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Pollen-based vegetation and climate reconstruction of the Ferdynandovian sequence from Łuków (eastern Poland)

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ABSTRACT. Early middle Pleistocene deposits from Łuków, correlated with the Cromerian complex, represent rare bi-partite Ferdynandovian pollen sequence encompassing two interglacial warmings (F1 and F2) separated by F1/2 cooling/glaciation and related to MIS 15–13. The paper presents pollen-based palaeoecological and palaeoclimate investigations in which plant climate indicators were applied. Additionally modern pollen dataset from the Roztocze region was used to evaluate vegetation history in terms of forest communities and presence and abundance of tree taxa sensitive to air temperature and humidity. Climate changes derived from pollen data indicate strong oceanic features of the climate of the first interglacial (F1) resembling those typical for the beginning of the Eemian, followed by cooling (F 1/2) with plant communities typical of the Pleistocene steppe-tundra, which undoubtedly indicate strong continentality, and subsequent return of more oceanic climate (F2) with mean remperature of the warmest month exceeding 18°C. Both pollen succession and climate changes recorded in the Łuków sediments correlate well with other bi-partite successions known from eastern part of European Lowlands.

KEYWORDS: Ferdynandovian pollen succession, Middle Pleistocene, Cromerian complex, Łuków Plain, MIS 15–13

INTRODUCTION

The profile from Łuków (Łuków Plain – eastern Poland) is regarded one of the most important and complete record of Ferdynandovian pollen sequence correlated with the Cromerian complex in West European stratigraphy (Zagwijn 1996a). In the Łuków Plain and adjoining it Żelechów Plain numerous palaeolakes filled with deposits of different interglacials occur (Żarski et al. 2005). Among them there is well recognized long-pollen sequence of Zdany which is not only located very close to Łuków but is of the same age, as well (Pidek 2000, 2003). The history of earlier studies on the Quaternary deposits found in Łuków dates back to 1960s (Rühle 1969) and was then related to Cromerian by Sobolewska (1969). The new coring Łuków – 3a (Fig. 1) drilled for the needs of the Detailed Geological Map of Poland scale 1: 50 000 – Łuków sheet (Małek & Buczek 2006) enabled new palynostratigraphic investigations to be presented against the background of the historical profile by Pidek and Małek (2010). The unique character of the Cromerian deposits from eastern Poland in the European scale was mentioned among others by Janczyk-Kopikowa et al. (1981), Turner (1996), Zagwijn (1996a), Lindner et al. (2001). The completeness of the Ferdynandovian sequence from Łuków-3a and long sequence of the middle Pleistocene age encourages to study all possible aspects concerning palaeoecology and palaeoclimate recorded within the two interglacial units and adjoing them cold units. In order to refine temporal resolution and the boundaries of pollen zonation 72 additional pollen samples were elaborated in 2010–2012 years. Thus the complete pollen diagram is based on the results of investigations of 161 samples and covers the

