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High-resolution record of Late Saalian and Eemian palaeoenvironments: the case study of Struga and Parysów (central Poland)

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Eemian organogenic deposits, analysed at the Struga and Parysów sites (Garwolin Plain, central Poland), reveal the vegetation history. Palynological analysis supported by plant macrofossil analysis revealed a pollen succession encompassing seven regional pollen assemblages zones, E1-E7 RPAZ, within which indicator taxa for various climate characteristics (mainly temperature and humidity, including *Tilia tomentosa* and *Hedera helix*) were recorded. Additionally, the Struga G-120 profile encompasses a Late Saalian section of deposits in which stadial and interstadial oscillations are inferred. The data corroborated earlier findings that the warmest and wettest part of the Eemian interglacial was during the hazel phase (E4 RPAZ) and the beginning of the hornbeam phase (E5 RPAZ). The younger part of the hornbeam phase bears the record of a decrease in humidity and gradual drop in air temperature. During the telocratic period encompassing the spruce-fir (E6 RPAZ) and pine (E7 RPAZ) phases, increased humidity and rising water levels in the lakes studied are again evident. The reconstructed plant succession and climatic conditions are discussed against a broader background of other Eemian profiles from Poland and neighbouring countries. They largely confirm that, at that time, the Garwolin Plain showed characteristics typical of a transitional climate from oceanic in Western Europe to continental beyond the eastern borders of Poland.

Key words: pollen succession, plant macrofossils, Eemian interglacial, climate changes, central Poland.

INTRODUCTION

The stratigraphic position of the Eemian interglacial and its correlation with Marine Isotope Stage 5e (MIS 5e) is widely recognised and unquestioned (Lisiecki and Raymo, 2005; Cohen and Gibbard, 2019). However, the vegetation and climate of this warm period, with related environmental transformations, have continued to be investigated (e.g., Shackleton et al., 2002; Velichko et al., 2005; Brauer et al., 2007; Brewer et al., 2008; Govin et al., 2015). The usefulness of detailed research on the Eemian, as the last interglacial without human influence in tracing natural climate variability, has been emphasized (Kukla et al., 2002; Bova et al., 2021).

The Eemian Lakeland extends across the European Lowland from sites in estern Europe on the Atlantic coast to sites deep into Russia. In western Europe, research has been conducted at the French sites of Les Echets near Lyon (de Beaulieu and Reille, 1989), La Grande Pile in the Vosges (de Beaulieu and Reille, 1992a), and in the Central Massif (de Beaulieu and Reille, 1992b), at sites from north-west Greece (Ioannina: Tzedakis et al., 2003), Netherlands (Amsterdam Terminal: van Leeuwen et al., 2000; and Amersfoort: Zagwijn, 1989), at German sites including Neubrandenburg-Hinterste Mühle (Börner et al., 2018) and Beckentine (Hrynowiecka et al., 2021). In eastern Europe, Belarusian sites have been described by Sanchenko and Rylova (2001) whose review was published by Granoszewski et al. (2012) and by Shalaboda

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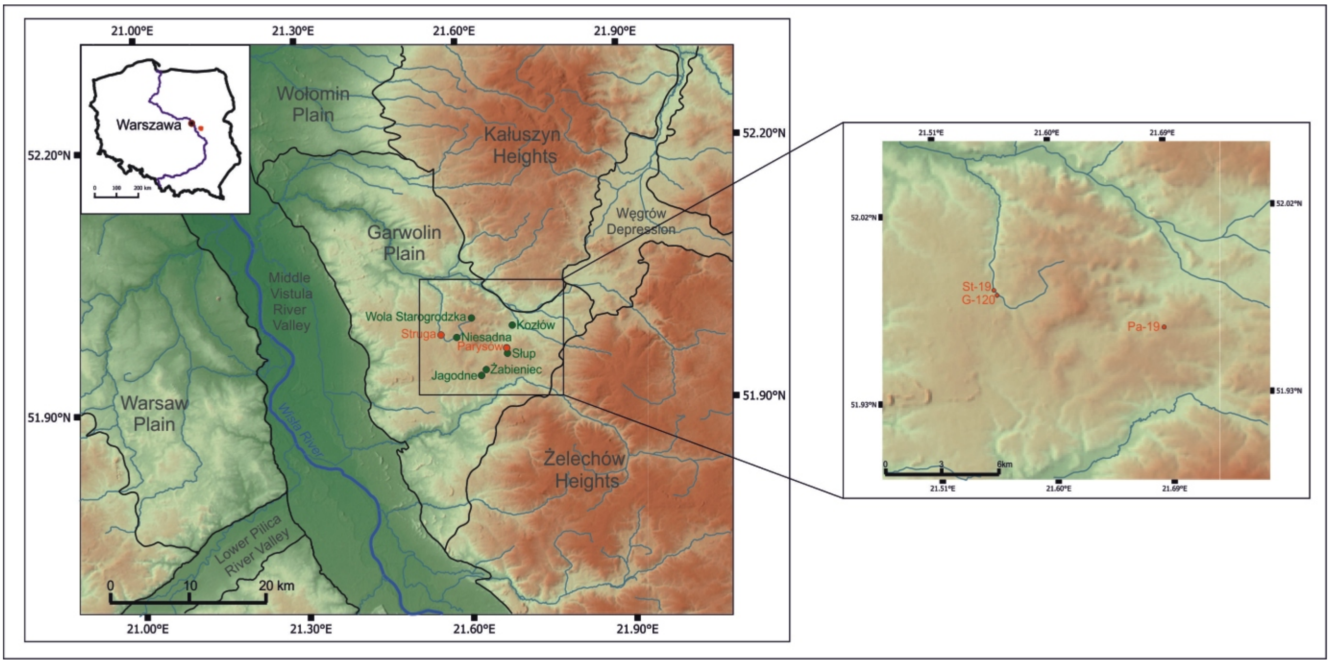

Fig. 1. Location of the Struga and Parysów sites on the Garwolin Plain (regional division according to Solon et al., 2018)

(2001). The current list of 184 Eemian sites studied by pollen analytical methods in Poland has been included in the isopollen monograph by Kupryjanowicz et al. (2018).

This study reconstructs the vegetation succession, palaeotemperature and humidity based on pollen and plant macrofossil analysis at two Eemian palaeolake sites, Struga and Parysów on the Garwolin Plain. An Eemian age was previously determined; however, as C^{14} carbon radioisotope dating cannot be applied to Eemian deposits, Kupryjanowicz and Granoszewski (2018) highlighted the difficulty of determining precisely the age and duration of the Eemian interglacial in Central and Northern Europe. Based on data from different sites, the duration varies from 12,000 years (131,000–119,000 years BP; Lambeck et al., 2006), to 15,500 years (~127,300–111,800 years BP; Tzedakis et al., 2002), 16,000 years (Guiot et al., 1993) and 17,700 years (~127,200–109,500 years BP; Brauer et al., 2007), to 23,000 years (129,000–107,000 years BP; Kukla et al., 1997). All these estimates were based on different criteria than those used in Poland. Kupryjanowicz and Granoszewski (2018) dated the upper limit of the interglacial to ~109,500 years BP within zone MIS 5d (analogous to Brauer et al., 2007); they emphasized that it is difficult to specify a single date due to the asynchronous development of the Eemian flora in different European regions. Different deposit types record the Eemian interglacial and a range of pollen spectra illustrate the various characters of the biogenic representation. This situation led to our current high-resolution investigation, to enable detailed tracing of temperature and humidity during in the period of deposition of these deposits.

STUDY SITE

The Struga site is located in the valley of the Struga stream, at an altitude of ~138.5 m a.s.l. (Fig. 1). The lake at Struga was formed in a post-glacial trough formed during the Late Saalian glaciation. As the ice sheet shrank, the subglacial channels were filled with dead ice, whose melting gave rise to the lake. This lake existed throughout the Eemian interglacial and was gradually filled with lake sediments. On both sides of the Struga valley there are kame terraces built of fine-grained sandy deposits, and river terraces from the Vistula glaciation period are developed. Above are kame terraces built of silty and fine-grained sands, which are immediately adjacent to the upland made up of glacial till of the Late Saalian glaciation (Fig. 2A).

The Parysów site is situated ~1 km south of the village of Parysów at an altitude of ~158 m a.s.l. (Fig. 1). The Eemian palaeolake is sited in glacial till of the Late Saalian glaciation, and formed by the melting out of dead ice blocks. Basal silts are overlain by lake-derived sediments of gyttja and peat. Above these are deluvial sands of the Vistula glaciation, and above that, Holocene alluvial sands (Fig. 2B).

MATERIAL AND METHODS

MATERIAL

Two profiles with organogenic deposits were sampled at the Struga site. The Struga St-19 profile was taken with a POWERPROBE core drilled to a depth of 12.00 m (Table 1). Eemian lake deposits were recognised at a depth of 2.10–9.00 m (Fig. 2C). The Struga G-120 profile was taken with a GEOPROBE core drill, and drilling was carried out to a depth of 8.50 m (Table 2). Eemian lake deposits were recognised between 1.38–6.51 m (Fig. 2C).

The Parysów Pa-19 profile was taken with a URB corer and drilled to a depth of 15.70 m (Table 3). Eemian lake deposits were recognised at a depth of 10.30–13.15 m (Fig. 2C).

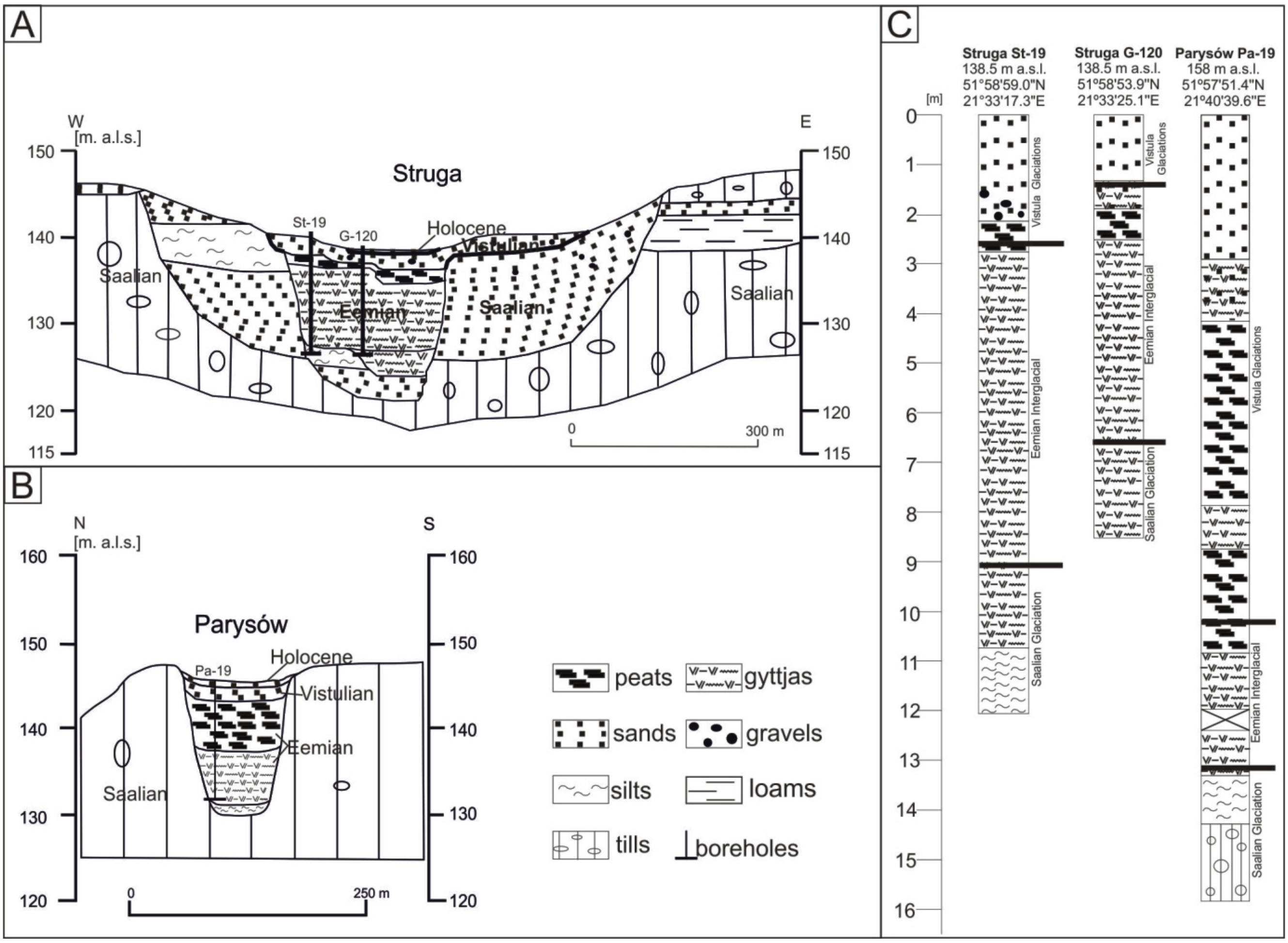

Fig. 2A – geological cross-section of Struga St-19 and G-120; B – geological cross-section of Parysów Pa-19; C – lithostratigraphic profile of the Struga St-19 and G-120 cores and of the Parysów Pa-19 core

Table 1

Lithological description of the St-19 core

Depth [m]	Lithology
0.00–1.50	fine- to medium-grained sands with plant remains
1.50–2.10	sands with gravels
2.10–2.55	well-decomposed peats
2.55–2.60	poorly decomposed peats with an admixture of sands
2.60–2.83	gyttjas with an admixture of fine sands
2.83–4.14	carbonate gyttjas
4.14–4.34	gyttjas with an admixture of fine sands, carbonate-free
4.34–7.20	carbonate gyttjas, sporadic occurrence of mollusc shell fragments
7.20–9.60	carbonate gyttjas
9.60–10.80	carbonate gyttjas with sands
10.80–12.00	silts

Table 2

Lithological description of the G-120 core

Depth [m]	Lithology
0.00–1.19	fine- to medium-grained sands with plant remains
1.19–1.35	fine sands
1.35–1.80	gyttjas with an admixture of medium sands
1.80–2.45	well decomposed peats
2.45–3.70	gyttjas, clayey, carbonate
3.70–4.90	gyttjas, locally silty, carbonate
4.90–5.75	carbonate gyttjas
5.75–8.50	clayey gyttjas

Table 3

Lithological description of the Pa-19 core

Depth [m]	Lithology
0–2.90	sands
2,90–4.14	gyttjas with admixture of fine sands
4.14–7.85	poorly decomposed sedge-moss peats
7.85–8.73	olive gyttjas
8.73–10.89	sedge-moss peat poorly decomposed
10.89–11.95	olive gyttjas
11.95–12.30	no sediment palynology
12.30–13.20	olive gyttjas. gravels at bottom
13.20–14.20	gray silts
14.20–15.70	tills gray

METHODS

POLLEN ANALYSIS

The samples were treated according to standard palynological procedures used in the analysis of lacustrine deposits, i.e. with HCl, KOH, HF and Erdtman's acetolysis (Berglund and Ralska-Jasiewiczowa, 1986). Pollen spectra were counted under a light microscope at a magnification of 400–600x on at least two slides with 18 ×18 mm coverslips. The mean terrestrial pollen count (Arboreal Pollen (AP) + Non-Arboreal Pollen (NAP) = 100%) was 700–800 per sample. The results are shown as percentage pollen diagrams plotted in the *Tilia*IT (Grimm, 2016) and *POLPAL* software (Nalepka and Walanus, 2003) and tables of characteristics of local pollen assemblage zones. The samples in which fossil algae *Pediastrum* and *Botryococcus* were present were counted under a microscope at the same time as pollen and spores to better determine changes in the palaeolake. Each palynological diagram is divided into Local Pollen Assemblage Zones (LPAZs), which are assigned to Regional Pollen Assemblage Zones (RPAZs), according to Mamakowa (1989) and the detailed palynostratigraphic subzones of the Regional Pollen Assemblage Subzones (RPAsZ) proposed by Kupryjanowicz and Granoszewski (2018).

PLANT MACROFOSSIL ANALYSIS

The deposits were first flooded by distilled water with the addition of 10% KOH and then washed through on a 0.2 mm sieve. The generative remains, mainly seeds and fruits, were picked out and then placed in a glycerine-thymol mixture. Then they were recognized using a stereoscopic microscope at a magnification of 10-100x, and counted. The remains were identified with the help of Kats et al. (1965), Grosse-Brauckamnn (1972, 1974), Berggren (1981), Cappers et al. (2006), Velichkevich and Zastawniak (2006, 2008), Mauquoy and van Geel (2007), the collection of macroscopic plant remains at the Faculty of Biology, University of Bialystok, and the collection of macroscopic plant remains at the National Collection of Modern Biodiversity and Fossil Organisms of the W. Szafer Institute of Botany of the Polish Academy of Sciences (KRAM herbarium) in Kraków.

RESULTS

The vegetation development at the Struga site was reconstructed from the results of the St-19 profile (Fig. 3). For the interpretation of the late glacial period of the Saalian glaciation, the Struga G-120 diagram (Fig. 4) was used, in which the thickest late glacial section is represented. For both profiles, an analysis of the plant macrofossils shown in the diagrams was also performed(Figs. 5 and 6).

The vegetation development at the Parysów site was reconstructed from the results of the Pa-19 (Fig. 7) pollen profiles and one plant macrofossil diagram of Pa-19 (Fig. 8). Detailed results of the palynological and plant macrofossils analysis are presented in Tables I–IV in Appendix 1.

HISTORY OF TERRESTRIAL VEGETATION DEVELOPMENT AT THE STRUGA AND PARYSÓW SITES

LATE SAALIAN/ EEMIAN TRANSITION

A long interval of the Late Saalian is recorded in the deposits of the Struga G-120 core. The lithology indicates that biogenic sedimentation in the palaeolake had already started at the time. In the Late Saalian part of the Struga G-120 profile (Fig. 4), three local pollen assemblages zones (LPAZ) were distinguished, presumably documenting minor local vegetation changes from open communities dominated by pine and birch patches (G-120 1 LPAZ), through interstadial-type pine boreal forest communities with a high proportion of birch and patches of herbaceous plants (G-120 2 LPAZ), then again returning to stadial-type communities with a higher proportion of *Artemisia*, Poaceae, Cyperaceae and a lower proportion of boreal trees (G-120 3 LPAZ). The high proportion of NAP, above 22%, indicates the open character of the landscape, where patches of pine-birch communities were present. It can be inferred that the significant proportion of *Pinus sylvestris* t. was related to the long-distance transport of pine pollen in the late-glacial landscape. *Salix* and *Juniperus communis* were present in the open landscape. High herbaceous pollen percentages persist at the Struga site.

On drier habitats, which were occupied by communities with Poaceae, *Artemisia*, Amaranthaceae and *Anthemis* t., *J. communis* continued to occur. However, willow was presumably common in moist habitats occupied mainly by Cyperaceae, with various plants of humid habitats.

In the Late Saalian, in the immediate neighbourhood of the Struga lake, there were sparse rushes, of *Phragmites australis* and *Sparganium* t.. Among the aquatic vegetation, *Nuphar* and other representatives of the Nymphaeaceae were present (Fig. 4).

PROTOCRATIC PERIOD OF THE EEMIAN INTERGLACIAL (E1-E2 RPAZS)

In the St-19 2 LPAZ (corresponding to the E1a RPAsZ), the significant proportion of *P. sylvestris* t. pollen suggests that some pine trees grew *in situ* as shown by the pine stomata recorded in the palynological slides (Fig. 3). At the Parysów site the diagram begins with the Pa-19 1 LPAZ (E1a RPAsZ; Fig. 7), which documents a much lower proportion of *P. sylvestris* t. than at the Struga site.

In the St-19 3 LPAZ (E1b RPAsZ), a significant increase in the proportion of birch pollen (maximum values of *Betula* pollen) may indicate that, in addition to the bearded birch – present in the composition of pioneer birch-pine forests – mossy birch may also have formed birch swamp communities with *B. pubescens* in wetland habitats. This is corroborated by plant macrofossil data, which suggest the occurrence of different birch species. By contrast, the following Pa-19 2 LPAZ (E1b RPAsZ) is well expressed, with high birch pollen percentages. Communities with *B. alba*, *P. sylvestris* t. and *Picea abies* occurred near the banks of the lake at Parysów, as indicated by the presence of their remains (Fig. 8).

Several differences are observable in the development of aquatic and reedswamp vegetation between the two lakes investigated. In the Struga lake, a reedswamp developed, in which sedges appeared next to *Sparganium* t. with *Carex rostrata* and *Typha latifolia*, *P. australis* t. among others. Representatives of the Nymphaeaceae, including *Nuphar*, continued to occur among the aquatic vegetation and *N. marina*.

The Parysów lake was overgrown by rushes of *T. latifolia*, *P. australis* and *Sparganium* t. (Fig. 8). Remains of *Thelypteris palustris, Carex pseudocyperus* and other *Carex* species are also present. Aquatic plant remains of Nymphaeaceae, *Stratiotes* sp., *Potamogeton natans* and statoblasts of *Cristatella mucedo* are abundant.

