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Mapping regional vegetation developments in Twente (the Netherlands) since the Late Glacial and evaluating contemporary settlement patterns

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Abstract

Interdisciplinary, landscape-oriented studies from an archaeological viewpoint in the Low Countries mainly concentrate on cultural and economic research questions. Focal points are the physical setting of settlements and cemeteries, land use patterns and subsistence economy. As a result, the collected data are rather site-based and one-dimensional. As a counterweight, this study aims to look beyond the boundaries of settlements and cemeteries by offering a regional and diachronic perspective on the development of the landscape, vegetation and habitation of Twente (the Netherlands) since the Late Glacial. A detailed search for existing pollen data yielded 125 sites containing information from a wide variety of sampling contexts. A series of six evidence-based regional vegetation maps have been constructed by analysing relations between pollen data, soil data and topography. The maps serve as first-stage generalised models that predict regional trends, allow subsequent testing and place site-specific archaeological data in a wider context. The method developed is applicable to other regions. A comparison with contemporary habitation patterns, based on archaeological and historical data, reveals spatio-temporal trends in human influence on vegetation and in physical factors influencing site location. Five maps have been 'translated' into artist impressions.

Keywords: habitation patterns, palynology, Pleistocene sandy soils, Late Glacial and Holocene, regional vegetation maps, Twente

Introduction

Recent research has demonstrated that the coversand landscapes of the Netherlands were far more dynamic and diverse than has been previously assumed, and that interdisciplinary research designs are indispensible in analysing long-term landscape and habitation processes (Kooistra & Kooistra, 2003; Spek, 2004; van Beek, 2009). In the Netherlands, detailed interdisciplinary studies on regional Late Glacial and Holocene landscape development are rare. Many interdisciplinary studies either focus on specific time frames, such as the Late Glacial and Early Holocene (e.g. van Geel et al., 1981; Hoek et al., 1999; Bos et al., 2005a,b; Heiri et al., 2007; van Asch et al., 2013), or on individual sites (e.g. Bos & Zuidhoff, 2011). Furthermore, most landscape reconstructions are based on archaeological or physical geographical sources. Geological and botanical data are mainly used to substantiate our images of the environment of settlements and burial sites, to explain (changes in) habitation patterns or to reconstruct human influence on the landscape. The strong emphasis on habitat, in the sense of the physical setting of past human activity (cf. O'Connor, 2001, 20), implies that these studies do not offer fully representative images of the structure and development of Holocene landscapes. This study aims to extend our views beyond the boundaries of settlements and cemeteries by reconstructing long-term vegetation developments on a regional scale. The Twente region, in the eastern part of the Netherlands, forms the pilot area (Fig. 1).

To arrive at accurate and detailed reconstructions of the vegetation history of any region, it is important to critically analyse palynological data from as great a variety of sampling contexts as possible (Jacobson & Bradshaw, 1981; Evans & O'Connor, 1999, 102; Dincauze, 2000, 377; Hjelle et al., 2012, 1368). The basis of this study is a detailed inventory of existing palynological data in Twente and immediately adjacent parts of the Netherlands and Germany. The integrated study of the large body of available data enables a reconstruction of the Late

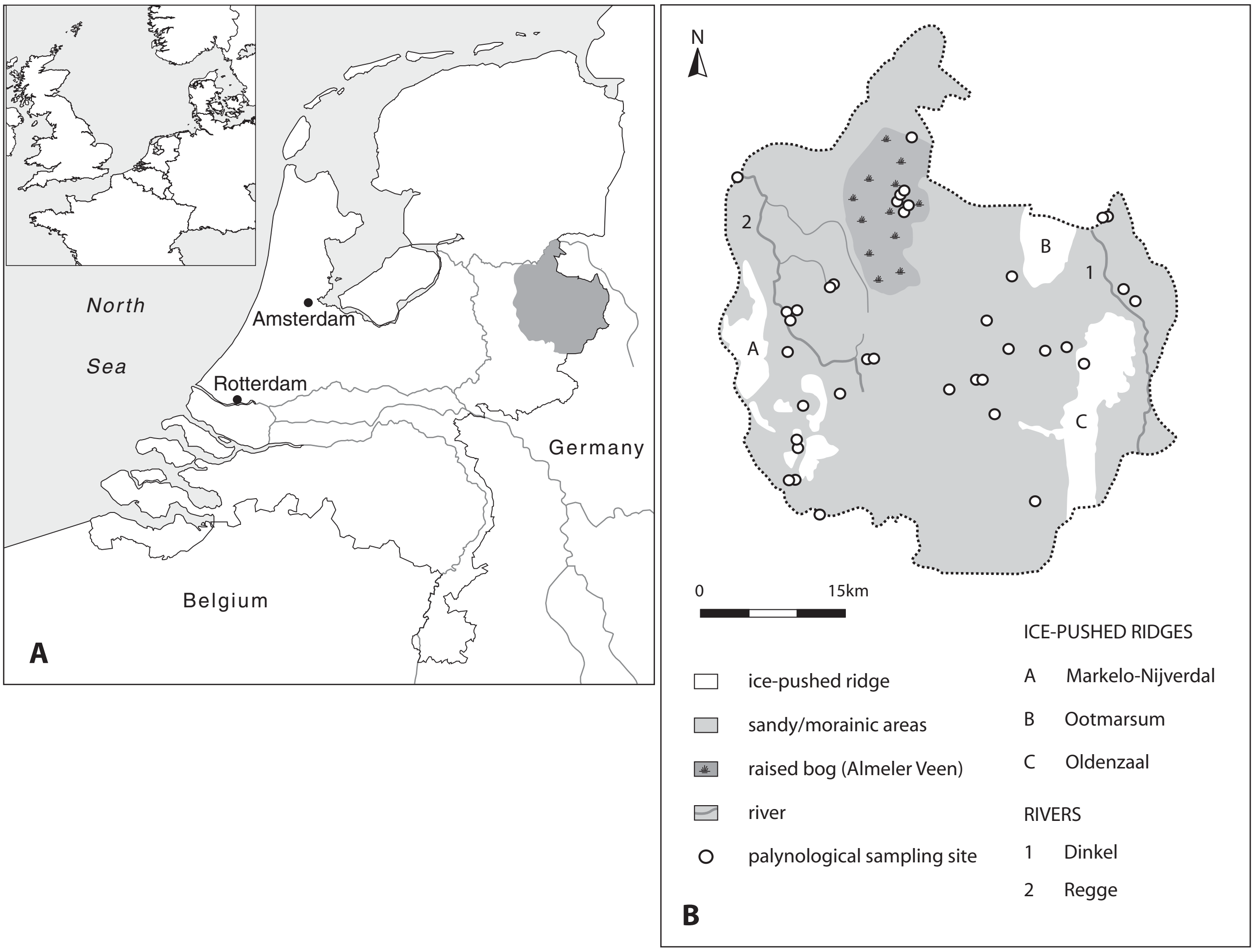

Fig. 1. A. Location of Twente (marked in grey). B. Simplified map of the most important landscape characteristics of the study area. The approximate maximum extension of the Almeler Veen raised bog is indicated. This situation was probably reached around the Late Middle Ages, before large-scale reclamations took place.

Glacial and Holocene vegetation development. Here we focus on the most important patterns, and especially on regional vegetation maps that are developed for six phases. These are based on a combination of palynological, geomorphological, hydrological and historical data (for more detail on the methodology, see also Bouman et al., 2013). The vegetation maps are used to study changes in vegetation and to analyse human–land relations by comparing them to archaeological and historical geographical data. The maps can be used as first-stage models to be tested against future palynological research, and to place site-specific archaeological investigations in a broader context. Five maps have been translated into digital, evidence-based artist's impressions.

This study aims to compare a diachronic series of evidence-based, regional vegetation maps to settlement data. Landscape reconstructions on this spatio-temporal scale have not yet been made in the Low Countries. A small number of vegetation maps have been published (e.g. van der Hammen & Bakker, 1971; de Kort, 2007; Neefjes & Willemse, 2009), but these generally focus on smaller areas and/or shorter time spans, and are based on smaller datasets. Hoek, for example, mapped the distribution of individual Late Glacial species in the Netherlands (Hoek, 1997a,b; see also Huntley & Birks, 1983). Some regional vegetation reconstructions have been made in neighbouring parts of northwest Europe. Burrichter (1973) reconstructed the 'potential natural vegetation' of the German Münsterland area, mainly based on geological data. Stobbe (1996) did the same for the Holocene of the German Wetterau area, based on palynological data using a modelling approach. Nielsen et al. (2012) reconstructed the landscape openness and distribution of selected species in northern Germany and Denmark. However, none of these studies comprises a detailed analysis of and comparison with contemporary settlement data.

The study area

Twente (Fig. 1) was selected as the pilot area because a large number of palynological analyses are available. Furthermore,

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most landscape types occurring in the Dutch coversand area are represented, therefore the vegetation development can be studied in various settings and be compared to similar sandy regions elsewhere. Also, heterogeneous landscapes enable variations in human behaviour to be tested against the environment (Evans & O'Connor, 1999, 96, citing Gamble, 1986, 306). This is also why parts of Twente were chosen as subjects for various earlier studies on site location and for archaeological predictive modelling (Brandt et al., 1992; Deeben et al., 1997).

Twente has a surface area of approximately 1500 km^2. This corresponds to the 'meso-scale' of research as defined by Dincauze (2000, 377–379), or more simply a 'regional' research level (e.g. Evans, 2003, 2–5). The region is part of the European Sand Belt (Koster, 2009; Tolksdorf & Kaiser, 2012). The major geological features were formed as a result of the combined activity of wind, water and ice during the Saalian and Weichselian Ice Ages (van Beek, 2009, 135–151). The expansion of land ice in the Saalian led to the formation of three ice-pushed ridges in the western (Markelo-Nijverdal), southeastern (Oldenzaal) and northern (Ootmarsum) parts of the research area (Fig. 1B). Rising to about 100 m above sea level, they form the most dominant landscape features. The areas between them can be classified as coversand landscapes. Their basic structure dates from the Pleniglacial, when sand drifts led to the formation of numerous sandy ridges. Even though the elevations do not generally differ from those of adjacent landscape units by more than a few metres, many of these ridges (especially the larger ones with more fertile soils) were favourable settlement locations throughout prehistoric and historic times. The coversand landscapes are intersected by various valleys. The most important rivers are the Dinkel (van der Hammen & Wijmstra, 1971) and the Regge. From the late Atlantic and Subboreal periods onwards raised bogs developed in various flat, poorly drained areas (German: *Plan-Hochmoore*; e.g. Lang, 1994, 219; Succow & Joosten, 2001). The largest by far is called Almeler Veen (also Vriezenveen/Engbertsdijksveen; van Geel, 1978; Dupont & Brenninkmeijer, 1984; van der Molen & Hoekstra, 1988). Until the Late Middle Ages, raised bogs and other wet depressions were scattered throughout the landscape, but due to reclamation and desiccation only a tiny fraction have survived into the present day (Borger, 1992; Gerding, 1995; de Rooi, 2008).

Methods and materials

Palynological data

The data have been collected by literature survey, from palynological archives and by contacting various research institutes and universities. In total 125 sites containing Late Glacial and Holocene palynological data were found (Fig. 2; Appendix 1). These are scattered over the eastern Netherlands and adjacent parts of Germany (northwest Westphalia and southwest Lower Saxony). Thirty sites are situated in Twente. The others are included because of their proximity to the region (never over 50 km away, but mostly much closer) and comparable landscape setting. All data were recorded in a detailed database similar to the Dutch National Pollen Database (Donders et al., 2010). Both natural (n = 91) contexts such as lakes, bogs and residual channels and anthropogenic (n = 34) contexts such as wells are represented. Obviously, the analysis of samples from anthropogenic contexts is not without problems (for an overview of the pitfalls see Groenewoudt et al., 2007). However, when treated carefully valuable additional information can be obtained that complements data from natural sources (cf. Dimbleby, 1985).