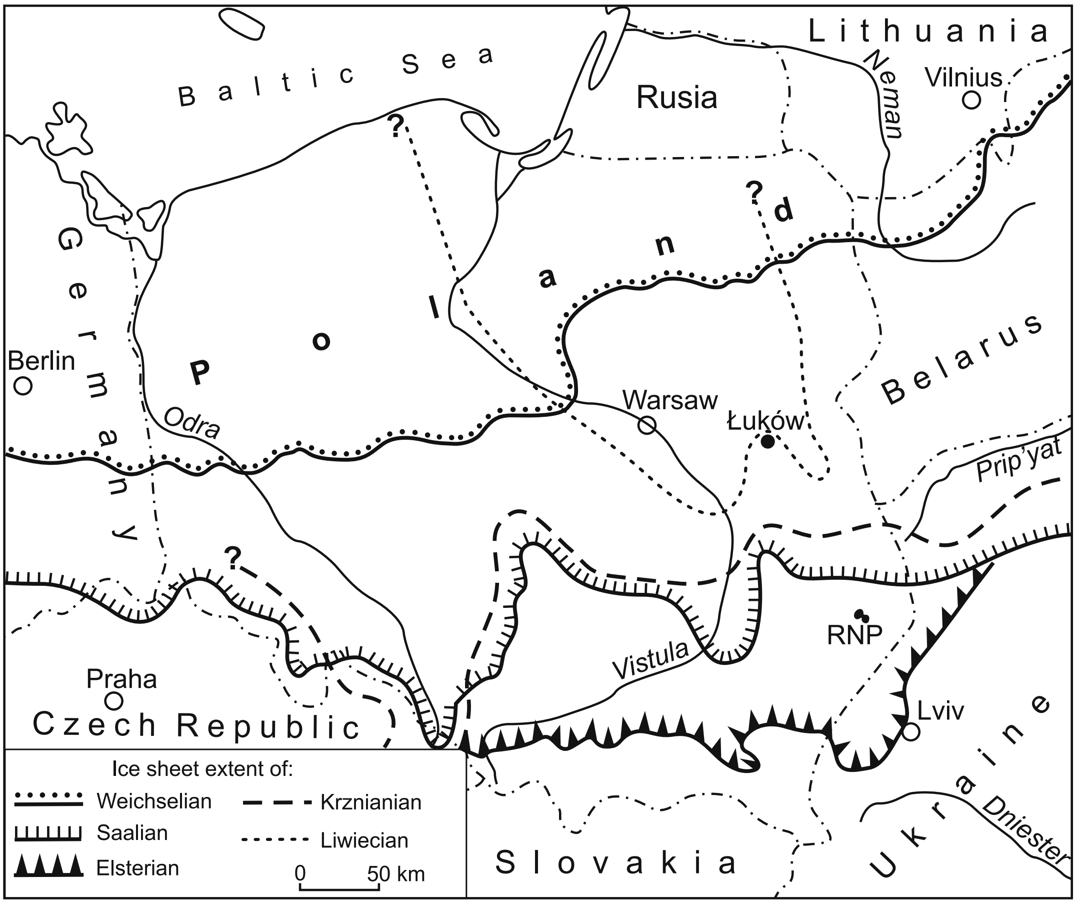

Fig. 1. Situation of the studied site in Łuków against the background of the limits of the ice sheets according to Lindner and Marks (2012). RPN stands for the Roztocze National Park

whole organogenic series among glacial deposits of the Sanian 1 and Sanian 2 (Małek & Buczek 2006). High temporal resolution enabled more precise interpretations of vegetation history and climate changes and especially allowed detailed recognition of the sequence of Sanian 2 (= Elsterian 2) early glacial deposits. Modern pollen analogues approach combined with plant-indicators taxa approach has been tested lately on the fossil dataseries from Łuków-3a and Zdany (Pidek & Poska 2013) in order to reveal history of climate changes throughout this long fossil seqences. Modern pollen analogues have been widely used in climate interpretations of fossil situations (examples in Guiot et al. 1989, 1990, Cheddadi et al. 1998, Tarasov et al. 2005) but were never applied to deposits older than the Eemian. In the present paper the potential of pollen presence/absence threshold values of several forest forming species has been tested to refine vegetation changes and climate interpretations. The theory behind this method was discussed lately by Lisytsyna et al. (2011) but they have never been used before in palaeoecological and palaeoclimatic interpretations to fossil situations older than the Holocene in the Scandinavia (Seppä & Hicks 2006). An essential question in these investigations is what pollen threshold values represent "in situ" occurrence of a species and what values can be atributed to long-distance transport of pollen (Hicks 2001). Long term Tauber-trap record from moderate climate zone (Roztocze region in south-eastern Poland) gathered by the author for 13 years (1998–2010) provide a rare opportunity to estimate pollen presence/absence threshold values and to test the results in fossil situation of the high resolution sequence from Łuków-3a.

From among different trapping media Tauber traps have been most commonly used to monitor annual pollen deposition in standardized ways (Hicks et al. 1996, Giesecke et al. 2010). They produce the results that can potentially be applied to interpret pollen records from lake cores. Hicks (2001) suggests that from long term average values of pollen accumulation two signals can be extracted, one of climate and one of plant abundance. When

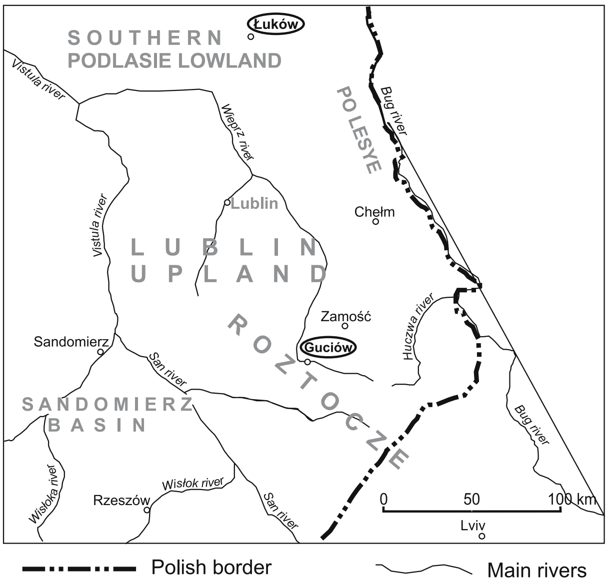

Fig. 2A. Situation of the fossil pollen site in Łuków and the site for monitoring modern pollen deposition in the Roztocze region (Guciów village). Regions after Kondracki (1998)

