Supplement

PART 1: GEOLOGY, SOILS AND SEDIMENTS

Introduction

Here we describe the nature of sediments and decomposed peat encountered, and pH values measured in groundwater obtained by squeezing core samples, during our survey of the soils and sediments of the Aamsveen peatland system. Figure S1 shows the geology of the glacial basin in which the Aamsveen is located, as background for the following description of the various transects and corings.

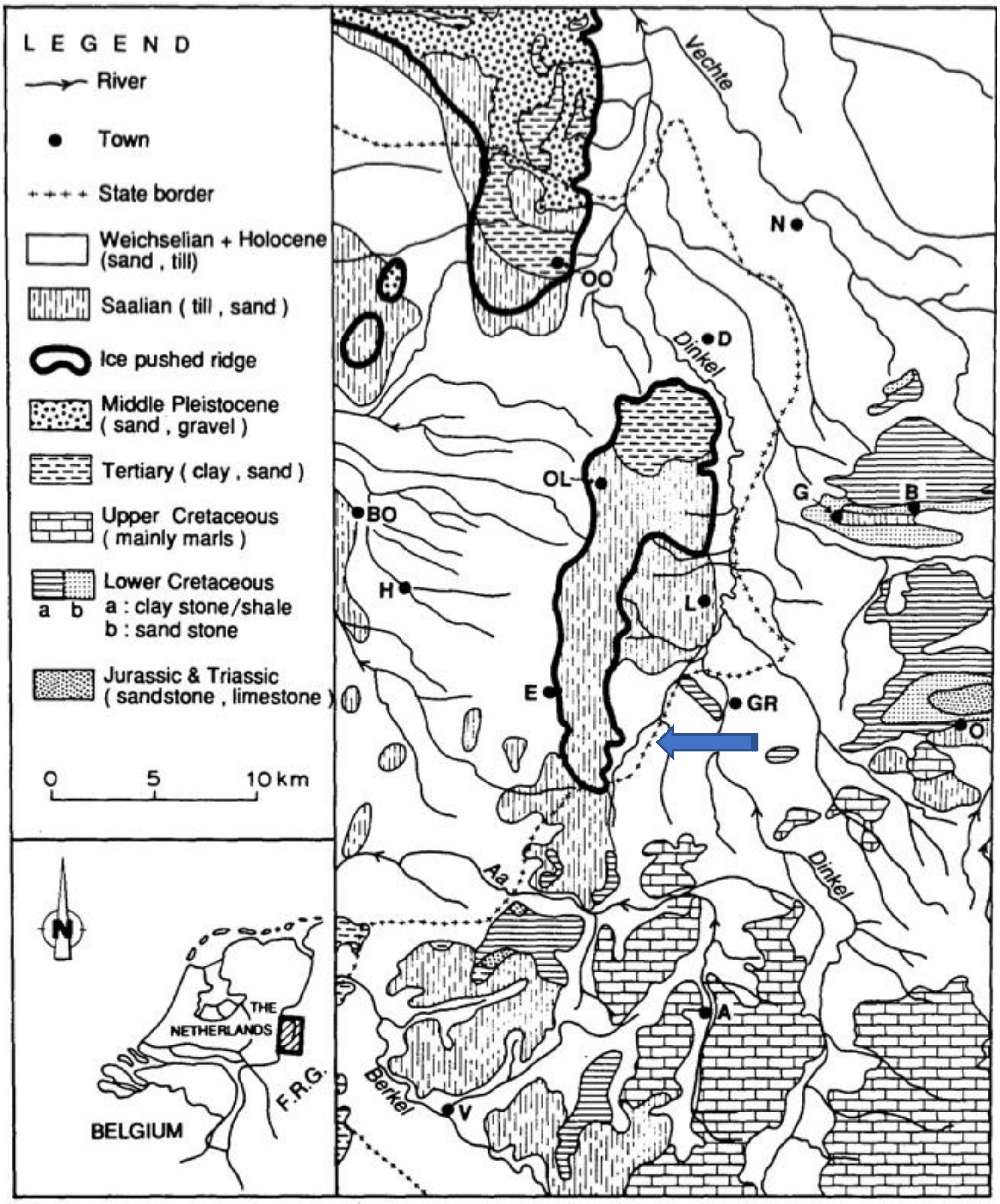

Figure S1. Geology of the Dinkel valley drainage basin, from Van Huissteden (1990). Ice pushed ridges include Lower Tertiary clays and sands, and Middle Pleistocene fluvial sands. A: Ahaus; B: Bentheim; BO: Borne; D: Denekamp; E: Enschede; G: Gildehaus; GR: Gronau; H: Hengelo; L: Losser; N: Nordhorn; O: Ochtrup; OL: Oldenzaal; OO: Ootmarsum; V: Vreden. The blue arrow indicates the Aamsveen area.

The corings

The locations of the transects and additional corings are presented in Figure S2 (enlarged from Figure 1 in main text). Figure S3 (enlarged version of Figure 4 in main text) gives an overview of the corings from the five transects that were studied, while Figure S4 provides additional information on the nature of the organic materials encountered in the topsoil as well as on pH values recorded in these profiles. Concise descriptions (per transect) of the soils and sediments, and of trends in soil formation, are presented below. The additional corings along the Middenpad are not shown in Figures S3 and S4 but summary descriptions are provided. For extensive descriptions of the various corings, the reader is referred to the report by Sevink & Jansen (2017).

Transect 1

Transect 1 is the southernmost transect, running from the lagg with a shallow mineral soil to the Dutch-German border with its raised bog remnants. In coring b16 the podzol has a stagnative Bh horizon, b15 has a thin layer of gliede, and in both profiles there is a thin residual layer of humified (Hemic) peatmoss. The mineral subsoil dips quite steeply to the east (by about 1 m between b15 and b14). In the raised bog area (b14–b12) a thick stratum of *Sphagnum*-dominated peat is encountered in many corings, with intercalated layers of *Eriophorum* in some corings in the central area. The top layer of peat is mostly strongly humified. At the base of the peat, gyttja is found resting on a mineral subsoil with very limited soil formation. pH values in the various layers are low, but those in the subsoil are slightly higher (4.0) than those in more superficial layers (3.5).

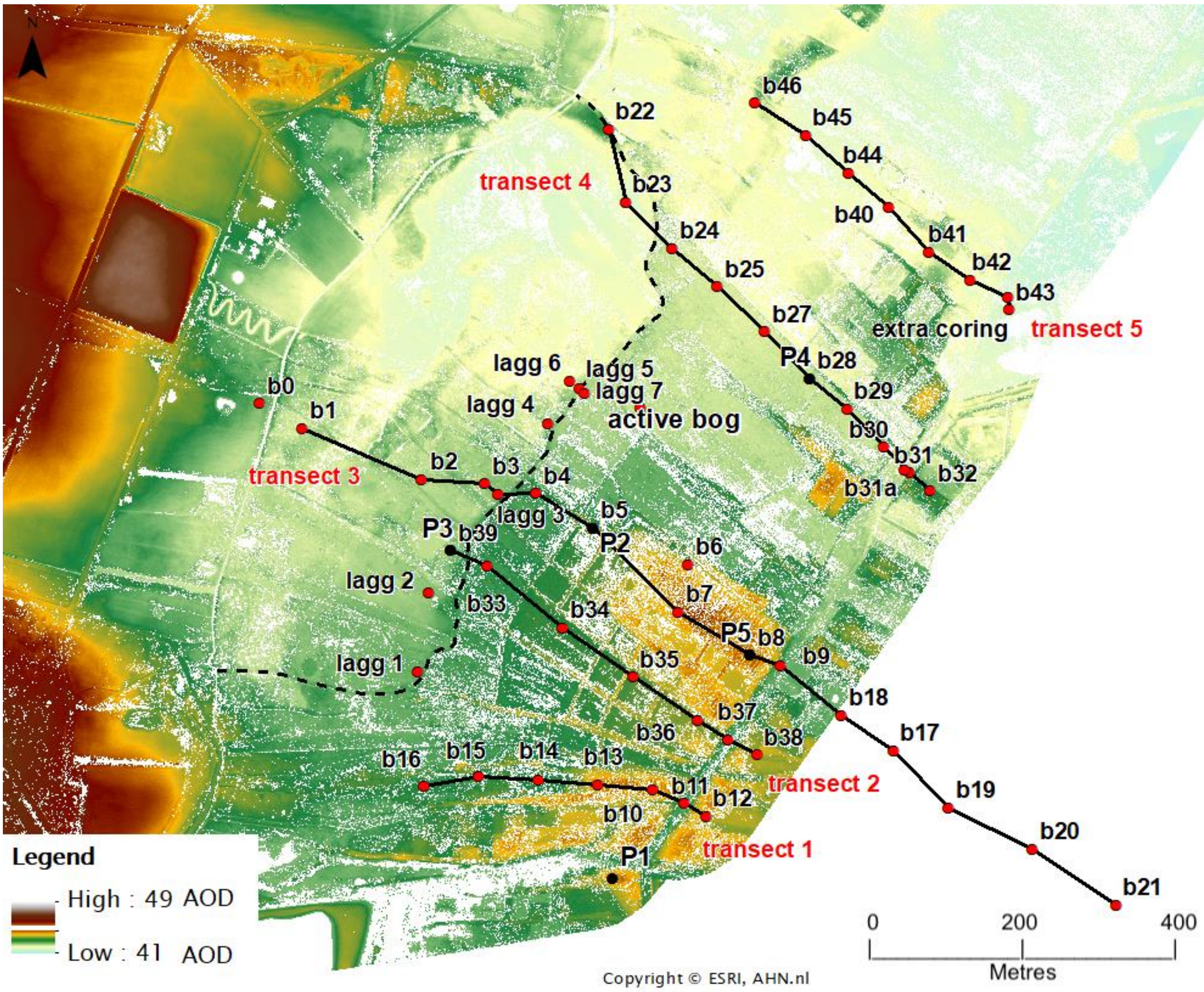

Figure S2. Topography of the Aamsveen from the Dutch AHN (0.5 m digital elevation model) with locations of transects and corings. The Middenpad is indicated by ------.

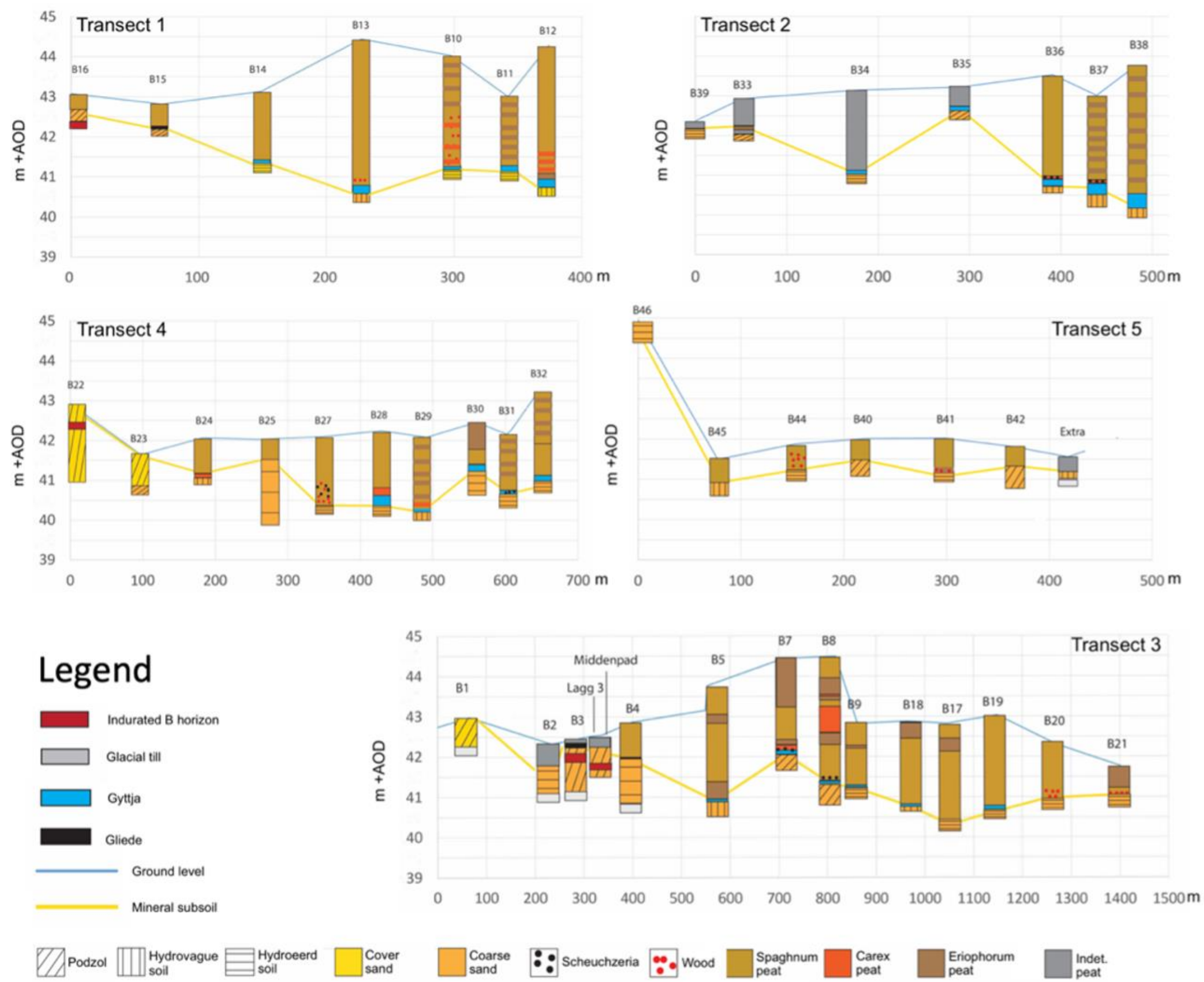

Figure S3. Diagrams of the coring transects showing the materials and soil types encountered. After Sevink & Jansen (2017).