The palynological sites are distributed more or less evenly over the research area (Fig. 2). There are some spatial biases in the data. For example, all the German contexts are raised mires (Burrichter, 1969, 1973; Isenberg, 1979; Pott, 1984; Kuhry, 1985; Fig. 2B). Most locations only contain information on parts of the Late Glacial/Holocene, therefore the distribution and composition of palynological information in any given phase varies (Fig. 3). In general, samples from anthropogenic contexts cover shorter timespans than those from natural contexts.

Vegetation reconstructions

Although a large amount of palynological data is available from the study area, much of the data are not suitable to be used in the models designed in recent years for vegetation reconstruction (e.g. Sugita, 2007a,b; Bunting & Middleton, 2005; Gaillard et al., 2008, 2010; Nielsen et al., 2012). Most models require uniform data (with regard to pollen sums) from large lakes or mires. However, our data is highly variable in terms of sampling context and the applied research methods. This does not mean that all existent data have to be dismissed because they are not in raw count form (e.g. Fyfe et al., 2013). For this study a new method was constructed using these types of data to identify regional trends and differences in vegetation development/land use. The basis of this methodology is formed by the inherent relationship between the abiotic landscape, vegetation development and human activities, and the assumption that these relations are consistent in a relatively uniform area. Using these relations, 'local' pollen-based vegetation reconstructions were extrapolated to a regional scale (see below).

When comparing and integrating samples from various locations and environmental settings, several pitfalls arise. Most problems occur due to various well-known factors which influence the composition of a pollen assemblage. These include the source area of pollen (e.g. Janssen, 1973; Broström, 2002; Bunting, 2002; Bunting et al., 2004; Sugita, 2007a,b; Bunting & Hjelle, 2010; Sugita et al., 2010a,b), the origin and transport method of pollen (e.g. Andersen, 1970; Janssen, 1973, 1974; Sugita, 1994, 2007a; Sugita et al., 1999, 2010a; Broström et al., 2008), vegetation characteristics and sediment

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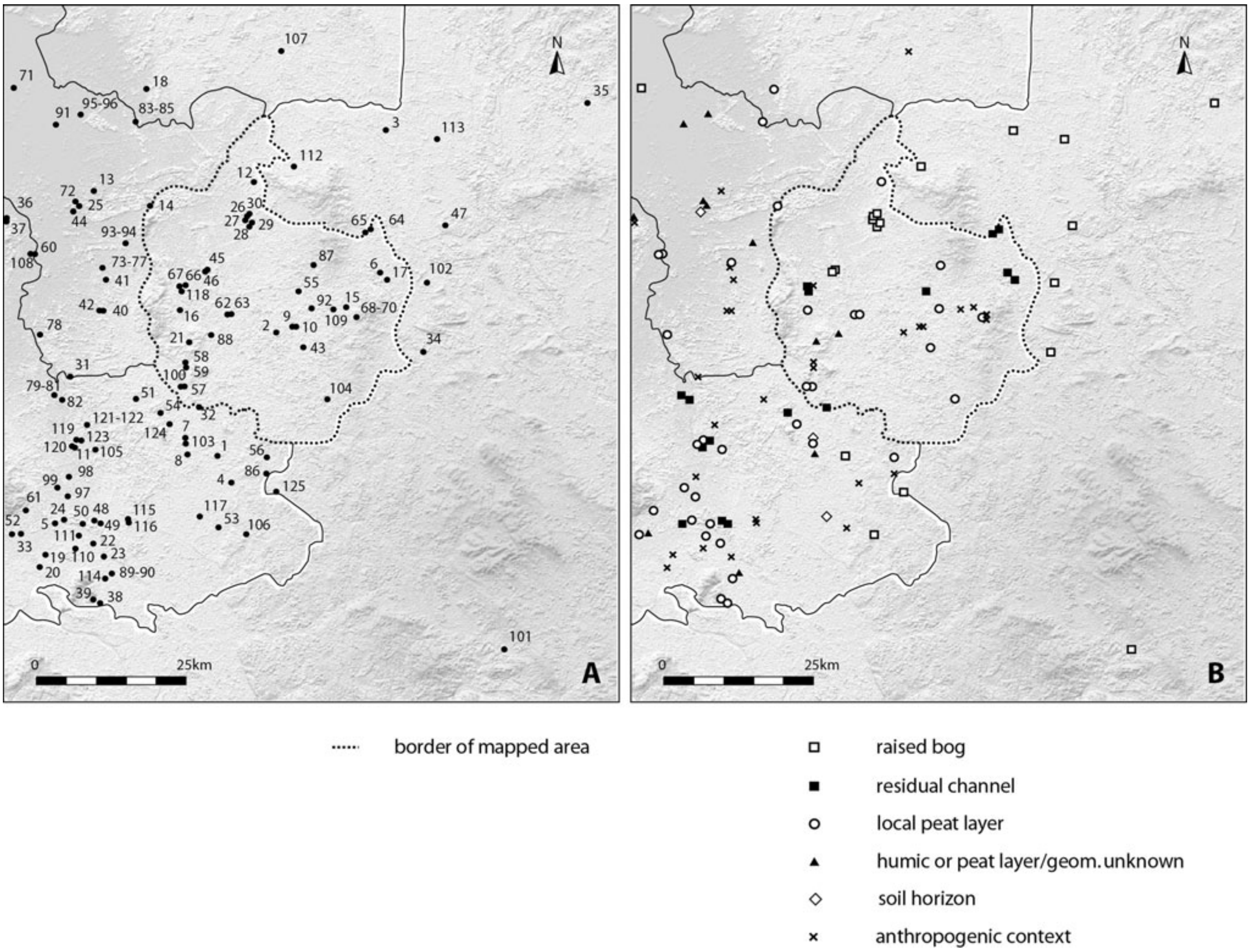

Fig. 2. A. Overview of all palynological sampling sites in and around Twente used in this study. The numbers refer to Appendix 1. B. Overview of sampling contexts.

accumulation (e.g. Sugita, 1994, 2007a,b; Sugita et al., 2010a; Broström et al., 1998; Bunting, 2002; Bunting et al., 2004) and pollen preservation (e.g. Havinga, 1967). In our study, most of these pittfalls were minimised by interpreting each dataset individually, therefore the vegetation reconstructions are not directly based on pollen data but rather on assumptions and relations derived from the pollen record.

A second set of problems relates to the variations in the structure of the data. These have been collected by different researchers with varying research methods and aims. This is reflected in the variety of pollen sums used. It was impossible to compare pollen percentages of specific species in different diagrams. To do so it would be necessary to consult the original data, which were not always available. The dominance of species and their relative ratio at each site were therefore used to estimate the spatial distribution of species and their relative importance. Additionally, we chose to base the reconstructions on vegetation communities instead of on individual species. Vegetation communities are groups of plant species that prefer comparable conditions and frequently occur together in present-day vegetation (Janssen, 1972). For each time-slice map a different set of vegetation communities was defined (Figs 5–10).

The first step in this study was to obtain a regional overview of vegetation development using a selection of well-dated pollen records with a high temporal resolution (e.g. van Geel, 1978; van Geel et al., 1981; Bos & Zuidhoff, 2011; Gerrets et al., 2012). This overview was used as a general reference and to estimate the relative age of undated sequences, based on the overall vegetation composition and the presence of key species. Samples from anthropogenic settings were mostly dated by archaeological evidence.

The second step was to reconstruct the vegetation around each sampling site (Fig. 4). Using the pollen data and the original ecological interpretations, the neighbouring vegetation communities were derived for these sites (Fig. 4A). Using the local geomorphology these vegetation communities were ascribed to specific geomorphological units (Fig. 4B). On average an area with a diameter of 1 km was analysed. To minimise personal bias, the original ecological interpretations were used as much as possible.

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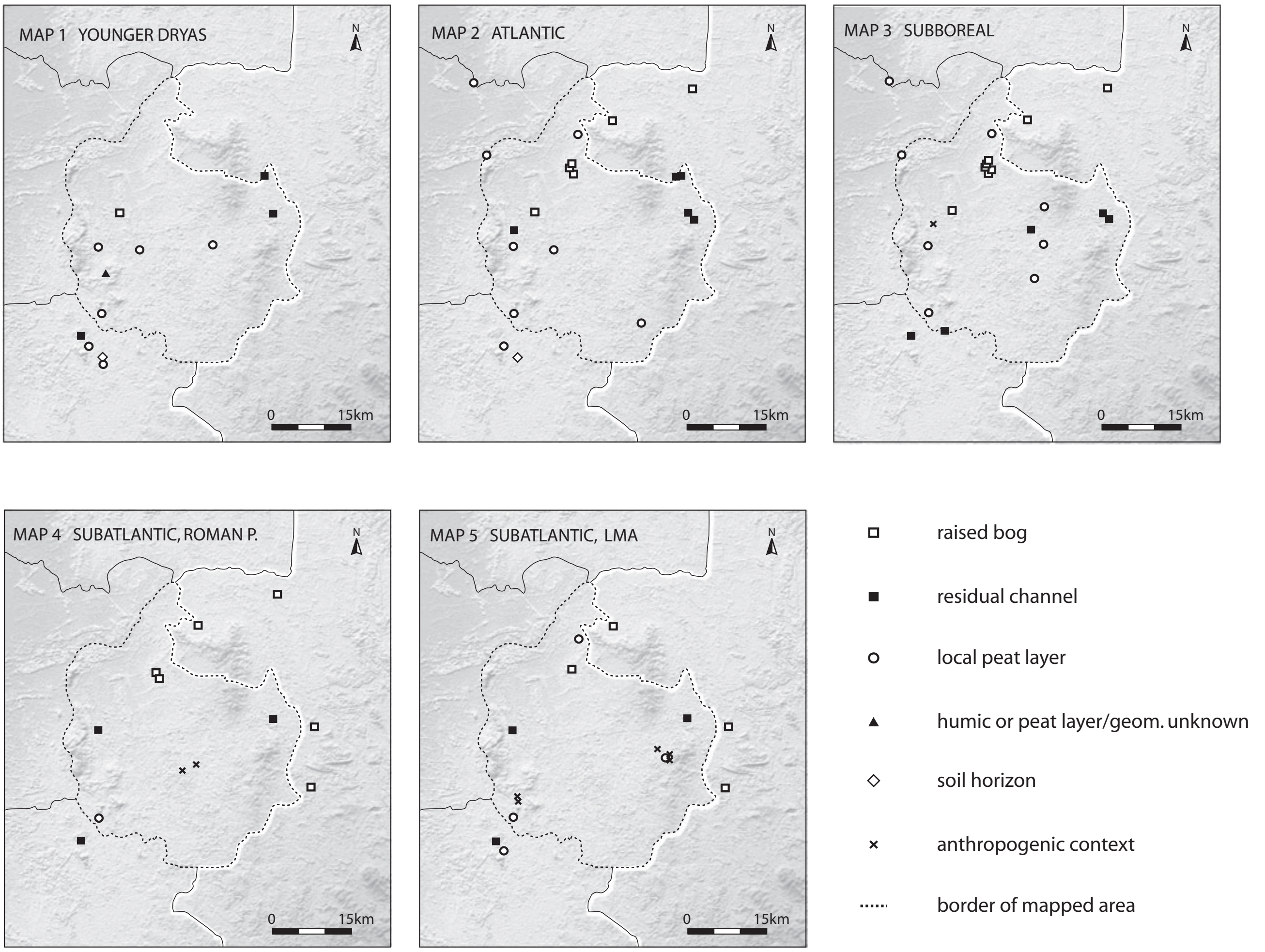

Fig. 3. Location of the most important palynological sampling sites used to construct the vegetation maps (Figs 5A–9A; time-slices 1–5). Fig. 10 (time-slice 6) is based on historical maps. LMA, Late Middle Ages.