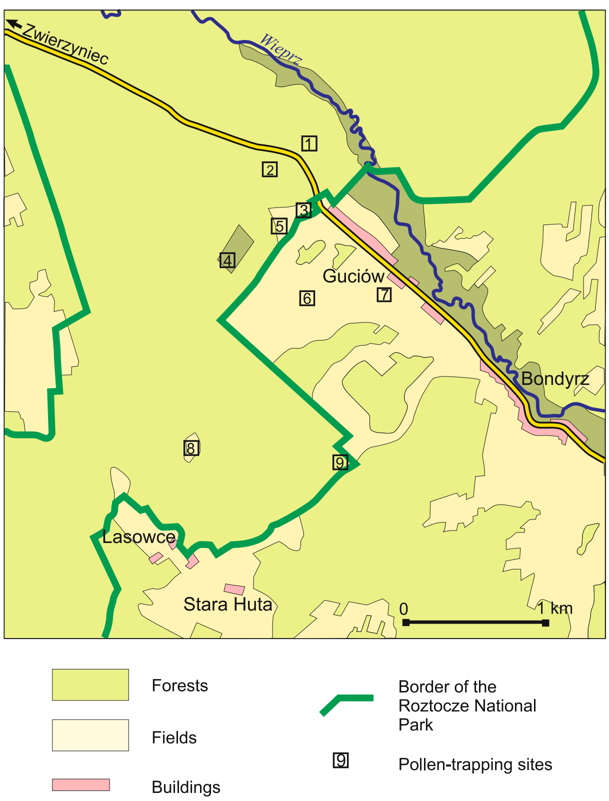

Fig. 2B. Location of pollen traps around the Guciów village in the Roztocze region. Explanations in Table 4

applied to fossil situations these can give more objective basis for interpretations of species presence and abundance by providing pollen presence/absence threshold values. Thermophilous plants and trees sensitive to the humidity of air and soil are of special interest in this interpretation as they can be used as climate proxies. In the present study modern pollen dataset from the Roztocze region (south-eastern Poland) has been used for rough estimates of pollen presence/absence thresholds for several major forest forming trees (*Abies*, *Fagus*, *Picea*, *Carpinus*, *Tilia*, *Quercus*, *Ulmus*, *Fraxinus*, *Alnus*). The modern dataset is the only one long-term pollen record from the moderate climate zone outside the mountain areas, which makes it free from interpretive problems connected with upslope transport of pollen and its deposition above the treeline frequently far from source plants. The potential of the data-series from Roztocze lies also in its well-recognized vegetation situation as pollen traps are placed in the Roztocze National Park and its protective zone (Fig. 2A, B). Calculated average percentage values for each of the investigated tree taxa have been adopted to long pollen sequence of the Ferdynandovian pollen diagram of Łuków-3a and used for palaeoecological and palaeoclimate interpretations. Main focus in these investigations is placed in terrestrial vegetation response to oceanic or continental climate features.

MATERIAL AND METHODS

POLLEN ANALYSIS OF THE ŁUKÓW-3A CORE

Fossil pollen samples from the Łuków-3a organogenic deposits (depth 24.48–34.60 m) were prepared according to standard palynological procedures (HCl, KOH, HF, Erdtman's acetolysis). Percentage pollen diagram (Fig. 3) was prepared using POLPAL software (Nalepka & Walanus 2003). Calculations of pollen percentages were based on the sum of trees and shrubs pollen (AP) and of terrestrial herbs and dwarf shrubs (NAP). Percentages of aquatic and lake-shore vegetation pollen, of Pteridophyta and Bryophyta spores, *Pediastrum* coenobia and of redeposited sporomorphs were calculated in relation to the sum AP+NAP+the examined taxon. The diagrams have been divided into 19 pollen assemblage zones (Ł-1 – Ł-19 L PAZs) following the criteria published by West (1970) and Janczyk-Kopikowa (1987). Characteristics of pollen spectra have been provided in Tab. 1.

