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Reconstruction of the forest and land use history from Neolithic to the Present for the Westensee area, Schleswig-Holstein, Germany, using a multi-proxy approach

By

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To my daughter Mila

Моей дочери Миле

Abstract

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Key words

vegetation history, forest composition, multi-proxy analysis, pollen, charcoal, human impact, megalithic graves, Neolithic period, Bronze Age

This project focuses on the reconstruction of land use and forest history in the Westensee moraine region in Northern Germany. With a combination of palaeoecological investigations including archaeological and radiocarbon data, the main objective of this investigation was the identification of interactions between natural processes of woodland dynamics and human impact. A chronology for three pollen records was established from 31 ^{14}C AMS radiocarbon dates. Chronological modeling was estimated with Bayesian-statistics using OxCal 4.1.7, which was intended to provide radiocarbon calibration and statistical analysis of chronological information. In this manner, an exact chronology of woodland composition and changes of the vegetation under anthropogenic influence in the study area was to be both chronologically and spatially reconstructed.

Three palaeorecords indicate that different land use practices occurred in the area from the beginning of the Neolithic period. The presence of frequent forest fires between 4100 and 3600 cal yr BC is inferred from the Brunsrade mire archive (core MDK) and it was interpreted as a consequence of hunting practices of people during Mesolithic and Neolithic periods.

At Krähenberg (core KRM), a study site with five megalithic graves, the deciduous forests experienced a reduction in their canopy around 3500 cal yr BC, suggesting an increased human impact. This could be possibly associated with the construction of the megalithic graves located in vicinity. Following the period of anthropogenic activity, forest recovery occurred over a period of ca. 400 years. We assumed that the surrounding area of the megaliths was mainly covered by deciduous mixed forests during the Funnel Beaker Culture and the megaliths were not exposed in the landscape. Based upon a very low occurrence of anthropogenic indicators, it is assumed that the closed surrounding of the megalithic graves was not used during the Funnel Beaker Culture or solely used as a specialised ritual place around 3500 cal BC. During the Neolithic period the study site was isolated from settlements and arable fields. Although forest disturbance occurred during the Neolithic period, intense human impact associated with arable farming first commenced during the Bronze Age.

In contrast, the Lünsee pollen diagram (core LNS-1) suggests an onset of cereal cultivation around 3800 cal yr BC. Only few cerealia-type pollen grains were identified for the Early Neolithic, probably indicating small and local arable fields in the study area. The results of charcoal analyses lead to the conclusion that the frequent use of fire, and possibly local small forest clearing, had occurred on the area since the Early Neolithic, around 4100–4000 cal BC. The remarkably high value of *Fagus*- pollen around 2100 cal. B.C. and an increase in the number of charcoal signals in the pollen diagram can be interpreted as an association between establishment of common beech and anthropogenic activities. Most probably, common beech was already present in the area since the Neolithic period in rather small populations. However, a major presence of common beech in the area of Westensee is clearly detectable only from ca. AD 100.

The high intensity of human activities on the area was observed first around 1200 cal BC, during the Bronze Age, followed by a period characterised by slight human impact during the Pre-Roman and Roman Iron Age and very low human activity during the Migration Period. During the Early Middle Age/Slavic Period a significant forest disturbance due to an intense human activity and forest clearance were detected. The intensity of land use increased significantly in the Late Middle Ages, from about AD 1200.

Zusammenfassung

Rekonstruktion der Wald- und Landnutzungsgeschichte im Westensee-Gebiet (Schleswig-Holstein, Deutschland) vom Neolithikum bis in die Gegenwart unter Verwendung eines Multi-Proxy Ansatzes

Schlüsselwörter

Vegetationsgeschichte, Waldzusammensetzung, Multi-Proxy-Ansatz, Pollen, Holzkohle, menschlicher Einfluss, Megalithgräber, Neolithikum, Bronzezeit

Das vorliegende Projekt befasst sich mit der Rekonstruktion von Landnutzung und Waldgeschichte in der Jungmoränenlandschaft um den Westensee (Norddeutschland). Durch eine Kombination aus paläoökologischen Untersuchungen, der Betrachtung archäologischer Daten und Radiokarbondatierungen konnten Interaktionen zwischen natürlichen Prozessen der Walddynamik und menschlichem Einfluss genauer untersucht werden. Basierend auf 31 ^{14}C AMS-Radiokarbondatierungen wurde eine Chronologie von drei Pollenarchiven erstellt. Die chronologischen Modelle wurden mit Hilfe von Bayesischen Statistiken abgeschätzt, die mittels OxCal 4.1.7 berechnet wurden, einem Programm, dass der Kalibrierung von Radiokarbonmessungen und der statistischen Analyse chronologischer Daten dient. Auf diese Weise konnte im Untersuchungsgebiet eine genaue Chronologie der Waldentwicklung und Vegetationsveränderungen unter menschlichem Einfluss sowohl zeitlich als auch räumlich rekonstruiert werden.

Die drei paläoökologischen Archive belegen, dass seit Beginn des Neolithikums unterschiedliche Arten von Landnutzung im Gebiet auftraten. Das häufige Auftreten von Waldbränden zwischen 4100 cal. BC und 3600 cal. BC wurde durch einen Profil aus dem Brunsrade Moor (Profil MDK) belegt und als Folge der Jagdpraktiken mesolithischer und neolithischer Menschen gedeuten.

Am Krähenberg (Profil KRM), dem Untersuchungsstandort mit fünf Megalithgräbern, nahm die Dichte der Laubwälder um ca. 3500 cal BC ab, was als Zeichen sich verstärkenden menschlichen Einflusses gedeutet wird. Dieser kann wiederum mit der Errichtung der Megalithgräber der Gegend in Verbindung gebracht werden. Einer Zeitperiode menschlicher Aktivitäten folgte eine ca. 400 Jahre lange Phase der Waldregeneration. Wir vermuten, dass während der Trichterbecherkultur das Gebiet der Megalithgräber von dichtem Laubmischwald bedeckt war und diese in der Landschaft nicht exponiert waren. Ausgehend von einer sehr geringen Zahl an Siedlungszeigern im Pollendiagramm kann angenommen werden, dass während der Zeit der Trichterbecherkultur die unmittelbare Umgebung der Megalithgräber von Menschen nicht oder lediglich zu rituellen Zwecken um ca. 3500 cal. BC genutzt wurde. Während des Neolithikums war der Untersuchungsstandort frei von

Besiedlung und Ackerbau. Obwohl Waldstörung auch für das Neolithikum nachweisbar ist, setzte der intensive anthropogene Einfluss im Zusammenhang mit dem Ackerbau erst in der Bronzezeit ein.

Dagegen deutet das Pollendiagramm des Lünsees (Profil LNS-1) auf das Einsetzen des Getreideanbaus um 3800 cal. BC hin. Nur wenige Getreidepollenkörner wurden für das frühe Neolithikum entdeckt, was wahrscheinlich auf kleinflächige, nur lokal vorkommende Getreideanbau innerhalb des Untersuchungsgebietes hindeutet. Die Ergebnisse der Holzkohleanalysen führen zu der Annahme, dass die häufige Nutzung von Feuer, und möglicherweise die lokale und kleinflächige Durchführung von Waldrodungen seit dem frühen Neolithikum (4100-4000 cal BC) stattgefunden haben. Der bemerkenswert starke Anstieg der Buchen-Pollen gegen 2100 cal BC und die Erhöhung der Anzahl von Holzkohlefragmenten [zur selben Zeit] kann als eine enge Verbindung zwischen der Verbreitung der Buche und menschlichen Aktivitäten gedeutet werden. Höchstwahrscheinlich war die Buche seit dem Neolithikum in kleinen Populationen in der Landschaft vorhanden. Allerdings kann eine massive Präsenz der Buche im Gebiet „Westensee“ erst ab ca. AD 100 nachgewiesen werden.

Eine hohe Intensität menschlicher Aktivität in der Landschaft ist erst gegen 1200 cal BC, während der Bronzezeit nachweisbar, gefolgt von einer Zeitspanne geringerem menschlichen Einflusses während der vorrömischen und römischen Eisenzeit sowie sehr geringem menschlichen Einfluss während der Völkerwanderungszeit. Zeichen intensiver Waldnutzung durch menschliche Tätigkeit (Rodungen) sind ab dem Frühmittelalter/ der Slavenzeit im Gebiet präsent. Im Spätmittelalter, ab ca. AD 1200 stieg die Intensität der Landnutzung signifikant an.

Part I Introduction

Palaeoecology and human impact

Early important human interventions in the vegetation cover appear in northern and north-western Europe first during the Neolithic period around 4000 cal BC (e.g. Dörfler 2001; Hartz et al. 2000; Segerström 1990). Since then, the diversity of the forest composition is not longer dependent solely of abiotic site conditions and biotic interactions. Regarding the forest development and extension, anthropogenic factor began to play the important role.

Current woodlands in Europe, the forest structure and the biodiversity of forests are results of a long term dynamic process of land use in the past and present as well as continuous interactions between human and nature. Sustainable protection of modern landscape and its forest communities is only possible, if the earlier, comparable conditions can be considered. Knowledge about the spatial and temporal dynamics of forest communities in high resolution is of crucial importance (Reinbolz et al. 2008).

Particularly in Schleswig-Holstein in northern Germany, where the forest covered area is only about 10.3 % (Ministry of Agriculture, the Environment and Rural Areas Schleswig-Holstein 2011), knowledge of the historical woodlands development, including both human and natural roles (Robin et al. 2012), is highly relevant for the preservation and management of the land ecosystems and nature conservation (e.g., Bürgi and Stuber 2003; Kral 1991). Detailed and specific information of the individual history of each forest site is essential (Kelm 1994). In this way, the goals of sustainable forest use, nature protection in woodland and future development can be reached, based on sources of the history of the development of the forest ecosystems (Swetnam et al. 1999). Precise reconstruction of landscape history demands a structured combination of appropriate methods. Only an integrated approach embracing both the temporal and spatial dynamics of related structures and processes can provide sufficient understanding of complex correlations in the landscape development (Bork 2006). For a complete reconstruction of landscape, forest and settlement history, a multidisciplinary combination of different scientific approaches, methods and techniques is necessary.

Currently, the integrative approach of palaeoenvironmental landscape reconstruction would be applied (e.g., Dreibrodt et al. 2006; Emadodin et al. 2009; Heine and Niller 2003;

Kooistra and Kooistra 2003). Applications of several methods permit not only the analysis and understanding of the development of the forest and landscape in the past, but also a comparison to the current forest situation (Gaillard et al. 1992).

Nowadays, as the postglacial and Holocene vegetation history is basically known, the palaeoecological studies focus on the subjects of the effects of long term anthropogenic changes on the vegetation development (e.g., Behre 1988; Berglund 2011; Kalis et al., 2003; Stobbe 1996). For example, according to multidisciplinary studies of Bork et al. (2006; 2003; 1988) large scale reforestation in Middle Europe could be detected after the Roman Age by pedological methods, being confirmed by pollen analyses.

Palaeoenvironmental data have shown that small mires and lakes represent valuable archives for the reconstruction of vegetation changes in the surrounding area (e.g., Prentice 1985; Rickert 2006). Behre and Kučan (1986) verify local human impact on the vegetation cover by the increase of anthropogenic indicators in the pollen diagrams, like cultural plants, apophytes and anthropochorous plants. Wiethold and Lütjens (2001) investigated with pollen analysis the sediments of the lake Belauer See in Schleswig-Holstein and estimated at more than three centuries long period of human absence, no evidences for settlements and completely reforestation of the area at the end of the Roman Iron Age (see also Bork 2006).

But how intense was the human influence on the woodland during the prehistory and how important was the human impact on landscape and vegetation? This interrelationships between changes in forest composition and intensity of human pressure on the landscapes are not completely understood today (e.g. Gaillard et al. 2008; Smith et al. 2009).This knowledge is specially lacking for the Neolithic period (Allen 2000). Several recent studies show the organisational complexity of Neolithic landscapes with a differentiation into farming areas, settlements, and burial sites (e.g., Andersen, 2010; Sjörgren, 2010). Consequently Neolithic people began to transform the natural woodland to the cultural landscapes (Behre 2008; Lang 1994). Moreover, there is still intensive debate about the forest disturbances during the Neolithic as the results of farming or as a natural factor (Davies et al. 2005; Innes et al. 2003; O'Connell and Molloy 2001).

In this respect, palaeoecology, and in particular palynology, anthracology, and geochemical sediment analysis are powerful tools to investigate the relationships between vegetation and environmental changes at the landscape (e.g. Berglund et al. 2008; Nelle et al. 2010; Selig et al. 2007). Palaeoecological research of archaeological sites has a long tradition in European archaeological sciences (Groenman-Van Waateringe 2005; Van Zeist 1966). In Germany, investigations on Neolithic landscapes took place e.g. within the frame of the projects „Megalithic landscapes of the Altmark“ in Saxony-Anhalt, (Demnick et al. 2008), „Archäologisch-Ökologisches Zentrum“ (AÖZA) in Albersdorf (Dörfler 2001; Kelm 2001) and “Agriculture and Environment as Basis for Early Monumentality” (SPP 1400) in Schleswig-Holstein.

From c. 620 paleoecologically studied sites in Schleswig-Holstein, only 47 profiles include the Neolithic period, of which approximately 15 are ^{14}C-dated (Early Monumentality and Social Differentiation 2011). Therefore, it is important to reconstruct the vegetation history, in order to understand the environmental and cultural backgrounds of Neolithic societies.

Holocene vegetation history in Schleswig-Holstein

Early studies of reconstruction of the postglacial and Holocene vegetation development in Schleswig-Holstein should be remarked, especially palaeoecological contributions of Aletsee (1959) at “Großen Moor” nearby Dätgen, Averdieck (1978) at lake “ Großer Plöner See” as well as investigations of Schmitz (1951) at “Wakenitzmoor” nearby Lübeck.
Overbeck (1975) provides stratigraphic zonation of northwestern Germany and a complete overview over the stratigraphic and pollen analysis investigations in Schleswig-Holstein before 1975. In the following decades mostly late glacial series were studied (Usinger 1981; Usinger and Wolf 1982). Several studies in lake Belauer See (Wiethold, and Lütjens 2001; Wiethold 1998), lake Großer Eutiner See (Wieckowska et al. 2012), Großen Moor in Angeln (Wiethold 1997), as well as from the raised bog “Dosenmoor” (Glos 1998; Schuschan 1989) are known.

It should be considered, that the postglacial and Holocene vegetation history of Schleswig-Holstein was mainly performed from the large lakes and mires, and based on the pollen diagrams with high amount of the regional pollen grains in sediments. Studies of small lakes and mires allow much more detailed information about the development of local postglacial vegetation (Rickert 2006) and are also particularly suitable to track the human impact on the landscape with a high taxonomical and temporal resolution (Behre 1981).

Currently, only a few contributions to the vegetation history and human impact of Schleswig-Holstein based on the pollen data of small lakes and mires are known. Rickert

(2006) investigated the vegetation history of five small mires northern to Rendsburg and Kiel. Dörfler (2008) presented the pollen data from the kettle hole mire "Moor Kosel 10".
Wieckowska et al. (2011) investigated by palaeoenvironmental methods the Holocene sediments from kettle holes on two islands in the Trammer See and in the Lanker See in the Ostholstein lakeland area. Only two pollen diagrams from Averdieck (1983) and Usinger (unpubl.), closed to the research area Westensee, were available.

According to phases of forest regeneration and indications of human activity in pollen diagrams, the Late Holocene human impact in northern Germany and in Schleswig-Holstein must have been differed from region to region (Dörfler 2008) and cannot be interpreted as a synchronous event (e. g. Behre 2006; Nelle and Dörfler 2008; Zolitschka et al. 2003). Therefore, the better understanding of the human impact and the complexity of the environmental change needs a fine-resoluted palaeoecological reconstruction of local development of small selected areas (e.g. Rickert 2006; Rösch 1992), possibly related to archaeological material.

Research questions and outline of the thesis

The aim of the project is reconstructing forest history and changes of the landscape, since the Neolithic to present in the Westensee-moraine-region in Schleswig-Holstein, northern Germany. The study focuses on the reconstruction of land use, forest history and changes of the landscape under anthropogenic influence, since the Neolithic and after the establishment of the common beech (*Fagus sylvatica*) at a high spatial and temporal resolution. The investigations based upon a multi-disciplinary approach with a combination of palaeoecological methods and supported by an archaeological background.
The following questions were investigated:

- When did the first human impact occur in the study area?
- Can pollen analysis confirm and support the numerous prehistoric findings and archaeological data?
- When did *Fagus* appear in the study area and when did it become established as a dominant component in the forest community?

The thesis includes results of three investigated sites in the Westensee area, Schleswig-Holstein, northern Germany (**Part III, *Chapters 1-4***).

In ***Chapter 1*** we focus on the reconstruction of the vegetation of the kettle hole mire "Brunsrade Moor", forest fire history under anthropogenic influence and the assessment of its suitability for the landscape conservation. The investigated core MDK is represented on the vegetation development from the early Holocene. Local pollen and non-pollen palynomorphs, micro and macro charcoals as well as loss-on-ignition of peat composition were studied to infer changes in the palaeoenvironment. Moreover, analysis of the historical maps using GIS set the concrete date of the shrinkage of the forest-free mire area, as a result of anthropogenic influence from the last 250 years. Applications of these methods allow the analysis of the vegetation of the mire and landscape development in the past and a comparison to the current forest situation.

Chapters 2-3 focuses on the reconstruction of land use, forest history and changes of landscape, highlighting on the period of the Funnel Beaker Culture at the research site "Krähenberg". In these papers we investigated Neolithic human impact on landscapes related to megalithic structures. Remains of this era are the megalithic structures located significantly closed to the investigated mire. By combining the pollen record (core KRM) with AMS radiocarbon dating and the archaeological data, our attempts are to identify whether local woodland clearance took place as a result of the first human impact and the construction of the megalithic graves, and when that happened in the study area. Micro- and macro charcoal fragments were additionally counted to reflect events related to local fires, as well as loss-on-ignition analyses were also used to estimate the organic and carbonate content in these peat sediments. Another aim of these papers was to investigate the relations between the presence of megaliths and cereal cultivation as well as changes in forest composition at the study site during the Neolithic period and Bronze Age. The morphology of the area adjacent to the megalithic graves was investigated using airborne laser altimetry data (LiDAR). In addition, the geomagnetic prospection of the surrounding landscape was done. The magnetogram shows unknown anomalies and remains of the mound fill and of the stone kerbs surrounding to the grave. The analysis of known archaeological sites using GIS-technique provides information of the intensity and time periods of human activities in the study area.

In ***Chapter 4*** we examined the intensity of forest openness and human impact with high spatial and temporal resolution and discussed the immigration of *Fagus* in forest covered moraine area in northern Germany. The aim of this paper is to compare the interactions between natural processes of the woodland dynamics and human impact, remarking a highlight on periods of human pressure on the landscape. The lake Lünsee presents an undisturbed sediment record and, therefore, provides a complete pollen record covering the Late Glacial and Holocene periods. In addition, the sediment core LNS-1 provides a complete record of the immigration of *Fagus* in the adjacent area, a period that, due to intensive peat cutting, is barely possible to analyse in peat sequences from the investigated mires. The palaeoecological studies (pollen, micro and macro charcoal, loss-on-ignition analyses) were performed. High-resolution palaeoecological analysis allows reconstructing the local vegetation history and landscaping development especially during the Neolithic, Bronze Age, Iron Age and Migration Period.

Methodological approaches

Analyses of historical maps using GIS and digital technique

Historical records, maps and data could be used to know in depth the landscape development in the past. They settled an important base for the reconstruction of landscape and forest development (Kienast 1993). Pfister (1999) divide this historical data in two classes – material evidences in the landscape and written sources. Schwenköper (1999) had pointed the importance of historical maps for the interpretation of landscape and forest history. Besides the historical maps, especially produced before 19th century, which cannot describe so accurately like the current ones, they provide relevant information about the forest cover, location of settlement, land use and opened landscapes (Reinbolz et al. 2003). Under certain conditions, the statement about the occurrence of single tree species and its quantitative interpretation is possible (Sadovnik 2006). However, generally only analysis of historical maps without a complete study of datasets is not enough for a full interpretation of past landscape development (Kušar & Hočevar 2005). Walz (2002) explained the advanced possibilities of the analysis the georeferenced digital data for the interpretation of historical maps, which are neither nearly nor available by analysis of analog source material. Among others, the quantitative analyses of changes in the landscape structure and evaluation of land use, as well as natural and anthropogenic factors, are mentioned. Development of methods to the digital landscape visualization was mainly performed by Bossel (1996), Lindner (1998) and Duttmann et al. (2007). In Schleswig-Holstein a complete digital recording of historical and current maps was collected and published as 'Historical Atlas Schleswig-Holstein' (Ibs et al. 2004; Schwedler and Schwedler 2004).

High resolution aerial image and LiDAR analyses

New opportunities of the investigations of historical and modern landscapes are arising with the development of the digital techniques, geographical information systems and digital analyses of aerial images (Schmidt et al., 2010; Gabler-Mieck and Duttmann 2007). Highly resoluted airborne laser scanning (LiDAR-*Light Detection And Ranging*) analyses allow not only the digital analysis of forest-covered areas, but also the data of relicts of human activity, hidden under the forest canopy (e.g. Devereuxet al. 2005; Crow et al. 2007). The application of LiDAR data and aerial images allows a different view of landscape geomorphology in areas with dense forest cover (Doneus et al. 2008). Arnold (2011) investigated using LiDAR data Celtic Fields and other prehistoric field systems in historical forests of Schleswig-Holstein. LiDAR-based visualizing of forest development under human impact was investigated e.g. by Csaplovics (2009), Hoyle (2010), Crutchley and Crow (2009).

Pollen analysis

For the complete detailed reconstruction of the postglacial vegetation and forest history appeared the pollen analysis to be the most important method in the recent years (e.g., Litt 2000; Lowe and Walker 1997). The basic principles for the interpretation of palaeoenviromental data and Holocene forest history are given in the early works of Fibras (1952, 1949), Iversen (1956), Overbeck (1975), Straka (1970) and described depth in the recent investigations.

The arboreal/non-arboreal pollen ratio (AP/NAP), developed by Fibras (1934) was, for example, used as an important indicator of anthropogenic impact (Aaby 1989) settled a basis for the calculation of the grad of openness in the landscape (e.g. Tauber 1977, Janssen 1981, Gaillard et al. 1994). Moreover, the amount of 95% arboreal pollen in the diagrams can confirm completely woodland landscape (Aaby 1994), while the increase of non-arboreal pollen of more than 20 % can be seen as an evidence for the significant landscape opening due to anthropogenic influences.

Biozones, developed for the Central Europe by Fibras (1949) and for the North-West Germany by Overbeck (1975), as well the radiocarbon-based chronozones (Mangerud et al. 1982), were long time the important tools for the stratigraphic and temporal correlation of european pollen diagrams. Alternatively, the inductive interpretation of regional and local pollen assemblage-zones a well the cluster analysis of the pollen data has been proposed (Birks 1986).

Moreover, the effect of the lake (or bog) size and catchments area is of crucial importance. The experimental studies of Sugita (1999, 1994) have shown that larger bogs and lakes (with radius > 750m) with their extended pollen catchment area are appropriate for the reconstruction of regional vegetation history.

In contrast, analyses of sediments in small lakes and mires with 50–100m diameter provide information about the vegetation and land use history in their closest surroundings (e.g., Behre and Kučan 1986; Jacobson and Bradshaw 1981; Kühl 1998; Rickert 2006). Prentice (1985) assumes the amount of local pollen in the sediments of small lakes and bogs of less than 30 m in diameter to be of 80–100%.

The palynological investigation of lakes and mires sediments allows the reconstruction of the vegetation, climate and human impact in the past and a comparison with the modern landscape development. (e.g., Gaillard et al. 1994; Prentice et al. 1996). A model of the past forest ecosystem development based on pollen data has been presented (Bradshaw et al. 1999; Holmqvist and Bradshaw 2005). For this purpose, data of European Pollen Database – EPD and Scandinavian pollen database NORDMAP (Berglund 1991) were used. Moreover, fossil pollen assemblages are currently used for the modeling of past ecosystems- like LPJ-GUESS-model (Smith et al. 2001), for the quantitative reconstructions of past vegetation, like POLLSCAPE simulation model (Nielsen 2004) and "Landscape Reconstruction Algorithm" and it's two models, REVEALS and LOVE (Sugita 2007 a, b).

AMS- measurements

The precision and application of radio-carbon method since the work of Arnold and Libby (1951) is nowadays strongly improved by AMS (*accelerator mass spectrometry*). The accelerator mass spectrometry (AMS) system by the Leibniz-Laboratory for Radiometric Dating and Stable Isotope Research, University of Kiel is a 3-Million Volt Tandetron 4130 AMS system from High Voltage Engineering, designed for the analysis of ^{14}C. (Grootes et al. 2004). The distinguishing feature of AMS system the Leibniz-Laboratory is the simultaneous acceleration and measurement of all three carbon isotopes (^{12}C, ^{13}C, ^{14}C), made possible by a separator-recombinator magnet system (Nadeau et al. 2004).

The ^{14}C-AMS-chronologies for this investigation were calibrated as calendar year chronologies using 'CALIB rev 5.02' (Stuiver et al. 2005), IntCal09 calibration dataset (Reimer at al., 2009) and calculated using OxCal 4.1.7 program deposition model (Bronk Ramsey 2009; 2011). A chronological frame work was provided by pollen-stratigraphic correlations and by 31 ^{14}C AMS radiocarbon dating. As the ^{14}C calibration curve includes several plateaus and inversions, it is advantageous to roughly estimate the age-depth model for the core based on the pollen record, if possible, select a few samples expected avoid the wider plateaus for measurement (2-3). By using an incremental sampling strategy instead of sampling at regular intervals and measure all the samples at once, it is possible to improve the final chronology of a core (or sequence) obtained from a Bayesian model without increasing the number of ^{14}C results (Nadeau, personal communication).

The chronological modelling of the AMS measurements of the cores and creation of the age-depth modelling were estimated with Bayesian-statistics (OxCal 4.1.7), which was intended to provide radiocarbon calibration and statistical analysis of chronological information. In this way, an exact chronology of woodland composition and changes of the vegetation under anthropogenic influence in the study area was being reconstructed both chronologically and spatially.

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Part II Research area and sample sites

The research area lies in northern Germany within the community of Westensee, about 20 km south-west from Kiel, Schleswig-Holstein, Germany **(Fig. 1)**. The moraine landscape was formed by the last inland glaciation (Piotrowski 1991), spreading from the Baltic Sea almost to the middle of Schleswig-Holstein during the Weichselian Glaciation 115.000 to 13.000 years ago. This area is described as Westensee end moraine region (Meynen and Schmithüsen 1962).

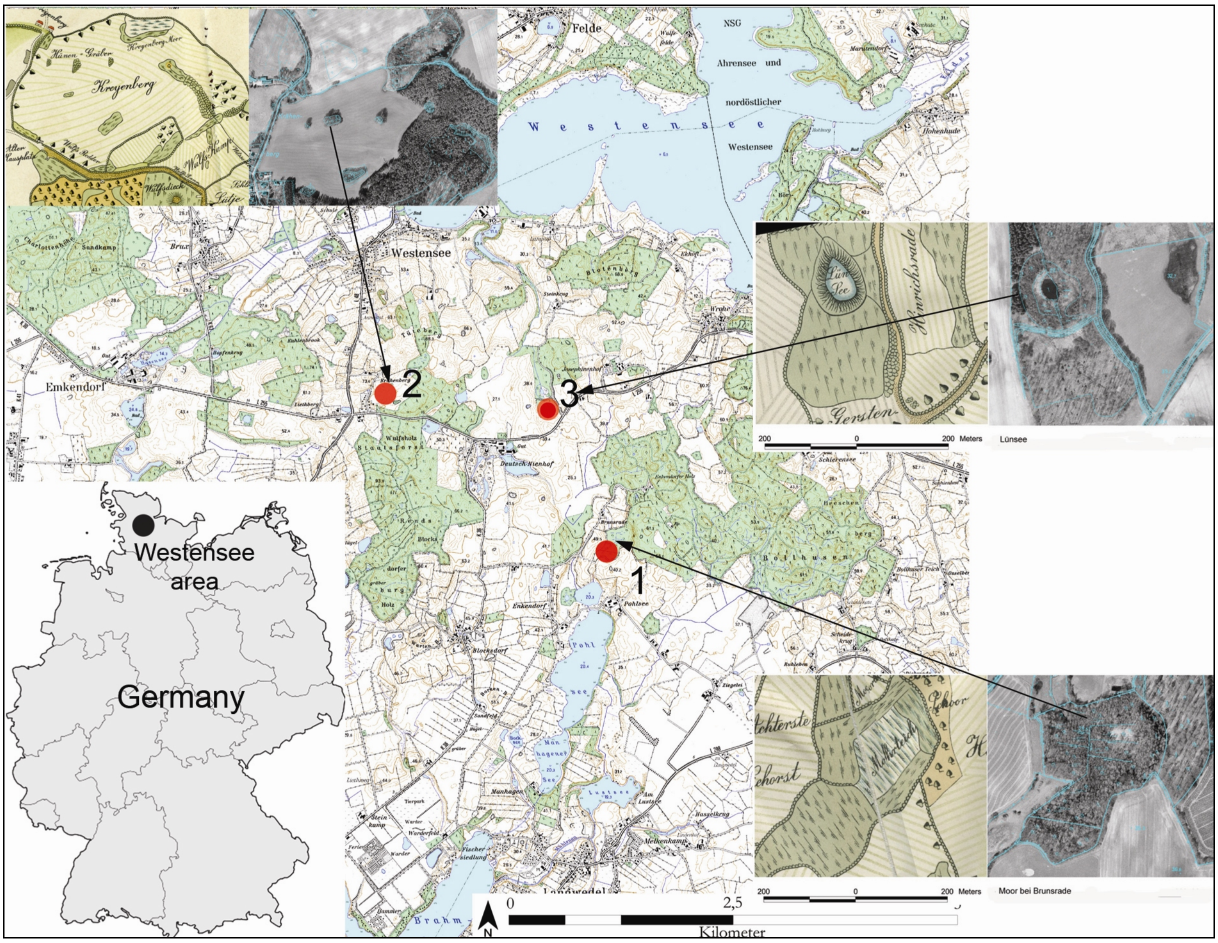

Figure 1. Map of localization of the investigation area Westensee. Pollen archives at the map TK 25 (LSO S-H ® 2007) and at the historical map of Reyer (1758): 1. Kettle hole mire "Brunsrade Moor"(core MDK); 2. Mire at "Krähenberg" (core KRM); 3. Lake "Lünsee" (core LNS-1).

The climate of the study area can be classified as temperate humid, with an average of 750–870 mm precipitation per year, an average January air temperature of 0.7 ºC and July temperature of 16.4 ºC (Deutscher Wetterdienst 2011). The long-term average temperature is 8.5 ºC. The dominating soils in the area in the area are cambisols on sand and clay or luvisols on boulder clay. These soils are subject to the constant alteration of water stagnation and dehydration (Kielmann 1996); in some areas due to considerable influence of slack water soils with stagnic properties have developed.

The earliest known human activities in the area of Westensee are represented from the Mesolithic period by findings of stone tools (State Archaeological Department Schleswig-Holstein-*unpublished data*). The archaeological findings and megalithic monuments are represented the visible evidence of human impact Neolithic, with a period of more intense human activity from the late Early Neolithic (~3500 cal. BC) until the early Middle Neolithic (~3300 – 3200 cal. BC) (Sadovnik et al. 2012). Archaeological studies of the early Bronze Age (Aner at al. 2005; Bauch 1988) show continuous and intensive human activities in the area. At the end of Bronze Age and in the following Iron Age, the climate conditions possibly suffered major changes (Bauch 1978). This was probably a reason to explain why German tribes left the area of East-Holstein during the Migration period. After the emigration of German population in the 5th century, the landscape around Westensee was once more completely covered by „Isarnho“, the „Iron Forest“. The colonization was mainly performed by Slavic tribes. In the early 13th century the area around Westensee was re-colonized by Saxons as a part of “East Colonization” movement. Thereby, the villages and manor houses were founded and a large scale forest clearance was performed (Ricker 1985).