In the St-19 4 and Pa-19 3 LPAZs (E2 RPAZ) features typical of the developing interglacial succession, such as *Quercus* and *Ulmus*, appear in the palynological diagram (Figs. 3 and 5). The presence of *Ulmus* pollen suggests that floodplain forests with elm and probably oak and occasionally ash were beginning to take shape in the river valleys. The landscape continued to be dominated by birch and pine forests, but it is likely that oak

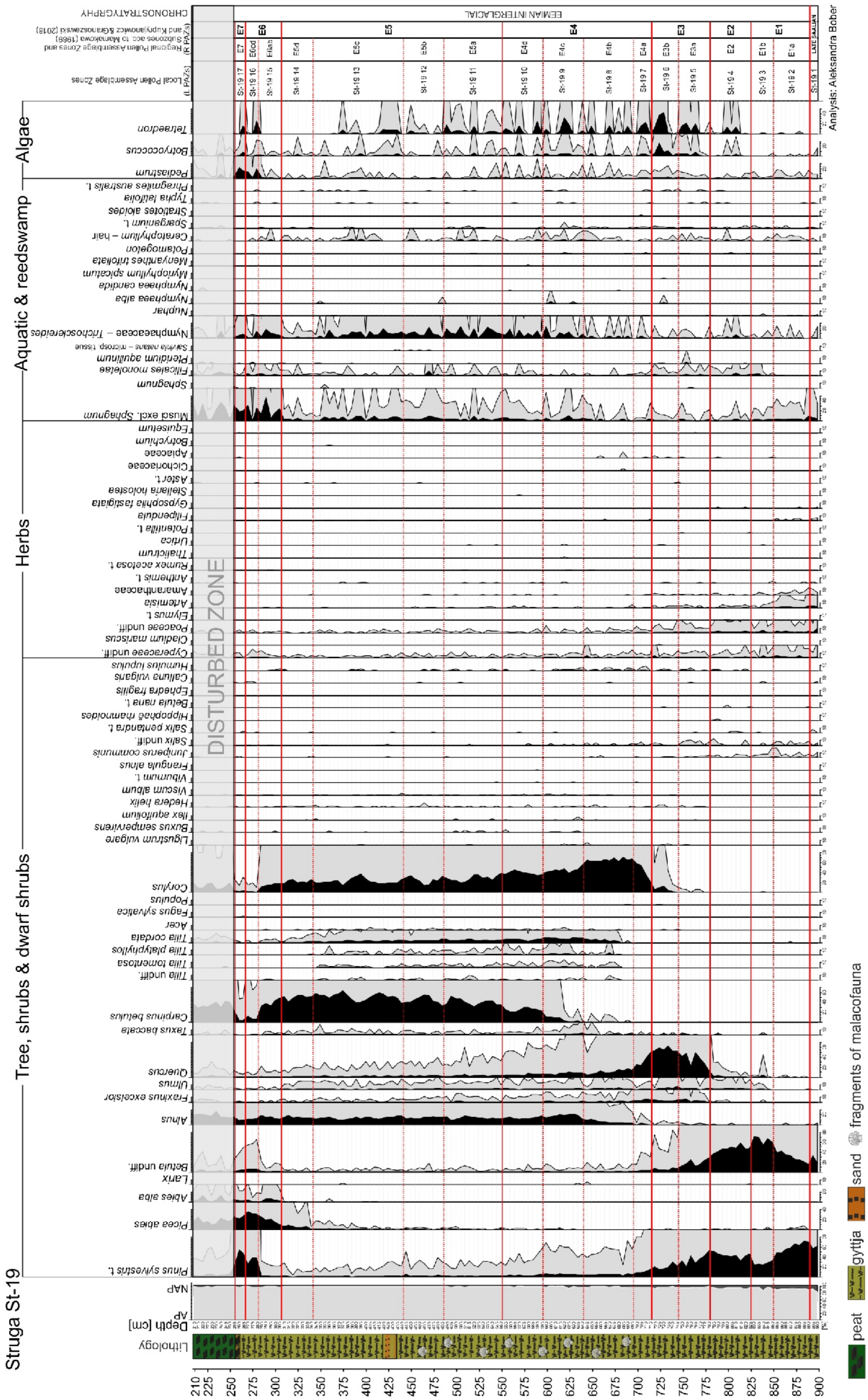

Fig. 3. Pollen diagram of the Struga St-19 core profile

St-19 1–18 – Local Pollen Assemblage Zones, LPAZ; E1–E7 – Regional Pollen Assemblage Zones, RPAZ; LG – late glacial of the Late Saalian glaciation)

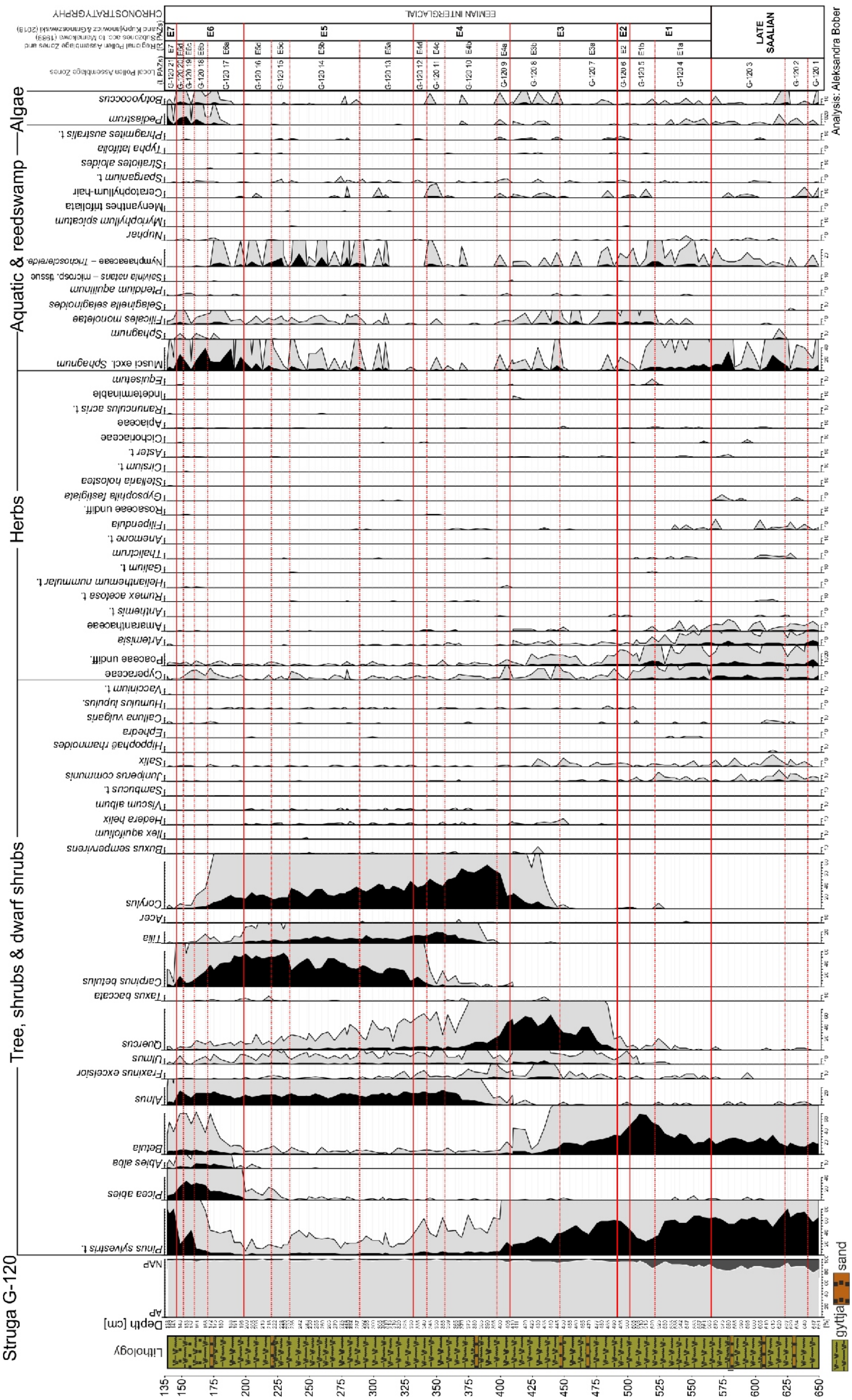

Fig. 4. Pollen diagram of the Struga G-120 core profile

G-120 1–21 – Local Pollen Assemblage Zones, LPAZ; E1-E7 – Regional Pollen Assemblage Zones, RPAZ; LG – late glacial of the Late Saalian glaciation

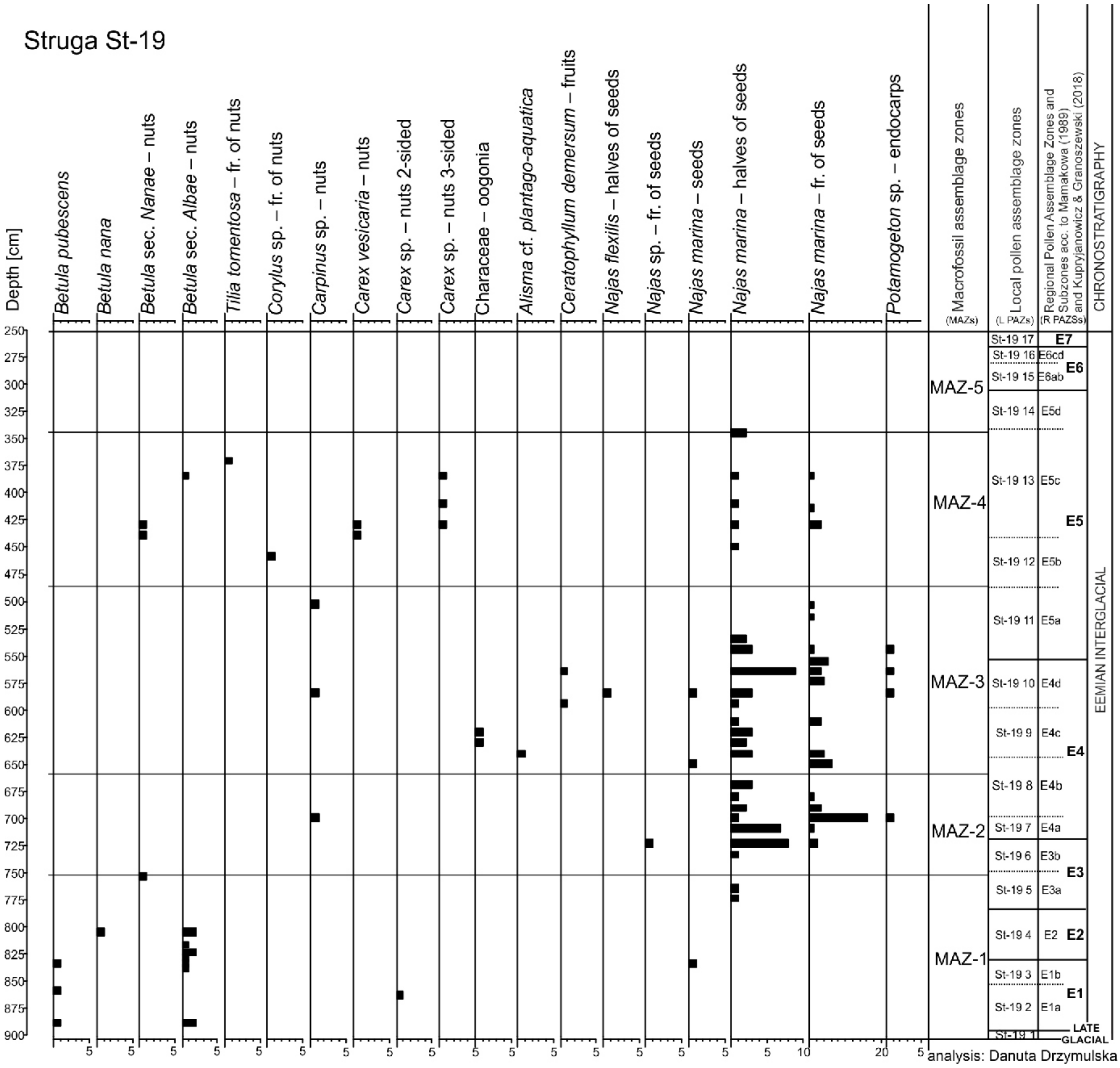

Fig. 5. Local macrofossil assemblage zones (LMAZs) of the Struga St-19 core

was also encroaching. Pollen of tree willow (*S. pentandra* t.) came from moist communities, perhaps associated with the floodplain of the river valley. Hops (*Humulus lupulus*) were present in riparian woodlands.

The delineation of the boundary between the Pa-19 3 and Pa-19 4 LPAZ (E2 and E3 RPAZ) in the Pa-19 profile raises some interpretation problems. Due to the lack of deposits of the beginning of the oak phase of the Pa-19 3 LPAZ (E3a RPAZ), the typical gradual increase in the pollen percentage curve of *Quercus* with a simultaneous decrease in *Betula* and *P. sylvestris* t. was not observed. Instead, there is a sharp change in the pollen spectra, which is marked by a high birch pollen percentage curve, whose curve is sharply truncated, with very high oak pollen values already present in the next sample. The absence of this transition section between E2 and E3 of the RPAZ makes the comparison with the St-19 diagram, in which it is well expressed, difficult. A hiatus is certainly the reason for this situation.

At the Struga and Parysów lakes, the rushes that occurred around the lake were composed of *Sparganium* t., *T. latifolia*, *P. australis* and representatives of sedges. Among the aquatic remains, there were *Ceratophyllum demersum* and representatives of the Nymphaeaceae (trichosclereids). In the pollen diagram Pa-19 (Fig. 4) Nymphaeaceae trichosclereids and *Nuphar* pollen are indicated. Among the remains are *Nuphar*, as well as *Stratiotes aloides* (Fig. 8). The presence of the latter species suggests the existence of a shallow lake.

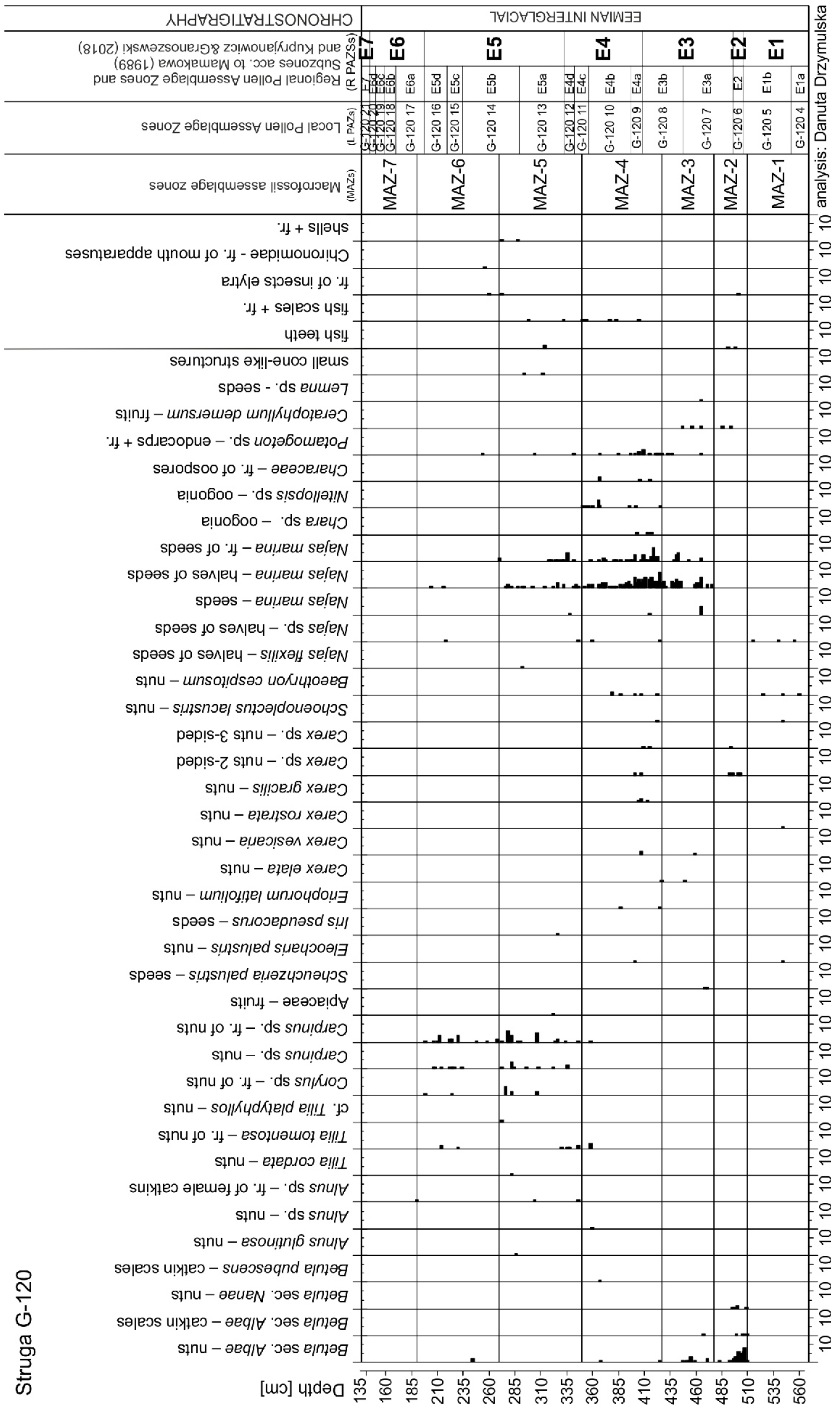

Fig. 6. Local macrofossil assemblage zones (LMAZs) of the Struga G-120 core

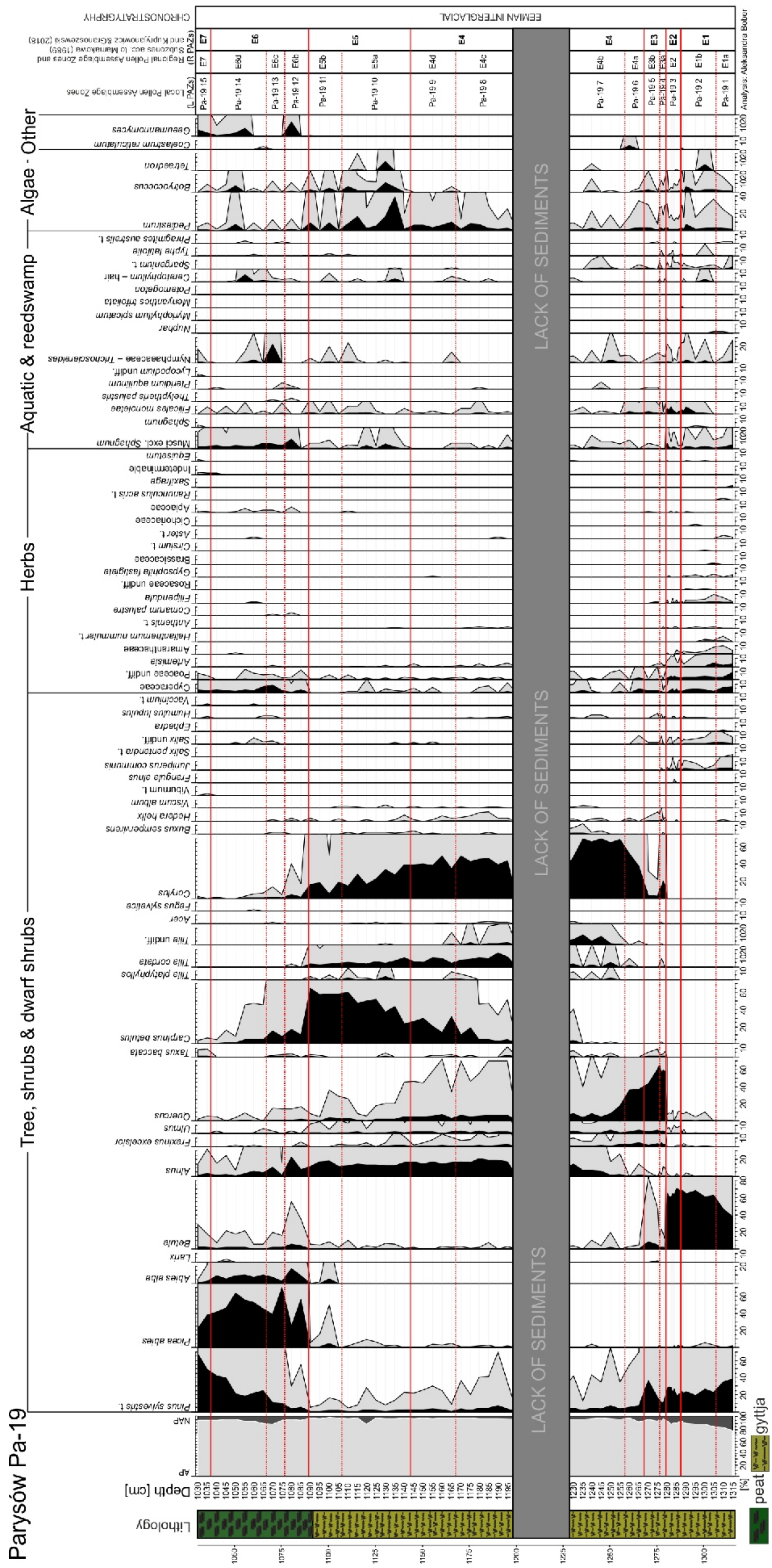

Fig. 7. Pollen diagram of the Parysów Pa-19 core profile

Pa-19 1–15 – Local Pollen Assemblage Zones, LPAZ; E1–E7 – Regional Pollen Assemblage Zones, RPAZ