MONITORING POLLEN DEPOSITION IN TAUBER-STYLE TRAPS IN THE CENTRAL ROZTOCZE REGION

Nine monitoring sites have been situated around the Guciów village (50°34′N; 23°04′E) in the Roztocze National Park and its protective zone (ca 160 km to the south from Łuków). Forests of different types cover more than half of the Roztocze area. The most natural parts include 19 different forest associations

(Izdebski et al. 1992). The upland relief is enriched with the Wieprz river valley, which causes the zonal distribution of forest communities. Silver fir woods (*Abietetum polonicum*) cover lower and middle parts of the hill slopes and beech forests (*Dentario-glandulosae – Fagetum*) – the summits of the hills (Izdebski et al. 1992). Bottom of the valleys are overgrown by swamps and alder carrs. Different pine communities occur on vast areas mainly on dunes and plains. Total surface occupied by particular forest communities is listed in Table 2. In the village of Guciów Grądziel et al. (2006) found several forest associations (Tab. 3) that occupy 52% of its area.

TAUBER-STYLE POLLEN TRAP

The trap design follows the Pollen Monitoring Programme (PMP) guidelines (Hicks et al. 1996). The trap is a 5-litre plastic container with 5 cm diameter opening. Nine traps are placed in different plant communities within the Park and around the village (for details see Pidek et al. 2010b). Every October traps are collected, the contents is filtered, acetolysed and subjected to microscopic analysis. In the present study percentage values of tree taxa occurring in pollen spectra are calculated. Average percentage values for each taxon is based on 13 years data (1998–2010) from all traps (Tab. 4, Fig. 2B). Two basic sums are used to percentage calculations: AP+NAP = 100% and AP = 100% sum (Tab. 5).

RESULTS

Average values of pollen percentages obtained in the course of monitoring pollen deposition in the Roztocze (Tab. 5) were used during interpretataion of vegetation history revealed by pollen diagram from the Łuków-3a profile.

Vegetation history and climate changes derived from pollen data have been described against the background of new division of the Ferdynandovian pollen sequence based on Podgórze B1 pollen succession (Mamakowa 2003) subsequently named F1 and F2 representing two warm periods of interglacial rank and F1/2 – cooling/glaciation separating them (acc. to Lindner et al. 2004, Winter 2006).

F1 INTERGLACIAL (Ł1–Ł8 L PAZs)

Ł1 *Betula–Larix*-NAP L PAZ. Numerous herb pollen, continuous curves of *Salix* undiff., *Betula nana* t., *Juniperus*, and *Artemisia* indicate presence of different plant communities of open landscape in cold climate conditions of the late glacial /interglacial transition. High values of redeposited pre-Quaternary sporomorphs testify to low stability of the ground thus pollen of thermophilous taxa common both in the Neogene and the Quaternary is probably rebedded, too. In the younger part of the zone reconstruction of plant communities is observable. Pioneer pine-birch forest spread, which must have been quite loose as evidenced by considerable percentages of Poaceae and Cyperaceae pollen as well as presence of *Pteridium aquilinum* and other heliophilous taxa (*Artemisia*, *Anthemis* t., *Aster* t.) Sharp decline of redeposited sporomorphs indicate stabilisation of the ground. Larch and spruce may have played important role in these pine-birch forests. Admixture of stone-pine is also probable (pollen of *Pinus cembra* t.).

The lake water must have been warm enough to enable development of *Ceratophyllum* sp. and *Nymphaea* sp. and was probably surrounded by reed belt with *Typha latifolia*.

Ł2 *Pinus-Betula* L PAZ. Communities of open landscape were replaced by forest as evidenced by increasing proportion of pine pollen. *Picea* and *Quercus* trees were probably scattered in pine forests with birch admixture at that time. *Betula nana* probably persisted on mires around the lake. In the lowermost sample also the presence of *Selaginella selaginoides* may be associated with these mire communities. Continuous curve of *Ulmus* up to 0.7%, which begins in this zone and increasing amount of *Quercus* pollen (up to 1.1%) might suggest that these trees began to encroach on more wet and fertile habitats of river valleys. Modern semi-cultural and partly open landscape of the Roztocze region, where elm trees are single and scattered among other trees, produces on average 0.2–0.4% of *Ulmus* pollen in the pollen traps (Tab. 5). Taking into account that Poaceae pollen is frequently overrepresented in Tauber traps (24% on average), it seems that 0.4% of elm pollen can potentially be adopted as local presence/absence threshold of *Ulmus* trees in the vegetation. In such an interpretation the value of 0.7% in fossil samples from Ł2 zone may suggest that elm trees were present in the surroundings of the lake in Łuków at that time. The value of 0.7% begins the continuous elm pollen curve and might indicate the beginning of formation of elm riverine communities. Among three elm species (*Ulmus glabra*, *U. laevis*, and *U. minor*) *Ulmus glabra* is the most tolerant to low air temperature (Zarzycki et al. 2002). *Quercus robur* might have also been the component of these early

