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Synthesis of Palaeo-data from On- and Near-site Sediment Sequences: a Diachronic Contribution to the Palaeoenvironment and Settlement History of the Duvensee Area with Special Reference to the Mesolithic

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ABSTRACT

This paper presents a synthesis of the results to date of the palynological research carried out in the Duvensee area of Schleswig-Holstein, Germany, referring to several published and unpublished on- and near-site sediment sequences. With the onset of the Mesolithic, humans were confronted with a gradual but continuous transformation of the environment: The initially light forests became darker and darker, the steep lake terraces became shallow and increasingly silted up, and islands appeared. After the transition to the Boreal, around 8750 cal BC, the islands seem to have played a special role in the use of the hazel *(Corylus)*. Especially for the early Boreal, it could be shown that the artefacts embedded in the profile columns from different camp sites correlate with the increased occurrence of *Corylus* pollen. However, the use of hazel was probably not limited to hazelnuts. Atypical changes within the *Corylus* spectra in pollen records from cultural layers indicate the use of hazel for additional purposes. Furthermore, synchronous local and regional fluctuations in the proportions of *Corylus* also point to phases with poorer growing conditions for hazel shrubs, which can be attributed to local hydrological changes and to climatic effects. Such environmental changes may have affected the behaviour pattern of hunter-gatherer societies. Mesolithic land use is difficult to capture through pollen analysis. It seems, however, that longer use of sites is reflected in the pollen spectra, rather than short-term stays. Anthropogenic land use in the Duvensee area remains relatively low after the Mesolithic. There is only minimal evidence for arable activities from the entire Neolithic. Instead, grazing was practised on a small scale, probably in the woodlands around the lake. It is only from the end of the Bronze Age that a clear change in land use is evident, consisting of a much stronger orientation towards the use of large-scale, open grassland areas. Another significant change in landscape use took place during the High Middle Ages, when intensive cereal cultivation and pastoral farming were practised, which also included management of the now-established peat bog or its immediate surroundings.

Keywords: Mesolithic, Duvensee, land use history, hydrological changes, On- and near-site sediment sequences

ZUSAMMENFASSUNG

Der vorliegende Beitrag stellt eine Synthese der bis heute im Gebiet von Duvensee (Schleswig-Holstein) durchgeführten palynologischen Untersuchungen dar, die sich auf mehrere veröffentlichte und unveröffentlichte Sedimentsequenzen von den archäologischen Fundplätzen selbst oder deren Umgebung bezieht. Mit dem Beginn des Mesolithikums wurde der Mensch mit einer sich allmählich, aber kontinuierlich verändernden Umwelt konfrontiert: Die ursprünglich lichten Wälder wurden immer dunkler, die steilen Seeterrassen wurden flacher und verlandeten zunehmend, und es entstanden Inseln. Nach dem Übergang zum Boreal um 8750 cal BC scheinen die Inseln eine besondere Rolle bei der Nutzung der Hasel gespielt zu haben. Insbesondere für das frühe Boreal konnte gezeigt werden, dass die in den Profilsäulen verschiedener Wohnplätze eingebetteten Artefakte mit dem vermehrten Auftreten von *Corylus*-Pollen korrelieren. Die Verwendung von Hasel war jedoch wahrscheinlich nicht nur auf Haselnüsse beschränkt. Atypische Veränderungen in den Pollenspektren von *Corylus* innerhalb

der Kulturschichten deuten auf die Verwendung der Hasel für verschiedene Zwecke hin. Darüber hinaus weisen synchrone lokale und regionale Schwankungen der *Corylus*-Anteile auf Phasen mit schlechteren Wachstumsbedingungen für Haselsträucher hin, die einerseits auf lokale hydrologische Veränderungen und andererseits auf klimatische Effekte zurückgeführt werden können. Solche Umweltveränderungen könnten die Verhaltensmuster der Jäger- und Sammlergesellschaften beeinflusst haben. Dennoch ist die mesolithische Landnutzung durch Pollenanalysen nur schwer zu erfassen. Es scheint jedoch, dass sich längere Nutzungen der Wohnplätze in den Pollenspektren widerspiegeln, im Gegensatz zu kurzfristigen Aufenthalten auf den Inseln. Auch über das Mesolithikum hinaus bleibt die Landnutzung im Gebiet von Duvensee relativ gering. Aus dem gesamten Neolithikum gibt es nur minimale Hinweise auf ackerbauliche Aktivitäten. Stattdessen wurde Weidewirtschaft, wahrscheinlich in den Wäldern rund um den damaligen See, in kleinem Umfang betrieben. Erst ab dem Ende der Bronzezeit ist ein deutlicher Umbruch in der Landnutzung zu erkennen, der in einer viel stärkeren Ausrichtung auf die Nutzung großflächiger offener Grünlandflächen bestand. Ein weiterer bedeutender Nutzungswandel fand im Hochmittelalter statt, als intensiver Getreideanbau und Weidewirtschaft betrieben wurden, wozu auch die Bewirtschaftung des nun entstandenen Moores bzw. seiner unmittelbaren Umgebung gehörte.

Schlagwörter: Mesolithikum, Duvensee, Landschaftsgeschichte, hydrologische Veränderungen, »On-« and »near-site« Sedimentsequenzen

INTRODUCTION

The ancient lake Duvensee region, in Schleswig-Holstein, northern Germany, is an archaeological hotspot, as many Mesolithic camp sites have been found during peat extraction. The intensive archaeological research that started in 1924 was in several instances accompanied by palaeoecological studies (Schwantes et al. 1925; Schwantes 1928; Schütrumpf 1981; Averdieck 1981; 1986 a; 1986 b; Bokelmann et al. 1981; 1985) (Table 1). An overview of the stratigraphic structure of the Duvensee sites has been given by K. Bokelmann in 2012, but a complete documentation and interpretation of the published and, additionally, several unpublished profiles has not been undertaken until now. Furthermore, the potential impact of human beings on the surrounding environment has never been evaluated, as it was generally agreed that anthropogenic activities prior to Neolithisation are difficult to trace due to both the lack of unambiguous palynological indicators and the hunter-gatherer-fisher way of life leaving only elusive imprints on the vegetation. However, having as accurate a picture of an environmental setting as possible is fundamental to understanding why Mesolithic people used the shore of lake Duvensee repeatedly over very

Table 1. Overview of the sites from Duvensee with palaeoecological investigations in chronological order. The table also shows a selection of specific characteristics (after Gross et al. 2018).

Island	Camp site identifier	Age	Evidence for hazelnut processing	No. of bark mats	Evidence occupation was short-lived	References
1	WP 8	Late Preboreal, 9050–8550 cal BC	yes	1	yes	Bokelmann et al. 1981
2	WP 11	Early Boreal, 8750–8250 cal BC	yes	20	no	Bokelmann 2012
2	WP 1	Early Boreal, 8750–8000 cal BC	yes	1	yes	Bokelmann 1971; Schütrumpf 1981; Schwabedissen 1949
2	WP 6	Early Boreal, 8650–7700 cal BC	yes	0	?	Averdieck 1981; Bokelmann 1980; Bokelmann et al. 1981
4	WP 21	Early Boreal	yes	0	?	unpublished
3	WP 13	Late Boreal, 8400–7350 cal BC	yes	3	yes	Averdieck 1986 b; Bokelmann 1986; 2012; Bokelmann et al. 1985
5	WP 17	Early Neolithic	?	?	?	Lübke 2000

long periods of time. Simultaneously, a detailed evaluation of the palynological data allows the identification of successive phases of different duration with reduced land use and raises question about their causes.

Near-site and especially on-site sediment sequences from short-term camp sites offer great potential for assessing local human–environment interactions over the course of the Mesolithic, i. e., the time window from 9200 to 6200 cal BC (Bokelmann 2012). Nevertheless, it should be borne in mind that the previous palynological work did not include the now-standard repertoire of proxies, such as analysis of microcharcoal or non-pollen palynomorphs, which provide additional evidence for anthropogenic disturbance. The absence of these additional settlement indicators complicates the detection of human impacts in the old data. The present re-evaluation is asking the following questions: How are the short-term but continuous utilisations of the Mesolithic camp sites reflected in the pollen data? Are there periods with differing patterns of land use? Have changes in the local environment affected the use of islands, for example by making them more difficult to access?

In this paper, the results of the palynological research carried out in the Duvensee area are synthesised and re-evaluated to provide a more accurate picture of the environmental development during the Mesolithic period. This compilation includes previously published as well as unpublished pollen data of the early Holocene on- and near-site sediment sequences from camp sites 1, 6, 8, 11, 13, 17, and 21 (Table 1). In addition, the so far unpublished standard pollen diagram, whose deposits cover the Late Glacial up to the Modern era, was finally described and interpreted to reconstruct the local vegetation and settlement history.

DATA ORIGIN AND HANDLING

Today's Duvensee peat bog (German: *Duvenseer Moor*) developed from a former ca. 4.6 km² lake that gradually silted up during the Holocene and that had been reduced in size to ca. 0.5 km² when it was drained in 1850 (Fig. 1). The lake itself arose before the Allerød, in the Late Glacial, within a dead-ice hole and reached its largest extent during the early Preboreal. The palaeolake basin features an irregular topography, characterized by numerous deep areas and shallows as shown by geophysical research (Corradini et al. 2020, 830 fig. 2). The latter emerged as peninsulas and islands in the late Preboreal, when the lake level began to fall (Averdieck 1986 a; Bokelmann 2012). Several islands were used for the establishment of camp sites during the Mesolithic, as indicated in Table 1 and Figure 2.

During the archaeological excavations by K. Bokelmann, which took place from 1966 to 2001, sediment sequences from the areas of camp sites WP 1, WP 6, WP 8, WP 11, WP 13, WP 17 and WP 21 were taken for palynological investigations. Among them were relatively short profiles containing the occupation layers, but also longer sediment stratigraphies that were cored outside the camp sites (partly in the direct vicinity, partly some distance away; Fig. 3). Additionally, a standard profile was cored in one of the deeper areas of the palaeolake basin, at about 300 m from the archaeological sites (Fig. 1). While the pollen records from the camp sites mainly represent local pollen input, the standard pollen record additionally includes an extra-local to regional pollen component. This is because its source area of pollen, due to its location in one of the deepest parts of the lake, only gradually became smaller as the water level decreases. Thus, for the Mesolithic period, it is expected that this standard profile includes a pollen load from the wider area of Duvensee.

The profiles of WP 6, 8, 11, 13, 17, 21 and the standard profile were examined by M. Neve, under supervision of F.-R. Averdieck, at the Institute of Prehistoric and Protohistoric Archaeology of Kiel University, but only the data from WP 6, 8 and 13 were published (Averdieck 1981; 1986 b; Bokelmann et al. 1981). As far as the standard profile is concerned, there have been no publications on the palynological data of that core other than a pollen stratigraphical classification of the sediment sequence (Averdieck 1986 b). The sediment sequences from WP 1 were studied at the Institute of Prehistoric and Protohistoric Archaeology of Cologne University and published by R. Schütrumpf (1981). The analyses of Averdieck and Schütrumpf on the camp site profiles were primarily intended to provide a time frame for both the infilling process and the different occupation layers using pollen stratigraphy. Statements on Mesolithic land use were made with reservations.

In the present compilation, the Holocene chronologies based on annually laminated sediment sequences from Poggensee (Zanon et al. 2021), 18 km northwest of Duvensee, and Belauer See (Wiethold 1998; Dörfler et al. 2012), 49 km north-northwest of Duvensee, were used to provide a temporal framework for the pollen stratigraphic developments and events evident in the standard profile of Duvensee (Figs. 4–6). For the Late Glacial period, the well-dated Nahe palaeolake record was used (Dreibrodt et al. 2021; Krüger et al. 2020), which was cored 30 km northwest of Duvensee. We are aware that dating based solely on pollen stratigraphic criteria cannot provide detailed information on, e. g., the duration of settlement

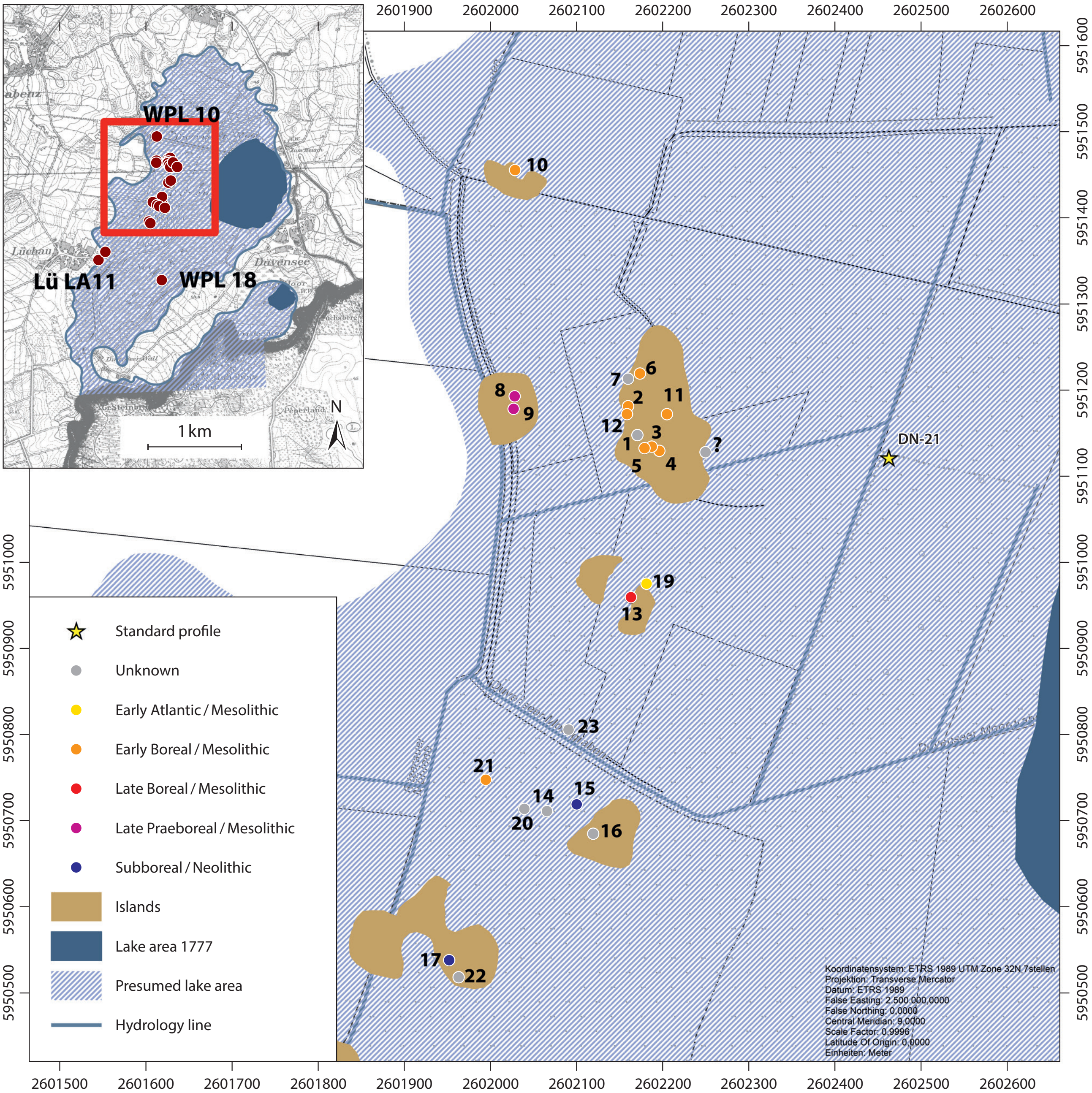

Fig. 1. Dating and location of camp sites on former islands in the Duvensee peat bog area. Also shown are the early Preboreal shoreline of the ancient lake and the remaining lake area in 1777 (Graphics: J. Nowotny/L. Schadler).

and the synchrony of land use and forest regeneration phases and that correlation with the archaeological record is difficult, too. The use of temporally high-resolution and well-dated (AMS, varves) reference sequences from the same natural area nevertheless allows a reliable description of the developmental trends within the environment and settlement history.

The present compilation makes use of the palynological data that were available in digital form – the pollen diagrams from WP 1, 8, 11, 13, 17 and 21 – as well as the standard pollen diagram. In addition to the palynological data, the stratigraphic information from the various profiles is also included (Averdieck 1981; 1986b; Bokelmann et al. 1981; Schütrumpf 1981), to assess to what extent the infilling processes of the lake differed on a small scale. In this context, the individual sediment sequences of WP 1, 6, 8, 11, 13, 17 and 21 were graphically related to each other using pollen stratigraphic transition horizons (Fig. 3). For the purpose of standardisation, the nomenclature of all pollen types shown in the pollen diagrams has been modified to follow

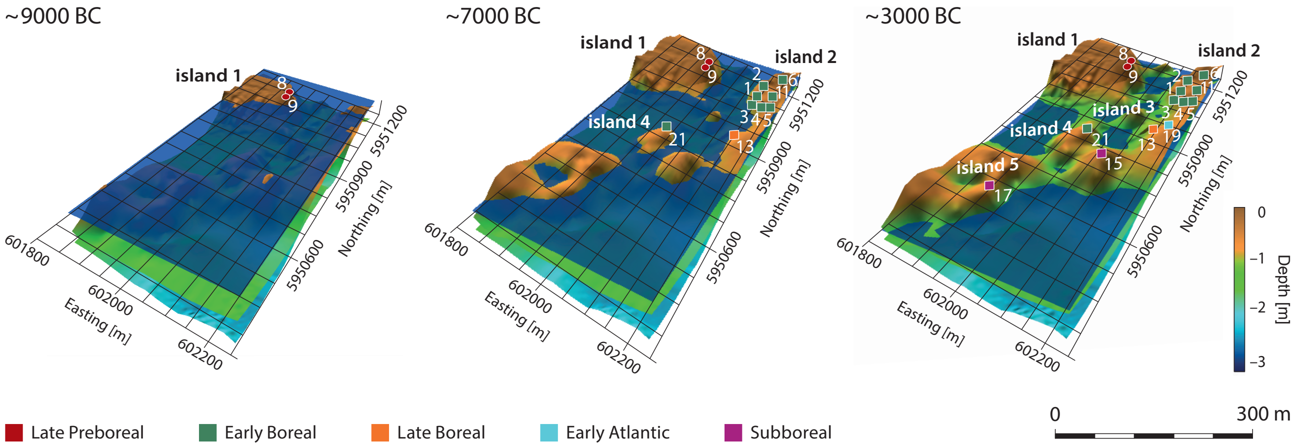

Fig. 2. Reconstruction of the Duvensee area for ca. 9000, 7000 and 3000 cal BC, showing the hypothetical regression of the lake level and the occupation of the islands (after Corradini et al. 2020, 830 fig. 8).

the taxa list of the European Pollen Database (EPD). Furthermore, the calculation of pollen percentages was carried out anew and is based on the sum of total terrestrial pollen (TTP: trees, shrubs, and dwarf shrubs + pollen of herbaceous terrestrial plants), excluding wetland and aquatic pollen types. The original pollen diagrams were biostratigraphically classified following the pollen zone characteristics for northwestern Germany (zone identifier NWD) after Overbeck (1975). This classification was retained for the updated pollen diagrams, but the standard pollen diagram was additionally subdivided into 26 local pollen assemblage zones (labelled DUV-PAZ 1 to 26) based on major changes within the pollen spectra.

In the following, we first describe and discuss the Duvensee standard pollen diagram in detail, before we turn to the discussion of the individual pollen diagrams from the camp sites, focusing on the Mesolithic. This necessarily entails some repetitions in the description of the sequences, but this is in our view unavoidable for the argumentation when it comes to the linkage between the individual and the standard pollen diagrams.

RESULTS AND DISCUSSION

Palaeoenvironment and settlement history in the local and wider Duvensee area based on the Duvensee standard pollen diagram

Due to irregular sample intervals and strongly fluttered basal pollen spectra, the starting point of the Duvensee standard diagram (Figs. 4–6) was placed in the Dryas period, probably Dryas 2 (II NWD). Because the profile is not radiocarbon dated and the terminology is entirely based on biostratigraphy, the possibility of misinterpretation must be acknowledged here. The pollen record of this stage, which lasted between ca. 11760 and 11660 cal BC (Krüger et al. 2020), is characterised by light-demanding herb communities represented by mugwort *(Artemisia)*, rockrose (*Helianthemum*-type), cinquefoils (*Potentilla*-type), avens (*Geum*-type), sorrel (*Rumex acetosa*-type), and the goosefoot family (Chenopodiaceae), along with grasses (Poaceae) (DUV-PAZ 1) (Fig. 5). These herbaceous taxa were accompanied by shrubs, such as willow *(Salix)*, juniper (*Juniperus*-type), and sea-buckthorn *(Hippophaë rhamnoides)* (Fig. 4). Dwarf birches *(Betula nana)* were certainly a significant part of the shrub formations, too. However, since the palynological studies did not yet distinguish between shrub and tree birch pollen, it is not possible to judge the proportion of tree birch *(Betula pubescens)* that was already present in the area. There were also some further scattered trees, as indicated by the presence of aspen *(Populus)*. The relatively high pine *(Pinus)* values are probably due to high aeolian activity and thus represent long-distance transport, but they could also have been redeposited, as indicated by the contemporaneous quite frequent finds of thermophilous tree taxa (e. g. *Fagus*, *Carpinus betulus*, *Quercus*, *Alnus*, *Picea*, *Abies*).