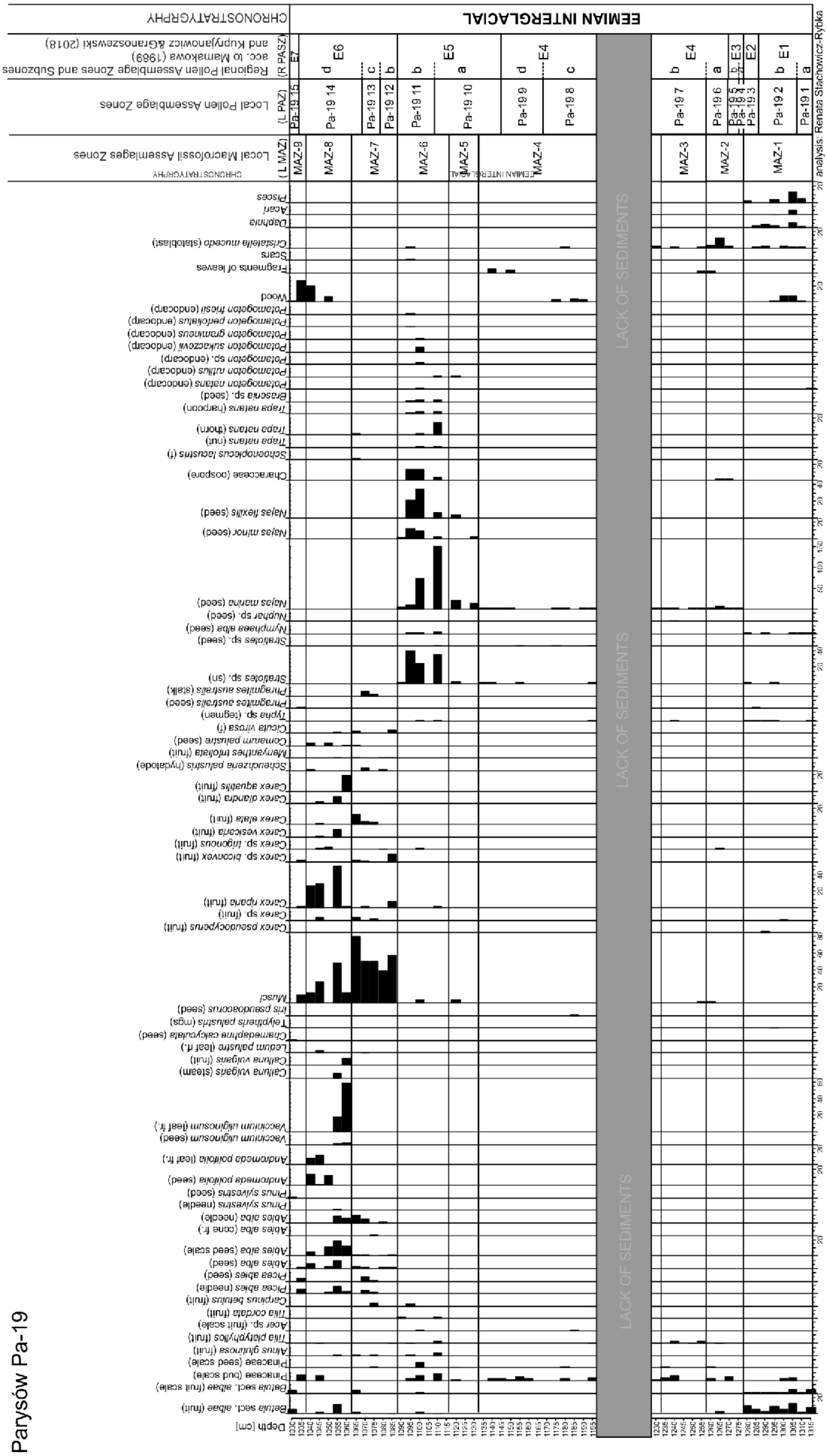

Fig. 8. Local macrofossil assemblage zones (LMAZs) of the Parysów Pa-19 core

MESOCRATIC PERIOD OF THE EEMIAN INTERGLACIAL (E3-E5 RPAZS)

The sharp increase in the proportion of *Quercus* pollen in the St-19 5 and Pa-19 4 LPAZs (E3a RPAsZ) with a simultaneous decrease in the percentage of *Betula* and *P. sylvestris* t. pollen indicates a retreat of the pioneer forest communities dominated by pine and birch in favour of the spreading of oak (Figs. 3 and 5). *Quercus* and *Ulmus* reach their maximum values at St-19 6 and Pa-19 5 LPAZs (E3b RPAsZ), which, together with the significant proportion of *Fraxinus excelsior*, suggests that the riparian communities were converted, presumably, into ash-elm forests with a high proportion of oak developed.

The highest values of these tree species suggest that the riparian forest reached the maximum of its Eemian expansion at this time. Towards the end of this subzone, the percentage of *Corylus* (probably *C. avellana*) increases significantly and continues into the next zone. Hazel probably encroached on drier habitats located at the back of river valleys where birch had previously dominated.

At Struga there were remains including *Scheuchzeria palustris*, *C. elata, C. gracilis*, *C. vesicaria, Eriophorum angustifolium, Scirpus lacustris*. Aquatic remains of *N. marina, N. flexilis, Potamogeton, C. demersum, Lemna,* Characeae and *Nitellopsis* were determined (Fig. 5). At the Parysów site Nymphaeaceae and Characeae were also present (Fig. 8).

In the St-19 7 and Pa-19 6 LPAZ (E4a RPAsZ) a dynamic spread of hazel is observable, with oak pollen values remaining high while hazel, initially presumed to occur at the edges of oak forests, also appeared more frequently in their undergrowth and in forest clearings (Figs. 3 and 5). Hazel reaches its maximum in the St-19 8 and Pa-19 7 LPAZ (E4b RPAsZ), with frequencies of ~70%. After the *Corylus* maximum, the proportion of *Carpinus* gradually increases in the pollen diagram. Fruits of the common hornbeam (*Carpinus betulus*) determined during plant macrofossil analysis at the Parysów site, testify to its presence in situ (Fig. 8). In the St-19 9 LPAZ and Pa-19 8 LPAZ (E4c RPAsZ), lime, of at least three species, begins to play an important role. Pollen of *Tilia cordata*, *T. tomentosa* and *T. platyphyllos* was recorded. Fruits of these lime species were also determined in the plant macrofossil record. In the St-19 10 LPAZ and Pa-19 9 LPAZ (E4d RPAsZ), a high proportion of lime pollen together with an already significant proportion of hornbeam and oak were noted. In riparian and oak-hornbeam communities, *Acer* and *Taxus baccata* were also present, besides *Quercus, F. excelsior* and *Ulmus*. With an increase in the percentage of *Corylus* in the pollen diagram, an increased proportion of *Alnus glutinosa* appears (a cone fragment was noted in the plant macrofossil analysis). The presence of *T. baccata* pollen, together with high proportions of *Alnus glutinosa* and the presence of *Hedera helix*, *Viscum album*, *Buxus sempervirens* and *Ilex aquifolium*, are clearly features of an oceanic climate. The increasing pollen values of *Alnus glutinosa* testify to the encroachment of alder into humid areas, where it may have formed alder forests in poor habitats and in undrained depressions, as well as alder-ash forests in river valleys. The minimal proportion and low diversity of herbaceous plants indicate that open communities were very limited.

At the Struga site, plant macrofossils indicate that the rushes zone included *Scirpus cespitosus*, sedges with *C. vesicaria* and *C. gracilis*, *P. australis*, *Sparganium* t. and *T. latifolia*. *Stratiotes aloides* and *Eleocharis palustris* appeared. *N. marina* and *N. flexilis* dominated among the aquatic vegetation. *Potamogeton*, *C. demersum*, Characeae and *Nitellopsis* and numerous nymphaeids were also abundant in the lake (Figs. 5 and 6). *Alisma plantago-aquatica* appeared (Fig. 5). Various species of green algae of the genera *Pediastrum, Botryococcus* and *Tetraedron* are also present in the pollen diagram (Fig. 3). Trichosclereids of Nymphaeaceae, *Ceratophyllum* hairs and pollen of *Sparganium* t., *P. australis* t. and *T. latifolia* come from the reed vegetation belt in the Parysów palaeolake (Fig. 7). In addition, the plant macrofossil diagram confirms the presence of aquatic plants, including *Stratiotes* sp., *N. marina* and *Iris pseudoacorus* in the coastal zone (Fig. 8).

In the St-19 11-14 and Pa-19 10-11 LPAZs (E5 RPAZ), pollen percentages of *Carpinus betulus* increase significantly, while the proportion of *Corylus* decreases. The hazel scrub habitats were probably covered by an expansion of hornbeam forests, while hazel was still abundant as an admixture at the edges of the fertile forests (a significant amount of hazel nuts was determined). In the initial part of the St-19 11 L and Pa-19 10 LPAZs (E5a RPAsZ), an increase in the percentage of *C. betulus* is evident, representing the beginning of the formation of hornbeam-oak - forests dominated by hornbeam with a small admixture of other trees, including lime (with presence of plant macrofossils). The presence of this species at the Parysów site is confirmed by hornbeam fruiting bodies (Fig. 8). Though there were large changes in the hornbeam-dominated forests, the alder forests seemed remain stable. *Alnus* pollen percentage values remained stable, suggesting that they formed separate communities probably of the alder type. By contrast, the decreasing proportion of *F. excelsior* pollen in the younger part of the zone may indicate a less important role of alder-ash riparian forests in the landscape.

In the St-19 12 LPAZ (E5b RPAsZ), the percentage values of *Corylus* continue to decrease, while those of *C. betulus* increase (Fig. 3). This shows that hornbeam was quickly taking over areas previously occupied by hazel scrub. A continuous percentage curve of *P. abies* appears. Initially, spruce may have appeared as an admixture in moist forests, e.g. in alder forests it may have entered the stand as a result of natural succession (Fig. 3). In the Pa-19 11 LPAZ (E5b RPAsZ), *C. betulus* reaches its maximum throughout the profile, while hazel and lime decrease their contribution (Fig. 7). Single pollen grains of *P. abies* and *Abies alba* appear (Fig. 7). Their pollen may possibly come from spruce and fir encroaching on alder and other types of moist forest.

In the St-19 13 LPAZ (E5c RPAsZ) *C. betulus* reaches its maximum. The abundant hornbeam may have formed independent, monospecific stands during the Eemian interglacial. The pollen percentages of *Corylus* and *Quercus* gradually decline, and the percentage of *Tilia* remains very low. *Alnus* pollen percentages remain stable, suggesting that alder trees continued to occur on previously occupied habitats.

In the St-19 14 LPAZ (E5d RPAsZ), continuing high percentages of *C. betulus* in the pollen diagrams document the important role of hornbeam-dominated communities. With the decrease in the proportion of lime and elm in the pollen diagram, not only an increase in the proportion of spruce is observed, but also the appearance of fir and pine pollen and the increasing presence of birch pollen. Possibly, the pollen comes from spruce and fir encroaching on alder and other types of moist forest. Riparian communities did not undergo such a radical metamorphosis as did the dry-ground forests. In the middle part of the Eemian interglacial, taxa such as *H. helix*, *V. album*, *I. aquifolium* and *B. sempervirens*, whose presence is closely linked to the prevailing warm and humid climate, still play an important role.

The boundary between the Pa-19 10-11 and Pa-19 12-14 LPAZs (E5 and E6 RPAZs) is difficult to interpret due to the absence of transitional subzones characteristic of the Eemian interglacial, associated with the gradual encroachment of spruce, E5c-E5d and E6a RPAsZ in the pollen diagram (Fig. 7). The absence of sediments recording these subzones may indicate rapid changes in the lake. Presumably, the lake became shallow and organogenic sediments were not deposited for some time. Re-establishment of the lake took place in the late Eemian, which includes the regional E6 and E7 RPAZs.

Among the vegetation of the Struga lake, remains of *Iris pseudoacorus*, sedges of *C. vesicaria* and pollen of *P. australis* t., *Sparganium* t. and *T. latifolia* were recorded. Remains of *N. marina* and *N. flexilis*, *Potamogeton* and pollen of *Nuphar* and other nymphaeids are still abundant. The tissue of a microsporangium of *Salvinia natans*, an aquatic fern growing on the surface of eutrophic lakes, was noted, in addition to pollen of *Menyanthes trifoliata*, which may grow on the margins of overgrown tidal flats, and pollen of *Stratiotes aloides*, which may also indicate shallowing of the lake, as well as various species of green algae of the genera *Pediastrum*, *Botryococcus* and *Tetraedron*.

Remains of *C.* sp. *trigonous* and *C. riparia* were recorded in the Parysów lake (Fig. 8). Taxonomically diverse aquatic plants were also recorded: pollen of *Stratiotes* sp, *Nymphaea* alba, Nymphaeaceae trichosclereids, *C. demersum* hairs, *Najas (N. marina, N. minor, N. flexilis)* macrofossils and *Potamogeton* (*P. natans, P. rutilus, P. sukaczevii, P. gramineus, P. perfoliatus, P. friesii*) and other *Potamogeton* sp. macrofossils (Figs. 5 and 8). In addition, a very rich spectrum of macrofossils includes the presence of *Trapa natans*, *Brasenia* sp. and Characeae oospores. Statoblasts of *Cristatella mucedo* were also recorded. The rushes included *T. latifolia* and *Sparganium* t.

TELOCRATIC PERIOD OF THE EEMIAN INTERGLACIAL (E6–E7 RPAZS)

From the beginning of the telocratic period of the Struga site St-19 15-16 LPAZ (E6 RPAZ), the pollen percentages of pine trees increase. In the St-19 15 LPAZ (E6ab RPAsZ) continuing high pollen percentage values of *C. betulus* and *A. glutinosa* are recorded, as well as the presence of *Corylus*, *Tilia*, *Quercus* and *Ulmus*. Remains of *C. betulus* and *A. glutinosa* were recorded in the upper part. These are the last recorded plant macrofossils at the site. This indicates that the hornbeam forest refuges were shrinking, with fir, oak and spruce being the main components, in addition to hornbeam.

The absence of the regional subzone E6a RPAsZ in the pollen diagram in the Pa-19 profile is equivalent to the absence of a record of the period of spruce encroachment into hornbeam-dominated communities. What is preserved, however, is a record of the Pa-19 12 LPAZ subzone corresponding to E6b RPAsZ. Here, the percentage of pollen of *C. betulus* decreases sharply, while the percentage of pine trees increases. The St-19 16 LPAZ (E6cd RPAsZ) is dominated by *P. sylvestris* t. pollen and maximum values throughout the profile are reached by *Abies alba*, followed by *P. abies*, with a decrease in the percentage of *C. betulus* pollen. The maximum values of spruce indicate its wide spread in forests. Spruce also encroached on alder habitats transforming them into alder-spruce communities and then into swamp spruce forests. Areas of ash and alder riparian forests may have declined. This is indicated by the very low pollen percentages of *F. excelsior*. These were probably replaced by alder-spruce communities. A significant role was gradually taken over by pine, creating pine-spruce and pine forests, which became the dominant communities at the end of the interglacial.

In the Pa-19 13 LPAZ (E6c RPAsZ) the maximum is reached by *P. abies*. This may indicate that spruce encroached on alder habitats and converted them into swampy spruce and spruce-alder forests. Areas of ash and alder riparian forests may also have declined. This is indicated by the very low pollen percentages of *F. excelsior*. It is likely that these were replaced by alder-spruce communities. In the Pa-19 14 LPAZ (E6d RPAsZ), pollen of trees such as *P. sylvestris* t., *P. abies* and *Abies alba* strongly dominated, suggesting a widespread occurrence of coniferous forests. Depending on the moisture content of the habitat, these were pine-spruce or spruce-pine forests with fir admixture, locally also with willow admixture. Single pollen grains of beech and larch may suggest the presence of these trees in the communities at that time. The spruce zone is recorded in peat deposits. Plant macrofossils in this zone include numerous remains of trees such as *B. alba*, *A. alba*, *P. sylvestris* t., *C. betulus*, *T. platyphyllos*, *A. glutinosa* and *P. abies*, hence present in situ from the start.

The vegetation of the Struga lake margins was *P. australis* t., *Sparganium* t. and *T. latifolia*. *Sphagnum* and Musci also appear. Nymphaeids with *Nuphar* and *C. demersum* are present among the aquatic vegetation, and the proportion of *Pediastrum* and *Tetraedron* increases significantly. In the palynological diagram of the Parysów lake *P. australis* t. and *T. latifolia* also were noted. Among the plants growing on the banks of the lake, *Andromeda polifolia* and *Vaccinium uliginosum*, *Calluna vulgaris*, *Ledum palustre*, *C. riparia*, *C.*sp. *biconvex*, *C.* sp. *trigonous* and *C. elata*, *Scheuchzeria palustris*, *Menyanthes trifoliata*, *Comarum palustre*, *Cicuta virosa* and *P. australis* t. and *T. latifolia* were present in large numbers. Among the aquatic vegetation, Musci, Filicales monolete and single remains of *Schoenoplecus lacustris* and *Trapa natans* were recorded.

In the Struga St-19 and G-120 profiles, the E7 RPAZ zone comprises a thin sedimentary interval. In the G-120 21 LPAZ profile (E7 RPAZ), maximum percentages are reached by pollen of *P. sylvestris* t. (up to 80%).

The Pa-19 15 LPAZ (E7 RPAZ) at the Parysów site is represented only by two samples (5 cm of peat). Maximum values are reached by *P. sylvestris* t., with continuing high percentages of *P. abies* pollen and the presence of *A. glutinosa*. This may indicate a strong expansion of spruce and, presumably, spruce also with alder in the form of patches of moist spruce-alder communities. Only single pollen grains of thermophilous trees were recorded. Terrestrial vegetation macrofossils are represented by pine tree remains and *Chamedaphne calcyculata*. Musci, *C. riparia*, *C.* sp. *biconvex*, *C. diandra* and *P. australis* are also present. In the Struga lake, continued presence of *Nuphar* pollen, and significant proportions of Nymphaeaceae trichosclereids, document the survival of a water body with higher water levels than in the previous E6 RPAZ. Aquatic plant macrofossils were not recorded at Parysów.

DISCUSSION

THE LATE SAALIAN SECTION OF THE G-120 PROFILE AND THE LOWER BOUNDARY OF THE EEMIAN INTERGLACIAL

Comparison of the palynological results from the G-120 profile at the Struga site (Fig. 3) with those from the Wola Starogrodzka G-122 profile from the Garwolin Plain (Kupryjanowicz et al., 2021) allows identification of the lower boundary of the interglacial at a decrease in the values of NAP, *J. communis* and *Salix* and an increase in *P. sylvestris* t. pollen together with a relatively high share of *Betula*. This boundary was similarly interpreted by Mamakowa (1989). In the pollen spectrum of the Struga G-120 profile, the considerable share of herbaceous plants, dominated by *Artemisia* (up to 8%) and Cyperaceae (up to 9.5%) and substantial share of Poaceae (11%) point to the open character of the landscape with shrubs with *J. communis* and *Salix*. The small share of pollen of *P. sylvestris* t. suggests that the northern boundary of the forest ran south of the Garwolin Plain. The percent values of pollen of these taxa are usually within the ranges marked on Eemian isopollen maps for the Late Saalian. This is exemplified by the pollen diagram of Warszawa Wawrzyszew XV (Krupiński and Morawski, 1993) with values of *Artemisia* (6%), similar to those shown in the diagram for Struga G-120. In central Poland, the values are ~7–10% (Kołaczek et al., 2018b), although the highest shares of *Artemisia*, reaching 20%, were recorded in the Rzecino profile in north-western Poland (Winter et al., 2008).

In the Struga G-120 diagram, the share of Poaceae (7–10%) does not deviate from values recorded over most of Poland (Fiłoc et al., 2018). Exceptions are sites from the north-central sector of the lowland belt, where up to 20% of Poaceae pollen was recorded in diagrams of the Late Saalian glacial. This is exemplified by the diagram from the Studzieniec site (Krupiński, 2005; Mirosław-Grabowska and Niska, 2007a). At the same site, shares of pollen of *J. communis* reach 7% and are among the highest (Krupiński, 2005; Kupryjanowicz et al., 2018c), whereas in the pollen diagram of Struga G-120 they reach 2%, similarly to many other diagrams covering the end of the Late Saalian (Kupryjanowicz et al., 2018c).

High July temperatures are also corroborated by the presence of *T. latifolia* in some profiles from the Garwolin Plain. At the Struga St-19 site, its presence may suggest that during mean air temperature in July in the region was ~+14°C (Väliranta et al., 2015). Similar inferences may also be drawn from the presence of *T. latifolia* and *Nymphaea* in Wola Starogrodzka G-122 (Kupryjanowicz et al., 2021).

In the vicinity of the Wola Starogrodzka G-122 and Struga G-120 profiles, other palynological diagrams from the Garwolin Plain document a much weaker, or even missing, late glacial section. Due to this, both the paper by Kupryjanowicz et al. (2021), and data from the Struga G-120 profile contribute valuable new palynological and palynostratigraphic data regarding the Late Saalian, allowing discussion regarding the opinion of Turner (2002) that no climatic oscillations analogical to the younger Dryas should be expected at the beginning of the Eemian.

In the context of the results at Wola Starogrodzka G-122, the G-120 pollen diagram from Struga presumably records only part of an older (un-named) stadial, followed by the Zeifen interstadial and Kattegat stadial. The record of these stadial-interstadial-stadial fluctuations is contained in zones Struga G-120 1-3 LPAZ. In the Greenland GRIP ice core, the MIS-6/MIS-5e transition also showed three fluctuations visible in ^{18}O data (e.g., Dansgaard et al., 1993; Landais et al., 1993). Kupryjanowicz et al. (2021) provide examples of stadial-interstadial fluctuations detected in palynological diagrams, e.g. Les Echets (de Beaulieu and Reille, 1989), and in the north of Europe at the Suur Prangli site in the Gulf of Finland (Liivrand, 1974; Raukas, 1978) and at the Danish site Anholt II, where a phenomenon similar to the Zeifen-like interstadial was described (locally called the Flakket Interstadial). In the same paper, the subsequent cool period was called the Kattegat Stadial (Seidenkrantz, 1993).