Table 1. Characteristic features of pollen spectra in the local pollen assemblage zones distinguished in the Łuków-3a pollen profile

Local pollen assemblage zone	Sample depth/ Number of samples	Characteristics of pollen spectra
Ł 1 *Betula-Larix-* NAP	34.35–34.60 m 4 samples	In the samples 34.60–34.45 m – very low frequency of sporomorphs; numerous pre-Quaternary taxa (*Sciadopitys*, *Ilex*, *Ligustrum*, *Juglans*, Gleicheniaceae, Dinoflagellate cysts, *Engelhardtia/Platycarya*, and other taxa common both in Neogene and Quaternary such as *Quercus*, *Carpinus*, *Tilia*, *Alnus* – the latter taxon mostly with 4-pored grains). In the samples 34.35–34.40m – the frequency improves and simultaneously the number of rebedded pre-Quaternary sporomorphs is reduced. *Pinus* pollen values range from 24.5 to 46.0%; those of *Betula* undiff. – from 33.0 to 48.5%; *Larix* percentages up to 2.0%; *Alnus* – up to 9.5%; *Picea* – up to 1%; frequent *Salix* pollen; single grains of *Ulmus*, *Quercus*, and *Fraxinus*; Cyperaceae – up to 4.0%; Poaceae – up to 10.5%. Reedswamp plants pollen occur (*Typha latifolia*, *Phragmites*), idioblasts of Nymphaeaceae, *Ceratophyllum* hairs, and *Pediastrum* coenobia (*P. kawraiskyi*, *P. boryanum* var. *boryanum*). In the upper part of the zone numerous are Musci excl. *Sphagnum* and *Sphagnum*, Filicales monolete and *Pteridium aquilinum* spores. Sporadic are *Equisetum* spores
Ł 2 *Pinus-Betula*	34.10–34.25 m 4 samples	Percentage values of *Quercus* increase to 1.1%; those of *Ulmus* – up to 0.7%, *Pinus* – up to 67.5%. *Betula* undiff. values fall to 27.5%. Continuous pollen curves of *Alnus*, *Larix*, *Picea* occur and single pollen grains of *Pinus cembra* t. NAP proportion decreases, in it Cyperaceae and Poaceae percentages – to 3–5%; among NAP different new taxa appear (*Filipendula*, Cichorioideae, *Rumex acetosella*, *Plantago media*); *Betula nana* t. pollen forms still continuous curve. Musci excl. *Sphagnum* spores are less numerous and those of *Sphagnum* occur sporadically. *Pteridium aquilinum* spores form a continuous percentage curve with values up to 3.3%, Filicales monolete spores are frequent, single spore of *Selaginella selaginoides* occurs, pre-Quaternary sporomorphs are less frequent as well as *Pediastrum* coenobia
Ł 3 *Pinus-Betula-Quercus*	33.85–34.05 m 5 samples	Pine pollen values still high (ca 60%); those of birch-range from 21.0 to 25.5%; *Picea*, *Larix*, *Fraxinus* pollen are still frequent, *Alnus* and *Ulmus* percentages increase to ca 3.5%, *Quercus* values rise to 8.5%; first pollen grains of *Tilia*, *Viburnum*, *Frangula*, and *Corylus* appear; pollen of *Humulus* forms continuous curve with values up to 1.2%. Poaceae and Cyperaceae values fall to ca 1–2%; those of *Artemisia* to less than 1%. *Betula nana* t. pollen disappears. Pollen of taxa associated with wet meadows: *Filipendula*, Apiaceae undiff., *Rumex acetosa*, *Ranunculus acris* t. are frequent as well as *Thalictrum* pollen especially in the lower part of the zone. High percentages of *Pteridium aquilinum* spores continue. Among aquatics pollen of *Potamogeton* sect. Coleogeton and *Ceratophyllum* hairs are present, *Tetraderon* is very abundant among algae, *Pediastrum boryanum* and *Pediastrum kawraiskyi* are present. Among reedswamp taxa *Typha latifolia* t. and *Phragmites* t. pollen occur