At the same time, the presence of areas with humid to waterlogged soils is indicated by the occurrence of sedges (Cyperaceae), meadow-rue *(Thalictrum)*, representatives of the parsley family (Apiaceae) and the bedstraw family (Rubiaceae), ferns (Polypodiaceae

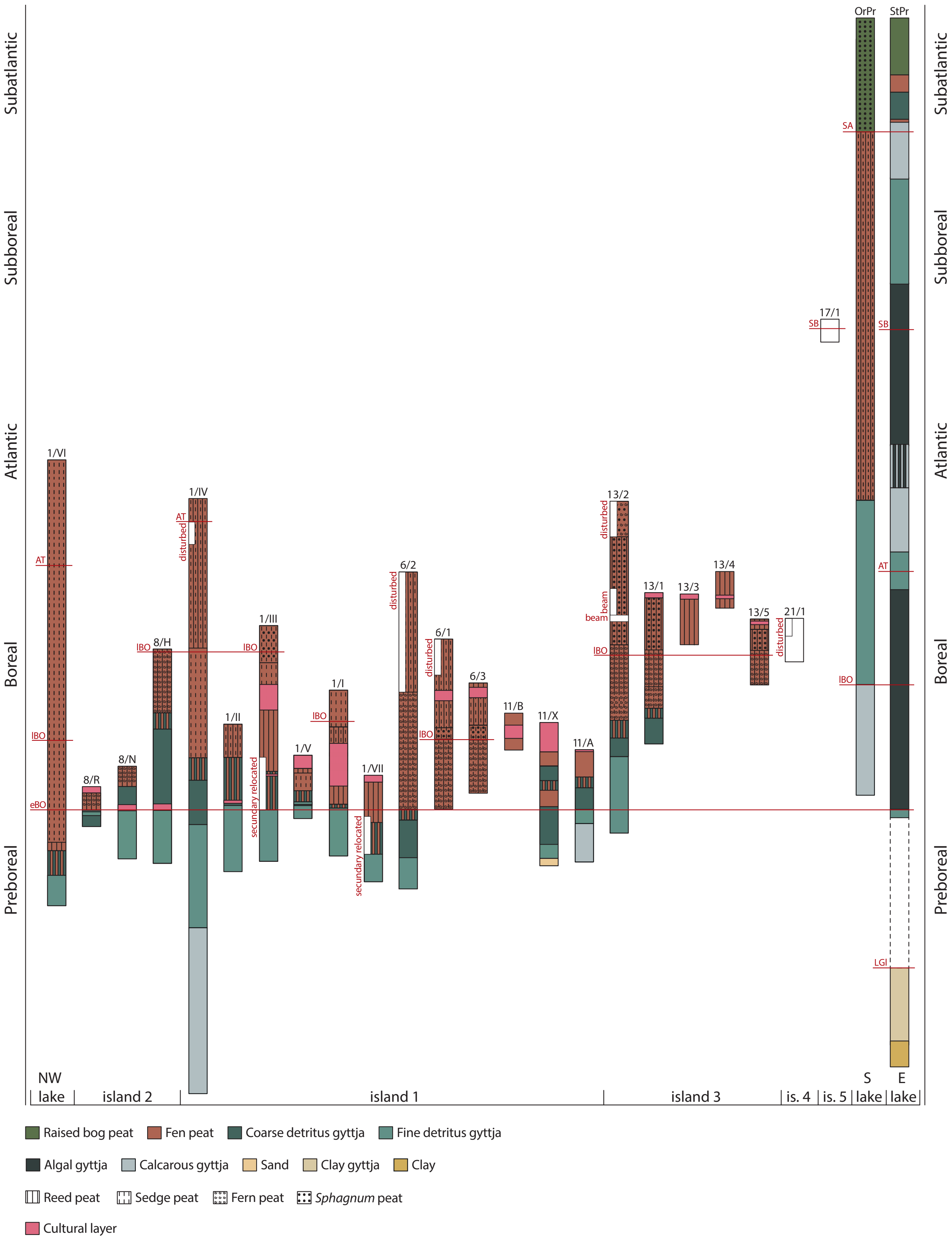

Fig. 3. Duvensee. The palynologically investigated on-site and near-site sediment sequences from camp sites WP 1, 6, 8, 11, 13, 17, and 21, as well as the standard profile with the corresponding stratigraphies (Graphics: M. Wieckowska-Lüth).

undiff.), and peat moss *(Sphagnum)* (Fig. 6). Pollen finds of pondweed (*Potamogeton*-type) and water-crowfoot (*Ranunculus aquatilis*-type) show that the lake basin was colonised by aquatic plants. In the shoreline areas, there was probably a light reed belt, as indicated by the appearance of bur-reed (*Sparganium*-type) and horsetail *(Equisetum)*.

This period is followed by a short spell characterised by a steep rise in the proportion of birch (III NWD), which indicates a very quick spread of tree birches as the climate became rapidly warmer during the Allerød (Usinger 1998). This is in line with the synchronous reduction in light-demanding grasses, terrestrial herbs and shrubs, such as willow and juniper (DUV-PAZ 2). The drop in sedges points to the expansion of birch in the more humid lowlands as well. Nevertheless, the still relatively high proportions of non-arboreal pollen (NAP) show that the landscape was not completely covered by trees. Along with the rise in birch pollen, pine pollen is also showing a marked increase. Since the proportion of relocated thermophilic pollen decreases somewhat in the pollen diagram, at this time this may indicate local occurrence of pine. Usinger and Wolf (1982) associate the spread of pine with that of the thermophilic meadowsweet *(Filipendula)*. And, indeed, the latter taxon appears for the first time with a peak. During this time, a change to a clayey gyttja is also visible in the sediment sequence. This is probably the result of increased autochthonous productivity by aquatic organisms, as well as the input of allochthonous organic material from the progressively vegetated surrounding. The synchronous reduction in the extreme heliophilous sea-buckthorn, which, as a pioneer shrub, usually colonises sandy and humus-poor soils, may be interpreted in the same way. Furthermore, the presence of nettle *(Urtica)* pollen suggests that nitrogen-rich sites also developed at this time, presumably in areas close to the palaeolake. However, compared with the Nahe record (Krüger et al. 2020), the Allerød sequence is only weakly represented, suggesting that this biostratigraphical unit was not completely preserved in the Duvensee profile.

The transition to the Dryas 3 period (IV NWD) is marked by a renewed increase in heliophilous grasses, terrestrial herbs, and dwarf shrubs around 10590 cal BC (Krüger et al. 2020). Among them are more cold-resistant and/or, as far as soils are concerned, less demanding taxa, such as dryas (*Dryas*-type), blueberries (*Vaccinium*-type) and crowberries (*Empetrum*-type). Juniper is also visibly growing in abundance, while the evidence of pine – although still relatively high – is clearly decreasing (DUV-PAZ 3). The parallel increase in the proportion of relocated thermophilous arboreal taxa (*Alnus*, *Carpinus betulus*, *Castanea* and *Corylus*) indicates that a certain proportion of the pine pollen may also have been rearranged from appreciably older sediments, probably due to increased erosional activity. Due to the now more open vegetation pattern, a certain long-distance transport component has to be considered for pine, too. The proportion of birch also decreases, but not as much as pine, probably due to the increased pollen signals of shrub birches, the presence of which is again more pronounced at this time. The increase in sedges suggests that the more humid localities have also become less covered with trees, in particular during the second half of this period (DUV-PAZ 4).

The beginning of the Holocene and thus also of the Mesolithic period is characterised by a steep rise in birch proportions (V NWD), demonstrating a rapid reforestation of the landscape around 9700 cal BC (Zanon et al. 2021). This is accompanied by the visible decrease in heliophilous grasses, terrestrial herbs, dwarf shrubs and shrubs of the Late Glacial flora. Nevertheless, pollen records of grasses and terrestrial herbs remain continuously present throughout the early Holocene. The temperature rise–induced increasing vegetation cover is also reflected in the sediment sequence, where a change from clayey to purely organogenic gyttja occurs at the transition to the Preboreal (Averdieck 1986 a). The simultaneous emergence of reed communities (*Sparganium*-type and *Typha latifolia*-type) suggests the presence of exposed lake terraces after the water table gradually began to decrease. However, the increase in birch is immediately followed by a steep increase in pine proportions, demonstrating changes in the composition of the forest (DUV-PAZ 5). Generally, pine does not spread to a greater extent until the second half of the Preboreal. Furthermore, the mass expansion of pine is not achieved until the onset of the Boreal. Therefore, it must be assumed that a major part of the Preboreal period was not recorded in the sediment sequence. The reasons for the discontinuity in the sediment can only be speculated on at this point. Perhaps a pronounced climate deterioration led to a reduction in aquatic biomass production and thus to a significantly lower sedimentation rate. There may also have been technical problems during the coring process that led to a loss of sediment and thus to a hiatus. Anyhow, the Preboreal is considered a period of intense climatic fluctuations. For instance, a climatic setback recorded around 9440 cal BC in the nearby Poggensee sequence (Zanon et al. 2021) reflects the Preboreal Oscillation or the Bond Event 8, respectively. Other records from Schleswig-Holstein even show two climate fluctuations during the Preboreal (Usinger 2004), counteracting the rise in temperatures.

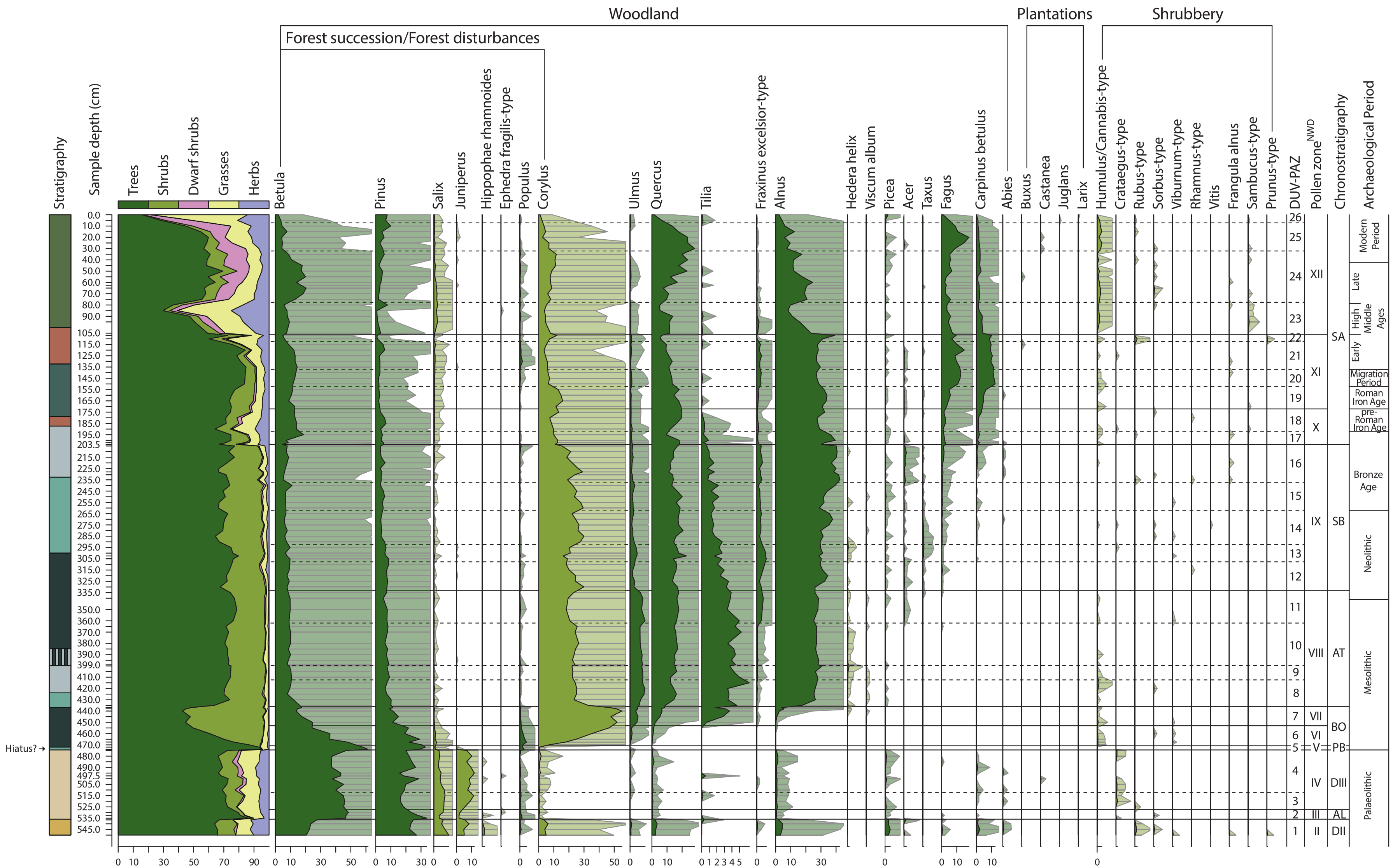

Fig. 4. Duvensee. Standard pollen diagram (in %) with the curves for selected trees, shrubs and creepers. Light-coloured curves are exaggerated by factor 10. For a description of the stratigraphy, see Figure 3 (unpublished; analysis: M. Neve; graphics: M. Wieckowska-Lüth).

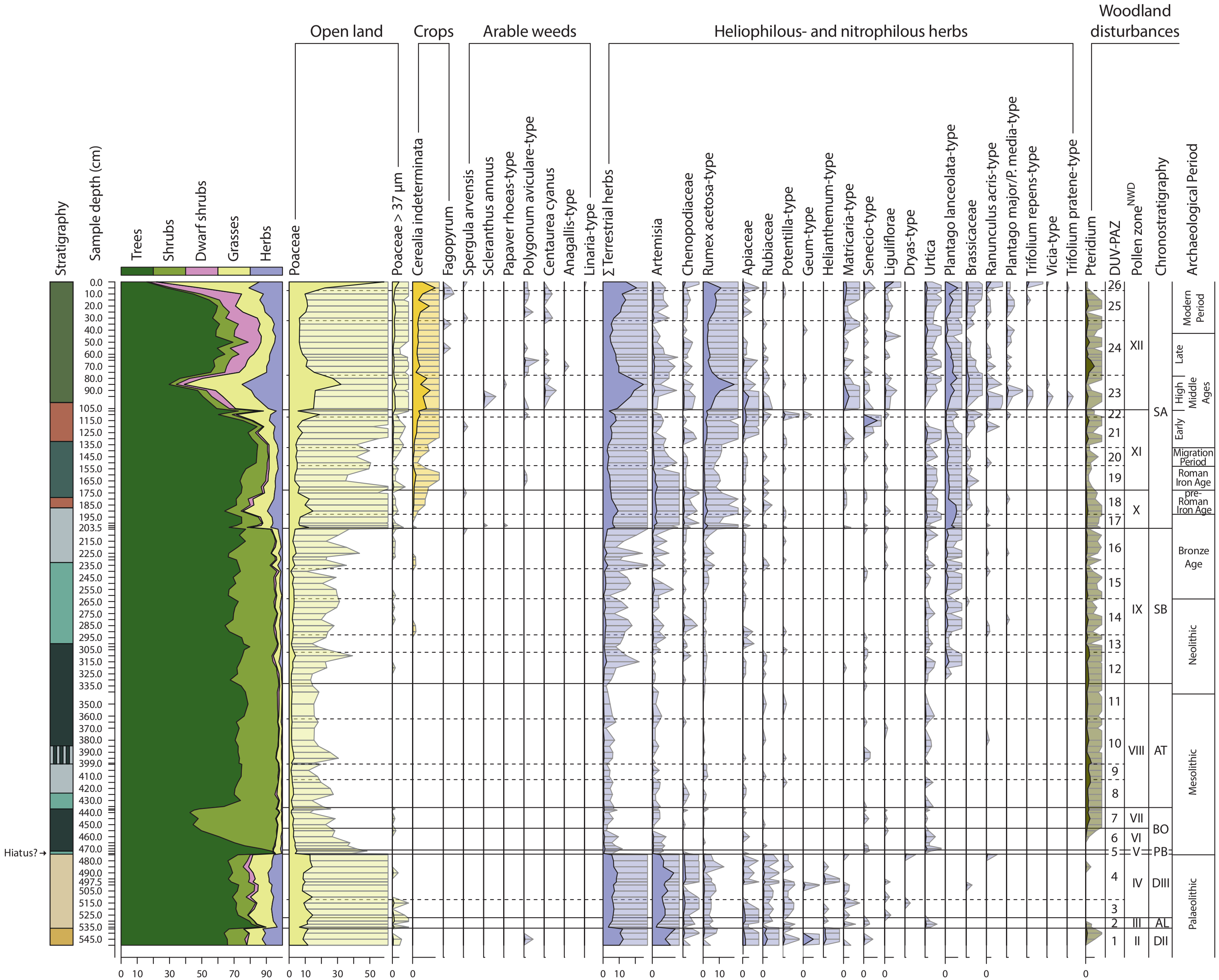

Fig. 5. Duvensee. Standard pollen diagram (in %) with the curves for selected open-land and settlement indicators. Light-coloured curves are exaggerated by factor 10. For a description of the stratigraphy, see Figure 3 (unpublished; analysis: M. Neve; graphics: M. Wieckowska-Lüth).

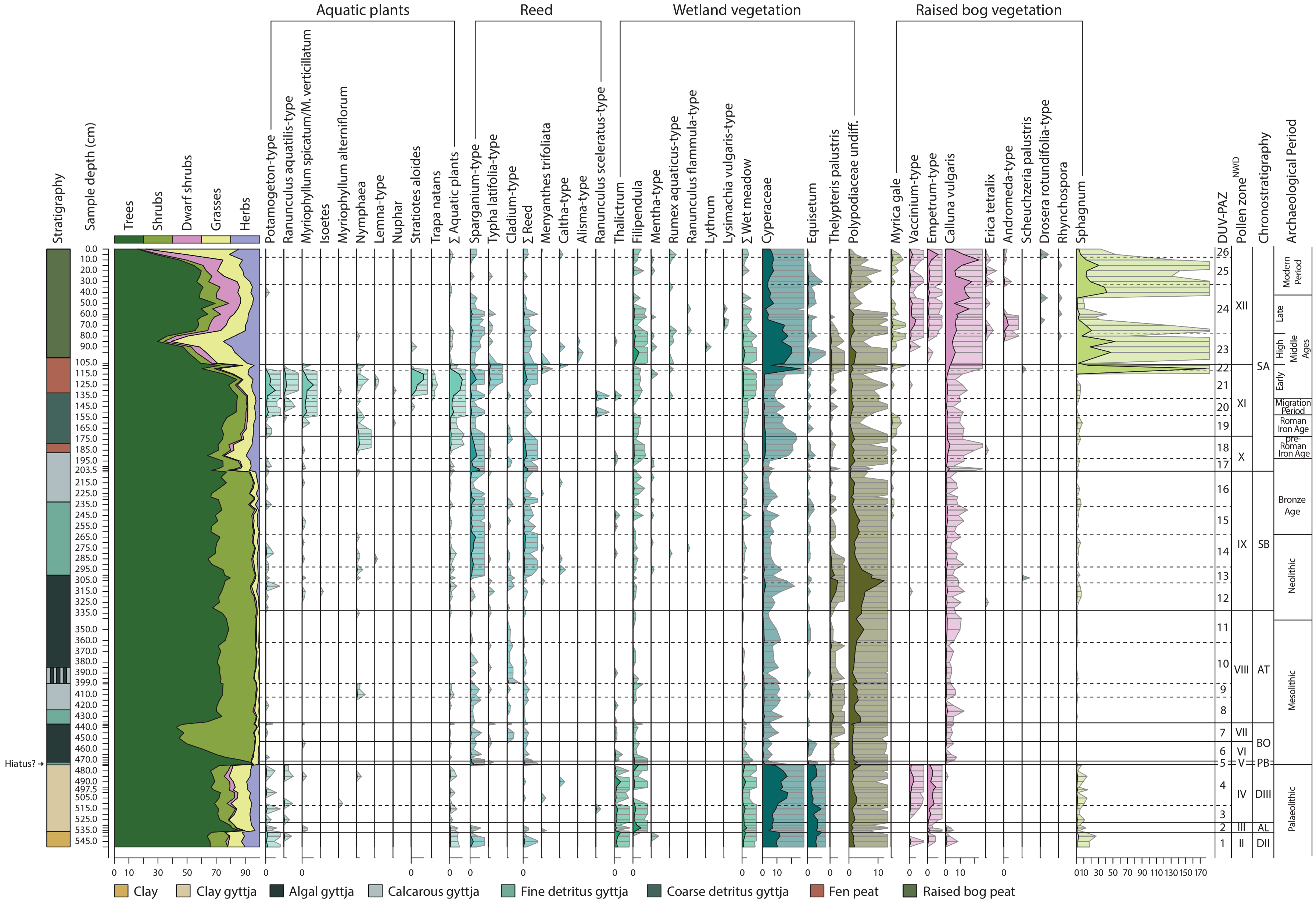

Fig. 6. Duvensee. Standard pollen diagram (in %) with the curves for selected aquatic plants, reed, wetland and raised bog vegetation. Light-coloured curves are exaggerated by factor 10. For a description of the stratigraphy, see Figure 3 (unpublished; analysis: M. Neve; graphics: M. Wieckowska-Lüth).

