Ages (appendix A). Some sites have yielded finds from different phases. Below we describe the main trends in habitation patterns through time.

4.1.1. Late Palaeolithic & mesolithic (c. 15,000–5000 BCE; hunter-gatherers)

Sites dating from the Late Palaeolithic (15,000–8000 BCE) and Mesolithic (8000–5000 BCE) are well-represented in the study area (Fig. 3). They generally consist of assemblages of flint artefacts collected on the surface during field surveys, or retrieved during reclamations or construction work. They are generally interpreted as temporarily used camp sites of hunter-gatherers. Further specification into e.g. ‘base camps’ or ‘hunting camps’ is often not possible based on the available data. Another large number of flint sites could not be dated precisely. Most of these probably date from the Late Palaeolithic/Mesolithic as well, which can be derived from their general appearance (flint scatters, lack of pottery) and site location (often nearby well-dated sites of similar age).

The Late Palaeolithic and Mesolithic sites generally appear on sand ridges and hummocks, near valleys and low-lying (originally wet) depressions. Noteworthy clusters of sites appear along the valleys of the Tjonger, Peizerdiep, Drentse Aa and Anreeperdiep rivers. One of these is the well-known Late Mesolithic site of Jardinga, which consists of a well-preserved assemblage of aurochs and red deer bones excavated in the peat-filled basin of the river Tjonger (Prummel et al., 2002). This location is interpreted as a kill and primary butchering site, which was used in two phases between c. 5500-5000 BCE. The finds were embedded in a peaty sand layer on top of the fluvial sand, that consecutively was overgrown with peat. Several sites are known from more ‘isolated’ sand ridges in the central part of the study area as well. A typical example is a Mesolithic site on a relatively narrow, elongated sand ridge called Bonghaar, in the center of the Fochteloërveen Natura 2000 area.

4.1.2. Neolithic & Early Bronze Age (c. 5000–1800 BCE; early farmers)

The Neolithic (5000–2000 BCE) and Early Bronze Age (2000–1800 BCE) sites in the study area can be divided in settlements, cemeteries and single finds of stone and flint objects (e.g. axes, daggers) (Fig. 4). Sites indicated as ‘settlement’ may both represent residential areas (in this phase consisting of single farmsteads or small hamlets) or sites where short-lived activities (e.g. hunting, fishing) were carried out. The available information often does not allow such distinctions. The transition from hunter-gatherers to early farming communities, which happened gradually in this part of the Northwest European mainland (Raemaekers, 1999), is poorly visible in the archaeological record of the study