Ł 4 *Quercus-Ulmus-Alnus-/Corylus/*	33.25–33.80 m 11 samples	Decrease of *Pinus* pollen to 22.0%; those of *Betula* – to 5–6%; *Picea* pollen is sporadic; considerable rise of *Quercus* percentages (up to 26.5%), *Ulmus* and *Alnus* – rise up to 17% and 20%, respectively; *Fraxinus* and *Tilia* undiff. – up to 1.0–1.5%, single pollen grains of *Tilia platyphyllos*, *Celtis*, *Pterocarya*, and *Viburnum*; sharp increase of *Corylus* – up to 19.5% in the upper part of the zone; frequent *Acer* and *Hedera* pollen; still continuous curve of *Humulus*; single pollen grains of *Vitis*; more frequent spores of *Pteridium aquilinum*. NAP values are low; Poaceae and Cyperaceae – below 1%, quite abundantly present pollen of taxa of wet meadows: *Lythrum*, *Valeriana officinalis* t., *Thalictrum*, *Plantago major*, *Ranunculus acris* t., *Rumex acetosa* t., *Galium* t., *Lysimachia*. *Typha latifolia* t. pollen occurs regularly and *Pediastrum* coenobia are more frequent (up to 1.7%)
Ł 5 *Corylus*	32.60–33.20 m 12 samples	Increase of *Corylus* values up to 37.0% in the upper part of the zone; the values of *Ulmus*, *Quercus*, and *Alnus* range from ca. 8 to 18%; *Tilia* undiff. percentages rise to 3.3% and those of *Fraxinus* – to 1.5% and *Acer* – to 0.9% and form almost continuous curve; pollen of *Tilia platyphyllos* t. and *Celtis* occurs regularly; in the upper part of the zone continuous pollen curve of *Taxus* appears and first pollen grain of *Abies* and *Carpinus*, *Pinus* values fall and range between 16–26%; those of *Betula* undiff. – to ca 2–6%; *Ligustrum* pollen is quite frequent, *Humulus* pollen curve continues and the presence of *Buxus*, *Hedera*, *Ilex*, *Viburnum* pollen is worth mentioning. Percentages of Poaceae and Cyperaceae are less than 1%, *Artemisia* and Chenopodiaceae pollen are not frequent, numerous are pollen grains of wet-meadow taxa: *Filipendula*, *Thalictrum*, *Galium* t.; *Lythrum*, *Valeriana officinalis* t., *Campanula*, Fabaceae undiff., *Sagina*, *Rhinanthus.* Percentages of Musci excl. *Sphagnum* and Filicales monolete fall. Among aquatic taxa coenobia of *Pediastrum* are more frequent and more diverse; fragment of *Salvinia* microsporangium tissue appears and pollen of *Trapa natans*. Beside *Phragmites*, among reed swamp taxa pollen, *Sparganium* t., *Typha latifolia* t., and *Scheuchzeria palustris* are found
Ł 6 *Quercus-Tilia-Abies-/Taxus/*	31.75–32.55 m 13 samples	Maximum of *Tilia* and *Picea* pollen – 4.5% and 8.8%, respectively; continuous pollen curves of *Taxus* and *Abies* with maxima up to 3.7% and 2.7%, respectively. *Alnus* percentages high – up to 25.5%; those of *Quercus* – to 36.5%; *Ulmus* and *Corylus* values fall simultaneously to ca 6% in the upper part of the zone; *Fraxinus* percentages do not change significantly, pollen of *Acer* is frequent; sedges and grasses appear sporadically in pollen spectra; pollen of *Tilia platyphyllos*, *Celtis*, *Ligustrum*, *Hedera*, *Vitis*, and *Ilex* occur, *Humulus* pollen is frequent