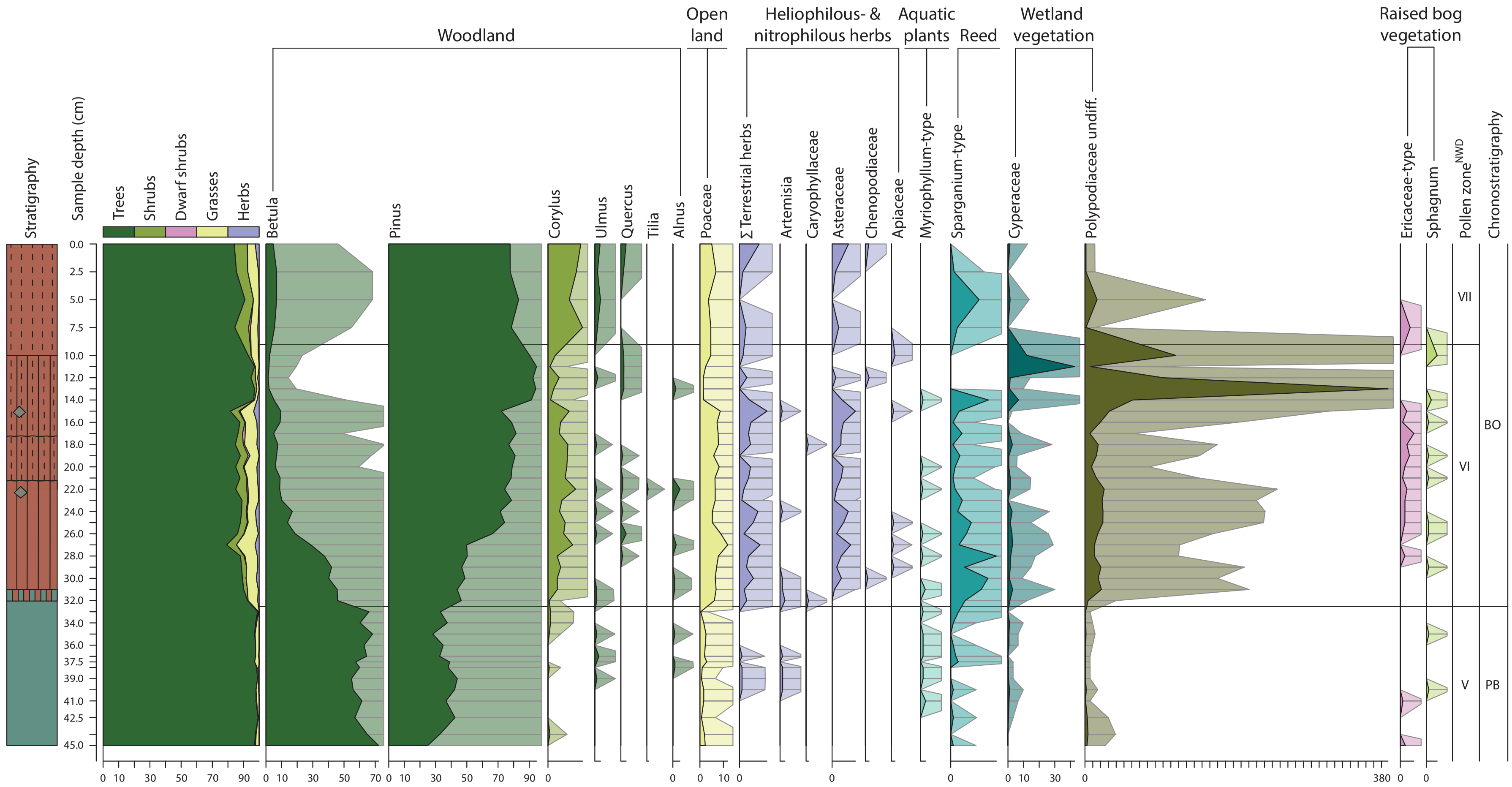

Fig. 7. Duvensee, camp site 1. Pollen diagram for profile WP 1/I (in %) with the curves for selected pollen taxa. Light-coloured curves are exaggerated by factor 10. For a description of the stratigraphy, see Figure 3 (Pollen diagram after Schütrumpf 1981, 169 fig. 5, modified by the authors; analysis: unknown; graphics: M. Wieckowska-Lüth).

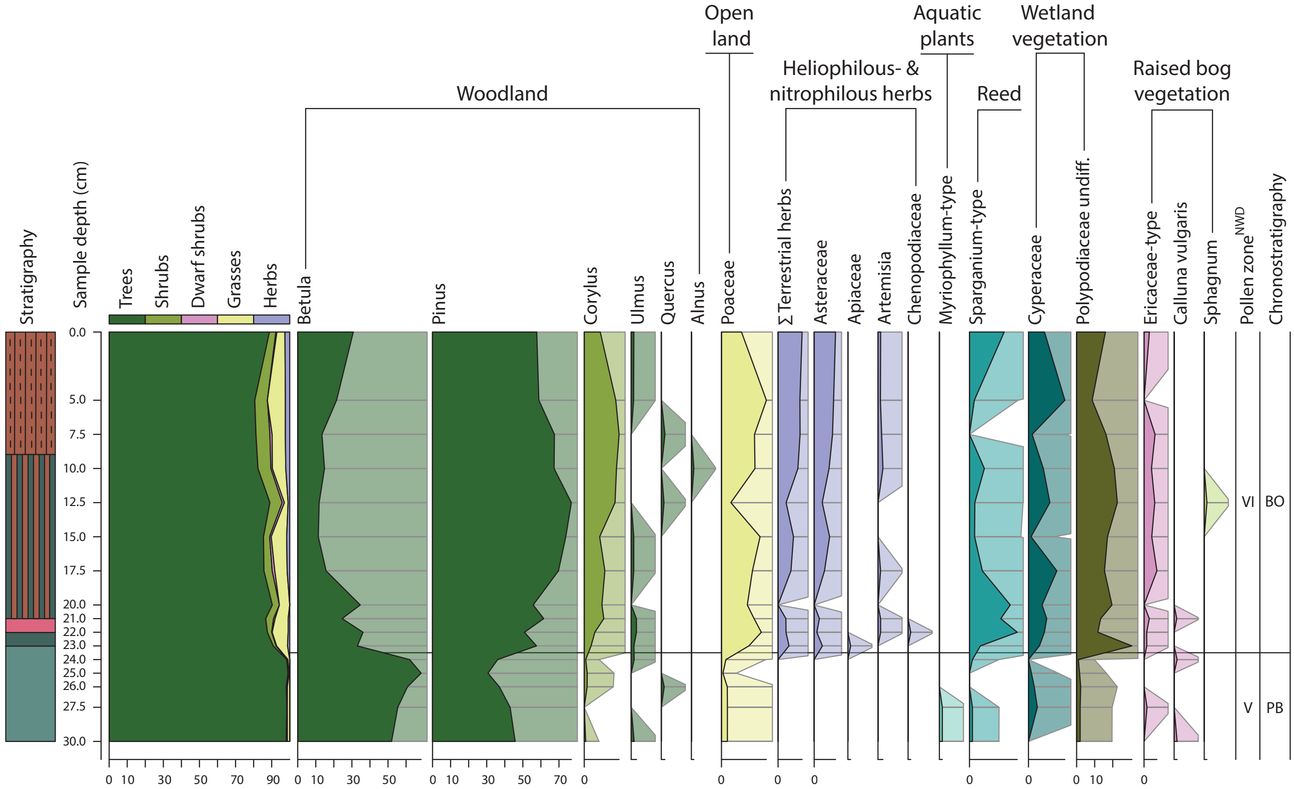

Fig. 8. Duvensee, camp site 1. Pollen diagram for profile WP 1/II (in %) with the curves for selected pollen taxa. Light-coloured curves are exaggerated by factor 10. For a description of the stratigraphy, see Figure 3 (Pollen diagram after Schütrumpf 1981, 170 fig. 6, modified by the authors; analysis: unknown; graphics: M. Wieckowska-Lüth).

The rise in hazel values directly following the pronounced pine peak indicates that the transition to Boreal has already taken place (VI NWD). In the Poggensee record, the onset of the Boreal is dated to ca. 8750 cal BC (Zanon et al. 2021). During this time, other thermophilous trees, such as elm *(Ulmus)* and oak *(Quercus),* were also slowly spreading in the woodland, which was characterised by a pronounced shrub layer of the more and more dominating hazel. This was probably joined by other scattered bushes, such as viburnum (*Viburnum*-type). Some palaeoecologists assume that the hazel migrated into the pine-birch forest as a shrub rather than as a tree (Firbas 1949; Küster 1995; Tallantire 2002). Whether shrub or tree, the hazel is a semi-shade plant (Ellenberg et al. 1991), which implies relatively light forests as its growing sites. Elevated as well as continuous evidence of grasses, mugwort and nettle supports the idea that sufficient light reached the forest floor (DUV-PAZ 6). Possibly these forest conditions were also favourable for the presence of Mesolithic people, who used the area of the ancient lake intensively for their subsistence activities. Furthermore, as hazel grows optimally on moist soils but does not tolerate being waterlogged (cf. Overbeck 1975; Pott 1985), its habitats would be probably in somewhat higher terrain. On the wetter soils surrounding the lake, a relatively light lowland forest developed, consisting of aspen trees, willow shrubbery and probably creepers, such as hop (*Humulus*/*Cannabis*-type). On these sites, birch will also have played a certain role, together with nettle, which includes strongly nitrophilous species (Ellenberg et al. 1991) that were able to flourish in the nitrogen-rich conditions of the near-shore locations. In this context, it should also be mentioned that the genus *Urtica* includes a somewhat less nitrogen-dependent species *(U. kioviensis)*, which may have been part of the plant communities of the reed beds (Wolters et al. 2005). At the same time, marsh fern *(Thelypteris palustis)* starts to spread. This fern flourishes in swampy, semi-open situations but is also able to grow in the shallow water zones. Its presence, along with records of reed plants (*Sparganium*-type, *Typha latifolia*-type), may indicate that some marginal areas of the lake were already in the process of becoming silted up. With the beginning of the Boreal, there is also a change within the sediment, from fine detritus to algal gyttja, showing that the lake was dominated by highly productive algal communities during this stage. Algal gyttja is usually among the first organogenic sediments in a lake basin and consequently develops in deeper-water areas.

Relatively high lake levels, at least at the sampling site, are also indicated in the pollen record by the low abundance of floating-leaved macrophytes and other submerged plants that indicate the infilling.

At the transition from early to late Boreal (VII NWD), dated to ca. 8050 cal BC (Zanon et al. 2021), the reed beds are joined by sawgrass (*Cladium*-type), which is likely to be *Cladium mariscus* (DUV-PAZ 7). The optimal growth conditions for this species are characterised by warm summers and a lack of intensive frost in winter (Conway 1938; Salmina 2004), thus pointing to a further increase in temperatures. At the same time, lime *(Tilia)*, which is the most warmth-demanding tree of the nemoral forest (Hafsten 1992), also arrived in the area. In parallel, hazel reaches its mass expansion, in a forest where birch and pine are increasingly losing their significance in favour of oak and elm. However, the progressing of hazel is temporarily delayed by a small drop in its proportions that correlates with a peak in the ecologically adaptable pine. In contrast to pine, hazel does not tolerate long-lasting summer heat and dry conditions (cf. Ellenberg et al. 1991). Therefore, this small drop may be indicative for a short phase of poorer growing conditions for oceanic hazel and probably a change to more continental climatic conditions. In the nearby Poggensee record, a notable increase in pine around 7870 cal BC coincides with a reduction in hazel, too. At the end of the Boreal period, the first finds of mistletoe *(Viscum album)* and ivy *(Hedera helix)* appear. For both species, high summer temperature is of vital importance (Troels-Smith 1960; Zagwijn 1994), suggesting that the highest temperatures were reached at the end of this period. But at the same time, they do not tolerate strong seasonal fluctuations (cf. Ellenberg et al. 1991), which points to the return of more oceanic conditions. In accordance with this, hazel shows its maximum abundance. It is during this time span that bracken *(Pteridium)* became present. This fern is considered a disturbance indicator, preferring acidic, alkaline-poor, sandy or fire-influenced soils (Düll/Kutzelnigg 2005; Bińka/Nitychoruk 2013; Tinner et al. 2000). The occurrence of bracken, together with the light-demanding and acid-tolerant heather *(Calluna vulgaris)*, may thus point to small-scale areas of disturbance with poorer soils in the woodland surrounding the palaeolake. Small-scale open locations are also indicated by the occurrence of different herbs, such as sorrel, mugwort, ragworts (*Senecio*-type) and representatives of the parsley, goosefoot, bedstraw and sunflower families. As there is no record of peat mosses at this time, the formation of larger bog areas, which could also be the source of the heather pollen, can be ruled out. Unfortunately, the role of fire as a potential source of disturbance cannot be assessed, as the pollen record did not include signals of microcharcoal.

The Atlantic (VIII NWD) begins with the mass expansion of the softwood species alder *(Alnus)* at ca. 7350 cal BC (Dörfler et al. 2012), and a visible decline in aspen, displaying the rapid occupation of wet depressions by alder. At the same time, lime, oak and elm spread further and the frequency of hazel declines considerably, reflecting important changes in the forest structure. The replacement of hazel was possibly driven by the spread of trees with dense canopies, which easily shade out the light-demanding hazel shrubs. Nevertheless, hazel continued to form an important part of the woodland, showing that there were still sites where sufficient light reached the lower forest layer. This is also supported by the continuous evidence for the open-land indicators, such as grasses, terrestrial herbs (*Artemisia*, Chenopodiaceae, *Rumex acetosa*-type, *Urtica*), heather, bracken and hop (DUV-PAZ 8). Such light locations may have been, for instance, the edges of the ancient lake terraces and preferred hunting grounds.

At the transition to the Atlantic, the sediment changes to fine detritus gyttja. This type of lacustrine mud is an almost pure plankton formation and characterises deep, calm-water areas. At the same time, the pollen record displays a temporary reduction in reed communities and the adjacent tall-herb wetland vegetation represented by meadowsweet, which may be indicative for a transgression phase. In accordance with this, a synchronous rise in ferns from the polypody family suggest an expansion of damp areas, possibly due to a general rise in the groundwater level.

With a renewed sediment change to calcareous gyttja, modifications in the lake's ecosystem are again indicated. While the fine calcareous gyttja is a typical deep-water sediment, the coarse calcareous gyttja is formed in shallow water. Unfortunately, no detailed information was provided in this regard during the sediment survey. In the corresponding pollen spectrum, this phase is represented by elevated values of ivy, mistletoe and reed plants (*Sparganium*-type), as well as the re-emergence of wetland vegetation *(Filipendula)*, along with the temporary presence of water lilies *(Nymphaea)* (DUV-PAZ 9). The latter indicates the development of a floating leaf zone and thus the existence of shallow water areas, possibly due to a lowering of the lake level. However, precipitation of calcium carbonate can also occur due to changes in the water temperature. With increasing water temperature, the solubility of calcium carbonate brought in by groundwater from the catchment area of the upper moraine decreases. As a result, the poorly soluble calcium carbonate sinks to the bottom of the lake, forming a calcareous gyttja. In this context, a prolonged period of high summer temperatures could be indicated by the almost continuous records of mistletoe during this time. Thus, the lake level lowering inferred from the pollen record and the simultaneous formation of calcareous gyttja perhaps indicate a phase of warmer climatic conditions occurring before the mid-Atlantic. At the same time, the forest seems to have become even denser, as can be seen from the decrease in grasses and hops.

However, after the mid-Atlantic, there is another change in the sediment facies, namely to an algal gyttja. In parallel to this, nearly all evidence of aquatic plants disappears (DUV-PAZ 10), which could support a lake level rise. The distinct reduction in pollen signals from both floating-leaved plants, such as *Nymphaea* or *Nuphar,* and submerged plants, such as *Potamogeton* or *Myriophyllum*, which penetrate to water depths of up to a maximum of 3–7 m, respectively (Düll/Kutzelnigg 2005), suggests at least that shallow water areas were considerably diminished. However, a change towards algae-dominated in-lake communities could indicate other in-lake processes that cannot be determined more precisely in this framework. At the same time, grasses and terrestrial herbs increase slightly, suggesting that there were again some small-scale open patches within the forest.

In the last third of the Atlantic period, elm is further gaining in prominence within the woodland, and other trees, such as ash (*Fraxinus excelsior*-type) and maple *(Acer)* (DUV-PAZ 11), which were previously scarce or not represented at all, occur more frequently since ca. 4690 cal BC (Dörfler et al. 2012). In parallel, hazel decreases slightly. Among the taxa mentioned, elm and ash, in particular, are more demanding with regard to their edaphic requirements for soil moisture (e. g. Düll/Kutzelnigg 2005) than the other tree species of the mixed oak forest. Their greater presence could therefore be an indication of more humid conditions. In accordance with this, the parallel rise in ferns also supports an expansion of damp locations. Perhaps increased waterlogging in lower-lying areas also led to a reduction in the hazel stands. The parallel reduction in ivy may, furthermore, be indicative of cooler summer temperatures during this time. In accordance with this, the subsequent decline in lime, a tree species that requires high mid-summer temperatures (Hintikka 1963; Pigott 1981; Pigott/Huntley 1978; Prentice/Helmisaari 1991; Seppä et al. 2005; Skre 1979), also point to climatic changes. A temporally corresponding decrease in *Tilia* was dated in the Poggensee record to 4500 cal BC (Feeser et al. 2012). As for the status of the remainder of the forest, apart from the slight increase in heather, no other signals of disturbance are recorded within the pollen record during this stage. This indicates that there was no increase in human impact in the surrounding of the palaeolake after the transition to the Neolithic, which is dated to 4100 cal BC (Müller et al. 2012). Finally, at the end of the Atlantic period, pollen of yew *(Taxus)*, an evergreen, shade-tolerant tree species that prefers oceanic to suboceanic climate conditions, is also recorded. Simultaneously, the already continuous curve for beech *(Fagus)* sets in.

The transition to the Subboreal (IX NWD) is marked by the classical elm decline, which is dated in the region to about 3900 cal BC (Dörfler et al. 2012). This marked reduction in elm populations is often associated with a fungal disease that affected elm trees in a woodland already stressed and disturbed by humans (e. g. Peglar/Birks 1993). Climatic changes as an additional factor are also discussed (e. g. Gaillard/Digerfeldt 1991). In the Duvensee record, the abundance of hazel pollen increases visibly in parallel. As no rise in open-land indicators was recorded at this time, their expansion seems to be related to the crown thinning after the reduction in the elm trees. The possibility of anthropogenic manipulation of the forest, for example through use as forest pasture, which would promote the spread of the light-demanding hazel, must also be taken into account. Elm trees may also have been managed in some way, either in the form of their wood or in the form of their foliage for fodder.

With the beginning of this period, marsh fern increases distinctly, along with other ferns of the polypody family (DUV-PAZ 12), reflecting the emergence of initially swampy and later damp habitats. Shortly thereafter, alder spreads increasingly, suggesting that a carr forest was expanding in the areas as silting up progressed. In parallel, signals from aquatic plants are again recorded, which increase further until about the middle of the Subboreal, thus reinforcing the idea that the lake was losing its volume. In addition, slightly increased records of peat moss may point to the development of small-scale locations with raised bog vegetation in the lake's surroundings.

It was also at this time that the first indicators of livestock husbandry were detected in the pollen record. The rising and continuous evidence of ribwort plantain (*Plantago lanceolata*-type) and grasses (DUV-PAZ 12) indicates that grazing took place in permanent open areas adjacent to the ancient lake. Ribwort plantain is considered an indicator not only of grazing, but also of fallow land (Behre 1981). However, since no evidence of arable activities at that time was detected, its occurrence can be attributed to grazing. With the increasing opening of the landscape, however, the proportion of hazel declines. This is probably due to the use of the light, hazel-covered forest sites for the creation of new settlement and/or grazing areas. In addition, the small rise in bracken – among others a fire-indicating fern – could be a hint that woodland clearance was carried out with the help of fire. However, the amount of total arboreal pollen decreases only moderately compared with the pre-agricultural setting, suggesting that land use was limited to rather small, open spots around the lake. Since the standard profile has no absolute dating, the beginning of farming activity cannot be assigned with absolute certainty to a particular part of the Neolithic. For the eastern part of Schleswig-Holstein, an expansion of agricultural activities and thus the creation of permanent open habitats are postulated for the time after ca. 3750 cal BC (Feeser et al. 2012; 2019) by the Funnelbeaker groups (German: *Trichterbecher*; TRB). The signs of permanent agricultural land use in the Duvensee pollen record can most probably also be attributed to this first phase of growing population and intensification of land use.

There is one more change in the sediment sequence in facies even before the middle of the Subboreal. With the onset of the subsequent fine detritus gyttja, a marked rise in the representatives of the reed plants occurs in the pollen record (DUV-PAZ 13), suggesting advanced ingrowth of near-shore vegetation into the lake. At the same time, probably somewhat drier conditions are attested by the distinct reduction in ferns. A brief warmer phase may also be indicated by the slightly elevated evidence of ivy. In parallel to the sediment change, however, there is also a marked drop in the open-land indicators, including ribwort plantain. Instead, elm, oak, ash and yew increase, demonstrating a phase of woodland recovery. This evidence for reduced land use could coincide with a supra-regional decline in human impact that was documented for the second half of the 4th millennium BC by other palaeoenvironmental records (Dörfler 2001; Feeser et al. 2012; 2019; Wieckowska et al. 2012; Wiethold 1998).