The third step was to deduce relations between geomorphology and vegetation from the small-scale site-based reconstructions (step 2) and the regional vegetation overview (step 1). Using a detailed geomorphological map (van Beek, 2009, Appendix 1) these relations were used to fill in the areas between the sites and arrive at regional maps (Fig. 4C).

The method used is based on analogical reasoning and comes with the risk of circular arguments and personal bias, therefore the assumed soil–vegetation relations were consistently tested against the actual palynological data and adjusted accordingly. Bias was minimised by consulting a specialist group (see acknowledgements) and where possible using the original authors' interpretations from each study.

In a single case (map 3) archaeological data were taken into account when making a vegetation map. Recent palynological research demonstrated that virtually all barrows in Dutch sandy landscapes were erected on either natural or created open spaces, more specifically heathland, and that these heaths were managed (de Kort, 2007; Doorenbosch, 2013). As these observations are corroborated by research abroad (Behre, 2000; Hannon et al., 2008; Karg, 2008; Fyfe, 2012), we chose to denote the poor sandy soils in the environment of barrows as heath-rich areas.

Regional vegetation maps were constructed for six time-slices. The selection of these time-slices is based on large changes in vegetation composition, the availability of palynological data and developments in habitation history. In this process, the vegetation changes and palynological data were most important. The availability of archaeological and historical data obviously is of vital importance as well, but these were not leading in the selection process, therefore the quality of cultural data varies for each time-slice. Obviously, this is a problem that would arise in every selected study region and is related to research history and post-depositional factors.

The chosen time-slices are:

(1) Younger Dryas, Late Palaeolithic, c. 10.000 BC (Fig. 5A)
(2) Atlantic period, Early/Middle Neolithic, c. 4.000 BC (Fig. 6A)
(3) Subboreal period, Middle Bronze Age, c. 1500 BC (Fig. 7A)
(4) Subatlantic period, Roman period, c. AD 200 (Fig. 8A)
(5) Subatlantic period, Late Middle Ages, c. AD 1500 (Fig. 9A)
(6) Subatlantic, submodern period, c. AD 1900 (Fig. 10)

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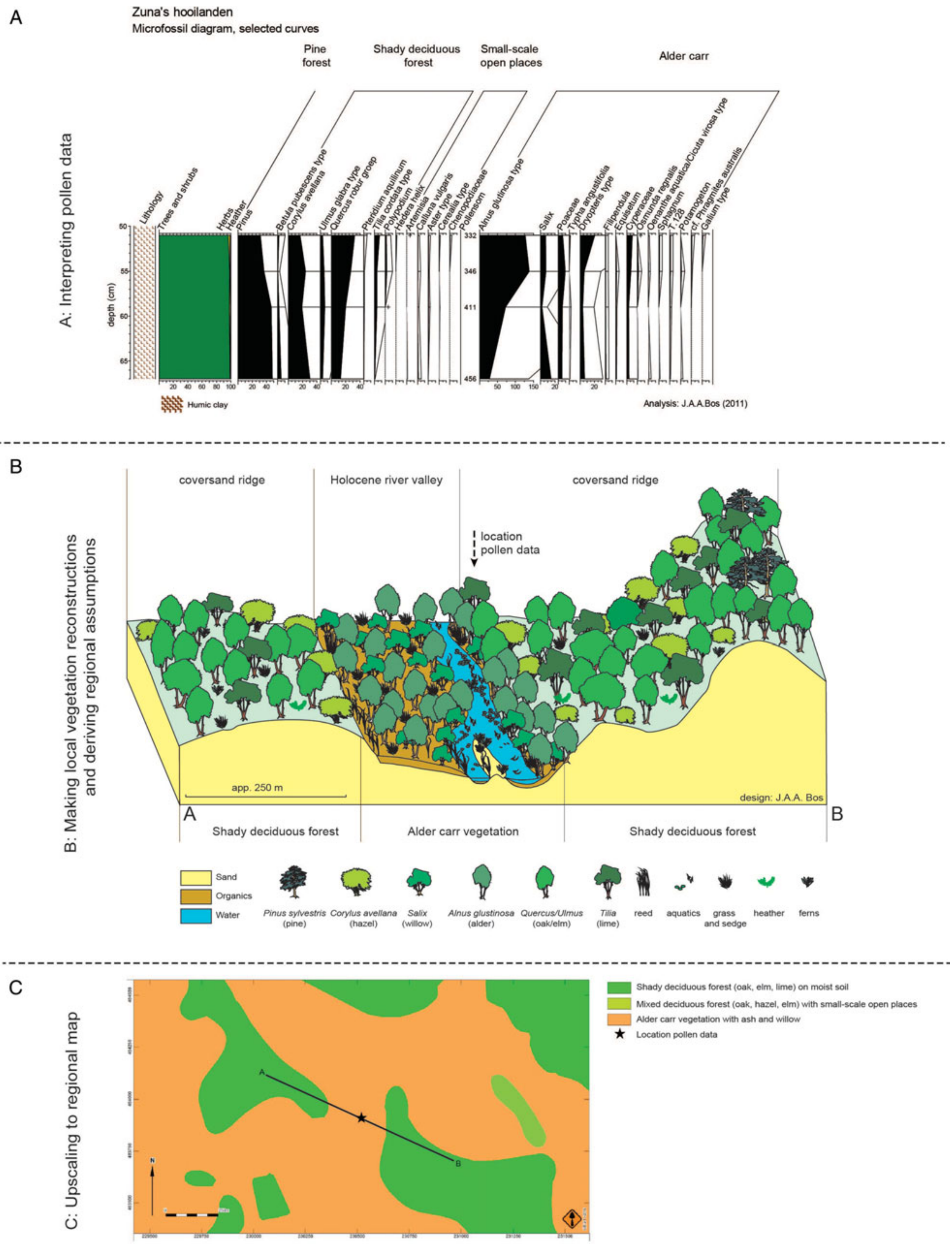

Fig. 4. Visualisation of the reconstruction process. A. An interpreted pollen diagram from Zuna's Hooilanden (originally published in Gerrets et al., 2012). B. Local vegetation reconstruction around the sampling site during the Atlantic period (modified after Gerrets et al., 2012; not to scale). C. Section of the final vegetation map showing the transect reconstructed in B. The high values of tree pollen in the diagram indicate a densely forested landscape. The local pollen spectrum indicates the presence of an alder carr. Pine forests are probably present on the nearby (distance 3 km) ice-pushed ridge towards the west (the location of Zuna is shown in Fig. 6A).

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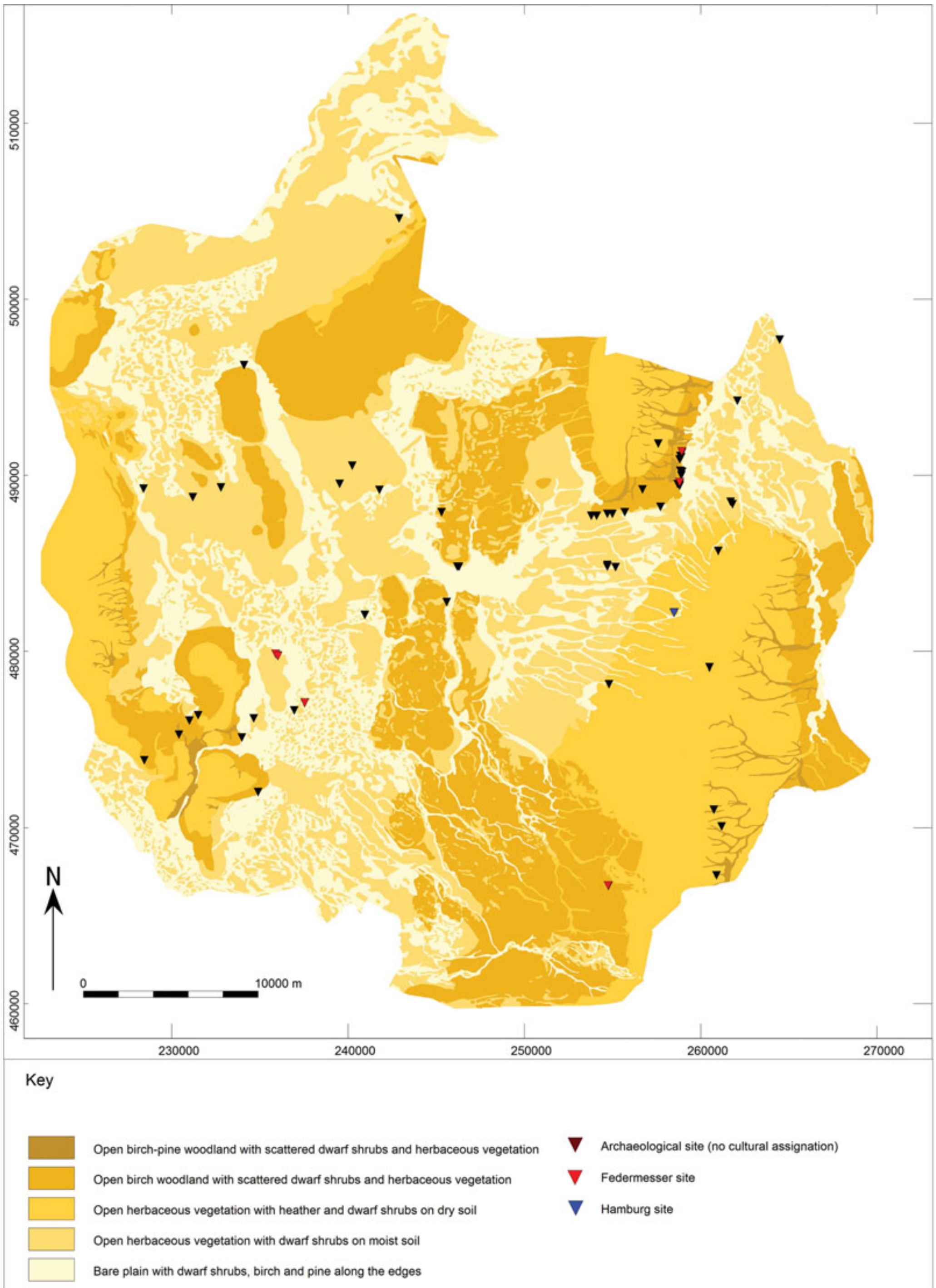

Fig. 5. A. Reconstruction map of the vegetation in the Younger Dryas period, around approximately 10,000 BC. The plotted archaeological sites date to the Late Palaeolithic period and mainly consist of flint scatters. Part of the Federmesser sites may date from the Allerød phase. Modified after Bouman et al., 2013, fig. 5.1, p. 39.

The basis of the first five maps is formed by a detailed physical geographical map of the eastern Netherlands (van Beek, 2009, Appendix 1). Map 6 is derived from historical maps (Grote Historische Atlas, 2005) instead of palynological data. The former provide a far more detailed and reliable impression.