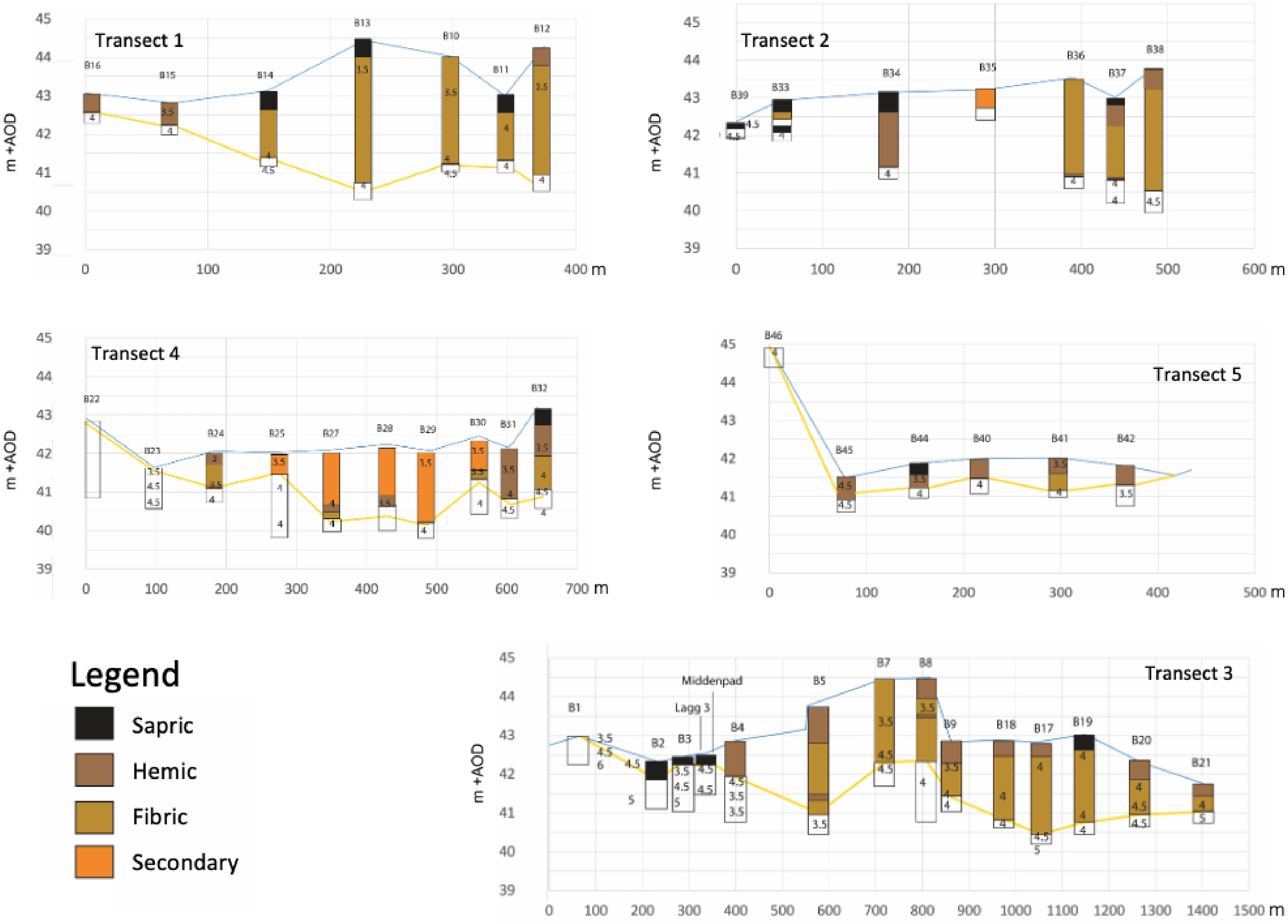

Figure S4. Diagrams of the coring transects showing the organic materials and pH values. After Sevink & Jansen (2017).

Transect 2

In this short transect, widely varying materials were encountered: shallow mineral soils with intercalations of sand in the thin peat stratum on a sandy subsoil near the Middenpad, changing into a deep peat profile with peat of uncertain provenance at b34. The latter might be secondary peat formed recently, after the period of peat extraction. Distinctly secondary peat is encountered at b35, where it occurs on top of a podzol with a thin intermediate layer of gyttja. This podzol developed in coarse sandy sediment that forms a low ridge. Farther towards the border path, at b37 and b38, thick strata of peat with a eutrophic peat-type basis were found. This peat consists of an alternation of *Sphagnum* and *Eriophorum vaginatum* dominated strata. A remarkable feature is the presence in coring b35 of a gyttja-type sediment in a relatively elevated position, which indicates a local development of a rather eutrophic environment by paludification due to a (regional) rise of the groundwater level. pH values vary little, ranging from 4.5 in the subsoil (also in the topsoil in the NW) to 4 in the other profiles.

Transect 3

This is the longest transect, running from far west in the lagg zone into the German part of the raised bog area. In the lagg zone the prevailing soils are Podzols which developed in a generally thin cover sand layer, with the highly stagnative till occurring at shallow depth. The Bh horizons of these Podzols may be stagnative (b2 and b3) and sometimes a stagnative layer of gliede is present (b3). Peaty topsoils are rare. Moving eastwards, deep (> 3m) peat profiles are encountered, but at b7 and b8 the mineral subsoil is found at slightly lesser depth because these corings are located on a slight rise in the mineral subsoil (as in Transect 2). In all other profiles the base of the peat is formed by a gyttja layer which often contains wood fragments, resting on a mineral subsoil with limited soil formation. In the corings at b7 and b8 a distinct podzol was found, overlain by a sequence of gyttja, through sedge peat with wood fragments, to *Scheuchzeria palustris* peat. Both of these corings resemble b35 in Transect 2 although the sequence is better developed in b8.

The changes in pH with depth and going from lagg to raised bog are characteristic; pH is relatively high in the lagg profiles and relatively low in the central peat area, but increases with depth in the latter.

Transect 4

This transect starts in a high cover sand ridge with a deeply drained Podzol. This ridge forms the northern boundary of the large disc-shaped depression in the Glanerbeek area (see Figure S2), while its lower southeastern extension forms a ‘threshold’ for water to drain from the Aamsveen basin. The Podzol at 43 m + AOD in coring b22 exhibits a distinct Bs horizon but lacks any sign of water stagnation, gleyic features being encountered at 41 m + AOD (2 metres below ground level). Moving to the southeast, peat occurs from coring b24 onwards but its thickness is limited to < 2 metres and it consists largely of secondary (recent) peat on a base of residual former peat - mostly gyttja, sedge peat, etc. - which was not extracted. Further to the southeast, the raised bog is better preserved and here alternating *Sphagnum* and *Eriophorum* peat layers were found on top of an early hydrosere, often with gyttja and sometimes with *Scheuchzeria palustris*. Soil development in the mineral subsoil (mostly rather coarse sand) is limited. In these mineral subsoils, pH values are somewhat higher in the subsoil than in the topsoil, while pH in the secondary peat profiles is distinctly lower (3.5).

Transect 5

Throughout this transect the mineral subsoil occurs at shallow depth, at an altitude of 41–41.5 m AOD. The residual peat layer is of limited thickness, and *Alnus* wood fragments are common at its base in corings b44 and b41. Generally, humic gleysol type soils were found below the residual peat, indicating soils that were already poorly drained becoming increasingly poorly drained through paludification under conditions of rising groundwater table. A transitional gyttja layer was not found anywhere in this transect. A remarkable feature found in an additional coring near the Dutch-German border is the presence of a dense and highly impermeable layer of loam beneath completely reduced ‘white sand’ and a humic Podzol Bh horizon, evidently resulting from the heavy stagnation of water on this loam which itself exhibits only weakly developed gleyic features. In further corings extending into Germany, only deeply disturbed and homogenised soils were found, often composed of peaty material mixed with mineral material. This is probably related to digging activities associated with the construction of large ponds/reservoirs in this area.

Corings near the Middenpad

The additional series of corings along the Middenpad (labelled ‘lagg 1–7’ and ‘active bog’ in Figure S2) was made to further investigate the soils in the lagg zone. Most soils here are Podzols with a thin and strongly humified peaty topsoil, regularly having a dense indurated Bh horizon. The often-coarse sandy texture of the mineral soil is remarkable, suggesting that this ridge consists of fluvioperiglacial sediment rather than of cover sand and, thus, that it is an erosional remnant rather than a dune. The relatively high pH values observed (pH 4.5–5) testify to the contact of the groundwater with a nutrient/mineral-rich subsoil. The sharp boundary between the lagg, to the west of the Middenpad, and the adjacent bog to its east, is very clear near the locations ‘lagg 5–7’ and the ‘active bog’ coring. In the coring at ‘lagg 7’ the pH is already low (3.5), while above the residual peat in the ‘active bog’ coring more than 1 m of recent acid peat is found, again with a pH value of 3.5. Such low pH values are not repeated in measurements from the adjacent corings west of the Middenpad.

PART 2: PALAEOECOLOGICAL ANALYSIS

Introduction

Here we provide an extensive overview of results from the analysis of each of the five cores that were sampled and studied in detail. Core P1 was studied for both macro and micro remains, while the analysis of Cores P2–P5 was limited to macro remains only. Core locations are shown in Figure S1 and Figure 1 (main text); for geographical coordinates and peat thickness see Table 1 (main text). The background for this sampling scheme was that pollen data provide an indication of vegetation at a more regional level, whereas plant macro remains are indicative for the truly local vegetation and thus provide more detailed information on spatial patterns in the vegetation. Trends in the vegetation pattern and succession, as presented in Figure 7 (main text), are largely derived from the compositions of the assemblages of plant macro remains; while dating of the historical development phases distinguished is based on both the palaeoecological data and the radiocarbon dates (see below). For the depths of pollen samples in Core P1, see Table S1. Full descriptions of the peat sections studied and results for those sections are provided by Van der Linden (2018), and the basic analytical data can be obtained on request from M. Van der Linden at BIAX Consult (Amsterdam, The Netherlands), email vanderlinden@biax.nl.

Pollen identifications were based on standard literature and the reference collection (Punt *et al*. 1976–2009, Van Geel 1976 (T.1–T.112), Van Geel *et al*. 1981 (T.368), 1983 (T.169, 171); Moore *et al*. 1991, Van Geel *et al*. 2003 (T.113), Beug 2004, Van der Linden & Van Geel 2006, Van der Linden 2007 (T.264), Miola 2012). Similarly, for macrofossil identification, standard literature and the reference collection were used (Berggren 1961, 1969; Körber-Grohne 1964, 1991; Anderberg 1994, Cappers *et al.* 2006). Interpretation of the pollen and macrofossil results is based on standard literature concerning the Dutch ecological flora, bog development and the Dutch abiotic indicator values of plant species (Weeda *et al.* 1985–1994, Aggenbach & Jalink 1998, Couwenberg *et al*. 2001, Succow & Joosten 2001, Smith 2004).

Radiocarbon dating

To establish the timing of the onset of peat formation in the Aamsveen area and the various phases in its further development, ten strata were radiocarbon dated (see Table 2, main text; also Possnert & Beckel 2018). Peat formation was found to have started at the locations P1 and P4. Later, it expanded to the locations P2 and P5, and finally into the lagg at location P3. Results from the radiocarbon dating were calibrated using Oxcal 2020 (Bronk Ramsey 2020) and the calibration curve by Reimer *et al.* (2020).

Current vegetation

The current vegetation has been extensively studied and surveyed. Figure S5 presents the vegetation map produced by Van der Veen & Attema (2012) and serves as a background for discussion of the palaeoecological data obtained from the cores. For descriptions of the various types of vegetation distinguished, in terms of plant species composition, the reader is referred to that publication.

Central/South (Location P1)

For this core, macro remains and pollen were studied. Results for macro remains are presented in Figure S6, and results for pollen, spores and non-pollen palynomorphs are presented in Figures S7–S9. A simplified pollen diagram is presented in Figure 6 (main text). Below, the results are described and discussed per biozone.

Table S1. Data on pollen samples from core P1.

Labcode	Description	Depth (cm below ground level)	m AOD
BX8001	*Sphagnum* peat	47–48	43.765
BX8002	*Sphagnum* peat	80–81	43.435
BX7946	*Sphagnum* peat	117–118	43.065
BX8003	*Sphagnum* peat	124–125	42.995
BX7947	*Sphagnum* peat	135–136	42.885
BX8004	*Sphagnum* peat	149–150	42.745
BX8005	*Sphagnum* peat	154–155	42.695
BX8006	*Sphagnum* peat	160–161	42.635
BX7948	*Sphagnum* peat	165–166	42.585
BX8007	*Sphagnum* peat	175–176	42.485
BX8008	*Sphagnum* peat	185–186	42.385
BX7949	*Sphagnum* peat	195–196	42.285
BX7950	*Sphagnum* peat	235–236	41.885
BX7951	*Sphagnum* peat	262–263	41.615
BX7952	*Sphagnum* peat	285–286	41.385
BX8009	*Sphagnum* peat	292–293	41.315
BX8010	*Sphagnum* peat	299–300	41.245
BX7953	*Sphagnum* peat	310–311	41.135
BX8011	*Sphagnum* peat	317–318	41.065
BX8012	*Sphagnum* peat	321–322	41.025
BX8013	*Sphagnum* peat	325–326	40.985
BX8014	peat	327–328	40.965
BX7939	peat	330–331	40.935
BX8015	peat	335–336	40.885
BX8016	peat	340–341	40.835
BX7940	peat	345–346	40.785
BX8017	peat	350–351	40.735
BX8018	peat	355–356	40.685
BX7941	basal peat	360–361	40.635
BX7942	light grey sand	362–363	40.615
BX7943	humic sand	369–370	40.545
BX7944	gyttja	374–375	40.495
BX7945	gyttja	383–384	40.455