After this longer-lasting break in settlement activity, there is a marked increase in ribwort plantain and in grasses and other ruderal herbs, such as the representatives of the goosefoot family and mugwort, in DUV-PAZ 14. Synchronously, the first finds of Cerealia-type pollen occur, showing that cereal fields have now also been established in addition to grazing areas adjacent to the ancient lake. This increase in anthropogenic indicators can probably be associated with the activity at WP 15 – a Late Neolithic domestic site situated on a peninsula (Fig. 2). Finds of charred cereal remains as well as other potential food plants, including hazel, show that plants were processed at this site for the preparation of food or for other purposes (Brozio et al. 2022). Another characteristic in this context is the high proportion of hazel, implying a greater forest openness than before, most likely also due to this settlement. Pollen finds of rowans (*Sorbus*-type), viburnum (*Viburnum*-type) and (wild) vine *(Vitis)* point in the same direction. At this time, there are also further changes in the forest composition, mirrored by the declines in the proportions of elm and ash, followed somewhat later by those of lime and ivy. The evidence for yew is also becoming less and less, while the pollen signals of beech and also of hornbeam *(Carpinus betulus)* are rising somewhat. These pollen stratigraphic events correspond to the regional vegetation pattern as observed at the transition to the 3rd millennium BC (Feeser et al. 2012) and point to similar land use strategies in the Duvensee area with the beginning of the Late Neolithic. However, as this period progresses, evidence of cereal cultivation disappears, while grazing seems to continue to play a role, as shown by the uninterrupted occurrence of ribwort plantain. A marked increase in alder (DUV-PAZ 14), for example, could imply that increasing waterlogging and an associated spread of wetland forest may have been responsible for the abandonment of the arable fields. The parallel small drop in hazel is probably also to be seen in this context. But further unequivocal evidence that would argue for hydrological changes is missing in the pollen record.

The following stage is characterised by a decrease in alder, while hazel again increases in proportion, displaying both the shrinking of the carr and better light conditions in the forest on higher ground (DUV-PAZ 15). The coinciding reduction in the representatives of the aquatic as well as the littoral vegetation suggest a rise in the water table, probably causing the decrease in the *Alnus* stands surrounding the ancient lake. At the same time, heather increases slightly, which may be evidence for more open patches in the forest, too. Elevated signals of *Calluna vulgaris*, along with those of *Corylus,* could thus indicate the use of the forest for browsing small herds of domestic animals. Lime seems to have benefited from these activities, as its slightly rising relative abundance demonstrates. The reason for this could have been a selective maintenance of lime trees for the purpose of harvesting fodder for livestock. During this time, however, all other open-land indicators remain at about the same level as before, indicating that there were no major changes in settlement intensity. Evidence for cereal cultivation is also missing. Similar but more pronounced land use patterns, including high proportions of heather and hazel and the absence of cereals, have been documented for the Early Bronze Age for the eastern upper moraine areas of Schleswig-Holstein (Wieckowska et al. 2012).

Slightly increased settlement activity was only recorded when a renewed sediment change took place. With the onset of calcareous gyttja deposition, evidence for cereal cultivation reappears in the pollen diagram. Ruderal vegetation is also reflected more intensely, in particular, by sorrel, mugwort and nettle (DUV-PAZ 16). These rising evidence for open-land habitats goes along with the declining presence of hazel, probably showing that once again the light sites within the forest were intentionally used for the creation of new settlement and/or arable land. It seems that oak and lime were also somehow affected by the clearings, as their proportions are now also declining. But growing abundance of beech and hornbeam

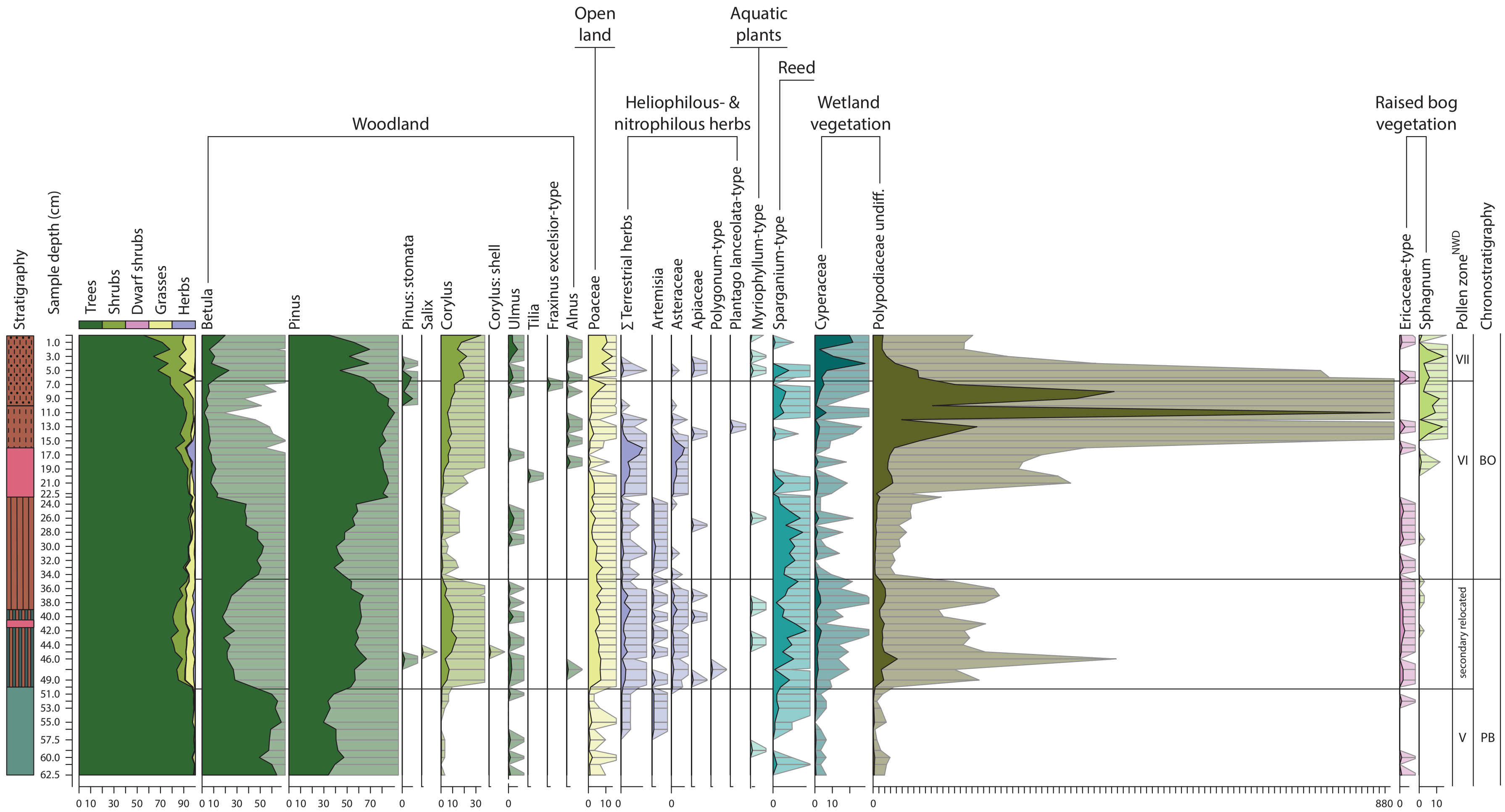

Fig. 9. Duvensee, camp site 1. Pollen diagram for profile WP 1/III (in %) with the curves for selected pollen taxa. Light-coloured curves are exaggerated by factor 10. For a description of the stratigraphy, see Figure 3 (Pollen diagram after Schütrumpf 1981, 171 fig. 8, modified by the authors; analysis: unknown; graphics: M. Wieckowska-Lüth).

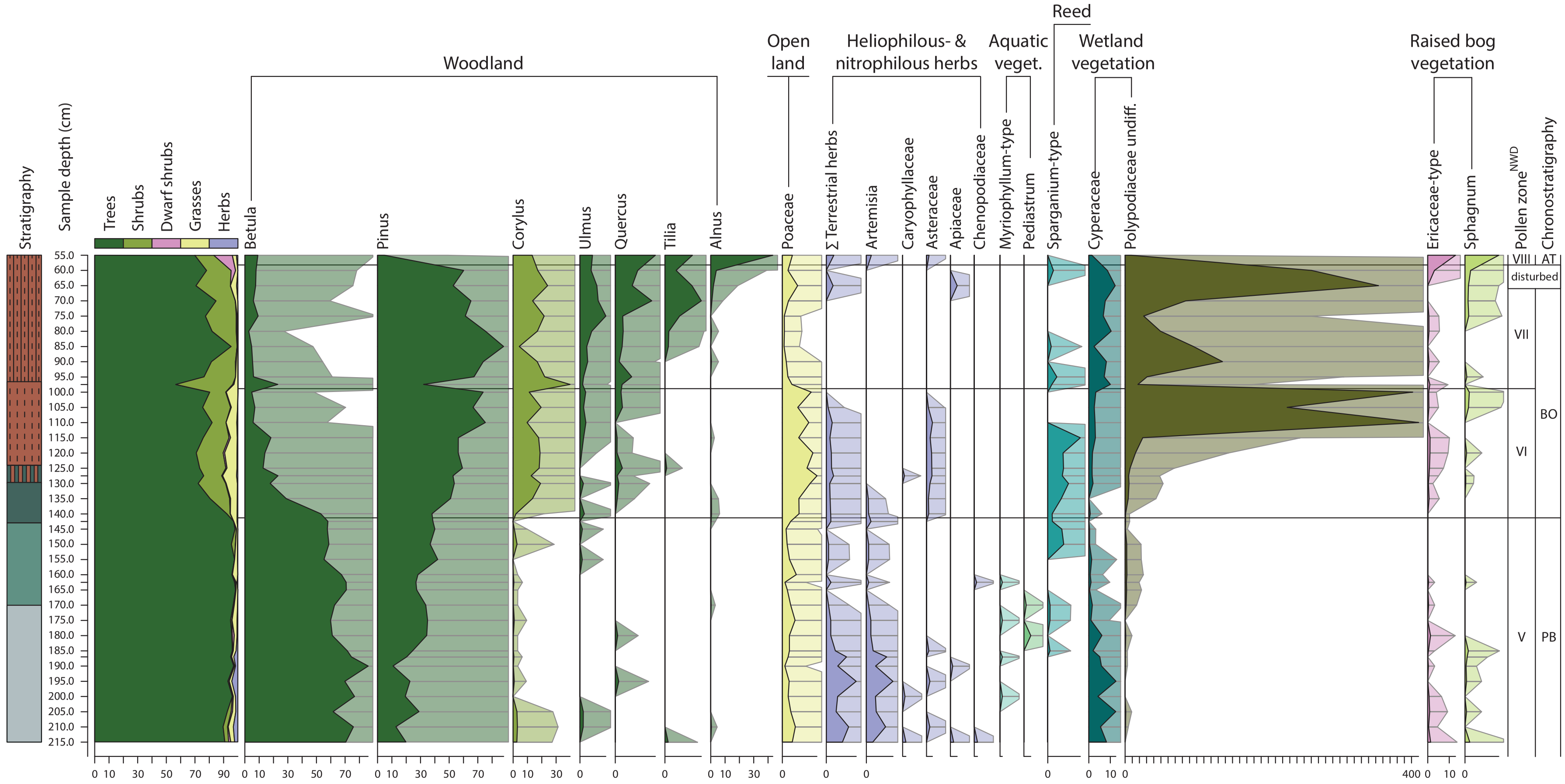

Fig. 10. Duvensee, camp site 1. Pollen diagram for profile WP 1/IV (in %) with the curves for selected pollen taxa. Light-coloured curves are exaggerated by factor 10. For a description of the stratigraphy, see Figure 3 (Pollen diagram after Schütrumpf 1981, 165 fig. 3, modified by the authors; analysis: unknown; graphics: M. Wieckowska-Lüth).

could also have been a factor in the fact that these tree taxa were now less represented in the forest. Whatever the case, at the same time, there are no visible changes regarding the grazing indicator ribwort plantain, suggesting that cattle breeding continued to be practised on a small scale in the Duvensee area. However, as cereal pollen was detected to a small extent at this time, its presence could also indicate fallow land after the abandonment of fields. Another characteristic feature of this period is the sharp increase in alder. Possibly due to the progressive silting up of the lake, as suggested by the sedimentation of the calcareous gyttja, new sites were created for the development of an extensive alder forest along the shore. Previously, these sites were probably colonised by shrubs adapted to wetter conditions, such as alder buckthorn *(Frangula alnus)*. Concurrently with this, there is an elevated frequency of maple and ash. The representatives of the two taxa are quite tolerant regarding soil moisture and probably also belonged to the inventory of the lowland forest. Somewhat later records of willow and aspen pollen, in parallel to the decline in the reed vegetation, also point to the spread of wood vegetation, probably due to increasingly drier situation on the shore.

The transition to the Subatlantic (X NWD) is defined by a distinct decline in lime and ash at around 750 cal BC (Dörfler et al. 2012). In parallel, hazel and maple show marked declines in the Duvensee record, whereas oak is initially expanding (DUV-PAZ 17), demonstrating that the forest became denser. These changes within the woodland structure were probably triggered by an incipient shadowing effect due to the increased presence of beech trees. At the same time, however, the proportion of forest pollen in general is clearly decreasing, as can be seen from the strong increases in grasses and terrestrial herbs. Of the latter, ribwort plantain takes the largest share, showing that pastoral activities were of great economic importance at that time. In contrast, weak signals of cereal pollen show that arable farming still played a minor role in the area around the lake. This clear increase in anthropogenic pressure on the landscape can be correlated pollen stratigraphically with the end of the Bronze Age. A subsequent strong increase in the proportion of birch indicates a regeneration phase of the forest, probably at the transition to the Pre-Roman Iron Age.

Thereafter, a renewed phase of even greater settlement activity is reflected in the pollen record by the growing abundance of ruderals (e.g. *Artemisia*, Chenopodiaceae, Brassicaceae, *Rumex acetosa*-type, *Matricaria*-type, *Urtica*). Coincidently, an elevated representation of pine in all likelihood results from increased long-distance transport due to a more open vegetation. During this time, the grazing indicators (Poaceae, *Plantago lanceolata*-type) initially increase strongly, too. In this context, the simultaneous decline in alder could indicate that the pastures were located in the wet depressions at the margins of the lake (DUV-PAZ 18). Over the course of time, however, the cultivation of cereals became increasingly important, whereas pasture farming seems to have receded into the background. Synchronously, an increase in evidence of heather may point to advanced deterioration of soils by continuous use of the fields, but the parallel increase in oak, together with the still elevated proportions of birch, also shows that the forest was able to regenerate. Perhaps, the cultivated areas were repeatedly shifted due to deteriorating soil conditions. The rising evidence of cereal pollen correlates with a new change in the sediment. At this time, a thin peat layer was deposited, which indicates that the lake may have been temporarily silted up. In accordance with this, the pollen record displays increases in reed vegetation, sedges and meadowsweet, which also suggests overgrowth by terrestrial vegetation at the sampling site. Perhaps, a phase of dry conditions is reflected here, which led to a general drop in the groundwater level, resulting in a strong shrinking or even temporary disappearance of the water surface. Alternatively, the lower groundwater table could be a reason why the cultivation of cereals on the areas closer to the lake was also possible, and their pollen signal was thus more strongly reflected in the pollen record.

However, lacustrine sediments deposits almost 1 m thick above the peat accumulation show that the lake once again existed for a longer period of time. Since the deposits consist of coarse detritus gyttja – a shallow water deposit – it must be assumed that the lake level was rather low. This is also illustrated by the continuous elevated evidence of water lilies (DUV-PAZ 18), which indicates the emergence of floating leaf vegetation and thus the existence of extensive shallow water areas.

In the further course of time, there is a clear decline in settlement intensity, reflected by the decrease in grasses and ruderal herbs. In contrast, however, the proportions of Cerealia-type pollen increase further, demonstrating that there were still arable fields in the surroundings of the ancient lake and that they had probably increased in area (DUV-PAZ 19). At the same time, the frequency of the light-demanding hazel is rising again, although the proportions of beech and hornbeam are growing steadily (XI NWD) in parallel. As there were no other signs of disturbance within the forest in the pollen record at the same time – bracken is only minimally present – the increased occurrence of *Corylus* could indicate the spread of hazel bushes on formerly cultivated land. It thus seems that, compared with human activities in the previous settlement phase, which had taken place on wide open areas, human activities were now more likely to be limited to smaller forest-free areas, which, however, were often abandoned and which then regenerated.

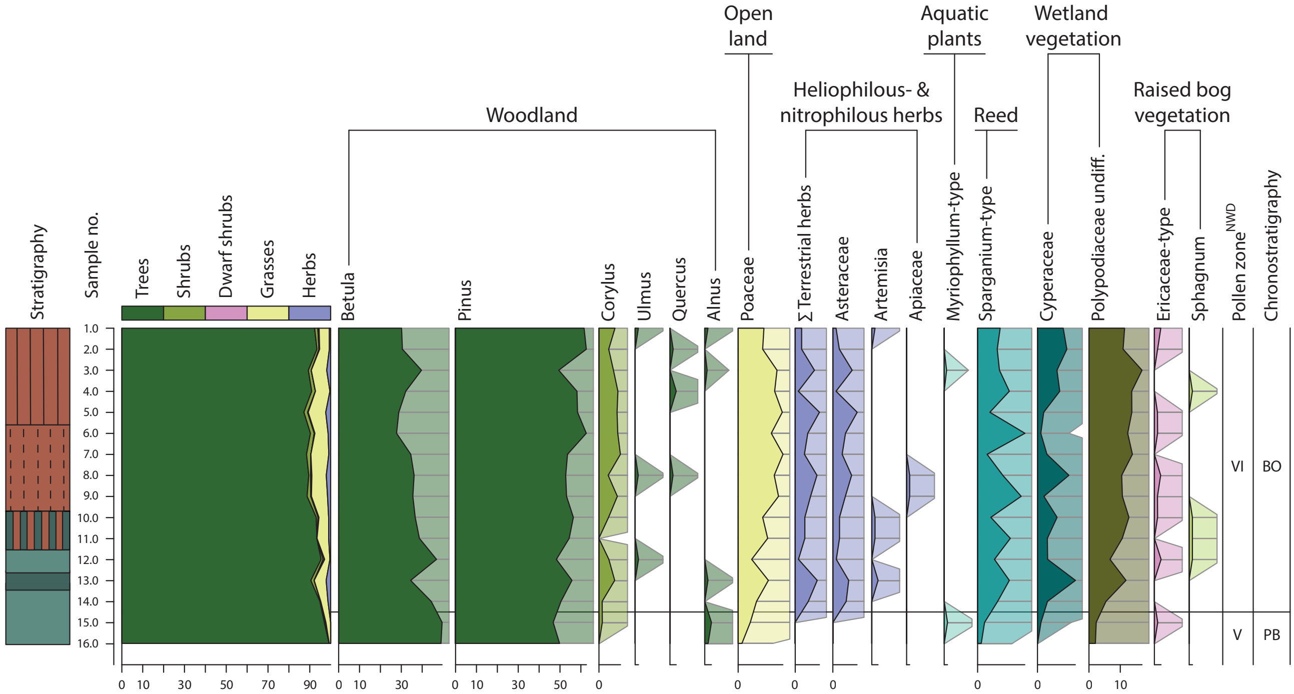

Fig. 11. Duvensee, camp site 1. Pollen diagram for profile WP 1/V (in %) with the curves for selected pollen taxa. Light-coloured curves are exaggerated by factor 10. For a description of the stratigraphy, see Figure 3 (Pollen diagram after Schütrumpf 1981, 170 fig. 7, modified by the authors; analysis: unknown; graphics: M. Wieckowska-Lüth).

Proportionately little evidence of heather, and thus for soil degeneration, corroborates this interpretation. As this phase progressed, there seems to have been another fluctuation in the lake level. This is illustrated by the simultaneous declines of aquatic plants, reeds and sedges, pointing to a rise in the water table.

A short time later, however, the lake level seems to have dropped again, as displayed by the growing assemblages of various aquatic plants (DUV-PAZ 20), such as pondweeds, water milfoils *(Myriophyllum spicatum/M. verticillatum)*, water lilies and water pineapple *(Stratiotes aloides)*. During this period, the settlement indicators continue to decline, whereas beech and hornbeam reach their mass expansion, reflecting the wide-scale regeneration of the forest during the Migration Period. But other tree species, such as elm and ash, were also able to recover slightly at this time. Nevertheless, continuous presence of Cerealia-type pollen along with those of ribwort plantain, mugwort, sorrel and grasses indicates that there was no complete interruption of settlement in the Duvensee area.

The following increase in the open-land indicators (DUV-PAZ 21) suggests somewhat higher levels of human activity with the onset of the Early Middle Ages, or the Slavic Period. During this time, the economic emphasis seems to have been placed first on livestock farming and later more on cereal cultivation, since the curve for ribwort plantain is the inverse of that for cereals. However, the continued relatively high proportions of arboreal pollen also demonstrate that the settlement areas were probably small, open patches within a dense forest, only gradually increasing in size. In the course of this time, the lake finally silted up, at least in the area of the coring site. This is initially reflected in the marked increase in aquatic plants, such as pondweed, water-crowfoot, water milfoils, water lilies *(Nymphaea, Nuphar)*, water pineapple and duckweeds *(Lemna)*. Among them is also the water chestnut *(Trapa natans)*, which is usually connected with the final stage of shallowing of a water body (Miotk-Szpiganowicz/Gałka 2009). These are directly followed by the representatives of reeds (*Sparganium*-type, *Typha latifolia*-type), which indicate a progressive ingrowth of subaquatic vegetation. This is accompanied by the beginning of fen peat accumulation. As shown by the increasing evidence of willow and aspen, woody taxa probably spread on sites that had been infilled for a while.