Habitation patterns

The vegetation maps are compared to settlement patterns, with two goals: to analyse human influence on vegetation, and to identify physical factors that may have influenced site

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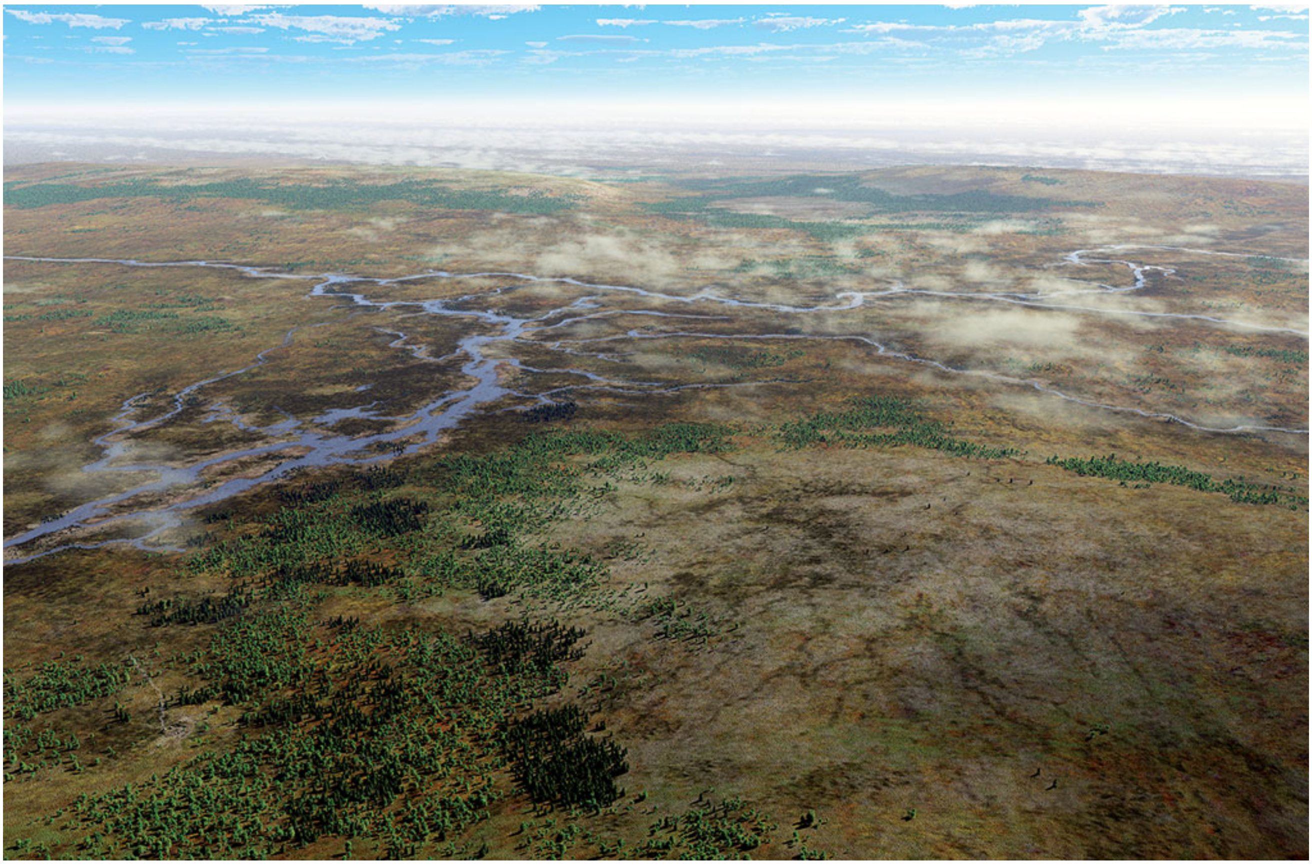

Fig. 5. B. Artist's impression of the landscape in the Younger Dryas period, around approximately 10,000 BC. All artist's impressions (Figs 5B–9B) are made by Mikko Kriek (BCL Archaeological Support). The viewpoint of all of them is approximately the centre of Twente, looking eastward.

location. With regard to the latter, vegetation maps provide a new perspective for the Low Countries. Studies into the relations between habitation and physical geography in and near the research area, on the other hand, are well-represented (e.g. van der Hammen & Bakker, 1971; van Beek, 2009, 2011; van Beek & Groenewoudt, 2013). The most important trends in site location documented in these studies are integrated into the discussions below because geomorphology and soil data are linked to vegetation. Some of the observations are therefore generated from the assembled modelled palynological datasets, whereas others are derived from previous (mostly recent) archaeological studies.

Archaeological data are plotted on the first four maps (Figs 5A–8A). Selections of specific site types are made that provide general impressions of occupation patterns and habitation density. The data are chiefly derived from national databases kept by the Cultural Heritage Agency of the Netherlands, complemented with a literature survey. The available data do not allow the reconstruction of fully reliable settlement patterns. They are biased as a result of post-depositional factors such as erosion and sedimentation, land-use history and research history (cf. van Beek, 2009, 493–508). Also, the 'archaeological' dates given to each vegetation map are general indications, therefore the site distribution patterns and their relation to vegetation can only provide general insights into human–land relations: they should be seen as working models. On the fifth map, which depicts the vegetation around AD 1500, the contemporary distribution pattern of farmsteads is plotted (Fig. 9A). These data are derived from historical geographical information (Werkgroep Historische Kaart van Twente, 1991) and provide a far more reliable and detailed picture. The sixth map (c. AD 1900) is not compared to habitation patterns as it is expected that the latter were not primarily dictated by environmental factors.

Relations between human activity and vegetation developments are not always straightforward (e.g. Loveluck & Dobney, 2001). They do not necessarily follow unilinear, irreversible evolutionary lines. As stated by Dincauze (2000), ecological relationships are mutually constitutive. Humans affect plant assemblages. Equally, changes in plant assemblages affect human behaviour by redefining the range of opportunities presented by the habitat (Dincauze, 2000, 391). Furthermore, positively correlated variables (characters that always occur together or change at the same time) do not by definition imply some causal link (Dincauze, 2000, 32). If, for example, all settlements of the Neolithic Funnel Beaker Culture appear to be situated in deciduous forests, this does not necessarily mean that Funnel Beaker people preferred forests as habitats. A third variable, such as soil

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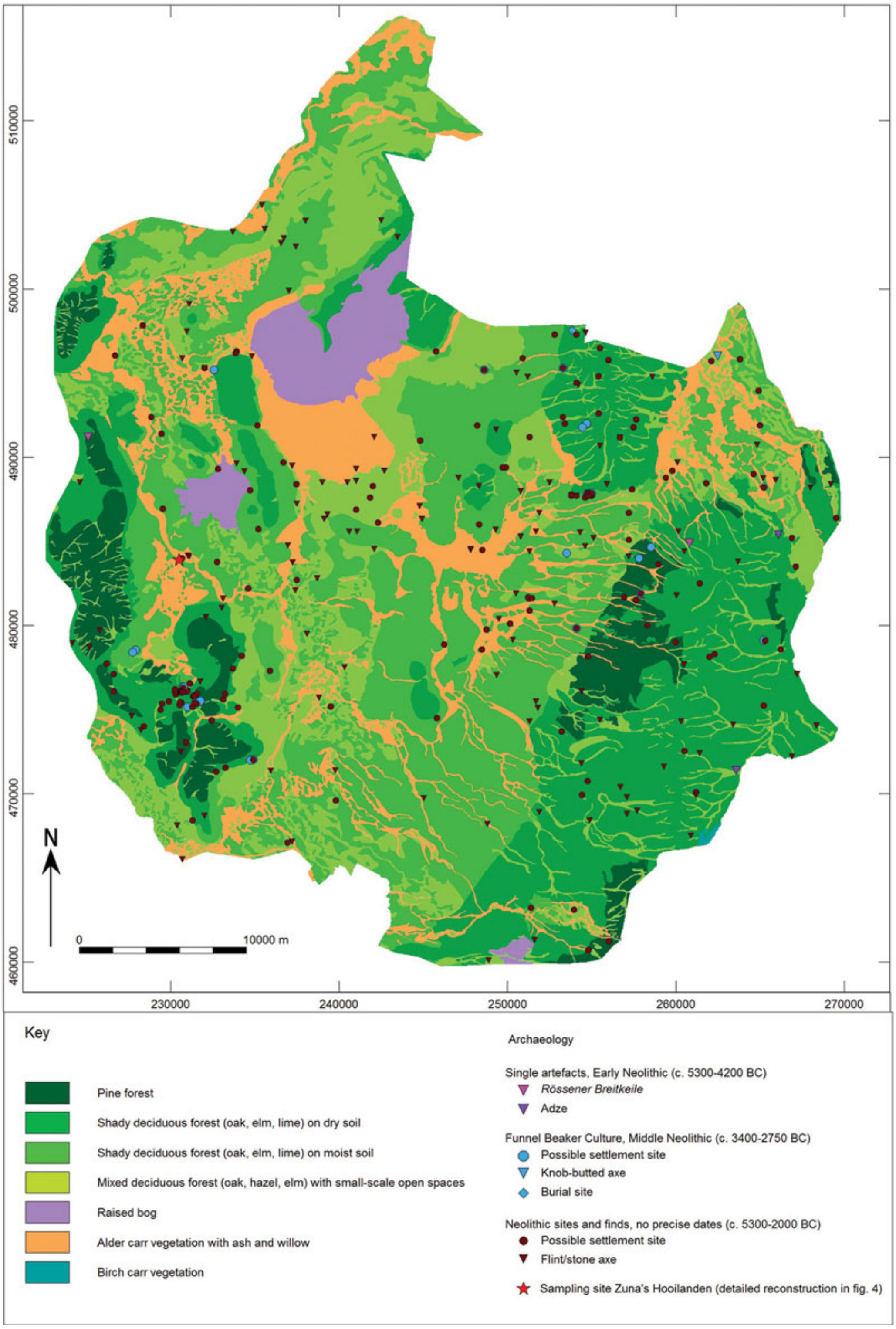

Fig. 6. A. Reconstruction map of the vegetation in the Atlantic period, around approximately 4000 BC. The plotted archaeological sites all date to the Neolithic period, but many cannot be dated more precisely. The vegetation at the indicated sampling site of Zuna's Hooilanden (red star) is mapped in detail in Fig. 4. Modified after Bouman et al., 2013, fig. 5.2, p. 41.

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Fig. 6. B. Artist's impression of the landscape in the Atlantic period, around approximately 4000 BC.

fertility, may have been more important, therefore it is imperative to analyse the mechanisms underlying such relationships and not just the patterns themselves (Dincauze, 2000, 32).

Human influence on vegetation can be demonstrated in various ways. Obvious examples in pollen diagrams are the decrease of arboreal pollen and increase of heather and grasses, as well as the appearance of cereals, weeds and other anthropogenic indicators (Behre, 1986). The position and context of sampling sites are of great importance. A pollen sample from the central part of a raised mire will demonstrate fewer (and different) human influences than one from a residual channel adjacent to a settlement site, let alone one from a well on a farmyard (Groenewoudt et al., 2007, 22). Furthermore, the information pollen spectra provide is spatially limited. A well-known palynological study at Flögeln (Germany) demonstrated that hardly any anthropogenic indicators were present in peat samples taken only a few kilometres away from archaeologically known settlements (Behre & Kucan, 1986; Groenewoudt et al., 2007, 22).