Table 1. Continued

Local pollen assemblage zone	Sample depth/ Number of samples	Characteristics of pollen spectra
Ł 6 *Quercus-Tilia-Abies-/Taxus/*	31.75–32.55 m 13 samples	Very low pollen values of *Pinus sylvestris* t. increase slightly in the upper part of the zone to 12%, *Betula* values are low too, as well as NAP. Still frequent are taxa associated with wet meadows: *Filipendula*, *Cirsium/Carduus*, *Galium* t., *Ranunculus acris* t., *Rumex acetosa* t., *Mentha*, *Lycopus. Liliaceae*, and *Thalictrum.* Among reedswamp taxa *Typha latifolia* t. and *Phragmites* are frequent, proportion of *Pediastrum* is higher and *Coelastrum reticulatum* and *Scenedesmus* appear among algae. In the younger part of the zone *Salvinia* mikrosporangium tissue appears again and *Ceratophyllum* hairs are present
Ł 7 *Pinus-Betula*	30.95–31.65 m 10 samples	Pine pollen values range from 54.0 to 84.0%; those of birch – from 10.5 to 30.0%; *Picea* pollen – more frequent in the lower part of the zone, in the upper part – falls to 0.4%; *Larix* appears again; percentages of *Alnus* fall considerably (to 0.2–0.5% in the upper part of the zone) as well as those of all thermophilous taxa i.e. *Fraxinus* pollen almost disappears except for a single pollen grains; *Ulmus* values fall to 0.3%, those of *Quercus* – up to 1.6%, *Corylus* pollen is rare, *Humulus* pollen curve decreases and *Filipendula* pollen is rare. *Hedera*, *Ligustrum*, *Buxus*, *Ilex*, and *Vitis* pollen do not appear, however single pollen grains of *Carpinus* are observed and pollen of *Juniperus*, *Betula nana* t. occurs again, *Calluna*, and Ericaceae undiff, are frequently found. In the older part of the zone pollen of taxa associated with wet meadows is frequent: *Thalictrum*, *Rumex acetosa* t., *Lychnis* t., *Sanguisorba officinalis* 2n = 56, *Galium* t., *Polygonum bistorta/ viviparum*, and *Peucedanum palustre* t. Pollen grains of taxa of dry habitats are not numerous: *Artemisia*, *Aster* t., *Dianthus* t. *Helianthemum nummularium* t. Proportion of Musci and *Sphagnum* spores increases, *Pteridium aquilinum* is frequent. *Trapa natans* pollen occurs in the sample of 31.30 m. *Pediastrum* is more frequent, *Coelastrum reticulatum* is still present and again *Ceratophyllum* hairs occur. Among reedswamp plants pollen of *Typha latifolia* occurs
Ł 8 *Betula-Pinus-* NAP	30.65–30.85 m 5 samples	*Betula* undiff. pollen is more frequent than in the previous zone (up to 42.0%); *Pinus* percentages are ca 30–40%; *Larix* forms again continuous pollen curve; *Picea* and *Quercus* percentages increase (up to 8% and 12.5%, respectively). In the upper part of the zone pollen of *Abies*, *Fraxinus*, *Ulmus*, *Quercus*, and *Tilia* occur as well as sporadic pollen grains of *Carpinus*, *Acer* and *Corylus.* Percentages of *Betula nana* t., *Juniperus* increase; in the younger part of the zone high values of Poaceae, Cyperaceae, *Artemisi*a, Chenopodiaceae occur. Pollen of Apiaceae undiff. forms continuous pollen curve throughout the zone, pollen of *Thalictrum*, *Sagina* t. *Rumex acetosa* t., *Urtica*, *Filipendula*, *Pleurospersum austriacum*, *Rhinanthus* t., *Galium* t., and Brassicaceae are present. Among reedswamp plants *Typha latifolia* t., *Phragmite*s t. and *Rumex aquaticus* t. pollen occurred. Percentages of Musci excl. *Sphagnum* and *Sphagnum* are the same as in the previous zone, similar to Filicales monolete and *Pteridium aquilinum* spores, the proportion of *Pediastrum* coenobia increases and their composition is more diverse
Ł 9 NAP-*Betula*	30.15–30.60 m 7 samples	NAP dominates – up to 64%. *Pinus* percentages increase up to 53–55% in the upper part, then decrease; proportion of *Betula* decreases, *Picea* is frequent in the lower part of the zone (up to 3.4%), then decreases, *Larix* forms continuous pollen curve up to 0.7%, in the lower part of the zone *Abies* pollen occurs regularly and *Ulmus*, *Quercus*, *Tilia* reach ca 1% each, proportion of *Salix* and *Juniperus* increase (up to 5.3% and 2.1% respectively), single pollen grains of *Salix polaris* t., *Ephedra fragilis* t., and *Hippophaë*, frequent are *Calluna* and other Ericaceae undiff. pollen, single pollen grain of *Bruckenthalia* cf. *spiculifolia* occur, NAP values increase rapidly; in it Poaceae up to 29%, *Artemisia* up to 16%, Cyperaceae up to 22.5%, Chenopodiaceae pollen forms continuous curve with maximum of 2%. Numerous pollen of taxa of wet meadows occur: *Lythrum*, *Filipendula*, *Comarum palustre*, *Rumex acetosa* t., *Ranunculus acris* t., *Anthemis* t., *Sanguisorba officinalis* 2n = 56, *Polygonum bistorta/ viviparum*, *Mentha* t., *Lychnis* t., *Sagina* t., *Trollius*, *Cerastium* t., *Polygonum aviculare* t., *Lysimachia vulgaris* t., *Thalictrum*, *Galium* t. Pollen of dry grasslands is represented by *Gypsophila fastigiata*, *Bupleurum* t., *Aster* t., *Dianthus* t., *Scleranthus perennis*, *Rumex acetosella* t., *Aster* t., *Anthemis* t. *Thalictrum*, *Ranunculus acris* t., *Comarum* t., Cichorioidae, *Galium* t., and *Filipendula*. Proportion of Musci excl. *Sphagnum* and *Sphagnum* spores is high, especially in the upper part of the zone. Among aquatic and reedswamp taxa pollen of *Typha latifolia*, *Myriophyllum spicatum*, *Alisma plantago-aquatica*, and *Ceratophyllum* hairs occur. *Pediastrum* coenobia are numerous
Ł 10 *Pinus-Betula*	29.95–30.05 m 3 samples	Again high proportion of *Pinus* 61–65.5%, values of *Betula* range from 25 to 31%, *Picea* pollen reach 2.3%, *Larix* forms continuous pollen curve up to 0.9%, *Alnus*, *Fraxinus*, *Ulmus*, *Quercus* percentages decrease. Very abundant is pollen of *Betula nana* t. up to 3.2%. Percentages of NAP are very low: Poaceae – 0.5–1.3%, *Artemisi*a – up to 0.2%, Cyperaceae – up to 0.7%. Sporadically occur: *Thalictrum*, *Galium* t., Apiaceae undiff., Rosaceae undiff. Percentages of Musci excl. *Sphagnum* and Filicales monoletae decrease, *Sphagnum* spores occur sporadically