With the subsequent steep peaks of sedges (DUV-PAZ 22) followed by one of alder, the signals of aquatic plants almost disappear in the pollen record, reflecting the rapid colonisation of the former lake area by terrestrial vegetation. The parallel very high proportion of grasses can possibly be partly attributed to the same context, indicating the spread of different Poaceae taxa adapted to wetter conditions, such as *Phragmites australis*. Furthermore, the contemporaneous evidence of pod grass *(Scheuchzeria palustris)*,

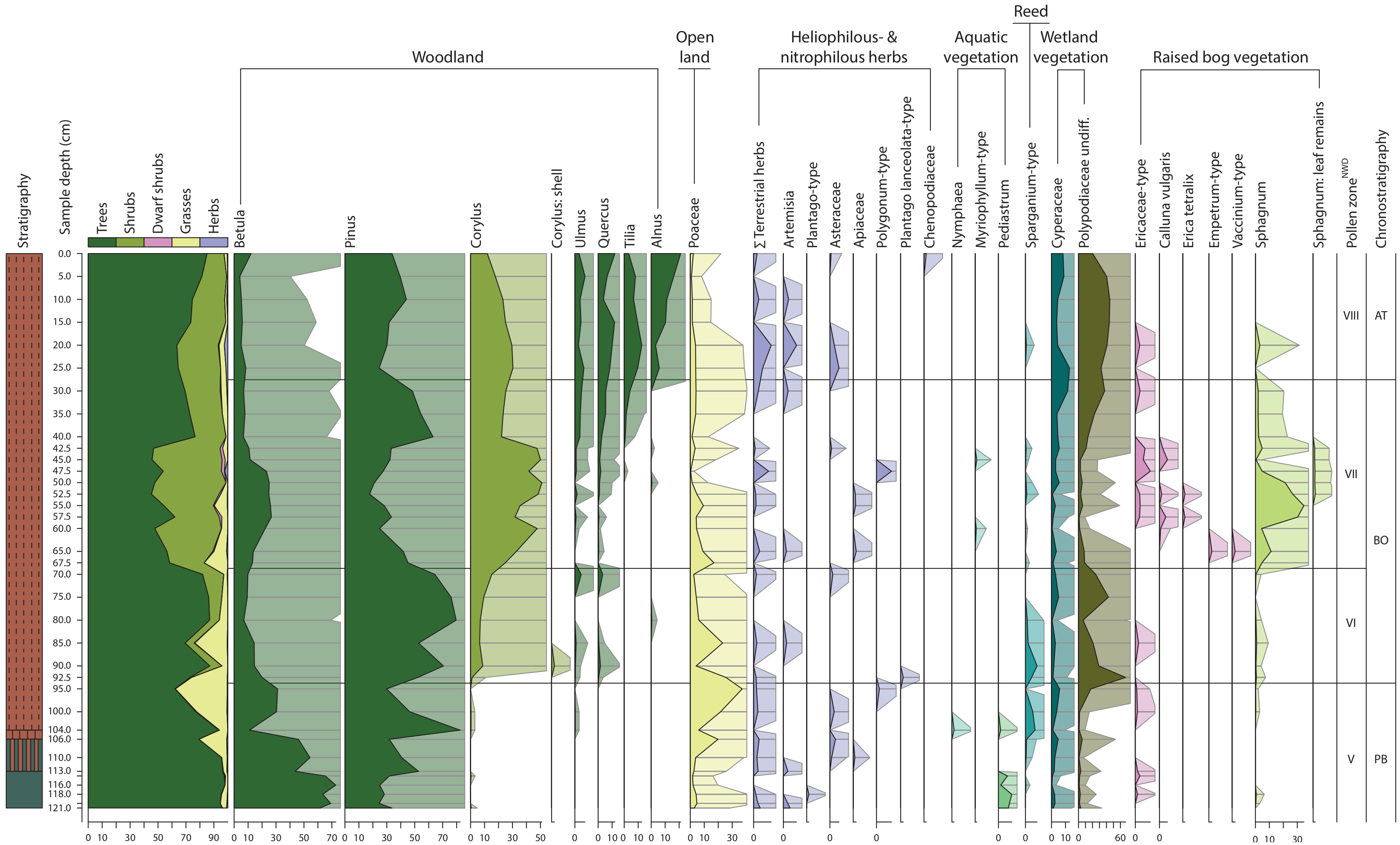

Fig. 12. Duvensee, camp site 1. Pollen diagram for profile WP 1/VI (in %) with the curves for selected pollen taxa. Light-coloured curves are exaggerated by factor 10. For a description of the stratigraphy, see Figure 3 (Pollen diagram after Schütrumpf 1981, 167 fig. 4, modified by the authors; analysis: unknown; graphics: M. Wieckowska-Lüth).

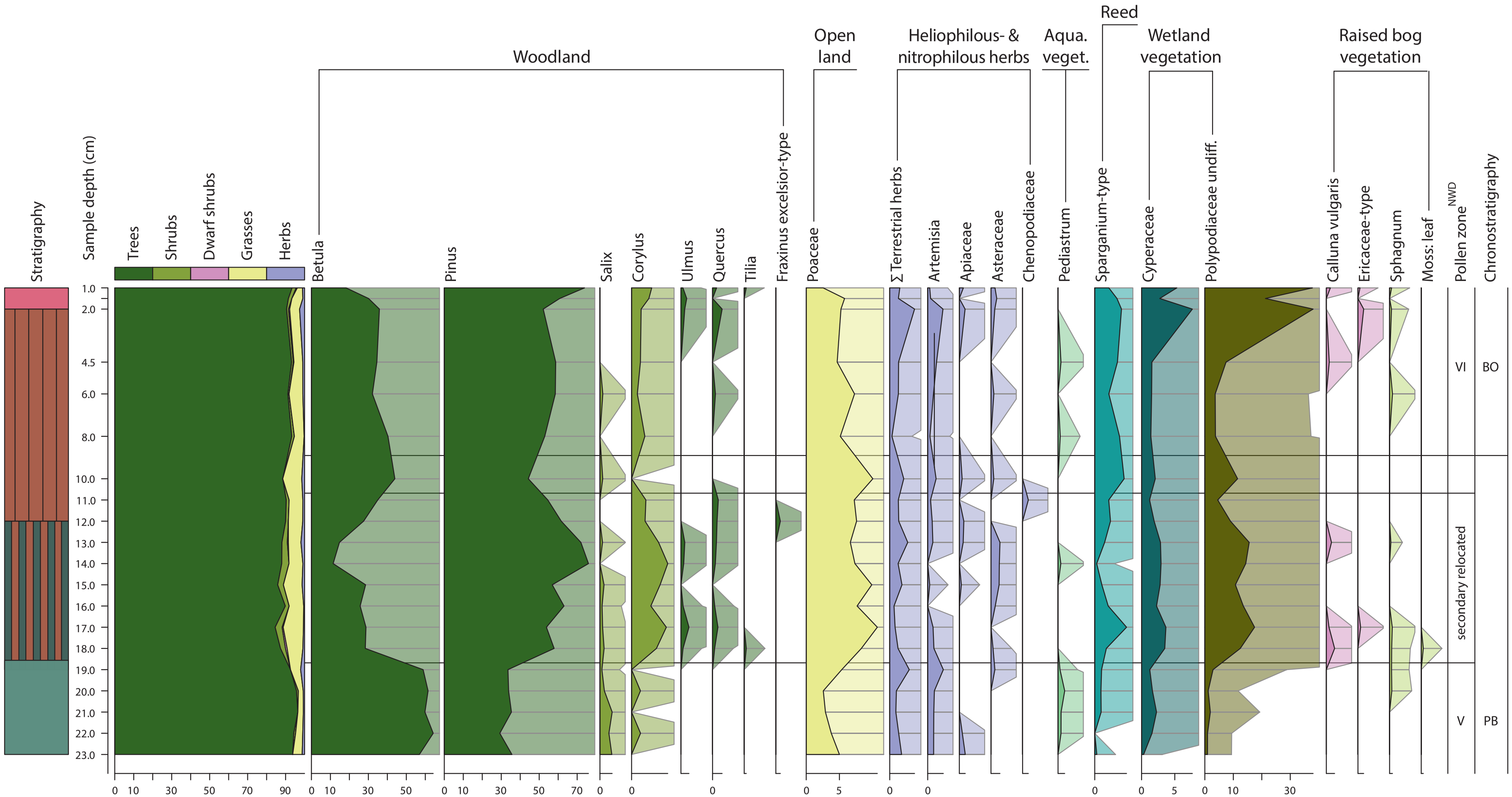

Fig. 13. Duvensee, camp site 1. Pollen diagram for profile WP 1/VII (in %) with the curves for selected pollen taxa. Light-coloured curves are exaggerated by factor 10. For a description of the stratigraphy, see Figure 3 (Pollen diagram after SCHÜTRUMPF 1981, 172 fig. 9, modified by the authors; analysis: unknown; graphics: M. Wieckowska-Lüth).

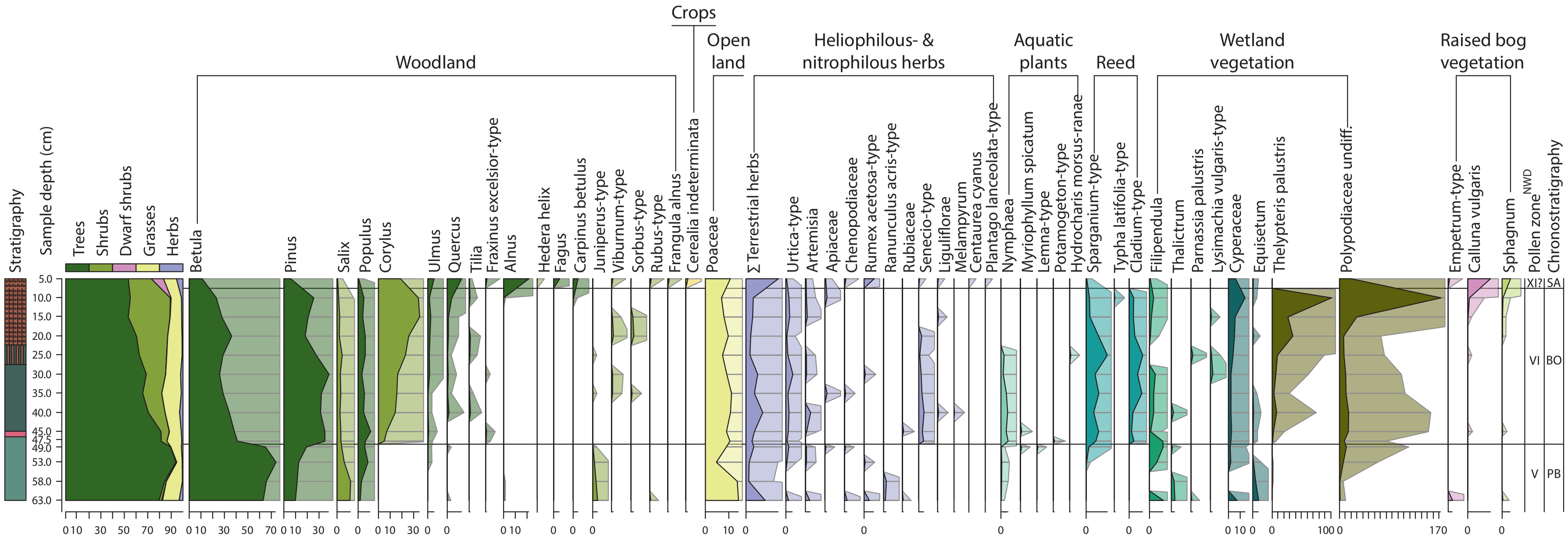

Fig. 14. Duvensee, camp site 8. Pollen diagram for profile WP 8/H (in %) with the curves for selected pollen taxa. Light-coloured curves are exaggerated by factor 10. For a description of the stratigraphy, see Figure 3 (Pollen diagram after Bokelmann et al. 1981, 33 fig. 1, modified by the authors; analysis: M. Neve; graphics: M. Wieckowska-Lüth).

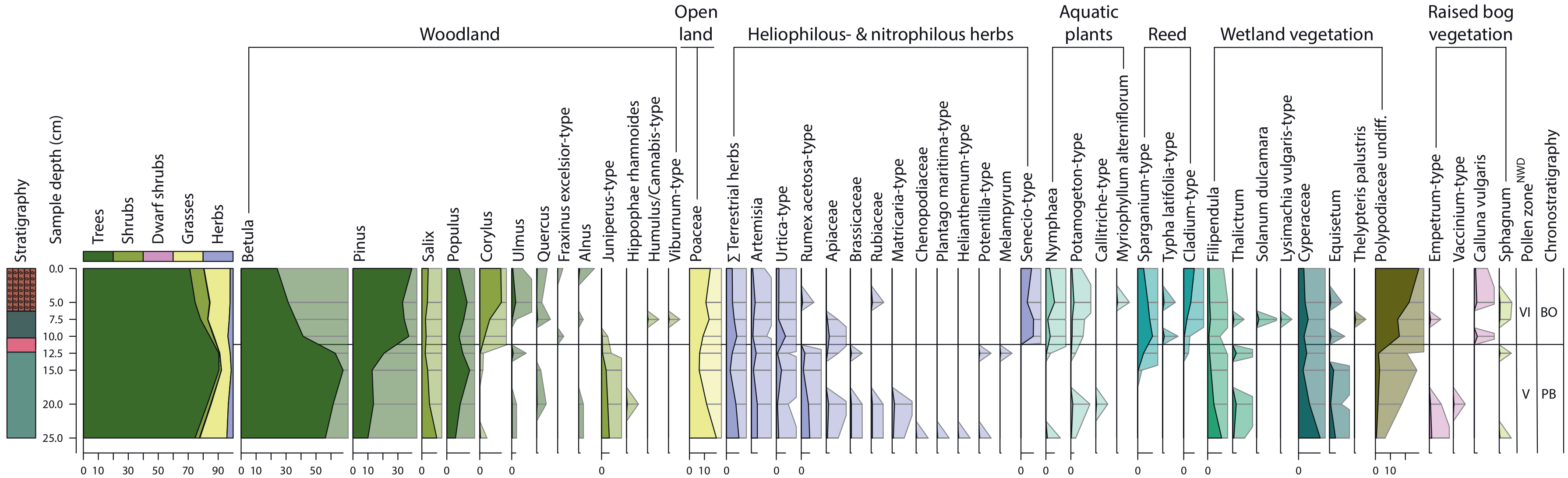

Fig. 15. Duvensee, camp site 8. Pollen diagram for profile WP 8/N (in %) with the curves for selected pollen taxa. Light-coloured curves are exaggerated by factor 10. For a description of the stratigraphy, see Figure 3 (Pollen diagram after Bokelmann et al. 1981, 33 fig. 1, modified by the authors; analysis: M. Neve; graphics: M. Wieckowska-Lüth).

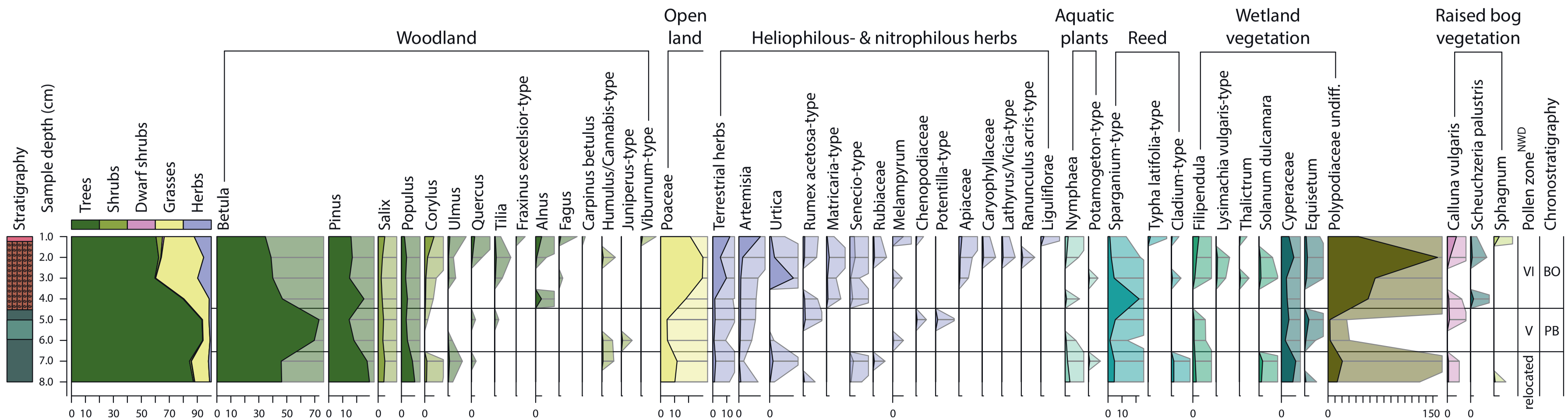

Fig. 16. Duvensee, camp site 8. Pollen diagram for profile WP 8/R (in %) with the curves for selected pollen taxa. Light-coloured curves are exaggerated by factor 10. For a description of the stratigraphy, see Figure 3 (Pollen diagram after Bokelmann et al. 1981, 33 fig. 1, modified by the authors; analysis: M. Neve; graphics: M. Wieckowska-Lüth).

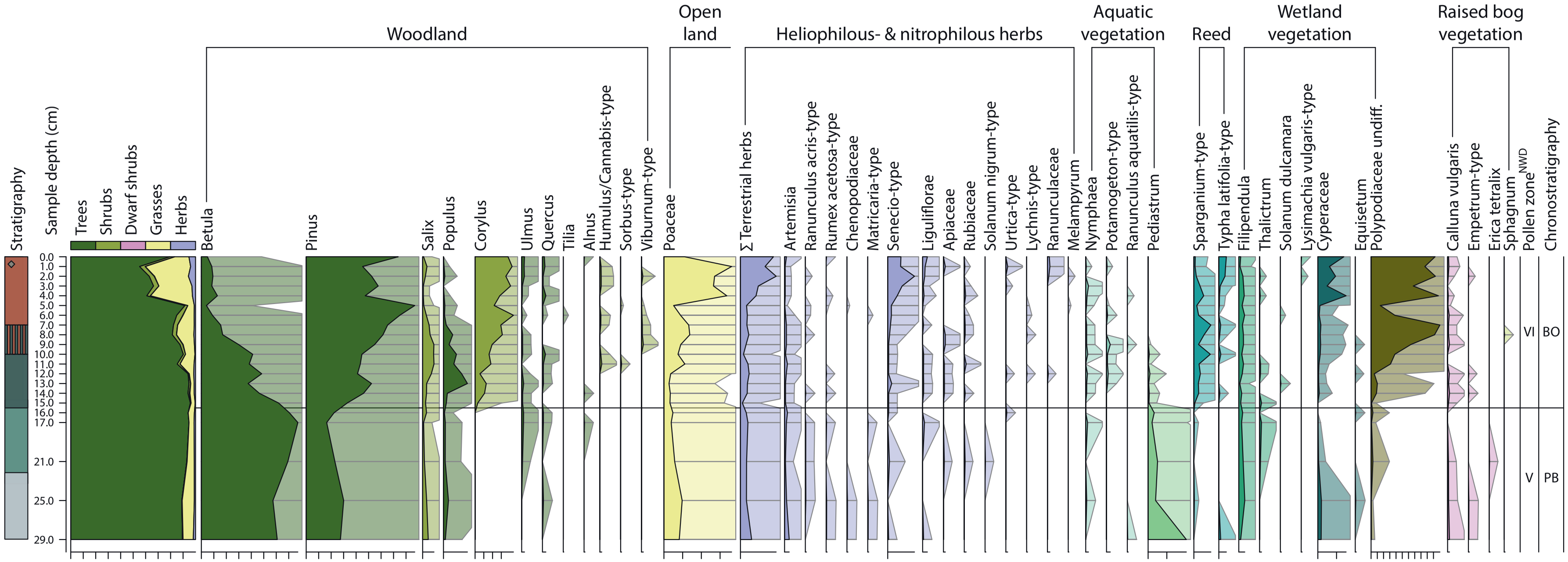

Fig. 17. Duvensee, camp site 11. Pollen diagram for profile WP 11/A (in %) with the curves for selected pollen taxa. Light-coloured curves are exaggerated by factor 10. For a description of the stratigraphy, see Figure 3 (unpublished; analysis: M. Neve; graphics: M. Wieckowska-Lüth).

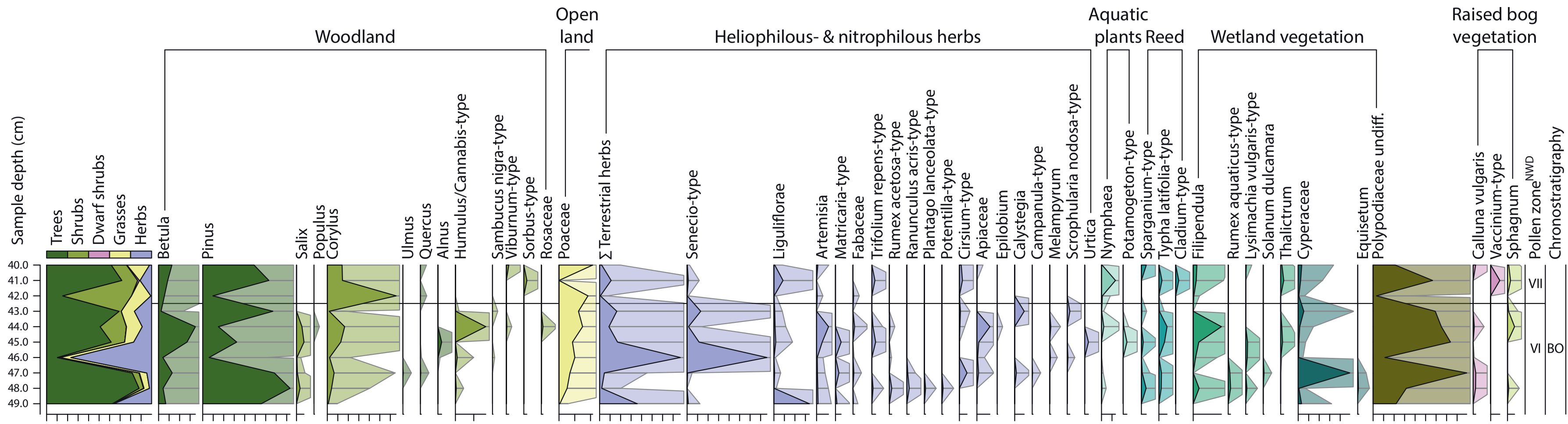

Fig. 18. Duvensee, camp site 11. Pollen diagram for profile WP 11/B (in %) with the curves for selected pollen taxa. Light-coloured curves are exaggerated by factor 10. For a description of the stratigraphy, see Figure 3 (unpublished; analysis: M. Neve; graphics: M. Wieckowska-Lüth).

along with the huge abundance of peat mosses, may suggest that the developing mire was already at the transition from fen to raised bog. During this time, the curves for anthropogenic indicators show no significant changes.