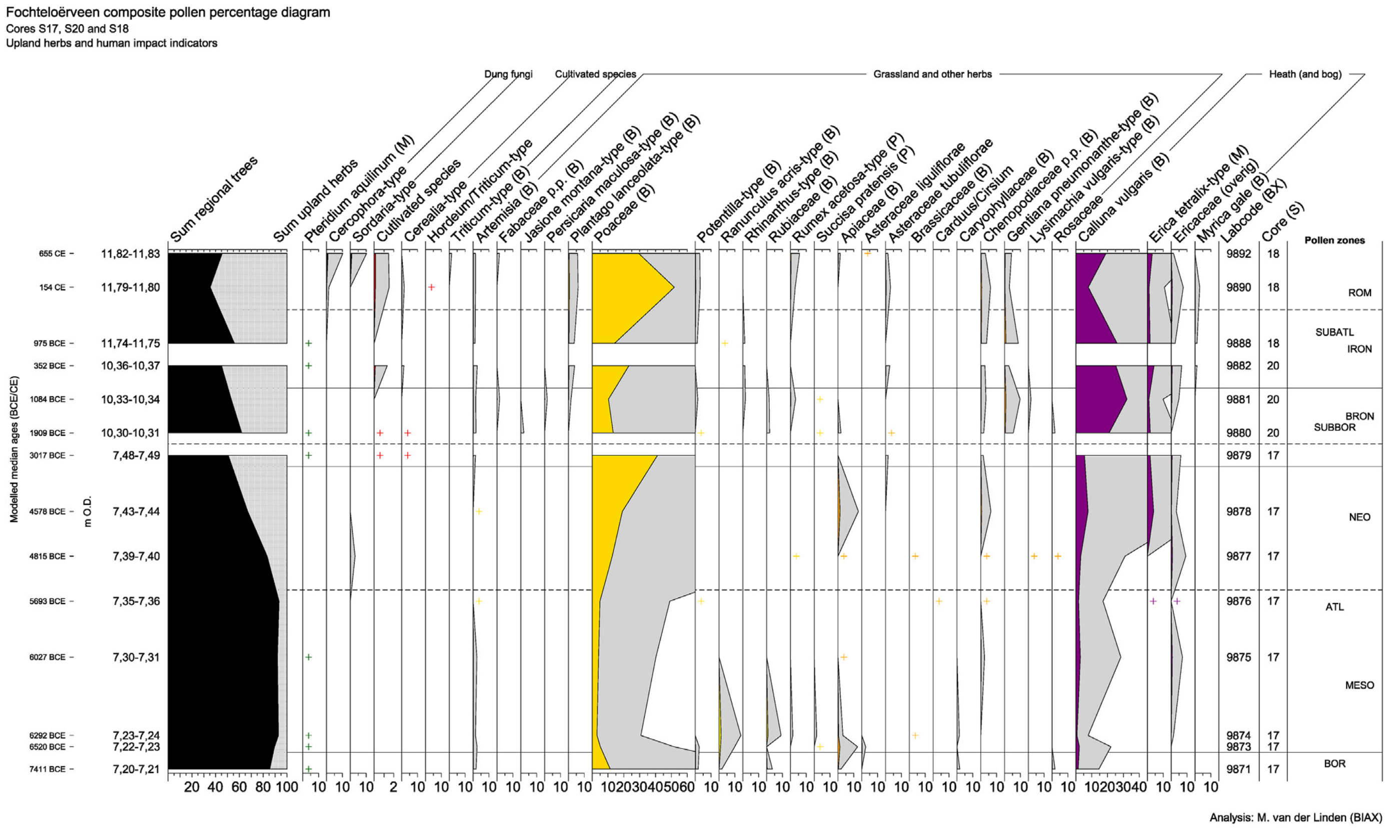


Fig. 9. Pollen diagram summary of human impact indicators based on the regional pollen sum (dry trees, *Alnus* and upland herbs excluding *Betula*). 2-Column image, color in print and online).

area, as not a single site is irrefutably dated in the 5th or first half of the 4th millennium BCE. This not does necessarily imply that the area was not inhabited at this time.

From the second half of the 4th millennium BCE onwards agrarian communities left a clear mark. Sites from the Funnel Beaker Culture (3400–2750 BCE) are represented by two megalithic graves (one with a nearby flat grave cemetery) in the north-eastern part of the study area. Various barrows and barrow groups form strong indications for habitation in the Late Neolithic (Single Grave Culture/Bell Beaker Culture; 2850–2000 BCE) and Early Bronze Age (2000–1800 BCE). Single finds of stone and flint axes and daggers are mainly known from valleys and other low-lying depressions. Such finds from ‘wet contexts’ are generally interpreted as deliberately deposited votive offerings for higher powers (e.g. Wentink, 2007). A short wooden trackway, dated to 2300–2200 BCE and made from alder, is found in the northern part of the study area where it served to cross the Slokkert valley (Ten Anscher et al., 2015).

From the overall site distribution pattern it can be derived that from 3400 BCE onwards (and possibly earlier) agrarian communities had settled in various parts of the study area. Compared to the previous phases less sites are present in the low-lying central areas, but they are not absent.

4.1.3. Middle/Late Bronze Age & Iron Age (1800–19 BCE; advanced farmers)

The distribution pattern of settlements, urnfield cemeteries and arable field complexes (Celtic Fields; see below) indicate that the higher sand ridges in the study area remained inhabited in the Middle/Late Bronze Age (1800 - 800 BCE) and Iron Age (800 - 19 BCE) (Fig. 5). The appearance of Celtic Fields, large field systems consisting of rectangular plots demarcated by earthen banks, is generally seen as an indication for agricultural intensification (e.g. Brongers, 1976; Arnoldussen, 2018). Various votive offerings are known from the study area. In this phase they mainly consist of bronze tools (axes, knife) and personal ornaments. Examples of the latter category are a bronze necklace (‘torc’) found in a peat layer near the present-day village of Fochteloo, and a bronze brooch (‘fibula’) from the Slokkert valley, both dating from the Iron Age.

Despite the evidence for continued habitation, and even agricultural intensification, there are indications that the landscape became increasingly wet. There are less signs for activity in the central part of the study area. Additionally, two stretches of the same wooden trackway, 280 and 170 m long, were excavated near the present-day village of Smilde (Casparie, 1985, 1987). The trackway, dated to the 3rd or early 2nd century BCE, was made of alder logs covered with heath sods and served to cross a peat-filled depression.

4.1.4. Roman period & early Middle Ages (19 BCE – 1000 CE; early historical period)

In the Roman period (19 BCE – 450 CE) and Early Middle Ages (450–1000 CE) the study area was largely deserted (Fig. 6). The most notable exception is the northeastern area, near the present-day villages Norg and Zeijen, which may have remained inhabited continuously until the High Middle Ages. Of particular interest are the Roman-period settlement remains that were excavated on a sand ridge near the present-day village of Fochteloo, on the western margin of the Fochteloërveen (Van Giffen, 1958; Waterbolk, 2009, 17–20). This sand ridge had already been inhabited since late prehistory. In the Roman period the habitation originally consisted of a small hamlet of two or three farmsteads, some outbuildings and accompanying arable fields. This location was abandoned, probably because it became too wet. Large drainage ditches around the farms indicate that measures had already been taken to keep the hamlet dry. The settlement was then moved to a nearby location on the same sand ridge. This site was left around the 3rd century CE as a result of the encroaching peatland, after which the whole ridge was overgrown with a layer of peat. This peat layer was still present when reclamations started in the 1930s (Waterbolk, 2009, 17–20).

4.2. *Peatland initiation and lateral expansion*

Quik et al. (2023) provide a detailed description of the palaeogeographical results regarding peatland initiation and lateral expansion at the Fochteloërveen area. Here we summarize the outcomes that are most important for the current study. The radiocarbon dating analyses have yielded dates of basal peat layers ranging from 9433 to 9142 cal y BP to 1690-1411 cal y BP (at 95.4% confidence interval). This indicates that the period of peat initiation and subsequent lateral expansion stretched over at least ~7.500 calendar years. In archaeological terms this period corresponds with the phase between the Mesolithic and start of the Early Middle Ages.