When reconstructing the probable course of vegetation changes during the Late Saalian on the Garwolin Plain, Kupryjanowicz et al. (2021) suggested that the first, unnamed period of the stadial involved the occurrence of a mosaic of tundra and cold steppe documenting relatively low temperatures in both summer and winter months. In the interstadial correlated with the Zeifen, the lake catchment was stabilised by dense vegetation (pine-birch forest with spruce). In the following stadial, correlated with the Kattegat, forest assemblages slightly decreased in area. Kupryjanowicz et al. (2021) suggested another probable cause for a decrease in tree pollen values in the stadial: reduced production of pollen in cold periods. This causes lower shares of a given tree in the pollen spectrum. Both causes, namely a reduction of the forest area and a decrease in tree pollen production, may have operated.

In comparison to other sites of the Eemian interglacial in Poland, the pollen diagram from the Struga G-120 site does not document a large percent share of pollen of *Hippophaë rhamnoides* and *J. communis,* as at the nearby Warszawa-Wawrzyszew XV site (Krupiński and Morawski, 1993) or of shrubs (e.g., *Betula nana*); although largely dependent on the local conditions, these undoubtedly represented the cold period together with with vegetation typical of steppe tundra.

Another issue is the share of *Picea obovata* in vegetation at the MIS6/MIS5e transition. Its presence was recorded in the plant macrofossil diagram from the Szwajcaria (Borówko-Dłużakowa and Halicki, 1957) and Ludomirowo (Bitner, 1957) sites, and in profiles from the Northern Podlasie (Kupryjanowicz, 2008).

It represents the so-called lower spruce zone (Mamakowa, 1989). Eastern Europe is probably the western boundary of occurrence of the species, with high abundances recorded in forest assemblages of the Siberian taiga (Tollefsrud et al., 2015). Therefore, reconstruction of the ranges of taiga species must involve the identification of macrofossils of *P. obovata*. This is still an open issue because despite the determination of the occurrence of spruce pollen in palynological diagrams at various sites (including at the Warszawa-Wawrzyszew site), it was not possible to identify whether it is of *P. obovata*. This and many other sites lack plant macrofossil analyses. It therefore cannot be directly determined whether this taxon occurred in the plant assemblages of central Poland during the late glacial of the Saalian, or whether its presence was limited to north-east Poland.

In this context, sites from the Garwolin Plain are similar to sites from central Poland such as Warszawa-Wawrzyszew XV (Krupiński and Morawski, 1993) and Parchliny (Wachecka-Kotkowska et al., 2018). Changes evident in the former profile were correlated by Kupryjanowicz et al. (2021) with the Zeifen stadial-interstadial alternation (Jung et al., 1972; Beug, 1973) and Kattegat (Seidenkrantz, 1993).

In the case of the Parchliny profile at the end of the Saalian glacial, a considerable share of NAP occurs (primarily *Artemisia* and Poaceae) together with *J. communis* and a substantial share of *P. sylvestris* t. The palynological analysis at Parchliny probably did not encompass the stadial-interstadial section.

In the south-western part of Poland, the Imbramowice profile (Mamakowa,1989) also shows the MIS 6/MIS 5e boundary. Assemblages of this interval mainly include non-forest shrubs with *J. communis, Salix herbacea*, and *Betula nana*. Herbaceous vegetation forming open assemblages primarily includes Cyperaceae, Poaceae, *Artemisia*, and Amaranthaceae (=Chenopodiaceae) (Mamakowa, 1976). The plant macrofossil analysis did not confirm the occurrence of *Picea obovata*. Later studies on the sites with with Late Saalian glacial, e.g. Parchliny (Wachecka-Kotkowska et al., 2018) and Dziewule (Bińka and Nitychoruk, 2001), also document a different character of vegetation at the beginning of the Eemian interglacial. They do not, however, include discussion regarding the potential occurrence of *P. obovata.*

EEMIAN VEGETATION AND CLIMATE CHANGES

In the E1 RPAZ, the expansion of boreal birch-pine forests at the beginning of the interglacial suggests an increase in air temperature. Pollen and fragments of birch macrofossils point to the occurrence of at least three species: the tree birches *B.* sect. Albae, *B. pubescens*, and the dwarf birch *B. nana*. Results of palaeobotanical research are in line with the synthetic image known from isopollen maps, documenting the maximum range of *Betula* in the E1b subzone (Balwierz et al., 2018). The broad expansion of tree birches in the protocratic stadium of the Eemian interglacial was related to low ecological requirements of the taxon. The occurrence of *B. alba* was related to mineral and moist soil, and *B. pubescens* primarily prefers a mesotrophic and humid, periodically flooded environment (Zarzycki et al., 2002). There was still a considerable share of open assemblages with Cyperaceae, Poaceae, and *Artemisia*. The occurrence of the birch species noted suggests that both in summer and winter, mean temperatures were higher than at the end of the late Saalian, and in July probably exceeded +12–13°C (Granoszewski, 2003), and the presence of *T. latifolia* suggests that the mean temperature in July may have oscillated around +14–15°C (Väliranta et al., 2015).

Changes observed in the palynological diagrams in the E2 RPAZ at the sites analysed reflect encroachment of new species to the assemblages. Next to still-abundant *P. sylvestris* t. and *Betula*, taxa such as *Ulmus*, *F. excelsior* and *Quercus* appeared. Granoszewski (2003) observes that along with elm, pedunculate oak (*Q. robur*) may have appeared at the beginning of the interglacial, as a tree better adapted to wet habitats than the sessile oak (*Q.* sessilis) and finding suitable habitat conditions on river valley terraces. Their introduction occurred through expansion in river valleys, where riparian forests started forming. Due to its broad tolerance to environmental conditions (e.g., temperature, humidity, content of soil mineral elements, light accessibility; *vide* Zarzycki et al., 2002), *Ulmus* appears strongly in palynological diagrams from the Eemian interglacial already at the end of the E2 RPAZ. This is consistent with isopollen maps, where Eemian expansion of elm starts from the east, and then from the north- and south-east (Granoszewski et al., 2018).

The expansion of *Ulmus* suggests that mean temperature in July was at least +16°C (Granoszewski, 2003). The occurrence in the E2 RPAZ at Struga of the thermophilic fern *Salvinia natans* suggests mild winter temperatures, not much below 0°C (Święta-Musznicka et al., 2011).

The beginning of the mesocratic period saw strong expansion of oak, which encroached onto habitats previously occupied by pine and birch, and expanded farther along river valleys together with elm, creating an elm-ash riparian forest with a high share of oak (*Q. robur*). In this zone, riparian forests of *Ficario-Ulmetum campestris* type show their maximum expansion. This is related to the ecological tolerance of oak which, despite considerably higher thermal requirements than pine or birch, copes well with both low temperatures in winter and snowmelt in spring (Kupryjanowicz et al., 2018d). Among the profiles analysed, the highest share of oak (65.5%) was recorded at Parysów, in the Pa-19 5 LPAZ corresponding with E3b RPAZ. The analysis of isopollen maps shows similar values of oak pollen over much of Poland. In palynological diagrams, marked expansion of oak is recorded at the beginning of the E3a subzone, and in the following E3b subzone it reaches its maximum values, locally exceeding 70% (Kupryjanowicz et al., 2018d).

Like oak, ash also reached its maximum values of up to 5% in the E3b subzone in profile St-19, as also seen on isopollen maps. Common ash encroached onto the territory of Poland from the south, and its strong expansion occurred in the E3b subzone from the south-east (Kołaczek et al., 2018a).

The presence of *V. album* in the E3 RPAZ suggests mild winters, and *I. aquifolium* additionally points to mean temperatures in January of ~~0°C and in July of +16°C (Iversen, 1944). This additionally shows a climate with more oceanic properties. At the end of the E3 RPAZ, pollen diagrams from the analysed sites begin to show a higher share of hazel. On isopollen maps (Kupryjanowicz et al., 2018b), the share in the E3b subzone reached up to 15% in the central and southern parts of Poland, e.g. in Ustków (Kołaczek et al., 2012).

In pollen spectra, the presence of *Ligustrum vulgare* corroborates a warm and mild climate (Środoń, 1989). Moreover, the aquatic taxa *Nuphar* and *N. marina* point to an even higher mean temperature in July, reaching up to +17°C (Mamakowa, 1997, after Granoszewski, 2003).

Pollen spectra for the Struga and Parysów profiles resemble those of the remaining sites on the Garwolin Plain. In profiles from Kozłów (Pidek et al., 2021; Suchora et al., 2022), Żabieniec (Pidek et al., 2022), and Jagodne (Bober et al., 2021), the E3 RPAZ is characterised by maximum shares of *Quercus* and *F. excelsior,* as well as encroachment of taxa of consecutive succession stages related to the development of climax forests in valleys and drier habitats.

The E4 RPAZ is related to broad expansion of *Corylus*. Kupryjanowicz et al. (2018a) noted that isopollen maps document the appearance of hazel already in the Late Saalian and at the beginning of the interglacial. This is related to the occurrence of its refuges in the north-western part of Europe, but its proper introduction in the Eemian interglacial occurred from the south. A high share of *Corylus* in palynological diagrams suggests that hazel grew not only in the forest underbrush, but developed expansive hazel thickets. This is also corroborated by the ecological requirements of *Corylus avellana* that show the preference of hazel for growth in full sun, and not under a canopy of other trees (Kupryjanowicz et al., 2018b). This image of *Corylus* on the Garwolin Plain accords with the record on isopollen maps, suggesting maximum shares of hazel of ~70% in sub-zone E4b RPAsZ (Kupryjanowicz et al., 2018b). Maximum expansion of *Corylus* determines the beginning of the climatic optimum of the interglacial.

Next to the expansion of hazel, an important taxon from the point of view of climatic reconstructions is *Tilia*. Both in pollen and plant macrofossil data, at the Struga and Parysów sites, more than one species of lime tree was recorded. The occurrence of *T. cordata*, *T. tomentosa*, and *T. platyphyllos* was observed, suggesting that the mean temperature in January was in the range 0–5°C, and mean temperature in July exceeded +21°C (Mamakowa, 1989; Granoszewski, 2003).

Nuts of *T. platyphyllos* and *T. tomentosa* recorded at the Hieronimowo site (Kupryjanowicz et al., 2018f) help determine the palaeotemperature. *T. tomentosa* currently occurs on the Balkan Peninsula (Kupryjanowicz et al., 2018b), which suggests that in the E4 RPAZ, the mean July temperature did not fall below +21°C, which is~2.3°C higher than the current mean temperature in the region of ~+18.7°C (IMGW, 2022). Lime culminates after the maximum of hazel. Its maximum share in palynological diagrams (12–20%) for the Struga and Parysów sites occurs in subzone E4c. This is in line with the pattern of expansion of lime according to the Eemian isopollen maps, showing that its expansion into Poland occurred from the west, and its culmination (25%) occurs in subzone E4c RPAsZ (Kupryjanowicz, et al., 2018). At of other sites, e.g. Kozłów (Suchora et al., 2022), Żabieniec (Pidek et al., 2022) and Jagodne (Bober et al., 2021) on the Garwolin Plain, lime reaches its maximum values in the older part of zone E4 RPAZ.

Sites on the Garwolin Plain correspond with variant “B1”, where lime is introduced to forest assemblages early and culminates late, after the hazel maximum (Mamakowa, 1989). The situation is repeated at other sites on the Garwolin Plain. Variant B1 is documented by palynological diagrams from Kozłów (Pidek et al., 2021; Suchora et al., 2022), Żabieniec (Pidek et al., 2022), Jagodne (Bober et al., 2021; Pidek et al., 2022) and Wola Starogrodzka (Kupryjanowicz et al., 2021).

In the profiles analysed, *Alnus* reaches its maximum values of 19.5–25.5% in the E4c subzone. This pattern accords with isopollen maps suggesting encroachment of *A. glutinosa* into Poland from the north-west in the E4 RPAZ, and reaching its maximum values in subzone E4c (15–25%; Pidek et al., 2018a).

The frequent occurrence at all the sites analysed of *H. helix*, *I. aquifolium* and *T. baccata* indicates oceanic climatic conditions. The maximum expansion of these taxa is also seen on isopollen maps (Kupryjanowicz et al., 2018a).

The E5 RPAZ is related to the *C. betulus* maximum in forest assemblages. The palynological data from the Struga site suggest that its culmination occurred in the E5c subzone. In the case of Parysów, hornbeam culminates in sub-zone E5b RPAZ. Hence, there is no representation of the upper part of the hornbeam zone and the lower part of the spruce-fir zone (E6 RPAZ). For these sites, the *C. betulus* culmination reached 57–60%.

The presence among macrofossils of *T. tomentosa* and *T. platyphyllos* fruits suggests that minimum temperature of the warmest month at the beginning of the hornbeam phase were still the same as in the previous hazel phase. The climate was very warm and humid, strongly oceanic, as suggested by several indicator taxa (*H. helix*, *T. baccata*, *B. sempervirens*, *Ligustrum vulgare* and *I. aquifolium*). An increase in total annual precipitation is indicated by the growing share of pollen of *P. abies* and the constant presence of *Abies alba* pollen in the younger part of the E5 RPAZ. Pollen diagrams from all sites also suggest a high share of hazel.

According to the isopollen maps, the expansion of *C. betulus* in Poland is coherent with that of hornbeam and hazel in the Eemian pollen diagrams from the Garwolin Plain. Hornbeam encroached from many directions, and its proper migration began from the south-west in the E4b subzone. In subsequent subzones, hornbeam encroached from both the east and west, and reached the maximum values (up to 70%) in the E5c subzone (Pidek et al., 2018b), whereas the highest values were recorded in diagrams from the east and north-east Poland, e.g. Horoszki Duże (Granoszewski, 2003), Starowlany (Kupryjanowicz, 2008) and Hieronimowo (Kupryjanowicz et al., 2018f).

The percentage shares of hornbeam at the Struga and Parysów sites are similar to those determined at other sites on the Garwolin Plain. At Kozłów in profiles K2-19 and K-0, the share is 67.5% and 50%, respectively; at Żabieniec Ża-19 and Ża-0, its share is approximately 40%, and in the Jagodne profiles Ja-19 and Ja-0 it is >50% (Hrynowiecka et al., 2020; Bober et al., 2021; Pidek et al., 2021, 2022; Suchora et al., 2022).

Results from the sites analysed correspond with previous opinion that the end of the hazel phase and beginning of the hornbeam phase were the warmest and most humid periods of the Eemian interglacial.

In the E6 RPAZ, the consequent increase in the percentage share of spruce and fir in palynological diagrams, with a simultaneous decrease in the percentage share of the thus-far dominant deciduous trees, points to a much cooler period. Strong expansion of coniferous trees in the E6a subzone, where *Abies alba* culminates first, followed by *P. abies* in subzone E6b RPAZS, accords with isopollen maps (Kupryjanowicz and Granoszewski, 2018b). Proper introduction of fir into tree assemblages began in the E5d subzone. It encroached from the south-west through the Sudetes and the Moravian Gate, and constituted one of the primary forest-forming trees in this part of Poland, unlike in the north-eastern part, where its share is low. This taxon in Poland in the Eemian interglacial extended considerably farther north than currently (Obidowicz et al., 2004). The maximum share of fir was recorded in the Parysów palynological diagram Pa-19, reaching 17.5%, similar to those at sites in central Poland, e.g. Kaliska (Janczyk-Kopikowa, 1965; Mirosław-Grabowska and Niska, 2007b), Żabieniec Południowy (Majecka, 2014) and Babin (Żarski et al., 2018).

P. abies reached 70% in the Parysów Pa-19 diagram. Such a high share of spruce at Parysów suggests a strong dominance of marshy spruce forests and spruce-pine forests, presumably with an admixture of fir. Similar values were recorded at sites such as Kontrowers on the Żelechów Plateau (Kupryjanowicz et al., 2003) and Babin on the Radom Plain (Żarski et al., 2018). Spruce, unlike fir, encroached into Poland from the north-east. Its considerable expansion began in the E5d subzone, and the maximum values (30–35%) are recorded in the E6c subzone (Kupryjanowicz et al., 2018f).

Pollen spectra suggest, at least at the beginning of the telocratic period, an increase in humidity, but no decrease in temperature, because of the persistence of species such as *H. helix* and *I. aquifolium*. Mean January temperature, based on the occurrence of *Abies alba*, was probably approximately –5°C (Mamakowa 1997, after Granoszewski, 2003). The presence of *V. album* and the remaining indicator taxa suggest that even at the end of the E6 RPAZ, mean temperature in July did not fall below +17°C (compare Iversen, 1944). The amplitude of temperatures increased between the warmest and coldest month, pointing to a continentalisation of the climate.

In all the profiles analysed, zone E7 RPAZ was recorded, although palynostratigraphic sub-zones could not be designated. Palynological diagrams from Struga and Parysów document maximum shares of *P. sylvestris* t., pointing to the transformation of deciduous forests into various types of coniferous forests dominated by pine with an admixture of spruce and fir, while in humid areas assemblages with spruce and alder occurred. An exception is the St-19 Struga profile, where the deposits are disturbed above sample 2.55 m. Within E7 RPAZ Kupryjanowicz (2008), a cooler climatic oscillation was identified during which the suggested mean temperatures of July and January were +12°C and –20°C, respectively.

RECORD OF EEMIAN INTERGLACIAL IN THE PROFILES STUDIED COMPARED WITH SOME EUROPEAN SITES

The Struga and Parysów (Garwolin Plain) profiles analysed were plotted against divisions of the Eemian interglacial at different sites on the European Lowlands.

PROTOCRATIC PERIOD OF EEMIAN INTERGLACIAL (E1-E2 RPAZS)

The widespread distribution of pioneer birch and birch-pine forests at the beginning of the interglacial is recorded in all pollen diagrams from western to eastern Europe. Tree birch pollen in the study sites is ~70–80%, similar to Neubrandenburg-Hinterste Mühle in northeastern Germany (Börner et al., 2018) as in Belarus (Granoszewski et al., 2012), as shown by the regional pollen assemblage zones.

In the Belarusian sites, the presence of *Picea* (*P. obovata*) and *Quercus* is notable. The proportion of spruce pollen reaches 30%. Meanwhile, this species in the Struga and Parysów diagrams in the late glacial and early interglacial is marginal; these differences are due to the regional presence of Siberian spruce in Belarus and the significant share of *Quercus*, whose expansion in the Eemian interglacial was from the east, as illustrated by isopollen maps (Kupryjanowicz et al., 2018d).

In the zone correlated with the E2 RPAZ in Belarus, where pine stands have their natural habitats, its high proportions, up to 95%, generally last longer. By contrast, at western European sites, the proportion of *P. sylvestris* t. in the E2 RPAZ zone is 45–55%. In German profiles, e.g. Beckentine (Hrynowiecka et al., 2021) and Neubrandenburg-Hinterste Mühle (Börner et al., 2018), and in profiles from Belarus (Granoszewski et al., 2012), the Eemian succession in the E2 RPAZ zone is similar and indicates a warming climate and the encroachment of elm. Turner's (2002) scheme lacks a separate distinction of the zone with a high proportion of *Ulmus* (Table 4), analogous to the E2 RPAZ, and the interval with a higher elm proportion is included in the zone with the *Quercus* maximum. *Ulmus* is also important in indicating the increasing temperature of the warmest month, which was not below +16°C.