A large-scale opening of the landscape (XII NWD) becomes visible with a significant increase in grasses, cereals and terrestrial herbs (DUV-PAZ 23), announcing the advent of the High Middle Ages. Now, a greater abundance than before of sorrel, ribwort plantain and other plantain species, buttercups (*Ranunculus acris*-type), clover (*Trifolium*-types), vetches (*Vicia*-type) and different representatives of the sunflower family (*Matricaria*-type, Liguliflorae) points to extensive management of sites either as pastures or as meadows. The marked decline in alder, along with the occurrence of wet meadow elements, such as meadowsweet, mint (*Mentha*-type), knotweeds (*Rumex aquaticus*-type) and horsetail, indicate that the lowlands were also affected by this kind of use. More pollen signals from several potential arable weeds, such as knawel *(Scleranthus annuus)*, poppy (*Papaver rhoeas*-type), knotgrass (*Polygonum aviculare*-type) and representatives of the mustard family (Brassicaceae) reflect the high value placed on cereal cultivation. At the same time, indicators for winter cereals, such as cornflower *(Centaurea cyanus),* as well as for new cultivated plants, such as hemp (*Humulus*/*Cannabis*-type), also appear in the pollen record. In this context, increasing values of heather hint towards advanced deterioration of soils by continuous exploitation. This High Middle Ages land use expansion negatively affected the beech and hornbeam stands in the forests in particular, whereas oak trees were presumably initially unaffected by the clearings, as their slightly increased proportions show. It is possible that oak became more important because it was used as a mast tree. The occasional presence of juniper could be another indication that livestock frequented the woodland. As far as the further development of the former lake area is concerned, there is a transition to raised peat bog in the sediment sequence during this period. This is reflected in the pollen spectrum by the high proportion of peat mosses. However, the huge proportion of sedges, together with that of the amphibious water-plantain (*Alisma*-type) and marsh fern, indicate that the deposits are not yet pure raised peat bog.

Only later is a change to ombrotrophic conditions visible, with the emergence of further plant communities of nutrient-poor sites, such as blueberries, crowberries, cross-leaved heath *(Erica tetralix)*, bog-rosemary (*Andromeda*-type), bog-myrtle *(Myrica gale)* and sundew *(Drosera rotundifolia)* (DUV-PAZ 24). As there is a marked decrease in human pressure on the landscape at this time, the increasing evidence of heather probably also mirrors locations with raised bog vegetation. Temporarily, heather probably dominates here, as shown by the increase in its presence and the pronounced drop in peat mosses, which may simultaneously be an indication for a phase of drier conditions. As already mentioned, this phase is characterised by large-scale forest regeneration, while the areas exploited for agricultural purposes clearly decrease. The use of lowlands for grazing purposes also seems to have decreased considerably, as alder was able to spread again on these locations. Instead, cattle were probably driven into the forest, as indicated by the marked rise in oak and the minimal increase in beech and hornbeam. A slightly increased occurrence of hazel, together with pollen signals of rowans, blackberries (*Rubus*-type) and elder (*Sambucus nigra*-type), indicates that the forest was relatively light. In addition, pollen from buckwheat *(Fagopyrum)* is found from this time onwards, which indicates that the reduction in settlement can be attributed to the Late Middle Ages, a period characterised by economic crises initiated by outbreaks of plague.

The following growing abundance of cereal pollen, arable weeds, such as cornflower, knotgrass and spurrey *(Spergula arvensis)*, grasses, ruderal herbs, and grazing indicators, such as sorrel, broadleaf/hoary plantain *(Plantago major/P. media)* and ribwort plantain (DUV-PAZ 25), reflects a gradual increase in settlement and economic areas, probably after the transition to the Modern Period. The decline in alder shows that the lowlands were particularly affected by clearance, presumably to provide pastureland. However, the initially still very high proportions of oak indicate that forest browsing may still have been practised. The relatively high representation of beech also suggests that the forests located in the higher terrain were not opened up on a large scale during this time.

This only changed in the recent past, when the most significant increase in human impact is visible in the form of an unprecedentedly sharp decrease in arboreal pollen (DUV-PAZ 26). The synchronous enormous rise in Poaceae mirrors the transformation of the landscape into extensive grassland. The first evidence of walnut *(Juglans)* and larch *(Larix)*, reflecting anthropogenic plantings, are further witness of a completely transformed landscape. As far as the area of the ancient lake is concerned, the clear declines in peat mosses and heather indicate that changes have also taken place within the raised bog vegetation. As indicated by slightly elevated pollen signals of reed plants (*Sparganium*-type, *Menyanthes trifoliata*, *Caltha*-type), an open water surface could have emerged again at this time, at least temporarily. One reason for this could have been the rise in the groundwater level as a result of the large-scale forest clearings that influenced the local hydrology.

Local environment and land use history during the Mesolithic based on the individual pollen profiles of the camp sites

The pollen records of almost all on- and near-site sediment sequences begin in the course of the Preboreal. In general, the pollen spectra of this period are characterised by a more or less continuous decrease in open-land indicators, such as grasses, terrestrial herbs and dwarf shrubs, reflecting the increasing degree of forest cover in the surrounding area. The investigated profiles mostly come directly from the camp sites. Thus, they represent on-site records with very local information. An exception is a near-site profile (WP 1/VI) whose sampling point was 250 m northwest from the insular camp site 1 and thus closer to the edge of the palaeolake. Here, an extremely high abundance of grasses was recorded in the sedimentary transition zone between gyttja to peat (Fig. 3) in the late Preboreal (Fig. 12). Since at the same time the proportions of reed vegetation, followed by fern spores (probably *Thelypteris palustris*) also increase, their high presence is very likely to be associated with the onset of infilling processes. This pollen signal may reflect the spread of the common reed *(Phragmites australis)* and other hygrophilous grasses, whose pollen grains are part of the total curve for all Poaceae. This near-site sequence thus illustrates that the lake had already lost volume by this time. Another profile, from a core taken at some distance outside the cultural layers of WP 6 (WP 6/2), shows that island 2 also gradually emerged from the lake (Fig. 2). This is reflected in the sediment of this sequence, which features a mixture of lacustrine and peaty deposits (Fig. 3) that are pollen-stratigraphically dated to the late Preboreal (pollen diagram: Averdieck 1981). The accumulation of peat at the end of the Preboreal in profile WP 1/VII confirms this development, which is reflected in the pollen spectrum by the increases in reeds (*Sparganium*-type), sedges, fern spores and grasses (Fig. 13). However, as inferred from the gyttja deposits of further sediment sequences of WP 1 as well as WP 11, parts of these two camp sites were still under water cover at this time (Fig. 3).

In the course of the Preboreal, hazel pollen is already recorded. Evidence for hazel is mostly occasional but in some records reaches a somewhat higher abundance at the end of this period, before declining or briefly disappearing (WP 1/I, WP 1/II, WP 1/IV) during the transition to the Boreal. In this context, Bokelmann and colleagues (1981) already suggested that a very short warming at the end of the Preboreal may have led to a rapid spread of hazel, a spread that was then slowed down by a subsequent cooler phase. Simultaneously, hydrological fluctuations are indicated in several of the profiles (WP 1/II, 1/III, 1/VI, 1/IV) by slight reductions in sedges, ferns, reeds and aquatic plants, probably pointing to a short phase of elevated lake levels. At the same time, a short phase of increased water levels may also be in evidence in an on-site sediment sequence from camp site 8 (WP 8/R), where a temporary change from coarse to fine detritus gyttja occurs (Fig. 3). A water level fluctuation at the Preboreal–Boreal transition or at the beginning of the Boreal was also considered by Bokelmann and colleagues (1981) in their interpretation of the archaeological features of WP 8.

At the beginning of the Boreal, the decrease in water level continued. This is reflected, for instance, in the stratigraphic change from fine to coarse detritus gyttja in the main profile of camp site 8 (WP 8/H), which was from a core taken close to the western shore of the ancient lake (Fig. 3; Gross et al. 2018). Just above the changeover from fine to coarse gyttja, an artefact was embedded in the limnic sediments. The layer is characterised by rising values of hazel pollen (Fig. 14). The same situation is present in a second near-site sediment sequence, from somewhat closer to the shore of island 1 (WP 8/N), where archaeological finds occur immediately after the transition from fine to coarse detritus gyttja, also coinciding with the increase in the hazel (Fig. 15) and thus the transition to the Boreal. However, the analysis of the artefacts revealed that they all date archaeologically to the late Preboreal. As already assumed by Averdieck (in Bokelmann et al. 1981, 35), parts of the cultural layers of WP 8 have probably been relocated. It is conceivable, for instance, that late Preboreal artefacts from the higher occupation layers of the island were eroded into the early Boreal gyttja deposits as a result of later wave action or water level fluctuations after the abandonment of this location. The fact that parts of the island were already walkable at the transition to the Boreal is indicated by the on-site profile taken from below a bark mat of camp site 8 (WP 8/R). This sediment sequence reveals that the camp area was already covered with terrestrial vegetation, as reflected by the high abundance of grasses and ferns (Fig. 16). But it also implies that the deposits under the bark mat must be of early Boreal rather than late Preboreal age, based on the already increased frequency of hazel pollen. In parallel, a quite high frequency of terrestrial herbs was also noted, probably reflecting human-induced disturbances of the local environment. In this respect, however, Averdieck states that from a palynological point of view there are no reliable connections between these pollen signals and human activities on-site. He argues that elevated NAP values are only related to disturbance horizons (e. g. younger infiltrations, selective pollen preservation) and that in

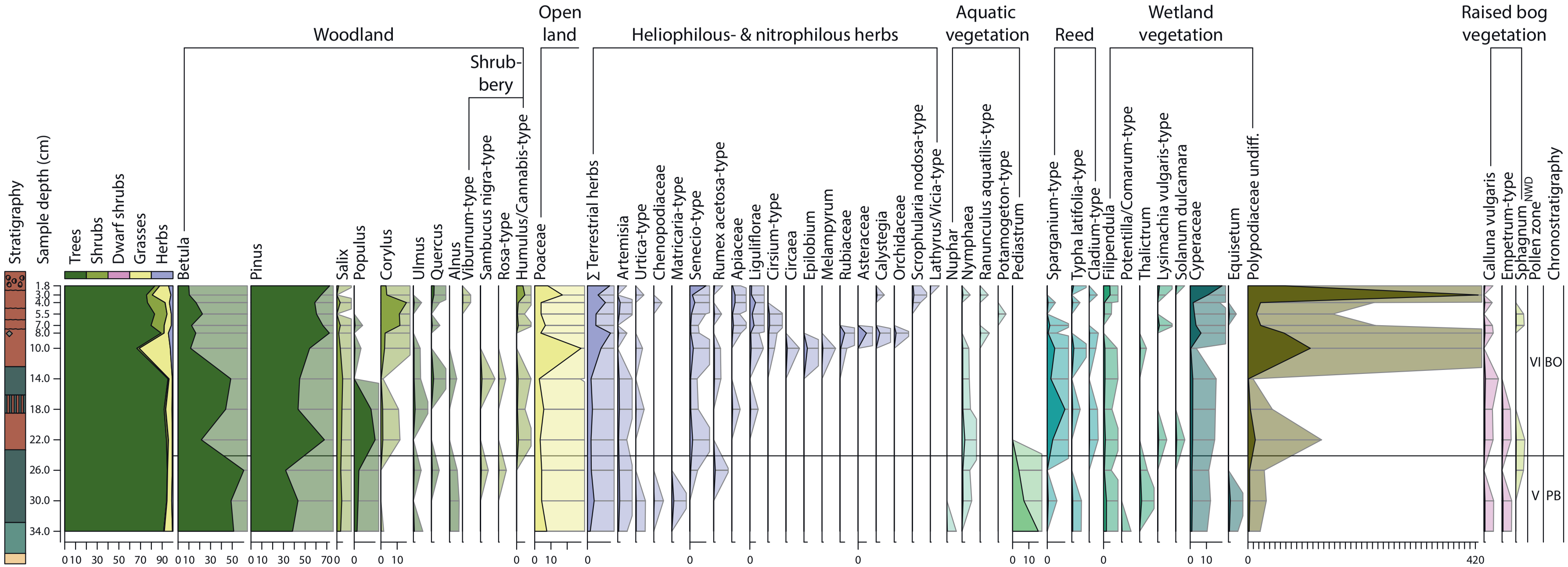

Fig. 19. Duvensee, camp site 11. Pollen diagram for profile WP 11/X (in %) with the curves for selected pollen taxa. Light-coloured curves are exaggerated by factor 10. For a description of the stratigraphy, see Figure 3. In the upper part of the sediment column a cultural layer with several birch mats and hazelnut shells above them is present (unpublished; analysis: M. Neve; graphics: M. Wieckowska-Lüth).

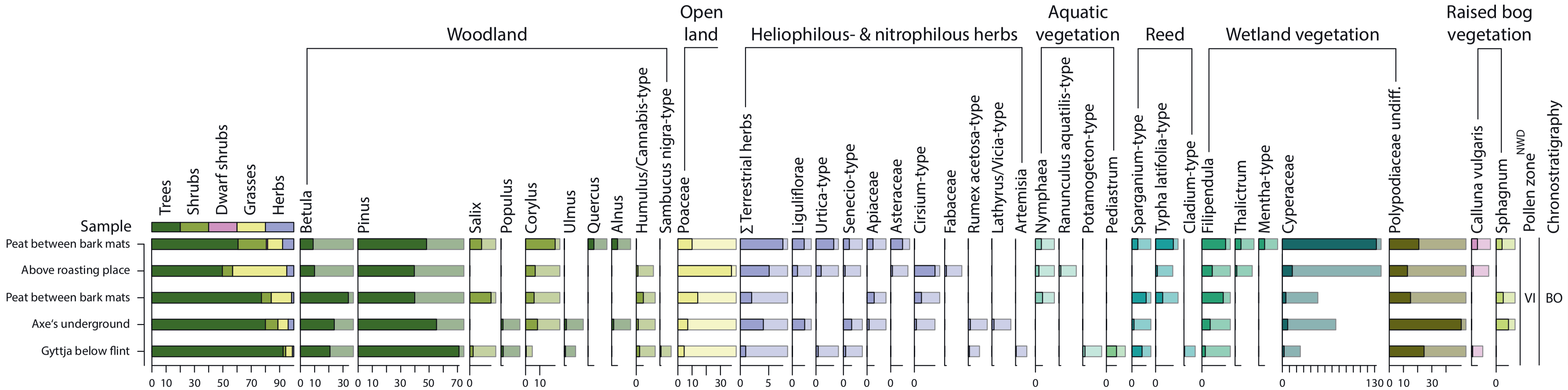

Fig. 20. Duvensee, camp site 11. Pollen diagram for profile WP 11/D (in %) with selected pollen taxa. Coloured bars are exaggerated by factor 10. For a description of the stratigraphy, see Figure 3 (unpublished; analysis: M. Neve; graphics: M. Wieckowska-Lüth).

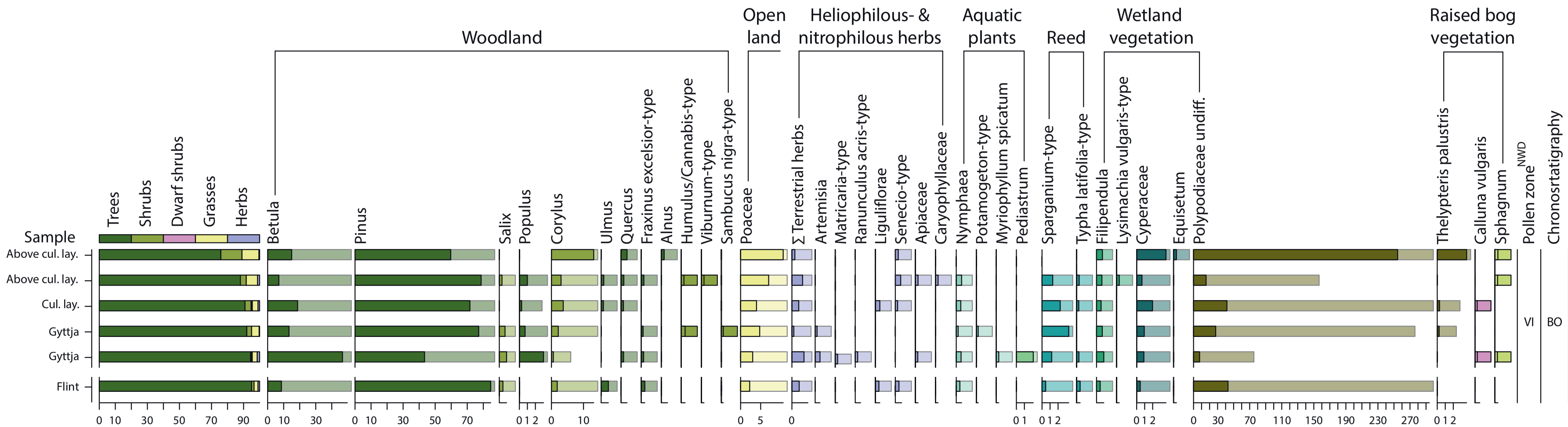

Fig. 21. Duvensee, camp site 11. Pollen diagram for profile WP 11/E (in %) from camp site 11 showing selected pollen taxa. Coloured bars are exaggerated by factor 10. For a description of the stratigraphy, see Figure 3 (unpublished; analysis: M. Neve; graphics: M. Wieckowska-Lüth).

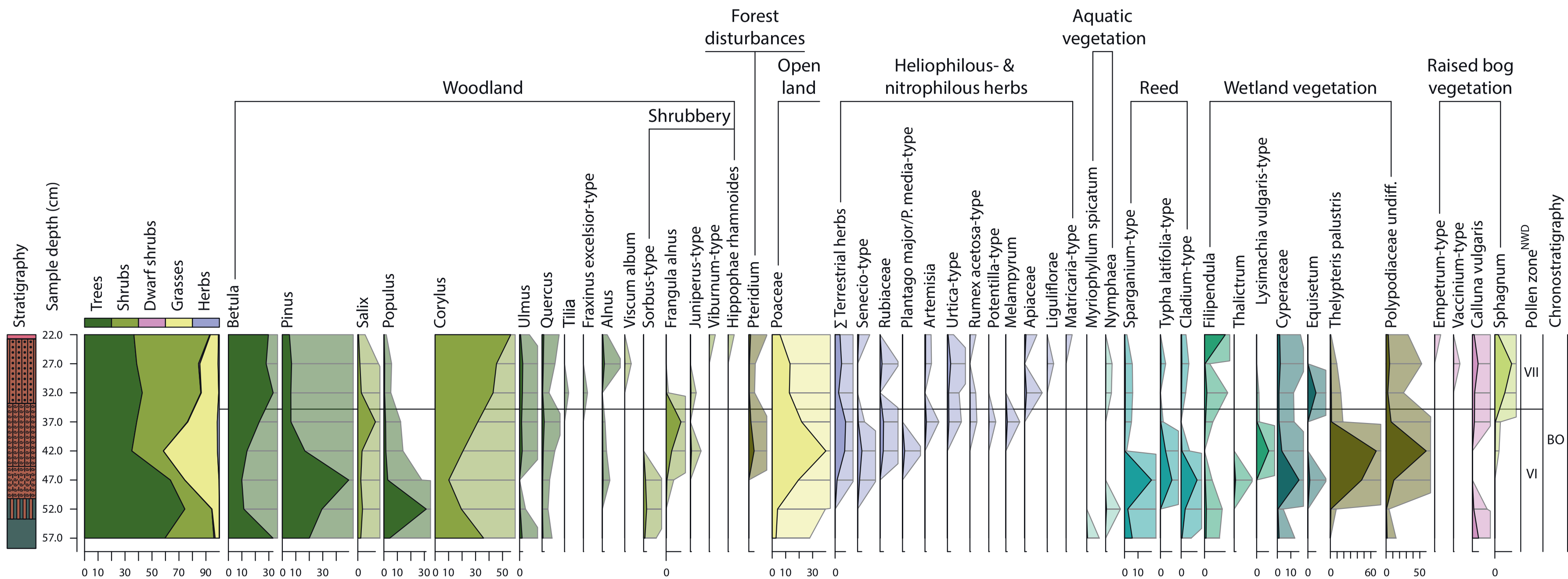

Fig. 22. Duvensee, camp site 13. Pollen diagram for profile WP 13/1 (in %) with the curves for selected pollen taxa. Coloured curves are exaggerated by factor 10. For a description of the stratigraphy, see Figure 3 (Pollen diagram after AVERDIECK 1986b, 166 fig. 1, modified by the authors; analysis: M. Neve; graphics: M. Wieckowska-Lüth).