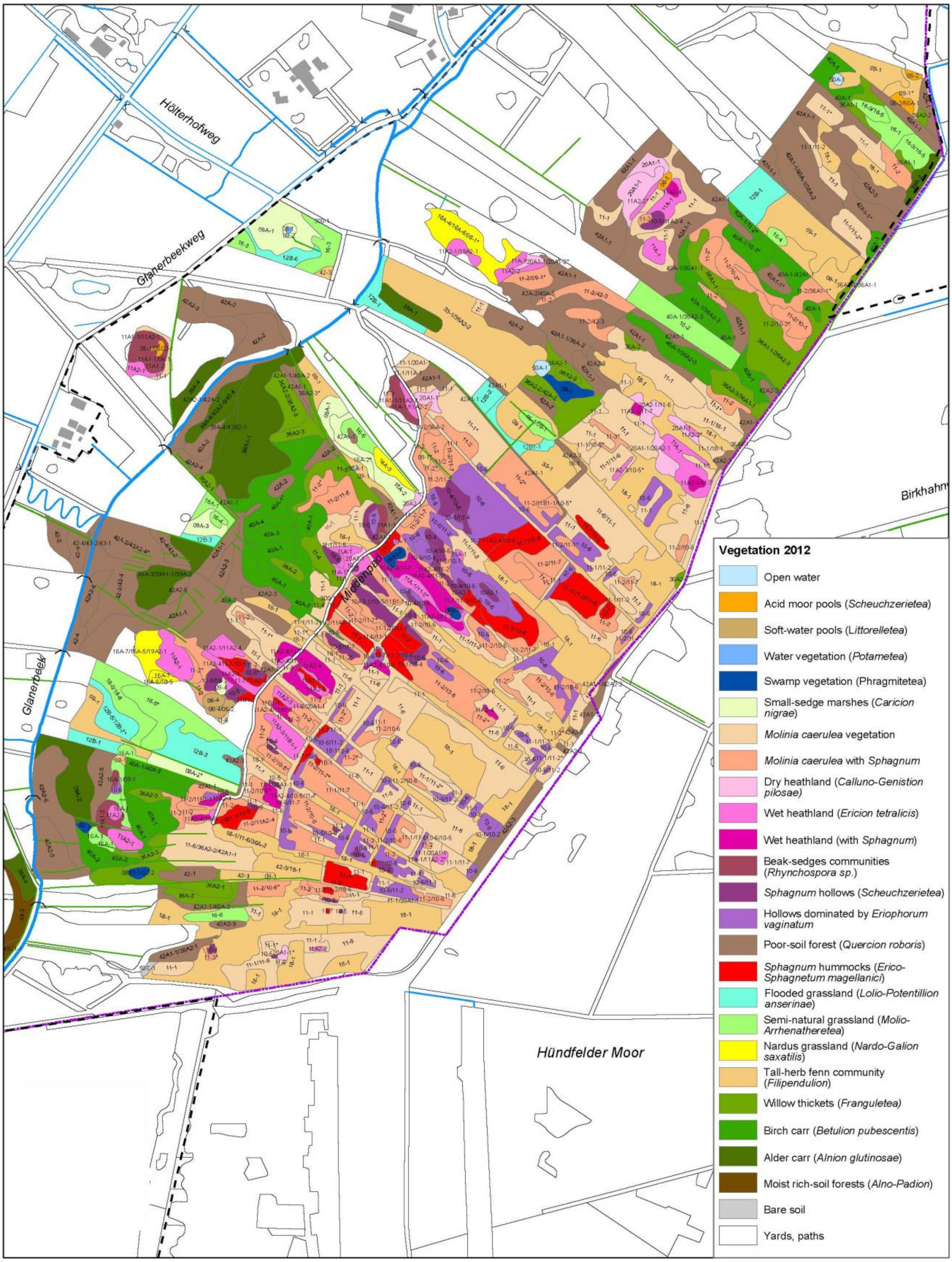

Figure S5. Vegetation map of the Aamsveen, after Van der Veen & Attema (2012).

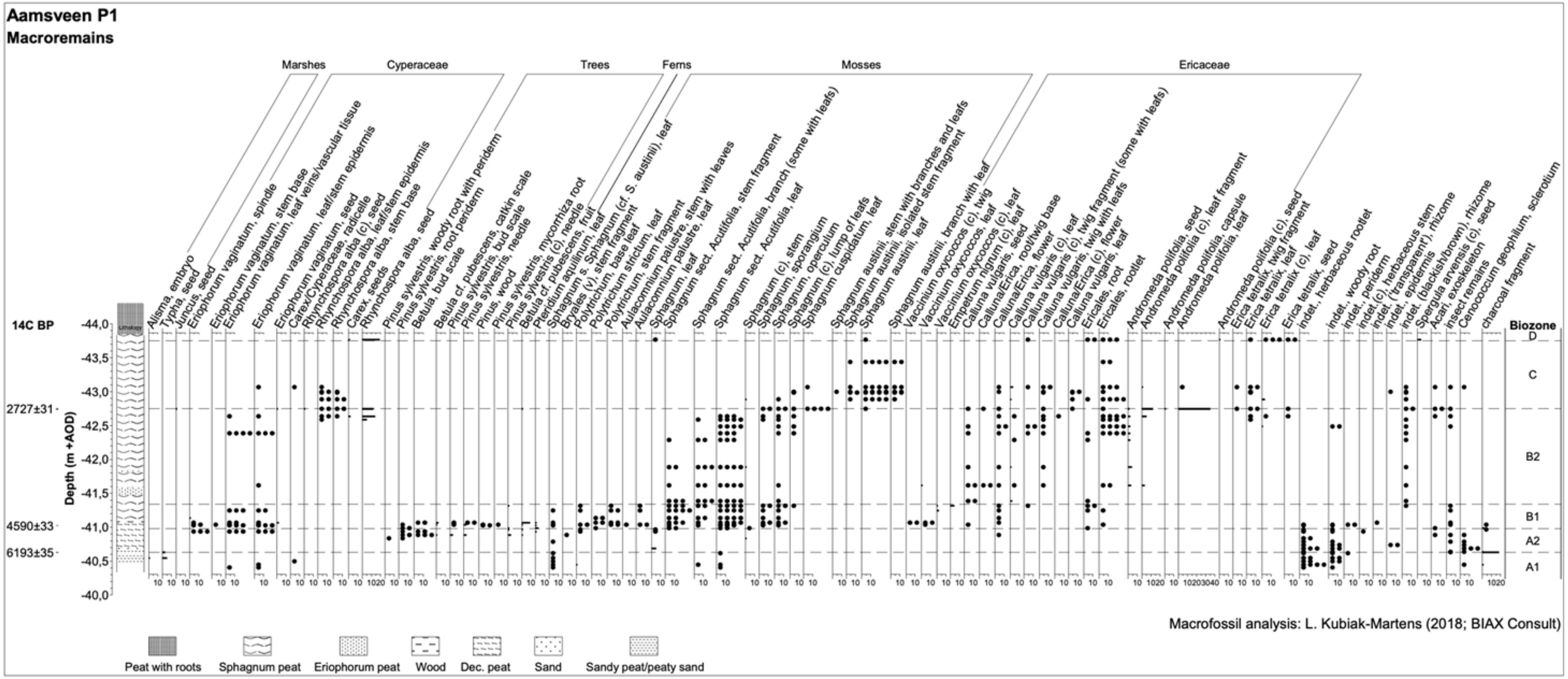

Figure S6. Macro remains from coring P1. Bars indicate the number of remains and filled circles reflect abundancy scores.

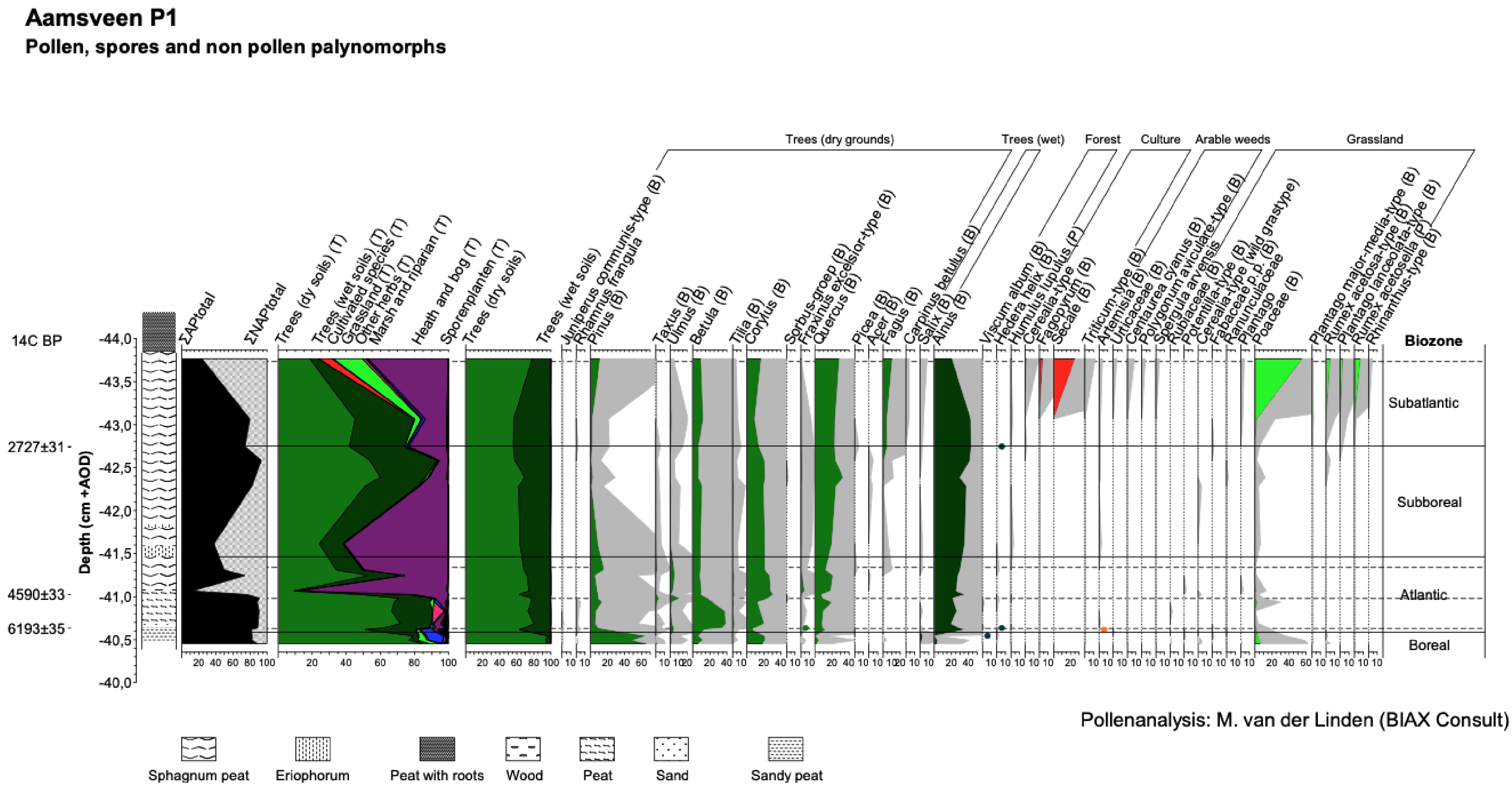

Figure S7. Pollen data for P1 (Part 1 of 3).

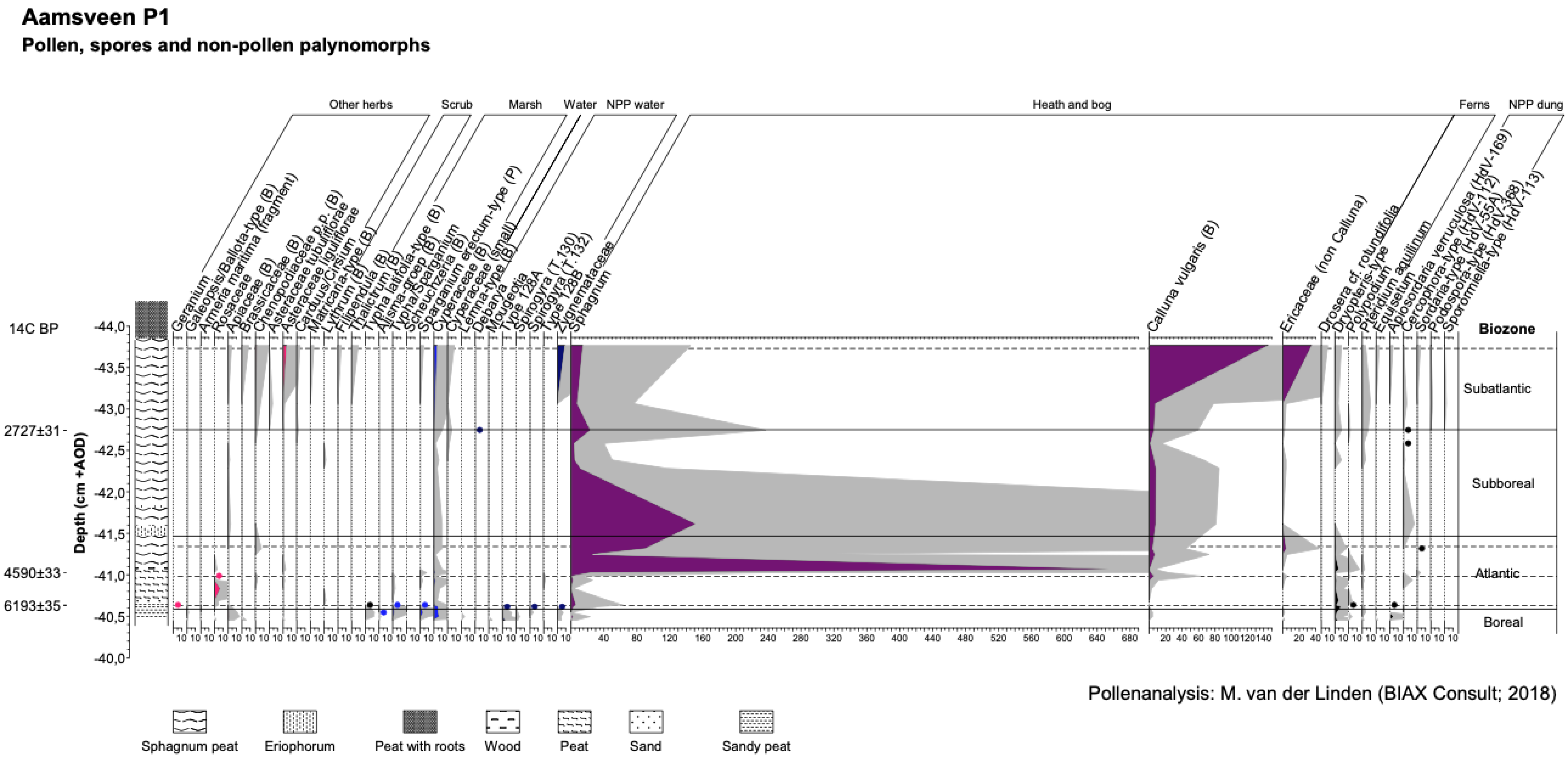

Figure S8. Pollen data for P1 (Part 2 of 3).