The land of the historic manor Deutsch-Nienhof is first mentioned in documents from 1472 as a property of noble landlords von Ahlefeld, followed by Ranttau, von Jessen and von Hedemann-Heespen. The written history of the manor and agricultural activity on its lands covers a period of over 500 years. The manor’s library and the archive of more than 11.000 volumes were catalogued by the landlord and historian Paul von Hedemann-Heespen (1862-1937) and thus is one of the most extensive collections of land use documents in Schleswig-Holstein (Schmidt 1993). A remarkable work of von Hedemann-Heespen should be also mentioned. In his book “Geschichte der adeligen Güter Deutsch-Nienhof und Pohlsee“ (1906) he studied landscape and forest development from Medieval to begin of 19th century in the area of Westensee.

Recent and historical woodland development in the area of Westensee was a topic of the work of Rothenhöfer (1997) and Dittrich and Lüdemann (1997). These authors studied the development of forested areas around Westensee between 1796 and 1993. Seltz (1997) regarded cultural and geographical aspects of the landscape development in the area.

Analyses of the current forest use are provided in the work of Menke (2000). Sadovnik (2006) focused on these forest sites, which could be classified as ancient woods, continuously existed during several centuries in common forest areas. These ancient woodlands (u. a. Wulf 2004, Härdtle 1994) were studied by methods of vegetation ecology, with analysis of structural and biological diversity of forests. To detect the historical woodland areas several historical maps were used. GIS- technique allows to the calculation and visualization of the forest areas. Using this technique, current location of historical woodlands was compared with contemporary forest situation.

Currently, woodlands are dominated by beech (*Fagus sylvatica* L.) or planted conifers. The forests are extended along the broad-leaf forest domain, with the dominant common beech (Galio-odorati-Fagetum) with oak, ash, maple and elm as subdominant tree species (Härdtle et al. 2008; Härdtle 1995). The common beech forests occupy 35% of the entire forest area. The woodland area is separated from agricultural fields by hedge rows. Ancient woodlands could also be found in the study area. These sites, continuously covered by woodland for several centuries, are of a particular relevance for nature conservation and forest management. The study area includes six large forests: "*Bruxer Holz*" in the west, "*Felder Holz*" in northwest, south to Westensee and south-west of manor Deutsch-Nienhof, all close to each other and located near to the forests of Tütenberg, "*Wulfsholz*" and "*Blocksdorfer Holz*". From east side from the manor Deutsch-Nienhof the forest "*Enkendorfer Holz*" is found. The next forest area is over "*Bollhusen*", connected to the forest areas "*Am Lustigen Bruder*" and forest at Blotenberg.

Land depressions contain a multitude of kettle holes which have either been transformed into lakes or developed into very small mires, these are known as kettle hole mires (Dierssen 2005). Due to the usually continuous deposition of sediments, these old, small (1-8 ha) mires are especially valuable for a high-resolution pollen analytical reconstruction of local vegetation and landscape history. Large mires and lakes with extended pollen catchments area, allow the reconstruction of vegetation history of the entire region. In contrast, the sediments of small mires and lakes allow to become precise information about the vegetation of their closed surrounding (e.g., Jacobson and Bradshaw 1981; Rickert 2006). By the combination of the results from small and tiny mires (reconstruction of local vegetation) and lakes (reconstruction of regional vegetation), the variety of the composition of vegetation in the area can be inferred. Based upon this principle, the selection of study sites for the actual project was done.

Three coring operations were sufficient to record the quantitative data of the local vegetation, as well as the quantitative landscape reconstruction of the whole area. The investigated sites are located approximately 2-3 km from each other and thus especially valuable for a high-resolution reconstruction of local vegetation and landscape history.

Brunsrade Moor

The kettle hole mire 'Brunsrade Moor' (54°14′41.08″N, 9°55′17.12″E, 26m a.s.l.) covers an area of 6.45 ha, of which, 0.21 ha is forest-free mire surface area (**Fig. 2**).

Figure 2: General view of the kettle hole mire 'Brunsrade Moor' (study site MDK)

Alder (*Alnus glutinosa*) and birch (*Betula pubescens*) carr surrounding the mire. To the north-east, the area is bordered by the woodland area Bookschur (Robin et al. 2012) a 160-year old beech forest. The Brunsrade Moor has characteristics of transition mire in closed woodland area, disturbed in 17th century by drainage and peat cutting along the edges of the mire (von Hedemann-Heespen, 1906). The hummocks are mostly covered with dominating purple moorgrass (*Molinia caerulea*) and heather (*Calluna vulagris*). The edge of the mire is covered with an alder swamp with high amount of deadwood.

Krähenberger Moor

The 3.45 ha mire of Krähenberg (54°15'40.15" N, 9°54'10.05"E, 63m a.s.l.) is surrounded by raps fields and planted conifers **(Fig. 3).** In the 18th century, the mire was partly used for peat cutting. Currently the mire vegetation consists predominantly of Cottongrass (*Eriophorum vaginatum*), sedges (*Carex spp.*) and *Sphagnum*-moos. The investigated mire is located in the immediate neighbourhood (ca.100m) of the five megalithic graves of the Funnel Beaker Culture (Sprockhoff 1966). The megalithic graves at the top of Krähenberg and the area adjacent to the graves were additionally investigated using geomagnetic surveys (Sadovnik et al. 2010).

Figure 3: Aerial image of the study site Krähenberg with megalithic graves 164 – 166 Sprockhoff (1966) and the coring location of the mire at Krähenberg (Foto: E. Halbwidl, Schleswig)

Lünsee Lake

The small lake Lünsee (56°15'33.58" N, 9°55'29.70"E, 26m a.s.l.) is well preserved and hydrologically intact, located in the Westensee watershed (Environmental Atlas of the Land Schleswig-Holstein 2010). It is approximately 100 m in diameter, covers an area of 0.8 ha, arose within a former dead-ice kettle hole (**Fig. 4**).

Figure 4: General view of the lake "Lünsee", study site LNS (Foto : O. Nelle)

The maximum water depth is currently about 0.5m The Lünsee Lake has no major inflow and one major outflow, which were partitioned off by a dam in historical time. In the 18th century the lake and surrounding swamp was separated from agricultural areas by ditches. Probably, the willow carr contributed to the colonisation of the open water after the dam construction. Currently, reed (*Phragmites australis*) and willow (*Salix sp.*) carr are still present at the surroundings. The upland vegetation is characterized by alder (*Alnus glutinosa*), hasel (*Corylus avellana*) and old-growth common beech (*Fagus sylvatica*) in the subcanopy.

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Part III Investigations

Chapter 1

Palaeoenvironmental investigation of the kettle hole mire 'Brunsrade Moor' in Schleswig-Holstein, northern Germany, contributing to a sustainable landscape management

Mykola Sadovnik, Vincent Robin and Oliver Nelle

Manuscript

Introduction

Kettle hole mires emerge under the influence of lateral water flow and originate from a swamp or a terrestrialisation mire (Eigner and Schmatzler 1991). They are mostly small (1–8 ha) and evolve in kettle-shaped depressions (Timmermann and Succow 2001). Under an oceanic-humid climate kettle hole mires can further develop into raised bogs. In Schleswig-Holstein in Northern Germany they developed after the last Weichselian glaciation when blocks of ice were trapped and thawed in land depressions (Dierssen 2005). Old kettle hole mires have spongy, highly water-saturated peat up to 10 m thick and their surface is characterised by hummock-and-hollow structures (Couwenberg et al. 2001; Hutter et al. 1997). Due to a continuous deposition of sediments and peat growth, respectively, these old mires are suitable for reconstruction of post-glacial vegetation development. In comparison to investigations of larger mires which have a large pollen catchment area and thus allow the reconstruction of the vegetation history on a regional scale, the profiles of small mires enable the drawing of very precise conclusions about the local vegetation (Behre and Kučan 1986; Jacobson and Bradshaw 1981; Rickert 2006). Investigation of a number of kettle hole mires provides the possibility for a very accurate reconstruction of the local forest and settlement history as well as the anthropogenic influence over time, using the palaeoenvironmental data (Lindbladh et al. 2007). Consequently, the smallest mires which survived extensive use and drainage over hundreds of years are especially valuable both for high-resolution characterisation of local environmental history and landscape development. While comprehensive research has been performed on vegetation and evolution history of almost completely meliorated and drained mires in northern Germany (Glos 1998; Overbeck 1975; Wieckowska et al. 2012; Wiethold 1998) only a few pollen analytical investigations in local or extra-local scale have been carried out in the young moraine area of Schleswig-Holstein (Rickert 2006; Wieckowska et al. 2011). With a multitude of small kettle hole mires and lakes, the area offers a high potential for the reconstruction of vegetation dynamics and human activity on a very fine scale.

In this paper, we report results of a palaeoenvironmental investigation of a kettle hole mire 'Brunsrade Moor' in the well-wooded Westensee young moraine area in Schleswig-Holstein, northern Germany. The study focussed on the reconstruction of the mire vegetation, revealing its history under anthropogenic influence, and the assessment of its suitability for landscape conservation. Pollen analysis, micro- and macrocharcoal quantification as well as loss-on-ignition of peat were studied to infer anthropogenic changes in the palaeoenvironment of the mire since the Early Neolithic. GIS-analysis of historical maps as well as current vegetation analysis were used to determine the results of anthropogenic influence from the Modern Period.

Material and methods

Investigated site

The research site 'Brunsrade Moor' lies within the Westensee Nature Park of the East Hill Land in Schleswig-Holstein federal state, northern Germany. The moraine landscape was formed by the last inland glaciations, with a multitude of lakes and kettle hole mires (Dierssen 2005). The well-wooded area includes six large forests, dominated by beech (*Fagus sylvatica* L.) with oak, ash, maple and elm as subdominant tree species or planted conifers. The forests are extended along the broad-leaf forest domain, with the 35% dominant beech of the entire forest area. Ancient woodlands could also be found in the study area (Sadovnik 2006). These sites, continuously covered by woodland for several centuries, are of a particular relevance for nature conservation and forest management.

The kettle hole mire 'Brunsrade Moor' (54°14'41.08''N, 9°55'17.12''E, 26m a.s.l.) covers an area 6.45 ha, of which, 0.21 ha, is forest-free mire surface, and 6.24 ha alder (*Alnus glutinosa*) and birch (*Betula pubescens*) carr surrounding the mire **(Fig. 1)**.

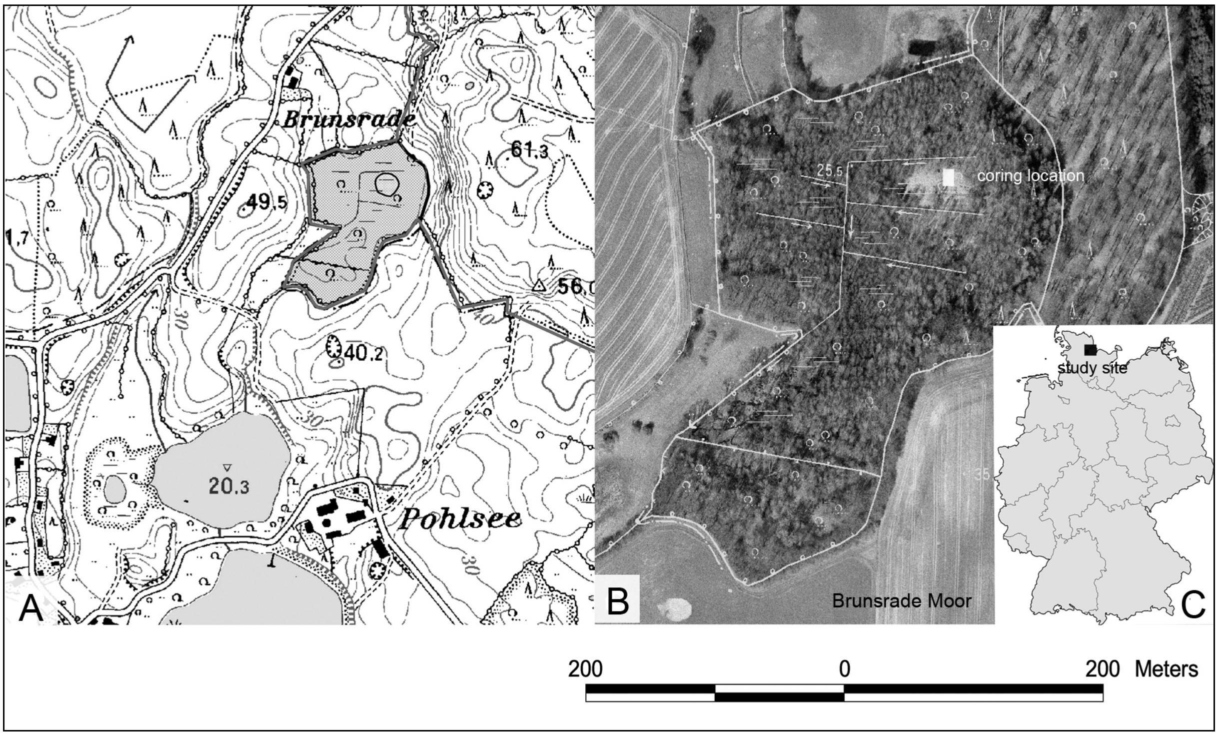

Figure 1. A: map of the kettle hole mire ’Brunsrade Moor‘. **B**: Coring location, the drainage ditches are clearly visible. Map source: topographic maps DTK 5 and ATKIS® Digital Orthophotos DOP 5 (Land Surveying Office Schleswig-Holstein® 2005) **C:** Location of the study site within Germany

To the north-east, the area is bordered by the forest site Bookschur (Robin et al. 2011), a 160-year old beech forest. The other boarders of the mire are separated from agricultural areas by hedges. The site is located in the Pohlsee Lake watershed (Environmental Atlas of the Land Schleswig-Holstein 2012). It is protected by law according to the §15 LNatSchG (Law on Protection of Nature of the Land Schleswig-Holstein) and is maintained by the forest management of the historical manor Deutsch-Nienhof. In the Modern Period, the drainage ditches were dug in the forest site Moordiek (Moorteich) in 1740 (Hedemann-Heespen 1906). Simultaneously, peat cutting was started at the edge of the mire, with the cuts being up to 6 feet (approximately 2 m) deep. Currently, the drainage ditches are well recognizable both on the topographic map TK 25, 1725 Westensee, and on the digital ortophoto DOP 5, (Land Surveying Office Schleswig-Holstein® 2005). During the field survey, residual peat cuts could be found at the edges, but not in the centre of the mire.

Stratigraphy and radiocarbon calibration

The coring was performed in October 2006 using a high-precision rod-operated Usinger piston corer (Mingram et al. 2007). The 5.55m core MDK was obtained from the centre of the kettle hole mire. The extracted undisturbed 1m cores were 80 and 55 mm in diameter. Stratigraphic features were recorded in the field. Refined stratigraphical analysis, including macro remains analysis of selected samples, was carried out in the pollen analytical laboratory of the Institute for Ecosystem Research, University of Kiel.

Nine ^{14}C AMS measurements were provided by the Leibniz-Laboratory for Radiometric Dating and Stable Isotope Research, University of Kiel (Grootes et al. 2004). Peat samples were checked under the microscope and an appropriate amount of material was selected for dating. Selected material was then extracted with 1 % HCl, 1 % NaOH at 60°C and again 1 % HCl alkali residue. The combustion to CO_2 was performed in a closed quartz tube together with CuO and silver wool at 900°C. The sample CO_2 was reduced at 600°C with H_2 over about 2 mg of Fe powder as catalyst, and the resulting carbon/iron mixture was pressed into a pellet in the target holder. Radiocarbon ^{14}C ages were calculated using the procedure of Stuiver and Polach (1977), with a $\delta^{13}C$ correction for isotopic fractionation based on the $^{13}C/^{12}C$ ratio measured by the AMS-system simultaneously with the $^{14}C/^{12}C$ ratio. The results of calibration were used for the calculation of age-depth model using OxCal v4.1.7 (Bronk Ramsey 2010; 2009), data set IntCal09 (Reimer et al. 2009). All dates are expressed as cal BC/AD.

<u>Pollen, charcoal and loss-on-ignition analyses</u>

For palynological analysis, 60 samples (1 cm^3) were taken. The mean sampling interval for the complete Holocene was 16 cm, for the Neolithic period / Bronze Age 2 cm. Samples were processed following standard laboratory techniques (Fægri and Iversen 1989), and microscopically analysed with 400x and 1000x magnification with a Leitz Diaplan light microscope by using the pollen reference collection of the Palaeoecology Research Group at the Institute for Ecosystem Research, University of Kiel. Pollen identification followed standard methods (Beug 2004; Moore et al. 1991). The percentage pollen diagram was constructed using the programs TILIA and TGView© (Grimm2004, 1994).

Percentage calculations of arboreal pollen, cereals, herbs, shrubs and anthropogenic indicators were based on the terrestrial pollen sum. A minimum of 500 arboreal pollen grains incl. *Corylus* were counted in each sample. The pollen diagram was composed as follows, from left to right: tree taxa indicating long distant pollen transport pine (*Pinus)*,

trees and shrubs of the local and regional vegetation, plants of the heath family (Ericales), upland herbs, Cereal pollen type, anthropogenic indicators, cryptogams, wetland and aquatic plants, non-pollen palynomorphs (NPP) and micro charcoal fragments. Microscopic charcoal particles (>10 µm) were counted on the same slides as pollen and calculated together with pollen based on the total pollen sum. Microscopic charcoal concentration (no.cm^{-3}) was calculated as a ratio to *Lycopodium* marker spore (Stockmarr, 1971).
Macroscopic charcoal particles (>200 µm) were quantified in concentration (mm^2cm^{-3}) and flux (i.e. accumulation rates per cm per year) (Mooney and Tinner, 2011). From every longitudinal cm of the core sequence, 5 cm^3 of material was sampled (Millspaugh and Whitlock 1995) and sieved gently through a 200 µm mesh size. The fraction resulting from the sieving was sorted under a stereo lens (x10 to 110). The content of every sample was quantified using digital measurement on the photos of the petri-dish taken with the same camera setting (Mooney and Black, 2003; Mooney and Radford 2001). The number of charcoal particles and their surface area was detrained based on the black/white contrast using the software Scion Image 4.0. Once the concentration and accumulation rate had been calculated, macro charcoal peaks, corresponding to local fire events, were identified (Higuera 2009; Higuera et al., 2010). Loss-on-ignition analysis was performed with 2 cm interval (3 cm^3 samples), according to the method described by Heiri et al. (2001). By method of Dean (1999), the content of organic matter and carbonate minerals in peat sediments was estimated.

Vegetation analysis

The vegetation analysis of the site was performed according to the method described by Braun-Blanquet (1964).Vascular plants were classified in accordance with nomenclature of Schmeil and Fitschen (2003). Mosses were classified in accordance with nomenclature of Jahns (1995). Vegetation surveys were performed using the GPS-device GARMIN® MAP 76.

Historical maps and geographical information systems

In order to study the mire development and the shrinkage of the open mire area in the course of the last 250 years, two historical maps were analysed. Historical maps were acquired in the archive of the manor Deutsch-Nienhof. The 'Map of the deforestation and reforestation and of the progressive enlargement of the manor lands of Deutsch-Nienhof' at a scale of 1:25.000 was drawn based on the map of the Prussian Royal Land Survey (1877) by von Hedemann-Heespen (1906). The map of manor lands Deutsch-Nienhof at a scale of 1:8.400 was drawn by the land surveyor P. Reyer in 1758. The latter provides very precise portrayal of the treeless mire area. Digital topographic maps at a scale of 1:5.000 DTK 5 and ATKIS® Digital Orthophotos DOP 5 at a scale of 1:5.000 (Land Surveying Office Schleswig-Holstein® 2005) served as geobasis data. Further processing of the mapping data was performed using ArcView® 3.2 (ESRI). This GIS-software was applied to precisely position the objects of investigation on digital maps, to calculate areas of the sites and to digitalise and georeference the historical maps.

Results and discussion

Stratigraphy and chronology

The uppermost layer of the sediment core (0.20–0.67m) was mainly characterised by strongly to moderately decomposed peat, composed of the remains of *Carex*, *Eriophorum* and *Sphagnum* (**Fig. 2**). This layer is interrupted by a layer of light brown, moderately decomposed peat. A strongly mineralized peat layer at a depth of 0.33 m confirms that the mire was drained. Homogeneous sedge-*Sphagnum* peat layers are found from 0.67m to 3.60m, with *Menyanthes* seeds around 3.20m and remains of *Bryopsida* around 2.45m and 3.32m. Very compacted sedge peat containing fragments of wood occurs from 3.62m to 4.20m. From 4.20m to 4.47m, a layer of light to dark brown gyttja is present. The lowermost layer of the core (4.47–5.55m) is characterised by minerogenic sediments which are interrupted by another layer of organic gyttja from 4.99m to 5.20m. The occurrence of layers of clay and gyttja between 4.20 m and 4.99 m indicate that temporal lake conditions prevailed in the basin due to a higher water level.

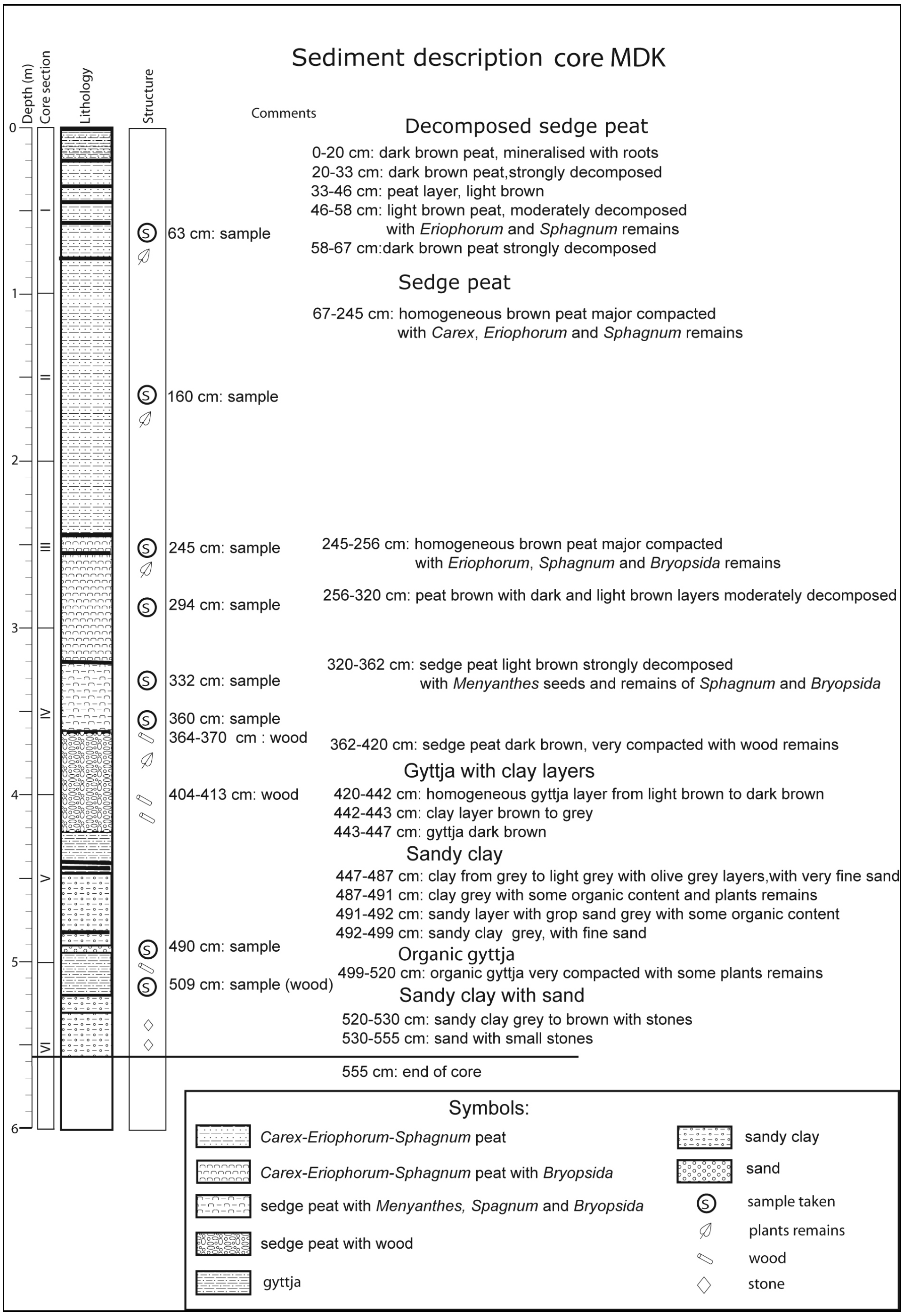

Figure 2. Sediment description of the core MDK 0.20–5.55m

Chronology

The chronology of the core sequence was based on nine ^{14}C-AMS measurements (**Table 1**). The chronological modelling of the AMS-measurements of the core MDK and an age-depth model were estimated with Bayesian-statistics using OxCal 4.1.7. (**Fig. 3**) The model included the period between approx. 11200 cal BC and AD 1840.

Table 1. AMS-^{14}C dates from the core MDK (Leibniz-Laboratory for Radiometric Dating and Stable Isotope Research, University of Kiel). 2σ calibrated with OxCal 4.1.7 (Bronk-Ramsey, 2010)

Lab. ID	Depth (cm)	Dated material	Radiocarbon age (BP)	Age cal BC/AD–2σ
KIA38777	60	plant remains	1160 ± 29	AD 778–968
KIA39173	68	peat	4396 ± 26	3091–2923 BC
KIA43923	80	peat	4971 ± 30	3893–3660 BC
KIA43924	90	plant remains	4926 ± 41	3783–3643 BC
KIA39172	106	peat	5044 ± 30	3953–3767 BC
KIA43925	203	wood	6368 ± 32	5468–5300 BC
KIA43926	295	peat	7157 ± 39	6084–5926 BC
KIA43927	410	peat	9568 ± 40	9123–8786 BC
KIA43928	510	wood	11322 ± 43	11331–11164 BC

However, strongly mineralized peat layers at the 0.62m depth and sequence calibration of AMS-data indicated extremely low accumulation rate of 1 cm/453yrs. between 0.60m and 0.67m. This suggests a *Hiatus* from around 0.62m depth. Therefore the uppermost layer only represents the periods from Early Middle Age/Slavic Period (AD 720–1143 cal). Upper layers of the core were caused by decomposition after peat cutting and mire drainage.

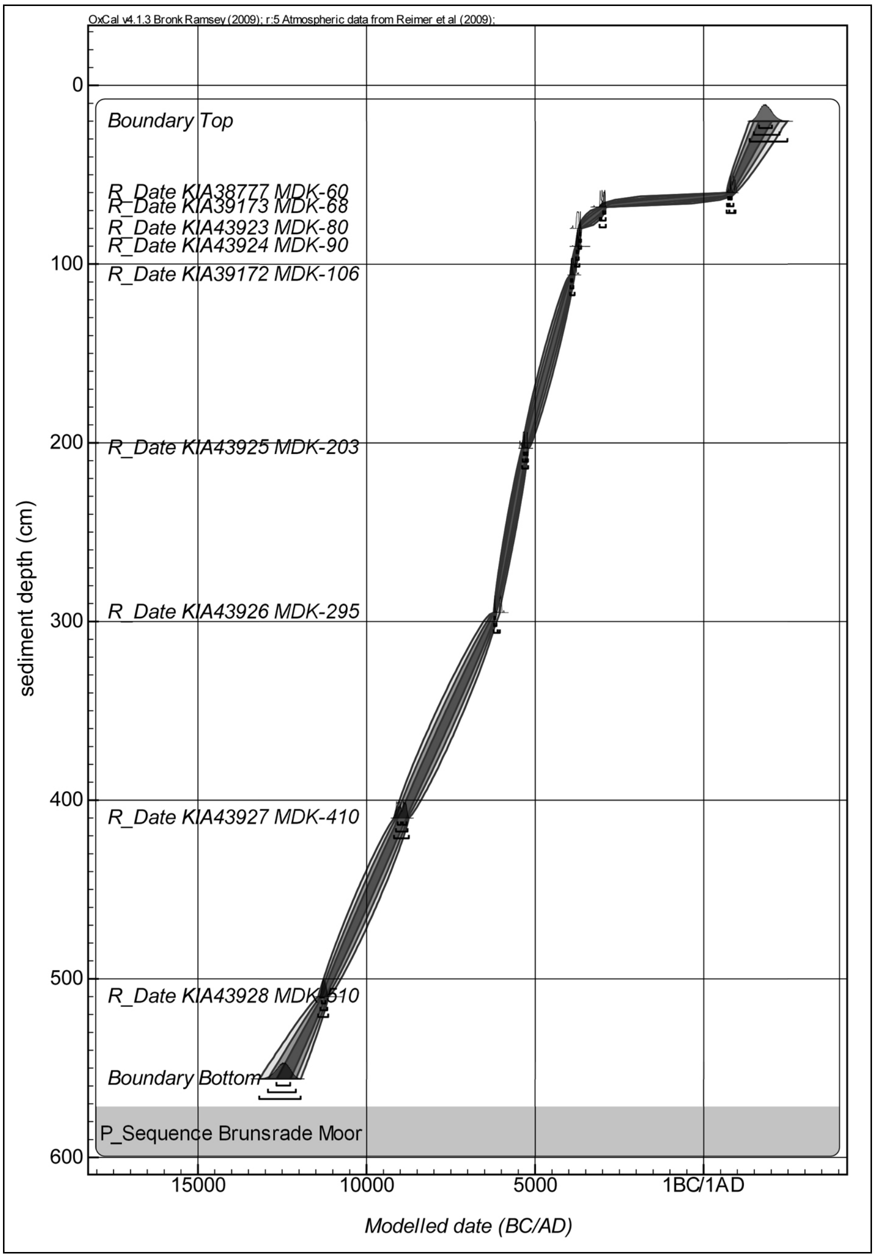

Figure 3. Age-depth model for the core MDK 0.20–5.10m (OxCal, Bronk Ramsey, 2010; IntCal09, Reimer et al. 2009)

Pollen analysis, charcoal analysis, loss-on-ignition

The simplified pollen diagram MDK (**Fig. 4)** was divided into nine local pollen assemblage zones (LPAZ) (Birks 1986), representing the post-glacial and Holocene vegetation history from the surrounding area of the mire. Median ages of the zone boundaries and samples ages were modelled using OxCal sedimentation plot based on the nine ^{14}C AMS measurements.