Artist impressions

All maps besides the 'youngest' one have been 'translated' into digital artist's impressions by a professional archaeological illustrator (Figs 5B–9B; Mikko Kriek, BCL Archaeological Support, Amsterdam). These are used to inform a wider audience, for example by displaying them in a local museum specialising in natural history, but are of interest for experts as well. The impressions are made in close cooperation between the illustrator and the present authors, and give an overview of the most important trends in vegetation and habitation (see below). The chosen viewpoint is approximately the centre of the research area, looking in an eastern direction towards the ice-pushed ridges of Ootmarsum (back left) and Oldenzaal (back right).

Results

Map 1: Younger Dryas, Late Palaeolithic, c. 10.000 BC (Figs 5A and 5B)

The Younger Dryas was characterised by a subarctic climate. It can be divided into a relatively wet and cold first part, and a slightly warmer and drier second part (e.g. van Geel et al., 1989; Hoek, 1997a,b). The first part is characterised by a high mortality in the birch (*Betula*) and pine (*Pinus*) forests that had developed in the preceding Allerød phase. In the second phase, depicted in Map 1 (Fig. 5A), large-scale sand drifts occurred due to the absence of a closed vegetation

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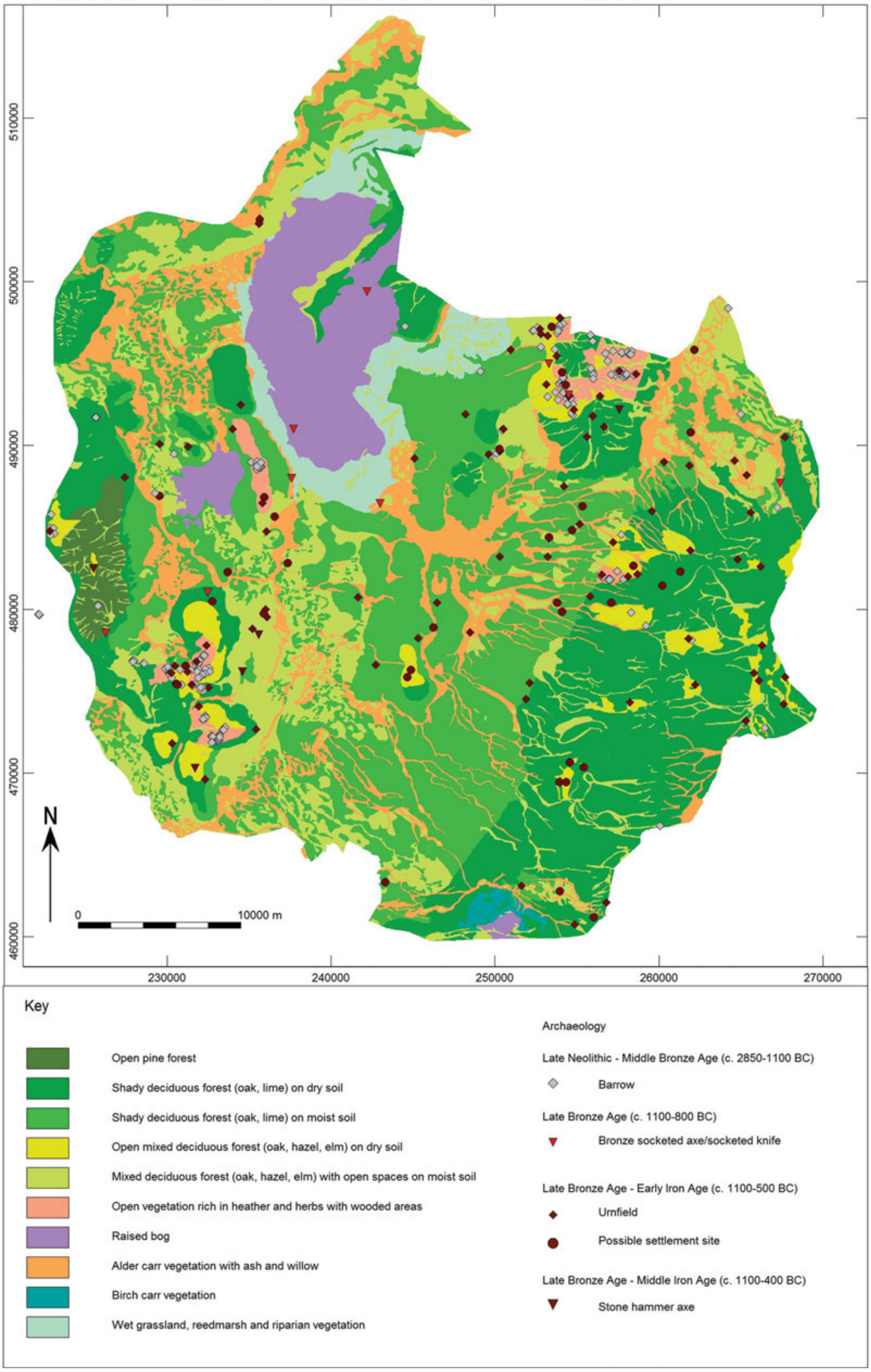

Fig. 7. A. Reconstruction map of the vegetation in the Subboreal period, around approximately 1500 BC. The plotted archaeological sites offer a general impression of the occupation pattern in the Bronze Age. Some may be slightly older (mainly barrows) or younger (mainly urnfields). Modified after Bouman et al., 2013, fig. 5.3, p. 43.

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Fig. 7. B. Artist's impression of the landscape in the Subboreal period, around approximately 1500 BC.

cover. On these young soils and on unsheltered higher parts of ice-pushed ridges an open, herbaceous vegetation developed. It consisted of Ericales, such as crowberry (*Empetrum nigrum*), grasses (Poaceae), sedges (Cyperaceae) and various herbs like wormwood (*Artemisia*), rockrose (*Helianthemum*) and dock (*Rumex*). Boulder clay occurs in parts of Twente. On these richer soils some scattered birches, dwarf shrubs, such as dwarf birch (*Betula nana*), willow (*Salix*), juniper (*Juniperus*) and many herbs were found. In local refugia, such as dry valleys on the eastern slopes of ice-pushed ridges, some pine survived. Braided rivers, with largely bare river plains, flowed through the lower parts of the landscape. Some trees and dwarf shrubs also occurred along sheltered river valleys.

Map 2: Atlantic period, Early/Middle Neolithic, c. 4000 BC (Figs 6A and 6B)

In the Atlantic period deciduous forests covered large parts of the landscape. They consisted mainly of oak (*Quercus*). Elm (*Ulmus*), lime (*Tilia*) and ash (*Fraxinus*) were also well-represented. The Atlantic woods probably consisted of a mosaic of different forest communities, dependent on local soil conditions. At forest edges and on slopes of sandy ridges a shrub vegetation is likely to have occurred, consisting of hazel (*Corylus avellana*) and bracken (*Pteridium aquilinum*). On poor and dry sandy soils pine forests were still present. These gradually disappeared during the Atlantic period. In forests on coversand plains, small-scale open spaces with heather and other herbs occurred. In moist valleys alder (*Alnus*) carr expanded significantly. Raised bogs started to develop in poorly drained areas. Locally, birch carr occurred.

Map 3: Subboreal period, Middle Bronze Age, c. 1500 BC (Figs 7A and 7B)

Large areas covered with deciduous forests were still present in the earliest stages of the Subboreal period. These were still dominated by oak, but contained less lime and elm than before. In the final phase of the Subboreal, beech appeared. Because of human activity, increasing numbers of small-scale woodland openings appeared. In some areas deforestation led to open vegetation rich in heath, herbs and some scattered shrubs. The area of pine forest decreased significantly. This forest type only survived on poor soils, such as ice-pushed ridges, and was probably more open than before. The anthropogenic indicator ribwort plantain (*Plantago lanceolata*) appeared, especially in areas with open grass vegetation that were heavily trampled or grazed. In residual channels and valleys alder carr was found, with willow (*Salix*) in the wettest places. Raised bogs expanded.

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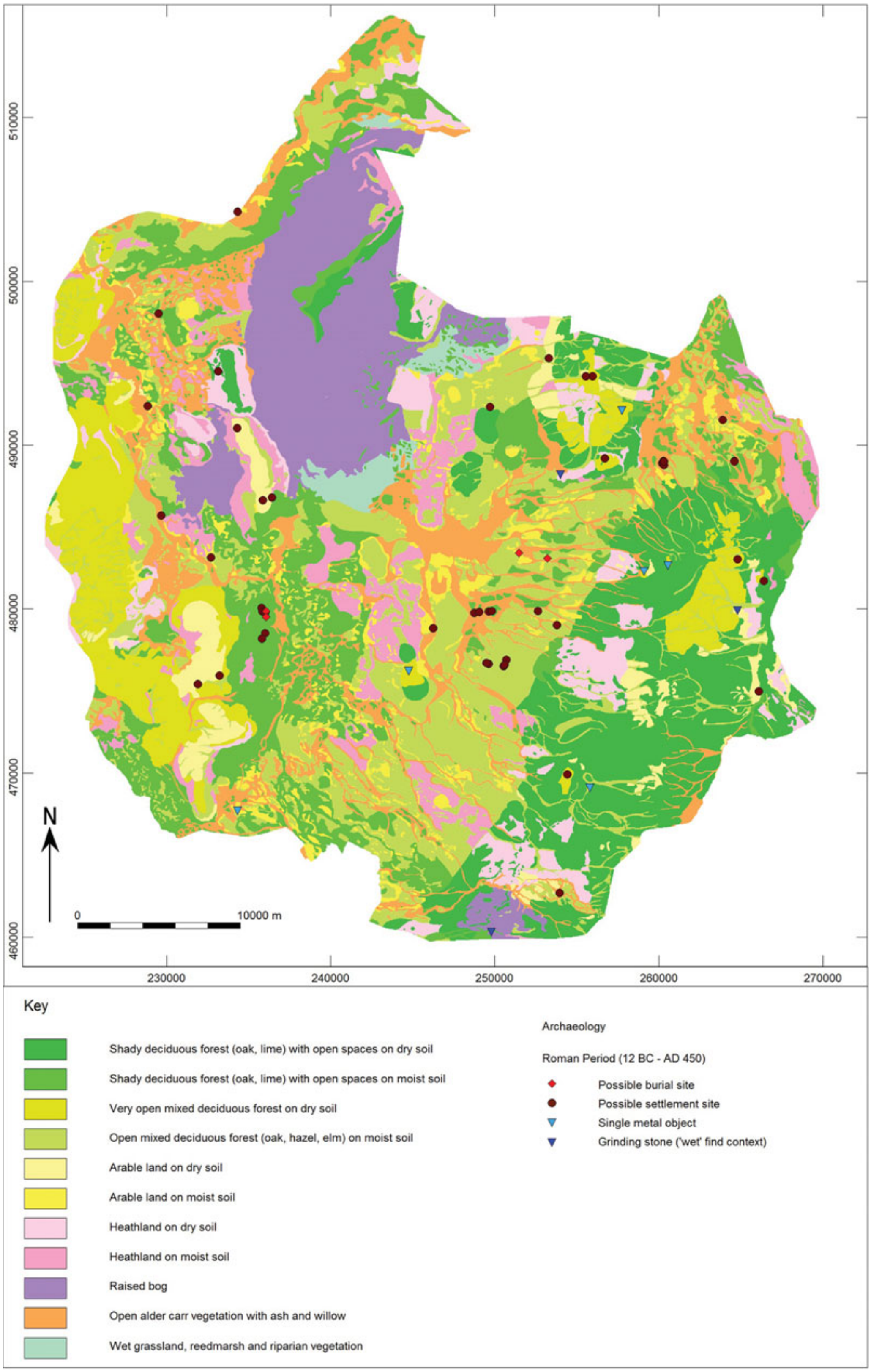

Fig. 8. A. Reconstruction map of the vegetation in the Subatlantic period, around approximately AD 200. All plotted archaeological sites date to the Roman period. Modified after Bouman et al., 2013, fig. 5.4, p. 45.