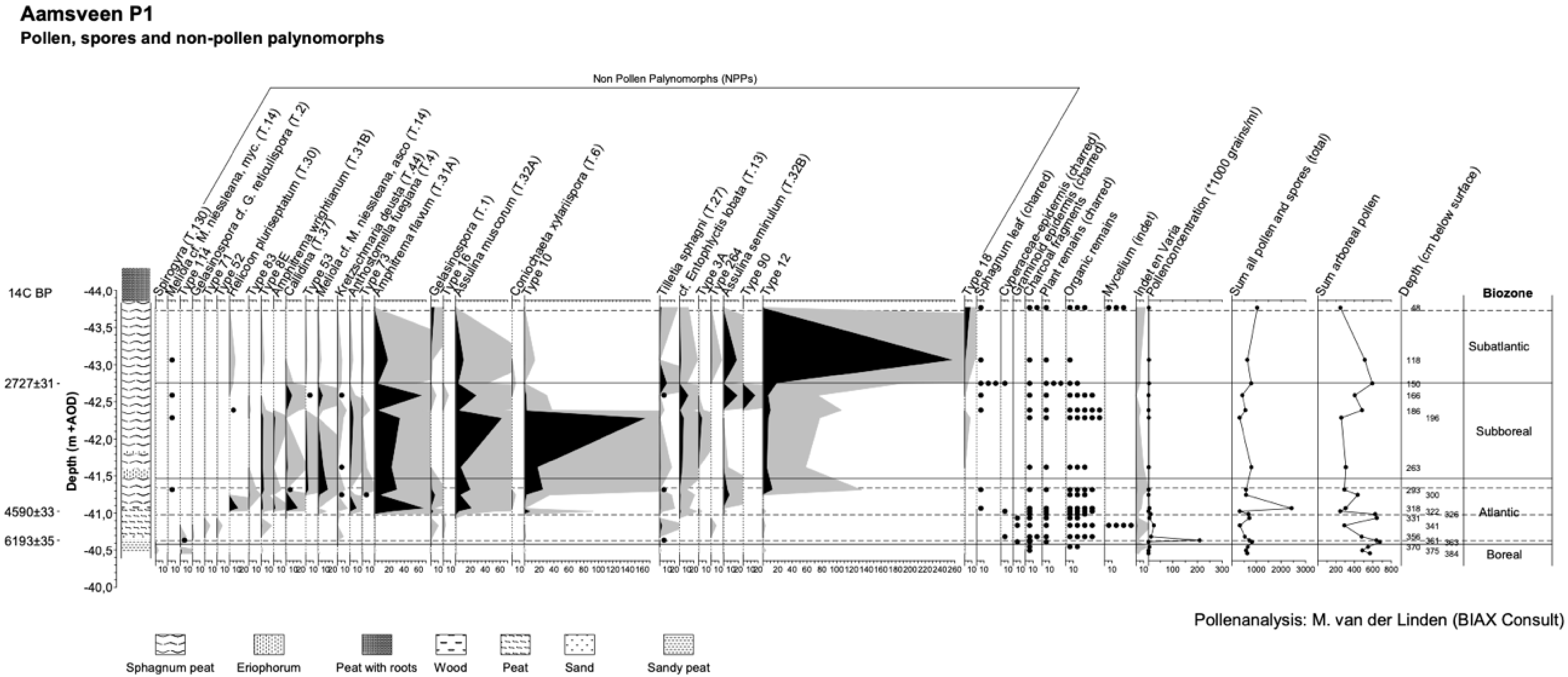

Figure S9. Pollen data for P1 (Part 3 of 3).

P1 biozone A1 (Boreal and Early Atlantic)

Based on the pollen assemblage encountered, Biozone A1 - the deepest part of Core P1 in the southern depression (samples at 40.400–40.625 m AOD) - dates from the Boreal and Early Atlantic. In the three lowest samples (40.625–40.545 m AOD), the forest dominantly consisted of *Pinus sylvestris* and *Corylus avellana*, while other deciduous tree species such as *Alnus, Ulmus, Quercus* and *Tilia* were rare. Such a forest composition is typical for the Boreal.[1]

Peat formation in this southern depression started in a marsh with sediment that consisted of very humic sand to sandy peat. This sediment contained many fine rootlets that could not be identified to species level, and only a few identifiable plant macro remains. The latter included seeds of *Typha* (5) and *Alisma* (1), encountered in the sample from 40.545 m AOD.[2] The genera *Typha* and *Alisma* are lakeshore and marsh species found in shore vegetation and on marshy soils that occasionally fall dry. In biozone A1, in addition to the pollen of (large) *Typha* and *Alisma*, pollen of species that are associated with poorly drained to fully inundated soils was encountered. At 40.495 m AOD, *Lemna*-type pollen was found. This provides no indication of water depth because the Lemnaceae, being floating aquatic plants, may equally well occur in open water, floating in between the shore vegetation, in forest pools that incidentally fall dry or in *Phragmites* and *Carex* marsh. However, they grow in neutral to (slightly) eutrophic freshwater environments.[3] No pollen or macro remains of other aquatic plant species were found, and macro remains of trees were absent. Pollen of *Salix* - a tree species with limited production of pollen - was found. This pollen is spread by insects and its presence thus indicates that *Salix* occurred in close proximity to the coring location. The overall conclusion is that *Salix* dominated marsh forest and *Carex* marsh were present in the wetter parts of the landscape. These vegetation types indicate relatively eutrophic conditions. The cerealia-type pollen encountered probably originated from wild Poaceae that also produce such large pollen grains, such as *Glyceria maxima* and *Glyceria fluitan*s.

The transition from the Late Boreal to the Early Atlantic is marked by a layer of grey sand at the top of biozone A1. At this time the percentages of *Pinus sylvestris* and *Corylus avellana* pollen declined sharply, while those of *Alnus*, *Quercus* and *Betula* strongly increased.[4] The concentration of pollen in the sand is very low, suggesting that this sediment was redeposited during a short event. Also, a fragment of pollen from *Armeria maritima* was found in the sand. Although *Armeria maritima* is encountered only in coastal areas of The Netherlands nowadays, this species formed part of the Lateglacial herbal tundra vegetation[5]. Furthermore, there is a rare '*elongata*' variety of *Armeria maritima* which today occurs on dry grassy sandy soils, largely limited to Limburg in The Netherlands but with a wider distribution in Germany.[6] The foregoing reasoning implies that two potential origins can be identified for the sand: a) it is drift sand blown into the marsh from a nearby dry sandy location; or b) it is alluvial sand that was deposited during an incidental flood. Recent studies of drift sand areas near Laren (NH) showed that, already by the end of the Boreal and in the Early Atlantic, acidification and degradation of the well-drained soils in cover sand was such that sand easily started to drift.[7] Thus, an aeolian origin for the sand layer encountered at the top of biozone A1 cannot be excluded. However, given the morphology of the early Aamsveen, which was a marshy depression with brooklets running in from the more elevated environs (ice-pushed ridges), it is more likely that the sand was indeed deposited during a flash flood. A further indication for the latter is found in the form of *Typha latifolia* pollen. This species is a marsh plant that prefers a dynamic environment; thus, its presence indicates that the landscape was still dynamic during this phase.[8]

Alhough no macro remains of *Alnus* were found, a small *Alnus* pollen peak and traces of *Dryopteris*-type spores suggest that in this phase *Alnetea glutinosae* existed nearby. *Dryopteris* comprises several fern species that may occur in *Alnetea glutinosae* such as *Thelypteris palustris* and *Dryopteris cristata*. However, some of

---

[1] See Van Geel 1981, 'De Borchert'.

[2] Other plant macro remains found include fragments of *Eriophorum vaginatum* and leaflets of *Sphagnum*. It is improbable that these species formed a significant component of the vegetation during the Boreal and, therefore, the possibility is not excluded that these fragments in fact originate from higher up in the section and their presence results from contamination during coring or later bioturbation. In this context, the presence of *Fagus* pollen at 40.495 m AOD is remarkable because this species did not occur in the Netherlands during the Boreal, which again indicates bioturbation or illuviation of pollen in this sandy sediment (Dimbelby 1961).

[3] Weeda *et al.* 1994, 231–235.

[4] Compare Van Geel 1981, pollen diagram 'De Borchert'.

[5] Van Geel *et al.* 2008.

[6] Westhoff *et al.* 1973, 207. Hultén 1950.

[7] Sevink & Van Geel 2018.

[8] Weeda *et al*. 1994, 244–255.

the pollen may have been transported with the sand and thus might not originate from a stream-accompanying vegetation. A remarkable finding is the occurrence of *Taxus* pollen, which is rarely encountered and, if present, is mostly found in Subboreal peat from the Dutch coastal area. In that area, *Taxus* is associated with a specific *Alentea glutinosa* and *Vaccinio-Betuletea pubescentis* marsh vegetation composed of *Alnus glutinosa, Betula, Potentilla palustris, Carex paniculata, Carex pseudocyperus, Lysimachia vulgaris, Lycopus europaeus* and *Thelypteris palustris.* In other parts of Europe such as England, Ireland, Luxembourg, Germany and Sweden, *Taxus* has been encountered sporadically in pollen diagrams from Late Boreal and Early Atlantic sediments.[9] *Taxus* is a forest undergrowth species that can grow on any soil, but in England and Belgium is found particularly on slopes with well drained highly calcareous soils.[10] In The Netherlands, more specifically in deciduous forests in Twente, *Taxus* is found here and there on loamy calcareous soils (possibly descending from garden trees).[11] However, the presence of *Taxus* pollen since the (Late) Boreal demonstrates that during this period *Taxus* was already present in Twente and might indicate either that the required site conditions - well drained highly calcareous soils - existed nearby or that *Taxus* occurred in the brook forest.

P1 biozone A2 (Mid Atlantic to Late Atlantic)

The basis of the peat at 40.628 m AOD dates from the Mid Atlantic (6193 ± 35 ^{14}C BP, 5295–5220 cal BC). The deepest sample of this peat contained three *Typha* seeds along with rootlets of herbs and woody plants that could not be identified to species level. Additionally, several charcoal fragments of *Pinus sylvestris* and sclerotia of *Cenococcum geophilum* were found. This implies that the soil was sufficiently drained to not inhibit the decomposition of organic matter, as is also evidenced by the extremely high concentration of pollen grains in this thin layer of sediment (nearly $21×10^6$ cm^{-3}). Such an extreme value also implies a very low rate of peat accumulation.[12]

Relative to biozone A1, biozone A2 exhibited a slight and continuous decline of *Alnus* pollen (to ~ 20 %), while *Betula* pollen increased strongly and became the dominant tree species (~ 35 %). This implies that, in places, the *Alno-Betuletum pubescentis* developed into a *Betulion pubescentis*, indicating acidification and declining availability of plant nutrients. Species encountered in this forest included *Sparganium erectum*, *Typha*, probably *Potentilla palustris* (occurs within the *Potentilla*-type) or another herbaceous or shrubby species of the Rosaceae, *Ramnus frangula* and *Polytrichum strictum*. The earliest sample still contained *Lythrum* and Geraniaceae pollen. Later *Calluna vulgaris* (or *Erica tetralix*) occurred, most probably in somewhat drier places, while mixed deciduous forest with *Quercus, Corylus, Tilia* and *Ulmus* occurred on the higher well drained soils. *Taxus* was present in or close to the peat area, while *Pinus* probably occurred on higher well drained soils. However, upwards from 40.835 m AOD, macro remains of *Pinus* were encountered, indicating that at least some *Pinus sylvestris* trees occurred in the marshy vegetation. Other macro remains encountered are from *Betula pubescens, Eriophorum vaginatum* and *Polytrichum* (leaf and stem remains), which are typical species for the nutrient poor and acidic soils of *Betulion pubescentis*. The *Dryopteris*-type spores may well originate from *Dryopteris cristata*, a species that is also encountered in this type of forest.[13]

P1 biozone B (Late Atlantic–Subboreal)

From 40.985 m upwards (ca. 4000–3500 BC) *Sphagnum* section *Acutifolia* is the dominant moss type.[14] *Sphagnum* sect. *Acutifolia* forms a hummock-hollow system which, once formed and growing above the groundwater level, creates a very wet and nutrient poor environment. This inhibits further growth of *Pinus* and *Betula* and explains the massive increase of *Sphagnum* and fungal spores along with other microfossils associated with bog vegetation. Initially, the peat held macro remains of *Pinus* and *Betula,* plus rather abundant *Eriophorum vaginatum,* but after 41.065 m AOD these tree remains disappeared and *Eriophorum vaginatum* declined. In this initial phase, the moderately minerotraphentic moss types *Aulacomnium palustre* and *Polytrichum* still occurred, but *Sphagnum* sect. *Acutifolia,* most probably *Sphagnum rubellum,* dominated and formed about 90 % of the matrix. It is in this earliest phase that *Vaccinium oxycoccus* colonised; this is an ericaceous species growing in the transitional zone between the hummocks and the hollows (see also Figures 7

[9] Deforce & Bastiaens 2007.
[10] Deforce & Bastiaens 2007.
[11] Weeda *et al*. 1985, 59.
[12] This concerns a layer that is 1.5 cm thick!
[13] Weeda *et al*. 1985, 91–93; Barkman 1992.
[14] In the core, the presence of a large piece of *Pinus sylvestris* wood between 40.99 and 41.03 m AOD prevented study of the pollen in this section.

(main text) and S10).[15] This is the first species of the typical peat succession sere to appear and it is followed by *Andromeda polifolia*, *Erica tetralix* and *Calluna vulgaris*. It is accompanied by the appearance of the fungal spores Type 10, Type 12 and *Meliola cf. Niessleana* (T.14), which are fungi that parasitise the various ericaceous species.[16] In the sample from 41.315 m AOD, five carbonised *Empetrum nigrum* leaves were found. *Empetrum* occurs on nutrient poor and acidic sandy and peaty soils, generally in somewhat drier places. In a bog system, this will have been on higher hummocks or locally outcropping sand. *Empetrum* is often associated with a *Juniperus* vegetation, but no indication for such an association was observed in the pollen assemblage encountered.[17]

From 41.385 m AOD, *Sphagnum* sect. *Acutifolia* constituted about 100 % of the matrix, while *Calluna vulgaris* was the dominant ericaceous species. Furthermore, *Eriophorum vaginatum* was present, presumably on hummocks. Based on the observed changes in composition of the tree pollen assemblage, we conclude that this change most probably took place at the transition from the Late Atlantic to the Subboreal (ca. 3500 BC). After 41.315 m AOD we also observed a decline in *Fagus* pollen and the change in *Ulmus* pollen which is known as the Elm decline.[18] This decline is ascribed to the increased effects of agriculture - the Landnam by the earliest farmers - but may also have been due to elm disease.[19] In our pollen assemblages we found no clear indications for such anthropic activities in the vicinity of the Aamsveen. *Alnus* forest and probably also *Betula* forest (possibly with *Pinus, Quercus* and *Taxus*) occurred in the lower-lying, wet parts of the landscape, while in the higher and drier areas *Quercus* and *Corylus* were present with *Ulmus, Tilia*, *Betula*, possibly *Pinus, Taxus* and *Fagus*. It is only from 42.385 m AOD (Late Subboreal) that we found *Rumex*-type pollen and a small increase in Gramineae pollen, but we did not find the typical indicator for deforestation, namely pollen of *Plantago lanceolata*-type species, in the Subboreal section of the core. Furthermore, we did not observe major changes in the composition of the tree pollen assemblage that might point to deforestation.