The modelled peat expansion is indicated in the insets in Figs. 3–6, aligned with the archaeological chronology, with the cumulative fraction of peat-covered area shown in Fig. 10. Peat initiation occurred simultaneously in different loci, distributed over the lower central, west and northwest parts of the Fochteloërveen Natura 2000 area. Initially lateral expansion happened on a slow pace. Later in time the process accelerated, with the strongest expansion between 5500–3500 cal y BP. Half of the Fochteloërveen area was covered by peat by ~4000 cal y BP. The entire modelled area, including coversand ridges that initially protruded above the peat landscape, was eventually overgrown by ~2500 cal y BP. With regard to the causes of peat initiation (paludification) the significant correlation between peat initiation age and the constructed variable reflecting groundwater-fed wetness suggests a strong influence of Holocene sea level rise, in combination with the position within large-scale geomorphology (high plains and incised valleys).

4.3. *Vegetation dynamics*

In the paragraphs below we list the (modelled) medians in BCE/CE notation when we refer to radiocarbon dating results.

4.3.1. *Boreal and first half Atlantic (≈ Mesolithic period; core S17)*

The basal peat layer of core S17 has a radiocarbon date of 7411 BCE, indicating a start of peat formation in the Boreal period (Fig. 7). In this phase the research area was mostly covered with coniferous forest dominated by pine (*Pinus*). Furthermore some deciduous forest containing birch (*Betula*) and hazel (*Corylus*) and sparsely oak (*Quercus*), elm (*Ulmus*) and alder buckthorn (*Rhamnus frangula*) was present. In the relatively few open spaces vegetation consisting of grasses (Poaceae) and other herbs occurred. In wetter parts of the landscape willows (*Salix*) and some alder (*Alnus*) and birch (*Betula*) trees were growing. The local conditions in the depression or valley

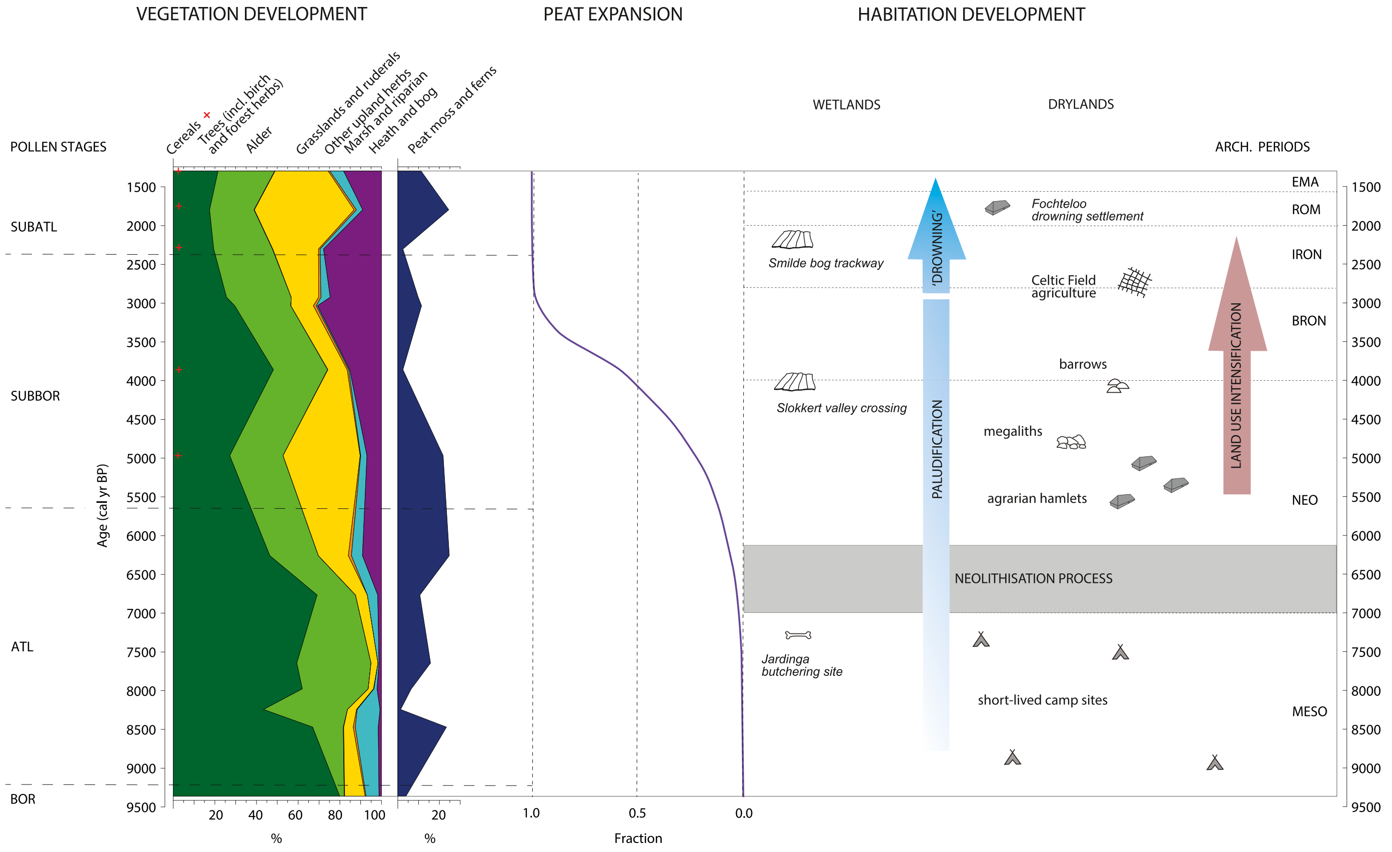


Fig. 10. Schematic, interpretative overview of key diachronic trends in vegetation development, peat expansion and human habitation. Left: combined, interpolated pollen record. Center: cumulative fraction of peat-covered area within the Fochteloërveen remnant (after Quik et al., 2023). Right: key archaeological processes, phenomena and sites. The paludification trend is derived from the center and left graphs. The 'drowning' trend is based on an interpretation of the peat expansion process combined with archaeological observations. Land use intensification is derived from integrated archaeological and palynological evidence. Note that the distinction between 'drylands' and 'wetlands' is subjective and changes over time. 2-Column image, color in print and online).