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Fig. 8. B. Artist's impression of the landscape in the Subatlantic period, around approximately AD 200.

Along the edges of the Almeler Veen raised bog, wet grasslands and reedbeds developed.

Map 4: Subatlantic period, Roman period, c. AD 200 (Figs 8A and 8B)

In the Subatlantic period, every pollen diagram shows a decrease in arboreal pollen and an increase in heather and grasses, combined with the appearance of cereal (Cerealia) pollen, arable weeds and other anthropogenic indicators. By the Roman period the forests on numerous sandy ridges had been cleared. The same accounts for the ice-pushed ridge of Markelo-Nijverdal, where open forests with hazel abundantly developed. Deciduous forests, mainly consisting of oak and beech (*Fagus sylvatica*), interspersed with large open spaces, were present on the other ice-pushed ridges and on low sandy plains. Heathlands developed on poor sandy soils. The Almeler Veen raised bog continued to expand.

Map 5: Subatlantic period, Late Middle Ages, c. AD 1500 (Figs 9A and 9B)

By the Late Middle Ages (AD 1300–1500), large areas were deforested. The remaining forests, mainly higher up on the ice-pushed ridges of Oldenzaal and Ootmarsum, were dispersed and open. An open landscape with scattered areas of shrub was present on the ice-pushed ridge of Markelo-Nijverdal. This vegetation type occurs on large sandy ridges as well. Heathlands became much more numerous and increased in size. In the valleys most alder carr had disappeared and was replaced by meadow. The size of the Almeler Veen raised bog decreased, and purple moor grass (*Molinia caerulea*) and birch started to expand onto its drier parts.

Map 6: Subatlantic period, submodern period, c. AD 1900 (Fig. 10)

As mentioned in the methodological section, historical maps are used to draw up the final vegetation map of c. AD 1900. It shows a very open landscape dominated by heathland, grassland and arable fields. Since the 19th century pine forests have been planted on a large scale. In some locations deciduous forests occur. Some dispersed forest remnants are found on sandy ridges, and heathland on nutrient-depleted ridges. Grasslands dominate the coversand plains and the valleys. Especially in eastern Twente these grasslands are frequently enclosed by hedges. In a few valleys alder carr is present. The Almeler Veen raised bog had been reduced significantly due to desiccation and large-scale reclamation. Reclaimed parts of the bog had been transformed into wet grasslands.

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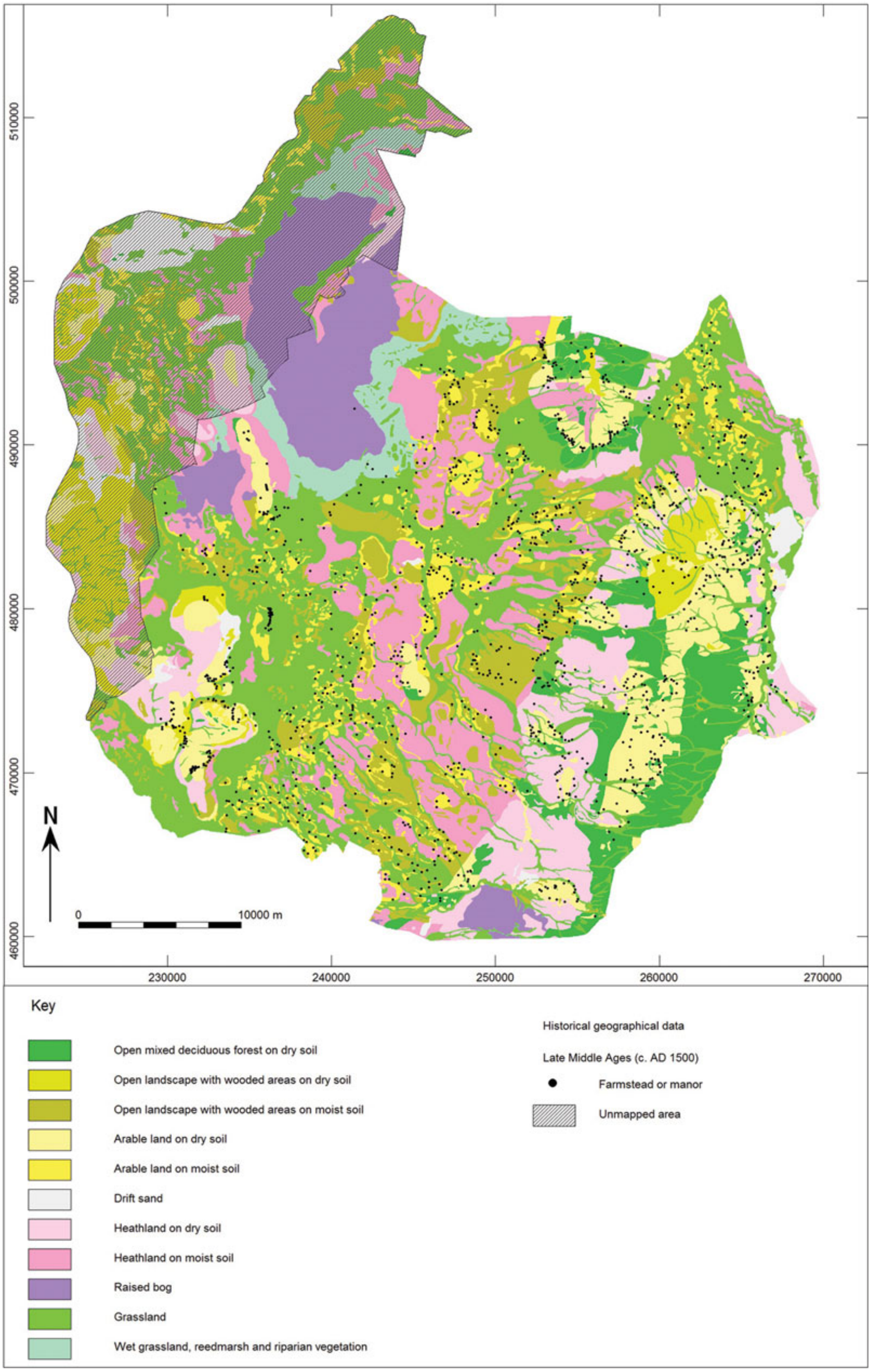

Fig. 9. A. Reconstruction map of the vegetation in the Subatlantic period, around approximately AD 1500. The plotted farmsteads and manors are known from historical geographic data to have existed at the end of the Late Middle Ages. Many were founded centuries earlier. Modified after Bouman et al., 2013, fig. 5.5, p. 47.

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Fig. 9. B. Artist's impression of the landscape in the Subatlantic period, around approximately AD 1500.

Discussion

In the Late Palaeolithic (c. 12.500–9.000 BC) human impact on the landscape was limited. Population density was low. Small groups of hunter-gatherers roamed across the landscape. Most Late Palaeolithic sites plotted on map 1 (Fig. 5A) probably belong to the Hamburg Culture, Federmesser Group and Ahrensburg Culture (Scholte Lubberink, 1998; van Beek, 2009, 362–364). However, many sites cannot be assigned to a specific culture or group as they generally consist of surface flint scatters that are often not dated very precisely, therefore the age differences of the plotted sites are probably in the order of millennia. It has to be mentioned that Federmesser sites are frequently assumed to date from the Allerød phase (e.g. Stapert, 2005). This would imply that they belong in an environment that is very different from Fig. 5A. However, the only precisely dated Federmesser site in the study area, excavated near Enter, actually was ^{14}C-dated to an early phase of the Younger Dryas (Deeben et al., 2006). Despite these problems the distribution pattern of Late Palaeolithic sites shows clear trends. Most sites are found along the sandy slopes of ice-pushed ridges. These relatively high areas in transitional zones between ice-pushed ridges and coversand landscapes were probably popular because these 'intermediate' areas had a high biodiversity and enabled the exploitation of different landscape zones. Many sites are situated in areas mapped as park landscape with birches, dwarf shrubs and many herbs. Others appear in open, herbaceous vegetations on high and dry soils. Previous studies on Late Palaeolithic site location in this region (Scholte Lubberink, 1998, 113–115; Deeben et al., 2006, 72–74; van Beek, 2009, 362–364) showed that, on a local level, the majority of sites occur on sandy ridges near moist depressions or active watercourses. This pattern fits well with our data.

Map 2 (Fig. 6A) reflects the vegetation around the transition from Early (5300–4200 BC) to Middle (4200–2850 BC) Neolithic. Early Neolithic sites are rare. Just some single finds of specific stone axe types date to this period (van der Waals, 1972; Raemaekers, 1999, 102–106). Hardly anything is known about the character of the Neolithisation process in this region, but it occurred later and was slower than in the southern loess belt (Bakels, 1978, 2009; Verhart, 2000; Vergne et al., 2004). Judging from both pollen data and archaeological evidence, human impact on the landscape in our study area was very limited in the earlier stages of the Neolithic. The Middle Neolithic Funnel Beaker Culture (3400–2750 BC), however, is clearly recognisable in both archaeological and palynological records (Bakker, 1979, 2003; Bakker & Groenman-van Waateringe, 1988; Spek, 2004, 124–130). Sites are found nearby or on ice-pushed ridges, or