Rhynchospora alba was encountered in the top of biozone B. This species occurs particularly in hollows and indicates that the peat was getting wetter in places. A similar trend is suggested by the increased presence of *Erica tetralix* in the top of Biozone B, since this species requires wetter site conditions than *Calluna vulgaris* (see Figure S10).

P1 biozone C (Subatlantic)

The transitions from the Subboreal to the Subatlantic and from biozone B to biozone C coincide, and are marked by a major transition in the dominant peatmoss species. This change has been associated with a climatic change towards wetter and cooler conditions[20] and is known as the transition from Old *Sphagnum* peat to Young *Sphagnum* peat. At location P1 the transition is marked by a thin layer of *Sphagnum cuspidatum* (42.745 m AOD). *Andromeda polifolia* and *Rhynchospora alba* leaflets from this layer were radiocarbon dated and were found to have a calibrated age of 927–809 BC. Above this layer, *Sphagnum austinii* dominated, while in addition macro remains of *Rhynchospora alba*, *Erica tetralix* and *Calluna vulgaris* were encountered. *Eriophorum vaginatum* was present in minor amounts. Thus, the bog peat was still marked by hummocks and hollows, though the hummocks were lower (wetter) than those in biozone B.

In the Subatlantic, *Fagus* increased and *Carpinus* appeared in the forest vegetation on the higher (drier) soils. Overall, forest pollen declined by about 10 %, which was particularly due to a decline of *Corylus* pollen, but the area remained wooded. This decline most probably had a natural cause and can be related to the expansion of *Fagus* during this period. A similar trend has been found in many European pollen studies, including another study of the Aamsveen.[21] The decline in forest pollen was accompanied by an increase in *Calluna vulgaris* pollen. *Calluna vulgaris* was a local component of the bog vegetation but could also occur in heathland vegetation on drier soils. Thus, the increase can be explained as being due to desiccation of the peat but also as evidence for an increase in openness of the forest vegetation on the higher and drier parts of the area. In relation to the latter, *Plantago lanceolata*-type and Cerealia-type pollen were found in this biozone, which implies that forest near the site had been cut and agriculture was being practised.

[15] Weeda *et al.* 1988, 50–51.
[16] Van Geel 1976; 1981.
[17] *Juniperus* pollen was found in a deeper part of the peat, at 40.685 m AOD, which is the earliest phase of biozone A2.
[18] Maes *et al*. 2006.
[19] Iversen 1941; Doorenbosch 2013, 21–24.
[20] Van Geel *et al*. 2014.
[21] Daniëls 1963, 71–74.

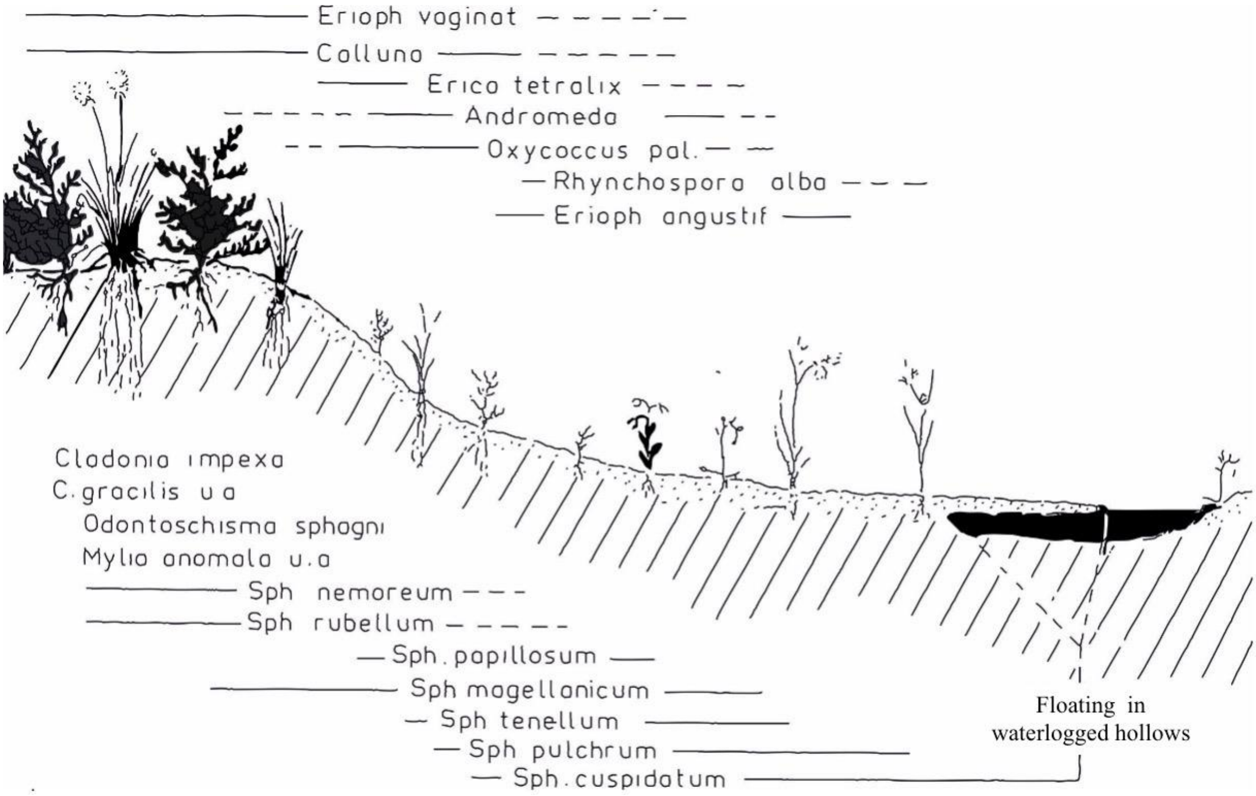

Figure S10. Schematic representation of hummock and hollow vegetation in a bog (adapted from Overbeck 1975).

Sclerotia of *Cenococcum geophilum* were present at a depth of 43.065 m AOD, as were many rootlets of Ericaceae (50 % of the matrix) and remains of *Calluna vulgaris*. Fungus type T-12 was extremely abundant in this layer, and this can probably be linked to a very dry phase. It is only in this layer that pollen of *Plantago major*, *intermedia* and/or *media*-type were found. *Plantago major* and *intermedia* occur on open moist and nutrient rich, well-trodden soils or on fields and in open spaces in grasslands. *Plantago media* is found on more or less calcareous soils in grasslands, on dikes and in roadsides,[22] and it is very unlikely that this species grew in the peat. Thus, the occurrence of this pollen type indicates an increase in the openness and use of the landscape, which may be associated with improved drainage of the bog. It is remarkable that at this level we encountered a small number of spores of dung fungi, which occur only on dung and involved the *Podospora*-type (T.368) and the *Sporormiella*-type (T.113). *Cercophora*-type (T.112) spores were also encountered, but this species grows on both dung and decaying plant remains (and was encountered in samples from other parts of the profile). In summary, during this phase the surface of the bog must have been dry enough to be trodden upon by animals.

P1 biozone D (Middle Ages and later)

Biozone D includes the uppermost peat, from about 50 cm below ground surface. It is represented by a macro sample from the moulded peat (43.765 m AOD). This sample contained leaflets of *Sphagnum austinii* and, additionally, remains of above-ground parts of *Erica tetralix* (abundant), *Calluna vulgaris* and *Andromeda polifolia* (lesser amounts), as well as rootlets of Ericaceae and seeds from *Rhynchospora alba*. This reflects a vegetation type that is characteristic for the transition from hollow to hummock in a bog. It is quite remarkable that four seeds of *Spergula arvensis* were also found in this layer, and that the pollen spectrum from this layer deviates strongly from that in the layers below. For example, the percentage of tree pollen is less than 24 %, suggesting that the surrounding landscape was very open.[23] Moreover, the area of *Alnus* forest had strongly declined, most likely having been replaced by pastures, and there was a strong increase in pollen from grasses

[22] Van der Meijden 2005, 996–997.
[23] Groenman-van Waateringe 1986.

and cultivated crops. Lastly, this layer contained pollen from *Secale* and *Fagopyrum esculentum*, and from several ruderal plants including *Spergula arvensis* and *Centaurea cyanus*. From the presence of *Fagopyrum* it can be concluded that the pollen assemblage dates from Late Middle Ages or later.[24] The observed increase in *Pinus* pollen might reflect reforestation of wasteland around the Aamsveen with this tree.

It is well known that, in the 18th and 19th centuries, *Fagopyrum* was cultivated on burnt-down mires - a practice which has been described as 'buckwheat cultivation'. In the north-east of The Netherlands and adjacent parts of Germany, this culture was widely practised. Parts of the bogs were drained by digging ditches, after which the vegetation and upper peat layer were set on fire. Once the fire had extinguished the crop was sown in the ash-rich burnt layer. The main crop type was *Fagopyrum*[25] but the method was also suitable for cultivation of *Secale* and *Spergula arvensis*. *Spergula* is not only a ruderal plant but also a food crop (also used as animal fodder) and is one of the rare crops that, like *Fagopyrum*, can be cultivated on poor sandy and bog peat soils.[26] Thus, our results suggest that buckwheat cultivation was practised in part of the Aamsveen or nearby. Another explanation may be that this pollen reached the Aamsveen in the excrement of animals that were grazed on the Aamsveen. The sharp increase of *Calluna vulgaris* pollen in this layer suggests that, at a certain moment, the bog surface became dry enough to allow cattle to graze. Another possibility is that the area of heathland dominated by *Calluna vulgaris* strongly expanded on the higher and drier soils around the Aamsveen. The historical topographic map from 1891 (and probably also earlier maps) indicated that the area west of the Aamsveen was wasteland with heath vegetation (see Figure S11). Considering the decline of *Alnus* pollen, the ongoing reclamations were mainly in the brook valleys, while the higher and drier areas had already been reclaimed during the Subatlantic.

If buckwheat cultivation was indeed carried out in the Aamsveen, it was probably implemented in the area with abundant ditches in between coring locations P2 and P5 (Figure S2). In the samples taken for study of plant macro remains, carbonised leaflets, stems and 'heads' (clusters of leaflets from the tops of *Sphagnum* plants), as well as carbonised remains of Ericaceae, were found at all coring locations and throughout the whole peat layer. The presence of carbonised 'heads' of *Sphagnum* plants may well reflect surficial fires, and distinct burnt peat layers were not encountered, implying an alternative possibility that the fires had a 'natural' origin. Westhoff *et al.* (1973) describe a process that happens in degrading raised bogs following buckwheat culture, in which the drainage ditches are filled up by *Molinia*, creating a complex of secondary hollows and low secondary ridges overgrown by *Molinia*.[27]

North-east, excavated (Location P4)

At this location plant macro remains (only) were studied. The results are presented in Figure S12.

P4 biozone A1

In the sandy gyttja-type base of coring P4, at 40.455 m AOD, a megaspore of *Selaginella selaginoides* was found, suggesting a Lateglacial age for this sediment. It is covered by a gyttja-like sediment layer with marsh species, i.e. *Typha* and Cyperaceae (including *Carex* species) which was probably formed in a relatively eutrophic environment during the Boreal and Early Atlantic, like the similar layer at location P1.

P4 biozone A2

The marshy vegetation with *Typha* was replaced by peat-forming vegetation *with Eriophorum vaginatum, Polytrichum, Sphagnum palustre, Sphagnum austinii* and *Pinus sylvestris,* and the peat that was formed also contains remains of *Thelypteris palustris* rhizomes. From its composition we conclude that minerotrophic conditions still existed, but also that the environment became less nutrient rich and more acidic. A cone scale of *Pinus sylvestris* encountered at 40.635 m AOD provided a calibrated date of 4965–4729 BC. From that depth upwards, remains of Ericaceous plants, notably *Erica tetralix* and *Calluna vulgaris*, were found. The presence in the next sample, at 40.645 m AOD, of a recent *Molinia* seed is problematic. Immediately above, between 40.695 and 40.705 m AOD, a layer of sand is present and this situation leads to the conclusion that the origin of the peat that lies on top is rather uncertain. The most likely interpretation is that the sequence was disturbed during exploitation of the peat and that the young bog peat was completely removed.

[24] Van Haaster 1997.
[25] Weeda *et al*. 1985, 45.
[26] Weeda *et al*. 1985, 199–200.
[27] Westhoff *et al*. 1973, Volume III, 183.