where core S17 was taken, were very wet. This is indicated by the presence of pollen from plants growing in riparian or marsh vegetation, such as Cyperaceae, water plantain (*Alisma*-type), fine leaf water dropwort (*Oenanthe aquatica*-type), broadleaf cat tail (*Typha latifolia*) and narrow-leaf cat tail (*Typha angustifolia*). During wet phases, shallow water may have been present here.

The start of peat formation is demonstrated by an increase in *Sphagnum* spores and Cyperaceous pollen (Fig. 8). In the basal peat many cysts of *Chrysophyta* and microfossils which possibly represent (cyano)bacteria were observed. These may indicate that microbial mats were present. These multi-layered sheets of microorganisms such as algae and bacteria may occur in locations with alternating dry and wet conditions. The presence of fungal spores of *Gelasinospora* and many charcoal fragments indicate that wild fires occurred.

The start of the Atlantic is marked by the change in dominant tree pollen-type from *Pinus* to *Alnus*. On the higher and drier soils mixed forest consisting of oak (*Quercus*), elm (*Ulmus*) and lime (*Tilia*) was present. On the more oligotrophic sand ridges some smaller stands of pine forest accompanied by birch trees probably remained. In the wet stream valleys alder (*Alnus*) forest occurred. The vegetation bordering the valleys mainly consisted of hazel (*Corylus*) trees. During the Atlantic the percentages of *Betula* pollen increased dramatically. This may be attributed to the local formation of birch carr at coring site S17 due to more oligotrophic conditions. Although no macro remains of birch (or alder) were found in these peat layers, the presence of scalariform perforation plates (HdV-114) suggests the local presence of birch, alder, willow or hazel trees (Van Geel et al., 1981). The occurrence of several Type 18 fungal spores, which are found elsewhere on remains of *Eriophorum vaginatum* (Van Geel et al., 1981), indicate further acidification of the local conditions.

4.3.2. Second half atlantic (≈Early/Middle Neolithic period; core S17)

In the second half of the Atlantic period peat formation continued. This is indicated by increased numbers of *Sphagnum* spores at level 7.39–7.40 m O.D. in core S17 (4817 BCE). Spores of *Tilletia sphagni* (HdV-27), a fungus which exclusively grows on *Sphagna*, were observed as well. The pollen values of trees growing on dry soils decreased, as well as pollen of *Alnus*. The presence of ash (*Fraxinus*) slightly increased, while birch strongly increased. The latter may be associated with local growth of birch, but could also be caused by a larger presence of birch forest in the drier parts of the landscape. At level 7.43 m O.D. (4310 BCE) the first macro remains of Ericaceae were observed in core S17, indicating local heathland or mire vegetation. In the pollen data this is visible by increasing values of grasses, heather and peat moss. At this point the pollen values of birch dramatically decreased. This sample contained charred macro remains of *Calluna vulgaris* and *Erica tetralix* as well. The proportion of regional tree pollen decreased, indicating a more general opening of the landscape. This landscape openness is likely to have increased naturally due to soil degradation, more oligotrophic conditions and increased wetness. During this period, burning of the (wetland) vegetation occurred as well, indicated by presence of charred plant remains among which peat moss leaves and epidermal remains of grasses and sedges.

4.3.3. Subboreal (≈ Late Neolithic – Late Bronze Age period; core S17/20)

The start of the Subboreal period is recorded at level 7.48–7.49 m O.D. in core S17 (3048 BCE). This phase continues in levels 10.30–10.31 m O.D. (1790 BCE) and 10.33–10.34 m O.D. (1100 BCE) in core S20. During the Subboreal the proportion of mixed oak forest and alder forest (regional tree pollen) further decreased. Beech (*Fagus*) grew in the forested areas on the higher grounds. Grassland, heathland and mire vegetation expanded. In the oldest two levels cereal pollen was observed, indicating agricultural activities in the area (Fig. 9). At the start of the Subboreal, grassland species increased at site S17. At this location charcoal fragments and charred plant remains were found, indicating burning of the vegetation. In the second part of the Subboreal *Calluna vulgaris* peaked near site S20. *Calluna* may have occurred in dry heath growing in open spaces on sand ridges. During the Subboreal acidic grasslands and wet heath developed as well, as can be derived from the occurrence of *Gentiana pneumonanthe* and *Erica tetralix*. The pollen values of the upland herbs *Artemisia* and Chenopodiaceae increased. *Pteridium* spores were regularly found. The growth of *Pteridium* ferns is promoted by the cutting of forest (e.g. Den Ouden, 2000). From c. 1100 BCE onwards *Plantago lanceolata* and *Rumex acetosa*-type, taxa which are often seen as indicators for prehistoric agricultural activity (Groenman-Van Waateringe, 1986; Bakker, 2003), were observed as well. Elm (*Ulmus*) and lime (*Tilia*) further decreased.