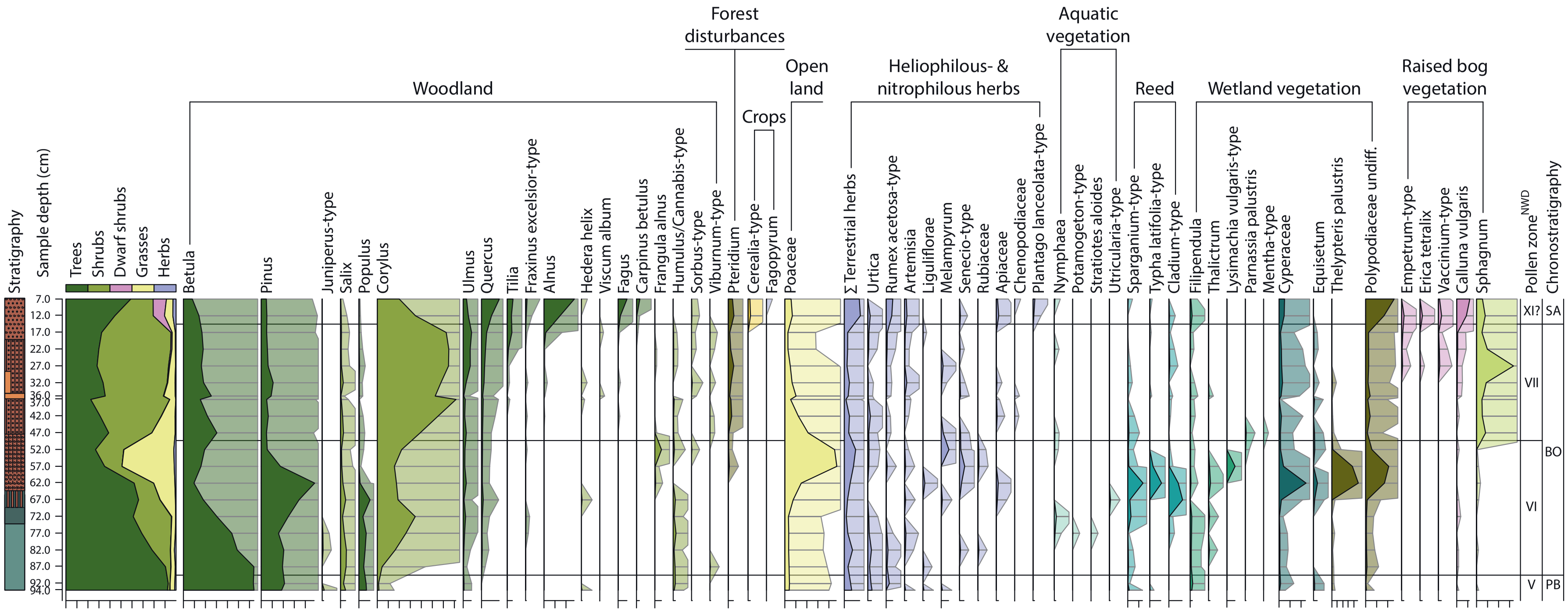

Fig. 23. Duvensee, camp site 13. Pollen diagram for profile WP 13/2 (in %) with the curves for selected pollen taxa. Coloured curves are exaggerated by factor 10. For a description of the stratigraphy, see Figure 3 (Pollen diagram after Averdieck 1986b, 166 fig. 1, modified by the authors; analysis: M. Neve; graphics: M. Wieckowska-Lüth).

disturbance-free spectra, no potential settlement indicators would occur to any significant extent. Only the conspicuously high occurrence of nettle pollen within a spectrum allows a different interpretation, according to him (Bokelmann et al. 1981). However, because the representatives of the infilling-indicating plant communities already show a decreasing trend at this time, a certain proportion of grasses that continue to show a consistently strong presence could also be due to the anthropogenic use of this site. The evidence for this early Boreal use of WP 8 does not, however, exclude prior utilisation of higher areas of the island and could therefore point to continuous visits to the site.

With the onset of the Boreal, the infilling process in the area of camp site 6, on island 2, was already completed. This is evidenced by peat accumulations in both the near-site (WP 6/2) and on-site (WP 6/1) profiles. In their pollen spectra, this development is again mirrored by an increase in reed plants, followed by strong increases in grasses, sedges and ferns (pollen diagrams: Averdieck 1981). In the on-site profiles of the other camp sites, 1 and 11 (WP 1/I, 1/II, 1/V, 11/A, 11/X), however, peat formation does not start synchronously with that of WP 6 but somewhat later, suggesting that the two sites were located on higher terraces of the island (Fig. 2) and therefore infilled only in the course of the early Boreal. Even later, namely in the second half of this period, the area of camp site 13, on island 3, emerged from the lake (WP 13/1, 13/2), as shown by the change from peaty gyttja to peat (Fig. 3).

The early Boreal is generally considered the period when hazel became increasingly present. This gradual rise in *Corylus* is reflected in some near- and on-site profiles (WP 1/II, 1/VI, 6/1, 6/2, 8/H, 8/N, 11/A) as well. After distinct increases in its curves at the beginning of this phase, however, some records – mainly those with small sample distances – show partly strong fluctuations within their courses (WP 1/I, 1/VI, 11/B, 11/X). This small-scale assessment thus reveals that the establishment of hazel did not proceed in the same way everywhere, but apparently also experienced setbacks, probably depending strongly on local factors. For instance, hydrological changes seem to have played a decisive role, as the declines in hazel pollen percentages often occur in parallel with significant changes within wetland plant communities. Within an environment subject to infilling, short but marked declines in sedges, reeds and ferns (cf. *Thelypteris palustris*) (Figs. 7; 12; 18; 19) may demonstrate that the water level has risen temporarily. Hazel stands growing too close to the shore would probably have suffered from sudden and heavy waterlogging. Conversely, long-lasting summer heat and dry conditions could also have affected pollen production and thus the hazelnut yield.

However, not only local factors, but also supra-regional phenomena may have been behind the fluctuations in the proportion of hazel. For instance, the first early Boreal phase with a drop in the hazel curve (hazel minimum [HM] 1) emerges in several profiles (Fig. 28) at a time when birch is again increasing in proportion, while pine shows a declining trend (WP 1/II, 1/V, 1/III, 1/IV, 11/A, 11/X). In temporal coincidence with this, two profiles show a sediment change from coarse to fine detritus gyttja (WP 1/V) or, respectively, from peat to coarse detritus gyttja (WP 11/X), thus indicating a water level rise. The increased presence of birch could at the same time be an indication of a short climatic setback. In the Poggensee pollen record, there is also an increase in birch in the first half of the early Boreal, while the curves for hazel and pine temporarily drop around 8500 cal BC. Here, however, the decline in *Corylus* is not as pronounced as in some pollen diagrams from the camp sites (Fig. 28). This and the relative dating of the Duvensee profiles therefore allow only cautious statements to be made about whether the same event as in Poggensee is reflected in these short-term shifts in the pollen spectra. With the subsequent renewed increase in the abundance of hazel, the evidence of grasses and various terrestrial herbs, such as mugwort, nettle, sorrel, cow wheat *(Melampyrum)*, willowherbs *(Epilobium)*, ragworts and thistles (*Cirsium*-type), increases in several profiles (WP 1/I, 1/V, 11/A, 11/X). However, as no archaeological evidence for Mesolithic settlement was found in the respective sedimentary sequences at this time, it is difficult to assess whether the presence of these ruderal taxa reflects the local presence of humans or whether it reflects natural successional processes following a drop in the water table. An exception to this is profile WP 1/II (Fig. 8), where a cultural layer correlates with the onset of the peaty gyttja, and which directly follows the birch peak. In this case, the corresponding pollen spectrum shows relatively high signals of grasses and could thus indicate anthropogenic activities. However, a previous decline in the hazel curve, as recorded in the other profiles, was not detected here. But the non-recognition of this development may be a matter of the lower temporal resolution.

Another marked decline in hazel representation (HM 2; Fig. 28) was recorded in parallel with a pronounced increase in pine around the middle of the early Boreal in several pollen records (WP 1/I, 1/II, 1/III, 1/V, 8/H, 11A, 11/X). At the same time, there were also changes among the wetland plant communities, which are expressed in particular in the reduction in reed vegetation, but sometimes also in a reduction in sedges and ferns. This, together with the increase in pine, may

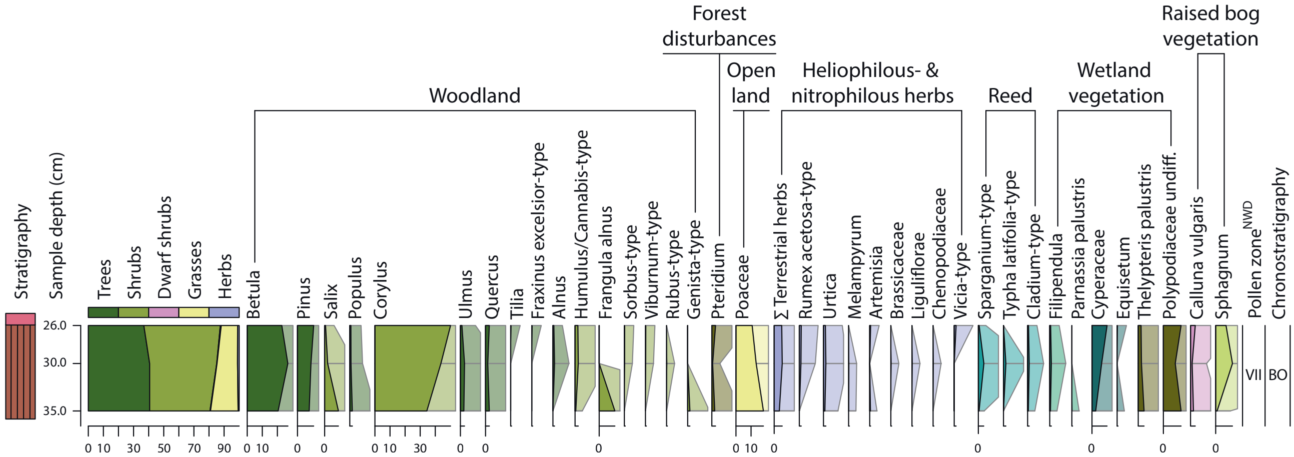

Fig. 24. Duvensee, camp site 13. Pollen diagram for profile WP 13/3 (in %) with the curves for selected pollen taxa. Coloured curves are exaggerated by factor 10. For a description of the stratigraphy, see Figure 3 (Pollen diagram after Averdieck 1986b, 166 fig. 1, modified by the authors; analysis: M. Neve; graphics: M. Wieckowska-Lüth).

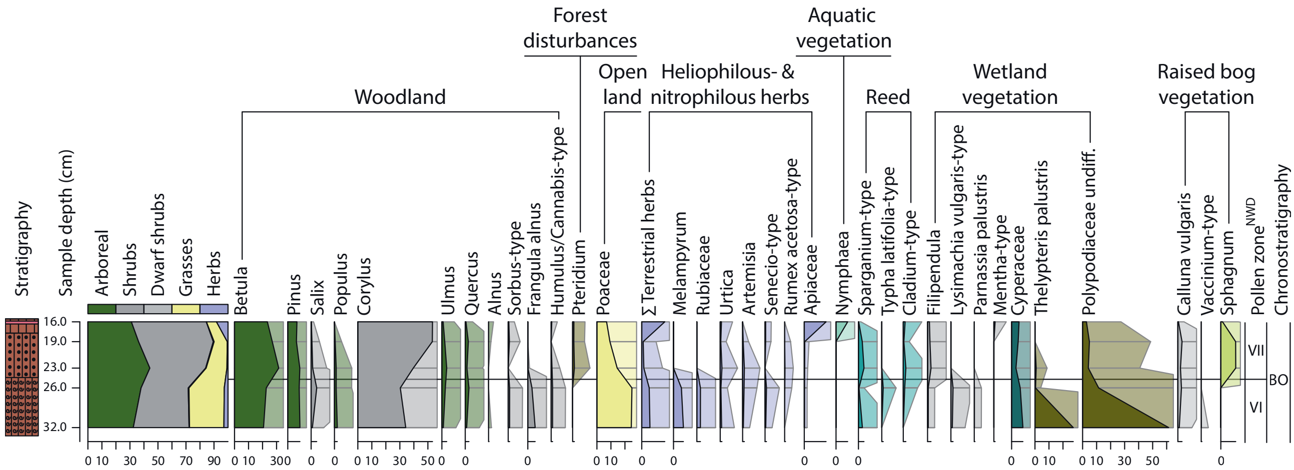

Fig. 25. Duvensee, camp site 13. Pollen diagram for profile WP 13/5 (in %) with the curves for selected pollen taxa. Coloured curves are exaggerated by factor 10. For a description of the stratigraphy, see Figure 3 (Pollen diagram after Averdieck 1986b, 166 fig. 1, modified by the authors; analysis: M. Neve; graphics: M. Wieckowska-Lüth).

be indicative of a period of drier conditions, which perhaps had a negative effect on hazel pollen production. Of interest here is that the grasses often show a clear decrease while the proportion of terrestrial herbs increases (WP 1/I, 11/A, 11/X). This can be explained by the fact that the grasses include taxa of reed and wetland plants, while the stronger presence of terrestrial herbs points to progressively drier environment. There is also a comparable signal in the Poggensee pollen record, where the persistence of high hazel values ends right after the ash deposition of the Saksunarvatn eruption, around 8300 cal BC (Zanon et al. 2021). Here, *Corylus* is being replaced first by *Betula* and then, to an even greater extent, by *Pinus*, indicating that climatic conditions have deteriorated for the thermophilic and oceanic hazel.

With the subsequent recovery of the hazel stands, as shown in the pollen data (WP 1/I, 1/II, 1/III, 1/VII, 8/H, 11/A, 11/X), traces of occupation were documented in several sediment sequences (WP 1/I, 1/III, 1/VII, 11/B, 11/X). These included bark mats, axes, flint artefacts, charcoal particles and partly charred hazelnut shells. The evident anthropogenic uses of the local environment deposited as cultural layers are also reflected in the corresponding pollen spectra. There are, for instance, visible rises in the abundance of the different terrestrial herbs (*Artemisia*, Chenopodiaceae, *Urtica*-type, *Rumex acetosa*-type, *Senecio*-type, *Cirsium*-type, *Matricaria*-type, Liguliflorae, *Trifolium*-type, Asteraceae, Fabaceae, Apiaceae, *Epilobium*, *Melampyrum*) (WP 1/I, 1/III, 11/B, 11/D, 11/E, 11/X), along with the occasional occurrence of the disturbance indicator bracken. However, the proportion of grasses in the cultural layers, although almost grasses are always present with increased evidence, is sometimes strongly declining compared with the phases before or after the use of the sites (WP 1/III, 11/B, 11/E, 11/X). This again shows that the Poaceae in a lakeshore environment are suitable as anthropogenic indicators to only a limited extent, as they also include a certain component of natural wetland vegetation. But there is also a record from camp site 1 where the proportion of grasses drops significantly along with that of terrestrial herbs after the occupation horizons end (WP 1/I). A similar development, but this time related only to a marked decline in terrestrial herbs, can be observed in another profile of the same camp site, also after the abandonment of the location (WP 1/III). In these two cases, the decrease in open-land indicators may indeed relate to an absence of human impact on the surrounding vegetation. These palynological records thus suggest that camp site 1 may have been visited over a longer period of time, whether over one or several seasons, so that the anthropogenic use of the local environment can be traced more clearly in the corresponding pollen assemblages. Furthermore, there are other near-site and on-site sediment sequences in which no cultural layers have been documented, but where, in the same temporal context and beyond, the abundance of open-land indicators follows the ups and downs of the hazel curve (WP 1/I, 1/II, 1/III and 1/VII, in the secondary, redeposited part). A particularly pronounced example is provided by a profile from camp site 11 (WP 11/A) where significant increases in both grasses and terrestrial herbs are recorded in parallel to a significant increase in hazel (Fig. 17). Contemporaneously, human presence is confirmed by the find of a flint artefact in the upper profile column. This emerging pattern in the pollen data thus suggests that the use of the Duvensee area, with its islands, may be related to the local presence of hazel stands, at least during the course of the early Boreal. However, there are also examples to the contrary. In a profile of camp site 11 (WP 11/X), for example, a distinct increase in the proportion of *Corylus* can be seen, which corresponds exactly to the cultural layer (several birch mats), but which is also accompanied by a decrease in terrestrial herbs and grasses (Fig. 19). The lowered signals from disturbance indicators in a part of the sediment sequence with clear traces of anthropogenic activities are thus obviously not an indication of reduced local human impact. Perhaps they reflect a different type of site use. Shorter stays on the island (even repeatedly over a longer period of time), for example, would probably have a weaker effect on the local vegetation than continuous stays over several days or weeks within a certain season, and accordingly no clear disturbance signal is visible in the pollen diagram after shorter stays. Averdieck (1981) furthermore emphasises that anthropogenic indicators are hardly to be expected in the archaeological layers close to the lake shore, due to site-related factors. While the local presence of hazel shrubs also seems to have played a role in the use of the area, in this case due to the increased proportion of hazel pollen in the cultural layer, this increased proportion could also indicate a use of the shrubs themselves and not only their nuts – hazelnut shells are in fact only found in the uppermost horizon, above the birch mats, in a section of the profile (Fig. 19). It is possible, for instance, that the young hazel shoots were processed on-site and that the site was thus visited in spring, when the hazel was still in flower. Alternatively, the maintenance or even the manipulation of hazel shrubs on the islands could have served to produce numerous tasty young shoots to attract prey for humans to hunt. This type of hazel use is assumed, for example, for the Mesolithic site on the island of Dudka, in northern Poland (Gumiński/Michniewicz 2003). Interestingly, in the upper horizon of profile WP 11/X, with the hazelnut shells, the evidence of *Corylus* pollen decreases considerably again, which could possibly indicate a renewed change in site use. At the same time, there are also signals from the wetland vegetation (a significant rise in Cyperaceae and Polypodiaceae undiff.), showing that the infilling processes were progressing more strongly at this time and thus hinting at changed local environmental conditions.

Towards the end of the Boreal period, a further phase with longer-lasting decreasing hazel proportions (HM 3) was detected in some profiles (WP 1/I, 1/III, 1/V). This is accompanied by a longer-lasting, marked decrease in or even disappearance of pollen signals from terrestrial herbs. Synchronously, the evidence for grasses also diminishes in two sediment sequences for a while, pointing to fewer disturbances among the local vegetation. At this point, the sediment sequences also no longer contain any traces of local human use. Instead, the ferns (cf. *Thelypteris palustris*) experience several significant rises, while the representatives of the reed plants are hardly detected at this time, which could be interpreted as a sign of a prolonged dry period. The parallel maximum spread of pine, which is more adaptable to drought than the now sharply declining birch, could point in the same direction. Incidentally, around this time the area of camp site 13 also emerges from the lake (WP 13/1, 13/2) (Fig. 3) and its profiles also show a clear decline in hazel (Figs. 22–23). Consequently, the pollen records again point to the fact that hazel seems to react sensitively to excessive environmental changes, which in turn leads to a reduction in its abundance or pollen productivity, respectively. A reduction in the proportion of *Corylus* at

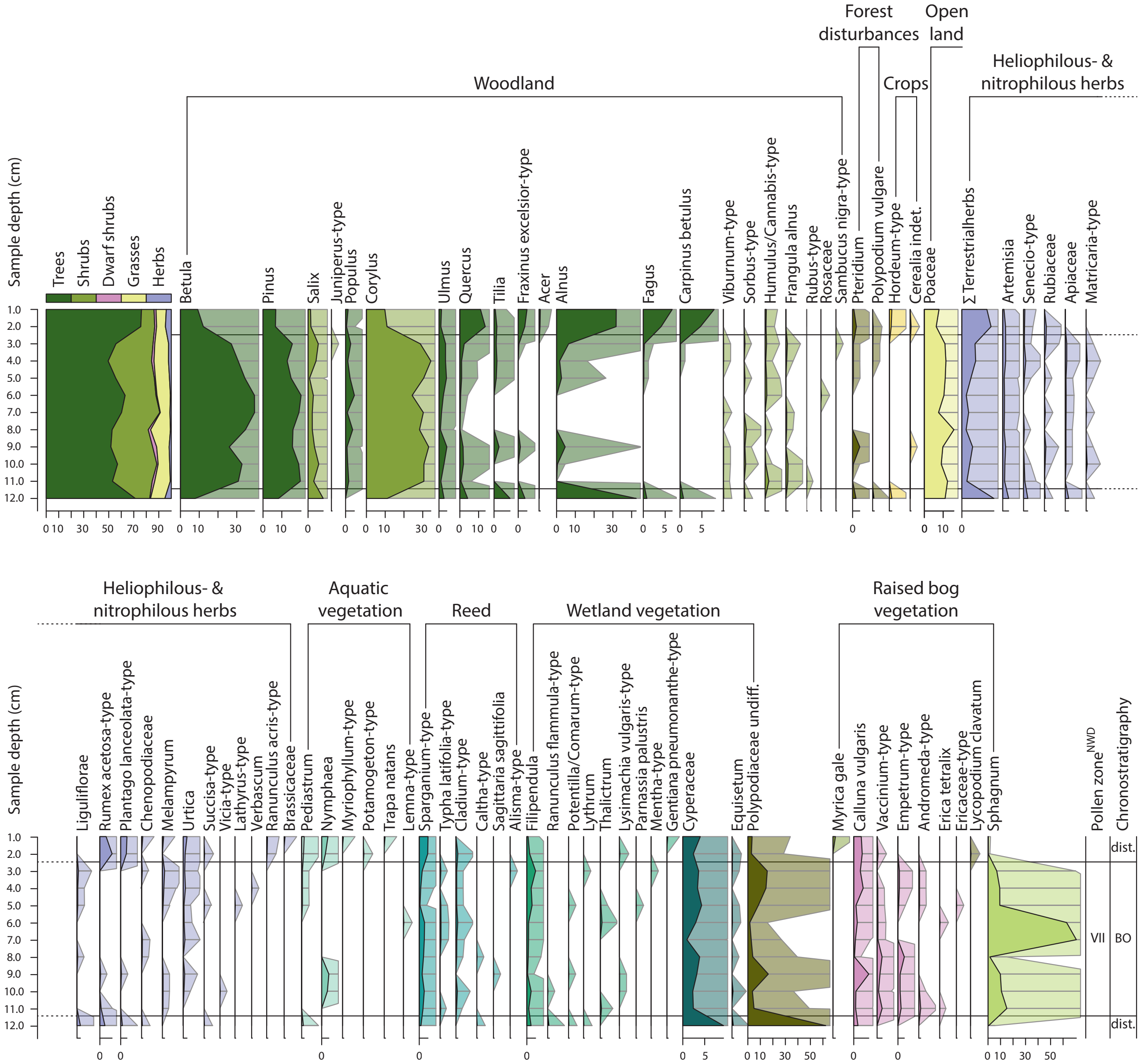

Fig. 26. Duvensee, camp site 21. Pollen diagram for profile WP 21 (in %) with the curves for selected pollen taxa. Coloured curves are exaggerated by factor 10. For a description of the stratigraphy, see Figure 3 (unpublished; analysis: M. Neve; graphics: M. Wieckowska-Lüth).

the end of the early Boreal is also documented in the pollen diagram for Poggensee. However, this is accompanied by marked increases in *Betula* and other environmental disturbances (Zanon et al. 2021). Hence, it remains unclear whether these are common regional developments.