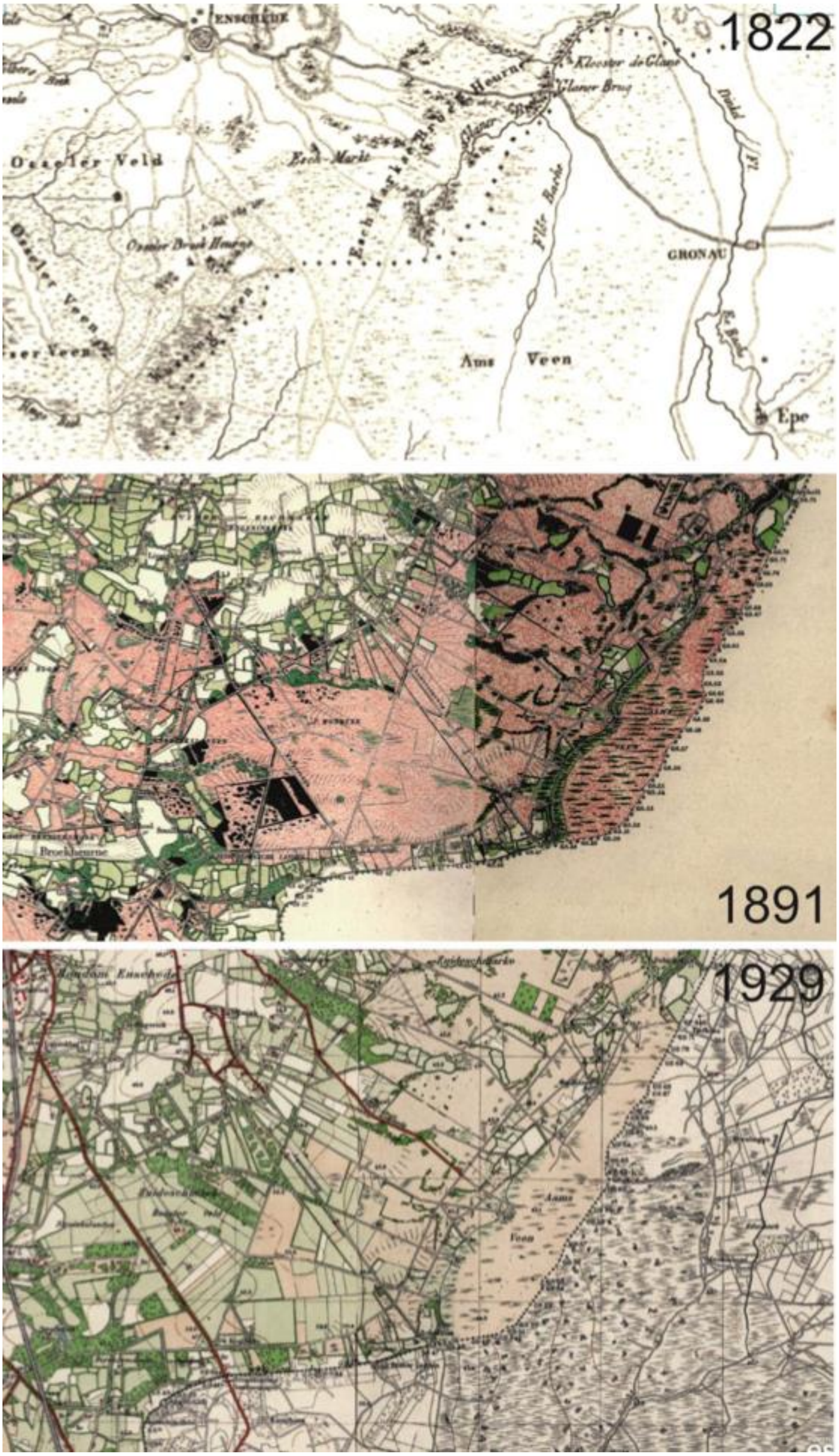

Figure S11. Chronological overview of regional topographic maps covering the Aamsveen area and its surroundings from ca. 1825 to 1940 (from www.topotijdreis.nl).

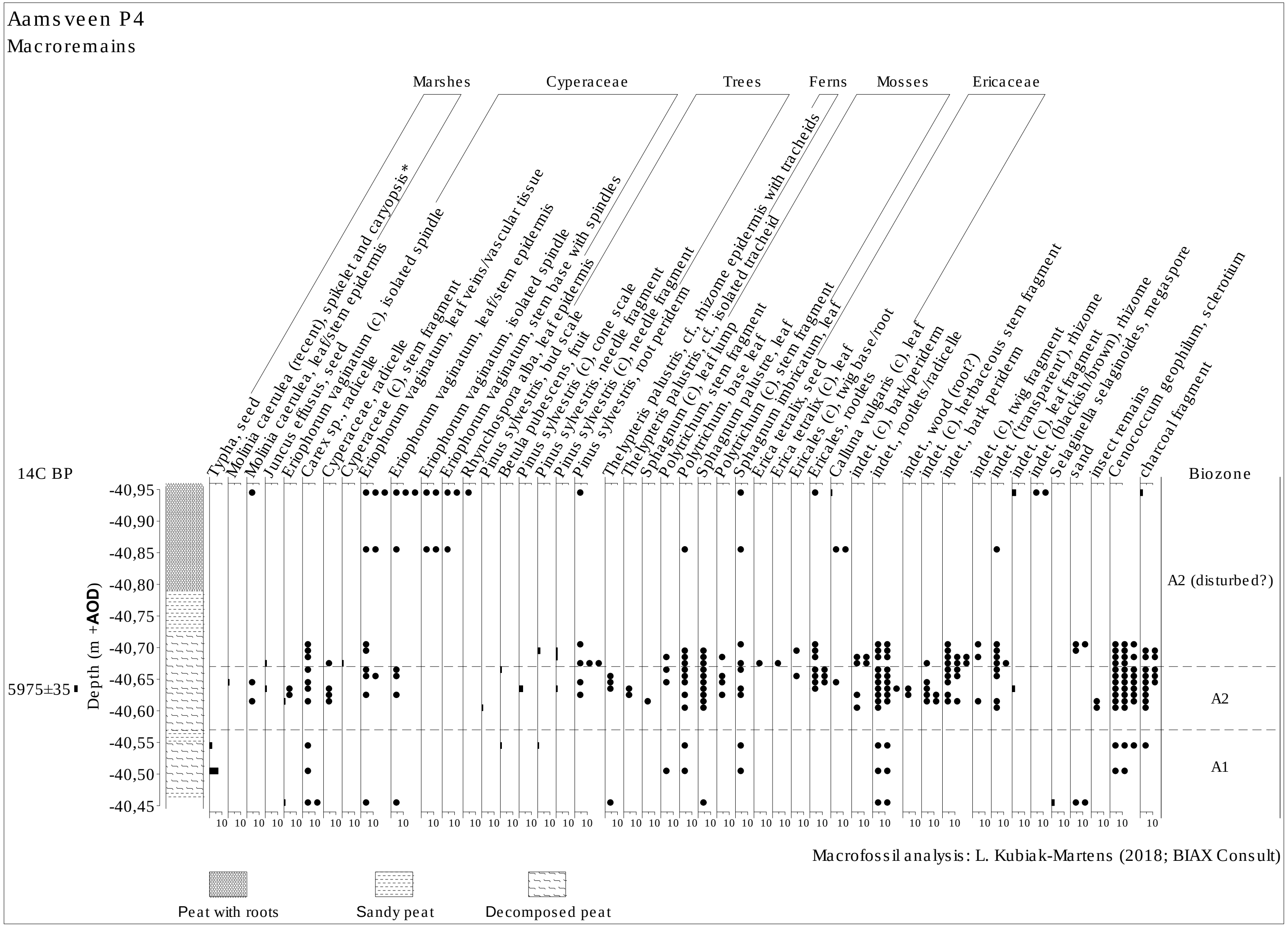

Figure S12. Macro remains from coring P4. Bars indicate the number of remains and filled circles reflect abundancy scores.

East, flank of sandy swell (Location P5)
Results for plant macro remains are presented in Figure S13.

P5 biozone A
The sandy peat base contained many unidentifiable root remains and sclerotia of *Cenococcum geophilum* (biozone A1, Figure S13). In between 41.305 and 41.345 m AOD, we found stem and rhizome epidermises of *Thelypteris palustris* - a fern species of soils where moderately nutrient rich to weakly acid groundwater stands close to the surface. Currently this species is frequently encountered in *Phragmites* marshes, but it may also occur in *Carex* marshes, around moorland pools and in marsh forests (e.g., in Alnetea glutinosae). However, based on the co-occurrence of root periderms, mycorrhiza (micro rootlets) and needle fragments of *Pinus sylvestris* it has to be concluded that the sample location was sufficiently well drained to allow local growth of this tree species. The disappearance of *Thelypteris palustris* can be seen as an indicator of development towards more acid and nutrient poor site conditions, which is likely to be related to the gradual rise of the bog surface. This phase is dated at 4315–4049 cal BC (41.345 m AOD).

In the subsequent phase (biozone A2), macro remains of *Pinus sylvestris*, *Calluna vulgaris* and *Erica tetralix* were encountered. At 41.415 m AOD, *Eriophorum vaginatum* dominated, indicating a wet phase. However, at 41.475 m AOD carbonised *Eriophoru*m seeds were encountered, suggesting that very dry hummocks existed in the bog at the same time. In other samples from biozone A2, *Polytrichum* and some leaflets from *Sphagnum* section *Acutifolia* and *Sphagnum austinii* occurred. These observations suggest that processes like impoverishment, acidification and rewetting took place at local scale.

P5 biozone B1
From 41.515 m AOD onward (extrapolated age ca. 3840 BC) the ombrogenic vegetation was found to be dominated by *Sphagnum* section *Acutifolia* and *Sphagnum austinii*. At this depth there still were rootlets of *Pinus sylvestris*. Higher up, at 41.575 m AOD, no remains of *Pinus sylvestris* were found and the overall aspect is that of a treeless raised bog (ca. 3500 BC). At 42.695 m AOD a short phase with *Aulacomnium palustre* was found, but the dominant bog forming *Spaghnum* was *Sphagnum* sect. *Acutifolia*. In addition, *Calluna vulgaris* and *Erica tetralix* were present. Remains of *Vaccinium oxycoccos* and *Andromeda polifolia* were found higher up in the zone, between 42.195 and 42.455 m AOD, with abundant *Eriophorum vaginatum* being encountered at the latter depth.

P5 biozone B2
Although *Sphagnum* sect. *Acutifolia* remains the dominant *Sphagnum* species, from 43.205 to 43.265 m AOD *Scheuchzeria palustris* was also present, and between 43.245 and 43.255 m AOD *Rhynchospora alba* was recorded. The occurrence of these species indicates a wetter phase of bog formation. *Scheuchzeria palustris* occurs in a wet, (very) weakly minerotrophic environment, e.g., in bog hollows or around pools. Thus, the occurrence of *Scheuchzeria palustris* marks the either a transition to more oligotrophic conditions or a very wet phase in peat formation.[28] Bog formation was already in progress at location P5 and the presence of *Scheuchzeria palustris* in biozone B2 might therefore indicate a temporary rise of nutrient status, which could be ascribed to a larger influx of minerotrophic groundwater. Whatever the cause, its presence suggests very wet conditions which may have a climatic origin. The (first) disappearance of *Scheuchzeria palustris* is dated at 1411–1225 cal BC, but *Scheuchzeria palustris* and *Rhynchospora alba* were encountered again between 43.355 and 43.395 m AOD. Abundantly present in biozone B2 was *Eriophorum vaginatum*, whose age in the top of this zone was found to be 1055–846 cal BC.

P5 biozone C
The transition from Old to Young peatmoss occurred after 1055–846 cal BC. From 43.475 m AOD upward, the bog was dominated by *Sphagnum austinii*. In this zone, *Eriophorum vaginatum* was not found but *Rhynchospora alba* did occur. Towards the top of this zone the proportion of Ericaceae seemed to decline and only *Erica tetralix* was encountered.

[28] Weeda *et al*. 1991, 237.

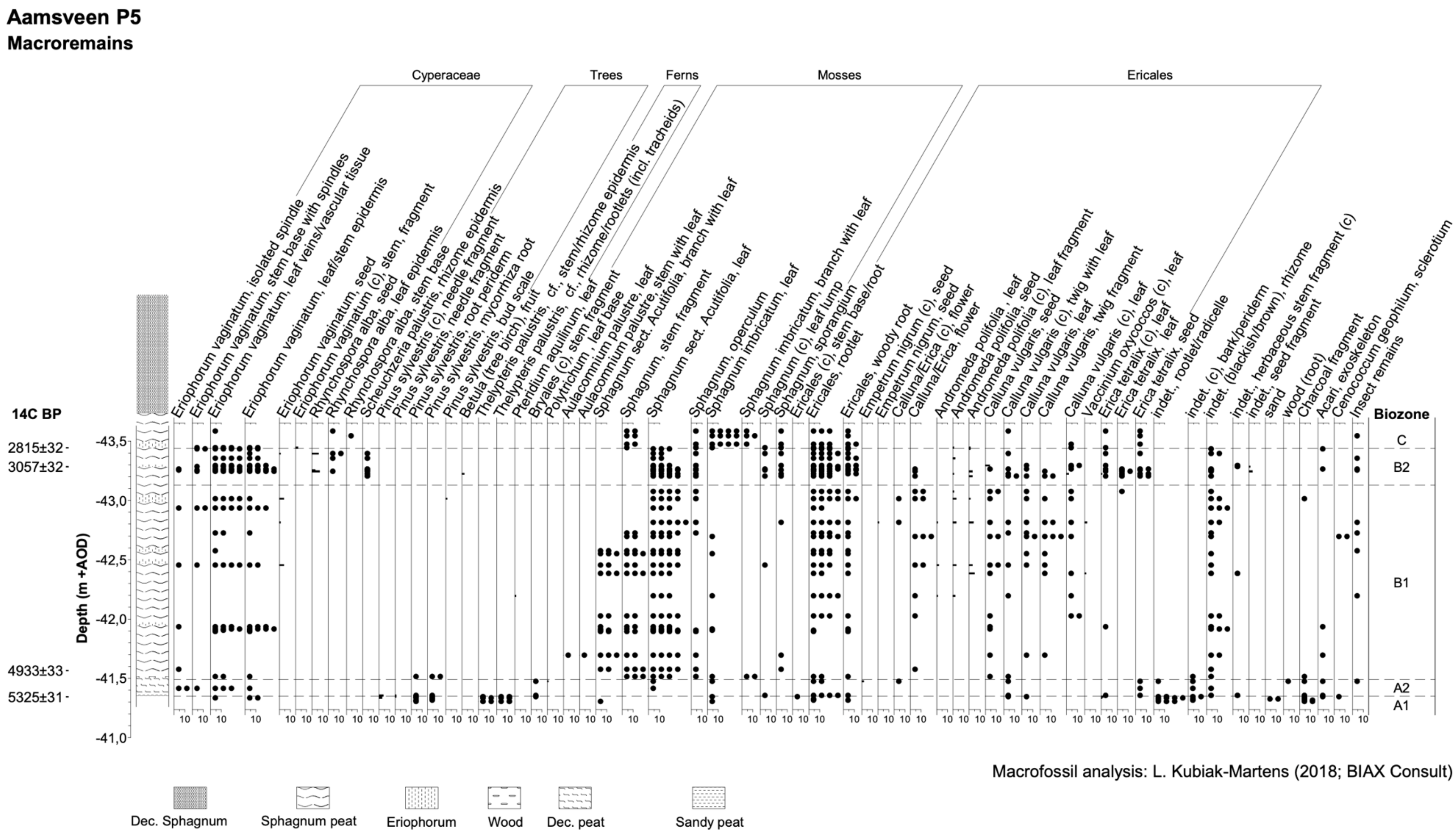

Figure S13. Macro remains from coring P5. Bars indicate the number of remains and filled circles reflect abundancy scores.

Western flank of ice-pushed ridge (Location P2)
Results for plant macro remains are presented in Figure S14.