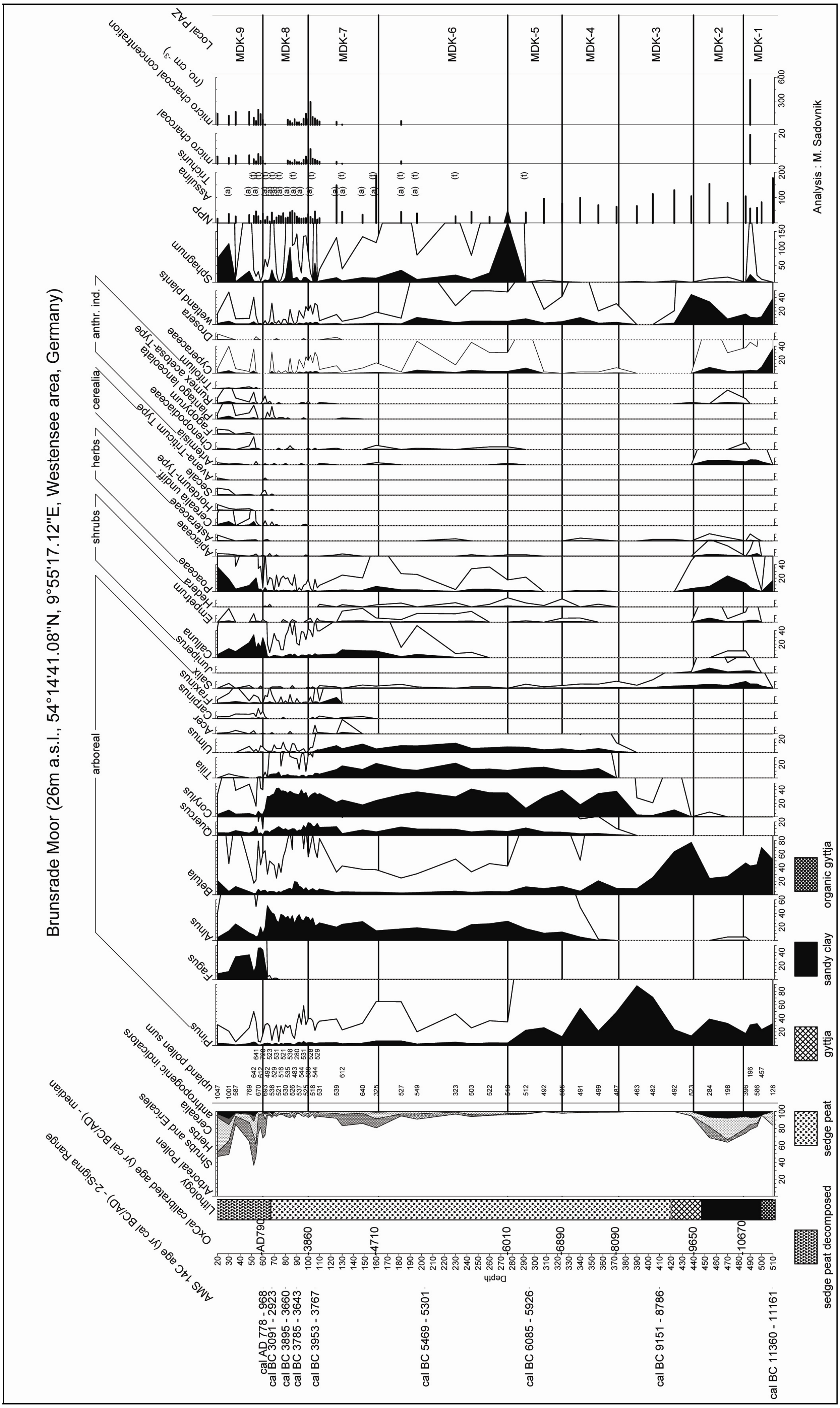

Figure 4. Percentage pollen diagram with selected taxa of the core MDK 0.20–5.10 m. Values refer to the upland pollen sum. White curves are exaggerated by 10, LPAZ, local pollen assemblage zone

The earliest known period of human activities in the area during the change from the Mesolithic culture of hunters and gatherers to Neolithic economic systems around 4100 cal BC (Behre 2008) is given in detail in **Fig. 5**. The results of macrocharcoal analysis, as well as loss-on ignition analysis are presented in **Fig. 6**.

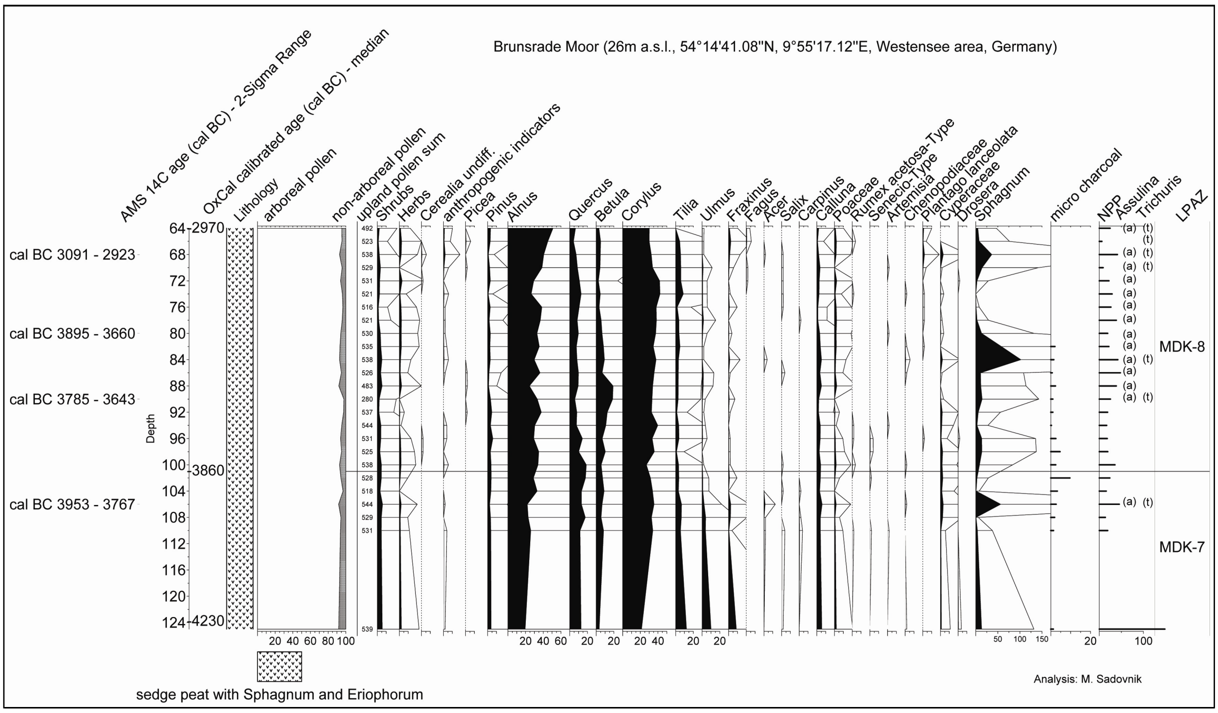

Figure 5. Percentage pollen diagram with selected taxa of the MDK core part 0.64–1.24m (Mesolithic/Neolithic periods ~4230–2970 cal BC). Values refer to the upland pollen sum. Values are exaggerated by factor 10 (white curves with depth bars). LPAZ, local pollen assemblage zone.

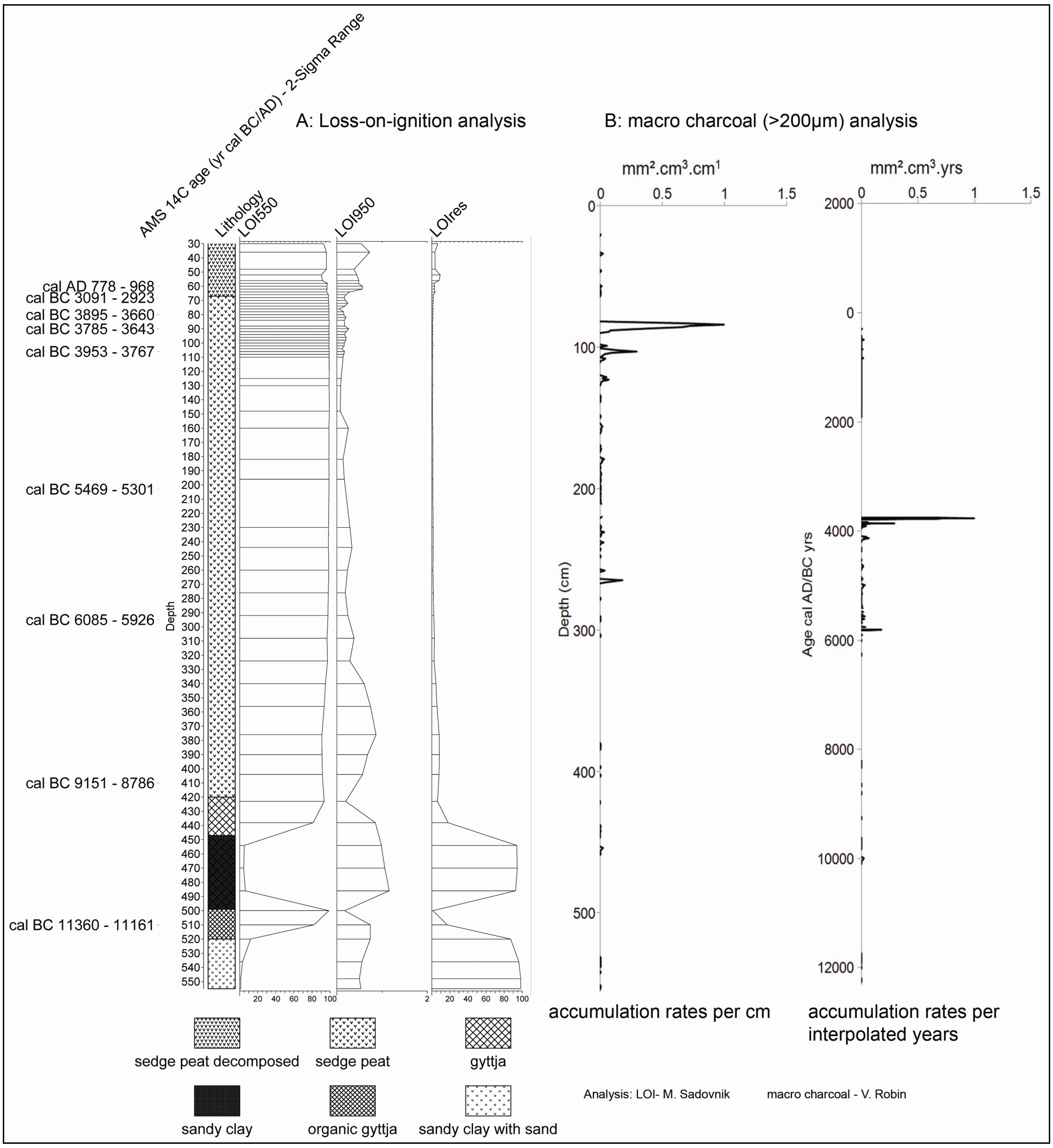

Figure 6. Loss-on-ignition and macro charcoal analyses of the core MDK. **A** : loss-on-ignition data; **B** : macro charcoal analysis (>200µm): accumulation rates per cm and macrocharcoal accumulation rates per interpolated years.

Environmental transformation in the Neolithic period

Archaeological research in the Westensee area has shown that Neolithic people were not the first humans living in this area. Several archaeological findings from the Paleolithic ~11000–9500 cal BC and Mesolithic ~9500–4100 cal BC are known in the area of Westensee (Sadovnik et al. 2010). However, the intensity of human activity during the Northern German Mesolithic/Neolithic transition in Schleswig-Holstein was low (Behre 2007). In the area of

Westensee the Neolithisation seems to be a long process of environmental transformation with individual chronological phases of intense human activity.

The pollen diagram MDK (**Fig.4**) represents this period in the LPAZ MDK-7 (4700–3800 cal BC). In this period, the area was characterised by deciduous mixed oak woodland with high amount of *Tilia, Ulmus* and *Corylus.* The increase in *Alnus* pollenindicates the beginning of Atlantic period (Overbeck 1975) around 6890 cal BC. Alnus grew on the mire forming an alder carr (Barthelmes et al. 2010). Pollen grains of Poaceae with c. 10% and *Calluna* with 5–7% occur in comparatively high values. Homogeneous peat consisted of high contents of *Carex*, *Sphagnum* sp. and *Eriophorum* macro remains. The 98–99% of LOI_{550} (**Fig. 6**) indicates a very high content of organic matter in the peat. Macrocharcoal signal occur periodically from the beginning of Atlantic period, but the signals are weak. Non-pollen-palynomorphs record (NPP) indicate the presence of *Thichuris*-eggs of animal's whipworm parasite. Eggs are deposited in peat through animal's faeces (Le Bailly et al. 2007; Wieckowska et al. 2011). It is possible that the mire was used as a refuge area for game animals for the duration of many centuries. The presence of *Eriophorum*, *Sphagnum* and *Bryopsida* macroremains from the beginning of Atlantic period are characteristic for transition bog development (Overbeck 1975). The presence of *Assulina* (van Geel 1978) in the NPP record as well as *Drosera* pollen suggests that from the end of Atlantic period the mire growth developed in the direction of an ombrogenic bog. It can be assumed that the mire probably developed towards a raised bog but did not reach this state completely due to peat cutting and drainage. The upper part of the LPAZ MDK-8 represents the transition between Atlantic period to Subboreal, ending in the pollen diagrams in Northern Germany with the decrease in *Ulmus*-pollen ("elm-decline"). This is not a strictly synchronous phenomena on a supraregional level (Nelle and Dörfler 2008; Parker et al. 2002), and occurred in the surrounding of the mire 'Brunsrade Moor', according to the age-depth model at approximately at 3860 cal BC.

Neolithic forest fires and human impact

Between approximately 4200 cal BC and 3600 cal BC (LPAZ MDK-8 and MDK-7) both micro and macrocharcoal records indicate strong fire activity. A considerable increase in the macrocharcoal record suggests occurrences of local fires events, which were likely caused by humans considering the broadleaf forest domination in the landscape. Relatively high fire activity and intensive forest burning from Neolithic times onwards are well known from some palynological and anthracological records in Europe (e.g. Wiethold 1998; Wieckowska et al. 2012; Robin et al. 2012; Clark 1983; Kloss 1987). It is possible that fire was used in the mire area by Mesolithic/Neolithic people for hunting, e.g. to attract animals by a fresh regrowth (Pelisiak et al. 2006). For this period, between 0.64–1.24m (4230–2970 cal BC), the pollen record MDK (Fig.5) indicates some significant changes in the woodland composition. *Quercus* decreased after the elm decline. Around 3750 cal BC an increase of *Betula* pollen might indicate secondary woodland succession by birch, colonising burned areas (Tinner et al. 1999). *Sphagnum* shows significant fluctuation. In the Late Neolithic, around 3000 cal BC the first occurrence of anthropogenic indicators *Plantago lanceolata* and *Rumex acetosa*-type show weak evidence of human activities, potentially by using the mire surroundings for grazing. However, very few Cerealia-type pollen grains were identified, this indicates small scale arable fields, if at all.

In the area of Westensee, 34 neolithic findings, as well as 17 megalithic graves represent the period of the relatively high human activities in the area in the Middle Neolithic (Sadovnik et al. 2012), in the time of the Funnel Beaker culture. However, the kettle hole mire 'Brunsrade Moor' within the dense forest, which was nearly inaccessible for regular human land use, was possibly utilized by Neolithic people as a hunting area. Currently, the kettle mire area and the surrounding swamp forests are also refuges for game animals.

Von Hedemann-Heespen (1906) investigated in particular the landscape change in the area from the Middle Ages until the beginning of the 19th century. Concerning the historical peatland use, he assumed that the excavation of drainage ditches and peat extraction in Brunsrade Moor (Moorteich) began in the 18th century. However, the results of pollen analysis indicate that peat was extracted from the mire earlier. In Northern Germany, peat was extracted by cutting since the second half of the 9th century in coastal and inland areas (Dierssen and Dierssen 2001). The peat was used primarily as fuel.

Unfortunately, the periods between 2970 cal BC and AD 790 are not presented in the peat layers. The pollen record as well as age-depth model indicates a *Hiatus* at the depth of 0.62m. The uppermost LPAZ MDK-9 represents the vegetation history from c. AD 790, i.e. from the Middle Age. High percentage of *Fagus* pollen suggests the dominance of beech forest in the surrounding area. However, from approximately AD 1500 very high amounts of non-arboreal pollen, as well as *Calluna* indicated a significant disturbance due to intense human activity and forest clearance, during the Middle Age. Around AD 1800, the occurrence of more than 50% of non-arboreal pollen, high percentage of Cerealia-type pollen grains *Fagopyrum, Secale* as well as anthropogenic indicators like *Plantago lanceolata* suggested intense land use and significant openness of the surrounding landscapes.

Reconstruction of the mire history using archive materials and GIS-techniques

Reliable information about modern landscape change can be inferred from comparison of contemporary and historical maps. However, this analysis is only possible when archive materials are available and in sufficiently good quality. Moreover, elucidation of landscape change using historical data is time consuming and problematic due to distortion of historical maps. Nevertheless, it was possible to georeference archive maps and to reconstruct the margins of the Brunsrade mire with high accuracy. The historical map by Reyer (1758) is of high quality, so that the error after overlay with digital ortophotos was minimal ranging from 8 to 20 m and could be easily corrected. Showing the high quality and accuracy of a map drawn 250 years ago without modern topographical appliances. Due to distortion of the historical maps the error arising after overlaying with digital ortophotos averaged 8–20m. Thus, the actual bog area named by von Hedemann-Heespen (1906) as Moordiek (in historical text and maps - Mohrteich) could be accurately located (**Fig. 7**). GIS-computation of the historical map by Reyer enabled us to calculate, that the forest-free mire area in 1758 covered 1.89 ha. Analysis of the map of the Prussian Royal Land Survey (1877) estimated that the forest-free mire area in 1877 covered 1 ha. Computation of the digital orthophotos DOP 5 (Land Surveying Office Schleswig-Holstein® 2005) showed that contemporary forest-free mire area covers 0.21 ha. Thus, over 250 years almost 89 % of the mire has been overgrown with downy birch forest.

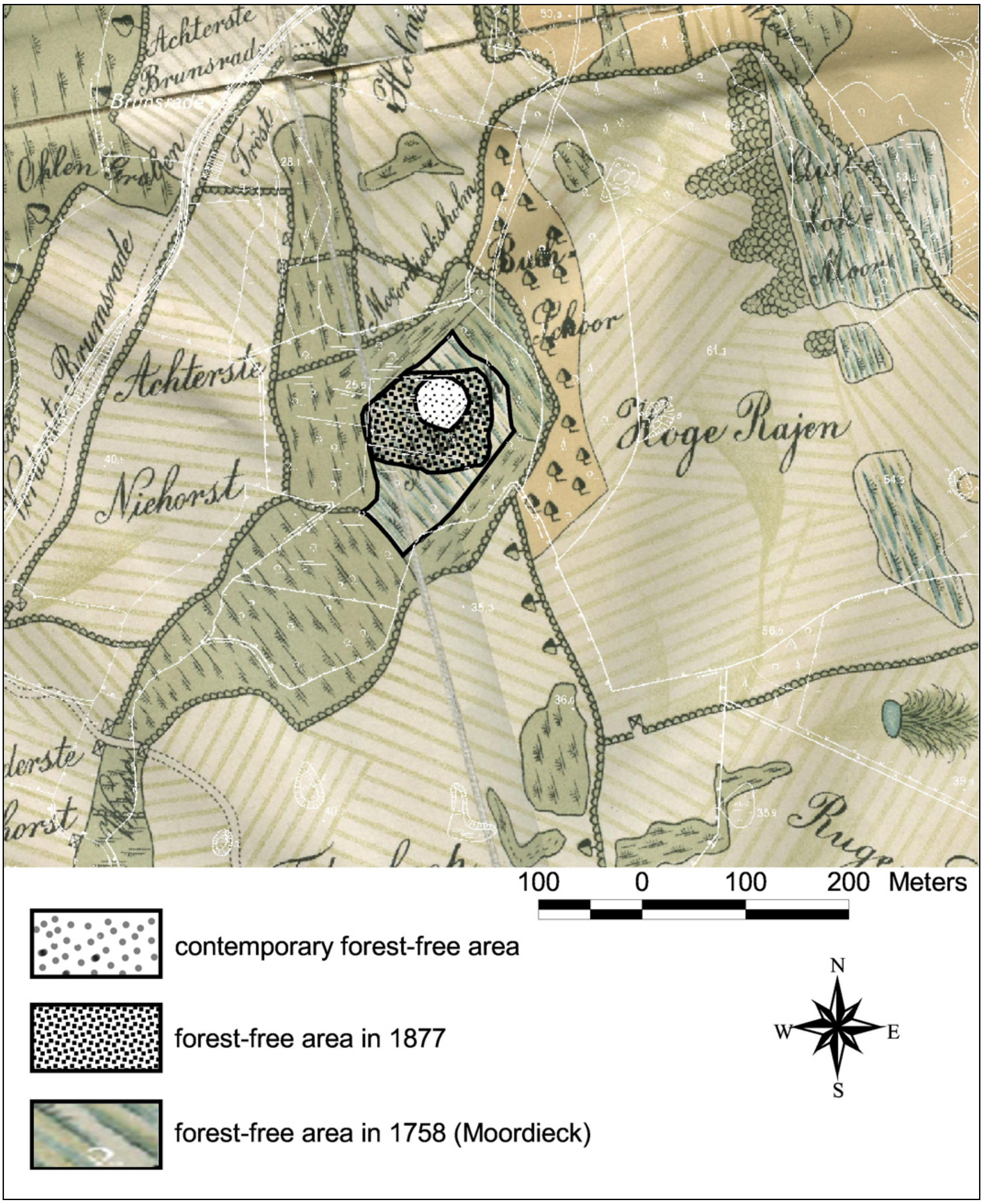

Figure 7. Historical map of the kette hole mire ’Brunsrade Moor‘ by Reyer (1758). Shrinkage of the treeless mire area in the course of 250 years: Georeferenced overlay of the forest-free mire area at historical layout of Reyer (1758), the map of the Prussian Royal Land Survey (1877), and digital ortophoto DOP 5 (2005).

<u>Contemporarily development of the mire</u>

Currently, the predominating mire vegetation consists of purple moorgrass (*Molinia caerulea*). The hummocks are mostly covered with heather (*Calluna vulagris*) and purple moorgrass (*Molinia caerulea*) (**Table 2**). Mosses grow in hollows and partially cover the drainage ditches (**Table 3**). The edge of the mire is covered with a birch swamp forest with high content of deadwood. Predominating tree species are downy birch (*Betula pubescens*) and European alder (*Alnus glutinosa*).

Table 2. Vegetation on Brunsrade mire. Forest-free surface, survey area: 200 m^2

Plant species (survey area 200 m^2)	Vegetation coverage degree
Eriophorum angustifolium	+
Carex acuta	M
Carex nigra	M
Calluna vulgaris	2
Erica tetralix	2
Viola palustris	1
Molinia caerulea	4
Potentilla palustris	2
Salix repens	1
Peucedanum palustre	1
Oxycoccus palustris	+ (3 individuals)
Drosera rotundifolia	r (1 individual)

Table 3. Mosses on Brunsrade mire. Forest-free surface, survey area: 50 m^2

Moss species (survey area 50 m^2)	Vegetation coverage degree
Sphagnum palustre	M
Sphagnum capillifolium	M
Sphagnum fallax	M
Sphagnum flexuosum	M
Pleurozium schreberi	M
Hypnum jutlandicum	M
Aulacomnium palustre	M
Aulacomnium squarrosum	M

The forest floor vegetation consists of, among others, *Iris pseudacorus*, *Scutellaria galericulata*, *Peucedanum palustre*, *Lysimachia vulgaris*, *Hydrocotyle vulgaris*, as well as *Paris quadrifolia* and *Maianthemum bifolium* at the eastern edge of the swamp. Of the northern border of the site the proportion of European alders increases, resulting in a gradual transition from birch to alder swamp forest. The traces of the former peat cutting are visible here. The alder trees are partially submerged, their multiple stems are evidence of the historical coppicing.

Classification of the mire and assessment of its condition using vegetation analysis

Determining the definition of the mire typology was possible only by a combination of stratigraphical, pollen and vegetation analysis. This is because correlations between vegetation composition, hydrological conditions and nutrients dynamics where altered due to anthropogenic influence over the last 250 years. After the marginal drainage of the mire in 1740, the heather vegetation (of the hummock) is now widely distributed over the entire mire. Further drainage lead to a strong increase of *Molinia caerulea*, single birches and even conifers have settled. This process is the consequence of dehydration and enrichment with nutrients. Finally, further development has lead to pure forest stage of downy birch carr with purple moorgrass *Molinia caerulea* dominating the forest floor vegetation (Eigner & Schmatzler 1991). Currently occurrence of mosses including *Sphagnum capillifolium, Sphagnum flexuosum, Sphagnum fallax, Aulacomnium palustre* as well as Ericaceae, such as *Calluna vulgaris, Erica tetralix* and *Oxycoccus palustris* is generally typical for raised bogs (Schwaar 1994). In the modern vegetation of the mire, they co-localise with *Sphagnum palustre* and *Potentilla palustris* which are not considered as raised bog species (Göttlich 1990), and with *Molinia caerulea* which dominates the site with a cover degree of 51–75 %. These facts indicate that the mire 'Brunsrade Moor' shows characteristics of a degraded transition mire which has suffered from artificial drainage.

Conclusions

Our investigations have shown that the kettle hole mire 'Brunsrade Moor" within the dense forest, which was nearly inaccessible for regular human landuse, was possibly utilized as hunting areas by Mesolithic/Neolithic people. Analyses of micro- and macrocharcoals have shown that around 4100–3600 cal BC major fire events occurred at the investigation site. This was interpreted as a consequence of hunting practices during the Late Mesolithic and Early/Middle Neolithic periods. In comparison to the smaller forest fire signals during the Atlantic period, which can be explained by natural reasons, the strong evidence of fires between 4100 and 3600 cal BC are likely caused by humans.

The mire 'Brunsrade Moor' has characteristics of a transition mire, disturbed by drainage and peat cutting along its edges in 18^{th} century. However, in the treeless centre of the mire, peat cutting has taken place earlier, as proven by the results of pollen analysis. Increased concentrations of *Fagus* pollen in the uppermost 30cm indicate a hiatus and the upper layer only represents periods from Middle Age/Slavic Period (AD 720–1143 cal). Analysis of the historical maps using GIS-techniques, enabled us to determine the shrinkage of the forest-free mire area as a result of anthropogenic influence, namely peat cutting and mire draining, over the last 250 years. The results of palaeonvironmental investigation suggest that peat extraction of the Brunsrade mire (Moorteich) did not begin in 18th century, but relatively early, possibly during the Middle Ages.

However, the mire is relevant for protection of nature and evokes scientific interest. The mire and the surrounding swamp forests are refuges for rare plant species protected in Schleswig-Holstein, Germany according to §§ 10; 11 BNatSchG (Federal Law on Protection of Nature), Red Lists and BArtSchVO (Federal Species Protection Regulations). This includes namely *Oxycoccus palustris*, *Drosera rotundifolia* (endangered), *Iris pseudacorus, Viola palustris, Paris quadrifolia,* as well as the especially rare *Sphagnum flexuosum* (State Agency for Nature and Environment Schleswig-Holstein 2005).

Thus, despite considerable anthropogenic influence from the Early Neolithic, the Brunsrade mire provides an important palaeoecological and biological archive which needs to be protected both as archive and habitat for the future.

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Chapter 2

Neolithic human impact on landscapes related to megalithic structures: palaeoecological evidence from the Krähenberg, northern Germany*

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Abstract

New aspects of prehistoric forest use and human activities around megalithic graves were inferred from a palaeoecological study at Krähenberg, northern Germany. Five megalithic graves of the Funnel Beaker Culture are located very close, i.e. ca. 100 m south-west of a small mire which was investigated for pollen and charcoal records. This unique situation provides a detailed reconstruction of the local vegetation development and fire history for the area surrounding the megalithic graves, by investigating a peat core sequence, and backed by 11 AMS ^{14}C measurements and archaeological data. The deciduous forests experienced a slight reduction in the canopy around 3500 cal. BC, suggesting an increased but weak human impact, possibly associated with the construction of the megalithic graves. Following the period of anthropogenic activity, forest recovery occurred over a period of about 400 years. Our results suggest that the designated site was isolated from settlements and arable fields during the Neolithic period. The graves were imbedded in a woodland landscape. Although forest disturbance occurred during the Neolithic period, intense human impact associated with arable farming first commenced during the Bronze Age.

Keywords

pollen analysis, micro- and macrocharcoal, megalithic graves, Funnel Beaker Culture, fire disturbance, landscape openness

1. Introduction

Recent archaeological and radiocarbon investigations of megalithic structures in northern Germany and southern Scandinavia indicate that most of the megaliths in these regions were constructed during a comparatively short time period. The construction period ranged from the late Early Neolithic to the Middle Neolithic ~ 3500–3000 cal. BC, during the period of the Funnel Beaker Culture ~ 4100–2800 cal. BC (Müller, 2011). It is assumed that about 25000 large stone tombs were built in the North European Plain during the fourth millennia BC (Zich, 2009). The most important periods of those constructions can be narrowed to ~ 3500–3200 cal. BC (Persson and Sjögren, 1995; Rasmussen and Bradshaw, 2005). The appearance of megaliths is an indication of new complex social and religious organisational systems (Müller, 2010; Sherratt, 1995) and they reflect the evolution of the relationship between humans and nature. Most of them were erected on the top of hills, thus being positioned at an important viewpoint within the landscape. Therefore, this often dominant topographical position of the monuments led to the assumption that the surrounding woodland must have been permanently opened, in order to make the monuments visible from the surrounding landscape (Cummings and Whittle 2003; Tilley, 2010) in connection with the construction and use of the megalithic graves (Andersen, 1992).

However, the relationship between megaliths and their surroundings, with the woodlands, cultivated fields and settlements, is not fully understood. The level and intensity of woodland clearance is not known, and it is unclear whether megalithic graves were integrated into the agricultural landscape or separate segregated places, presumably reserved for ritual or cultic purposes. Knowledge about their environmental setting during the Neolithic is especially lacking. Moreover, it is impossible to answer these questions based only upon archaeological evidence, thus, making an interdisciplinary approach necessary. Several recent studies show the organisational complexity of Neolithic landscapes with a differentiation into farming areas, settlements, and burial sites. The so-called 'landscape openness' hypothesis, is intensively discussed for the Bronze Age burial monuments (Dreibrodt et al., 2009; Hannon et al. 2008), and can be rejected in some cases for the megalithic graves. Investigations from Denmark (Andersen, 2010) and Sweden (Axelsson, 2010; Sjörgren, 2010) point towards the spatial and visual separation of the tombs from settlements and cultivated areas in the landscapes of the Funnel Beaker Culture.

According to pollen evidence from a Late Neolithic stone cist in southern Sweden, Lagerås (2000) concluded that flowers were ritually deposited in the area, and a semi-open woodland with pasture and small-scale cereal fields surrounded the site. The investigation of Neolithic monuments in Netherlands has revealed evidence of ritual activity, inside and outside the graves (Wentink, 2006). In Germany, multidisciplinary studies in the Altmark region (Demnick et al., 2008) indicate numerous ritualistic activities together with a continuous forest coverage of the megalithic tomb and its immediate surroundings during the vast majority of the Neolithic period.

In this paper, we used palynology together with micro- and macrocharcoal quantification to reconstruct the environmental and vegetational changes of the surrounding area of five megalithic graves of the Funnel Beaker Culture, which are located at the top of Krähenberg-Hill in Schleswig-Holstein, northern Germany. These megalithic graves are located close (100-400m) to the investigated small mire at Krähenberg within its relevant pollen source area (Sugita, 1994). Small mires and lakes are valuable archives to trace environmental and vegetational changes within their immediate vicinity (e.g. Davies and Tipping 2004; Fyfe et. al., 2003; Rickert, 2006). Our hypothesis was that Neolithic people cleared the surrounding woodland area at the top of a hill for the erection of these monuments, as well as for the visibility of these five megaliths, which form a prominent line in the landscape. Another aim of this study was to investigate the relationships between the presence of megaliths and cereal cultivation, as well as changes in forest composition at the study site during the Neolithic period and Bronze Age.

2. Study site

The study site of Krähenberg (Crows Hill) is located in northern Germany 2 km south of Lake Westensee in the federal state of Schleswig-Holstein, northern Germany. Land depressions along the Weichselian moraine landscape (Piotrowski, 1991) contain a multitude of lakes and kettle hole mires (Dierssen, 2005) with very good conditions for the preservation of organic material (Rickert, 2001). Cambisols and luvisols are the dominating soil types in the area (Kielmann, 1996). Currently agricultural fields and planted conifers dominate this landscape, although closed woodlands with common beech (*Fagus sylvatica* L.) still gain a significant presence. Regional land use and settlement history is known basically from archaeological (Aner et al., 2005) and historical investigations (Von Hedemann-Heespen, 1906).