4.3.4. Subatlantic (≈ Iron Age – Roman period/start early Middle Ages; core S20/18)

The initial phase of the Subatlantic period is recorded in level 10.36–10.37 m O.D. (326 BCE) from core S20 and in three samples from core S18. The latter cover the final stage of the Iron Age and the Roman period (possibly just including the start of the Early Middle Ages). During the Subatlantic the arboreal pollen percentages decreased further, with the lowest percentages reached in the Roman period (218 CE). An open landscape consisting of mire vegetation, wet heath and grasslands was present. On the drier grounds cereals were cultivated. Trees were scarcely present. On the highest sand ridges probably some birch, oak and possibly hazel were still growing. Pollen of hornbeam (*Carpinus*) is found as well. A large mire complex of the Atlantic or plateau raised bog type (Moen, 1985; Casparie and Streefkerk, 1992; Charman, 2002; Moen et al., 2017, 133) developed. *Myrica* may have grown on the mire edges. The sand ridges near the mire surface and the areas which were almost overgrown by peat moss were probably treeless. In these areas wet heath and acidic grasslands were present. The observed microfossils, including fungal spores, support the pollen trends. During the transition from Subboreal to Subatlantic Type 18 fungal spores were found, which indicate the presence of *Eriophorum vaginatum* (Van Geel, 1978). In level 11.82–11.83 many charcoal fragments and charred plant remains were found, as well as *Gelasinospora* fungal spores which are associated with burned wood or vegetation.

5. Integration and discussion

In this section the archaeological, palaeogeographical and palaeobotanical data are integrated, interpreted and placed in a wider context. A division is made in three subsections. First, and in line with the main research questions of this study, we focus on the diachronological relations between peatland initiation and lateral expansion, human habitation patterns and vegetation development. The combination of these lines of evidence, with the main trends visualised in Fig. 10, leads to several new insights in the landscape history of the study area. Second, we discuss the wider implications of our study in relation to the understanding of long-term human-landscape relations in the Northwest European mainland. Third, we present some methodological reflections that might be helpful in future research in this field.

5.1. The drowning landscape of fochteloërveen: integrated trends

5.1.1. Hunter-gatherers (c. 15,000–5000 BCE)

In the Late Palaeolithic and Mesolithic small groups of hunter-gatherers roamed the pre-peat landscape of Fochteloërveen and surroundings. Habitation density was relatively low. Even though the available data is scanty, most Late Palaeolithic sites probably belong to the Hamburg Culture, Federmesser Group and Ahrensburg Culture, which were present in the Northern Netherlands in the Bölling-Allerød, Younger Dryas and early Preboreal (Stapert, 2005). No palaeobotanical evidence was collected on these phases in the current study. Nevertheless, during the colder phases of the Late Glacial the landscape probably was largely dominated by open, herbaceous vegetation (cf. Hoek, 1997; Van Beek et al., 2015). During warmer phases (Bölling-Allerød, Preboreal) birch and pine forest may have occurred in the drier areas (e.g. Hoek, 1997). In the early Holocene the landscape rapidly became forested (e.g. Bos et al., 2005). It is generally assumed that the transition from Late Palaeolithic to Mesolithic, and from relatively open to densely forested landscapes, amongst others resulted in a decrease in human mobility and smaller territories with temporary settlements (for the northern Netherlands, see e.g. Stapert, 2005; Peeters and Niekus, 2005). Our data demonstrate that the vegetation in the study area changed from a coniferous forest in the Boreal to a mosaic-like mixed oak forest in the Atlantic. In the Late Mesolithic, peat formation started on a local scale in different loci, distributed over the lower central, west and northwest parts of the Fochteloërveen area (e.g. around sampling site S17). Variable mineral content of the soil caused a patchiness in the forest, with lime (*Tilia*) flourishing in some (mineral rich) areas and oak on other (nutrient poor) soils (cf. Behre and Kučan, 1994, 145–146; Spek, 2004, 121–123). At some locations open spaces were present. These spots probably formed ideal camp sites for hunter-gatherers. Natural open areas also occurred in wetland areas, where sedge vegetation dominated. These locations, such as the Tjonger basin, were used by large herbivores to graze and drink. Therefore they formed ideal hunting grounds, with the aurochs and red deer kill and butchering site of Jardinga as a prime example (Prummel et al., 2002). The Late Mesolithic landscape of Fochteloërveen is visualised in Fig. 11 (see Fig. 3 for the exact viewpoint).