The increase in temperature and annual precipitation on the Garwolin Plain area proceeded steadily. This agrees with the pattern of climate change of the Eemian interglacial outlined in Western Europe (Zagwijn, 1996; Aalbersberg and Litt, 1998), indicating a temperature of the coldest month of ~–2°C for the phase correlated with the E2 RPAZ and +16°C as the tempera-

Table 4

Position of the local pollen assemblage zones from the Struga and Parysów (Garwolin Plain) sites compared with Eemian interglacial subdivision at various sites on the European Lowlands and their main forest-forming tree communities

	1. Grande Pile	2. N Deutschland	3. Bispingen	4. Garwolin Plain	5. Poland	6. Belarus
Telocratic	E7 Po-*Art*-Cy	E7 NAP	VIb NAP-*Be-Pin* VIa *Pic-Pin*	**Struga St-19:** 17 LPAZ *Pin*; **G-120:**19 LPAZ *Pic-Pin*; 20 LPAZ *Al-Ca*; 21 LPAZ *Pin*; Struga **Parysów Pa-19:**15 LPAZ *Pin*	E7 *Pin*	mr9 *Pin*
Telocratic	E6 *Pin-Pic-Abi*	E6 *Pin*; *Pin-Pic-Abi*	Vb *Pin Pic-Abi* Va *Pin-Pic-Ca*	**Struga St-19:** 15 LPAZ *Pic-Abi*; 16 LPAZ *Pic*; **G-120:**17 LPAZ *Pic-Ca*; 18 LPAZ *Abi-Pic*; **Parysów Pa-19:**12 LPAZ *Abi*; 13 LPAZ *Pic*; 14 LPAZ *Pin-Pic*	E6 *Pic-Abi-Al*	mr8 *Pic-Pin* mr7 *Ca-Pic*
Mesocratic	E5*Abi-Ca* *Ca –(Qu)* *Co-Qu-Tax*	E5 *Ca-Pic*	IV *Ca*	**Struga St-19:** 11 LPAZ *Ca-Co-Ti*; 12 LPAZ *Ca-Co*; 13 LPAZ *Ca*; 14 LPAZ *Pic*; **G-120:** 13 LPAZ *Ca-Co*; 14 LPAZ *Ca-Al*;15 LPAZ *Ca*; 16 LPAZ *Ca-Pic*; **Parysów Pa-19:** 10 LPAZ *Ca-Co*;11 LPAZ *Ca*	E5 *Ca-Co-Al*	mr6 *Ca-Ti*
Mesocratic	E4 *Co-Qu*	E4 *Co-Tax-Ti*	IIIc *Ti-Ul-Co* IIIb *Co* IIIa *Qu-Co*	**Struga St-19:** 7 LPAZ *Qu-Co-Fr;* 8 LPAZ *Co*; 9 LPAZ *Tax-Al-Ti;* 10 LPAZ *Co-Ca*; **G-120:** 9 LPAZ *Co-Qu*; 10 LPAZ *Co*; 11 LPAZ *Ti-Al*; 12 LPAZ *Co-Ca*; **Parysów Pa-19:** 6 LPAZ *Co-Ca*; 7 LPAZ *Co*; 8 LPAZ *Co-Ti-Al*; 9 LPAZ *Co-Ca*	E4 *Co-Qu-Ti*	mr5 *Ti-Co-Ca* mr4 *Co-Qu-Ti*
Mesocratic	E3 *Qu-Ul*	E3 *Pin*-Quercetum mixtum	IIb *Pin-Qu*	**Struga St-19:** 5 LPAZ *Qu-Ul-Pin*; 6 LPAZ *Qu-Pin*; **G-120:** 7 LPAZ *Pin-Qu*;8 LPAZ *Qu* **Parysów Pa-19:** 4 LPAZ *Qu-Fr-Ul*;5 LPAZ *Qu*	E3 *Qu-Fr-Ul*	mr3 *Qu-Pin-Co*
Protocratic	E2 *Ul-Pin* *Be-Pin*	E2 *Pin-Be*	IIa *Pin-Be*	**Struga St-19**: 4 LPAZ *Pin-Be-Ul*; **Struga G-120:** 6 LPAZ *Pin-Be*; **Struga WH-15**: 4 LPAZ *Pin-Be-Ul*; **Parysów Pa-19:** 3 LPAZ *Be*	E2 *Pin-Be-Ul*	mr2 *Pin-Be-Qu*
Protocratic	E1*Ju-Be*	E1*Be*	I *Be*	**Struga St-19:** 2 LPAZ *Pin-Be*; 3 LPAZ *Be-Pin*; **G-120:** 4 LPAZ *Pin*-NAP; 5 LPAZ *Be*; **Parysów Pa-19:**1 LPAZ NAP-*Pin*; 2 LPAZ *Be-Pin*	E1 *Pin-Be*	mr1 *Pin-Be-Pic*
Late Glacial	Po-*Art*-Cy	*Hipp-Ju*-NAP		**Struga St-19:** 1 LPAZ *Pin*-NAP; **G-120**: 1 LPAZ NAP-*Pin*; 2 LPAZ *Pin*; 3 LPAZ *Pin-Be*-NAP	Cyp-*Art-Be nana*	pt-3-f-NAP-*Pin-Pic ob*

1 – Grand Pile (de Beaulieu and Reille, 1992a), 2 – northern Germany (Turner, 2002), 3 – Bispingen (Lauterbach et al., 2012), 4 – Garwolin Plain, 5 – Mamakowa (1989), 6 – Belarus (Savchenko and Rylova, 2001)

ture of the warmest month. Rapid disappearance of the ice sheet at the onset of the Eemian has been postulated (Zagwijn, 1983), probably related to a marine transgression in the Baltic Sea basin (Makowska, 2009) and more widely. Govin et al. (2015), when analyzing climate conditions of the beginning of the Eemian, inferred strong boreal summer insolation and an increase in global mean sea level, up to 5–10 m above present-day.

MESOCRATIC PERIOD OF EEMIAN INTERGLACIAL (E3-E5 RPAZS)

The E3 RPAZ zone is marked by the absolute dominance of oak and the expansion of ash and elm. The proportion of *Quercus*, over 65% in the Parysów Pa-19 profile (Fig. 7), is significantly higher than those recorded in northern Germany, France and the Belarusian sites. In contrast, the proportion of elm and ash varies from site to site. Perhaps the differing pollen percentages of these riparian trees was related to the local spread of these communities in river valleys.

At the transition between E2 and E3 of the RPAZs, there is a sharp increase in the temperature of the coolest month (to ~+1.5°C), accompanied by a slightly smaller increase in the temperature of the warmest month and an increase in annual precipitation. These phenomena are observed in data for Poland, in synthetic studies for Western Europe (Zagwijn, 1996; Aalbersberg and Litt, 1998), and in Brewer et al. (2008), based on climate reconstructions from 17 sites across the European continent. Significant changes in the mean temperature of the coldest month caused subsequent change in seasonality with a weakening of the seasonal contrast.

In the hazel phase of the E4 RPAZ, distinguished by a high proportion of *Corylus* pollen (up to 70%), yew also plays an important role. The long-term presence of *T. baccata* in forest communities indicates the favourable moisture conditions prevailing during the optimum of the Eemian interglacial (Król, 1975), and is also an important element of palynological diagrams in Western Europe. This is expressed in the names of pollen zones e.g.: *Corylus*-*Taxus*-*Tilia* in northern Germany (Turner, 2002) and *Corylus*-*Quercus*-*Taxus* in the Grande Pile diagram in France (de Beaulieu and Reille, 1992a). Its presence at the sites studied (Table 4), reaching up to 3.2% in the Struga St-19 profile (Fig. 3), suggests the influence of a humid oceanic climate, which situates the Garwolin Plain region in the transition zone between a climate with continental characteristics towards the east, having lower winter period temperatures (Kupryjanowicz, 2008) and oceanic conditions towards the west. During the E4 RPAZ the humid climate helped form the highest water level of the palaeolakes. This is consistent with earlier findings from central Poland including Studzieniec (Mirosław-Grabowska and Niska, 2007a) and others analyzed by Roman et al., (2021). Simultaneously with *Corylus*, *Tilia* appears (in the range 10–25%). The lower value of this range corresponds to the percentages of lime pollen in profiles from Western Europe (e.g., 14% in Neubrandenburg-Hinterste Mühle, 10% in Bispingen and 7.2% in Beckentine). Meanwhile, in Belarusian sites, linden reaches 55.8% (Granoszewski et al., 2012), according with Eemian lime migration from the north-east (Kupryjanowicz et al., 2018e).

In the E5 RPAZ, the hornbeam maximum in the diagrams from the sites studied is about 65% (Fig. 5). The share of hornbeam in the Beckentine profile was 45% (Hrynowiecka et al., 2021) and at the Belarusian site Svetlogorsk (Hursevič et al., 1995 after: Granoszewski et al., 2012) over 80%. Granoszewski et al., (2012) states that hornbeam maintains high values in palynological diagrams from Belarus much longer than in Poland. This has to do, probably, with hornbeam refugia likely being located in this part of Europe, as isopollen maps also suggest. In addition, fir and yew are absent from the Belarusian diagrams. A comparison of the abundance of trees such as *Taxus*, *Tilia* and *Carpinus*, which were important forest components of the Eemian optimum, shows a significant decrease in the moisture gradient towards the east in the lowlands of northern Europe, favouring the spread of communities with linden and hornbeam towards the east, while the higher proportions of yew and fir were restricted to western areas. This is reflected in the names of the zones, e.g. at Grand Pile (de Beaulieu and Reille, 1992a), in the zone corresponding to E5 RPAZ, a subzone was separated with both yew *Corylus*-*Quercus*-*Taxus* and fir *Abies*-*Carpinus* (Table 4). However, there was also an inferred reduction in annual precipitation. Cheddadi et al. (1998) suggested that at the beginning of the hornbeam phase, both the temperature of the winter period (winter months) and the precipitation decreased significantly, the latter by ~200–300 mm per year.

TELOCRATIC PERIOD OF EEMIAN INTERGLACIAL (E6-E7 RPAZS)

In the E6 RPAZ, forest communities with *Abies* alba were widely distributed during the telocratic period of the Eemian interglacial. Fir pollen reaches 17.5% on the Garwolin Plain (Parysów Pa-19; Fig. 7). Similarly to *Taxus*, *Abies* is absent from Belarusian sites, whereas in north-eastern Germany it is an important component at a level described as *Pinus*-*Picea*-*Abies* (Turner, 2002; Kühl and Litt, 2003). The wetness of the climate is indicated in the E6 RPAZ also, by the significant proportion of spruce, with percentages of 70% at the Parysów site (Parysów Pa-19; Fig. 7). Again, this indicates the strong W-E moisture gradient in the European lowlands. The Garwolin Plain falls in the middle part of this gradient.

Conclusions from palaeoecological studies on the Garwolin Plain concur with climate reconstructions for the spruce-fir phase of the Eemian in Poland and western Europe. At that time, a decrease in the temperature of the coldest and warmest month and a decrease in annual precipitation were recorded (Granoszewski, 2003; Kupryjanowicz, 2008; Kołaczek et al., 2016; Pidek et al., 2021). Our data are in line with earlier suggestions that there was greater decrease of winter than summer temperatures, leading to seasonality increase and the inferred return to a more continental climate (Cheddadi et al., 1998; Rioul et al., 2001; Klotz et al., 2003; Sánchez-Goñi et al., 2005). However, Brewer et al. (2008) note that these changes seemed to have been restricted to northern Europe, with only slight change in the south.

In the E7 RPAZ, Granoszewski et al. (2012) indicate that in Belarus, as in Poland, very high pollen shares of *P. sylvestris* t. up to 99% are recorded, and the share of *P. abies* is >22%, with a lower share of *Abies* up to 1.4%. They note the occurrence of a local pollen zone at some Belarusian sites with a significant proportion of birch, >80%, before the pine succession.

CONCLUSIONS

The record of vegetation in palynological and plant macrofossil diagrams from the Struga and Parysów sites is typical of the Eemian interglacial and fully comparable with other Eemian sites from Poland, as well as from eastern and western Europe.

The Struga record shows the vegetation development from the Late Saalian, through the initial zones of the Eemian interglacial (E1 and E2 RPAZs), followed by the climate optimum (E3, E4, and E5 RPAZs), to the telocratic phase of the interglacial (E6 and E7 RPAZs).

The warmest phase was the end of the hazel phase (E4 RPAZ) and the beginning of the hornbeam phase (E5 RPAZ) with mean temperature in July of at least +21°C, and mean temperature in January >0°C. The reconstruction of these values is primarily based on the presence of *T. tomentosa* and *Viscum album,* and *Hedera helix* and *Ilex aquifolium*, respectively. This agrees with temperatures inferred for the Eemian interglacial in central Poland. The oceanic character of the climate postulated by other authors is corroborated.

The best expressed climate changes are in the younger/upper/top part of the hornbeam phase (E5 RPAZ), particularly well documented in pollen diagrams from Struga. These accompanied an increase in climate continentality caused by decreases in mean winter temperature and in precipitation. A decrease in lake level (Struga) was also recorded, while in the Parysów palaeolake, pauses in sedimentation occurred. These Eemian sites therefore join a long list of palaeolakes with disturbances recorded from the end of the hornbeam phase, presumably caused by local geological/geomorphological factors and supraregional climatic factors.

The Struga G-120 pollen diagram contributes new data regarding the stadial-interstadial climate oscillation preceding the protocratic period of the Eemian. The oscillation shows features similar to those recently described by Kupryjanowicz et al. (2021) correlated with the Zeifen interstadial and Kattegat stadial.

Palynological data from the Garwolin Plain may be compared with profiles analyzed at high resolution from eastern and western Europe, with many indicator plants corroborating the intermediate character of the climate between the oceanic west of Poland and the continental conditions in the north-east and beyond the eastern border.

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APPENDIX 1

Table I. Description of the Local Pollen Assemblage Zones (LPAZs) of the St-19 core

L PAZ number	L PAZ name	Numbers samples [m]	Zone Characteristics
St-19 1	*Pinus*-NAP	9.00–8.95	Low frequency of sporomorphs. Share of pollen of *Pinus sylvestris* t. about 57.5% and *Betula* undiff. ~33%. Pollen of other trees appears sporadically. *Salix* undiff., *Salix pentandra* and *Juniperus communis* together ~1.5%, *Calluna vulgaris pollen* grains occur singly. In this zone, there is a maximum NAP for the whole profile - 17.3%, including mainly: *Artemisia* (3%), Poaceae undiff. (8%), Cyperaceae undiff. (3%) and Amaranthaceae (2%). The presence of *Filipendula* pollen grains is noteworthy. Among the pollen of rush plants, *Sparganium* t. and *Typha latifolia* appear (~0.5% each). Aquatic plants are represented by *Nuphar pollen*, Nymphaeaceae trichosclerides and *Ceratophyllum* trichosclerides. The proportion of Musci spores ~7%. *Pediastrum* and *Botryococcus* cenobia are present. The upper limit of the zone was set at a decrease in the proportion of NAP and an increase in *Pinus sylvestris* t..
St-19 2	*Pinus*-*Betula*	8.90–8.55	The sporomorph frequency increases and remains high up to the ceiling of the profile. At the beginning of the zone *Pinus sylvestris* t. reaches a maximum in the whole profile - 72%, then the proportion of *Betula* undiff. increases to ~42%. Single pollen grains of *Picea abies, Quercus* and *Ulmus* are often found. Pollen of other woody taxa appears sporadically (*Tilia cordata*, *Alnus*). The proportion of *Salix* undiff. and *Juniperus communis* is continuous respectively: 0.8% and 1.7%, single pollen grains of *Betula nana* t. were recorded. Still high shares of NAP ~8% mainly: *Artemisia* (3.3%), Poaceae undiff. (3.5%), Cyperaceae undiff. (3.5%), Amaranthaceae (1.3%) and also *Anthemis* t. and *Gypsophila fastigiata*. There is a continuous curve of *Filipendula* contribution with low values. Among the pollen of rush plants, *Sparganium* t. and *Typha latifolia* appear. Aquatic plants are represented by *Nuphar pollen*, Nymphaeaceae trichosclerides, and *Ceratophyllum* trichosclerides. The proportion of Musci spores ~9% and a continuous percentage curve of Filicales monolete appears. *Pediastrum* and *Botryococcus* are present. *Tetraedron* is occasionally recorded. The upper limit of the zone was set by a sharp increase in the proportion of *Betula* undiff. and a concomitant decrease in *Pinus sylvestris* t.
St-19 3	*Betula*-*Pinus*	8.50–8.30	The pollen value of *Pinus sylvestris* t. decreases and ranges from 24% to ~32%, while the proportion of *Betula* undiff. increases. and reaches a maximum in the whole profile of 71%. *Quercus* and *Ulmus* reach 4.5% and 1.5% respectively. Single pollen grains of *Fraxinus excelsior*, *Taxus baccata, Corylus* and *Picea abies* were recorded. The present continuous curve of *Salix* undiff. and single pollen grains of *Salix pentandra* t., *Juniperus communis* reaches a maximum throughout the profile of 2%. The proportion of NAP drops to ~11.1% including *Artemisia* (1.2%), Poaceae undiff. (5.5%), Cyperaceae undiff. (4.5%) and Amaranthaceae (1.5%). Apiaceae, *Anthemis* t., and *Urtica* occur as single pollen grains. Among the pollen of rush plants, *Sparganium* t. appears, aquatic plants are represented by *Nuphar pollen*, Nymphaeaceae trichosclerides and *Ceratophyllum* trichosclerides. There is an increase in the proportion of Filicales monolete spores to 4.6% and a decrease in the proportion of Musci to 3%. A continuous percentage curve of *Pediastrum* is present. The upper limit of the zone was placed on an increase in *Pinus sylvestris* t. and *Ulmus* and *Quercus*, as well as a decrease in the percentage of *Betula* undiff. and a significant decrease in the percentages of *Artemisia*.
St-19 4	*Pinus*-*Betula*-*Ulmus*	8.25–7.85	An increase in the pollen percentage of *Pinus sylvestris* t. to ~45% at the same time as a decrease in *Betula* undiff. to ~37%. *Quercus* and *Ulmus* pollen curves reach 3.3% and 3.5% respectively. *Fraxinus excelsior* values form a continuous low percentage curve. *Alnus*, *Taxus baccata* and *Picea abies* appear sporadically. The maximum in the whole profile is reached by *Salix* undiff. 1.4 per cent, pollen of *Salix pentandra* t. is still present, while the proportions of *Juniperus communis* decrease. *Humulus lupulus* and *Hippophaë rhamnoides* occur as single pollen grains. The share of NAP drops to 7% in which the main shares are, Poaceae undiff., *Elymus* t., Cyperaceae undiff., *Artemisia,* Amaranthaceae and Apiaceae. Single pollen grains of *Anthemis* t., *Gypsophilia fastigiata*, Cichoriaceae, *Potentilla*, *Filipendula* and *Rumex acetosa* t. are noted. Among the pollen of rush plants, *Phragmites australis* t., *Sparganium* t. and *Typha latifolia* appear. Aquatic plants are represented by sporadic *Potamogeton* pollen, *Nuphar* pollen and increasing proportions of Nymphaeaceae trichosclereids, and *Ceratophyllum* trichomes. Spores of *Pteridium aquilinum* appear singly. There is an increase in the proportion of spores of Filicales monolete ~5%, a decrease in the proportion of Musci to 1% and a slight decrease in the proportion of *Pediastrum*. In the younger part of the zone, the number of *Botryococcus* and *Tetraedron* increases. The upper boundary of the zone was set by a sharp increase in the proportion of *Quercus, Ulmus and Fraxinus excelsior* with a simultaneous decrease in NAP, *Pinus sylvestris* t. and *Betula* undiff.
St-19 5	*Quercus*-*Ulmus*-*Pinus*	7.80–7.50	The pollen share of *Quercus* rises sharply to 50%, while the values of *Ulmus* (3.5%) and *Fraxinus excelsior* (6.3%) also increase. At the same time, the percentage share of *Betula* undiff. decreases to ~12% and *Pinus sylvestris* t. to ~20%. The beginning of a continuous low percentage curve of *Corylus* and *Alnus* and single pollen grains of *Picea abies*, *Carpinus betulus*, *Taxus baccata*, *Hedera helix* and *Ilex aquifolium* are recorded. *Pollen* grains of *Humulus lupulus*, *Juniperus communis* and *Salix* undiff. *and Salix pentandra* t. NAP value drops to ~4.5% including mainly *Artemisia*, Poaceae undiff. and Cyperaceae undiff., a continuous percentage curve of Amaranthaceae persists. The remaining