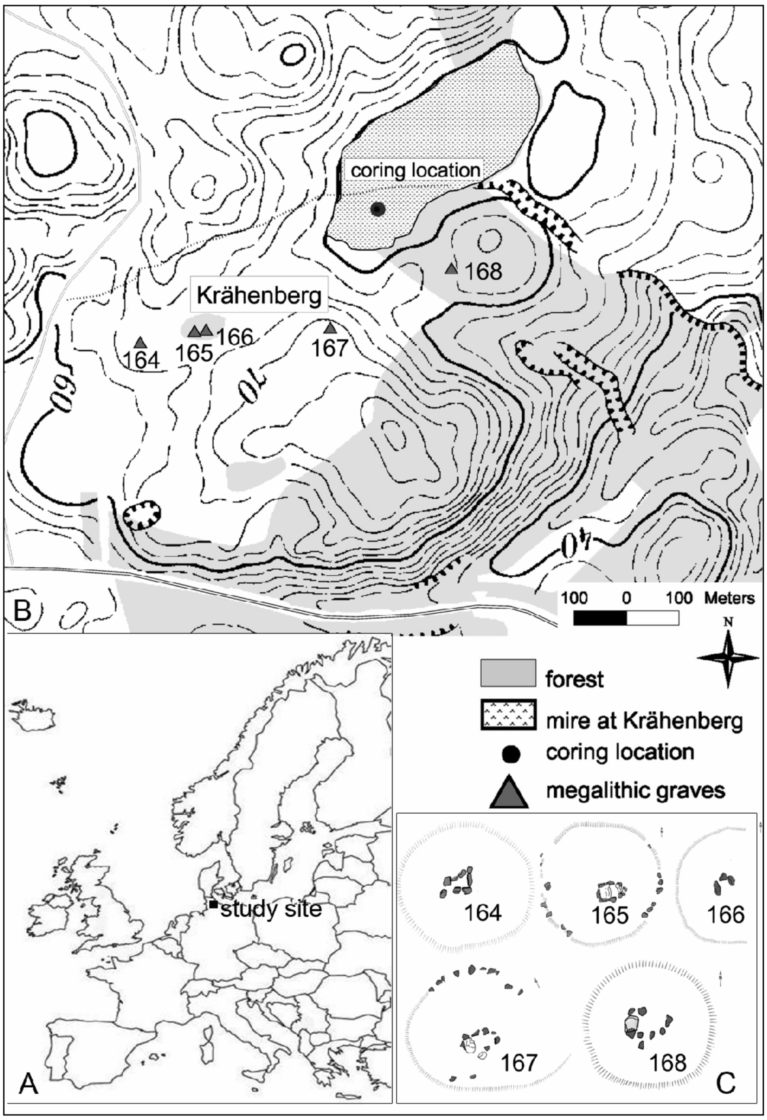

Fig. 1: A. Location of study site within Europe. **B.** The five megalithic graves and investigated mire at Krähenberg (54°15'40.15" N, 9°54'10.05"E), Schleswig-Holstein, northern Germany. **C**. Megalithic graves 164 – 168, modified after Sprockhoff (1966)

Approximately 250 prehistoric sites are known within a 5 km radius around Krähenberg. Several archaeological sites from the Paleolithic ~ 11000–9500 cal. BC and Mesolithic ~ 9500–4100 cal. BC were found in the study area (State Archaeological Department of Schleswig-Holstein 2010, unpublished data). The archaeological findings show a period of more intense human activity from the late Early Neolithic ~ 3500 cal. BC to early Middle Neolithic ~ 3300–3200 cal. BC. Neolithic sites were analysed using GIS-techniques (Sadovnik et al., 2012). Some of the items found were 17 megalithic graves, 9 earth-graves, 34 findings of polished flint axes and flint chisels, 4 records of flint knifes and 7 stone axes.

Five megalithic graves of the Funnel Beaker Culture are located at the top of Krähenberg-Hill (54°15'36''N, 9°54'04''E; 66 m a.s.l.) (Fig.1). The mounds, which are arranged in a straight line, are up to 16 m in diameter and 3–4 m high. The monuments are well visible in the landscape, and were not covered with sand. The side stones of the burial chamber lay more or less open. Sprockhoff (1966) described the graves under the numbers 164–168 as three extended dolmens and two passage-graves. The graves are known by the archaeological records of State Archaeological Department of Schleswig-Holstein, but have not been investigated archaeologically until now. The results of a geomagnetic survey adjacent to the megaliths at Krähenberg are presented by Sadovnik et al. (2010). The mire ’Krähenberger Moor’ is located approximately 100-400 m north-east from the five megaliths. It is c. 300 m long and 100 m wide, with an area of less than 3 ha. In the 18th century, the mire was divided into several parts, and used for peat cutting (Von Hedemann-Heespen, 1906).

3. Material and Methods

3.1 Stratigraphy and radiocarbon calibration

A 5.60 m long peat core sequence KRM was retrieved in July 2009 from the western part of the mire (54°15'40.15" N, 9°54'10.05"E; 63 m a.s.l.) using a “Usinger” piston corer (Mingram et al., 2007). Stratigraphic features were recorded in the field and in the laboratory on cleaned core surfaces. Eleven samples (peat and wood) of the sequence core KRM 0.20–2.24 m were taken for radiocarbon dating. The AMS-measurements were performed by the Leibniz-Laboratory for Radiometric Dating and Isotope Research, University of Kiel. As the ^{14}C calibration curve includes several plateaus and inversions, it is advantageous to roughly estimate the age depth model for the core based on the pollen record, if possible, and select the first two or three samples expected to avoid the wider plateaus for measurement. By using an incremental sampling strategy instead of sampling at regular intervals and measuring all the samples at once, it is possible to improve the final chronology of a core (or sequence) obtained from a Bayesian model without increasing the number of ^{14}C results. Calendar year chronologies were calibrated using “CALIB rev 5.01”, IntCal09 calibration dataset (Reimer et al., 2009) and calculated using OxCal 4.1.6 program deposition model (Bronk Ramsey, 2010, 2009).

3.2 Pollen analysis and loss-on-ignition

90 samples (1 cm^3) were taken from the upper 2 m of the core at 2 cm interval in most parts for pollen analysis. Pollen chemical preparation followed standard procedures (Faegri and Iversen, 1989; Moore et al., 1991). Pollen grains were counted using a light microscope with magnification 400× up to 1000×. The reference pollen collection of the Institute for Ecosystem Research, University of Kiel was used for pollen grain identification. Pollen taxonomy and nomenclature followed Beug (2004). The pollen diagram was compiled and plotted using the TILIA and TILIA-GRAPH software packages (Grimm, 2004, 1994). Percentage calculations of pollen taxa were based on the terrestrial pollen sum. A minimum of 500 arboreal pollen grains (AP) were counted in each sample. Non-arboreal pollen (NAP) were composed of shrubs, plants of the heath family (Ericales), upland herbs, cereals, and indicators of anthropogenic disturbance (Behre and Kučan, 1986). Pollen grains of Cyperaceae and wetland plants were excluded from the terrestrial pollen sum. One surface sample from the borehole location was counted. Loss-on-ignition analysis was performed on 90 samples (3 cm^3), according to the method described by Heiri et al. (2001). Organic matter and carbonate mineral content were calculated according to Dean (1974).

3.3 Micro- and macrocharcoal quantification

Microscopic charcoal particles ≥10 µm were counted on the same slides as the pollen. *Lycopodium* spore tablets (Stockmarr, 1971) were added to each sample (1 cm^3) for the estimation of microcharcoal concentration (no.cm^{-3}) (Tinner and Hu, 2003).

Macrocharcoal fragments ≥200 µm from each 1 cm^3 pollen sample were counted in Petri dishes after chemical preparation using a stereoscope with magnification up to 112×.

Additionally, peat samples (5 cm^3) from each longitudinal cm of the second half of the core were treated with sodium hypochlorite solution during 24 h, and sieved gently through a 200 µm sized mesh (Millspaugh and Whitlock, 1995). Then, for each sample, the sections larger than 200 µm were sorted with a stereo lens to keep only charcoal pieces. The samples were then digitally photographed with identical camera settings, and digitally analyzed using the Scion Image Program (Scion Corporation) to obtain the number and the surface area of macrocharcoals (density slice function) (Mooney and Black, 2003). Finally the macrocharcoal concentration per samples (mm^2cm^{-3}) and accumulation rate (CHAR; $mm^2cm^{-2}yr^{-1}$) were calculated, following the age-depth model. This allowed for identification of macrocharcoal peaks (CHAR peaks), corresponding to local fire events, based on the analysis of the variability of the CHAR signal, using the program CharAnalysis 0.9 (Higuera et al., 2010).

4. Results

4.1 Peat stratigraphy and age-depth model

According to stratigraphical evidence, the upper layers of the mire are missing due to historical peat cutting. Therefore, the upper 30 cm of the core were not considered for further analysis. Below the surface, eight peat layers were identified along the 0.30m to 2.24m section of the core (Table 1). Age-depth modelling is based on eleven ^{14}C AMS radiocarbon measurements (Table 2).

Table 1 Stratigraphic details of the investigated peat sections KRM 0.20–2.24

Layers	Depth (m)	Stratigraphic description
IX	0.30-0.20	strongly decomposed sedge peat with *Eriophorum* and *Sphagnum*
VII	0.34-0.30	*Sphagnum*- peat, *Eriophorum* -roots and well-decomposed grass-sedge peat
VII	0.66-0.34	dark brown sedge-*Sphagnum* peat, medium decomposed
VI	0.77-0.66	brown sedge peat with *Eriophorum* and *Sphagnum*
V	1.54-0.77	dark brown sedge-*Sphagnum* peat, slightly decomposed
IV	1.64-1.54	brown sedge peat with *Eriophorum*
III	1.76-1.64	brown sedge-*Sphagnum* peat
II	1.83-1.76	brown sedge peat with *Bryopsida* and *Sphagnum* remains
I	2.24-1.83	light brown sedge peat with *Eriophorum* , *Oxycoccus,* wood remains, medium decomposed

A significant change of the peat layers from VI to VII were found. The calibrated age of the sample KIA40649 (1882–1694 cal. BC-2σ) indicates the beginning of the Bronze Age in northern Germany. Sequence calibration of AMS-data shows that during this period peat accumulation is very low, probably caused by decomposition after peat cutting and mire drainage in the 18th century. The ^{14}C concentration of the sample KIA 41716 falls within the ^{14}C age plateau caused by an increase of sun (spot) activity during the Maunder minimum and by fossil fuel burning (Suess effect), so it was not possible to determine the calendar age of the sample to better than a wide range from AD1520–1955. Thus the youngest three AMS-dates KIA41716, KIA40648 and KIA41660 were not used for the calculation of the age-depth model for the Neolithic period. In order to construct an age-depth model, weighted average estimates the probability of distributions of this calibrated age (1, 2 and 3σ regions) were calculated. Based on Bayesian-statistics, modelled ages from each sample for the Neolithic peat sequence were calculated from 4050 cal. BC to cal. 1770 BC (Fig. 2). This gave a mean sedimentation rate of 1 cm/14.4 yrs.

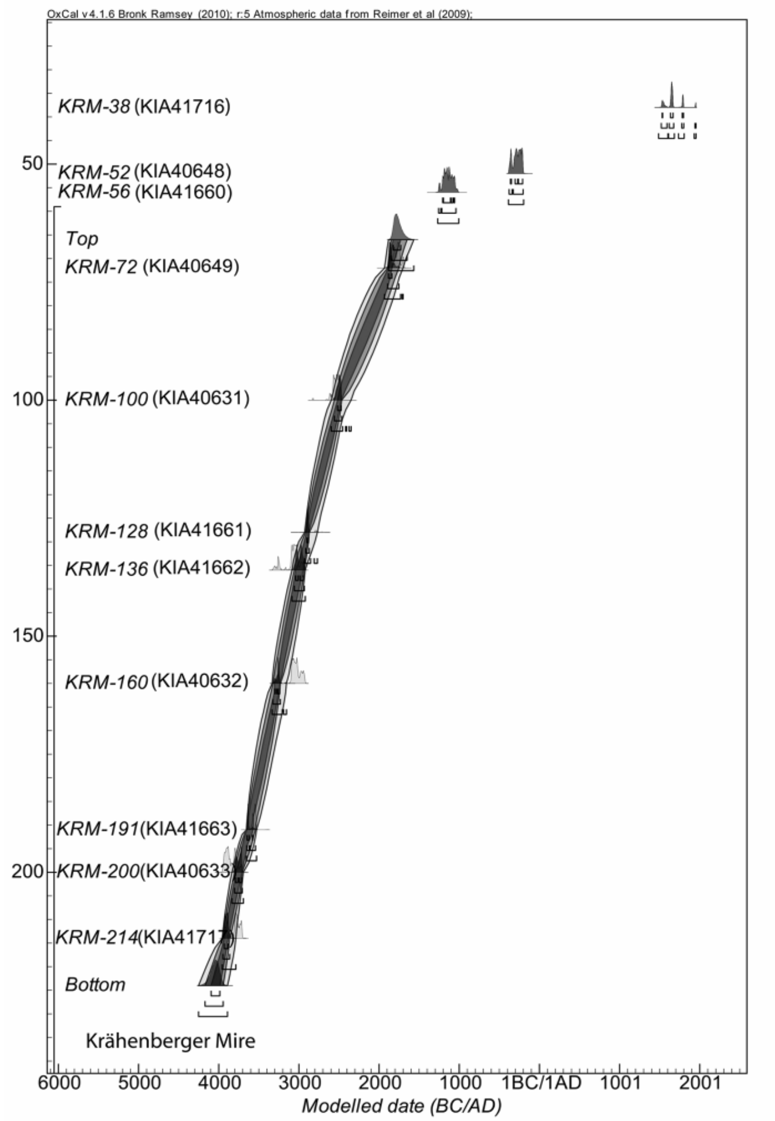

Fig. 2 Age-depth model of the core KRM 0.20–2.24 m based on eleven calibrated radiocarbon dates, respectively, Oxcal 4.1.7 (Bronk-Ramsey, 2010)

Table 2 Results of AMS-radiocarbon datings of the core KRM 0.20–2.24 m (Leibniz-Laboratory for Radiometric Dating and Stable Isotope Research, University of Kiel, Germany). 2σ calibrated with Oxcal 4.1.7 (Bronk-Ramsey, 2010)

Lab. ID	Sampling site, depth (cm)	Sample type	Radiocarbon age (BP)	BC/AD cal. age (2σ)
KIA41716	KRM-38	plant remains	255 ± 30	AD 1522–1951
KIA40648	KRM-52	peat	2219 ± 21	BC 378–204
KIA41660	KRM-56	peat	2930 ± 25	BC 1258–1040
KIA40649	KRM-72	peat	3466 ± 27	BC 1882–1694
KIA40631	KRM-100	peat	4020 ± 30	BC 2619–2471
KIA41661	KRM-128	peat	4259± 30	BC 2919–2763
KIA41662	KRM-136	peat	4425 ± 25	BC 3312–2925
KIA40632	KRM-160	peat	4416 ± 25	BC 3264–2921
KIA41663	KRM-191	wood (*Corylus*)	4800 ± 25	BC 3646–3525
KIA40633	KRM-200	peat	5032 ± 31	BC 3946–3714
KIA41717	KRM-214	peat	5010 ± 30	BC 3942–3705

4.2 Pollen analysis, charcoal analysis, LOI

The simplified percentage pollen diagram (Fig. 3) displays 38 of the most frequent and important taxa out of 68 pollen and 11 spore types encountered. Eleven local pollen assemblage zones (LPAZ) were identified (Birks, 1986). The results of loss-on-ignition, micro- and macro-charcoal analyses are presented in Fig. 4. Zone boundaries are given as OxCal-modelled ages (medium ages BC of the calibrated range) according to the age-depth model.

In the *Zone 1 (4050–3840 cal. BC),* arboreal pollen prevails with 90-94% of the total pollen, represented mainly by *Quercus*, *Corylus*, *Tilia*, *Alnus* and *Ulmus* pollen. The zone boundary is characterised by the decline of *Ulmus* from 11% down to 0.6% and a slower decrease of *Tilia* pollen from 16% down to 7%. Pollen grains of Poaceae with c.1% and *Calluna* with 4–5% occur in comparatively low values. The 98% LOI_{550} (Fig. 4) indicates a very high content of organic matter in the peat. Micro as well as macro-charcoals are virtually absent. A slight increase of Poaceae and *Calluna* within *Zone 2 (3840–3520 cal. BC)* is accompanied by a conspicuous *Corylus* peak of up to 66 %. *Tilia* decreases to 1% and the pollen grains of long distance transported *Pinus* increase up to 4%. The values of arboreal pollen (AP) fluctuate between 93% and 79%. The first record of Cerealia-type (unidentified) was observed in the upper part of the zone. Macro and micro-charcoals are present, but no local fire event is detected based on the CHAR peaks analysis.

During the *Zone 3 (3520 –3310 cal. BC), Tilia* increases up to 9-12% and *Quercus,* up to 21 %. Pollen of *Plantago lanceolata* and Poaceae has 0.7% and 3% respectively. The carbonate content decreased slightly in the zone, up to 0.1% LOI_{950}. No significant evidences for both micro and macro-charcoals accumulation is observed.

Zone 4 (3300 –3130 cal. BC) is characterized by a change in peat composition and an increase of *Sphagnum*-spores in the pollen record, up to 40% of the total pollen and spores sum. *Alnus* reaches a first maximum, up to 47 %. *Tilia* decreases from 10% to 2%. A few pollen grains of the *Avena-Triticum*-type were detected. Once again, only a small accumulation of micro and macro-charcoals was observed, but with a first statistically identified CHAR peak.

Zone 5 (3130 –2970 cal. BC), shows an absolute *Alnus* maximum, with *Alnus*-clumps present. *Tilia* pollen declines down to 1%. Non- arboreal pollen (NAP) varies between 7% and 17%, and is dominated by *Calluna*. *Plantago lanceolata* and Poaceae occurred up to 0.5% and 1% respectively. Micro as well as macro-charcoal accumulation increases, with two distinct micro-charcoal peaks and several macro-charcoal CHAR peaks. LOI-–values do not show marked changes.

Zone 6 (2970 –2610 cal. BC) is characterised by the decrease of *Alnus* down to 20% and by elevated values of *Corylus*, grasses and ruderal herbs. The *Fagus*-curve is discontinuous. Anthropogenic indicators like *Plantago lanceolata, Rumex,* and *Artemisia* are present in very low values (1%). *Calluna* fluctuates and reaches high values at the transition to *Zone 7*. The LOI_{550}-curve shows firstly a depression. The micro-charcoal signal shows a relatively important accumulation. The macro-charcoal values are low but still allow the detection of two CHAR peaks.

In *Zone 7 (2610 –2280 cal. BC), Corylus* increases up to 50%. This high value of *Corylus* was coeval with the increase of Poaceae and anthropogenic indicators, as well as an increase of micro and macro-charcoal. In the middle of the zone, the curves of *Tilia* and *Betula* decrease progressively to 1% and 5% respectively.

Zone 8 (2280 –1940 cal. BC) exhibits high values of *Betula*, and an increase of *Tilia* pollen, while values of AP fluctuate between 75 % and 90%, and *Calluna* declines up to 1% or disappears. Only one grain of Cerealia-type pollen (unidentified) was observed in the upper part of the zone.The micro-charcoal signal is weak. The opposite is observed for the macro charcoal, which shows an important quantity of charred material with two CHAR peaks identified.

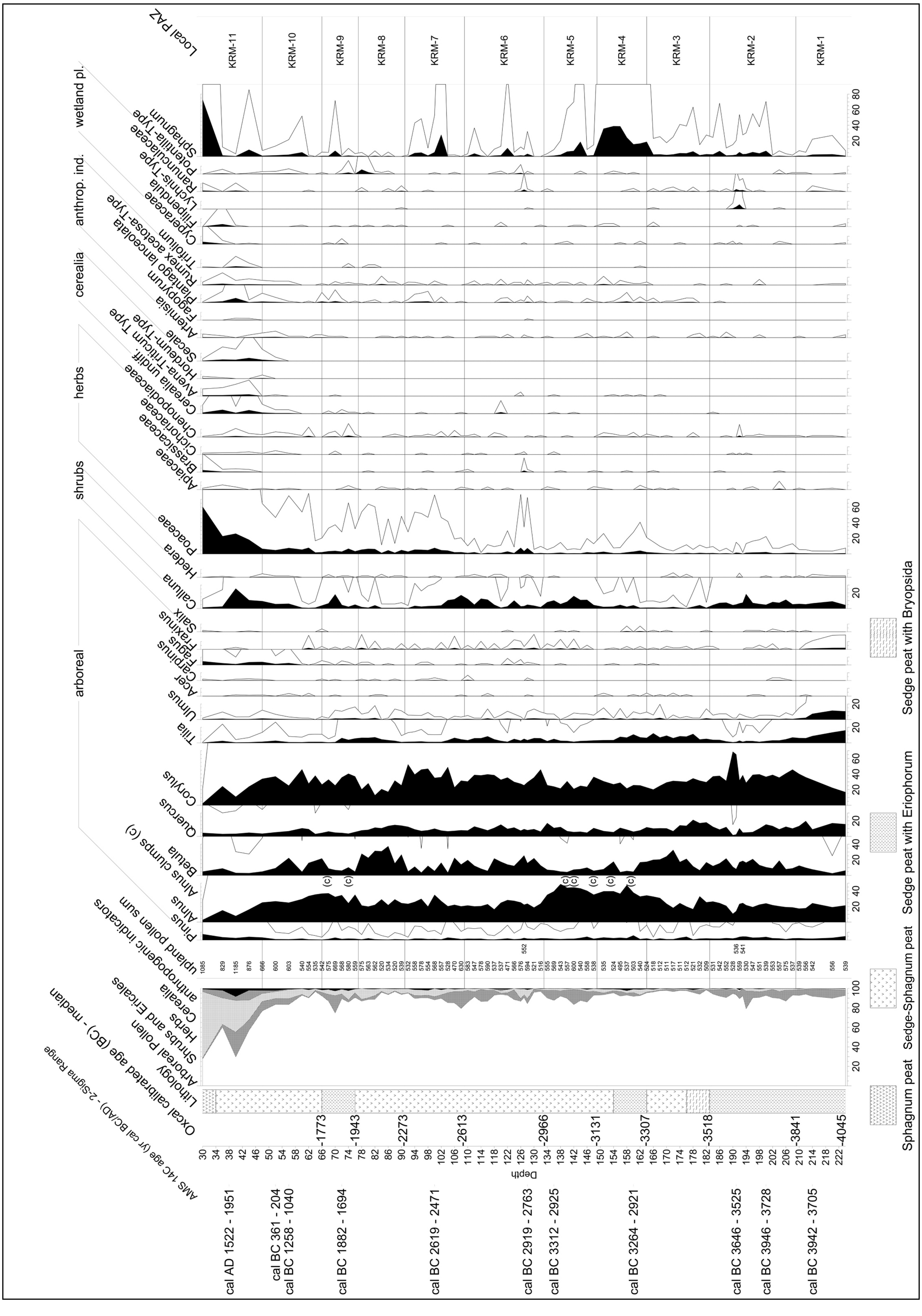

Fig. 3 Percentage pollen diagram with selected taxa of the core KRM 0.30–2.24 m. Values refer to the upland pollen sum. White curves are exaggerated by 10

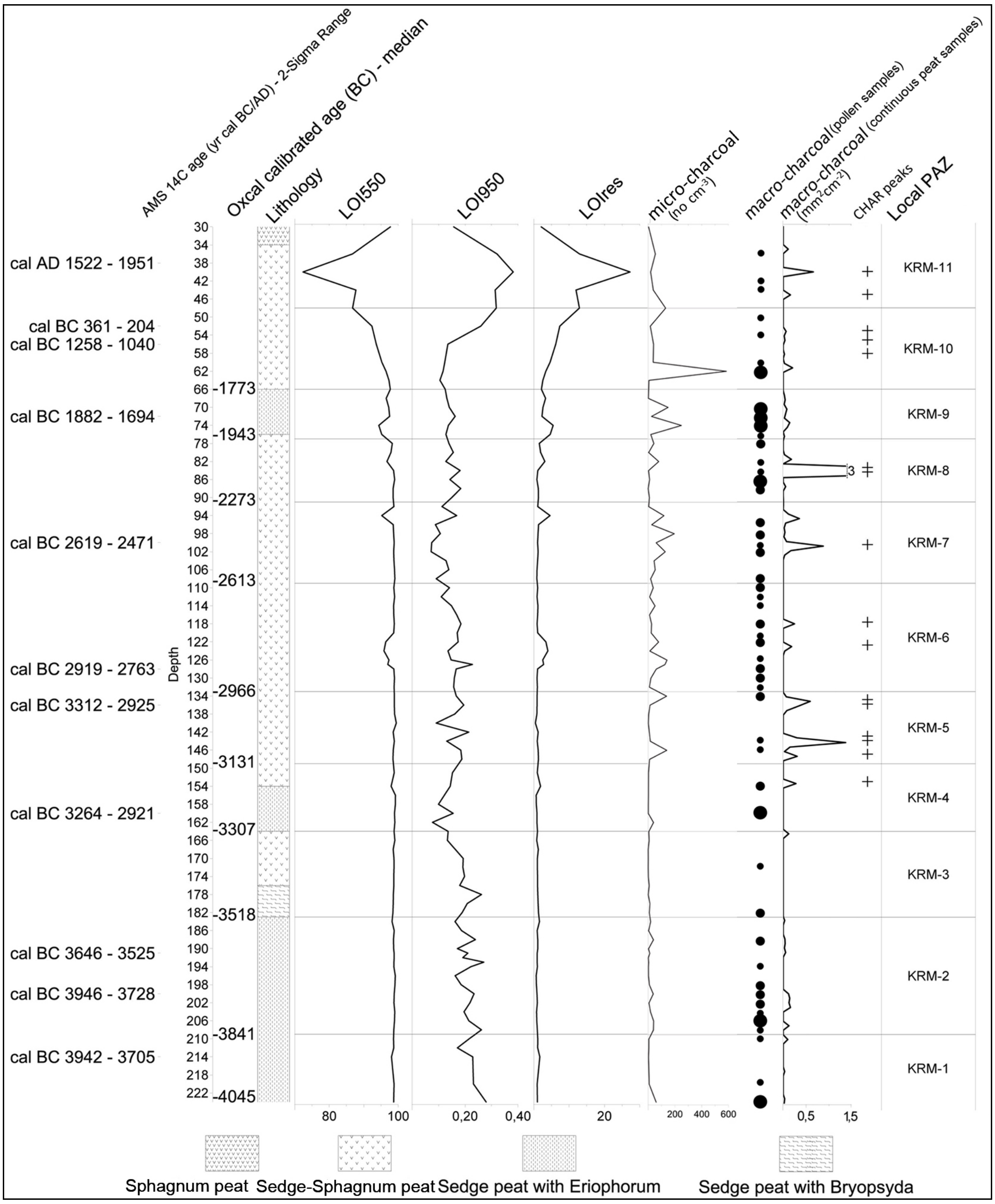

Fig. 4 Loss-on-ignition, micro and macro-charcoal diagram of the core KRM 0.30–2.24 m

Zone 9 (1940 –1780 cal. BC) is marked by an increase of *Alnus* and a slight dominance of *Corylus* pollen percentages. In the upper part of the zone, *Tilia* pollen declined down to 1%, arboreal pollen decreased down to 70% while values of *Calluna*, Poaceae and ruderal herbs increase. A slight increase of cereals pollen is detectable. Results of LOI analyses showed a low organic content (95% of LOI_{550}) of sediments in the current zone. While micro-charcoals peak, only few macro-charcoals are present.

Zone 10 (from 1780 cal. BC) is characterised by the beginning of a gradual decline in arboreal pollen, in the upper part of the percentage of AP declines below 57%. *Alnus* decreases from 35% down to 25%, the continuous curve of *Fagus* pollen reaches from 0.5% to 3%. *Calluna* and Poaceae increase, as well as *Plantago lanceolata* cereal pollen like Cerealia-type undiff., *Avena-Triticum*-type, and *Hordeum*-type occur. The organic matter decreased continuously down to 87% of LOI_{550}, the carbonate content increased slightly in the zone, up to 0.3% LOI_{950}. Micro-charcoals peak followed by three macro-charcoal CHAR peaks, though accumulation is low.

In *Zone 11,* arboreal pollen prevails with 35–65%, and the continuous curve of *Fagus* reaches 5%. The presence of long-distance transported pollen of *Pinus* increases up to 8%. Finally, arboreal pollen declines to 27%. Poaceae values increase up to 60%, and *Calluna*, cereals and *Plantago lanceolata* pollen display their highest values of the entire diagram. Two CHAR peaks were identified. The organic matter decreases considerably down to 73% of LOI_{550}, the carbonate content increased up to 0.4% LOI_{950} and mineral matter mainly mirrors the loss on ignition curves.

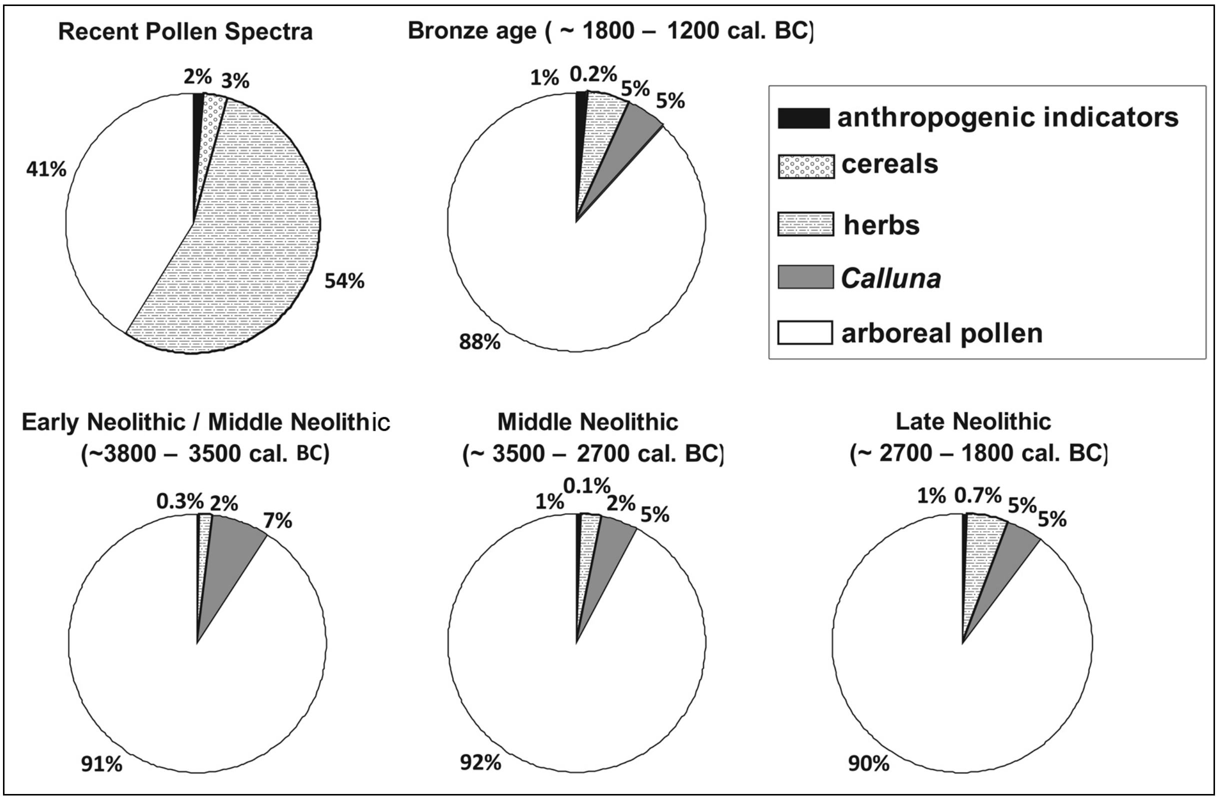

Fig. 5 Recent AP/NAP ratio and fossil pollen spectrum from the Early Neolithic, Middle Neolithic, Late Neolithic and from the Early Bronze age

Recent AP/NAP ratio was calculated and compared with median values of fossil pollen spectrum, from the Early Neolithic (16 samples), Middle Neolithic (36 samples), Late Neolithic (17 samples) and 10 samples from the Early Bronze age (Fig. 5).

5. Discussion

5.1 Local Neolithic vegetation history

Palynological investigations in Schleswig-Holstein, northern Germany indicate no lasting anthropogenic effect on the landscape during the period of Mesolithic, and a small-scale agriculture at the beginning of Neolithic around 4100 cal B.C. (Behre, 2007).