5.1.2. Early farmers (c. 5000–1800 BCE)

The palaeobotanical data demonstrate that in the second half of the Atlantic the study area became increasingly open. The peatland areas expanded, initially on a relatively slow pace. Other Dutch peatlands, including the Bourtangermoor (northern Netherlands) and Aamsveen (eastern Netherlands), also started developing in this phase (e.g. Casparie, 1972; Dupont, 1985; Sevink et al., 2022). The first farming communities emerged. In the northern Netherlands the transitional phase from hunting and gathering to farming is generally linked to the Swifterbant Culture (c. 4900–3400 Raemaekers, 1999). This important change appears to have left hardly any archaeological traces in the study area. The scarcity of finds from this phase is also documented in other sandy ‘upland’ regions of the Netherlands (e.g. Van Beek, 2009). It is assumed that the subsistence economy in the earlier stages of the Swifterbant Culture mainly depended on animal husbandry and fishing. Cereal cultivation may only have been introduced on a small scale after c. 4200 BCE (Brinkkemper et al., 1999; Bakker, 2003; Raemaekers and De Raemaekersde Roever, 2020). In this respect the absence of cereal pollen in our Early Neolithic pollen samples (c. 4817 and 4310 BCE) may not be surprising. The environmental conditions of the study area may have been very suitable for livestock breeding. Leaves of elm and possibly lime may have been used as fodder (Bakker, 2003, 267–268). Increased wetness and more oligotrophic conditions led to the development of wet grasslands and heath vegetation, providing good opportunities for grazing.

From the second half of the 4th millennium BCE onwards significant changes are witnessed in peatland expansion, vegetation dynamics and human habitation (Fig. 10). The peatland modelling demonstrates a clear acceleration in peatland expansion between 5500 and 3500 cal y BP, which in archaeological chronology roughly equals the phase between the Middle Neolithic and Middle Bronze Age. The pollen record indicates an increasing openness, coinciding with the expansion of (wet) grassland, heath and mire vegetation. This process is at least partly linked to increased wetness and acidification of the sandy soils. Simultaneously, agrarian communities of the Funnel Beaker, Single Grave and Bell Beaker Culture started leaving clear archaeological and palaeobotanical marks. They structured the landscape by founding new

Fig. 11. Evidence-based artist impression of the Fochteloërveen landscape around 6000 BCE (Late Mesolithic), created by Ulco Glimmerveen based on data provided by the authors. (2-column image, color in print and online).

settlements, cleared forests to create arable fields and erected burial monuments (megaliths, barrow cemeteries). A wooden trackway, dated to 2300–2200 BCE, was constructed to pass the Slokkert valley (Ten Anscher et al., 2015). Various finds of deliberately deposited votive offerings from valleys and low-lying depressions indicate that these 'wet' locations took an important position in the belief system of early farming communities. This pattern continued throughout late prehistory. For the nearby site Gietsenveentje (where a peatland formed inside a pingo remnant), Bakker (2003) also described an expansion of the agricultural economy between 3450–2600 BCE. According to him, livestock breeding may have been more important than arable farming in this phase (Bakker, 2003, 70).

It has been pointed out by Zagwijn (1986, 8–10) and Spek (2004, 116–117) that the effect of human deforestations of the Dutch higher sandy soils, leading to decreased evapotranspiration and higher ground water tables, may have contributed to peat formation. In this respect the approximately simultaneous trends of human land use intensification, increasing landscape openness and accelerating peatland expansion at Fochteloërveen are striking. As such, a locally increased peat growth or expansion rate as an indirect consequence of intensified human land use cannot be excluded (see also Behre, 1988, 665). Similar links have also frequently been postulated for blanket bog expansion in the United Kingdom (e.g. Moore et al., 1984; Tallis, 1998). However, the validity of such claims has been questioned by Gallego-Sala et al. (2016) who, using a prediction model based on summer temperature and moisture index thresholds, indicate that climate change is a more likely explanation for blanket bog expansion than anthropogenic activity. In general, the relations between human-induced deforestation or dynamics in forest structure and wetland development are complex and varied, with many different local scenarios (e.g. Woodward et al., 2014; Lamentowicz et al., 2020).

Another possible cause of (further) lateral peat expansion at Fochteloërveen may be increased wetness of the edges of the mire due to input of infiltration water from the raised bog surface.

5.1.3. *Advanced farmers (1800–19 BCE)*

In the Bronze Age the pollen percentages of trees growing on dry soils, including elm, lime and oak, decreased. Hazel and oak became dominant, pointing to an impoverishment of the forest composition. Exhaustion of these sandy soils hampered forest regeneration and promoted growth of dry heath vegetation. During the Iron Age the openness of the landscape slightly increased. The pollen record provides many indications for human land-use. The presence of *Plantago lanceolata* may be associated with cultivation of crops as well as livestock breeding. Several wetland herbs from marsh or riparian vegetation probably indicate amplified wetter conditions. During the Bronze and Iron Ages the mire complex kept expanding. According to the peatland modelling this still happened at a rapid pace in the initial stages of the Bronze Age, after which lateral expansion rates dropped in the Iron Age. Previous arguments that initial peat formation was stimulated in the Iron Age, resulting from a wetter climate (Van Geel et al., 1998), are not corroborated by our research (see also Quik et al., 2022, 2023). However, our research was aimed to study initial peat formation in basal peat. Therefore, the transition to ombrogenous peat and in addition the transition in dominating *Sphagnum* species from mainly S. s. Acutifolia to *S. austinii* has not been fully documented in the studied sequences. Thus, the vertical expansion of the peat bog and peat accumulation of raised bog vegetation could not be modelled in detail. In the various Fochteloërveen basal peat samples used for reconstructing the initial peat dates a branch with leaves of *Sphagnum austinii* was present in sample S4-M9 (806 BCE; Quik et al., 2022). In the older samples *Sphagnum palustre, S. papillosum, S. cuspidatum* or *S. s. acutifolia* leaves were found. Probably, from c. 800 BCE *Sphagnum austinii* started to dominate in peat bog vegetation (Klaver, 1981; Van Geel et al., 1998; Sevink et al., 2022). The pollen of grassland species increased as well. The Celtic Fields, which emerged from the Late Bronze Age onwards, various urnfields and some settlement sites indicate that the higher sandy soils around the expanding Fochteloërveen were still suitable for habitation and agriculture by the (beginning of) the Iron Age. Celtic Fields demonstrate agricultural intensification (Arnoldussen, 2018). In the Celtic Field of Zeijen, situated in the northeastern part of the study area, barley (*Hordeum*) and wheat (*Triticum*) were cultivated (Arnoldussen and van der Linden, 2017). In the central part of the study area a decrease of archaeological sites is visible. This area probably became less accessible rapidly, which is corroborated by the construction of the Late Iron Age trackway near Smilde (Casparie, 1985, 1987, 55–59).