			herbaceous plants Apiaceae, *Anthemis* t., *Ligustrum vulgare*, *Gypsophilia fastigiata*, *Potentilla* t., *Filipendula* and *Rumex acetosa* t. appear as single pollen grains. Among the pollen of rush plants are *Phragmites australis* t., *Sparganium* t. and *Typha latifolia*. Aquatic plants are represented by *Nuphar* and *Potamogeton* pollen, Nymphaeaceae trichosclerides and a significant proportion of *Ceratophyllum* trichomes. At the end of the zone, *Pteridium aquilinum* values increase significantly. Spores of Filicales monolete (2.7%), Musci (2.8%) and *Pediastrum* cenobia are present. A high proportion of *Tetraedron* and *Botryococcus* was also recorded. The upper limit of the zone was placed on the growth of *Quercus*, *Ulmus* and *Fraxinus excelsior* at the beginning of the growth curve of *Corylus* and with the simultaneous decrease of *Pinus sylvestris* t., *Betula* undiff. and NAP.
St-19 6	*Quercus-Ulmus*	7.45–7.20	The percentage of *Quercus* increases to 63% of the maximum throughout the profile and *Ulmus* also reaches its maximum throughout the profile to 6.5%. The proportion of *Fraxinus excelsior* decreases slightly to ~5%. The percentage of *Corylus* increases to 12.5% and a continuous low percentage curve of *Alnus* is also present. *Populus, Carpinus betulus, Picea abies, Taxus baccata, Acer, Hedera helix, Viscum album* and *Humulus lupulus* occur sporadically. The percentage of *Pinus sylvestris* t. to ~15.5% and *Betula* undiff. to ~1.6% decreases. A low proportion of NAP; mainly *Artemisia*, Poaceae undiff. And Cyperaceae undiff. Reach 0.4%, 2.3% and 3% respectively. Other herbaceous plants occur as single pollen grains: Amaranthaceae, *Cladium mariscus*, *Aster* t., *Anthemis* t., *Ligustrum vulgare* and *Urtica*. The rush plants are represented by pollen of *Sparganium* t. and *Phragmites australis t. The* aquatic plants are represented by pollen of *Myriophyllum spicatum*, *Nymphaea alba* and *Ceratophyllum trichinis*. The proportion of Nymphaeaceae trichospecies decreased from the previous zone, while *Botryococcus* and *Tetraedron* reached their maximum values throughout the profile at 26% and 37.5%, respectively. The proportion of Filicales monolete and Musci spores similar to the previous zone. *Pediastrum* cenobia are present. The upper limit of the zone was set by a sharp decrease in the percentages of *Quercus* and a simultaneous increase in *Corylus*. At the same time, the percentage of Poaceae undiff., Cyperaceae undiff. Drops. And the Amaranthaceae curve disappears completely.
St-19 7	*Quercus-Corylus-Fraxinus*	7.15–7.00	The proportion of *Corylus* increases sharply to 58% at the same time as the proportion of *Quercus* decreases to 23.5%. *Fraxinus excelsior* reaches its maximum in the entire profile – 6.5%. The shares of *Pinus sylvestris* t. and *Betula* undiff. Remain very low to a few percent. A continuous low percentage curve of *Alnus and Taxus baccata.* Single pollen grains of *Populus*, *Picea abies*, *Hedera helix*, *Ilex aquifolium, Viburnum* t. and *Humulus lupulus*. The percentages of *Artemisia*, Poaceae undiff. And Cyperaceae undiff. Do not exceed 1.5%. The rush plants are represented by pollen of *Sparganium* t., *Phragmites australis* t. and *Typha latifolia*. The aquatic plants are represented by pollen of *Stratiotes aloides, Potamogeton and Nuphar*, as well as trichoscleraceae Nymphaeaceae and *Ceratophyllum* trichosclerides. The proportion of Filicales monolete decreases to 0.5 %, and the presence of Musci and *Pteridium aquilinum* spores is noted. *Pediastrum* cenobia are present. Among algae, the proportion of *Botryococcus* and *Tetraedron* decreases. The upper limit of the zone was set by a sharp decline in *Quercus* and *Fraxinus excelsior* and a simultaneous increase in *Corylus*, *Alnus* and the appearance of a continuous curve of *Tilia* (including *Tilia cordata, T. platyphyllos, T. tomentosa* and *Tilia* undiff.) with its rapidly increasing proportions.
St-19 8	*Corylus*	6.95–6.45	*Corylus* pollen reaches a maximum in the profile - 71%. An increase in the value of *Alnus* (11%) occurs and very quickly the percentage of *Tilia* pollen increases to ~7% (including *T. cordata, T. platyphyllos, T.tomentosa,* and *Tilia* undiff.) and *Carpinus betulus* (2%). The percentage of *Taxus baccata* increases to 2.3%, while the percentage of *Quercus* decreases to 5%. *Populus*, *Acer*, *Hedera helix*, *Viscum album, Ligustrum vulgare, Ilex aquifolium* and *Humulus lupulus* pollen are sporadic. There is a low percentage of *Artemisia* (0.5%), Poaceae undiff. (1%) and Cyperaceae undiff. (3%). Other herbaceous plants appear sporadically as single pollen grains: Amaranthaceae, Apiaceae, Cichoriaceae undiff., *Filipendula and Rumex acetosa* t. The rush plants are represented by the pollen of *Sparganium* t. Aquatic plants are represented by *Potamogeton* pollen, *Nymphaea candida*, Nymphaeaceae trichosclerides and *Ceratophyllum* trichinellae. Single spores of Filicales monolete and Musci of ~3% each were recorded. There was a low proportion of *Pediastrum* (3.5%) and *Botryococcus* (5%) and still a significant proportion of *Tetraedron* (15.5%). The upper limit of the zone was set by an increase in the percentage of *Tilia, Alnus* and the appearance of a continuous curve of *Carpinus betulus* with its rapidly increasing shares and a simultaneous decrease in *Corylus*.
St-19 9	*Taxus-Alnus-Tilia*	6.40–6.00	At the beginning of the zone, *Alnus* ~22% and *Taxus baccata* ~3.2% reach maximum shares throughout the profile, while in the younger part of the zone *Tilia* 13% (including *T. cordata, T. platyphyllos, T. tomentosa* and *Tilia* undiff.) reaches maximum values. An increasing proportion of *Carpinus betulus* (11.5%) is also recorded. The proportion of *Corylus pollen* is stable at ~45%, while the percentage of *Quercus* decreases to 5.5%. Pollen grains of *Picea abies*, *Acer*, *Hedera helix*, *Viscum album*, *Ligustrum vulgare, Ilex aquifolium*, *Buxus sempervirens* appear frequently. *A* continuous curve of *Humulus lupulus* is still present. NAP value at the lowest zone throughout the profile, notable for single pollen grains of *Anthemis* t., *Thalictrum*, *Filipendula, Rumex acetosa* and *Urtica*. The rush plants are represented by pollen of *Phragmites australis* t., *Sparganium* t. and *Typha latifolia*. Among aquatic plants there is pollen of *Potamogeton*, *Nymphaea alba* a significant proportion of Nymphaeaceae trichosclereids and *Ceratophyllum* trichosclerides. The increase in the proportion of Musci to 10.5% is noteworthy. The spores of Filicales monolete and the cenobia *Pediastrum*, *Botryococcus* are present and in individual samples the proportion of *Tetraedron* increases to 31%. The upper limit of the zone was placed on a significant increase in the percentage of *Carpinus betulus* pollen.
St-19 10	*Corylus-Carpinus*	5.95–5.55	*Carpinus betulus* pollen percentage increases to 30%. The share of *Tilia* (including *T. cordata, T. platyphyllos, T. tomentosa* and *Tilia* undiff.) at a constant of ~4%, *Alnus* ~18%

			and *Corylus* ~40%. The proportion of *Quercus* does not exceed 6%. *Taxus baccata, Ulmus*, *Fraxinus excelsior* in the form of low percentage curves of 1.5%, 2.5% and 1.5% respectively. *Picea abies* pollen grains are frequently present. *Acer*, *Hedera helix*, *Viscum album*, *Buxus sempervirens*, *Ilex aquifolium*, *Viburnum*, *Fragnula alnus* and *Humulus lupulus* are present as individual pollen grains. The proportion of NAP analogous to the previous zone, the presence of pollen grains of *Anthemis* t., *Stellaria holostea* and *Filipendula is* noteworthy. Among the rush plants, pollen of *Sparganium* t., *Typha latifolia* and *Menyanthes trifoliata* is present. Aquatic plants are represented by Nymphaeaceae trichosclerides and *Ceratophyllum* trichosclerides. The spores of Filicales monolete (3%) and Musci (6%) and the cenobia *Pediastrum*, *Botryococcus* and *Tetraedron* are present. The upper limit of the zone was set by a rapid increase in *Carpinus betulus* and a further decrease in *Quercus, Corylus* and *Tilia*.
St-19 11	*Carpinus-Corylus-Tilia*	5.50–4.90	A further increase in the percentage of *Carpinus betulus* to 52.5%. *Corylus*, *Alnus* and *Tilia* (including *Tilia cordata, Tilia platyphyllos, Tilia tomentosa* and *Tilia* undiff.) hold steady at 25%, 18% and 4% respectively. Shares of *Quercus, Ulmus* and *Fraxinus excelsior* similar to the previous zone. A continuous low percentage curve of *Taxus baccata* and also pollen of *Picea abies, Acer*, *Hedera helix*, *Viscum album*, *Buxus sempervirens*, *Ligustrum vulgare*, *Ilex aquifolium* and *Viburnum* are present. Pollen grains, *Calluna vulgaris* and *Humulus lupulus* are common. The low proportion of NAP (1%) is highlighted by *Anthemis* t., *Thalictrum*, *Rumex acetosa* t. and *Urtica*. The rush plants are represented by pollen of *Phragmites australis* t., *Sparganium* t., *Typha latifolia* and *Menyanthes trifoliata* and among the aquatic vegetation, pollen of *Stratiotes aloides, Potamogeton*, *Nuphar*, a significant proportion of Nymphaeaceae trichoscleraceae (23.5%) and *Ceratophyllum* trichosclerides are present. Spores of Filicales monolete occur infrequently, as do Musci. *Pediastrum* cenobia and *Botryococcus* and *Tetraedron* are present. The upper limit of the zone was placed at the further growth of *Carpinus betulus* and the further decline of *Corylus*.
St-19 12	*Carpinus-Corylus*	4.85–4.45	A further increase in *Carpinus betulus* to 56% was recorded. *Corylus*, *Alnus* and *Tilia* (total: *T. cordata, T. platyphyllos, T. tomentosa* and *Tilia* undiff.) remain stable at 25%, 16% and 4% respectively. Low percentages of *Quercus*, *Ulmus*, *Fraxinus excelsior. Picea abies, Taxus baccata*, *Acer*, *Hedera helix*, *Viscum album* and *Buxus sempervirens* occur frequently as does *Humulus lupulus.* A low proportion of NAP, similarly to the previous zone; attention is drawn to single pollen grains of *Aster* t. and *Filipendula*. The rush plants are represented by pollen of *Phragmites australis* t., *Sparganium* t. and *Typha latifolia*. Among the aquatic plant taxa, the frequent presence of *Salvinia natans* microsporangium tissue and *Nymphaea alba* pollen, a significant proportion of Nymphaeaceae trichoscléreids (23%) and *Ceratophyllum* trichosclereides are noteworthy. In the older part of the zone, a significant proportion of Filicales monolete spores ~9% was recorded as was Musci. The proportion of *Pediastrum and Botryococcus* algal colonies is very low throughout the zone. The upper limit of the zone was placed on a further increase in *Carpinus betulus* and a further decrease in *Quercus* and *Corylus.*
St-19 13	*Carpinus*	4.40–3.45	*Carpinus betulus* reaches maximum values of 63.5% throughout the profile and *Picea abies* forms a continuous percentage curve of ~2%. The proportion of *Corylus* decreases to ~22% and *Alnus* to ~13%. Low percentages of *Quercus, Ulmus and Fraxinus excelsior*. Share of *Taxus baccata* as in the previous zone. Share of *Tilia* (total) ~5%. *Acer*, *Hedera helix, Ligustrum vulgare* and *Viscum album pollen* and single pollen grains, *Buxus sempervirens* and *Ilex aquifolium* are constantly present. NAP taxa appear infrequently, with *Aster* t., *Anthemis* t. and *Filipendula* drawing attention. As in the previous zone, the rush vegetation is represented by the occasional appearance of pollen grains of *Sparganium t*., *Phragmites australis* t. and *Typha latifolia*. Among the aquatic plant taxa, tissues of *Salvinia natans* microsporangium, *Nuphar pollen, Nymphaea alba,* a significant proportion of Nymphaeaceae trichosclereids and *Ceratophyllum* hairs are still present. Spores of Filicales monolete, *Pteridium aquilinum*, *Botrychium*, *Sphagnum* and Musci are present. Again, *Pediastrum* and *Botryococcus* cenobia are present after a break. The upper limit of the zone was set by a significant decrease in the percentage of *Carpinus betulus*, *Tilia*, *Quercus* and at the same time an increase in *Picea abies*.
St-19 14	*Carpinus-Picea*	3.40–3.10	The proportion of *Carpinus betulus* pollen falls to ~40% at the same time as the proportion of *Picea abies* increases to 9.5%. The proportion of *Corylus* initially rises to 26% and then falls to 18% in the younger part of the zone, the proportion of *Alnus* between 15 and 19%. Pollen of the other trees *Quercus, Ulmus*, *Fraxinus excelsior* and *Tilia* below 1%. Pollen of *Taxus baccata*, *Hedera helix, Viscum album and Ilex aquifolium* is common. The proportion of NAP taxa remains low, with pollen grains of Poaceae undiff. occurring singly. The rush vegetation is represented by *Sparganium* t. and *Phragmites australis* t.. Aquatic vegetation is represented by Nymphaeaceae trichosclerides at a lower proportion than in the previous zone of ~4% and *Ceratophyllum* trichosclerides. Filicales monolete spores appear infrequently. A low proportion of Musci ~4%. *Pediastrum* cenobia and *Botryococcus* appear in small numbers. The upper limit of the zone was placed on the further growth of *Picea abies* and at the same time on the decline of *Corylus, Tilia* and *Fraxinus excelsior.*
St-19 15	*Picea-Abies*	3.05–2.85	The percentage of *Picea abies* increases to 25% and *Abies alba* reaches a maximum throughout the profile of ~7.5% in the 290 cm sample. The proportion of *Carpinus betulus* drops sharply in the younger part of the zone to ~32%. *Alnus* share at a constant averaging 16%. Pollen of all thermophilous taxa and *Corylus* disappears. Among the NAP taxa, an increased proportion of Cyperaceae undiff. and Poaceae undiff. Among the pollen of rush plants, *Phragmites australis* t., *Sparganium* t. and *Typha latifolia* are represented. The aquatic vegetation is represented by the trichoscale Nymphaeaceae (18%) and a significant proportion of Musci (24%) and again high values of *Pediastrum and Tetraedron.* The upper limit of the zone was set by a further increase in *Picea abies* and *Abies alba* and at the same time a slight decrease in the percentage of *Carpinus betulus*, the pollen of the other trees remains at a similar zone, with the exception of *Ulmus*, which is rarely

			encountered. Musci spores and Nymphaeaceae trichosclerides are again more common.
St-19 16	*Picea*	2.80–2.70	The maximum share of *Picea abies* in the entire profile at 36%, at the same time the increase of *Pinus sylvestris* t. to 39% and *Betula* to 6.6%. Low percentages of *Carpinus betulus* and *Alnus* remains at 12% and 11.5% respectively. Among NAPs, the proportion of Cyperaceae undiff. increases slightly, and the presence of *Calluna vulgaris* draws attention. The composition of the rush plants is similar to the previous zone. Aquatic plants are represented by *Nuphar* pollen, a significant proportion of Nymphaeaceae trichosclereids (18%) and *Ceratophyllum* hairs. Spores of Filicales monolete (4%) and *Pteridium aquilinum* are present. The maximum proportion in the whole profile is reached by Musci ~47%. There is a significant proportion of *Pediastrum* (20%) and *Tetraedron* (25%), with *Botryococcus* cenobia also present. The upper limit of the zone was set on a further increase after a temporary decrease in *Pinus sylvestris* t. and *Betula* undiff. and on a decrease in *Picea abies* and disappearance of the percentage curve of *Abies alba.*
St-19 17	*Pinus*	2.65–2.60	*Pinus sylvestris* t. pollen values increase to 54%, *Betula* to 5% and *Picea abies* to 14%. The presence of *Fagus sylvatica* pollen grains is notable*. Corylus, Alnus* and *Carpinus betulus* have very low values and *Ulmus*, *Quercus*, *Fraxinus excelsior*, *Tilia,* and *Abies alba are* noted as single pollen grains. Sporadic occurrences of *Juniperus communis*, *Salix* undiff. and *Calluna vulgaris*. NAP taxa (2%) include Poaceae undiff., Cyperaceae undiff., *Anthemis* t. *Gypsophilia fastigiata*, Apiaceae and *Filipendula*. Aquatic vegetation is represented by *Nuphar* pollen and Nymphaeaceae trichosclerides. Spores of Filicales monolete, *Equisetum* and *Pteridium aquifolium* are present. There is a significant percentage of Musci spores ~30%. *Pediastrum* and *Botryococcus* cenobia are present. The upper limit was placed at the rapid decline of *Pinus sylvestris* t. and the renewed growth of *Carpinus betulus, Alnus, Corylus, Quercus, Picea abies and Abies alba*.
St-19 18	Disturbed zone	2.55–2.10	This zone is considered disturbed and has therefore not been subject to description.

Table II. Description of the Local Pollen Assemblage Zones (LPAZs) of the G-120 core

L PAZ number	L PAZ name	Sample numbers [m]	Zone characteristics
G-120 1	NAP-*Pinus*	6.51–6.47	Low frequency of sporomorphs. Significant proportion of *Pinus sylvestris* t. 65.5% and *Betula* 20%. Continuous curve of *Juniperus communis* present. Maximum proportion of NAP throughout the profile 22.8% mainly *Artemisia*, Poaceae undiff. and Cyperaceae respectively: 8%, 11% i 8%. Single pollen grains of Amaranthaceae and *Filipendula* are present. The rush vegetation is represented by single grains of *Sparganium* t. Aquatic vegetation is represented by *Nuphar* pollen, Nymphaeaceae trichosclerides and *Ceratophyllum* trichosclerides. A proportion of Musci spores up to 9.5% and *Pediastrum* and *Botryococcus* cenobia were recorded. The upper limit of the zone was set by an increase in *Pinus sylvestris* t. and a decrease in the percentage of NAP.
G-120 2	*Pinus*	6.40–6.27	Still low frequency of sporomorphs. The proportion of *Pinus sylvestris* t. increases to 79%. The proportion of *Betula* does not exceed 19.5%. Continuous curves of *Juniperus communis* and *Salix* and single pollen grains of *Quercus* and *Alnus* and *Calluna vulgaris* are present. Share of NAP ~12%, mainly *Artemisia* (3%), Poaceae undiff. (3.5%) and Cyperaceae (5%) and Amaranthaceae (2%). In addition, single pollen grains of *Gypsophila fastigiata, Thalictrum, Filipendula* and *Anthemis* t. are present. The aquatic vegetation is represented by *Nuphar pollen*, Nymphaeaceae trichosclerides and *Ceratophyllum* hairs. The presence of *Selaginella selaginoides* is notable. A proportion of Musci up to 7.5% was also recorded with cenobia of *Pediastrum* and *Botryococcus*. The upper zone limit was placed at *Betula* growth and NAP growth.
G-120 3	*Pinus*-*Betula*-NAP	6.20–5.70	Increase in sporomorph frequency. An increase in the proportion of *Betula* to ~32.5%, and a simultaneous transient decrease in *Pinus sylvestris* t. to 48.5%. Single pollen grains of *Quercus*, *Fraxinus excelsior*, *Alnus* and *Picea abies* were recorded. Maximum proportions are reached by *Juniperus communis* 1.9% and *Salix* 2.1%. Of note is the presence of *Hippophaë rhamnoides* and *Calluna vulgaris*. Again, the share of NAPs increases to 19%, mainly *Artemisia* (7.5%), Poaceae undiff. (7%) and Cyperaceae (8%). Pollen of Cichoriaceae undiff., *Gypsophila fastigiata*, *Thalictrum*, *Filipendula*, *Rumex acetosa* t., and *Anthemis* t. is present. The rush vegetation is represented by *Phragmites australis* t. and *Sparganium* t.. The aquatic vegetation is represented by *Nuphar* pollen, Nymphaeaceae trichosclerides and *Ceratophyllum* hairs. A significant proportion of Musci up to 26.5% and spores of *Sphagnum* and Filicales monolete were recorded. *Pediastrum* and *Botryococcus* cenobia were recorded. Upper zone limit placed on a decrease in NAP and an increase in the proportion of *Pinus sylvestris* t. and the beginning of continuous curves of *Quercus* and *Fraxinus excelsior*.
G-120 4	*Pinus*-NAP	5.65–5.25	Increase in sporomorph frequencies. Significant share of *Pinus sylvestris* t. 69% and a decrease in *Betula* to 17%. Continuous curves of *Salix* and *Juniperus communis*. Beginning of percentage curves of *Quercus*, *Ulmus* and *Fraxinus excelsior*. *Corylus*, *Alnus*, *Picea abies* and *Acer* pollen appear sporadically. Single pollen grains of *Ephedra fragilis* and *Calluna vulgaris* were also recorded. NAP decline averaged up to 9%, mainly *Artemisia*, Poaceae undiff. and Cyperaceae and single pollen grains of Amaranthaceae, Apiaceae, Cichoriaceae undiff. *Gypsophila fastigiata*, *Thalictrum*, *Filipendula* and *Rumex acetosa* t. The rush vegetation is represented by *Sparganium*