The transition from hunter-gatherer to farmer societies and the “landnam” *sensu* Iversen (1941) was interpreted as a long process of adaptation, lasting more than 1500 years (e.g. Nelle and Dörfler, 2008; Zvelebil and Dolukhanov, 1991). The woodland composition of Early Neolithic landscapes in northern Germany was characterised by an oak-dominated deciduous mixed forest, with a considerable proportion being made up of *Ulmus* and *Tilia*, while wet areas were dominated by *Alnus* carrs (Dörfler, 2001; Overbeck, 1975). High-resolution pollen regional diagrams (Glos 1998; Wiethold, 1998; Wieckowska et al. 2012), from the large lakes and mires indicate that the first period of forest opening at regional level could be connected with human impact dates to approx. 3500 cal. BC.

However, the analysis of peat or sediments in smaller sites with 50–100 m in diameter provide more information about the vegetation and land use history in their closest surroundings (e.g. Hellman et al. 2009; Jacobson and Bradshaw, 1981; Prentice 1985; Sugita et al. 1999). According Sugita (1994), the pollen rain found when sampling in small sites represented for the most part the local vegetation and palaeoenvironmental development from the sites within 300–400 m of the surrounding area. The pollen diagram from the 300 m long and 100 m wide mire at Krähenberg reflects mainly the local vegetation of the area surrounding the megaliths from approx. 4000 cal. BC.

Thus, the palaeoecological investigations were designed to study the local development of the monuments and provide detailed information about the complexity of environmental change and small-scale human activity on the landscape (Fyfe, 2012, this issue), related to the megalithic graves. In contrast to the regional pollen records, the local pollen diagram from Krähenberg mire shows very low presence of anthropogenic indicators during the whole Neolithic period.

5.2 Human impact related to megaliths

The *Ulmus*-decline, a phenomena not yet chronologically fixed to a certain date on a supraregional scale, (Parker et al., 2002) can be dated at Krähenberg with the most probable OxCal-modelled age around 3840 cal BC (*Zone 1*). In parallel to the *Ulmus*-decline, *Tilia* decreases possibly due to human impact. The first evidence of human activity in the landscape can be observed at Krähenberg, in the *Zone 2,* by a very slight increase of Poaceae pollen. Increase of the charcoal signals was followed by the elm decline. Remarkably high values of *Corylus* pollen from 191 cm depth might be the result of high pollen productivity after disturbances and can possibly be interpreted as the result of hazel coppicing (Göransson, 1988). Otherwise, *Corylus*, which is known of being a species with high light demand, might have dominated locally after a short opening of the deciduous forest. A *Corylus* wood fragment from this depth was AMS-dated to 4800 ± 25 uncal. BP (KIA41663) giving a calibrated date range of 3646–3525 cal. BC (2σ). The high amount of pollen from wetland plants might have been a result of the increase of surface runoff and spring activity, which furthered the wetness of the mire after the assumed short forest opening. The pollen grains of *Pinus* could be considered to have reached the study site by long distance transport (Tipping, 1989). Their increase can also be seen as a further evidence of short surrounding forest openness. This concomitance of evidence could be in connection with the construction of the megaliths. The most probable OxCal modelled ages for this period are 3651–3543 cal BC-2σ, which gives a good agreement with the typological dating of the extended dolmens and passage-graves of the Funnel Beaker Culture ~ 4100–2800 cal. BC (Müller, J. 2010; Schuldt, 1976; Sjögren, 2011).

It is widely known that megalithic monuments of the Funnel Beaker Culture were used for burial rituals (Hoika, 1990; Mischka, 2009). However, several recent archaeological studies have demonstrated that the megaliths were probably not primarily burial places immediately after their erection in the late Early Neolithic, and were used secondarily as collective burial places in the Middle Neolithic (Steinmann, 2009; Veit, 1993). A number of investigations indicate the phenomenon of re-using of megalithic graves during the Single

Grave Culture ~ 2800–2200 cal. BC (Andersen, 2010; Holtorf, 2000-2008), and a significant opening of the surrounding area during the Bronze Age (Zich, 1992).

At Krähenberg, we could not detect forest disturbance in the surrounding of the megaliths between approx. 3500 cal. BC and 3100 cal. BC due to the fact that the percentages of Poaceae and *Plantago lanceolata* pollen (up to 3% and 0.7% respectively), were too low to confirm intensive human activity. This suggests that during the majority of the Funnel Beaker Culture period the graves of Krähenberg were embedded in a woodland landscape with only small forest openings.

5.3 Forest recovery in the Middle Neolithic?

Following the short period of forest disturbances around 3500 cal. BC, in the late Early Neolithic, proximate increases of *Tilia* and *Quercus* in the diagram indicate the recovery of forest ecosystems in the surrounding area, between approx. 3500 cal. BC to 3100 cal. BC. Otherwise there is only a slight increase in pollen of Poaceae and anthropogenic indicators like *Plantago lanceolata* and *Rumex*-type. Andersen (1992) interpreted this phenomenon as a sign of using the trees to provide fodder for livestock husbandry, as pollarding causes high flower and pollen production in the upper parts of the crown of the affected trees. Behre (2008) describes *Tilia* as to be especially sensitive to the effects of human impacts in the landscape. This pollarding usage of Neolithic forests may have existed only locally, and no longer than 500 years (Rickert 2006). Around 3000 cal. BC, cattle raising based on leaf fodder seems to be no longer in practice (Behre 2008).

At Krähenberg the changes in the forest composition are detectable. Between approx. 3100–3000 cal. BC the pollen record shows the increase of *Alnus* and a decrease of *Corylus* as well as *Tilia,* with the simultaneous increase of Poaceae. These events could both reflect human activity in the wider area as well as the result of the decrease in local tree canopy. Presence of clumps of *Alnus* pollen grains in the Zones 4 and 5 indicate that alder pollen rain reflects mainly local vegetation, and thus *Alnus* pollen in the diagram seems to be over represented. Paralleling the increase of *Alnus*, *Sphagnum* spores show high values. This might reflect local wet conditions of the mire development. The cereal curve is scattered, while the continuous curves of Poaceae and anthropogenic indicators like *Plantago lanceolata* and *Rumex acetosa*-type occurred in very low values.

5.4 Evidences for fire events

Macrocharcoal records are defined as providing evidence for local fire occurrences (e.g., Clark et al., 1998; Mooney and Tinner, 2010; Ohlson and Tryterud, 2000), in contrast to microcharcoal records, which can represent the fire occurrences at the regional level (Conedera et al., 2009; Tinner et al., 1998).

In the micro- as well as macrocharcoal record of Krähenberg, in most zones there is evidence for fires (Fig.4), with a significant increase since 3000 cal. BC. Before that, only weak fire indications are present, the most significant (though not enough so for a CHAR peak) around 3800–3700 cal. BC, during the decline of *Tilia*. The presence of such macrocharcoal records might be related to the occurrence of certain type of fire (e.g. intensive crown forest fire) possibly inducing long distance macrocharcoal transportation (Tinner et al., 2006). This fits in later with the high values of the microcharcoal signal which seems to support the important fire activity at the regional level. However, , a good quantity of the macrocharcoals are derived from *Calluna* leaves or even moss leaves, which clearly indicates a fire event on the mire itself. As no distinct black layer was observed in the stratigraphy, we assume that the intensity of these fires on the mire surface was low and did not burn significant parts of the peat.

The first CHAR peak is detected in *Zone 4* appears to indicate local fire events, while the evidence of fires at a regional scale is weak. In the *Zone 5*, between approx. 3100–3000 cal. BC, the micro and macrocharcoal signal appears to synchronously indicate regional and local fire occurrences, with the identification of five CHAR peaks. Between approx. 3000–2600 cal. BC (*Zone 6*) the microcharcoal signals most likely indicate regional fire events, while local fire evidence is very small despite the detection of two CHAR peaks.

The trend to more fire events in the upper part of the record, and especially during *Zones 7-9* (2600–1700 cal. BC) is in accordance to the slight increase of Poaceae and *Plantago lanceolata*. Around 2100 cal. BC a strong macrocharcoal signal occurred with two CHAR peaks, clearly indicating intensive local fire activity. An increase of *Betula* pollen can be interpreted as the spread of this pioneer tree, however in the past a different relationship was identified by Tinner et al. (1999), where *Betula* is identified as fire dependant and *Betula* peaks post date fire outbreaks. It is clear from the pollen diagram that the *Betula* preceded the fire, and then coincides with these peaks (Fig. 3 and 4, LPAZ KRM-8). This could be due to the presence of *Betula* in an open forest structure with fire sensitive fuel, presenting local condition suitable for fire ignition. Therefore fire occurred after the establishment of *Betula*, and not as a consequence of the opening due to fire. Otherwise, the following increase of *Tilia* pollen indicates a new period of slight forest regeneration. Between approx. 2000–1800 cal. BC, the microcharcoal record indicates a higher level of burning, possibly from the larger catchment area, resulting from a general increase of human activities at regional level. Micro and macrocharcoal signals from the Bronze Age (~1800 cal. BC) indicate intensive fire activity.

5.5 Cereal cultivation

Very low signals of cereal pollen cannot confirm the presence of arable fields close to the megalithic graves during the Neolithic period. The under represented value of cereals can be seen as evidence that the area surrounding the megaliths, in spite of some signals of human impact, was not significantly integrated in the agricultural activities of the Neolithic people. Major ecological changes in the local environment are detected from the Bronze Age onward by the decrease in local tree canopy as well as by the higher values of grasses and light-demanding ruderal herbs. Only a few cereal grains were observed. A change of the peat composition of the mire possibly suggests the opening of landscape and the recession of the deciduous forest, combined with signs of clearance and fire events. Lower organic content of sediments samples could have been caused by the input of mineral components into the peat after the forested area surrounding the mire was opened. However, continuous curves of cereals such as *Avena-Triticum*-type and *Hordeum*-type, detectable only from ~ 1200 cal. BC, are most likely associated with the presence of small scale arable fields in the vicinity. Pollen evidences of *Plantago lanceolata*, *Artemisia*, Chenopodiaceae and high value of Poaceae suggest the onset of the formation of an open agrarian landscape (Bourgeois and Fontijn, 2008; Fokkens, 1999; Kristiansen, 2010) and the creation of the first pastures at Krähenberg in the Bronze Age.

6. Conclusions

High resolution pollen analysis and age depth modelling using OxCal modelling allow a detailed reconstruction of the vegetation dynamics in the surrounding area of the megaliths during the Neolithic period. Archaeological findings give clear evidence for the presence of people of the Funnel Beaker Culture in the area of Krähenberg. Palaeoecological results have shown that the forest at Krähenberg was opened possibly in connection with the construction of the megaliths around 3500 cal BC. The following period of forest recovery of about 400 yr cal. leads to the conclusion that during the Funnel Beaker Culture the surrounding area of the megaliths was mainly covered by mixed deciduous forests and the megaliths were not exposed in the landscape. No significant evidence of local fire activity between approx. 3500 cal. BC and 3100 cal. BC was found. A very low occurrence of anthropogenic indicators allows the assumption that the closed surrounding of the megalithic graves was not used during the Funnel Beaker Culture or was used solely as a specialised ritual place around 3500 cal. BC. More intensive human impact with forest disturbance is detectable later, in the period of the Single Grave Culture, followed by a period of forest regeneration and low human impact. The signs of anthropogenic activity in this period are observed but give no reason for the assumption that the surrounding area of the megaliths was used for cereal cultivation. Although anthropogenic forest disturbance and fire events already occurred during the Neolithic period, the intense human impact associated with higher level of burning and arable farming commenced during the Bronze Age, which can be seen as an evidence of a different perception of megalithic graves and cultivated areas in the landscape than in the Neolithic period.

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Chapter 3

Archaeological evidence for prehistoric landscape use *

***Chapter based on papers**:

Sadovnik M., Bork H-R., Nadeau M-J., Nelle O. (2012). Can the period of Dolmens construction be seen in the pollen record? In: Kluiving S.J., Guttmann-Bond, E. (eds.): *Landscape Archaeology between Art and Science. From a Multi- to an Interdisciplinary Approach. Series of Heritage & Landscape*, AUP, Amsterdam, 195–207

Sadovnik, M., Schafferer, G., Mischka, C. and O. Nelle (2010). Pollendiagramm und Magnetogramm. Eine Verknüpfung von paläobotanischen und archäologischen Methoden in der neolithischen Forschung am Krähenberg, Gemeinde Westensee. *Archäologische Nachrichten aus Schleswig-Holstein* 16, 23–29

Introduction

In the prehistory of northern Europe, megalithic graves are some of the most remarkable and mysterious structures. The time of their construction, as well as their function and role in the development of human culture are intensely discussed topics, not only in archaeology, but also in the natural sciences, dealing with the impacts of human activities on the landscape. The boulders pertaining to the megalithic structures in the study area potentially yield information on their geological age and origin, however they do not provide evidence either on their function nor by whom the structures were erected. In archaeology, the question of dating megalithic structures to a particular Neolithic cultural period can be done by characteristic finds (Müller 1997), which are potentially related to different cultures.

Difficulties of such dating are mainly caused by the reuse of megaliths and their surrounding area during thousands of years. Even if the megaliths originally had a particular primary function, this could have changed several times during the Neolithic and Bronze Age periods (Steinmann 2009). Currently, using archaeological and radiocarbon dating methods (Klassen 2001; Persson and Sjögren 1995), the construction time of northern German and Scandinavian megalithic graves is estimated to have occurred between the late Early Neolithic and early Middle Neolithic period. These monuments were probably erected during a very short time period (Schuldt 1976). Forests in the surroundings have been opened possibly in connection with the construction of the megaliths (Andersen 1992). After their construction the monuments were used as graves by the people associated with the Funnel Beaker Culture (short TRB –culture from *germ.* Trichterbecherkultur) (Hoika 1990). Over time the megaliths became part of the landscape as elements and indicators of human influences on the landscape.

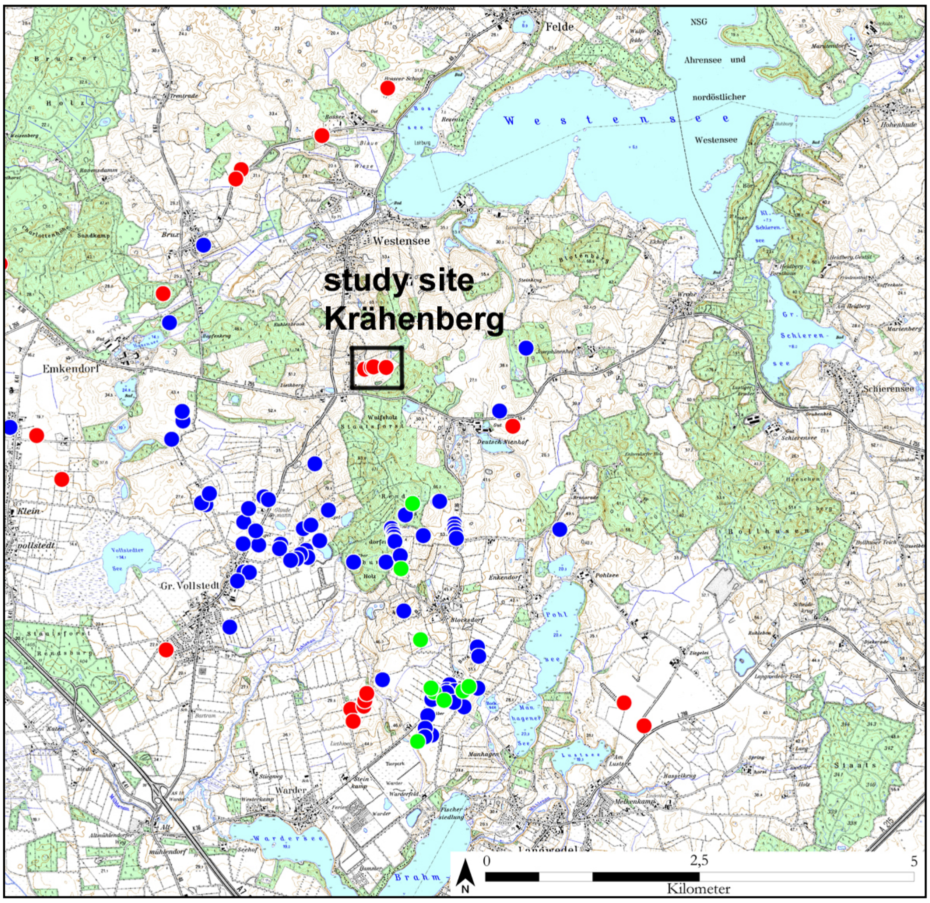
Methods

Results of palaeoecological investigations at Krähenberg needed to be located in a general environmental context. To do this all known archaeological records of prehistoric time periods (State Archaeological Department of Schleswig-Holstein) in a periphery of 5 km diameter of the study site were analysed using GIS-techniques. To date the findings in study area, especially for the Neolithic period, we refer to Hartz et al. (2000); Hübner (2005); Lübke et al. (2009) and Terberger (2002). The most of megalithic archaeological studies focus on the content of grave chambers. Investigations on the surrounding area of megaliths are still rare. Therefore, the morphology of the area adjacent to the megalithic graves of Krähenberg was investigated using airborne laser altimetry data. Additionally to the palaeoecological investigation, geomagnetic surveys were carried out in the area of Krähenberg. Thus, the diverse intensity of human impacts between the times of settlement and abandonment (with comparatively few archeological findings) could be related to the results of palaeoecological studies. Analysis of known findings keeps track of the highlights of the periods of human activities in the study area.

Results

Chronological context

In a periphery of 5 km (approximately 78 km²) of the study site there are roughly 250 locations with significant findings, from all archaeological periods. Archaeological objects from the Palaeolithic (~11000–9500 cal. BC) and Mesolithic (~9500–4100 cal. BC) are represented by three records of stone tools including a tranchet axe. There are several megalithic structures and Neolithic findings recorded in the area: 17 megalithic graves, 9 earth-graves, 34 findings of flint-axe, flint-chisel, four records of flint-knifes and seven stone axes. Altogether 58 archaeological records in the surroundings of Krähenberg date back to the Neolithic (**Map 1**).



Map.1 Archaeological sites from the Neolithic period:
Red: 17 megalithic graves
Green: 9 earth-graves
Blue: 34 archaeological findings (flint-axes, flint-chisel, flint-knifes and stone axes) (~4100–1800 cal BC).
Map source: *Land Surveying Office S-H ® 2005*

For the Neolithic period, a further chronological classification of the sites is partly possible. Dependant on the available artefacts the abovementioned findings (**Fig. 1**) could be compared to the typical form of flint- and stone tools of Early and Middle Neolithic of northern and central Europe. In this way, two sites were identified as Early Neolithic (~4100–3500 cal. BC), based on the form of flint axes. Middle Neolithic (~3500–2700 cal. BC) were represented by 4 findings, these too were dated based on the form of flint axes. Due to the typical form of flint axes, 3 sites were classified as Single Grave Culture (~2700–2200 cal. BC) from the Late Neolithic. Six findings were identified as Late Neolithic (~2200–1800 cal. BC). This assumption was based on the form of the flint dagger and flint sickle, which was typical of the time known as *Nordic Flint Dagger Neolithic Period* (Kristiansen 2010).

Figure 1: Neolithic flint axes from the area of Krähenberg

Further flint tools (e.g. scrapers and blades) and other flint artifacts (lithic flakes, debris, etc.) are known from 57 sites, although positive identification as Neolithic was not always possible as sometimes their temporal origin is not clearly determinable. Nevertheless, it can be assumed, that most of these findings belong to the Neolithic period. The Bronze-age artefacts found were mainly devices and decoration objects made of bronze or amber. Burial mounds were also identified as belonging to the Bronze Age. Iron Age (~500 cal. BC–600 cal. AD) artefacts were found in 21 archaeological sites and were primarily ceramic findings and the remains of urn grave fields. Middle Ages and Modern Time (from 600 cal. AD) remains were found in 6 sites. These localities were characterized by settlement remnants and ceramic objects.

Megalithic graves at Krähenberg

The graves at Krähenberg (**Fig. 2**) have been described by Sprockhoff (1966) as three extended dolmens and two passage-graves, these are referred to numbers 164-168, however they have not been investigated in detail or dated radiometrically. Dating of similar structures in Schleswig-Holstein and in northern Germany (Fansa 2000; Baldia 2009; Midgley 1992) yielded dates of early to middle Neolithic age.

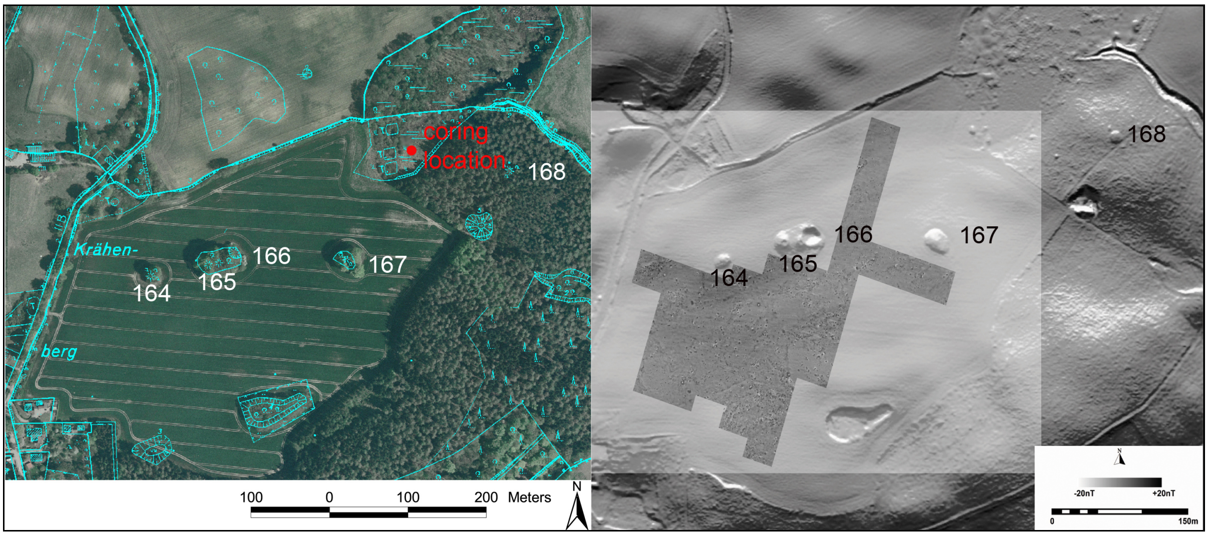


Figure 2. Left: study site Krähenberger mire 54°15'40.15"N, 9°54'10.05"E (coring location: point) and five megalithic graves (164-168) after Sprockhoff (1966)(digital orthophoto 1:5000, Land Surveying Office Schleswig-Holstein ® 2007). Right: digital terrestrial model based on airborne laser altimetry data (LiDAR) and magnetogram of the study site.

Based on the artefacts found, especially the flint-axes, the human habitation in the study area was estimated to date mainly in the time of Middle Neolithic (~3500–3200 cal. BC). In the archaeological records of Schleswig-Holstein, only the megalithic graves as 164, 165 and 166 are recorded. They are registered as Langwedel 13-16 while the grave with Sprockhoff-Nr. 165 is listed in the State archaeological record with two numbers (14 and 15), as it actually consists of two separate constructions (**Fig. 3**).

Figure 3. General view of Krähenberg and megalithic graves 165-166 (after Sprockhoff (1966))

Geomagnetic surveying

A magnetic prospection of the area closest surrounding the megaliths at Krähenberg of about 5.8 ha was performed. Geomagnetic survey can be compared to published results of other geomagnetic investigations. The significance of this method for the archaeological investigations is the possibility to detect and describe archaeological sites_without excavation.

Discussion

Archaeological sites

In summary, the artefacts found are many single specimens very diverse in nature. Burial places such like megalith graves, burial mounds and urn fields were easily detected. Some of these sites (e.g. Groß Vollstedt LA 15, LA 17, LA 18 – grave mounds of Bronze Age; Groß Vollstedt LA 44 – flat graves of Bronze Age; Langwedel LA 66, LA 57 –grave mounds of Bronze Age) have been systematically archaeologically excavated and documented. Regarding settlements, a lack of knowledge still prevails. In the study area, as of yet, no clear settlement remnants of the relevant time periods of Neolithic and Bronze Age have been detected. Those settlements which were archaeologically identified date to the beginning of the Iron Age and later mainly as Medieval.

The archaeological findings in the study area can generally be divided into two time periods. Besides the Bronze and Iron Age, Neolithic is the time period most prolific for these findings. Due to the restricted availability of data, a better specific classification of this archaeological data of the Neolithic findings was not possible. Remarkable is the occurrence of burned flint and stone in an archaeological context, which was detected at the archaeological site Krähenberg, as well as at 9 further sites. This represents human activities in the area, the temporal classification of these finds was non-conclusive. However associated findings, like flint artefacts, support the assumption that these are Neolithic sites. Some of the burned stones could be interpreted as remnants of hearths and fireplaces, together with flint flakes proves that these are remnants of working places. These archaeological sites can be considered as places of mid to long-term human activities and probably also settlement areas. There is a possibility that this specific distribution of burned stones and flint flakes is also related to the megalithic graves. The variety of recorded types of flint axes (most typically from Early and Middle Neolithic) leads to the archaeological conclusion that the probable time of the erection of megalithic graves in Krähenberg was between the end of the Early Neolithic to the beginning of Middle Neolithic. The Krähenberg megaliths represent the first, clearly visible evidence of the landscape use by people during the Middle Neolithic in the area (Sadovnik et al. 2012).

According to modern dating methods, the construction age of megalithic graves in northern Europe as well as southern Scandinavia, could be estimated at between the end of Early Neolithic and Middle Neolithic. The most important periods of those constructions can be narrowed to ~3500–3200 cal. BC (see Persson and Sjögren 1995). Besides the five megalithic graves of Krähenberg, there are other 11 graves known in the study area. There are a further six constructions which, as of yet, are not clearly identified as megalithic graves. We believe there may be another 17 megalithic graves in the surrounding of Krähenberg, as well as a distinct possibility of further undiscovered graves in the area. In the study area 74 grave hills and nine further artificial hills are detected. Only a fraction of them can be positively identified as graves from Bronze and Iron Age. It is also possible that some of these hills are buried megaliths, however this still remains undetermined. It is noteworthy, that megalithic graves (single constructions or groups of graves) are situated within the landscape with a regular distance of approximately 1 km relative to each other. The question whether this regularity is a consequence of Neolithic community structure, or can be explained by the preservation background of the constructions, demand further investigations.

In contrast to the archaeological records of the Archaeological State agency of Schleswig-Holstein, which consists of only 15 archaeological findings, studies of the early Bronze Age show regular and extensive human activity, especially in the surrounding of the study area (see Aner et al. 2005). Spatial distribution of these findings is relatively constant with a higher concentration being observed in the surroundings of Groß Vollstedt and in the area north-west of Langwedel. However, we estimated that the number of Bronze Age findings should have been much higher, considering that a significant number of these archaeological artefacts are currently in private collections were not recorded by the State Archaeological Office, and a precise estimation of the original localities is no longer possible. In the northern part of study area this density declines slightly. We hypothesise that most of the archaeologically unexamined burial mounds on the surface are Bronze Age burial monuments. The consequent results of previous excavations in the study area confirm this hypothesis. Nevertheless, it is still possible, that some of supposed Bronze Age burial mounds include the remnants of older megalith graves. According to chronologically dated archaeological sites, the Neolithic, the early Bronze Age and the Iron Age are likely to be the most important periods of human activities in the study area.

Interpretation of detected anomalies of Krähenberg

A digital relief simulation in the surroundings of the study site Krähenberg revealed unfamiliar patterns that are interpreted to be the boundaries of previously cultivated land similar to the Celtic Fields in the Late Bronze Age field system (Speck et al. 2003). The magnetogram shows the remains of the mound fill, stone kerbs surrounding the graves and unidentified anomalies (**Fig 4**). In the area of Krähenberg three possible archaeological features could be detected.

The first archaeological feature consists of two parallel lines 11 m apart, extending 100 m near the grave 165. The accurate parallelism of the rows within an otherwise unimpaired range south of the graves are clearly of human origin. They can be interpreted as prehistoric construction structures (Sadovnik at al. 2010). It is possible that these structures are a ritual road marked by burned stones. Such roads are known from the Bronze Age burial mound of Husby (Freudenberg 2008). It could be suggested that due to the existence of these stone rows, the continuous use of these graves shared a common cause even after the Neolithic.

The other possible interpretation of these anomalies is that they are remnants of basic elements of one or more megalith graves, which have not been well preserved. With the total length of about 100 m they would be unusually large, compared to the other graves in the surroundings. The third analogy of the results of geomagnetic studies in Krähenberg can be found in the Middle Neolithic of Jutland where there are many diverse graves arranged in rows, directly pointing towards the megaliths (Jørgensen 1977). However, clarity can only be brought through an excavation, and with the collection of more data identifying the correct hypothesis.

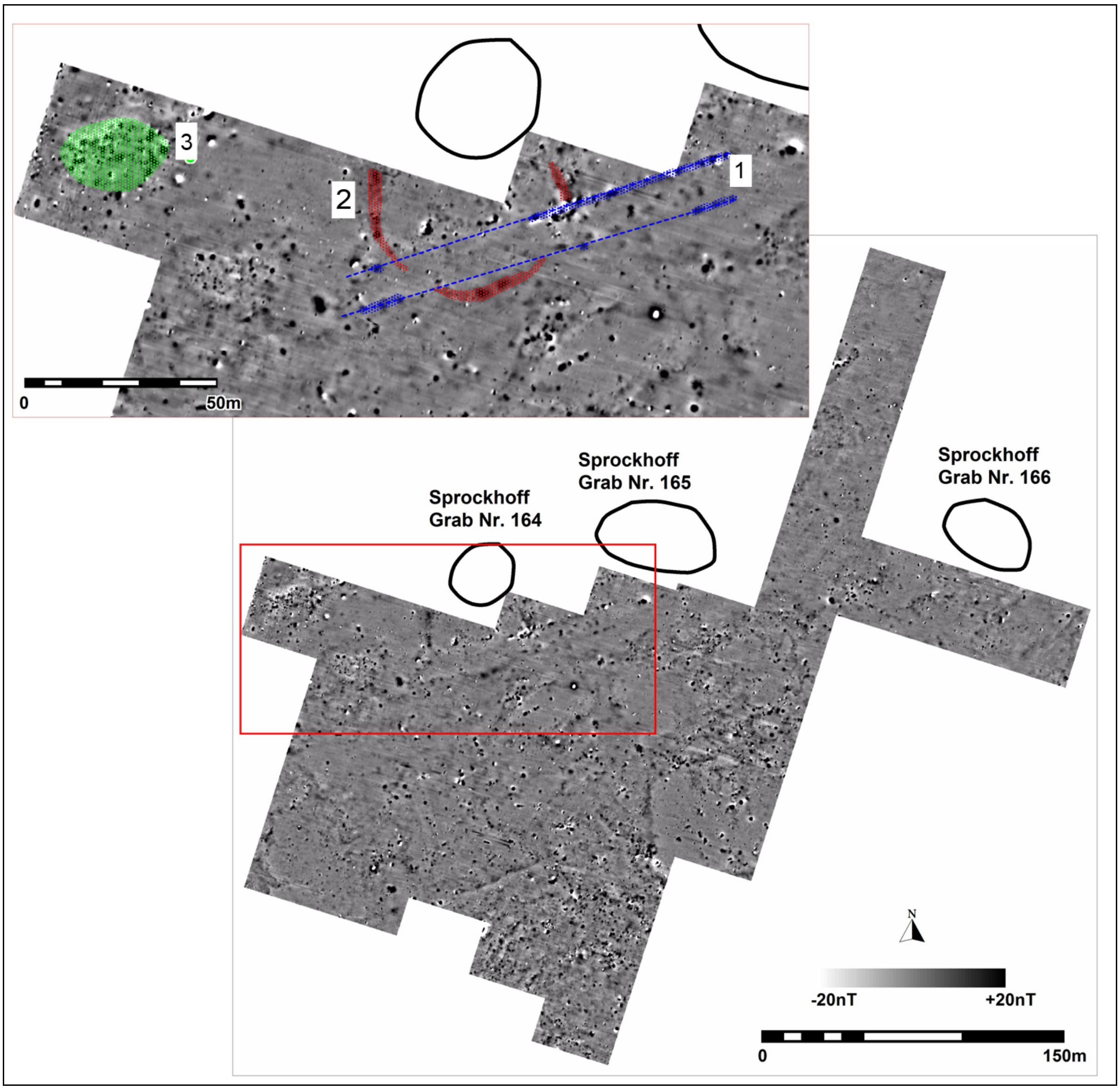


Figure 4. Magnetogram with partly zoomed fragments and the interpretation of detected anomalies of Westensee-Krähenberg (Sadovnik et al. 2010)

The second archaeological feature, visualised using the geomagnetic survey at Krähenberg is a clearly pictured hemicycle of approximately 50 m diameter, located south of grave 164. It is composed of isolated depressions or, in some cases, linear anomalies in rill form. The structure can be identified as remnants of the setting of a grave mound. At the present the mound can no longer be detected on the surface, the presence of only the half of the original, leads to the conclusion of the destruction of this monument. Unfortunately it is not possible to reconstruct the relationship between the grave and depression rows based solely on the results of geomagnetic investigations. Even though the setting of grave the mound shows a gap exactly in the form of the depression rows, the smaller potholes in this part of the construction indicate erosion, rather than a connection to another archaeological finding. The last feature, which can be seen as an anthropogenic structure, is an approximately 20 m diameter oval pile of small dipoles, located 65 m west of the grave 164. It part of the pattern of curved row of megaliths, and the oval is almost equidistant to both megalith 164 and 165. The structure can be identified as remnants of the grave mound. The grave could also be placed within this topographical pattern. Thus, one more monument was detected with geomagnetic surveys, which have been completely destroyed.