P2 biozone A1
At the base of the sandy peat, between 41.185 and 41.265 m AOD, charcoal fragments, rootlets of *Carex* and seeds were encountered. In Figure S15, this layer is visible as greyish brown sandy material (right). *Carex acutiformis* occurs in wet to relatively dry locations within a range of deciduous forest types on moderately drained nutrient rich soils (most likely *Alnetea glutinosae*). On less fertile soils it occurs with *Calamagrostis canescens*[29] and indeed seeds of *Calamagrostis canescens* were encountered at the base of this zone. Furthermore, a single seed of (possibly) *Rubus* was encountered. Bog formation on this flank started with a *Carex* marsh where peat accumulated under relatively nutrient-rich conditions. Remains of *Betula* cf. *pubescens* were found in the top of biozone A1, which indicates the nearby presence of a *Betulion pubescentis* and a gradual acidification of the system. In this sandy base some remains of *Eriophorum vaginatum* were also present. Remarkably, these remains provided a more recent ^{14}C age than did samples from two overlying layers, which led to the conclusion that this ^{14}C date is not representative of the *Carex* peat. Comparing vegetation succession and depth between locations P2 and P5, we conclude that bog formation at P2 started ca. 4200 BC. Given the low-lying position of P2 (in a depression) relative to P5, it is likely that bog formation started somewhat earlier at P2.

P2 biozone A2
Upwards from sample level 41.355 m AOD, many above and below ground macro remains of *Pinus sylvestris* were found, indicating the local presence of this tree species. In addition, remains of *Betula pubescens* were present. In this phase, *Eriophorum vaginatum* and various moss types such as *Polytrichum strictum* and *Sphagnum* sect. *Cuspidata* were encountered. This level (41.445 m AOD) was radiocarbon dated at 3711–3531 cal BC. Local conditions became wetter and more acid, as exemplified by the preservation of even fragile leaf fragments of *Betula*. From 41.445 m AOD upwards, the *Sphagnum* species composition changes to *Sphagnum magellanicum* and *Sphagnum riparium. Sphagnum magellanicum* is well known from relatively recent peats formed during the last 1500 years, replacing *Sphagnum austinii* as the dominant peat forming *Sphagnum* type. This replacement is ascribed to the capacity of *Sphagnum magellanicum* to withstand a larger atmospheric supply of nutrients.[30] In The Netherlands, *Sphagnum magellanicum* is also present in 'hillside bogs', which is a bog type that occurs on slopes and is groundwater-fed.[31] Its classic role, however, is that of a hummock-former in well developed (living) raised bog that is rainwater-fed.[32] *Sphagnum riparium* occurs in the transitional zone between acid rainwater-fed and groundwater-fed subsystems, and for that reason is described as a 'lagg species'. This species, which is very rare in The Netherlands, is currently encountered at only a few locations, of which two are in Twente.[33] In the phase P2 biozone A2, the vegetation still reflected the influence of groundwater, but the expanding raised bog system (in the southwest of the Aamsveen around location P1) induced increasing wetness and acidification.

P2 biozone B1
At the base of biozone B1, *Sphagnum magellanicum* is the dominant peatmoss species and peatmoss hummocks were formed. In this earliest phase of bog formation, *Scheuchzeria palustris* was present indicating some effect of groundwater on the vegetation. *Aulacomnium p*alustre was still present, but macro remains of tree species were encountered no more. Ericaceae such as *Vaccinium oxycoccos* and *Andromeda polifolia* established first during this bog development phase. The calibrated age of the base of biozone B1 is 3640–3370 BC.

[29] Weeda *et al*. 1991, 308–311.
[30] McClymont *et al*. 2008, McClymont *et al*. 2009.
[31] Joosten *et al*. 2017, 525.
[32] Smith 2004, 54. https://www.verspreidingsatlas.nl/3011.
[33] Smith 2004, 100. https://www.verspreidingsatlas.nl/3021.

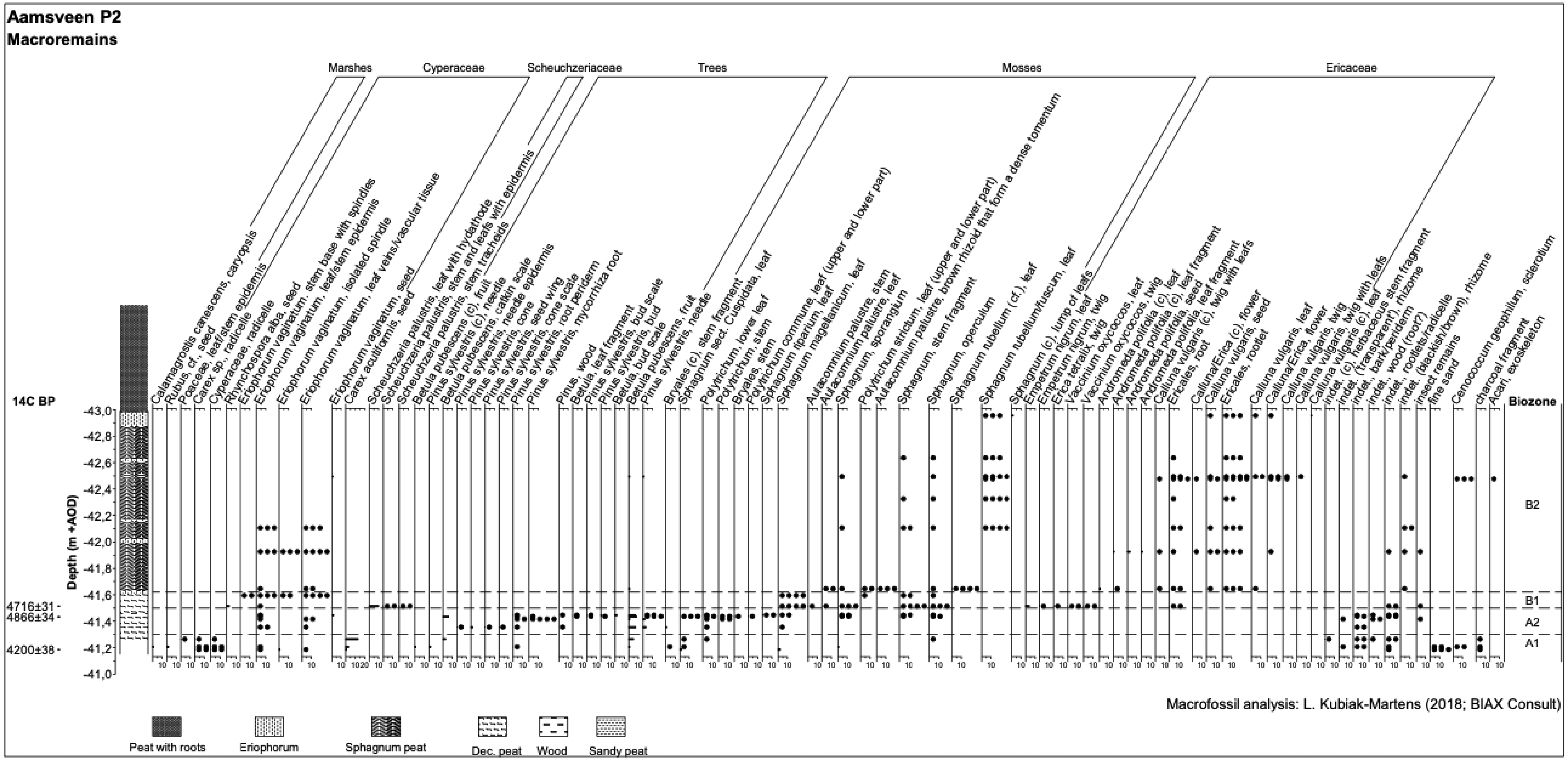

Figure S14. Macro remains from coring P2. Bars indicate the number of remains and filled circles reflect abundancy scores.

Figure S15. Peat basis (right) on top of the mineral subsoil as observed at location P2.

P2 biozone B2

From 41.645 m AOD *Sphagnum* section *Acutifolia (Sphagnum rubellum/fuscum)* dominated and *Sphagnum magellanicum* was no longer encountered. In the base of this zone *Eriophorum vaginatum* was abundant. From 42.325 m AOD upwards, *Calluna vulgaris* was very frequently encountered, growing on the relatively dry peatland. Between 42.820 and 42.940 m AOD a phase with very many *Eriophorum vaginatum* remains was identified, while above this level the vegetation again consisted of *Sphagnum* sect. *Acutifolia* and *Calluna vulgaris* (42.955 m AOD).[34]

Lagg zone (Location P3)

Results for plant macro remains are presented in Figure S16.

P3 biozone A/B

A seed of *Betula* that was found 29.5 cm below ground level was radiocarbon dated, but was found to be recent with a calibrated age of 2013–2016 AD. The current vegetation is indeed a *Betulion pubescentis*.[35] In the basal peat, remains of several vegetation types were encountered. Results from the hydro-ecological study by Bell *et al*. (2016) provide an explanation for this phenomenon by showing that the groundwater level is below the base of the peat during the dry summer period. In other words, the basal peat is subject to desiccation and is thus highly decomposed and bioturbated.[36] The outcome is that biozones A1, A2 and the earliest part of zone B, as observed at location P2, are seemingly pressed together. This explains the co-occurrence of *Carex radicelle* with *Rhynchospora alba, Thelypteris palustris* and *Ericales*. Peat formation at this location appears to have started with a vegetation of *Pinus sylvestris* and *Betula (pubescens),* but possibly all the remains of *Betula* and *Eriophorum vaginatum* are recent. Thus, the possibility of a preceding phase with *Carex* peat is not excluded. *Sphagnum palustre* was probably present in this vegetation. *Sphagnum palustr*e occurs in water saturated places with water that is not acid and extremely nutrient poor, for example in carrs, but is also found in marshy areas, nutrient poor forests and wet heathland. Locations with base or nutrient rich water are not suitable for this species.[37] In any case, the species composition of *Pinus sylvestris, Eriophorum vaginatum* and *Sphagnum palustre* indicates that peat development started under acid and nutrient poor conditions. The remains of *Eriophorum vaginatum* from the peat base (42.195 m AOD) provided a calibrated age of 2916 – 2675 BC. A transition to peat with Ericaceae such as *Calluna vulgaris* and *Erica tetralix* probably followed.

[34] Because of the strong decomposition and prominent rooting at the top of the peat, this part of the core has not been further studied for its macro remains.
[35] The fieldwork dates from October 2017.
[36] Personal communication with Bell & Hullenaar by email on 20 Apr 2018.
[37] Smith 2004, 52.

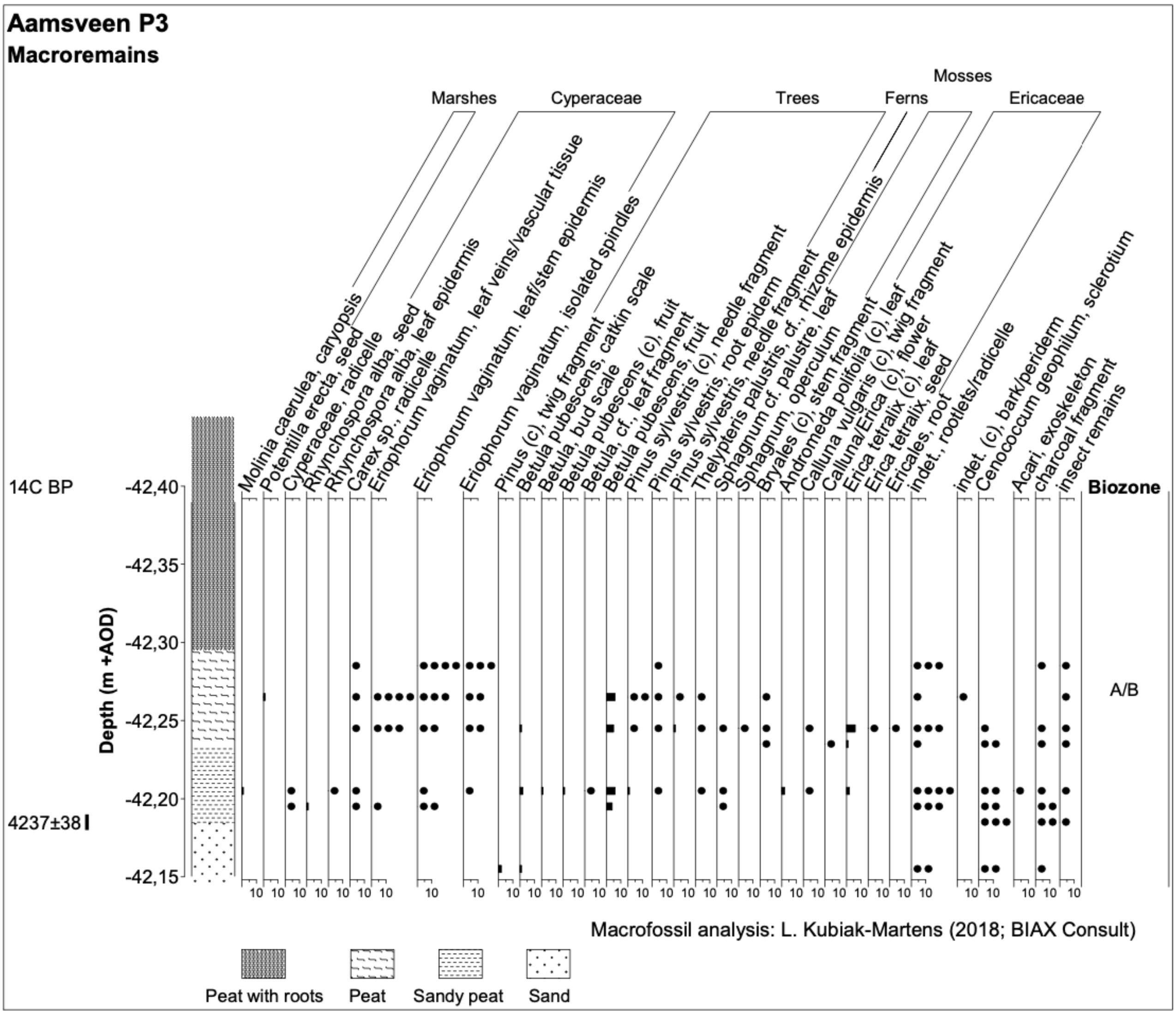

Figure S16. Macro remains from coring P3. Bars indicate the number of remains and filled circles reflect abundancy scores.

REFERENCES

Aggenbach, C.J.S., Jalink M.H. (1998) *Indicatorsoorten voor verdroging, verzuring en eutrofiëring van plantengemeenschappen in hoogvenen* (*Indicator Species for Desiccation, Acidification and Eutrophication of Plant Communities in Raised Bogs*). Staatsbosbeheer, Driebergen, 138 pp. (in Dutch).