			t.. Aquatic vegetation is represented by *Nuphar* pollen and other trichosclereids. The proportion of Musci decreases to 11% and single spores of *Pteridium aquilinum* and Filicales monolete are present. *Pediastrum* and *Botryococcus* cenobia were also recorded. The upper limit of the zone was set by a significant increase in the percentage of *Betula* and a decrease in *Pinus sylvestris* t.
G-120 5	*Betula*	5.20–5.05	Decrease in *Pinus sylvestris* t. 23.5%, simultaneous increase and culmination of *Betula* 69%. Continuous curve of *Quercus* and *Ulmus* and beginning of continuous curve of *Fraxinus excelsior*. Single pollen grains of *Corylus* appear. *Salix* and *Juniperus communis* still present and occasional *Calluna vulgaris* and *Humulus lupulus*. Low proportion of NAP mainly *Artemisia*, Poaceae undiff., Cyperaceae and Amaranthaceae and Apiaceae undiff., Cichoriaceae undiff., *Thalictrum* and *Galium* t. occur sporadically. The rush vegetation is represented by *Sparganium* t. and *Typha latifolia*. The aquatic vegetation is represented by Nymphaeaceae trichosclereides and *Ceratophyllum* trichosclerides. There is an increase in Filicales monolete to 5.4 % and *Equisetum* 1.2 % and Musci 5.5 %. *Pediastrum* and *Botryococcus* cenobia were recorded. The upper zone limit was placed at the decline of *Betula* and NAP and the increase of *Pinus sylvestris* t.
G-120 6	*Pinus-Ulmus*	5.00–4.95	An increase in the proportion of *Pinus sylvestris* t. to ~59.5% and at the same time a decrease in *Betula* to 31.5%. Continuous low percentage curves of *Quercus* ~3%, *Ulmus* 2.5% and *Fraxinus excelsior* 0.5%. A decrease in *Juniperus communis* was recorded, while the proportion of *Salix* is at a constant. Single pollen grains of *Corylus* and *Alnus* were noted. The presence of *Humulus lupulus* is notable. Low NAP values mainly of *Artemisia*, Poaceae undiff. and Cyperaceae as well as Apiaceae and *Anthemis* t. The rush vegetation is represented by *Phragmites australis* t. and *Sparganium* t. pollen. Aquatic vegetation is represented by pollen of *Myriophyllum spicatum*, tissues of *Salvinia natans* microsporangium, Nymphaeaceae trichosclerides and *Ceratophyllum* trichosclerides. Spores of Filicales monolete 5.4% and Musci 2.3% are present. *Botryococcus* cenobia were recorded. The upper limit of the zone was placed on the decline of *Betula* and the growth of *Pinus sylvestris* t. and *Quercus*.
G-120 7	*Pinus-Quercus*	4.90–4.50	A sharp increase in the percentage of *Quercus* to 40%, *Ulmus* to 3.5% and *Fraxinus excelsior* to 1.5%. *Corylus*, *Alnus*, *Picea abies* and *Acer* and *Hedera helix* were also recorded as single pollen grains. A constant share of *Pinus sylvestris* t. ~60% and a simultaneous decrease of *Betula* to 14%. Low proportion of *Salix* and *Juniperus communis* and presence of single pollen grains of *Humulus lupulus* and *Calluna vulgaris*. Low NAP percentages mainly of *Artemisia*, Poaceae undiff. and Cyperaceae as well as Apiaceae, Amaranthaceae and *Anthemis* t., *Aster* t., and *Filipendula*. The rush vegetation is represented by *Phragmites australis* t. and *Sparganium* t. Aquatic vegetation is represented by *Nuphar* pollen, Nymphaeaceae trichosclereides and *Ceratophyllum* trichosclus. Filicales monolete 6%, Musci 3% and single spores of *Pteridium aquilinum* are present. *Pediastrum* and *Botryococcus* cenobia were noted. The upper limit of the zone was set at a further increase in *Quercus* and a simultaneous decrease in *Pinus sylvestris* t..
G-120 8	*Quercus*	4.45–4.10	*Quercus* growth and climax ~60.5%. *Ulmus* and *Fraxinus excelsior* reach a maximum of 6.5% and 4% respectively. An increase in the proportion of *Corylus* to 26.5% and the beginning of a continuous curve of *Alnus*. Single pollen grains of *Carpinus betulus*, *Taxus baccata*, *Acer*, *Tilia* and *Picea abies* were recorded. The continuous curve of *Hedera helix* and single pollen grains of *Buxus sempervirens* and *Humulus lupulus* are notable. Decrease in *Pinus sylvestris* t. to ~14% and *Betula* to 1%. Low proportion of NAP, single pollen grains of *Aster* t., and *Filipendula* present. The rush vegetation is represented by *Sparganium* t., *Phragmites australis t*. and *Typha latifolia*. Aquatic vegetation is represented by *Nuphar* pollen, Nymphaeaceae trichosclerides, *Salvinia natans* microsporangium tissues and *Ceratophyllum* trichomes. A maximum proportion of Filicales monolete spores of ~6.5% was recorded, as well as Musci, *Equisetum* and *Pteridium aquilinum*. *Pediastrum* and *Botryococcus* cenobia are still present.The upper limit of the zone was placed at the decrease of *Quercus* and the further increase of *Corylus*.
G-120 9	*Corylus-Quercus*	4.06–4.00	A further increase in *Corylus* to 61% and a simultaneous decrease in the percentage of *Quercus* 25.5%. Share of *Ulmus* ~1.7% and *Fraxinus excelsior* 1.9%, *Alnus* ~1.5%. Beginning of a continuous percentage curve of *Carpinus betulus*. Low proportion of *Pinus sylvestris* t. ~6%, *Betula* below 1%. Low proportion of NAP: less than 1%. Riparian vegetation represented by *Sparganium* t. and *Phragmites australis t.*. Aquatic vegetation is represented by Nymphaeaceae trichosclerides and *Ceratophyllum* trichosclerides. Single spores of Filicales monolete, *Pteridium aquilinum* and Musci and *Pediastrum* and *Botryococcus* cenobia were recorded. The upper limit of the zone was placed at further growth of *Corylus* and further decline of *Pinus sylvestris* t., *Betula* and decline of *Quercus*.
G-120 10	*Corylus*	3.95–3.59	Maximum share of *Corylus* ~74.5%. Gradual decline in *Quercus* to 3%, *Ulmus* and *Fraxinus excelsior* ~2% each. *Alnus* share increases to 22%, *Tilia* share to 14.5% a continuous low percentage curve of *Carpinus betulus* is also present. *Pinus sylvestris* t. and *Betula* reach minimal values throughout the profile. Notable is the presence of *Taxus baccata*, *Acer*, *Hedera helix, Viscum album*, *Buxus sempervirens*, *Picea abies*, *Humulus lupulus* and *Calluna vulgaris. Artemisia*, Poaceae undiff. and Cyperaceae of approximately 1% each. The remaining herbaceous plants, i.e. Apiaceae, *Thalictrum*, and *Rumex acetosa* were recorded as single pollen grains. The continuous percentage curve of *Filipendula* is noteworthy. The rush vegetation is represented by *Sparganium* t. and *Typha latifolia*. The aquatic vegetation is represented by Nymphaeaceae trichosclerides and *Ceratophyllum* trichosclerides. Single spores of Filicales monolete, Musci and *Pteridium aquilinum* were recorded. *Pediastrum* and *Botryococcus* cenobia are present. The upper limit of the zone was placed at the decline of *Corylus* and the

			growth of *Tilia* and *Alnus* .
G-120 11	*Tilia-Alnus*	3.55–3.45	*Alnus* reaches its maximum of 25.5% as does *Tilia* 20%. The share of *Corylus* drops to 39% and *Quercus* to 6.6%. Low proportions of *Carpinus betulus* up to 2.8%, *Picea abies*, *Juniperus communis* and *Salix* in the form of single pollen grains. Of note is the presence of *Acer*, *Hedera helix* and *Buxus sempervirens*. *Humulus lupulus* occurs as single pollen grains. *Artemisia*, Poaceae undiff. and Cyperaceae do not exceed 1%. The remaining herbaceous plants Apiaceae, Amaranthaceae, Rosaceae, *Thalictrum*, *Filipendula* and *Rumex acetosa* occur as single pollen grains. The rush vegetation is represented by *Sparganium* t.. The aquatic vegetation is represented by Nymphaeaceae trichosclerides and *Ceratophyllum* trichosclerides. Spores of Filicales monolete, Musci and *Pteridium aquilinum* were recorded. *Botryococcus* cenobia were recorded. The upper zone limit was placed at the decline of *Corylus, Tilia* and the growth of *Carpinus betulus*.
G-120 12	*Corylus-Carpinus*	3.40–3.35	The proportion of *Carpinus betulus* pollen increases to 16%. The proportion of *Corylus* ~36%, *Alnus* ~19.5% and *Tilia* ~12.5%. *Quercus*, *Ulmus*, *Fraxinus excelsior* 6.3%, 2.2% and 1.4% respectively. Single grains of *Picea abies, Viscum album* and *Buxus sempervirens* were recorded. The proportion of NAP at a very low. The rush vegetation is represented by *Sparganium* t. and *Phragmites australis* t. Aquatic vegetation is represented by *Nuphar*. The upper zone limit was placed at further growth of *Carpinus betulus*.
G-120 13	*Carpinus -Corylus*	3.30–2.92	*Carpinus betulus* increase initially to 9% and then to 36.5%. *Corylus*, *Alnus* and *Tilia* fall to 42%, 22.5% and 13.5% respectively. Low proportion of *Quercus* to 5%. Onset of continuous low proportion of *Picea abies*. *Acer*, *Hedera helix* and *Viscum album* as continuous low percentage curves and *Buxus sempervirens*, *Calluna vulgaris*, *Humulus lupulus* occur as single pollen grains. Among the NAP, pollen grains of *Gypsophila fastigiata*, *Thalictrum*, *Filipendula* and *Rumex acetosa* t. The rush vegetation is represented by *Sparganium* and *Menyanthes trifoliata*. In the younger part, the aquatic vegetation is represented by *Nuphar* pollen, Nymphaeaceae trichosclerides and *Ceratophyllum* trichosclerides. After the break, spores of Filicales monolete and Musci appear sporadically as do *Pediastrum* cenobia.The upper limit of the zone was set at a further increase in the percentage of *Carpinus betulus* and a decrease in *Tilia* and *Corylus*.
G-120 14	*Carpinus -Alnus*	2.87–2.36	The proportion of *Carpinus betulus* pollen increases to 48.5%. *Corylus*, *Alnus* and *Tilia* persist at 37%, 11% and 11.5% respectively. *Picea abies* pollen share ~1%. *Taxus baccata*, *Acer*, *Hedera helix*, *Viscum album*, *Buxus sempervirens* and *Ilex aquifolium* occur as low percentage curves or as single pollen grains. Like *Calluna vulgaris*, *Humulus lupulus* appears as single grains. *Filipendula*, *Rumex acetosa* t., *Galium* t. and *Ranunculus acris* also occur among NAPs. The rush and aquatic vegetation is represented by pollen of *Phragmites aust*ralis t., *Sparganium* t., *Menyanthes trifoliata*, *Myriophyllum spicatum*, Nymphaeaceae trichosclereids and *Ceratophyllum* hairs. There was a low proportion of Filicales monolete and *Pteridium aquilinum* spores, a significant proportion of Musci up to 7.5% and single *Botryococcus* cenobia. The upper zone limit was placed at the growth of *Carpinus betulus* and the decline of *Tilia* and *Corylus*.
G-120 15	*Carpinus*	2.33–2.22	*Carpinus betulus* reaches a maximum of 58%, the share of *Picea abies* increases to 2%. Share of *Corylus* and *Alnus* fall to 15.5% and 13.5% respectively, low share of *Tilia* below 3%. Low proportion of *Quercus*, *Ulmus* and *Fraxinus excelsior.* Single pollen grains of *Taxus baccata*, *Hedera helix* and *Viscum album* present. Single grains of *Humulus lupulus* present. NAP in very low proportion. The rush vegetation is represented by *Sparganium* t., *Phragmites australis* t., *Typha latifolia* and *Menyanthes trifoliata*. Aquatic vegetation is represented by *Nuphar* pollen and Nymphaeaceae trichosclerides. The upper limit of the zone was placed at the fall of *Carpinus betulus*.
G-120 16	*Carpinus -Picea*	2.18–2.00	Still high proportion of *Carpinus betulus* 57%. The share of *Picea abies* increases to 3% and the beginning of the curve of *Abies alba* appears. *Corylus* ~20% and *Alnus* ~15% remain constant. Low proportions of *Quercus* and *Tilia*, *Fraxinus excelsior*, *Taxus baccata Hedera helix* and *Viscum album* are still present. *Humulus lupulus* in the form of single pollen grains. Low proportion of NAP. The rush vegetation is represented by *Sparganium* t. and *Typha latifolia*. Aquatic vegetation is represented by *Nuphar pollen*, Nymphaeaceae trichosclerides and *Ceratophyllum* trichosclerides. Spores of Filicales monolete appear infrequently. The proportion of Musci increases to 13.5%. The upper limit of the zone was set at an increase in *Picea abies* and a significant decrease in *Corylus* and *Tilia*.
G-120 17	*Picea-Carpinus*	1.96–1.72	The proportion of *Picea abies* increases to 16% and *Abies alba* to ~8%. In the older part of the horizon, there is still a significant proportion of *Carpinus betulus* ~53.5% and *Alnus* 20%. There is a decrease in the proportion of *Corylus* and *Tilia* 6.7% and 1% respectively and *Quercus* and *Ulmus* ~1% each. Single pollen grains of *Taxus baccata Hedera helix*, *Calluna vulgaris* and *Humulus lupulus* present. Still low proportion of *Pinus sylvestris* t. whereas the proportion of *Betula* increases to 7%, *Juniperus communis* and *Salix* as single pollen grains. The rush vegetation is represented by *Sparganium* t. and *Typha latifolia*. Aquatic vegetation is represented by *Nuphar pollen*, Nymphaeaceae trichosclereides, *Salvinia natans* microsporangium tissues, *Ceratophyllum* hairs and *Stratiotes aloides* pollen. Spores of Filicales monolete 2% and singly of *Pteridium aquilinum* were recorded. A significant proportion of Musci ~38%. *Pediastrum* and *Botryococcus* cenobia appear again after a break. The upper zone limit was placed at the growth of *Picea abies*, *Abies alba* and the decline of *Carpinus betulus* and *Corylus*.
G-120 18	*Abies-Picea*	1.68–1.61	*Abies alba* reaches its maximum throughout the profile at ~9.2%, a further increase in the percentage of *Picea abies* to ~29.5%. There is an increase in the proportion of *Pinus sylvestris* t. to 11% and *Betula* to 7%. *Alnus* holds steady at ~20%, *Carpinus*

			betulus ~14.5%. *Corylus* <3%, *Tilia* and *Quercus* each ~2% and *Ulmus* below 1%. The proportion of *Taxus baccata*, *Calluna vulgaris*, *Juniperus communis* and *Salix* as single pollen grains. NAPs increase slightly. Poaceae undiff. and Cyperaceae oscillate ~1%. The remaining herbaceous plants, i.e. *Aster* t., *Helianthemum nummularium*, Apiaceae, Amaranthaceae and *Galium* t. occur as single pollen grains. The rush vegetation is represented by *Sparganium* t.. Aquatic vegetation is represented by *Nuphar* and the trichoscale Nymphaeaceae. Maximum proportion of Musci ~39%, *Sphagnum* spores are also present. Share of Filicales monolete ~1.5%. A significant proportion of *Pediastrum* ~10% and *Botryococcus* 2.8%. The upper limit of the zone was placed at the growth of *Pinus sylvestris* t..
G-120 19	*Picea-Pinus*	1.57–1.53	An increase and culmination of *Picea abies* >33% at the same time as an increase of *Pinus sylvestris* t. to 42% and a decrease of *Abies alba* to ~2%. The share of *Alnus* remains constant at ~15%, as does *Betula* 7%. The share of *Carpinus betulus* decreases to 5%, *Quercus* <1%, as does *Corylus*. Continuous low percentage curves of *Ulmus*, *Fraxinus excelsior* and *Tilia*. *Juniperus communis*, *Salix*, *Calluna vulgaris* and *Humulus lupulus as* single pollen grains. There is an increasing proportion of NAPs, mainly Poaceae undiff. and Cyperaceae oscillate ~1.5%. Other herbaceous plants are represented by: *Aster* t., *Helianthemum nummularium*, Roasceae and *Cirsium*. The rush vegetation is represented by *Sparganium* t. and *Phragmites australis* t.. Aquatic vegetation is represented by *Nuphar* pollen*,* Nymphaeaceae trichosclereids are disappearing. Spores of Filicales monolete, *Pteridium aquilinum* and still a significant proportion of Musci ~39% were recorded. A significant proportion of *Pediastrum* up to 14% and *Botryococcus* ~2.6%. The upper zone limit was placed at the decline of *Picea abies* and *Pinus sylvestris* t. and the transient growth of *Alnus* and *Carpinus betulus*.
G-120 20	*Alnus-Carpinus*	1.48	In one sample, the proportion of *Pinus sylvestris* t. temporarily decreases to 19%, *Alnus* increases to 24.5% and *Carpinus betulus* increases to 17.5%. *Picea abies* drops from 33% to 24%. Most of the percentage curves of the basic trees remain at fairly low zones. *Salix* also appears in small numbers. The proportion of Poaceae undiff. and Cyperaceae increases. Other herbaceous plants occur as single pollen grains: Amaranthaceae, Apiaceae and Cichorioideae. Aquatic vegetation is represented by *Nuphar pollen*. Spores of Filicales monolete and *Equisetum* are recorded. The proportion of *Sphagnum* increases to 1% and Musci decreases to 28%. The proportion of *Pediastrum* drops to 12.5% and *Botryococcus* ~2.6%. The upper limit of the zone was placed at the increase of *Pinus sylvestris* t. and the decrease of the percentage of other trees.
G-120 21	*Pinus*	1.43–1.38	Maximum proportion of *Pinus sylvestris* t. 80%, *Betula* ~5.5%. *Picea abies* ~10% and *Abies alba* 1.5%. Share of *Carpinus betulus*, *Alnus* and *Corylus* 3%, 6%, and 0.5% respectively. *Tilia*, *Salix* and *Calluna vulgaris* in the form of single pollen grains. Among the NAPs mainly *Artemisia*, Poaceae undiff. and Cyperaceae and singly *Stellaria holostea* and *Ranunculus acris* t. *Sparganium* t. is present among the pollen of the rush vegetation. The presence of spores of Filicales monolete and Musci was noted. A significant proportion of *Pediastrum* >15%, single *Botryococcus* cenobia were recorded.

Table III. Description of the Local Pollen Assemblage Zones (LPAZs) of the Pa-19 core

L PAZ number	L PAZ name	Sample numbers [m]	Zone characteristics
Pa-19 1	NAP-Pinus	13.15–13.10	High frequency of sporomorphs. Share of *Pinus sylvestris* t. pollen ~38.5% and *Betula* ~47.5%. Maximum proportion of *Juniperus communis t.* 2% and proportion of *Salix t.* ~1.3% in the whole profile. Single pollen grains of *Picea abies* and *Hedera helix* were recorded. The highest NAP values in the whole profile at 22%, mainly Poaceae undiff. (8.5%), Cyperaceae (7%), *Artemisia* (3.7%) and Amaranthaceae, *Aster* t., *Helianthemum nummularium* t., *Gypsophila fastigiata*, *Saxifraga*, *Ranunculus acris* t. and a continuous curve of *Filipendula*. The rush vegetation is represented by pollen of *Phragmites australis* t. and *Sparganium* t.. Aquatic vegetation is represented by *Nuphar pollen*, Nymphaeaceae trichosclereides and *Ceratophyllum* trichosclus. Musci spores about 4.2%. *Pediastrum* cenobia, *Botryococcus* and *Tetraedron* are present. The upper limit of the zone was placed at the fall of *Pinus sylvestris* t. and the rise of *Betula*.
Pa-19 2	Betula-Pinus	13.05–12.87	*Pinus sylvestris* t. pollen values drop to ~20%, while *Betula's* share increases to 68.5%. The beginning of continuous percentage curves of *Quercus* and *Ulmus.* The presence of single pollen grains of *Fraxinus excelsior and Picea abies* is noted. *Salix* reaches a maximum throughout the profile of 1.6%, the proportion of *Juniperus communis* drops to ~1%. Single pollen grains of *Humulus lupulus* are recorded. The proportion of NAP drops to 14%, including *Artemisia* (5%), Cyperaceae (4.3%) and Poaceae undiff. (5%) and *Anthemis* t., *Gypsophila fastigiata*, Apiaceae, Rosaceae, Amaranthaceae, Cichoriaceae, *Helianthemum nummularium* t., Brassicaceae, *Cirsium* t. and *Filipendula*. The rush vegetation is represented by *Sparganium* t. and *Typha latifolia*. Aquatic vegetation is represented by pollen of *Menyanthes trifoliata*, *Potamogeton*, *Nuphar*, Nymphaeaceae trichosclereids and *Ceratophyllum* trichosclerides. Spores of Filicales monolete (5%), Musci (1%) and *Sphagnum* and *Equisetum* were