Conclusions

The multidisciplinary study of the megalithic graves at Krähenberg illustrates the importance of the combination of methods of modern archaeology and paleoecology. Geomagnetic surveying, as one of the methods of landscape archaeology, provides important references about the remnants of human activities in the landscape. However, the information collected solely by this method is restricted. Only the multidisciplinary approach of archaeological methods, combined with methods of vegetation history and geomagnetic investigations can provide a comprehensive understanding of interactions between human, megaliths and their surroundings. This was demonstrated by the study at Krähenberg.

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Chapter 4

Holocene forest dynamics and human impact: A Palaeoecological study of Lake Lünsee in the Westensee area, northern Germany

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Abstract

The intensity of forest opening during the Neolithisation process as well as the first appearance of beech (*Fagus sylvatica* L.) were investigated from a 14.7m sediment core from the Lünsee Lake in the wooded Westensee area, northern Germany. The results of microscopic charcoal analyses indicated relatively high fire activity during the Neolithic period, which occurred in the surrounding area between 4100 cal B.C. and 2100 cal B.C. The pollen diagram suggests a slight increscent of periodic human activities on the landscape around 3500 cal B.C. The high intensity of human activities on the area was first observed around 1230 cal B.C., during the Bronze Age. The Neolithisation process corresponds to the long practice of environmental changes under anthropogenic pressure. In contrast to the regional pollen records, the Lünsee Lake record indicated a significantly earlier expansion of *Fagus* for northern Germany, during the high anthropogenic intensity of forest disturbance of human activities in the Bronze Age. *Fagus* occurred in its culmination stage during the periods of lower human impact in the Roman Iron Age, around A.D. 100.

Presumably, *Fagus sylvatica* L. was already present in the area of Lünsee Lake since the Late Neolithic period, but in rather small populations. Our results suggested expansion of population of *Fagus* as a product of succession, mainly caused by human influence at a local level. *Fagus*-dominated forest first showed a major disturbance in the Early Middle Age/Slavic Period. The intensity of land use increased significantly in the Late Middle Ages, around A.D. 1260.

Introduction

The change from Mesolithic Hunter-Gatherer to Neolithic Farmer societies had a significant impact on the development of Europe. In northern Germany this cultural transition resulted in the formation of a new cultural group, the Funnel Beaker Culture (~4100–2800 cal B.C.). However, in contrast to a rapid spread of Neolithic farming across Central Europe and in the loess regions of southern Germany, the northern German Neolithic transition occurred rather slowly (e. g. Behre 2008; Hartz et al. 2000; Zvelebil 1998), and there seems to be a long-lived forager-farmer boundary in Europe (Rowley-Conwy 2011).

According to phases of forest recovery and indications of human activity in pollen diagrams, the process of Neolithisation in northern Germany must have been different from region to region (Dörfler 2008) and cannot be interpreted as a synchronous event (e.g. Zolitschka et al. 2003; Behre 2006). Especially in the case of forest covered areas in Schleswig-Holstein, the transition to farming seems to be not a revolutionary one, but a long term process of adaptation and a gradual change of the environmental and cultural traditions (Nelle and Dörfler 2008). Thus, these terrestrial forest areas in northern Europe offer a better understanding of the process of the Neolithisation, representing an alternative view of the transition whose gradual development results in a better palaeoecological record of the process (Zvelebil and Dolukhanov 1991).

From a palaeoecological point of view, Neolithic anthropogenic activities, such as burning, cultivation of livestock, arable farming (Ehrmann et al. 2009) or the construction of megalithic graves and ritualistic landscapes (Mischka and Demnick 2011; Demnick et al. 2008; Lagerås 2000) may have resulted in landscape clearance, changes of woodland composition and formation of pastures.

These interrelationships between changes in forest composition and intensity of human pressure on the landscapes are not completely understood as of yet (e.g. Smith et al. 2009; Gaillard et al. 2008; Küster 2000). Moreover, there is still an intensive debate, over the date of the first introduction of crop plants in northern Europe (Out 2009, 2008; Behre 2007; Kirleis et al. 2012). It is also widely discussed, if forest disturbances during the Neolithic are the result of farming or just a natural factor (O'Connell and Molloy 2001; Innes et al. 2003).

Therefore, in order to gain a better understanding of Neolithic and Bronze Age human origin and the complexity of the environmental change, a palaeoecological reconstruction with fine-resolution is needed, encompassing the local development of small selected areas (e.g. Lagerås, 1996; Rösch 1992), possibly related to archaeological material.

The aim of this paper is to compare natural processes of woodland dynamics and human impact, concentrating on the period from the Neolithic to the Iron Age. We examined the intensity of forest disturbance during the Neolithisation process and human impact on the wooded Westensee moraine area in northern Germany. The palaeoecological studies (pollen, micro charcoal, loss-on-ignition analyses) were performed on a sediment core sequence from the small lake Lünsee with high temporal resolution. Lünsee presents an undisturbed sediment record and, therefore, provides a complete record of the immigration of *Fagus sylvatica* L. in the adjacent area, a period that, due to intensive peat cutting, is barely possible to analyse in peat sequences from the investigated mires. The local pollen record was used to approximate when *Fagus* appeared in the study area and potential factors controlling the spread of this tree species in northern Germany are discussed.

Material and methods

Investigated site

The Lünsee Lake is located in the Westensee area of the eastern hill Land in Schleswig-Holstein federal state, northern Germany. The moraine landscape was formed during the Weichselian Glaciation (Piotrowski 1991). The area is characterised by gentle hills and valleys, with a multitude of small lakes and kettle hole mires (Dierssen 2005). The dominating soils in the area are cambisols and luvisols (Kielmann 1996), the climate is temperate humid, with 750–870 mm mean annual precipitation and 8.5 ºC as mean annual temperature. The Westensee area is partially covered by woodland which is mainly dominated by common beech (*Fagus sylvatica* L.), oak (*Quercus spp.*) and ash (*Fraxinus excelsior)* (Galio odorati-Fagetum, Härdtle, 1995). However, agricultural fields and planted conifer stands dominate the landscape.

The small Lünsee Lake (56°15'33.58" N, 9°55'29.70"E, 26m a.s.l.) (**Figure 1**) is well preserved and hydrologically intact with optimal conditions for the preservation of organic material. The lake is part of the Westensee Lake watershed (Environmental Atlas of Schleswig-Holstein 2012). It has a diameter of ca. 100 m and covers an area of 0.8 ha. It formed within a former dead-ice kettle hole. The maximum water depth is currently about 0.5 m. The lake water comes solely from springs and surface runoff, but no stream inflow is present. The outflow was dammed in historical time, potentially connected with a water mill downstream. Currently, a reed (*Phragmites australis*) zone and a dense willow (*Salix sp.*) carr with some alder (*Alnus glutinosa*) surround the open water area. The upland vegetation is characterized by hazel (*Corylus avellana*) and old-growth common beech (*Fagus sylvatica*).

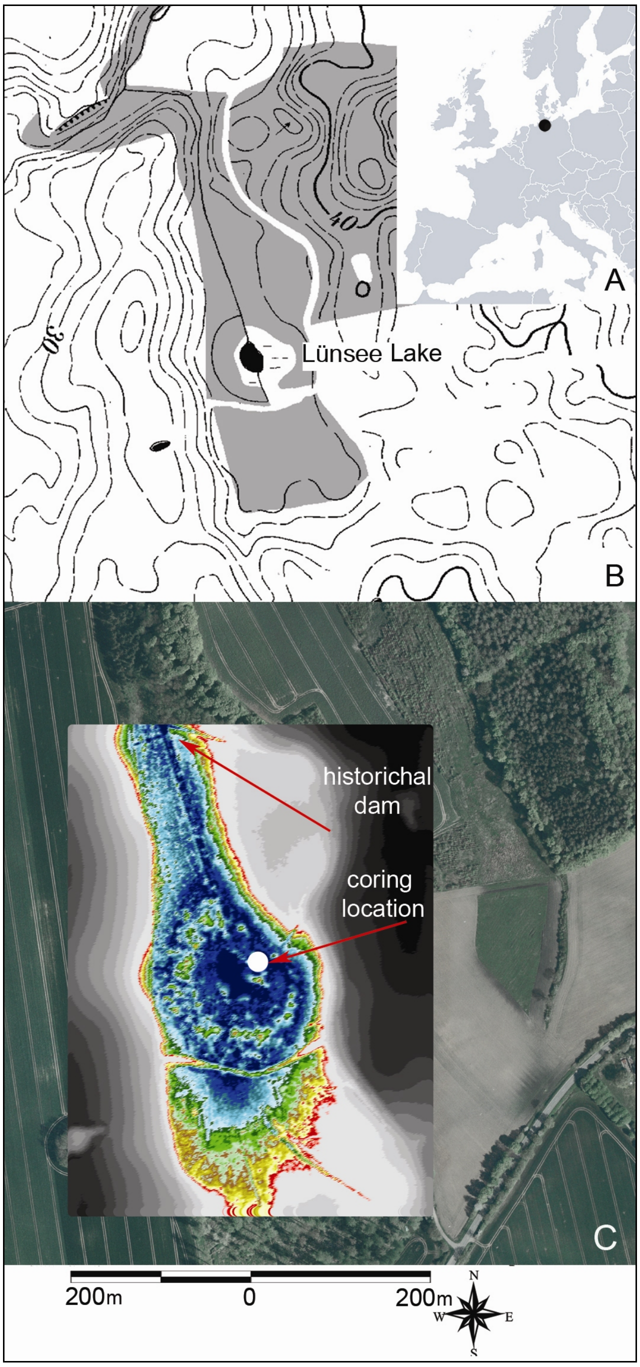

Fig.1 A. Location of study site within Europe; **B.** topography of the study site Lünsee Lake
C. coring location core LNS-1 and a historical dam on digital terrestrial model of the lake, based on LiDAR data (Land Surveying Office Schleswig-Holstein ® 2009)

Sampling and pollen analysis

A 14.7 m long sediment core LNS-1 was taken in October 2009 from the eastern territorialized area at the shore of the lake using a high-precision 'Usinger' corer (Mingram et al. 2007). The core was described in the field and in the laboratory on cleaned surfaces. The upper sequence of LNS-1 from 1.04-7.12 m was investigated palynologically with 142 samples (1 cm^3 sliced), with a mean sampling interval of 4 cm. Pollen preparation and identification followed standard methods (Fægri and Iversen 1989; Moore et al. 1991; Beug 2004) with the addition of *Lycopodium* spore tablets (Stockmarr 1971). Pollen grains were counted using a Leitz Diaplan light microscope (400× and1000× magnification). The percentage pollen diagram was constructed by using the TILIA and TILIA-GRAPH software (Grimm, 1994; 2004) and divided into ten local pollen assemblage zones LPAZ (Birks 1986). A minimum of 500 arboreal pollen grains were counted in each sample. Percentage calculations of arboreal pollen included *Corylus*, cereals, herbs and *Calluna*, anthropogenic indicators are based on the terrestrial pollen sum. Poaceae pollen grains with ≥40 µm in diameter and a minimum annulus diameter of 8 µm were identified as Cerealia-type pollen grains. The anthropogenic indicator taxa were grouped following Behre (1981) and Berglund (1991). Wetland and aquatic plants were excluded from the terrestrial pollen sum, as well as Cyperaceae, spores of cryptogams, non-pollen palynomorphs and micro charcoal fragments.

Microcharcoal analysis, loss-on-ignition (LOI) and radiocarbon calibration

Microscopic charcoal fragments (>10 µm) were counted on the same slides as pollen and calculated together with pollen based on the total pollen sum and as a ratio to *Lycopodium* marker spore (no.cm^{-3}) (Tinner and Hu, 2003). Sequential loss-on-ignition (LOI) analysis (3 cm^3 sliced) was performed with 4 cm intervals (Heiri et al., 2001; Santisteban et al., 2004). The method of Dean (1999; 1974) was used for the estimation of the content of organic matter and carbonate minerals in lake sediments.

The chronology of the core sequence 1.04–7.12 m was based on 10 ^{14}C-AMS measurements, performed by the Leibniz-Laboratory for Radiometric Dating and Isotope Research, Christian-Albrechts-University of Kiel.

Results

Stratigraphy, Dating and Chronology

Five sediment layers were identified (**Table 1**). The chronology of the core sequence, based on 10 ^{14}C-AMS measurements (**Table 2**), was calibrated according to Reimer et al. (2009). Based on Bayesian-statistics modelled ages (1, 2, 3σ) regions and median value from each sample were calculated using OxCal 4.1.7 (Bronk Ramsey 2010; 2009). These calibration results were used for calculation of the age-depth model. The ages of the bottom and upper layers of the core sequence LNS-1 1.04–7.12m were determined between approx. 5320 cal B.C. and A.D. 1680. This gave a median accumulation rate of 1 cm/11.5 yrs.

Table 1 Stratigraphic details of the investigated core sequence LNS-1 1.04–7.12m

Layers	Depth (m)	Stratigraphy	Description
–	0.50–0.00	roots, mosses	mooses, *Carex.sp*., roots of *Phragmites australis*, *Salix sp.*
–	1.04–0.50	water	water cushion
V	1.20–1.04	rootlet peat	rootlet peat with *Phragmites* roots ,dark brown
IV	1.36–1.20	organic gyttja	organic gyttja, from black to very dark brown
III	2.03–1.36	organic gyttja	fine organic gyttja from black to dark gray
II	5.15–2.03	gyttja	fine detritus gyttja with shell fragments, dark gray to olive (4.72-4.30 m: wood fragments)
I	7.12–5.15	gyttja with some clay	fine detritus gyttja with clay layers, sticky with shell fragments, dark gray to olive

Table 2 AMS-^{14}C dates from the peat sequences LNS-1 (Leibniz-Laboratory for Radiometric Dating and Stable Isotope Research, University of Kiel, Germany). 2σ calibrated using Oxcal 4.1.7 (Bronk-Ramsey, 2010)

Lab. ID	Depth (cm)	Dated material	Radiocarbon age (BP)	Cal. age (2σ) (B.C./A.D.)
KIA44983	154	plant remains	810 ± 42	A.D. 1155–1281
KIA43931	248	gyttja	2350 ± 23	506–384 cal B.C.
KIA43932	288	gyttja	2655 ± 27	894–792 cal B.C.
KIA43933	312	gyttja	3057 ± 25	1403–1264 cal B.C.
KIA43934	384	gyttja	3662 ± 26	2135–1955 cal B.C.
KIA43935	434	wood (undiff.)	3729 ± 29	2203–2034 cal B.C.
KIA40635	472	wood (undiff.)	4078 ± 24	2850–2497 cal B.C.
KIA43937	516	gyttja	4162 ± 23	2877–2638 cal B.C.
KIA43938	600	gyttja	5635 ± 37	4540–4368 cal B.C.
KIA40634	675	wood (*Corylus*)	5928 ± 27	4892–4722 cal B.C.

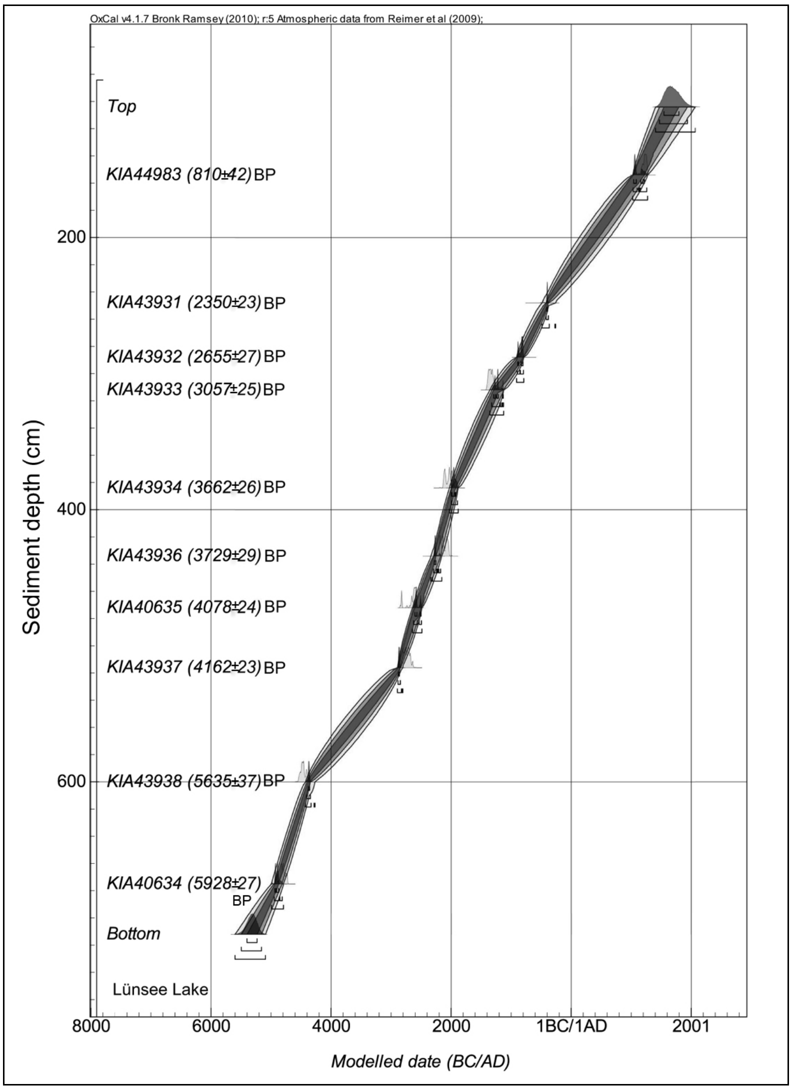

Fig. 2 Age-depth model for the core sequence LNS-1 1.04–7.12m
(OxCal, Bronk Ramsey, 2010; IntCal09, Reimer et al. 2009)

According to the age-depth model, based on ten ^{14}C AMS-dating (**Figure 2**), the core sequence LNS-1 1.04–7.12m represented a time scale ranging from the Late Mesolithic to the Middle Ages. The ages of the bottom and upper layers have been extrapolated to 5320 cal B.C. and AD 1680. The radiocarbon dating of the core sequence is also supported by the pollen-stratigraphical correlation, e. g. by the presence of *Fagopyrum*-pollen in the upper part of the core (*Zone 10*), whose cultivation began in the first half of the 13th century (Röhrer-Ertl and Averdieck 2006). The lower part of core sequence represents the Atlantic period (6800–3800 cal B.C.) in northern Germany (Overbeck 1975), ending with the decrease in *Ulmus*-pollen ("elm-decline").The elm decline (Nelle and Dörfler 2008; Parker et al. 2002) in the subcanopy of the Lake Lünsee (*Zone 2*), according to the age-depth model occurred at 4024–3714 cal B.C. (2σ-range) or 3870 cal B.C. (median age). This elm decline in the area of

Westensee was dated using ^{14}C AMS-dating at 3840 cal B.C., from the mire at Krähenberg (Sadovnik et al. 2010) Thus, the results of ^{14}C AMS-measurements of the samples from the Lünsee Lake, especially of wood particles in the upper part of the core, did not suffer from any reservoir effect.

Pollen analyses, micro charcoal analysis and loss-on-ignition (LOI)

Ten local pollen assemblage zones (LPAZ) were identified for the percentage arboreal and non-arboreal pollen diagrams, according to major changes in pollen proportions. The main characteristics of the zones are summarized in **Table 3**. The simplified percentage pollen diagrams (**Figures 3; 4**) display 33 of the most frequent and important taxa out of 59 pollen and 10 spore types encountered. Ages of the LPAZ boundaries were presented as medium ages cal B.C./A.D. of the calibrated range due to the age-depth model. Microcharcoal concentration is generally high in zones 1-4 and 10, while less in zones 5-9 (**Figure 5**). Loss-on-ignition data show that there is a general trend of higher organic contents along the 7000 yrs record. The time resolution was 11.5 yrs/1 cm per sample.

Table 3 Description of the pollen, microcharcoal, loss-on-ignition of the core LNS-1 1.04–7.12m

LPAZ	depth [cm]	vegetation	Pollen spectrum description	Microcharcoal	LOI	cal B.C./A.D.
10	104-140	*Fagus* forest with *Quercus* and *Carpinus*, opened landscape, arable fields	Gradual decline of arboreal pollen, below 52% in the upper part of the zone. *Fagus* decreases significantly to 10%, while pollen percentage for long distance transported *Pinus* and for *Betula* increase to 9% and 8%, respectively. *Quercus*-curve with 8% of pollen percentage remains constant trough the zone, *Salix* reaches up to 2%. Herbs increase. The major part of the non arboreal pollen consists of *Poaceae* (23%) and *Cyperaceae* (9%). Cerealia-type undiff. (7%), *Secale* (2%), *Avena-Triticum*-type (1%) show remarkable values. The curve of *Fagopyrum* is continuous.	High values of microcharcoal in both curves appear, from approx. A.D. 1350	The augment of mineral content up to 45 % of LOIres was observed in the beginning of the zone.	A.D.1260-1680
9	140-169	*Fagus* forest with *Quercus* and *Carpinus*, forest opening, arable fields	Gradual decline of *Fagus*. General increase of non-arboreal pollen. The lower value of *Fagus* in the middle of the zone is coeval with increase of *Alnus* and *Corylus* between approx. A.D. 950–1110. *Quercus* increases again up to 13%. Pollen percentages for *Plantago lanceolata*, *Artemisia* and *Rumex acetosa* are high, *Poaceae* reaches up to 10%. The combined pollen percentages for *Cerealia* increased continuously from 2% to 6%, during this time the pollen curve of *Secale* has ca. 1%.	low, with just a small raise of microcharcoal particles at the beginning of the zone	Short increase of mineral content (45 % of LOIres) between approx. A.D. 950–1110 was observed. The carbonate content was low and still constant (4% of LOI950).	A.D. 890-1260
8	169-247	*Fagus* forest with *Quercus* and *Carpinus*	*Fagus* expands rapidly and constantly up to 50–55% around A.D. 100. Accordingly, *Alnus*, *Corylus* and *Quercus* have after their declines constant low values. Tilia is not present any more. During the first half of the zone, all anthropogenic indicators have low proportions, and the recording of Cerealia is discontinuous, with only few grains in the upper part. In the upper part of the zone, *Poaceae* slightly increase to 5%.	low amounts	Results of LOI analyses showed a high organic content with 75% of LOI550 of sediments in the current zone, the carbonate content was low with 4% of LOI950 and still constant. A short increase of mineral content (40 % of LOIres) around A.D. 100 was observed.	400 cal B.C.-A.D. 890
7	247-288	*Quercus* forest with *Fagus* and *Corylus*, second expansion of *Fagus*	*Alnus* decreases distinctively from 580 cal B.C., while *Corylus* first increases slightly, before its decline towards zone 8. *Fagus* increases at the end of the zone around 400 cal BC, from 16% in this zone towards its maximum in the next zone. *Poaceae*, *Plantago lanceolata* and *Rumex acetosa* show lower percentages than in zone 6. Cerealia undiff.-curve is continuous, but with low proportions (1%). *Avena-Triticum*-type and *Hordeum-type* occur. First *Secale* pollen grains are recorded.	low amounts	low organic content (38% of LOI550) in the upper part of the zone ca. 400 cal B.C.	810-400 cal B.C.
6	288-340	*Quercus* forest with *Corylus*, forest opening, small arable fields; expansion of *Fagus*	*Fagus* curve rises up to 3%, together with pollen of long distance transported *Pinus*. Arboreal pollen decrease to to ca. 75% mainly due to high values of *Calluna*, Poaceae and ruderal herbs. Around 800 cal B.C. *Tilia* distinctly declines to a near absence. *Ulmus* declines as well. Anthropogenic indicators are high, with 4–5% of the pollen sum. From 1200 cal BC. *Plantago lanceolata* and Rumex acetosa reach a maximum, up to 4% and 3% respectively. *Calluna* increases up to 2%. Cerealia undiff. and *Avena-Triticum*-type pollen curves are still scattered, while Poaceae has a considerable 16% now. First *Trifolium* pollen grains occur.	continuous recording, but low amounts	Around ~1200 cal B.C. the increase of mineral content up to 40 % of LOIres was correlated with an increase of the Poaceae, anthropogenic indicators and ruderal herbs in the pollen diagram	1480-810 cal B.C.
5	340-384	*Quercus* forest with *Corylus* and *Alnus*	arboreal pollen with 90% of the pollen sum. Poaceae continuing with up to 10%, *Plantago lanceolata* has a continuous curve. *Alnus* reaches a maximum for the whole diagram, up to 45%. *Fagus* with close-to continuous curve, shows a slight decline. In the upper part of the zone, *Quercus*, *Ulmus* and *Tilia* increase slightly. Only single Cerealia undiff. occur.	small amounts, no significant signals	no marked changes	1950-1480 cal B.C.
4	384-435	*Quercus* forest with *Corylus*, small openings of the forest	Gradual decline of arboreal pollen at start of zone, down to 90%, while *Poaceae* and *Plantago lanceolata* increase up to 6% and 1% respectively. Cerealia-type (undiff.) and *Avena-Triticum*-type occur.This is followed by a peak of *Fagus* around 2100 cal B.C., after a microcharcoal peak. *Tilia* and *Ulmus* decrease progressively to 1% and 0.7%. *Fraxinus* decreases to 1%.	High content at beginning of zone, ca. 2200 cal B.C.	lower organic content (50% of LOI550) in the middle part of the zone	2300-1950 cal B.C.
3	435-487	mixed deciduous forest with *Quercus, Alnus* and *Corylus*	*Corylus* reaches its highest proportion, with up to 40%, around 2500 cal B.C.*Tilia* and *Ulmus* have very low values, 1% and 0.5% respectively. *Plantago lanceolata* slightly increases, up to 1%. *Alnus* shows a slight decrease in the upper part. Cereal pollen curve is scattered, with only few grains.	Signals are relatively high, but without identified peaks.	The organic matter first decreases to 40% of LOI550 and later increases up to 65%.	2700-2300 cal B.C.
2	487-571	mixed deciduous forest with *Quercus*, *Alnus* and *Corylus*	*Alnus* reaches a first maximum, up to 40% from ca. 3800 cal B.C. onwards. Betula reaches up to 8%, *Fraxinus* increases. Slight increase of anthropogenic indicators like *Plantago lanceolata* and *Artemisia*, as well as *Poaceae* from ~3500 cal B.C. Cereal-type pollen (Cerealia undiff. and *Avena-Triticum* type) occurrs for the first time, together the first *Fagus* grain. Discontinuous *Fagus* curve increases up to 1% around 2900 cal B.C. *Fraxinus* with significant values.	Both curves show significant values, peaking around 3500 cal B.C.	organic content increases continuously up to 55 % LOI550, but on the upper part of the zone, a decrease in the LOI550 curve from 55% down to 40%	3870-2700 cal B.C.
1	571-712	mixed deciduous forest with *Quercus*, *Alnus*, *Tilia*, *Ulmus* and *Corylus*	Arboreal pollen with 98% of the total pollen sum. *Tilia* decreases in the upper part of the zone, *Ulmus* declines from 12% to 2%. Few pollen grains of anthropo-indicators like *Rumex*-*acetosa*-type, *Artemisia* and Chenopodiaceae. Wild grass up to 2%.	fire evidences in upper zone part, ca. 4100 cal B.C.	45% of LOI550 indicates organic matter as major sediment content. In upper part, carbonate and mineral content shows a slight increase up to 18% LOI950 and 48% LOIres.	5320-3870 cal B.C.