Anderberg, A.-L. (1994) *Atlas of Seeds and Small Fruits of Northwest-European Plant Species, Part 4: Resedaceae-Umbelliferae*. Swedish Museum of Natural History, Stockholm, 281 pp.

Barkman, J.J. (1992) Plant communities and synecology of bogs and heath pools in the Netherlands. In: Verhoeven, J.T.A. (ed.) *Fens and Bogs in the Netherlands. Vegetation, History, Nutrient Dynamics and Conservation*. Springer Netherlands, Dordrecht, 491 pp.

Bell, J.S., Van 't Hullenaar, J.W., Jansen, A.J.M. (2016) *Ecohydrologische systeemanalyse dal van de Glanerbeek* (*Ecohydrological System Analysis Glanerbeek Valley*). Bureau Bell Hullenaar & Unie van Bosgroepen report, Bell Hullenaar Ecohydrologisch Adviesbureau, Zwolle, 114 pp (in Dutch).

Berggren, G. (1961) *Atlas of Seeds and Small Fruits of Northwest-European Plant Species, Part 3: Salicaceae-Cruciferae*. Swedish Museum of Natural History, Stockholm, 261 pp.

Berggren, G. (1969) *Atlas of Seeds and Small Fruits of Northwest-European Plant Species, Part 2: Cyperaceae*. Swedish Museum of Natural History, Stockholm, 55 pp.

Beug, H.-J. (2004) *Leitfaden der Pollenbestimmung für Mitteleuropa und angrenzende Gebiete* (*Guidelines for Pollen Identification for Middle Europe and Adjacent Areas).* Verlag Friedrich Pfeil, München, 542 pp. (in German).

Bronk Ramsey, C. (2020) *Oxcal 4.4*. https://c14.arch.ox.ac.uk/oxcal/OxCal.html

Cappers, R.T.J., Bekker, R.M., Jans, J.E.A. (2006) *Digitale zadenatlas van Nederland* (*Digital Seed Atlas of The Netherlands*). Barkhuis, Groningen, 502 pp. (in Dutch)

Couwenberg, J., de Klerk, P., Endtmann, E., Joosten, H., Michaelis, D. (2001) Hydrogenetische Moortypen in der Zeit - ein Zusammenschau (Hydrogenetic mire types over time - an overview). In: Succow, M., Joosten, H. (eds.) *Landschaftsökologische Moorkunde* (*Landscape Ecological Mire Science*). Schweizerbart Science Publishers, Stuttgart, 399–403 (in German).

Daniels, A.G.H. (1963) A contribution to the investigation of the Holocene history of beech in the eastern Netherlands. *Acta Botanica Neerlandica*, 13, 66–75.

Deforce, K., Bastiaens, J. (2007) The Holocene History of *Taxus Baccata* (Yew) in Belgium and neighbouring regions. *Belgian Journal of Botany*, 140, 222–237.

Doorenbosch, M. (2013) *Ancestral Heaths: Reconstructing the Barrow Landscape in the Central and Southern Netherlands*. Sidestone Press, Leiden, 279 pp.

Groenman-van Waateringe, W. (1986) Grazing possibilities in the Neolithic of the Netherlands based on palynological data. In: Behre, K.-E. (ed.) *Anthropogenic Indicators in Pollen Diagrams*. A.A. Balkema, Rotterdam, 187–202.

Hultén, E. (1950) *Atlas of the Distribution of the Vascular Plants of Northwest Europe: Atlas over växternas utbredning i norden*. Generalstabens Litografiska Anstalts Förlag, Stockholm, 512 pp.

Iversen, J. (1941) *Landnam i Danmarks Stenalder: En pollenanalytisk Undersøgelse over det første Landbrugs Indvirkning paa Vegetationsudviklingen* (*Land Occupation in Denmark's Stone Age: A Pollen-Analytical Study of the Influence of Farmer Culture on the Vegetational Development*). Danmarks Geologische Undersøgelse II. Række 66, C.A. Rietzels Forlag, Copenhagen, 96 pp. (in Danish).

Joosten, H., Grootjans, A., Schouten, M., Jansen, A.M.J. (2017) Netherlands. In: Joosten, H., Tanneberger, F., Moen, A. (eds.) *Mires and Peatlands of Europe: Status, Distribution and Conservation.* Schweizerbart Science Publishers, Stuttgart, 523–535.

Körber-Grohne, U. (1964) Bestimmungsschlüssel für subfossile *Juncus*-Samen und Gramineen-Früchte (Identification key for subfossil *Juncus* seeds and Gramineae fruits). *Probleme der Küstenforschung im südlichen Nordseegebiet*, 7, 47 pp. (in German).

Körber-Grohne, U. (1991) Bestimmungsschlüssel für subfossile Gramineen-Früchte (Identification key for subfossil and Gramineae fruits). *Probleme der Küstenforschung im südlichen Nordseegebiet*, 18, 169–234 (in German).

Maes, B. (2006) *Inheemse bomen en struiken in Nederland en Vlaanderen. Herkenning, verspreiding, geschiedenis en gebruik* (*Native Trees and Shrubs in the Netherlands and Flanders, Identification, Distribution, History and Use*). Boom, Amsterdam, 400 pp. (in Dutch).

McClymont, E.L., Mauquoy, D., Yeloff. D., Broekens, P., Van Geel, B., Pancost, R.D., Chambers, F.M., Evershed, R.P. (2008) The disappearance of *Sphagnum imbricatum* from Butterburn Flow, U.K. *The Holocene*, 18, 991–1002.

McClymont, E.L., Mauquoy, D., Yeloff, D., Broekens, P., van Geel, B., Charman, D.J., Pancost, R.D., Chambers, F.M., Evershed, R.P. (2009) The disappearance of *Sphagnum imbricatum* from Butterburn Flow, UK: a reply to comments by Bjorn Robroek *et al*. *The Holocene*, 19, 1094–1097.

Miola, A. (2012) Tools for Non-Pollen Palynomorphs (NPPs) analysis: A list of Quaternary NPP types and reference literature in English language (1972–2011). In: Van der Linden, M., Kooistra, L.I., Engels, S. (eds.) *Review of Palaeobotany & Paly*nology, 186, 142–161.

Moore, P.D., Webb, J.A., Collinson, M.E. (1991) *Pollen Analysis*. Blackwell, Oxford, 216 pp.

Overbeck, F. (1975) *Botanisch-geologische Moorkunde unter besonderer Berücksichtigung der Moore Nordwestdeutschlands als Quellen zur Vegetations-, Klima- und Siedlungsgeschichte* (*Botanical-Geological Peat Science with Special Reference to the Peats of Northwest Germany as Sources for the History of its Vegetation, Climate and Settlement*). Karl Wacholtz Verlag, Neumünster, 719 pp. (in German).

Punt, W., Clarke, G.C.S., Blackmore, S., Hoen, P.P., Stafford, P.J. (ed.) (1976–2009). *The Northwest European Pollen Flora I–IX*, Elsevier, Amsterdam.

Reimer, P., Austin, W.E.N., Bard, E., Bayliss, A., Blackwell, P.G., Bronk Ramsey, C., Butzin, M., Cheng, H., Edwards, R.L., Friedrich, M., Grootes, P.M., Guilderson, T.P., Hajdas, I., Heaton, T.J., Hogg, A.G., Hughen, K.A., Kromer, B., Manning, S.W., Muscheler, R., Palmer, J.G., Pearson, C., Van der Plicht, J., Reimer, R.W., Richards, D.A., Scott, E.M., Southon, J.R., Turney, C.S.M., Wacker, L., Adolphi, F., Büntgen, U., Capano, M., Fahrni, S., Fogtmann-Schulz, A., Friedrich, R., Köhler, P., Kudsk, S., Miyake, F., Olsen, J., Reinig, F., Sakamoto, M., Sookdeo, A., Talamo, S. (2020) The IntCal20 Northern Hemisphere radiocarbon age calibration curve (0–55 cal kBP). *Radiocarbon*, 62(4), 725–757.

Sevink, J., Jansen, A.M.J. (2017) *Bodemonderzoek Aamsveen, 29 oktober 2017* (*Soil Study Aamsveen, 29 October 2017*). Internal report, Stichting Bargerveen, 26 pp. (in Dutch).

Sevink, J., Van Geel, B. (2018) Early Holocene forest fires, drift sands, and Usselo-type paleosols in the Laarder Wasmeren area near Hilversum, the Netherlands: Implications for the history of sand landscapes and the potential role of Mesolithic land use. *Catena*, 165, 286–298.

Smith, A.J.E. (2004) *The Moss Flora of Britain and Ireland*. Cambridge University Press, 1026 pp.

Succow, M., Joosten, H. (2001) *Landschaftsökologische Moorkunde* (*Landscape Eology of Mires*). Schweizerbart Verlagsbuchhandlung, Stuttgart, 622 pp. (in German).

Van der Linden, M., Van Geel, B. (2006) Late Holocene climate change and human impact recorded in a South Swedish ombrotrophic peat bog. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 240, 649–667.

Van der Linden, M. (2007) *Effects of Climate Change and Human Impact on late-Holocene Species Composition and Carbon Accumulation in Bog Ecosystems*. PhD thesis, University of Amsterdam, 224 pp.

Van der Linden, M. (2018) *Palaeoecologisch onderzoek naar de ontwikkeling van het Aamsveen in ruimte en tijd* (*Paleaeoecological Study of the Spatial and Temporal Development of the Aamsveen*). BIAX-consult in opdracht van de Unie van Bosgroepen en Landschap Overijssel, 50 pp. (in Dutch).

Van der Meijden, R. (2005) *Heukels' Flora van Nederland* (*Heukel's Flora of the Netherlands*). Wolters-Noordhoff, Groningen etc., 685 pp. (in Dutch).

Van der Veen, K., Attema, S. (2012) *Vegetatiekartering Aamsveen 2012 (Vegetation Survey Aamsveen 2012)*. A&W-rapport 1854, Altenburg & Wymenga ecologisch onderzoek, Veenwouden (in Dutch).

Van Geel, B. (1976) *A Palaeoecological Study of Holocene Peat Bog Sections, Based on the Analysis of Pollen, Spores and Macro- and Microscopic Remains of Fungi, Algae, Cormophytes and Animals*. PhD thesis, University of Amsterdam, 120 pp.

Van Geel, B., Bohncke, S.J.P., Dee, H. (1981) A palaeoecological study from an Upper Late Glacial and Holocene sequence from "De Borchert", The Netherlands. *Review of Palaeobotany and Palynology*, 31, 347–448.

Van Geel, B., Hallewas, D.P., Pals, J.P. (1983) A Late Holocene deposit under the Westfriese Zeedijk near Enkhuizen (Province of N-Holland, the Netherlands): palaeoecological and archaeological aspects. *Review of Palaeobotany and Palynology*, 25, 377–392.

Van Geel, B., Buurman, J., Brinkkemper, O., Schelvis, J., van Aptroot, A., Reenen, G., Hakbijl, T. (2003) Environmental reconstruction of a Roman Period settlement site in Uitgeest (The Netherlands), with special reference to coprophilous fungi. *Journal of Archaeological Science*, 30, 873–883.

Van Geel, B., Aptroot, A., Baittinger, C., Birks, H.H., Bull, I.D., Cross, H.B., Evershed, R.P., Gravendeel, B., Kompanje, E.J.O., Kuperus, P., Mol, D., Nierop, K.G.J., Pals, J.P., Tikhonov, A.N., Van Reenen, G., Van Tienderen, P.H. (2008) The ecological implications of a Yakutian mammoth's last meal. *Quaternary Research*, 69, 361–376.

Van Geel, B., Heijnis, H., Charman, D.J., Thompson, G., Engels, S. (2014). Bog burst in the eastern Netherlands triggered by the 2.8 kyr BP climate event. *The Holocene*, 24(11), 1465–1477.

Van Haaster, H. (1997) De introductie van cultuurgewassen in de Nederlanden tijdens de Middeleeuwen (The introduction of cultivated crops in the Low Countries during the Middle Ages). In: Zeven, A.C. (ed.) *De introductie van onze cultuurplanten en hun begeleiders van het Neolithicum tot 1500 AD* (*The Introduction of Our Cultivated Plants and Their Companions from the Neolithic to 1500 AD*), Vereniging voor Landbouwgeschiedenis Wageningen, 53–104 (in Dutch).

Weeda, E.J., Westra, R., Westra, Ch., Westra, T. (1985) *Nederlandse oecologische flora. Wilde planten en hun relaties 1* (*Ecological Flora of the Netherlands: Wild Plants and Their Relationships 1*). IVN, Deventer, 304 pp. (in Dutch).

Weeda, E.J., Westra, R., Westra, Ch., Westra, T. (1987) *Nederlandse oecologische flora. Wilde planten en hun relaties 2* (*Ecological Flora of the Netherlands: Wild Plants and Their Relationships 2*). IVN, Deventer, 304 pp. (in Dutch).

Weeda, E.J., Westra, R., Westra, Ch., Westra, T. (1988) *Nederlandse oecologische flora. Wilde planten en hun relaties 3* (*Ecological Flora of the Netherlands: Wild Plants and Their Relationships 3*). IVN, Deventer, 302 pp. (in Dutch).

Weeda, E.J., Westra, R., Westra, Ch., Westra, T. (1991) *Nederlandse oecologische flora. Wilde planten en hun relaties 4* (*Ecological Flora of the Netherlands: Wild Plants and Their Relationships 4*). IVN, Deventer, 400 pp. (in Dutch).

Weeda, E.J., Westra, R., Westra, Ch., Westra, T. (1994) *Nederlandse oecologische flora. Wilde planten en hun relaties 5* (*Ecological Flora of the Netherlands: Wild Plants and Their Relationships 5*). IVN, Deventer, 400 pp. (in Dutch).

Westhoff, V., Bakker, P.A., Van Leeuwen, C.G., Van der Voo, E.E., Zonneveld, I.S. (1973) *Wilde planten. Flora en vegetatie in onze natuurgebieden. Deel 3: De hogere gronden* (*Wild Plants. Flora and Vegetation in Our Nature Reserves. Part 3: The Higher Grounds*). Vereniging tot behoud van Natuurmonumenten in Nederland, 359 pp. (in Dutch).

Author for correspondence: Professor Dr Jan Sevink, Institute for Biodiversity and Ecosystem Dynamics (IBED), University of Amsterdam, Sciencepark 904, 1098 XH, Amsterdam, The Netherlands.
Tel: 0031 623614096; E-mail: j.sevink@uva.nl