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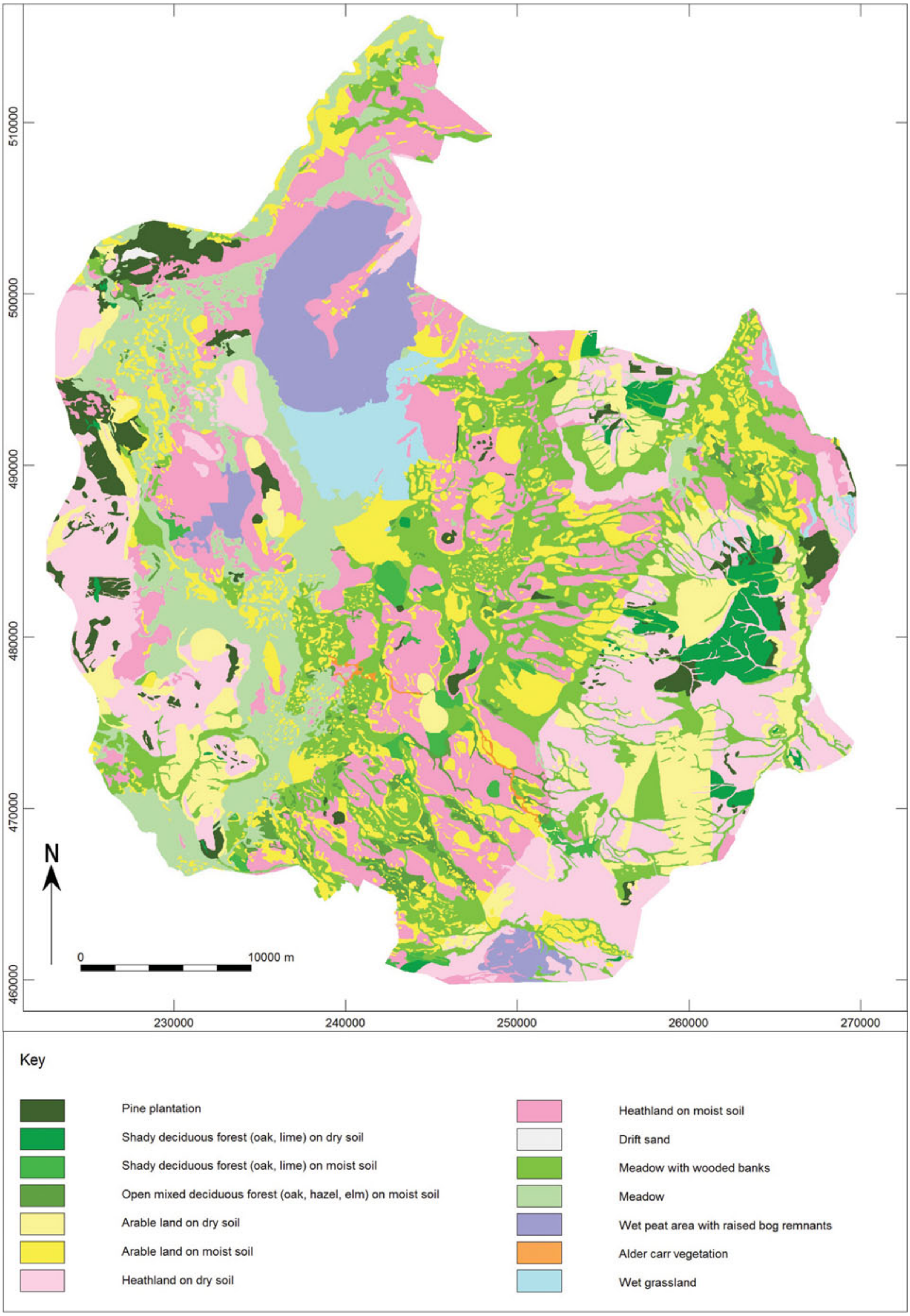

Fig. 10. Vegetation map of the Subatlantic period, around AD 1900. This map is based on historical maps. Modified after Bouman et al., 2013, fig. 4.12, p. 35.

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on sandy ridges along rivers such as the Dinkel (Bakker, 1982, 107–108; van Beek, 2009, 370–372). These areas are mainly mapped as shady deciduous forests on dry soils. Settlements did not have fixed locations, but shifted frequently. Unfortunately, many Neolithic settlement sites, and flint and stone axes cannot be dated precisely. With regard to site location, the majority can be divided in two groups. The first consists of sites found in relatively high places, such as the slopes of ice-pushed ridges. Here shady deciduous forests were probably present. At the tops of the ice-pushed ridges, which are shown mainly covered with pine forests, fewer sites occur. The second group consists of sites near watercourses and in low and moist areas. Here, site densities are low. Depending on soil conditions, deciduous forest, alder carr or birch carr occurred. As the exact spatio-temporal development of the Almeler Veen raised bog is unknown, its precise extension during this phase is uncertain. The cluster of axe finds along its southern edges may represent deliberate depositions in a paludifying environment.

Map 3 (Fig. 7A) reflects the vegetation in the Middle Bronze Age (1800–1100 BC), but the plotted archaeological sites again cover a longer time span. For example, many barrows (Lohof, 1991; van Beek, 2011) are probably older than 1500 BC. However, most cannot be dated precisely due to a lack of excavation data. As hardly any Middle Bronze Age settlement sites are known, these are not depicted. Much more information is available on the Late Bronze Age and Early Iron Age (1100–500 BC). Urnfields (collective burial sites) are especially numerous (Verlinde, 1987; van Beek & Louwen, 2013). Combined with various settlement sites and single stone and bronze objects, they probably offer a good impression of late prehistoric habitation patterns. Because of human activity increasing numbers of small-scale woodland openings appeared, especially on high and dry sandy soils used for settlements and arable fields (e.g. Groenewoudt et al., 2007; Bos & Zuidhoff, 2011). Barrow clusters are mainly found at (the higher parts of) ice-pushed ridges. As mentioned in the methodological section, the poor sandy soils in the environment of all barrows have all been denoted as heath-rich areas. Large parts of the Oldenzaal ice-pushed ridge appear to have been more heavily forested than the ice-pushed ridges of Markelo-Nijverdal and Ootmarsum, which were mainly covered with open deciduous forests. This is probably due to differences in both geology and habitation density (van Beek, 2011; van Beek & Louwen, 2013). Wet areas mapped as alder carr, birch carr and raised bogs were probably uninhabited. In some of these areas isolated (bronze) objects have been found.

Map 4 (Fig. 8A) represents the vegetation around AD 200. In the Dutch archaeological chronology this corresponds to the Middle Roman period (AD 70–270). Nevertheless, all Roman-period sites in Twente – which was never incorporated in the Roman Empire – are indicated. The small number of known sites can partly be explained by the relatively short time span they cover, compared to the previous maps. Furthermore, a change in settlement system occurred. The typical late prehistoric shifting settlements consisting of single farmsteads (van Beek, 2011) were gradually replaced by fixed, nucleated settlements (van Beek, 2009, 440–446; van der Velde, 2011; van Beek & Groenewoudt, 2013), therefore the total number of archaeologically traceable settlement sites decreased significantly. Most settlements were situated on large sandy ridges. These are partly mapped as open deciduous forests. Various pollen samples from archaeological contexts (mainly wells) show that open and half-open landscapes developed at intensively inhabited locations, especially during the Iron Age and Roman period (Groenewoudt et al., 2007). At the transition from the Roman period to the Early Middle Ages some pollen diagrams evidence forest regeneration on both dry and wet soils (van Geel et al., 1981; Bos & Zuidhoff, 2011). This trend might have been caused by decreased habitation density or a change in habitation pattern or subsistence economy.

The historical geographical data used to reconstruct habitation patterns around AD 1500 (Werkgroep Historische Kaart van Twente, 1991) do not cover northwest Twente. However, map 5 (Fig. 9A) demonstrates that information on other parts of the region is more detailed and less biased than the archaeological patterns used before. Twente was dotted with (mostly single) farmsteads. The ribbon-like strings of farms alongside ice-pushed ridges immediately catch the eye. Also, numerous sites are found alongside the Dinkel valley. The availability of arable land was the most important site location factor. The site distribution pattern reflects both the actual situation around AD 1500 and a palimpsest of site location choices. Many farms founded centuries earlier, from the 9th century onwards, had not shifted significantly (van Beek et al., 2014). Farmsteads are always found at the transition of sandy ridges to other landscape units, and therefore other vegetation types: heathland, grassland, open landscapes with dispersed shrubs or open deciduous forests. Homogeneous and nutrient-poor areas such as heathlands or open deciduous forests were hardly inhabited. The specific microregional setting of each farm probably influenced its subsistence economy, but evidence on this topic is very scant. Also, socio-political factors influencing site location should not be overlooked (cf. Evans, 2003, 3–5). In the final stages of the Middle Ages large-scale reclamations took place in the lower parts of the landscape. From the 14th century onwards buckweed (*Fagopyrum esculentum*) was cultivated on peaty soils. These soils were frequently burned to increase their fertility (Lenting, 1853). This led to large-scale destruction of the upper parts of peat profiles and the palynological information they contained.

No formal comparison to habitation patterns is made for the AD 1900 map (Fig. 10). These are clearly far less determined by environmental factors than in any of the phases discussed before.

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Conclusions

The main aim of this paper is to offer a new regional and diachronic perspective on the structure and development of the vegetation and habitation of one of the Low Countries' sandy regions. As site-based studies and microregional reconstructions so far have prevailed in archaeological research, there is a need to understand regional trends in order to place local changes in context. This wider perspective is often lost in commercial research, where studies are generally only small-scale and site-specific, with little to no regional context, which itself is frequently only derived from generalised patterns of regional change. Except for the 'youngest' one, the constructed vegetation maps do not offer exact 'snapshots' of the vegetation at specific moments in time. In reality, vegetation structure was endlessly more complex and dynamic than any map suggests. The maps can, however, serve as first-stage generalised models that predict regional trends, allow subsequent testing and place site-specific archaeological data in a wider context.

The main trends in the Late Glacial and Holocene vegetation development of Twente are similar to those found in neighbouring parts of northwest Europe (e.g. Munaut, 1967; Lang, 1994; Berglund et al., 1996). On closer inspection, however, no two regions are the same. In this context the term 'contingency' might be appropriate. Contingencies can be defined as 'unique, historical configurations of phenomena' (Dincauze, 2000, 22; citing Gould, 1986). In our study the spatio-temporal differences in vegetation development mainly originate from variations in elevation, soil and hydrology, combined with human activity. The landscape of Twente was increasingly influenced by humans. Especially since the Bronze Age human interferences had a more noticeable and permanent impact on vegetation. Besides vegetation changes, human activity was also reflected in drifting sands, soil degradation and acidification, erosion and sedimentation and so on. In turn, these landscape changes influenced vegetation. Different developments led to a great spatial variety in vegetation development, on different scale levels, and ultimately to the present-day mosaic of landscapes in Twente.

Within a northwest European context, this research mainly stands out for its spatio-temporal scale, the incorporation of data from different sampling contexts and their translation into evidence-based vegetation maps. The main focus was on regional trends and their correlation with contemporary archaeological data. However, the dataset has a far greater potential and can be used to answer additional questions. It could prove interesting, for example, to create several vegetation reconstructions on different scale levels and compare these to habitation patterns (cf. Groenewoudt et al., 2007, for a site level). All the palynological data used are registered in the Dutch National Pollen Database (Donders et al., 2010) and remain accessible.

This study demonstrates that large pollen datasets can be used to identify regional trends and changing vegetation cover, which in turn can be studied in relation to archaeological and historical patterns. The research method can be applied to other regions as well, provided some basic conditions are met. Obviously an adequate number of (preferably high-quality) palynological sources has to be available. In this study, the number of available sources greatly exceeded expectations. Various national institutions appeared to manage substantial bodies of relevant unpublished data, which were available for study. Not a single new pollen sample was taken. This indicates that the inventorying and integral analysis of 'old' data has a high research potential, provided that the data are used in a scientifically sound way and their limitations are acknowledged. Furthermore, information has to be available on the geomorphological development of the area under study, combined with detailed soil maps.

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Appendix 1. Overview of inventoried palynological sites in and near Twente. Sites may be recorded more than once if samples were analysed on different occasions or by different organisations. Only the most important literature sources are listed. Map numbers (last column): 1 = Younger Dryas, Late Palaeolithic; 2 = Atlantic period, Early/Middle Neolithic; 3 = Subboreal period, Middle Bronze Age; 4 = Subatlantic period, Roman period; 5 = Subatlantic period, Late Middle Ages.