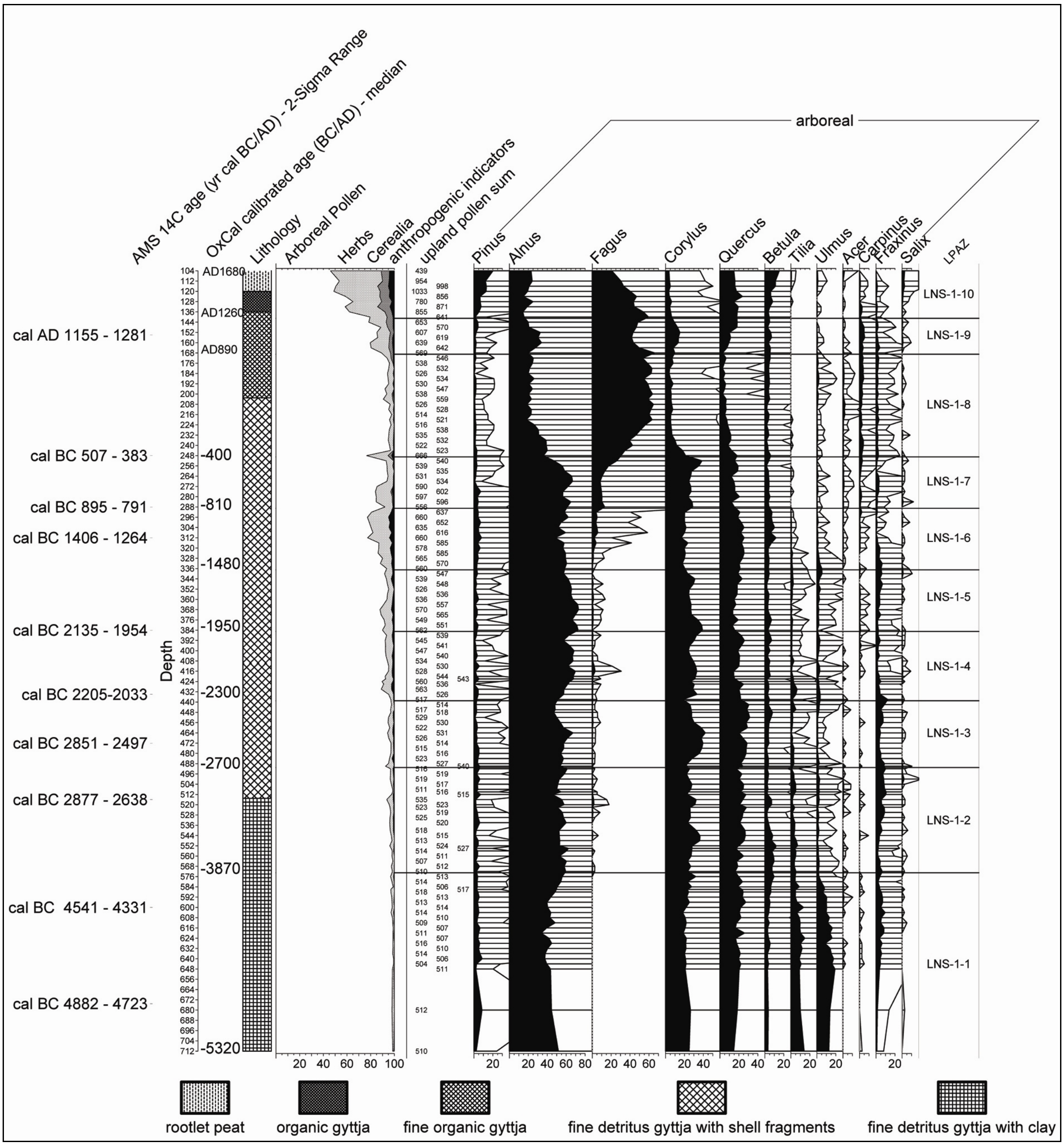

Fig. 3 Percentage arboreal pollen diagram with selected taxa of the core sequence LNS-1.04–7.12 m

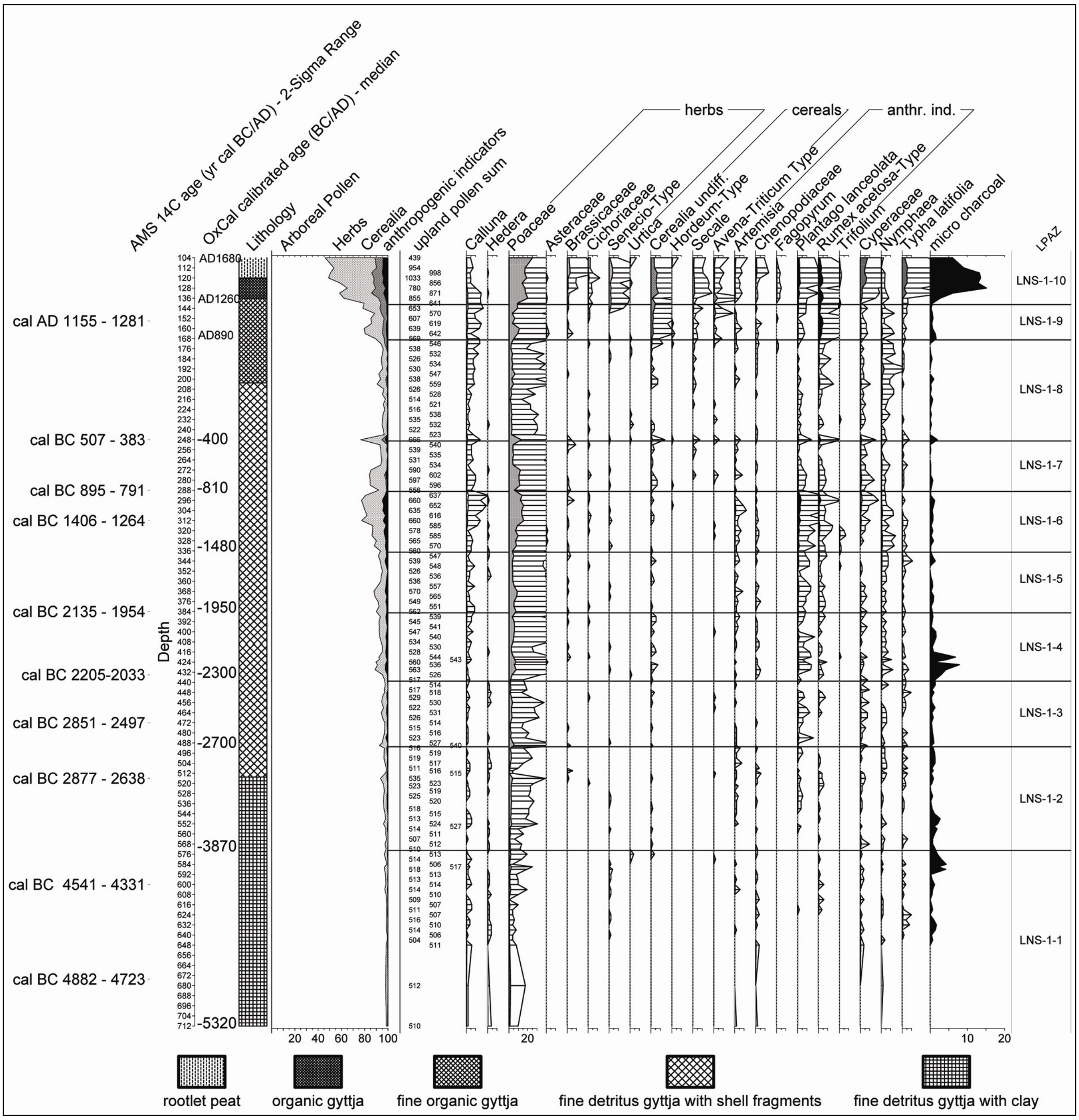

Fig. 4 Percentage non-arboreal pollen diagram with selected taxa of the core sequence LNS-1.04–7.12 m

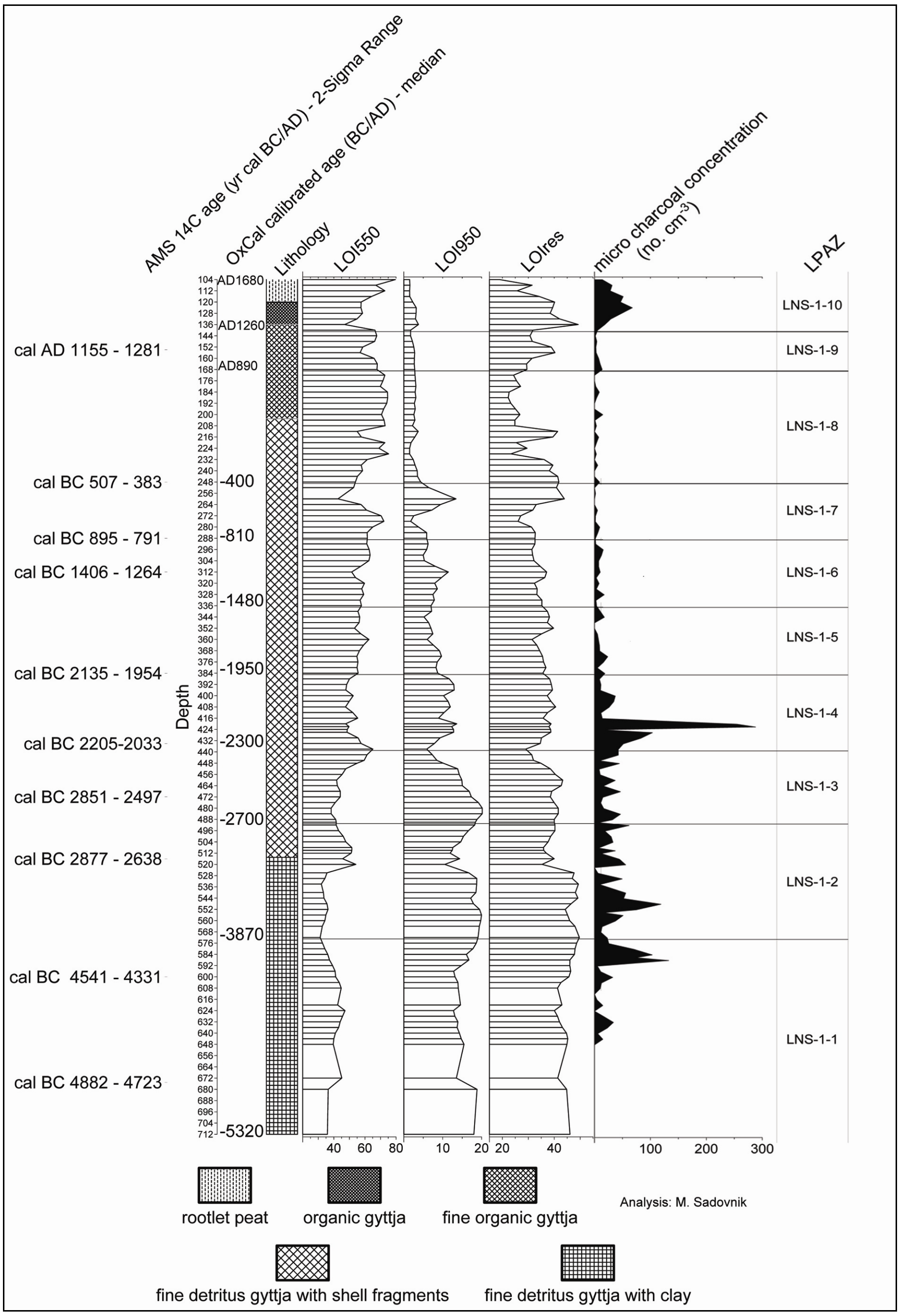

Fig. 5 Loss-on-ignition and micro charcoal concentration diagram of the core sequence LNS-1.04–7.12 m

Discussion

Local paleoenvironmental development

Land use history and vegetation changes in northern Germany are relatively well palynologically investigated on a regional scale, due to a number of regional pollen studies (e.g. Glos 1998; Overbeck 1975; Wieckowska et al. 2012; Wiethold 1998; Wiethold and

Lütjens 2001) from larger lakes and mires. In contrast, only few palynological contributions were made based on data from small lakes and mires (Dörfler 2008; Rickert 2006; Wieckowska et al. 2011), providing locally significant information on vegetation development.

However, palaeoecological investigations designed to study the local development in small selected sites allow for much more detailed information about the complexity of environmental change and settlement history (Behre 1981; Rickert 2006). The effect of the lake size and catchments area is of crucial importance. The experimental quantitative reconstructions of past vegetation (Sugita2007, 1994) have shown that larger lakes (with radius > 750m) with their extended pollen catchment area are appropriate for the reconstruction of regional vegetation history. In contrast, analyses of sediments in small lakes with 50–100m in diameter provide information about the vegetation and land use history in their closest surroundings (e.g. Hellman et al. 2009; Prentice 1985; Sugita et al. 1999). According to Sugita (1994), the pollen in small lakes reflects mainly the local vegetation and paleoenvironmental development from the lake within 300–400 m of the surrounding area. Prentice (1985) assumes the amount of local pollen in the sediments of small lakes of less than 30 m in diameter to be of 80–100%.

The Lünsee Lake, with its 14.7 m sediment record, allows the palaeoenvironmental reconstruction of local vegetation history and human impact due to its small size (100m in diameter) and in the absence of a major inflow. The current small size of the lake is likely an effect of the growth of the surrounding *Salix*-swamp, which occurred after the historical construction of drainage ditches and a dam. The digital terrestrial model based on LiDAR-data (**Fig. 1**) shows that the lake arose from the middle of a former dead-ice kettle hole, whose primary diameter was not more than 200m. However, the local topography of the Lünsee Lake within a former dead-ice kettle hole with wind-sheltered forest cover allows for further interpretation of the results of pollen and micro charcoal analysis, with a relevant significance at a local level.

Human impact during the Neolithic period (4100–1800 cal B.C.)

From an archaeological point of view, the earliest known human activities in the Westensee area are known from the Mesolithic period and represented by findings of stone tools (State

Archaeological Department Schleswig-Holstein - *unpubl. data*). The first appearance of agrarian food production (Kirleis et al. 2012) coincided in northern Germany and south Scandinavia with the construction of thousands of megalithic tombs of the Funnel Beaker Culture (~4100–2800 cal. B.C.) (e.g. Müller 2011; Müller et al. 2010; Rasmussen and Bradshaw 2005). There are 17 megalithic graves, as well as 34 findings of flint tools, give evidence of human activities in the wider area during the Middle Neolithic (Sadovnik et al. 2010), with a period of more intense human activity from the late Early Neolithic ~3500 cal B.C. to the early Middle Neolithic ~3300–3200 cal B.C. (Sadovnik et al. 2012).

During this period, the landscape was dominated by a *Quercus*- forest with high proportions of *Ulmus* and *Tilia,* before the distinct decline in elm (Zone 1). The first occurrence of Cerealia-type pollen grains (*Triticum- Avena*-type) around 3870 cal B.C. coincides with the elm decline and correlates with the first appearance of *Fagus*-pollen in the record (*Zone 2*). An increase of *Betula* pollen (~3870–3370 cal B.C.), followed by the elm decline, can be interpreted as secondary woodland succession of birch colonisation of burned areas (Tinner et al. 1999).

In contrast to the regional pollen records (Wieckowska et al. 2012; Wiethold 1998), the increase in anthropogenic activities in the Middle Neolithic from the Lünsee Lake record may have been a more gradual process. This intensification in human impact is reflected in the increase of Poaceae, *Artemisia*, *Rumex acetosa-t*ype and *Plantago lanceolata* around 3500 cal B.C*.,* which indicates small-scale arable farming and grazing near the lake. Further expansion of the heliophytic hazel at around 3370 cal B.C. is correlated with the strong charcoal peak, this suggests that the forest clearing that occurred was caused by fire.

However, only few Cerealia-type (undiff.) pollen grains were identified for the Middle Neolithic period (~3500–2700 cal B.C.). It is possible that the small scale arable fields occurred locally, due to the poor dispersal characteristics of most cereal pollen types (Behre and Kučan 1986). Between ~2930–2800 cal B.C. the number of anthropogenic indicators was significantly low. This is in accordance with a period of low human activity, recorded in the regional and local pollen records (Dörfler 2008; Schuschan 1989). A settlement discontinuity in the area during the transition period between Funnel Beaker and Single Grave Culture could be one explanation. A further period of Neolithic human activities and disturbance in the forest composition can be dated to ~2470–2370 cal B.C., during the Single Grave Culture. The high value of *Corylus* indicates a large-scale forest clearing, as well as distinct decrease in

Fraxinus and short-term decrease in *Quercus*. For this period the *Ulmus* curve was relatively scarce, around 2500 cal B.C., and *Tilia* has a distinct drop. The relatively high charcoal signal, together with high occurrence of Poaceae and *Plantago lanceolata,* suggest forest grazing and burning practices. In the opposite, single grains of Cerealia-type are recorded in the lowermost values. The remarkable decrease in *Alnus*-pollen at 2630 cal B.C. possibly indicates a Late Neolithic coppice of alder forest in the surrounding of the lake (see Wiethold 1998).

A distinct drop in indicators of anthropogenic activities occurred in the upper part of the *Zone 3*, around 2370–2250 cal B.C, which is reflected again in the regeneration of elm and lime in the forest composition. The input of organic material in the lake sediments was remarkably high, but declined notably after 2300 cal B.C. This phase correlated well with the period of low human activities in the region during the Nordic Flint Dagger Neolithic Period (Kristiansen 2010). During the Late Neolithic ~2200–1950 cal B.C. (*Zone 4*) a high occurrence of Cerealia-type as well as increases in the anthropogenic indicators like *Plantago lanceolata Rumex acetosa*-type and Poaceae can once again confirm a major human impact around the lake and the presence of small arable fields in the vicinity.

Evidence of fire

According to previous palaeoecolocigal investigation from Schleswig-Holstein, the intensity of human activity during the Mesolithic/Neolithic transition seems to be low (Behre 2007).

No reliable evidence of cultivated plants exists younger than 4100 cal B.C. (Hartz et al. 2002; Kirleis et al. 2012). The pollen data of Lünsee Lake supports this suggestion. Low occurrence of indicators of opened landscape in the subcanopy indicate a very small localized opening around the lake in the Early Neolithic.

However, the micro charcoal record for this period is notable. The first high levels of microscopic charcoal indicate frequent and intensive fires in the area of the forest, close to the Lake Lünsee, at 4100–3870 cal B.C., and this was correlated to the elm decline. The periods of intense forest fires during the Early Neolithic period with notably high peaks of charcoal signals are detectable at4100 cal B.C., 3510–3370 cal B.C. and 2300–2150 cal B.C.

Anthracological studies (e.g. Conedera et al. 2009; Tinner et al. 1998) have demonstrated, that microscopic charcoal particles reflect fire in at all scales, including local and regional source areas within 20–100 km around a site. The microscopic charcoal signal can also indicate transported micro charcoal particles.

The Early Neolithic fire evidence from the catchments area of Lünsee Lake corresponds to some of the palynological and anthracological records from northern Germany and southern Scandinavia, indicating relatively high fire activity and intensive forest burning from Neolithic times onwards (e.g. Greisman and Gaillard 2009; Wieckowska et al. 2012). These fire occurrences seem to be connected to human usage of fire as a tool to manage the landscape, during the initial phase of the landuse (Robin et al. 2012a). Analyses of micro and macro charcoals from the kettle hole mire 'Brunsrade Moor', (Sadovnik and Robin -*unpubl*.), located c. 2 km southwest of Lünsee Lake, showed that around 4100 cal B.C. major fire events occurred at the investigation site. In comparison to the smaller forest fire signals during the Atlantic period, which can be explained by natural reasons, the strong periodic evidence of fires between 4100 and 3600 cal B.C. are likely to be caused by humans.

Strong signals of microscopic charcoal in the Lünsee Lake record match with the periods of human activity and forest disturbances during the Neolithic. It is possible that frequent anthropogenic forest fires in the area may have additionally resulted in the elm decline (see Wiethold 1998). However, the value of microscopic charcoal from the Bronze Age is lower compared to the Neolithic period. This evidence stands in contrast to a higher number of charcoal signals during the Bronze Age in the regional pollen records. This led to the assumption that micro-charcoal signals seem to support the important Neolithic fire activity at the local level. It is possible that Bronze Age settlers used the surroundings of the lake mainly for livestock farming, resulting in lower amounts of micro charcoal.

Bronze Age (~1800–550 cal B.C.) activities

Archaeological investigations and historical studies (Aner et al. 2005; Von Hedemann-Heespen 1906) indicate an increasing intensity of land use during the Bronze Age, but there are no settlements known.

In the pollen record most of the anthropogenic indicators were still present without a significant change in the beginning of the Early Bronze Age (*Zone 5*). No cereal cultivation was detected from ~1800–1700 cal B.C. Moreover, slightly increasing in *Quercus, Fraxinus* and *Ulmus* indicating a forest regeneration and possible lower anthropogenic pressure on the local woodlands. From around 1230 cal B. C. a significant human pressure on the landscape was detected. With the beginning of the *Zone 6*, the pollen record showed remarkable changes in the local vegetation composition, which were closely connected to high human activities. The low percentage of arboreal pollen can be seen as an evidence for a more opened landscape. The strong increase in wild grasses Poaceae, *Plantago lanceolata*, *Artemisia*, *Rumex-acetosa,* reflected pastoral activities. *Calluna* served as an indicator of heathland (Nelle and Dörfler 2008) and occurred in this period. The high presence of *Typha latifolia* indicated the formation of swampy terrain along the lake margin. Together with the increase in *Nymphaea*, this suggests a decline in the lake level (Stolze et al. 2012). A high degree of human activities and soil erosion near the lake also reflects in the high carbonate and minerogenic content in the lake sediments around 530 cal B.C. Cerealia-type pollen grains points to a more intensive arable farming in the surroundings. Remarkable is the presence of *Betula,* indicating several forest successional stages. The increase of long distance transported *Pinus* pollen grains (Tipping 1989) can also be seen as a further evidence of forest openness. *Fagus* begins to spread, *Tilia* and *Ulmus* present underrepresented low values. However, it is possible that in addition to local human activities the climatic Subboreal-Subatlantic transition ~850 yr B.C. (van Geel 2001; Mauquoy et al. 2004) accompanied with cold and wet conditions, affected the vegetation composition and environmental conditions for this period. The warm adapted *Tilia* became fragmented during this period of time, possibly due to the human disturbance (Björkman 1997) or climatic deterioration (Wieckowska et al. 2012).

Establishment and expansion of *Fagus sylvatica*

Despite the fact that the Holocene spread of *Fagus sylvatica* in central and Northern Europe can be obtained from the fossil pollen records, as *Fagus*-pollen does not disperse far from its source (Bradshaw 2004; Küster 1995), the history of establishment of European beech forest is still under debate. Different factors like multiplicative biological processes, climate conditions and competition with other tree taxa may have affected its spread from glacial refugia during the Holocene. Local microclimatic conditions or site disturbance might be important for the establishment of beech stands in a scattered pattern (Bialozyt et al 2012).

Palaeoecological investigations from Scandinavia have demonstrated a close connection between Holocene *Fagus* spread and human activities (Björkman 1999; Bradshaw and Lindbladh 2005). The investigation of beech ecology in North America suggested a strong correlation between *Fagus* pollen frequency and beech abundance in forests within 5 km of the pollen site (Bradshaw and Webb 1985). It is also known that a 1% of beech pollen in the terrestrial pollen sum is strong evidence of an existing of *Fagus grandifolia* population within 20 km. (Woods and Davis 1989). Magri (2008) discussed periods of establishment and expansion of *Fagus* in Europe and pointed out that 2 % of *Fagus*-pollen is strong evidence for presence in the local vegetation and suggests the establishment of small populations of *Fagus*, which were unable to expand in forest communities for thousands of years.

According to the “patch dynamics theory” (Amarasekare and Possingham 2001; Bradshaw and Lindbladh 2005) the steep rise of the *Fagus*-pollen in the local diagrams is almost abrupt, especially in comparison to the records from the large lakes and mires (Rickert 2006). This can be explained by the fact that *Fagus*-pollen became a part of the regional pollen rain for the first time only after its establishment as a part of local forest vegetation. Due to the dominance of local pollen rain in the record, the regional temporal distribution of *Fagus* cannot be conclusively estimated in this way. Schmitz (1951) had already shown a presence of *Fagus* pollen with low values in the middle of the Atlantic period for the pollen diagram Wakenitzmoor near Lübeck in the Eastern Hill Land in Schleswig-Holstein. This was considered as evidence of the occurrence of some local, isolated beech populations in the region. This early finding was not confirmed by later pollen studies (Wiethold 1998).

In some diagrams from northern Germany, the presence of *Fagus*-pollen is detectable for the first time from the transition period from the Atlantic to the Subboreal (Wiethold 1998 Wieckowska et al. 2012) but as very low value. Moreover, the establishment of *Fagus* in northern Germany occurred preferentially on the young moraine cambisols and luvisols rather than on the poor sandy soils of the geest in northwestern Germany (Rickert 2006).

Thus, it is necessary to confirm the possibility of early occurrences of *Fagus* with studies of plant macrofossils. Currently, the oldest macrofossil evidence of *Fagus sylvatica* L. in northern Germany is a charcoal from a soil profile in the Stodthagen Forest, situated approximately 30 km north-east from the Lake Lünsee, which was dated by ^{14}C AMS-measurement to 2623–2473 cal B.C. (Robin et al. 2012b). This demonstrates the Neolithic local presence of *Fagus* in the region, earlier than expected from the general knowledge about *Fagus* immigration in the northern part of Central Europe Certainly, a better understanding of the complexity of establishment and expansion of *Fagus sylvatica* L. in northern Germany and relations between human activities and this species needs further palaeoecological investigations.

At Lünsee, pollen grains of *Fagus* occurred for the first time around 3870 B.C., fitting with the first cerealia-type pollen and the elm decline. Around 2150 cal B.C., a significantly strong charcoal peak is fitting with a notable peak of *Fagus* pollen. This evidence led to the conclusion that human-mediated disturbances may have spread up *Fagus* stands in the area during the Late Neolithic, though only for a short term. It seems possible that small populations of *Fagus* occurred in the area since the Late Neolithic period, but were able to spread only after the period ofmore intense human activities in the Bronze Age. According to the age-depth model, the local expansion of *Fagus* at Lünsee happened during the Bronze Age. This was significantly earlier, compared to regional pollen diagrams in the wider area. At the end of the Bronze Age, and followed by Pre-Roman Iron Age (~550 cal B.C.– A.D. 0) human impact decreased. Around 480 cal B.C. a low percentage of anthropogenic indicators was once again present in the pollen record, indicating a time when the human settlements were probably relocated outside the lake surroundings. The *Fagus*- curve appears to reach a maximum in two steps and obtained a value of 16% in the pollen diagram around 400 cal B.C. in the Pre-Roman Iron Age. A second local expansion of *Fagus* took place at several points with a culmination state of *Fagus* stands from cal A.D.100 onwards. This generally coincided with lower local human impact during the Iron Age, followed by the disturbance of the pre-existing forest composition in the Bronze Age. Further *Fagus* abundance in the Roman Age (A.D. 0–400), lead to the conclusion that its culmination stage occurred during the period, with a minimum of local evidence of human activities. The landscape around the small Lake Lünsee was finally covered by *Fagus* forest, dominated in the surroundings during the Roman Iron Age and Migration Period (A.D. 400–720). The pollen record shows a long period of forest regeneration (*Zone 8*) and lower abundance of anthropogenic indicators. The discontinuous presence of Cerealia-type pollen and Poaceae also reflects reduced human impact in the surroundings of the lake. *Secale*-pollen occurred, but in very low value. Around A.D. 510 the pollen diagram showed very low anthropogenic activities and forest recovery, which shows a settlement interruption, recorded in some regional pollen records during the Migration Period (see Wieckowska et al. 2012). *Fagus*-forests showing a significant disturbance due to intense human activity and forest clearance during the Early Middle Age/Slavic Period (*Zone 9*). The intensity of land use and disturbance of *Fagus* forest increased significantly in the Late Middle Ages (*Zone 10*), from about A.D. 1260. The intensity of fire signal increased significantly again, due to an intense forest clearance in the Late Middle Ages.

Conclusions

The Lünsee record provides fine-scaled information about the development of local human activities as well as vegetation dynamics in the Westensee moraine area of the East Hill Land, northern Germany. The study shows the significant potential of small lakes for the new assessment of vegetation dynamics and human impact in a region which hitherto was investigated predominantly by regional palynological records. The recorded data indicate human activity from the Early Neolithic, around 4100 cal B.C., with increasing intensity around 3500 cal B.C, probably as small-scale arable farming and grazing near the lake.

The microcharcoal record show the frequent use of fire possibly connected to small local forest clearing, from the Early Neolithic onwards, with an increase of frequent fire signals during the Late Neolithic. However, during Bronze and Iron Age fire seems not to play a role for land management. Significant human pressure on the landscape was first observed around 1230 cal B.C., during the Bronze Age (~1800–550 cal B.C.), followed by a period characterised by slight local human impact during the Pre-Roman Iron Age. Very high local anthropogenic activities during the Bronze Age led to the assumption of the existence of a settlement in the closed surroundings of the lake, which is so far not known archaeologically. Low human impact and expansion of beech was detected during the Roman Iron Age (A.D. ~0–400) and the Migration Period (A.D. ~400–720). Due to cultural and social changes it is possible that the site was isolated from settlements and arable fields and was completely recovered by forest. The intensity of fire increased significantly again from about A.D. 1280, connected to an intense forest clearance during Late Middle Ages. An early local population of *Fagus* may have been present at the site in the Late Neolithic, as a result of beneficial effects of natural conditions as well as anthropogenic activities on the landscape. *Fagus* expansion occurred significantly earlier than can be seen in regional pollen records in northern Germany, during the Bronze Age, and seems to be connected to human activities.

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Part IV Synthesis and Conclusion

The present reconstruction of the forest history and landscape development was performed on the Westensee area in East Holstein Hill Land of Schleswig-Holstein for the first time. The investigated moraine woodland area of Westensee contains a multitude of lakes and kettle hole mires (Dierssen, 2005) with optimal conditions of the preservation of organic material. The archaeological evidence of prehistoric landscape use suggests earlier known human activities in the area from the Mesolithic period and also a period of more intense human activity from the late Early Neolithic ~3500 cal. BC until the early Middle Neolithic ~3300–3200 cal. BC (Sadovnik et al. 2012). Archaeological studies show continuous and intensive human activity on the area during Bronze Age (Aner et al. 2005).

In order to gain a better understanding of Neolithic and Bronze Age human origin and the complexity of the environmental changes, three selected sites in the area were investigated, with a multidisciplinary combination of different scientific approaches. The palaeoecological studies (pollen analysis, micro and macro charcoal analysis, loss-on-ignition analyses) were performed on woodland and opened agricultural landscapes, related to prehistoric sites of human activity. The palynological investigation allows the reconstruction of the vegetation composition and human impact in the past (Berglund 2011; Dörfler 2008) and a comparison with the modern landscape development (Gaillard et al. 1994). The pedoanthracological methods appear synchronous to indicate regional and local fire occurrences, as well as information about local woodland composition and fire history (Robin et al. 2012; Nelle et al. 2010). The results of loss on ignition, carbonate and mineral content analysis were used for the interpretation of the input of terrigenous mineral material, as an indication of forest clearing activities and other anthropogenic effects (Wieckowska et al. 2011; Wiethold 1998). Based on Bayesian-statistics, a chronological frame work was provided by 31 ^{14}C AMS radiocarbon dating and pollen-stratigraphic correlations. Consequently, an exact chronology of the vegetation changes under anthropogenic influence in the study area was to be both chronologically and spatially reconstructed.

Many different factors such as possible climate change or local population dynamics took part in the increase of human pressure on the landscape. Based solely on only one method of investigation, it is difficult to understand the periods of settlement abandonment, reduced human activity and forest regeneration (e.g. Robin 2011; Emadodin et al. 2009;

Dreibrodt et al. 2006). Therefore, the multi-proxy palaeoecological investigations for the Westensee area were combined with archaeological evidences. In a periphery of 5 km diameter the known archaeological records of all prehistoric time periods were analysed.

In order to study the landscape development in the Modern period, historical material and two historical maps (1758 and 1877) were used. Historical maps were acquired in the archive of the manor Deutsch-Nienhof. ATKIS® Digital Orthophotos DOP 5 and LiDAR data (Land Surveying Office Schleswig-Holstein® 2009) served as geobasis data. GIS-software was applied to precisely position the objects of investigation on digital maps, to calculate forest areas of the sites and to digitalise and georeference the historical maps.

Indicators of sudden intensification in land use and of major human impact were detected in the area during the last 6000 years. It can be assumed that in the beginning of the Neolithic period, the local population used the landscape in the surroundings of Westensee, in correspondence to their requirements, this being dependent on the social structure, landform configuration and environmental conditions. The first human impact on the landscape, was around 3800 cal BC, being discontinuous, nonetheless significant. Neolithic people used the landscape of Westensee and its resources for several purposes, such as burning, cultivation of livestock and small arable farming (Ehrmann et al. 2009, Nelle and Dörfler 2008) for the construction of megalithic graves, using them for ritualistic purposes (Andersen 2000; Lagerås 2000). The Neolithic transition from hunter-gatherer to farmer societies was interpreted in the woodland area of Westensee as a long process of adaptation, lasting more than 1500 years (see Nelle and Dörfler, 2008; Zvelebil and Dolukhanov, 1991).

The archaeological material from the study area indicate that human impact in the area took place in the Middle Neolithic, Bronze Age and Iron Age, which is corroborated by the pollen and charcoal records. This could suggest that human impact in the study area occurred periodically from the end of the Atlantic period. According to the changes of cultural periods and social structure of human societies, several forms of human activity within the same territory were observed.

It is possible that the forest at study site Krähenberg (core KRM) with five megalithic graves was opened in connection with the construction of the megaliths around 3500 cal BC. After this short, moderate opening, forest recovery in the surrounding area took place over a period of c. 400 years. The megalithic graves were present in a wooded landscape.

In accordance to the high-resolution pollen regional diagrams (Lütjens and Wiethold, 1999; Wiethold and Lütjens, 2001;), especially from the lake Belauer See (Wiethold, 1998), the first period of small forest opening at local level could be connected with human impact dates to approx. 3500 cal. BC. However, in the vicinity of these megalithic graves there is a very low occurrence of anthropogenic indicators and underrepresented value of cereals in the pollen diagram, during the Neolithic Period. At the end of Neolithic period the surrounding megalithic landscape was used as a semi-open pasture, but without cereal cultivation.
This can be seen as evidence that the site was not used during the Funnel Beaker Culture or that it was solely used as a specialised place of ritual. Similar to the results of current investigations of the megaliths of Altmark in Saxony-Anhalt in Germany (Demnick et al. 2008), in Denmark (Andersen 2010) and in south Sweden (Sjörgren 2010; Axelsson 2010), investigated graves were isolated from settlement and arable fields areas in the time of the Funnel Beaker Culture. Forest composition during the Neolithic period changed with a succession from *Quercus* to *Betula* to *Alnus* periodically. The reasons and processes of this phenomenon are yet to be understood. Clear indication of land use with arable fields and cereal cultivation was recorded only around 1200 cal BC. Pollen and charcoal evidence suggests the onset of the formation of an open agrarian landscape and the creation of pastures at Krähenberg first in the Bronze Age. Palaeoecological research at the Krähenberg study site provides possible explanations of the role of megalithic graves in the landscape of Middle Neolithic in Schleswig-Holstein. The results point towards the spatial and visual separation of the megalithic graves of the Funnel Beaker Culture, from settlements and cultivated areas in the landscapes during the Neolithic period.