5.1.4. *Early historical societies (19 BCE – 1000 CE)*

By the start of the Roman period a large mire complex had developed in the Fochteloërveen area. In the Middle Roman period the openness of the landscape, as demonstrated by pollen data (c. 218 CE), was at its greatest. Grasses dominated the vegetation and few trees were present. The higher grounds near the mire were almost treeless. Only birch, oak and hazel could grow here. Further away from the mire, forest consisting of beech and hornbeam was present. The pollen values of alder were at their lowest in the Middle Roman period, and increased again in the Late Roman period (or possibly the start of the Early Middle Ages). Their original decline may well be associated with the cutting of wood in the stream valleys. These may have been used for grazing by livestock or as hay fields. Several spores of dung fungi were observed indicating that animals, probably livestock, were present near coring site S18.

By the end of the Roman period the study area was largely abandoned by humans. Only the highest, contiguous sand ridges, mainly in the northeastern part of the study area near Norg and Zeijen, probably were never overgrown with peat and may have remained inhabited longer. The abandonment of the study area did not coincide with the phase in which the peatland acceleration pace was highest, more than two millennia earlier. This early acceleration caused the peatland to expand relatively rapidly over the low-lying parts of the study area. The slopes of the adjacent higher sand ridges, which were inhabited and cultivated, only drowned at a later stage. This is when the effects of peat expansion were felt most by the local agrarian communities. This process is clearly visible in the habitation history of the Fochteloo ridge on the western margin of the Fochteloërveen. The small hamlet situated there was probably one of the last inhabited locations in the study area. The landscape character at this time is visualised in Fig. 12 (see Fig. 6 for the exact viewpoint). This location was eventually left around the 3rd century CE as well, when the local conditions were not suitable anymore for a sustainable agricultural existence. In the transition phase from the Roman period to the Early Middle Ages small-scale reforestation may have occurred. Patterns of woodland regeneration correlated with a decrease of human landscape pressure, most notably in the so-called 'Dark Ages', are well-documented in the Low Countries (e.g. Groenewoudt et al., 2007; Groenewoudt et al., 2007).

5.2. *Wider implications: human-landscape interactions in the northwest european mainland*

Large parts of the Northwest European mainland were once covered with peat (e.g. Overbeck, 1975; Succow and Joosten, 2001; Vos et al., 2020). The 'drowning' process reconstructed for the

Fig. 12. Evidence-based artist impression of the Fochteloërveen landscape around 200 CE (Middle Roman period), created by Ulco Glimmerveen based on data provided by the authors. (2-column image, color in print and online).

Fochteloërveen area was no local or regional phenomenon, but happened in many parts of the Northwest European mainland. This for example is clear from well-preserved ‘prehistoric landscapes’ documented in the northern part of the Bourtangermoor (Groenendijk, 2003) and the northern German Stade and Ahlen-Falkenger Moor areas (Pantzer, 1986; Nösler, 2017). The latter regions are known for the presence of various overgrown megalithic burial monuments (Behrens et al., 2019). The impact of peat expansion on human habitation may have varied locally, depending on the environmental conditions, human population density and settlement patterns. The current study provides a methodological blueprint that may serve to unravel regional trends in human-landscape interactions in detail. Knowledge on the initiation, expansion pace and maximal extension of peatlands helps to contextualise archaeological peatland sites, both relating to *in-situ* remains and finds that were done in the distant past (e.g. Chapman et al., 2019; Van Beek et al., 2019). Such data are also vital to understand long-term human habitation patterns in a more general sense. A prime example of a relevant topic for the Northern Netherlands and Northern Germany is the potential relation between the colonisation of the salt marshes along the North Sea coasts in the Iron Age, and the large-scale ‘drowning’ of the sand landscapes in their ‘hinterland’ (Van Gijn et al., 1984).

Scientific knowledge on the location, age and conservation of peat remnants is also important from a heritage management perspective, as they form essential archaeological and palaeoenvironmental knowledge archives. In the present study the high archaeological potential of peat layers in valleys is both demonstrated by the Mesolithic site of Jardinga and the Late Neolithic wooden trackway crossing the Slokkert valley. The possible presence of well-preserved organic archaeological remains in stream valleys flanked by (inhabited) sand ridges has been established in other parts of the Netherlands as well (e.g. Groenewoudt et al., 2001). Integrated palaeobotanical, palaeogeographical and archaeological knowledge could potentially feed into high-resolution predictive models for peat remnants. Knowledge on the past character of peatlands (e.g. hydrology, vegetation, peatland type) may also be highly valuable in peatland restoration, and in nature development or ‘rewilding’ efforts in general (for a recent example, see Sevink et al., 2022).