After this phase, a marked decrease in pine proportions, accompanied by a rapid spread of *Corylus*, demonstrates that growing conditions have become highly favourable for hazel, thus marking the transition to the late Boreal. Another common feature is the parallel significant drop in ferns (WP 1/I, 1/III, 1/IV, 1/VI, 6/1, 6/2, 6/311B, 13/1, 13/2), while the increasing evidence of grasses and, in other profiles, sedges or representatives of the reeds, again indicate locally wetter conditions. In addition, at this time more evidence of aquatic plants (WP 1/III, 1/VI) could be documented in some sediment sequences, probably mirroring episodes of temporary lake level increases. In other profiles, the increased occurrence of peat mosses (WP 1/VI, 13/2, 21/1) hints at the existence of moist *Sphagnum* carpets on the insular sites.

At the time when the hazel curve is still rising sharply, further archaeological traces of Mesolithic occupation are documented on island 3. Among the remains were the bark mats from camp site 13,

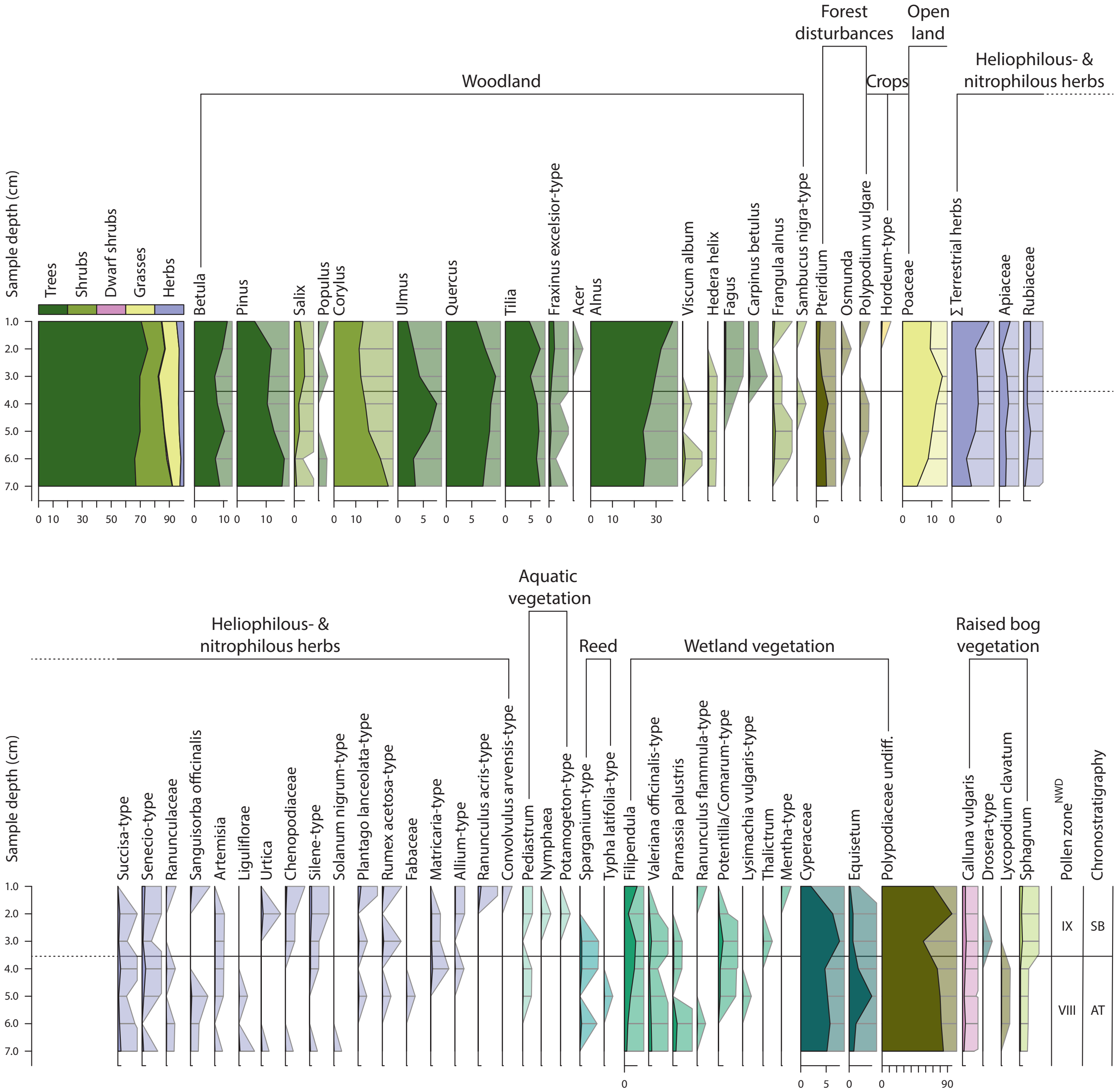

Fig. 27. Duvensee, camp site 17. Pollen diagram for profile WP 17 (in %) with the curves for selected pollen taxa. Coloured curves are exaggerated by factor 10. For a description of the stratigraphy, see Figure 3 (unpublished; analysis: M. Neve; graphics: M. Wieckowska-Lüth).

which were located just above the *Sphagnum* peat, indicating that such sites, with soft bog vegetation, were deliberately chosen. The associated pollen records (WP 13/1, 13/2, 13/3, 13/5) show elevated signals of some herbs (*Artemisia*, *Urtica*, *Rumex acetosa*-type, Chenopodiaceae, Apiaceae) as potential anthropogenic indicators (Figs. 22–24). However, these also occur both before and also after the horizons with the archaeological relicts in the pollen diagrams. This fact was already highlighted by Averdieck (1981). Thus, this more or less continuous evidence of helio- and/or nitrophilous herbs may be indicative of a rather short period of use, during which the surrounding vegetation was no more disturbed than before and afterwards. At the same time, the herbaceous pollen signals outside the cultural horizons could also indicate visits that took place before and after their deposition but without leaving visible archaeological traces, or ones that were later destroyed. In the late Boreal cultural layer of WP 13/2, which contains wooden beams, signs of human presence are also indicated by a visible increase in grasses (Fig. 23). Perhaps this location was impacted more by human activity. It is also interesting that a decline in the proportion of hazel is documented at the same time. This gives the impression that in times of reduced hazel presence, the use of the islands is more strongly reflected in some of the on- and near-site pollen records.

If the further course of the hazel curve is considered, a descending trend (HM 4) can be observed in some profiles even before the middle of the late Boreal (WP 1/I, 1/IV, 1/VI, 11/B, 13/2). Concurrently, the frequency of pine pollen increases, probably pointing to a climatic oscillation towards more continental conditions. The same development can be observed in the Poggensee record, where a hazel decline parallel to a steep pine peak dates to about 7850 cal BC. As some sediment sequences exhibit a declining trend in ferns at this time (WP 1/I, 1/IV, 1/VI), this could be a further indication of generally drier conditions, under which the hazel shrubs may have suffered.

Only shortly after, this setback is followed by the mass expansion of *Corylus*. At the time when this expansion happened, potential anthropogenic uses were documented in the pollen profiles, this time in the area of camp site 6. The occupation manifested itself in particularly conspicuous increases in grasses and terrestrial herbs (pollen diagram: Averdieck 1981). However, Averdieck (1981) attributes this rises in NAP representation to redepositions from younger deposits. In fact, no equivalent patterns were observed in the other profiles that contained the late Boreal deposits. Instead, at the time when the hazel shows its highest proportions, the open-land indicators tend to decrease (WP 1/I, 1/IV, 1/VI, 13/2). An exception to this is the sediment sequence of camp site 21, which contains relatively high proportions of grasses (Fig. 26). But these remain almost constant throughout the entire period, reflecting natural wetland vegetation signals rather than ongoing human disturbance. This supposition is also backed up by the rather low representation of terrestrial herbs. However, there is a slightly increased presence of grasses, and also bracken, at the beginning and end of the late Boreal, which is indeed probably due to increased anthropogenic activity during these times.

Still during the predominance of the hazel, another small drop in its proportions (HM 5) is recorded (WP 1/VI, 21/1). Unfortunately, the few profiles covering this period cannot be clearly correlated with each other, as some of them (WP 1/VI, 1/IV) seem to be blurred (Schütrumpf 1981, 167), which makes the search for the cause of this renewed drop in hazel difficult. However, parallel fluctuating proportions within the wetland vegetation (ferns, peat moss, sedges) and hydrological changes derived from this could be a possible trigger for the renewed shrinking of the hazel stands along the lake. For the further course of the late Boreal, the pollen diagram for Poggensee also shows further fluctuations in the *Corylus* curve that are opposite to those of *Betula*. Whether these are local phenomena or regional events cannot be assessed, due to the insufficient temporal linkage with the Duvensee profiles.

A brief insight into the local environment of the Atlantic period is provided by two of the sediment sequences. While one shows that at the beginning of this phase the open-land indicators (WP 1/VI) are somewhat more strongly represented, the other reveals an increased degree of openness at the end of this phase (WP 17/I), where a pollen find of ribwort plantain (Fig. 27) suggests that the activities of Neolithic farmers may already be reflected here. Furthermore, compared with the preceding late Boreal, the evidence of ferns and sedges is much more pronounced during this stage, which could indicate an accelerated infilling of the lake.

The transition to the Subboreal is only represented by the short sequence from site 17 (Fig. 27). With the beginning of this phase, evidence for the grazing indicator ribwort plantain is again present, albeit at a low level. The signals of grasses and terrestrial herbs also do not exceed the late Atlantic level. However, local cereal cultivation is already be proven for this point in time, with a record of barley (*Hordeum*-type).

SUMMARY AND CONCLUSIONS

The combination and joint synthesis of the previously published as well as the legacy on- and near-site pollen data presented here enabled a detailed reconstruction of the environmental framework conditions for the use of the islands gradually emerging as a result of the shrinking of the lake and how the environmental setting changed in the course of the Mesolithic. In addition, the cultural layers embedded in the profiles from the camp sites provided a unique opportunity to assess the impact of the hunter-gatherer groups on the surrounding vegetation. Furthermore, the more secure linkage of the sediment column of the standard profile with the pollen data has enabled assignment to the individual archaeological periods, as a complement to the already known pollen stratigraphic classification of the facies, and this latter could be refined based on more recent, well-dated pollen records from the region. This additional palynological interpretation of the standard profile has made it possible to trace the history of the Duvensee area from the transition to the Holocene onwards, including lake genesis, vegetation history and settlement history, back to the recent past.

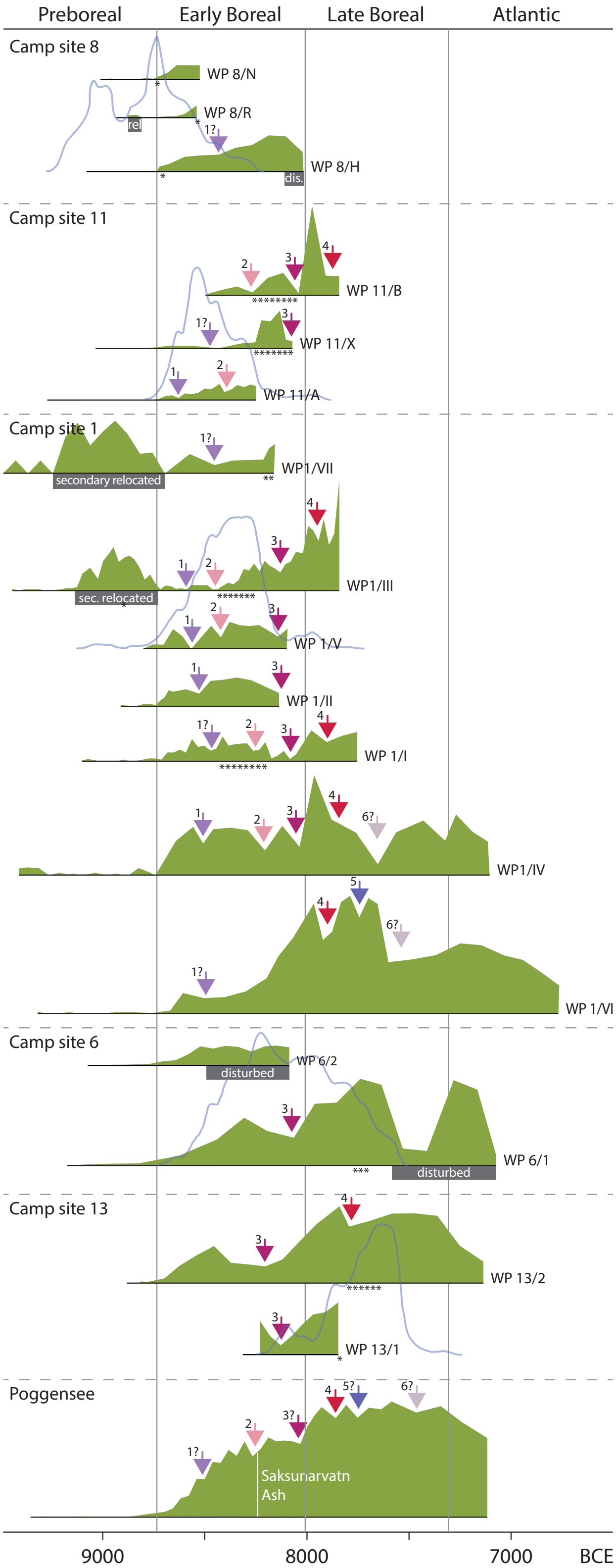

Fig. 28. Duvensee. Overview of the *Corylus* curves for selected on-site and near-site profiles, with hazel minima plotted in comparison with the Poggensee *Corylus* record. The figure also shows the radiocarbon dates (blue line) of the individual camp sites (after Bokelmann 2012, 372 fig. 3) and the location of the individual cultural layers (asterisks) (Graphics: M. Wieckowska-Lüth).

The shrinking of the lake, which began in the Preboreal, is reflected particularly clearly in the on- and near-site profiles by the stratigraphic change from fine to coarse detrital gyttja. However, these profiles also contain palynological evidence that the lake level fluctuated at the end of this period. While the standard profile for the Boreal provides no evidence for hydrological changes, the sediment sequences from the more western area of the palaeolake show that elevated lake levels may also have occurred in the early Boreal. The Atlantic period is characterised by fluctuating water tables, which manifest themselves in frequent sediment changes. However, the silting up of the lake progresses further with the transition to the Subboreal, and with the onset of the Subatlantic, a peat bog is already emerging in the central area of the lake basin. But even before the end of the Pre-Roman Iron Age, there is another transgression phase that lasts until the Migration Period. The middle part of the lake finally silted up completely at the transition to the Early Middle Ages. Then, in the High Middle Ages, a raised bog developed over the previously existing fen.

During the Mesolithic, the higher surroundings around the palaeolake were covered by a quite light forest. This initially consisted of birches and pines and gradually changed into a forest rich in hazel shrubs after the transition to the Boreal, at ca. 8750 cal BC. The mass expansion of *Corylus* begins after 8050 cal BC. However, fluctuations in the proportions of *Corylus* also indicate phases with poorer growing conditions for hazel shrubs, which can be attributed to both local hydrological changes and climatic effects. Occasionally, there must have been somewhat larger gaps in the forest canopy that provided good growing conditions for more light-demanding plant communities, such as dwarf shrubs and various herbs. In the moister depressions and along the lakeshore, there was a fairly light birch-aspen forest, with a rich shrub layer consisting of willows and creepers. These were probably adjoined by more or less extensive fringes of wet meadows, marsh plants and reed beds, particularly during the rapidly progressing infilling phases.

With the onset of the Atlantic, around 7350 cal BC, however, the forest became denser due to the expansion of trees with denser canopies. This increasing shading effect had a negative impact on hazel populations, which were in sharp decline. Even in the lowlands, which were now covered with alder stands, the sites exposed to light seem to have become fewer, as expressed by the decline in creepers, in particular. Only after the mid-Atlantic are heliophilous plant communities evidenced somewhat more frequently, demonstrating that there were again some small-scale open patches within the forest during the Late Mesolithic.

As far as the form of subsistence strategy is concerned, the transition to the Neolithic is not apparent in the standard pollen record from Duvensee. Only after the elm decline, around 3900 cal BC, which was accompanied by a renewed spread of hazel, are there the first signs of agricultural activities in the vicinity of the former lake. However, these are almost exclusively potential grazing indicators, which are at only a low level. It is therefore possible that in this early stage of the Neolithic the emphasis was on forest grazing, and that this was practised in some higher-lying areas, leaving the lakeshore largely untouched by human activity. In the further course of the Neolithic, the reduction in hazel and the growing evidence of ribwort plantain shows that now also open areas could have been grazed. Evidence for arable activities, however, remains very low. In the Late Neolithic and the Bronze Age, the repeatedly high representation of *Corylus* indicates that forest grazing may have continued to play a significant role. It is only from the end of the Bronze Age or the beginning of the Subatlantic, around 750 cal BC, that a clear change in the use of the landscape can be seen in the pollen data. Strong increases in grasses and various herbs, including grazing indicators, show a much stronger orientation towards the use of large-scale open sites. At the same time, the forest is becoming even denser due to the spread of beech, which occurs particularly at the expense of hazel stands. Cereal cultivation, however, only gains importance from the Pre-Roman Iron Age onwards.

While agricultural activities diminish somewhat over the course of the Roman Iron Age, a decline in cereal cultivation indicates that there was even less human activity during the Migration Period. The next significant change in land use does not take place until the High Middle Ages, when an unprecedented intensive form of land use, including cereal cultivation and pastoral farming, is practised. At this time, the now-established peat bog or its immediate surroundings must have been strongly managed as well, as shown by the considerable decline in alder stands. After a reduction in agricultural activities in the Late Middle Ages, the area around Duvensee was again more exposed to human impact during the Modern Period.

For the Mesolithic, it could be shown that the archaeological horizons were formed during phases when relatively dry conditions prevailed on the islands. At the edge of the lake and probably also on the islands themselves, the first local hazel populations were able to colonise such increasingly dry sites. Especially for the early Boreal, it could be illustrated that the artefacts embedded in the profile columns correlate with the increased occurrence of *Corylus* pollen. However, in times of wetter or fluctuating hydrological conditions, the archaeological features disappear, often in parallel with the decline in the hazel. The local presence of hazel shrubs thus seems to be one factor for the use of the Duvensee area. Such environmental changes may consequently have affected the behaviour patterns of hunter-gatherer societies.

However, there are also indications that the elevated hazel pollen signals found in some cultural layers may have been mediated by human activity. A different type of use of the hazel, for instance the use of the vegetative parts of the shrubs rather than their nuts, could be an explanation for unusual changes within the on-site *Corylus* spectra.

As far as the potential anthropogenic indicators in a Mesolithic context are concerned, it is still quite difficult to judge whether they actually display human impact, as they may just as well represent natural succession processes. For example, although different heliophilous and nitrophilous herbs, such as mugwort, nettle, sorrel and members of the goosefoot family, are always documented within the cultural layers, they also occur in some layers without archaeological remains, and in some cases even more frequently. But especially within the cultural horizons, one would expect a greater abundance and diversity of herbs, especially nitrophilous species, reflecting nitrogen-rich areas associated with human activities around dwellings. Yet, the occurrence of disturbance indicators outside the occupation layers could indicate that humans were present but without leaving archaeological traces. One reason for this challenging assignment of disturbances within the vegetation is certainly the methodological approach used in the past, which did not include palynomorphs besides pollen that could have provided additional valuable information on anthropogenic disturbance processes. The failure to consider microcharcoal is also regrettable, as it could have been used to more unambiguously parallel palynological disturbance signals with human impact. Nevertheless, in some cultural horizons an increased presence of ruderal herbs and sometimes also grasses were recorded, which may be an indication of longer stays on the islands. In contrast, the fewer signals of possible anthropogenic indicators within other archaeological horizons could be a reflection of short-term visits of the camp sites. Short-lived campsites directly on the lakeshore do not seem to have left any traces in the pollen archives. In summary, pollen analysis alone can only reflect the Mesolithic way of life if the use of a site was of longer duration. Short-term human activities, on the other hand, do not allow for obviously assignable effects on the vegetation.

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