The palaeoenvironmental reconstruction of the vegetation of the kettle hole mire 'Brunsrade Moor' (core MDK) is represented in the vegetative history in the Westensee area from the early Holocene. Analysis of the historical sources set the results of anthropogenic influence from the Modern Period. Our investigations have shown that the kettle hole mire within the dense forest, which was nearly inaccessible for regular human landuse, was possibly utilized as hunting areas by Mesolithic/Neolithic people. Analyses of micro and macro charcoals have shown that around 4100–4000 cal BC major fire events occurred at the investigation site. This was interpreted as a consequence of hunting practices during the Late Mesolithic and Early Neolithic periods. In comparison to the smaller forest fire signals during the Atlantic period, which can be explained by natural reasons, the strong periodic evidence of fires between 4100 and 3600 cal BC are likely caused by humans.

The mire probably developed a raised bog stage at the end of the Atlantic period, but did not reach this state completely due to peat cutting in the Middle Age and drainage in the 18th century. Determination of the mire typology was only possible by a combination of stratigraphical, pollen and vegetation analysis. This is because of correlations between vegetation composition, hydrological conditions and nutrients dynamics, which were altered due to anthropogenic influence over the last 250 years. Marginal drainage of the mire had a strong influence on the growth of mosses. Changes in the vegetation of the mire and surrounding landscape were mainly caused by human influence. The study has also shown, that in spite of visible anthropogenic impact in the beginning of the Early Neolithic, the kettle hole mire 'Brunsrade Moor' contains ample regenerative potential and functions as a refuge area for protected plants and game animals. The Brunsrade mire is relevant for nature conservation and evokes great scientific interest, providing the possibility of a detailed investigation of vegetation, landscape, hydrological and climatic changes in the area.

Investigations at the study site Lünsee Lake, (core LNS-1) include the period between approximately 5300 cal BC and AD 1600. The pollen diagram suggests first the onset of cereal cultivation in the area around 3800 cal BC, which occurred at the same time as the decline in the elm and correlates with the first increase in *Fagus*-pollen in the pollen record. Only few Cerealia-type pollen grains were identified for the Middle Neolithic, probably indicating small and local arable fields in the study area. Presumably, common beech was already present in the area since the Neolithic period, but in rather small populations.

The remarkably high value of *Fagus*-pollen around 2150 cal BC and an increase in the number of charcoal signals in the pollen diagram can be interpreted as an association between establishment of common beech and anthropogenic activities like clearings and fire events. It is widely assumed that first appearance and the spread of *Fagus sylvatica* L. in northern Germany and south Scandinavia was additionally supported by human activity (e.g. Bradshaw et al. 2010; Bradshaw and Lindbladh 2005; Tinner and Lotter 2006). However, a major presence of common beech in the area of Westensee is clearly detectable from ca. AD 100. The high-resolution pollen regional diagram from the Belauer See determines the 'landnam period' *sensu* Iversen (1941) between ca. 3340-2780 cal BC (Wiethold 1998). In contrast, the pollen diagram LNS-1 from the Lünsee Lake shows low presence of anthropogenic indicators during the Middle Neolithic period. Only few Cerealia-type pollen grains were identified for the Middle Neolithic, probably indicating small and local arable fields in the study area.

Nevertheless, the results of charcoal analyses from the core LNS-1 lead to the conclusion that the frequent use of fire, and possibly local small forest clearing, had occurred on the area since the Early Neolithic, around 4100–4000 cal BC, with an increase of frequent fire signals during the Late Neolithic, around 2200 cal BC. The high intensity of human activities on the area was observed first around 1200 cal BC, during the Bronze Age (~1800–550 cal BC), followed by a period characterised by locally slight human impact during the Pre-Roman Iron Age (~550 cal BC–AD 0). Significant low human impact and forest regeneration was detected around Lünsee Lake during the Roman Iron Age and (AD 0–400) and Migration Period (AD 400–720). Common beech forests, dominated in the surroundings from AD 100 showing a significant disturbance due to an intense human activity and forest clearance, during the Early Middle Age/Slavic Period (AD 720–1143). The intensity of land use increased significantly in the Late Middle Ages, from about AD 1280.

The recorded data from the end of the Atlantic period (i.e. from the Neolithic transition during the period of the Funnel Beaker Culture) was completed with the qualitative reconstruction of the vegetation and human impact in the area of Westensee. The detected interactions between human and nature provide the conclusion that about 6000 years of human influence on vegetation and land use activities resulted in the modern landscape of the Westensee area.

The results of palaeoecological investigations suggest that modern forest ecosystems with a high population of common beech are a product of succession, mainly caused by human influence. Therefore they are elements of a cultural woodland landscape. Thus, according to our investigation, a concept of 'Cultural Landscape' in northern Germany can be applied to the study area having begun in the Neolithic period.

The presented investigations provide detailed information about the development of local vegetation and human impact on the area of Westensee. However, a better understanding of the complexity of the environmental changes and relations between human and nature needs further palaeoecological reconstructions of small selected areas in northern Germany, on a detailed, fine spatial scale, using a multi-proxy approach.

References Part IV

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Part V Appendixes

Index of Appendixes:

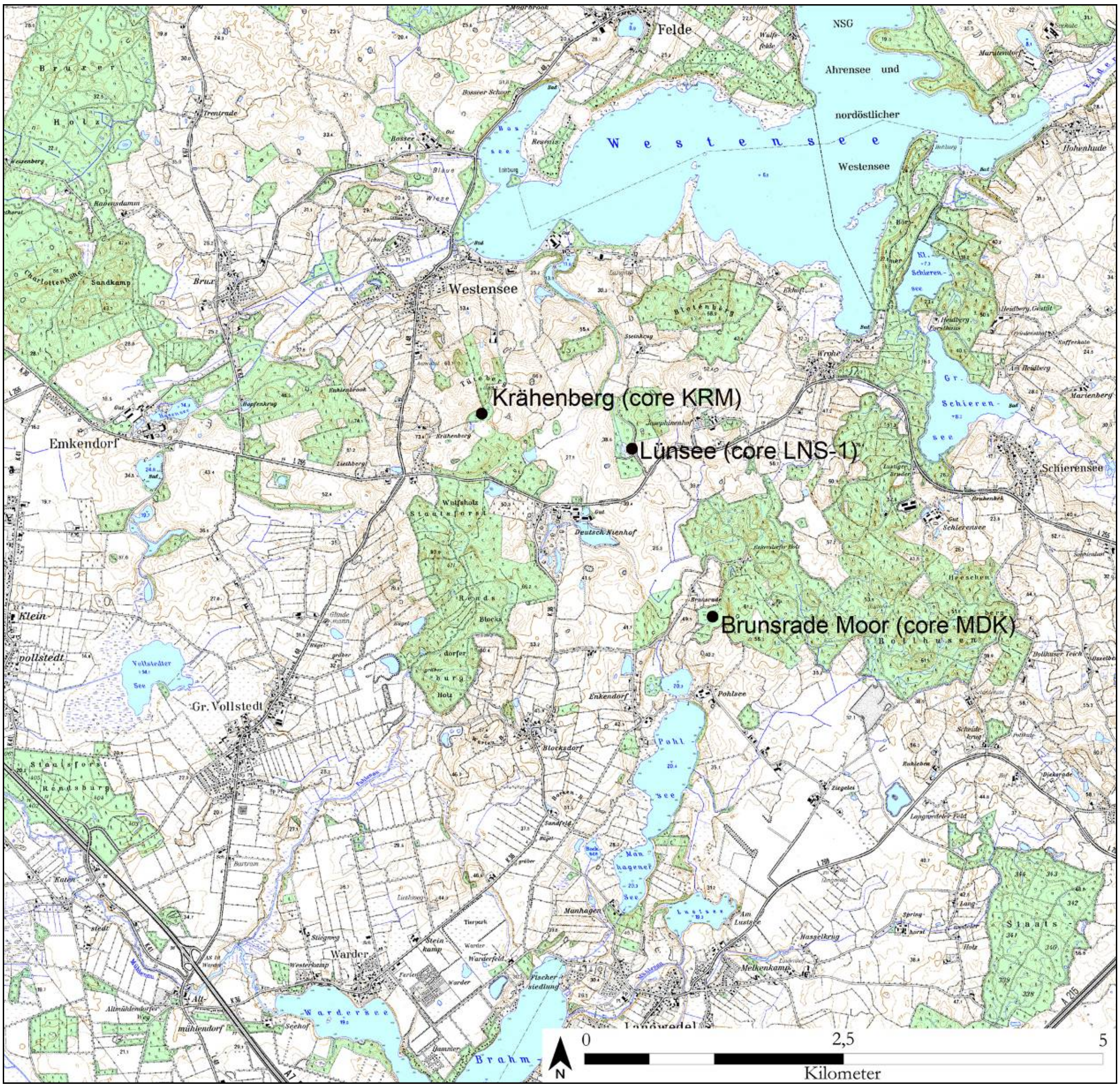

Figure 1. Investigated sites at the map TK 25 1725 Westensee: Kettle hole mire ’Brunsrade Moor’ (core MDK); mire at Krähenberg (core KRM); Lünsee Lake (core LNS-1)

Figure 2. Sediment sequence of the core MDK 0.20–5.55m (kettle hole mire ’Brunsrade Moor’). Two parts of the core in length and both half are shown

Figure 3. Sediment sequence of the core KRM 0.20–5.60m (mire at Krähenberg)

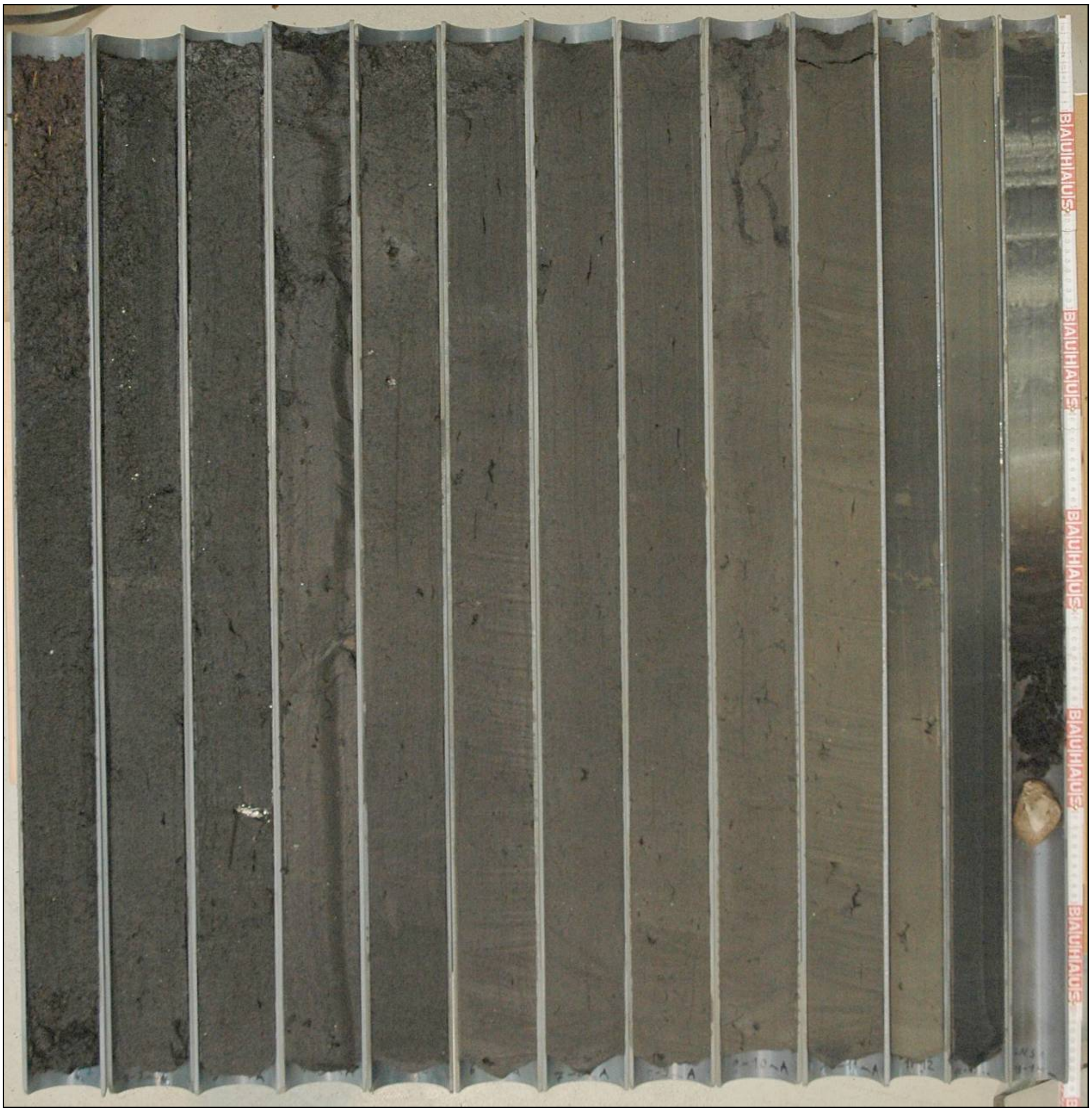

Figure 4. Sediment sequence of the core LNS 1.04–14.70m (Lünsee Lake)

Figure 5. Megalithic graves and investigated mire at Krähenberg

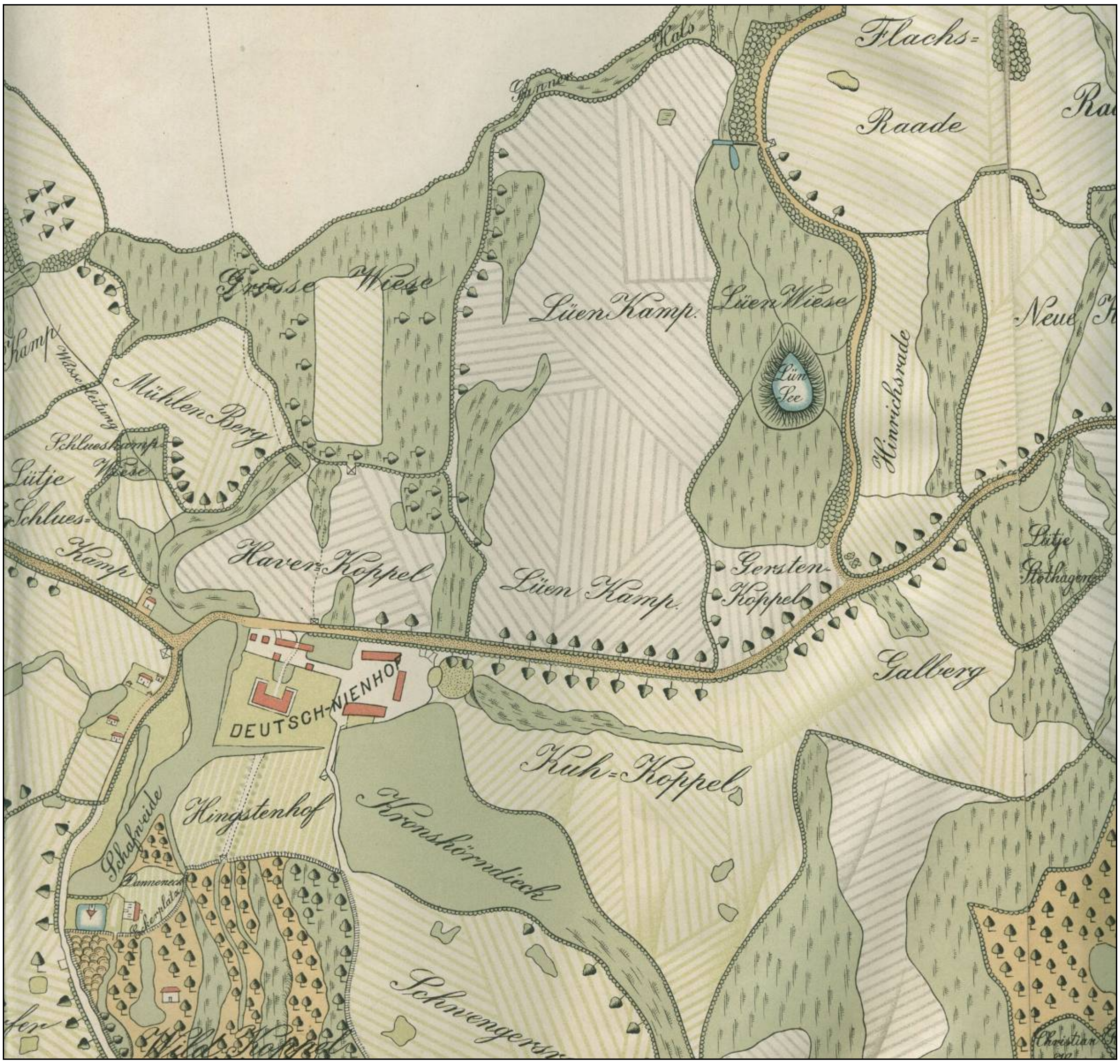

Figure 6. Lünsee Lake (Lün See) at historical map by the land surveyor P. Reyer (1758)

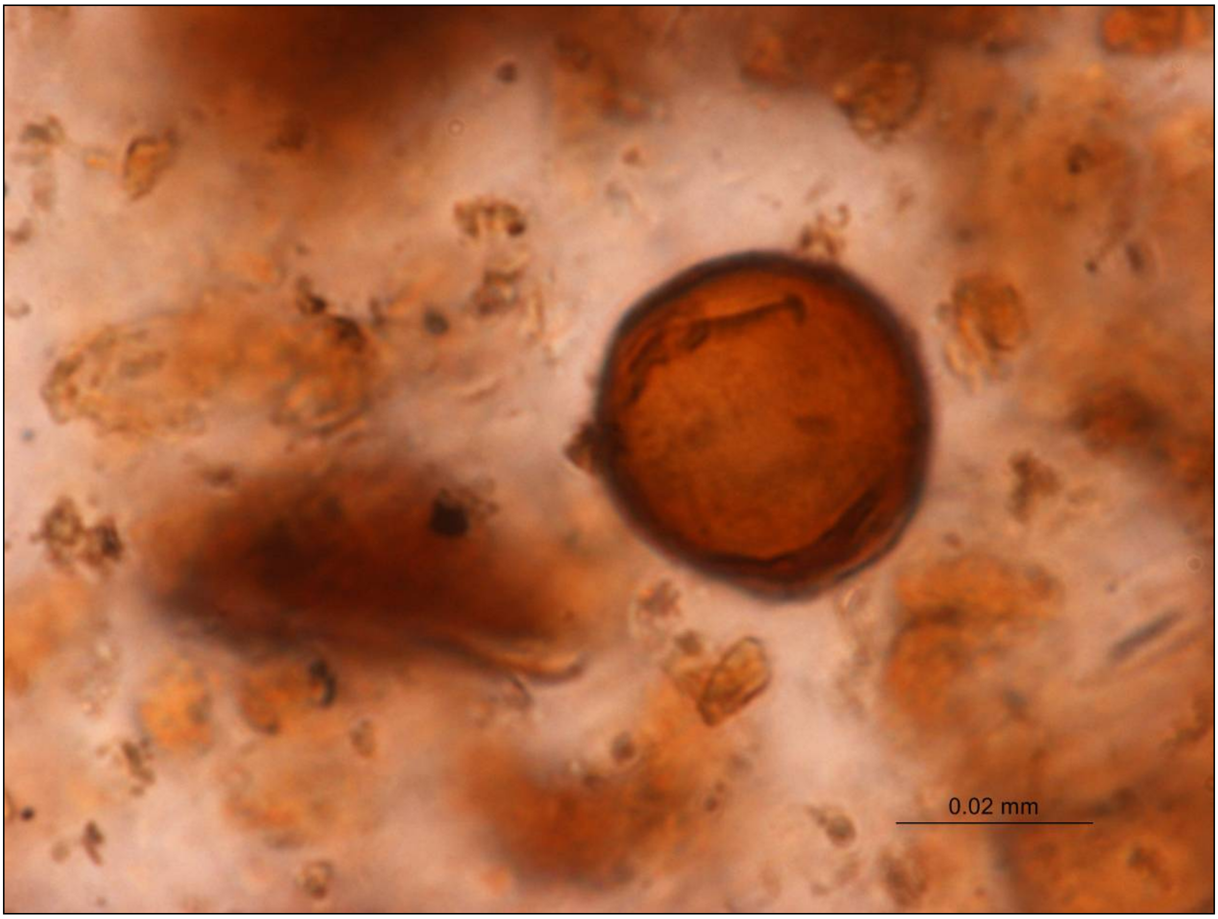

Figure 7. *Fagus*-pollen from the core LNS-1, sample depth 4.12m, OxCal modelled age: 2180–2050 cal BC (2-Sigma)

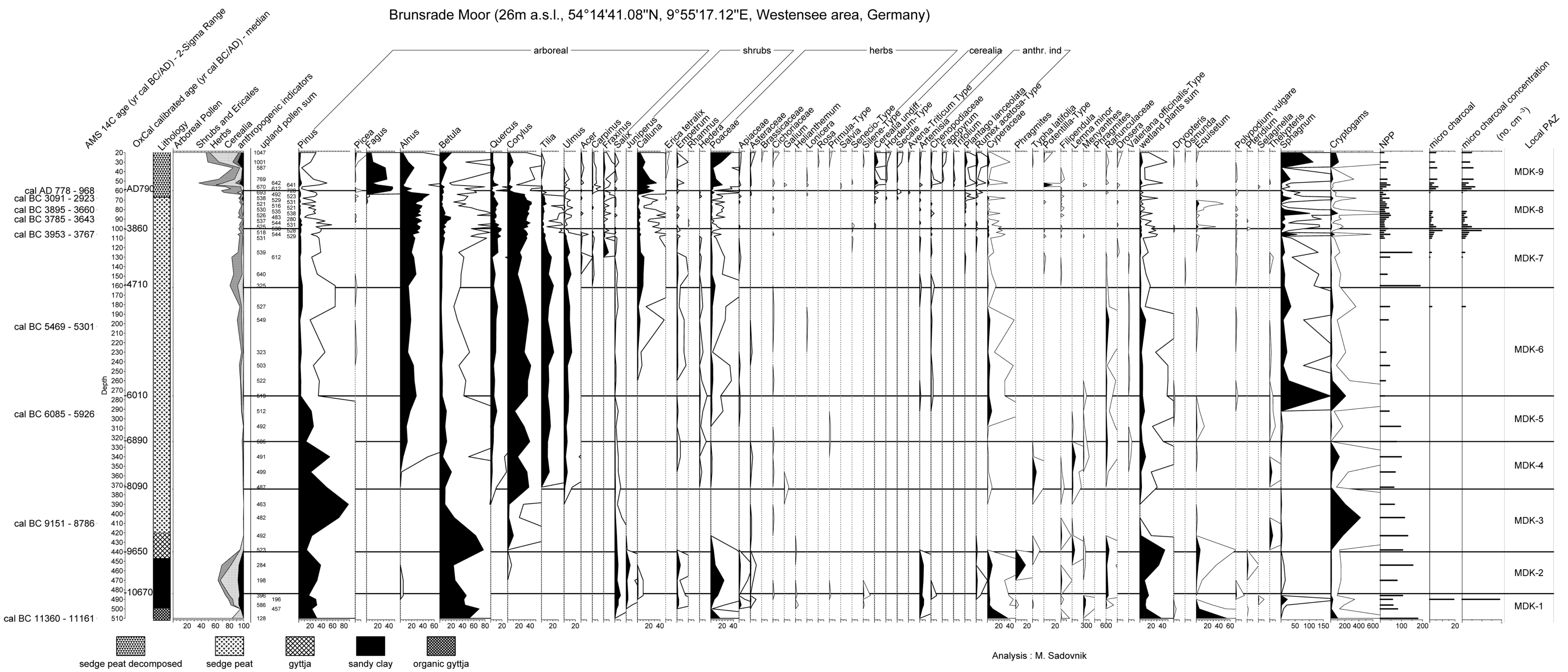

Diagram 1. Percentage pollen diagram MDK 0.20–5.10 m. Values refer to the upland pollen sum. White curves are exaggerated by 10, LPAZ, local pollen assemblage zone

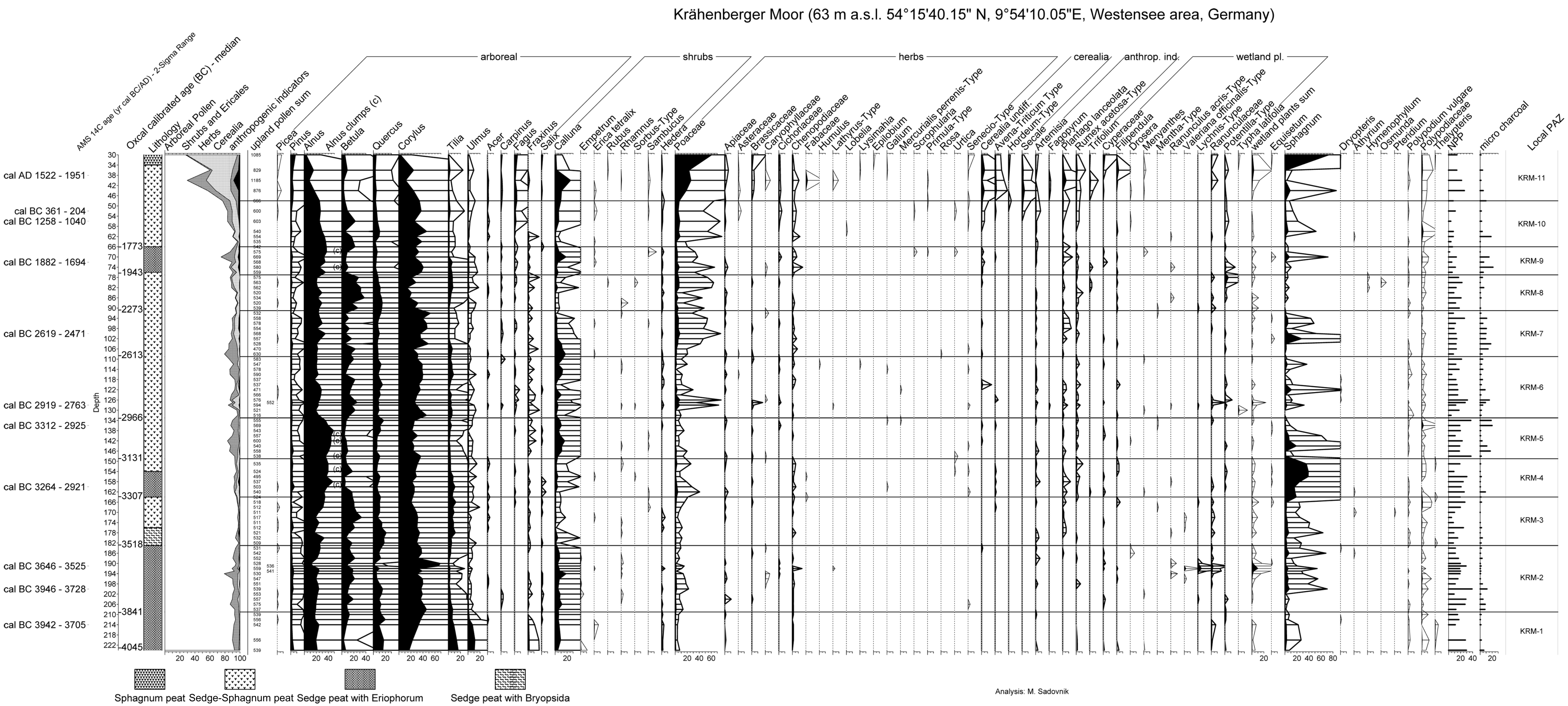

Diagram 2. Percentage pollen diagram KRM 0.20–2.24 m. Values refer to the upland pollen sum. White curves are exaggerated by 10. LPAZ, local pollen assemblage zone.

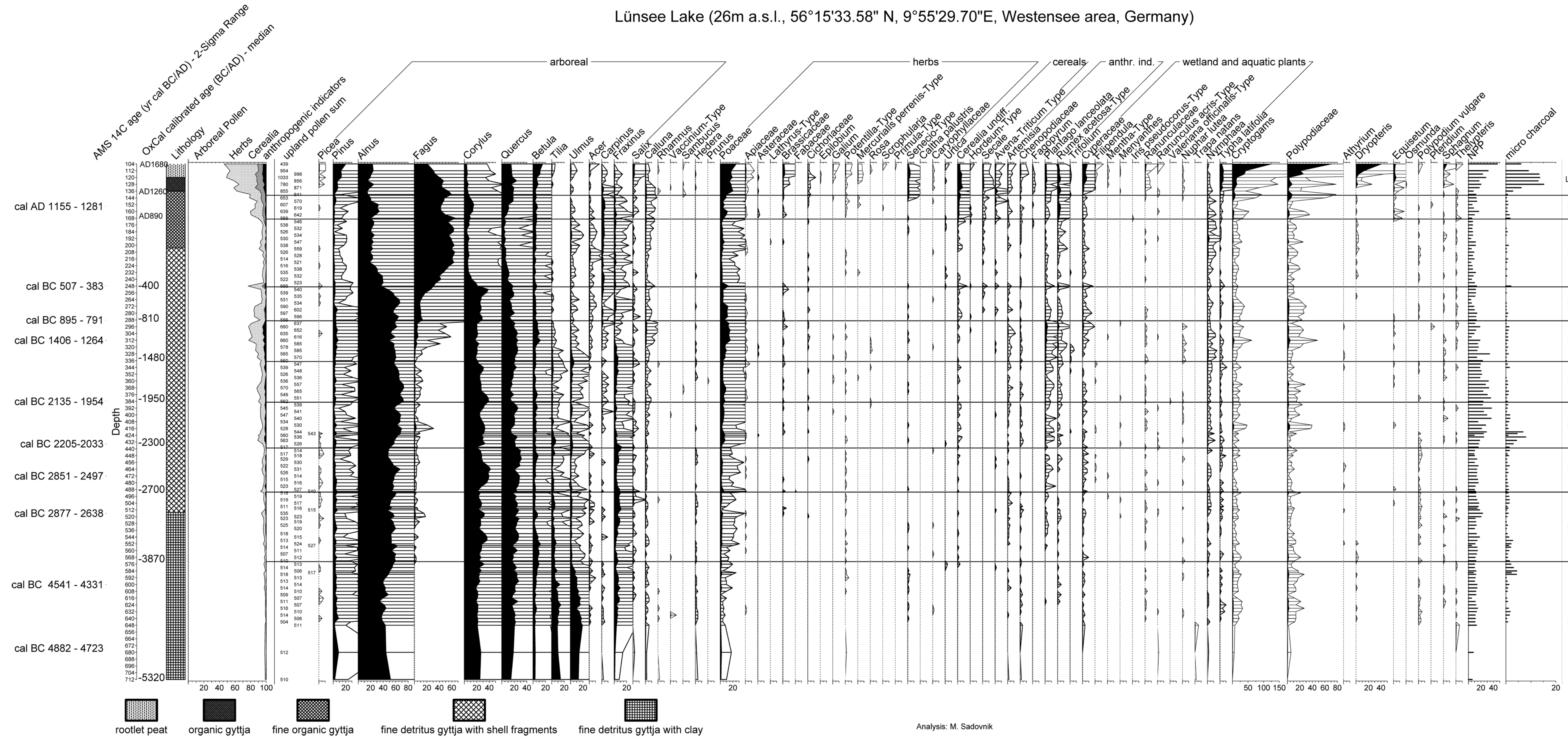

Diagram 3. Percentage pollen diagram LNS-1.04–7.12 m. White curves are exaggerated by 10. LPAZ, local pollen assemblage zone.