			recorded. *Pediastrum* cenobia, *Botryococcus* and *Tetraedron* are present. The upper limit of the zone was set at a further increase in *Betula, Ulmus* and *Quercus* and a decrease in *Pinus sylvestris* t. and NAP.
Pa-19 3	Betula	12.86–12.80	Culmination of *Betula* throughout the profile at 71% and at the same time a decrease in *Pinus sylvestris* t. to 18%, Increase in the proportion of *Quercus*, *Ulmus* and *Fraxinus excelsior*. *Juniperus communis* and *Salix* each ~1%. Pollen grains of *Picea abies, Hedera helix* and *Humulus lupulus* singly present. Further decline in NAP to 8%, including Cyperaceae (4%), Poaceae undiff. (4%) and *Artemisia* (2%) and *Anthemis* t., *Gypsophila fastigiata*, Apiaceae, Amaranthaceae, Cichoriaceae and *Filipendula*. The rush vegetation is represented by *Phragmites australis* t., *Sparganium* t. and *Typha latifolia*. Aquatic vegetation is represented by *Nuphar* pollen and Nymphaeaceae trichosclerides. There was an increase in the proportion of Filicales monolete spores to 9%, a proportion of Musci 2% and the occasional presence of *Equisetum*. *Pediastrum* cenobia, *Botryococcus* and *Tetraedron* are still present. The upper limit of the zone was set at a rapid increase in *Quercus,* an increase in *Ulmus, Fraxinus excelsior, Corylus* and a further decrease in *Pinus sylvestris* t. and *Betula.*
Pa-19 4	Quercus-Fraxinus-Ulmus	12.79–12.77	A sharp increase in *Quercus* to 59.5%, *Fraxinus excelsior* to 4% and *Ulmus* to 3.5%. Significant increase in *Corylus* to 19.5% and also the start of a curve in *Taxus baccata* and *Hedera helix*. Decrease in *Pinus sylvestris* t. to 11% and *Betula* to 2.2%. The proportion of NAP drops to 2.5%, with pollen of *Artemisia,* Cyperacea undiff. Poaceae undiff. and *Anthemis* t. recorded among them. The rush vegetation is represented by pollen of *Sparganium* t. and *Typha latifolia*. Aquatic vegetation is represented by Nymphaeaceae trichosclerides and *Ceratophyllum* trichosclerides. The spores of Filicales monolete and cenobia of *Pediastrum*, *Botryococcus* and *Tetraedron* are still present. The upper limit of the zone was placed at further growth of *Quercus* and slight growth of *Pinus sylvestris* t.
Pa-19 5	Quercus	12.76–12.70	Maximum values throughout the profile are reached by *Quercus* ~65.5%. A temporary increase in the percentage of *Pinus sylvestris* t. to 37% and *Betula* to 8.5%. *Ulmus* percentage up to 4.6%, *Fraxinus excelsior* up to 3.5% and a temporary decrease in *Corylus* 10%. A continuous curve of *Taxus baccata*, *Hedera helix* and *Salix*. *Tilia* (species *T. cordata*), *Picea abies* and *Humulus lupulus* recorded as single pollen grains. The proportion of NAP is up to 4.5%, with pollen of *Artemisia*, Cyperaceae, Poaceae undiff. and *Filipendula* recorded among them. The rush vegetation is represented by *Sparganium* t. The aquatic vegetation is represented by Nymphaeaceae trichosclerides and *Ceratophyllum* trichosclerides. The spores of Filicales monolete, *Pteridium aquilinum* and Musci and the cenobia *Pediastrum* and *Botryococcus* and *Tetraedron* were recorded. The upper limit of the zone was set at a sharp increase in the proportion of *Corylus* and a decrease in *Quercus*, *Pinus sylvestris* t. and *Betula*.
Pa-19 6	Corylus-Quercus	12.65–12.60	Significant increase in the percentage of *Corylus* to 68.5%, and the beginning of a continuous curve of *Alnus* (3%). Maximum percentage share of *Ulmus* 4.5% and *Fraxinus excelsior* 4.5% throughout the profile. At the same time, a decrease in the percentage of *Quercus* to 37%, *Pinus sylvestris* t. to 4.5% and *Betula* to 0.5%. *Hedera helix* and *Salix* were recorded as single pollen grains. Low proportion of NAP mainly Poaceae undiff. and Cyperaceae. Riparian and aquatic vegetation is represented by *Sparganium* t. pollen and Nymphaeaceae trichosclereids. Spores of Filicales monolete and Musci and *Pediastrum* and *Botryococcus* cenobia were recorded. The upper limit of the zone was placed at the further growth of *Corylus* and the beginning of the curve of *Carpinus betulus* and *Tilia* and on the significant decline of *Quercus*.
Pa-19 7	Corylus	12.55–12.30	Maximum proportion of *Corylus* 70% throughout the profile. Increase in *Alnus* to 14.5%, *Carpinus betulus* ~4% *and Tilia* ~12%. Decrease in share of *Quercus* to 8%, share of *Ulmus* ~3.6% and *Fraxinus excelsior* ~2%. Low proportion of *Pinus sylvestris* t. and *Betula*. Pollen grains of *Taxus baccata*, *Acer*, *Hedera helix*, *Viscum album*, *Buxus sempervirens* and *Humulus lupulus* appear sporadically*.* Low NAP values mainly of Poaceae undiff. and Cyperaceae. Riparian plants are represented by *Sparganium* t. pollen and aquatic plants are represented by Nymphaeaceae trichosclerides and *Ceratophyllum* trichosclerides. Single spores of Filicales monolete, *Equisetum* and *Pteridium aquilinum* and Musci were recorded. *Pediastrum* cenobia, *Botryococcus* and *Tetraedron* present. The upper limit of the zone was placed at a sample from a depth of 12.30 cm. A sedimentation break followed, again counted from a sample of 11.95 cm.
Pa-19 8	Corylus-Tilia-Alnus	11.95–11.70	*Tilia* (*T. cordata, T. platyphyllos* and *T.* undiff.) culminate at 19% with *Corylus* still high at 45%. Increasing share of *Carpinus betulus* to 19%. Low share of *Quercus* below 5%. *Ulmus* and *Fraxinus excelsior* 3% and 2.5% respectively. Regular pollen of *Taxus baccata* (1.2%)*, Hedera helix, Picea abies, Acer*, *Buxus sempervirens*, *Viscum album* and *Humulus lupulus.* Low proportion of NAP (2%) mainly *Artemisia*, Poaceae undiff., Cyperaceae, *Aster* t. and *Anthemis* t.. Aquatic plants are represented by Italian *Ceratophyllum*. Spores of Filicales monolete, *Pteridium aquilinum* and Musci are present. *Pediastrum* and *Botryococcus* cenobia are present. The upper limit of the zone was placed at further growth of *Carpinus betulus*.
Pa-19 9	Corylus-Carpinus	11.65–11.45	*Carpinus betulus* pollen share gradually increases to 32%. Still significant share of *Corylus* ~49%, share of *Alnus* ~17.5% and *Tilia* 10%, (*T. cordata, T. platyphyllos* and *T.* undiff.). *Quercus* share ~5%, *Ulmus* and *Fraxinus excelsior* 1.8% and 1% respectively. *Picea abies, Hedera helix*, *Taxus baccata*, *Acer*, *Buxus sempervirens* and *Viscum album* occur as single pollen grains. NAP in a

			low proportion (1.5%). The rush vegetation is represented by *Sparganium* t. pollen. Aquatic vegetation is represented by Nymphaeaceae trichosclerides and *Ceratophyllum* trichosclerides. A low proportion of Filicales monolete spores, as of Musci and *Pediastrum* and *Botryococcus* cenobia. The upper limit of the zone was placed at the further growth of *Carpinus betulus*, the decline of *Corylus*, *Quercus*, *Fraxinus excelsior* and *Ulmus*.
Pa-19 10	Carpinus-Corylus	11.40–11.10	Significant increase in *Carpinus betulus* to ~60%. Share of *Alnus* ~16% and *Tilia* 11%. *Corylus* decreases to ~14%. *Quercus*, *Ulmus*, *Fraxinus excelsior* 2%, 1.2%, 0.5% respectively. The beginning of a continuous curve of *Picea abies*. Pollen grains of *Buxus sempervirens, Taxus baccata*, *Acer*, *Hedera helix*, *Viscum album* and *Salix are* regularly present. Low proportion of NAP (1%). The rush vegetation is represented by *Sparganium* t. and *Typha latifolia*. Aquatic vegetation is represented by Nymphaeaceae trichosclerides ca (2.5%) and *Ceratophyllum* trichosclerides (4%). The spores of Filicales monolete and Musci are present and the maximum proportion of *Pediastrum* ~40%, *Botryococcus* and *Tetraedron* 11% each is notable. The upper limit of the zone was placed at the growth of *Carpinus betulus*, *Picea abies,* the beginning of the curve of *Abies alba* and the decline of *Tilia* (total) and *Corylus*.
Pa-19 11	Carpinus	11.05–10.90	Maximum proportion throughout the profile of *Carpinus betulus at* 65%. Beginning of the percentage curve of *Abies alba* and increasing to 5.5%. Decreases in percentage of *Corylus*, *Alnus* and *Tilia* 19%, 18% and 9% respectively. Low percentages of *Quercus* and *Ulmus. Fraxinus excelsior, Hedera helix, Taxus baccata,* and *Viscum album* appear as single pollen grains. At the zone boundary, the disappearance of thermophilous shrubs is evident. The proportion of NAP is consistently at a low. However, a higher proportion of Poaceae undiff. was noted. The rush vegetation is represented by *Phragmites australis* t. and appears regularly from the previous zone *Typha latifolia*. Aquatic plants are represented by Nymphaeaceae trichosclerides and *Ceratophyllum* trichosclerides. The spores of Musci and Filicales monolete are still present in a small proportion, as are the cenobia *Pediastrum* and *Botryococcus*. The upper limit of the zone was placed at the growth of *Abies alba* and *Picea abies* and the rapid decline of *Carpinus betulus.*
Pa-19 12	Abies	10.85–10.80	Increase and maximum proportion of *Abies alba* ~17.5%, high proportion of *Picea abies* between 25-56%. Share of *Carpinus betulus* decreases to 10%, *Alnus* values temporarily increase to 23%, *Corylus* decreases to 4%, *Tilia* occurs as single pollen grains. Low proportions of *Quercus* below 2% and *Ulmus* and *Fraxinus excelsior* occur as single pollen grains. *Taxus baccata* and *Hedera helix* pollen appear sporadically. While still a low proportion of NAP, there was an increased frequency of pollen from Poaceae undiff. and Cyperaceae. Aquatic vegetation is represented by Nymphaeaceae trichosclerides and *Ceratophyllum* trichosclerides. Spores of Filicales monolete, *Pteridium aquilinum* and a significant proportion of Musci ~11% are present. The proportion of Musci highest in the whole profile 11%, *Pediastrum* and *Botryococcus* at low zones. Of note is the significant presence of Gaeumannomyces 16.5%. The upper limit of the zone was set at the growth of *Picea abies*, *Pinus sylvestris* t. and the decline of *Abies alba*.
Pa-19 13	Picea	10.75–10.70	Maximum proportion of *Picea abies* throughout the profile ~70%. Decrease in percentage of *Abies alba* to 8%, increase in *Pinus sylvestris* t. to 11%. Decrease in proportion of *Carpinus betulus* to 9% and *Alnus* to 6%. *Betula*, *Quercus* and *Corylus* in the form of low percentage curves. *Taxus baccata*, *Acer*, *Hedera helix*, *Buxus sempervirens* and *Humulus lupulus* appear as single pollen grains. NAP growth up to 10% in mainly Cyperaceae, appear as single pollen grains of *Artemisia*, Poaceae undiff., Cyperaceae and Apiaceae. The rush vegetation is represented by *Comarum palustre* and *Phragmites australis* t. Among the aquatic plants, the maximum proportion is reached by Nymphaeaceae trichosclereids and *Ceratophyllum* trichosclerides. Spores of Musci, Filicales monolete and *Pteridium aquilinum* are present. The upper zone limit was placed at the growth of *Pinus sylvestris* t., the transient decline of *Picea abies* and the permanent decline of *Carpinus betulus* and *Alnus*.
Pa-19 14	Pinus-Picea	10.65–10.35	A gradual increase in the proportion of *Pinus sylvestris* t. to ~42% in the upper part of the zone, the proportion of *Betula* does not exceed 3%. The pollen percentage of *Picea abies* is ~50% and *Abies alba* ~10%. Noteworthy is the presence of *Fagus sylvatica* at 10.60 cm and *Larix* at 10.45 cm. Low percentage curves of *Quercus*, *Corylus*, *Alnus* and *Carpinus betulus* are present and *Ulmus* and *Fraxinus excelsior* and *Vaccinium* t. appear as single grains. *Salix* pollen is regularly present. *Humulus lupulus* pollen grains are also present. The proportion of NAP as before, mainly *Artemisia*, Poaceae undiff., Cyperaceae, regularly Apiaceae and Amaranthaceae and *Filipendula*. The rush vegetation is represented by *Phragmites australis* t. and *Typha latifolia*. In the older part, the presence of *Coelastrum reticulatum* is notable. The aquatic vegetation is represented by Nymphaeaceae trichosclereides and *Ceratophyllum* trichosclerides. Spores of Filicales monolete, *Pteridium aquilinum* and Musci are present, as well as a significant proportion of *Pediastrum* and *Botryococcus* (7.5% each) in the younger part of the zone. The upper limit of the zone was placed at a significant increase in *Pinus sylvestris* t. and a decrease in the percentage of *Picea abies* and a decrease in other trees and shrubs.
Pa-19 15	Pinus	10.30	Maximum proportion *Pinus sylvestris* t. 68%, *Betula* approximately 3%. Still significant proportion of *Picea abies* 37.5%. Percentage curves of *Quercus*, *Corylus*, *Alnus* and *Carpinus betulus* below 1%. The presence of *Vaccinium* t. is

			notable. NAP contribution up to 5% mainly Cyperaceae and Apiaceae. The aquatic vegetation is represented by the Nymphaeaceae trichosclereids. Spores of *Lycopodium* undiff are present. Filicales monolete, *Equisetum*, *Sphagnum* and Musci. *Pediastrum* and *Botryococcus* cenobia are occasionally present.

Table IV. Description of the Local macrofossil assemblage zones (LMAZs) of the St-19 core

MAZ number	Sample numbers [m]	Zone characteristics
MAZ 1	9.00–7.52	Terrestrial plant macrofossil are represented by *Betula pubescens* fruit scales, *Betula sec*. Albae, *Betula nana* and *Betula sec*. *Nanae* and *Carex* sp. nutlets. Aquatic plant macrohabitats are represented by individual seeds and seed fragments of *Najas marina*.
MAZ 2	7.42–6.58	Terrestrial plant macrofossils are represented by *Carpinus* sp. nuts. Aquatic plant macrofossils are represented by seed fragments of *Najas marina*, *Najas* sp. and *Potamogeton sp*.
MAZ 3	6.48–4.85	Terrestrial plant macrofossils are represented by the nuts of *Carpinus* sp. Aquatic plant macrofossils are represented by seeds of *Najas marina, Najas flexilis, Alisma plantago-aquatica*, fruits of *Ceratophyllum demersum* and endocarps of *Potamogeton* sp. In addition, oogonia of Characeae are present.
MAZ 4	4.67–3.43	Terrestrial plant macrofossils are represented by *Betula* sec. *Albae* and *Betula sec*. *Nanae*, nut fragments of *Tilia tomentosa* and *Corylus* sp., *Carex* sp. nuts including *Carex vesicaria* are also recorded. Aquatic plant macrofossils are represented by seeds of *Najas marina*.
MAZ 5	3.33–2.43	Lack of plant macrofossils.

Table V. Description of the Local macrofossil assemblage zones (LMAZs) of the G-120 core

L MAZ number	Sample numbers [m]	Zone characteristics
MAZ 1	5.65–5.10	Terrestrial plant macrofossil are represented by few nuts and catkin scales of *Betula sec*. Albae and *Betula sec*. Nanae, nuts of *Carex rostrata*, *Eleocharis palustris*, *Baeothryon cespitosum* and *Schoenoplectus lacustris*. The macro-nodules of aquatic plants include seeds of *Najas* sp.
MAZ 2	5.09–4.77	Macrofossil of terrestrial plants are represented by nuts and catkin scales of *Betula sec*. *Albae* and the nuts of *Betula sec*. *Nanae* and *Carex* sp. Aquatic plant macrofossils are represented by the fruis of *Ceratophyllum demersum*.
MAZ 3	4.75–4.27	Terrestrial plant macrofossil are represented by the fruit scales and nuts of *Betula* sec. *Albae*, as well as the nuts of *Carex elata* and *Carex vesicaria*, and the seeds of *Scheuchzeria palustris*. The macrofossil of aquatic plants are represented by seeds and seed fragments of *Najas marina* and *Lemna* sp., endocarps of *Potamogeton* sp. and fruits of *Ceratophyllum demersum*.
MAZ 4	4.25–3.50	Terrestrial plant macrofossil are represented by nuts and nut fragments of Betula sec. Albae, Alnus sp., Tilia tomentosa, Carpinus sp., Eleocharis palustris, Eriophorum latifolium, Carex vesicaria, Carex gracilis, Carex sp., Schoenoplectus lacustris and Baeothryon cespitosum and catkin scales of Betula pubescens. Aquatic plant macrofossils are represented by numerous seeds and seed fragments of Najas marina and Najas sp., oogonia of Chara sp. and Nitellopsis sp., fragment of Characeae oospore and endocarps of Potamogeton sp. are also marked, as well as fragments of fish scales.
MAZ 5	3.48–2.70	Terrestrial plant macrofossils are represented by nuts and nut fragments of *Alnus* sp., *Tilia cordata*, *Tilia tomentosa, Tilia platyphyllos*, *Corylus* sp. and *Carpinus* sp. and female catkins of *Alnus*. Apiaceae fruits and *Iris pseudoacorus* seeds are also present. Aquatic plant macrofossils are represented by seeds and seed fragments of *Najas flexilis*, *Najas marina*, *Najas* sp. endocarps of *Potamogeton* sp. Fish teeth and scale fragments, insect cover fragments and a mollusc fragment also are recorded.
MAZ 6	2.68–1.90	Terrestrial plant macrofossil are represented by nuts and nut fragments of *Betula* sec. *Albae*, *Tilia tomentosa*, *Corylus* sp. and *Carpinus* sp. and female catkins of *Alnus* sp.. Aquatic plant macrofossil are represented by seeds and seed fragments of *Najas* sp., *Najas marina* and endocarps of *Potamogeton* sp. Insect cover fragments and fragments of the head apparatus of Chironomidae were also recorded.
MAZ 7	1.88–1.36	Lack of plant macrofossils

Table VI. Description of the Local macrofossil assemblage zones (LMAZs) of the Pa-19 core

L MAZ number	Sample numbers [m]	Zone characteristics
MAZ 1	13.15–12.80	Terrestrial plant macrofossil are represented by fruiting bodies and scales of *Betula* sect. Albae, bud scales of Pinaceae, megaspores of *Thelypteris palustris*, fruiting bodies of *Carex pseudocyperus*, *Carex* sp., tegmena of *Typha* sp. and seeds of *Phragmites australis*. Aquatic plant macrofossils are represented by *Stratiotes* sp. (spines), seeds of *Nymphaea alba* and endocarps of *Potamogeton* natans. Additionally, tree fragments, leaves, *Cristatella mucedo* statoblasts, fish and mite remains were recorded.
MAZ 2	12.78–12.65	Macrofossil of terrestrial plants are represented by fruiting bodies of *Betula* sect. Albae, bud

		and seed scales of Pinaceae and fruiting bodies of *Tilia platyphyllos*. Musci and fruiting bodies of *Carex* sp. *trigonous* are also present. Aquatic plant macrofossils are represented by seeds of *Najas marina* and oospores of Characceae. In addition, leaf fragments and statoblasts of *Cristatella mucedo* were recorded.
MAZ 3	12.55–12.30	Terrestrial plant macrofossils are represented by bud and seed scales of Pinaceae, fruits of *Tilia platyphyllos*, Musci and tegmena of *Typha* sp. Aquatic plant macrofossils are represented by seeds of *Nuphar* and *Najas marina*. Additionally, leaf fragments and statoblasts of *Cristatella mucedo* were recorded.
MAZ 4	11.95–11.35	Terrestrial plant macrofossils are represented by bud scales and seed scales of Pinaceae, fruits of *Tilia platyphyllos and fruit* scales of *Acer* sp. and seeds of *Iris pseudoacorus* and tegmena of *Typha* sp. Aquatic plant macrofossil are represented by *Stratiotes* sp. (spines), seeds of *Stratiotes* sp. and *Najas marina*. Tree and leaf fragments and *Cristatella mucedo* statoblasts were also recorded.
MAZ 5	11.30–11.20	Terrestrial plant macrofossils are represented by bud and seed scales of Pinaceae and Musci. Aquatic plant macro-nodules are represented by *Stratiotes* sp. (spines), seeds of *Najas marina*, *Najas minor* and *Najas flexilis* and endocarps of *Potamogeton rutilus*.
MAZ 6	11.10–10.90	Terrestrial plant macrofossils are represented by fruiting bodies and fruit scales of *Betula* sect. Albae, bud and seed scales of Pinaceae, fruiting bodies of *Alnus glutinosa*, *Tilia platyphyllos*, *Tilia cordata*, *Acer* sp. and *Carpinus betulus* and Musci, and fruiting bodies of *Carex riparia* and *Carex sp*. trigonous and, tegmena of *Typha* sp. Aquatic plant macrofossils are represented by a very abundant occurrence of *Stratiotes* sp. (spines), seeds of *Stratiotes sp*., *Nymphaea alba*, *Najas marina, Najas minor*, *Najas flexilis* and endocarps of *Potamogeton natans*, *Potamogeton rutilus*, Potamogeton sp., *Potamogeton sukaczevii, Potamogeton gramineus*, *Potamogeton perfoliatus* and *Potamogeton friesii*. Numerous remains of *Trapa natans* in the form of nuts, spines and harpoons. Seeds of *Brasenia* sp. and oospores of Characeae are also present. Statoblasts of *Cristatella mucedo* have also been recorded.
MAZ 7	10.85–10.65	Terrestrial plant macrofossil are represented by fruiting bodies and scales of *Betula* sect. Albae, seed scales of Pinaceae, fruiting bodies of *Alnus glutinosa*, *Tilia platyphyllos* and *Carpinus betulus*, needles and seeds of *Picea abies and seeds*, seed scales, cone fragments and needles of *Abies alba* and leaf fragments of *Ledum palustre*. Musci, fruiting bodies of *Carex* sp., *Carex riparia*, *Carex* sp. *biconvex*, *Carex* sp. *trigonous* and *Carex elata* and hyatodes of *Scheuchzeria palustris,* fruiting bodies of *Menyanthes trifoliata,* seeds of *Comarum palustre*, fruiting bodies of *Cicuta virosa* and stems of *Phragmites australis* t. *australis* are abundant. Aquatic plant macrofossil are represented by single fruits of *Schoenoplecus lacustris* and spikes of *Trapa natans*.
MAZ 8	10.60–10.40	Macrofossil of terrestrial plants are represented by fruits of *Betula* sect. Albae, bud scales of Pinaceae, fruiting bodies of *Alnus glutinosa*, *Tilia platyphyllos,* needles of *Picea abies*, seeds, seed scales and needles of *Abies alba,* needles of *Pinus* sylvestris t., seeds and leaf fragments of fruiting bodies and leaf fragments of *Ledum palustre*. Musci, fruiting bodies of *Carex* sp., *Carex riparia*, *Carex* sp. *trigonous*, *Carex vesicaria*, Carex *elata*, *Carex diandra* and *Carex aquatilis* and also, hydatodes of *Scheuchzeria palustris,* fruiting bodies of *Menyanthes trifoliata*, seeds of *Comarum palustre* and fruiting bodies of *Cicuta virosa* are abundant. Aquatic plant macrophytes are absent. Tree fragments are present.
MAZ 9	10.35–10.30	Terrestrial plant macrofossil are represented by fruits and fruit scales of *Betula* sect. Albae, bud scales of Pinaceae, needles and seeds of *Picea abies*, needles of *Abies alba*, seeds of *Pinus sylvestris* t. and *Chamedaphne calcyculata*. Musci, fruiting bodies of *Carex riparia*, *Carex* sp. *biconvex*, *Carex diandra* and seeds of *Phragmites australis* t. are also present. Aquatic plant macrophytes are absent. Tree fragments are present.