No.	Site	Context	Year analysis	Organisation	Reference	Dating evidence	Used in map no. (see also Fig. 3)
1	Amstven (Germany)	Raised bog	1985	UVA	Kuhry, 1985	14C	
2	Azelo	Anthropogenic (well)	2006	BIAX		Arch.	4
3	Bathorner Diek (Germany)	Raised bog	1979	UM	Isenberg, 1979	14C	2, 3, 4
4	Beltrum	Anthropogenic (*plaggen* soil)	1960	StiBoKa		Arch.	
5	Bevermeer	Residual channel	1965	StiBoKa			
6	Denekamp-de Borchert I	Residual channel	c. 1981	UVA	van Geel et al., 1981	14C and Arch.	1, 2, 3, 4, 5
7	Borculo	Soil	1955	StiBoKa			1, 2
8	Borculo-Kerkmeijer	Humic or peat layer		RGD			
9	Borne-Zuid Esch	Anthropogenic (various features)	2005	BIAX		Arch.	4
10	Borne-Bornsche Maten	Anthropogenic (waterholes)	2009	BIAX		Arch.	
11	Zutphen-Bronsbergen	Residual channel		RGD			
12	Bruchterveld	Peat layer	1960	StiBoKa			2, 3, 5
13	Dalfsen Gerne Marke	Anthropogenic (well)	2006	BIAX		Arch.	
14	Dalmsholte-Gietmen	Peat layer	1952	StiBoKa			2, 3
15	Oldenzaal-de Hoesstie	Anthropogenic (wells)	2005	BIAX		Arch.	5
16	Rijssen-De Mors	Peat layer		UVA		14C	1, 2, 3
17	Denekamp-Klokkenberg	Residual channel	1971	UVA	van der Hammen & Bakker, 1971	14C and Arch.	2, 3
18	Derkswijk	Peat layer	1964	StiBoKa			
19	Didam-Aalsberg	Anthropogenic (wells, posthole)	1998	CHE		Arch.	
20	Didam-Kollenburg	Anthropogenic (wells)	2005	BIAX		Arch.	
21	Markelo-De Borkeld	Humic or peat layer	1953	StiBoKa			1
22	Dichteren	Peat layer	1959	StiBoKa			
23	Doetinchem-Wijnbergen	Anthropogenic (various features)	2006	BIAX		Arch.	
24	Drempt I	Peat layer	1965	StiBoKa			
25	Emmer Hooilanden	Humic or peat layer	1952	StiBoKa			
26	Engbertsdijksveen IA	Raised bog	1988	UVA	van der Molen & Hoekstra, 1988	14C	2, 3, 5
27	Engbertsdijksveen V	Raised bog	1984	UVA	Middeldorp, 1984	14C	2, 3, 4
28	Engbertsdijkveen I	Raised bog	1978	UVA	van Geel, 1978	14C	2, 3, 4
29	Engbertsdijkveen VII	Raised bog	1984	UVA	Dupont & Brenninkmeijer, 1984	14C	3

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Appendix 1. Continued.

No.	Site	Context	Year analysis	Organisation	Reference	Dating evidence	Used in map no. (see also Fig. 3)
30	Engbertsdijkveen XV	Raised bog	2003	UVA	Blaauw, 2003	14C	3
31	Epse-Olthof	Anthropogenic (wells)	2011	CHE		Arch.	
32	Gelselaar	Residual channel	1967	StiBoKa			3
33	Genders	Humic or peat layer	1963	StiBoKa			
34	Gildehauser Venn (Germany)	Raised bog	1979	UM	Isenberg, 1979	14C	4, 5
35	Hahnenmoor (Germany)	Raised bog	1986	UVA	Middeldorp, 1986	14C	
36	Hattemerbroek-Bedrijventerrein N.	Humic or peat layer	2007	BIAX		14C	
37	Hattemerbroek-Bedrijventerrein Z.	Anthropogenic (waterhole, burials)	2009	BIAX		Arch.	
38	s-Heerenberg-Bergse Wetering	Peat layer		RGD			
39	s-Heerenberg-Rondweg	Peat layer		RGD			
40	Heeten-de Telgen	Anthropogenic (wells)	2005	BIAX		Arch.	
41	Raalte-de Zegge	Anthropogenic (wells)	2005	BIAX		Arch.	
42	Heeten-Hordelman Oost	Anthropogenic (wells)	2005	BIAX		Arch.	
43	Hengelo-Stadhuis	Peat layer		RGD			3
44	Hoonhorst	Soil	1953	StiBoKa			
45	Huurner Veld	Raised bog	1953	StiBoKa			3
46	Huurner Veld	Raised bog	1943				1, 2
47	Klausheide (Germany)	Raised bog	1979	UM	Isenberg, 1979	14C	
48	Hummelo-Klein Pas	Residual channel		RGD			
49	Hummelo-Kruisberg III	Residual channel	1970	StiBoKa			
50	Laag Keppel	Peat layer	1967	RGD			
51	Laren-Dorpses	Anthropogenic (well, postholes)	2004	BIAX		Arch.	
52	Lathum A	Peat layer	1967	StiBoKa			
53	Lichtenvoorde	Anthropogenic	2007	BIAX		Arch.	3
54	Lochem-Ampsen	Residual channel	1999	UVA		14C	1, 3, 4, 5
55	Enter-Loolee	Residual channel		RGD			
56	Eibergen-Luttikholt	Peat layer	1963	StiBoKa			
57	Markelo-Moeraskalk	Peat layer		FUA			1
58	Markelo-Noordachteres	Anthropogenic (well)	2004	BIAX		Arch.	5
59	Markelo-Noordachteres	Anthropogenic (well)	2005	BIAX		Arch.	5
60	Marle	Peat layer		RGD			
61	De Steeg-Middachten	Peat layer		RGD			
62	IJpelo-Mokkelengoor I	Peat layer	1980	StiBoKa	van Geel et al., 1989	14C	1, 2

Appendix 1. Continued.

No.	Site	Context	Year analysis	Organisation	Reference	Dating evidence	Used in map no. (see also Fig. 3)
63	IJpelo-Mokkelengoor II	Peat layer	1980	StiBoKa	van Geel et al., 1989	14C	
64	Breklenkamp-New Dinkel Ch. 1	Residual channel	1971	UVA	van der Hammen & Wijmstra, 1971	14C	1, 2
65	Breklenkamp-New Dinkel Ch. 1	Residual channel	1971	UVA	van der Hammen & Wijmstra, 1971	14C	2
66	Nijverdal-Eversberg	Anthropogenic (various features)	2013	ADC	Gerrets et al., 2012	Arch.	3
67	Nijverdal-Regge	Residual channel	2012	ADC	Gerrets et al., 2012	14C	4, 5
68	Oldenzaal-Schoolstraat	Peat layer	2002	BIAX		Arch.	5
69	Oldenzaal St. Plechelmus	Anthropogenic (cesspit)	2005	BIAX		Arch.	5
70	Oldenzaal St. Plechelmus moat	Anthropogenic (moat)	2005	BIAX		Arch.	5
71	De Wieden-Schutsloot Olden Diek	Raised bog	1953	StiBoKa			
72	Zwolle-Poppenallee	Humic or peat layer	1952	StiBoKa			
73	Raalte-Raan	Anthropogenic (fossil cult. layer)	1998	BIAX		Arch.	
74	Raalte-Raan, profile	Anthropogenic (*plaggen* soil)	1998	BIAX		Arch.	
75	Raalte-Raan, profile II	Anthropogenic (*plaggen* soil)	1998	BIAX		Arch.	
76	Raalte-Raan	Anthropogenic (ditches)	1998	BIAX		Arch.	
77	Raalte-Raan	Peat layer	1998	BIAX		Arch.	
78	Diepenveen-Rande	Peat layer	1962	StiBoKa			
79	Gorssel-Ravenswaarden I	Residual channel	1969	StiBoKa			
80	Gorssel-Ravenswaarden II	Residual channel	1969	StiBoKa			
81	Gorssel-Ravenswaarden III	Residual channel	1969	StiBoKa			
82	Gorssel-Ravenswaarden IV	Residual channel	1969	StiBoKa			
83	Reest, upstream	Peat layer	1997	BIAX		14C	2, 3
84	Reest, midstream	Peat layer	1997	BIAX		14C	2, 3
85	Reest, downstream	Peat layer	1997	BIAX		14C	2, 3
86	Rekken II	Anthropogenic (*plaggen* soil)	1963	StiBoKa		Arch.	
87	Reutum	Peat layer		RGD			3
88	Rijssen-Enter	Humic or peat layer	1953	StiBoKa			
89	Etten-Rode Wetering	Peat layer	1967	StiBoKa			
90	Etten-Rode Wetering	Peat layer		RGD			
91	Rouveen	Humic or peat layer	1984	StiBoKa			
92	Saasveld	Peat layer		RGD			1, 3
93	Lemelerveld-Schanebroek I	Humic or peat layer	1952	StiBoKa			

Appendix 1. Continued.

No.	Site	Context	Year analysis	Organisation	Reference	Dating evidence	Used in map no. (see also Fig. 3)
94	Lemelerveld-Schanebroek II	Humic or peat layer	1952	StiBoKa			
95	Staphorst I	Humic or peat layer	1955	StiBoKa			
96	Staphorst II	Humic or peat layer	1955	StiBoKa			
97	Steenderen-Grote Beek	Peat layer		RGD			
98	Steenderen-Steenderdiek	Anthropogenic (wells)	2009	BIAX		Arch.	
99	Steenderen	Peat layer		RGD			
100	Stokkum-Stokkumerbroek	Peat layer	1967	RGD			2, 3, 4, 5
101	Süskensbrocksmoor (Germany)	Raised bog	1984	UM	Pott, 1984	14C	
102	Syenn Venn (Germany)	Raised bog	1979	UM	Isenberg, 1979		4, 5
103	Usselo	Peat layer	1989	UVA	van Geel et al., 1989	14C	1
104	Usselo-Rioolzuiveringsinstallatie	Peat layer		RGD			2
105	Vorden-Gassleuf	Peat layer		RGD			
106	Vragender Veen	Raised bog					
107	Wachtum-Noordes	Anthropogenic (waterhole, *plaggen* soil)	2000	BIAX		14C and Arch.	
108	Wapenveld	Peat layer		RGD			
109	Weerselo-Gammelke	Anthropogenic (barrow)	1973	CHE	Verlinde, 1973	Arch.	
110	Wehl	Anthropogenic (well)	2000	BIAX		Arch.	
111	Wehl-Wehlse Beek I-II	Peat layer	1967	StiBoKa			
112	Wielener Moor (Germany)	Raised bog	1979	UM	Isenberg, 1979		2, 3, 4, 5
113	Wietmarscher Moor (Germany)	Raised bog	1979	UM	Isenberg, 1979		
114	Zeddam-Vinkwijksche Broek	Peat layer		RGD			
115	Zelhem-'t Soerlant III	Anthropogenic (well)	2003	BIAX		Arch.	
116	Zelhem-Zelhemse Enk	Anthropogenic (various features)	2001	BIAX		Arch.	
117	Zieuwent	Soil	1953	StiBoKa			
118	Zuna-Zuna's Hooilanden	Residual channel	2008	CHE			2
119	Zutphen-IJsselflat	Peat layer		RGD			
120	Zutphen-Bronsbergen	Peat layer		RGD			
121	Zutphen-Looërenk	Anthropogenic (wells)	2003	BIAX		Arch.	
122	Zutphen-Looërenk	Anthropogenic (wells)	2004	BIAX		Arch.	
123	Zutphen-VI Ooijerhoek	Residual channel	2004	UVA	Bos et al., 2005b	14C	
124	Zwiep	Peat layer	1967	StiBoKa			1, 2, 5
125	Zwillbrocker Venn (Germany)	Raised bog	1969	UM	Burrichter, 1969	14C	

Abbreviations: UVA = University of Amsterdam; BIAX = BIAX Consult, Zaandam; UM = University of Münster, Germany; StiBoKa = former Foundation for Soil Mapping (Stichting voor BodemKartering); RGD = former National Geological Survey (Rijks Geologische Dienst); CHE = Cultural Heritage Agency of the Netherlands, Amstersfoort; FUA = Free University, Amsterdam.