5.3. Methodological reflections

The interdisciplinary approach applied in this study has yielded a variety of important new insights. The main added value from a methodological viewpoint is in data triangulation: diachronological trends visible in different scientific disciplines can be studied integrally, which increases scope, depth and consistency (cf. Flick, 2002, 226–227). The approach may provide information on cause-and-effects of certain trends and events, help to assess the validity and reliability of obtained results, and may inspire future research. For example the simultaneous ‘drowning’ process of the Fochteloërveen area, captured in palaeogeographical and palaeobotanical data, and its abandonment in Roman times as demonstrated by archaeological sources, can hardly be a coincidence.

Interdisciplinary research on a ‘landscape’ scale brings challenges as well. The availability and resolution of data may vary substantially across the involved disciplines. The archaeological data in our study, for example, have a wide geographical distribution and provide insights in human behaviour on long time scales. However, many of the sites (especially the stone age flint surface scatters) are not dated precisely. To some extent this hampers a detailed comparison with the high-resolution data provided by the palaeobotanical analyses.

Moreover, it is important to be aware of the scope of the applied techniques. In our study we did not find evidence of human landscape impact during the Late Palaeolithic and Mesolithic, for example. However, it has become increasingly clear over the last decades that hunter-gatherers could have small-scale impacts on their environment, potentially deliberately by lighting fires to create open spots to attract wildlife (e.g. Bos et al., 2005; Bos and Urz, 2003). However, to catch such weak signals in pollen data the sampling spots should be located very nearby stone age camp sites.

As demonstrated by Quik et al. (2023), different methods can be applied in the palaeogeographical modelling of lateral peat expansion, mainly depending on the potential presence of a (partial) peat cover. In general modelling becomes increasingly complex and less trustworthy when reclaimed landscape zones are incorporated. In general, finding suitable locations for palaeobotanical and palaeo-environmental research may be challenging in reclamation landscapes.

Humans were not the prime drivers of peat expansion in our study area. Nevertheless, it is possible that prehistoric human land use intensification caused an accelerated peatland expansion. This may be an interesting topic for more in-depth studies, for example from an interdisciplinary modelling perspective. This would provide a different viewpoint from previous studies in the Northwest European mainland, which have mainly focused on human responses to peatland expansion – rather than on humans potentially being one of the (indirect) driving forces behind the process. Various authors have already indicated that disentangling human from natural influences on ecosystems can be dauntingly complex (e.g. Behre, 1988, 633; Carleton and Collard, 2020, 120). Most of the environmental archives used for study respond to both kinds of influence, especially in the areas where human impacts have a long history (Oldfield and Dearing, 2003). A related issue is that various ecosystems may respond very differently to similar external (either 'human' or 'natural') processes (e.g. Behre, 1988, 633; Dearing, 2006). This implies that tailor-made research designs to answer such questions are of the utmost importance.

6. Conclusions

Peat initiation occurred simultaneously in different loci distributed over the lower central, west and northwest parts of the Fochteloërveen area. This started in Mesolithic times, when the region had already been inhabited by small, mobile groups of hunter-gatherers for millennia. In this period a relatively dense mixed oak forest, locally with some natural open spaces, was present on the sand ridges surrounding the Fochteloërveen. Even though small-scale Neolithic agricultural communities probably may have been present earlier, the first clear archaeological evidence (settlements, cemeteries, votive offerings) relating to these groups dates from the second half of the 4th millennium BCE. From this moment onwards, human landscape impact expanded significantly until Roman times. This amongst others is demonstrated by increasing deforestation of the sand ridges surrounding the Fochteloërveen, as well as a wide range of other anthropogenic indicators in the pollen data (e.g. cereals).

Initially lateral peat expansion was slow, but the process accelerated between 5500 and 3500 cal y BP (Middle Neolithic – Middle Bronze Age). This coincided with the expansion of (wet) grassland, heath and mire vegetation. Natural processes have probably been the main underlying causes. It is possible that increased human landscape impact, most notably by deforestations for arable farming (in 'dryland' areas) and maintenance and propagation of pasture lands (in 'wetland' areas), locally amplified the paludification process. The first clear archaeological indications for human responses to peatland expansion and generally wetter conditions, including the construction of wooden trackways, date from the Iron Age. In the course of the Roman period the continuing 'drowning' process of the sand ridges surrounding the Fochteloërveen seems to have made a sustainable agricultural existence impossible, after which the region was largely abandoned by humans.

Author contributions

Roy van Beek: Conceptualization, Formal Analysis & Investigation (archaeology), Writing – Original Draft, Visualisation, Project administration, Funding acquisition, **Cindy Quik**: Conceptualization, Formal Analysis & Investigation (palaeogeography), Writing – Review & Editing, Visualisation, Funding acquisition, **Marjolein van der Linden**: Formal Analysis & Investigation (palaeobotany), Writing – Review & Editing, Visualisation.

Declaration of competing interest

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

Data availability

All data used for this paper is available in the supplementary materials.

Acknowledgements

This study is part of the research programme *Home Turf - An integrated approach to Dutch raised bogs*, supported by the Netherlands Organization for Scientific Research (grant number 276-60-003). Additional funding was obtained from the Province of Drenthe (*Subsidieregeling Archeologie en Publiek*) and Natuurmonumenten (programme *Fochteloërveen Toekomstbestendig*). We thank Ulco Glimmerveen for the pleasant cooperation and open discussions that led to the two artist impressions.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.quascirev.2023.108170.

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