Table 1. Continued

Local pollen assemblage zone	Sample depth/ Number of samples	Characteristics of pollen spectra
Ł 11 NAP-*Salix-Juniperus*	29.55–29.85 m 6 samples	New sharp decrease of *Pinus* pollen up to 18.5%, less frequent are *Betula*, *Picea*, and *Larix*, percentages of *Alnus* increase slightly, those of *Quercus*, *Ulmus*, *Tilia*, *Corylus* decrease, very high are values of *Salix* undiff. up to 8%, *Betula nana* t. – up to 3.7%, *Juniperus* up to 3.5% in the middle part of the zone and up to 19% in the upper part. Different dwarf-shrubs from Ericaceae family are present (*Calluna*, *Bruckenthalia* cf. *spiculifolia*, *Vaccinium* t.). Sporadically found is also *Empetrum* pollen. NAP increase considerably again: Poaceae up to 22.5%, *Artemisia* up to 6.5%, and Cyperaceae up to 15%. Spectrum of pollen of steppe-like communities is very diversified: *Centaurea scabiosa* t., *Saussurea* t., *Rumex acetosella* t., *Aster* t., *Gypsophila fastigiata*. Pollen of wet meadows occurs: *Armeria maritima* B-type, *Thalictrum*, *Polygonum bistorta/viviparum*, *Mentha* t., *Rumex acetosa* t., *Ranunculus acris* t., *Filipendula*, *Comarum* t., *Saxifraga granulata* t., and *Saxifraga hirculus* t. High is the proportion of Musci spores – up to 49.5%, *Sphagnum* spores form continuous curve up to 7.5%, sporadic occurrence of *Botrychium* t., numerous *Pediastrum* coenobia are worth mentioning
Ł 12 *Betula-Pinus-Artemisia*	28.90–29.50 m 11 samples	*Betula* undiff. pollen increases up to 75.5%, then drops to 34–40%, the proportion of pine pollen is very low (2.2% in the lowermost sample), then increases up to 49.5%, sporadically found are *Sorbus*, *Populus*, *Abies*, *Alnus*, *Ulmus*, *Quercus*, *Fraxinus*, and *Corylus*. *Salix* pollen values decrease and reach 2%. High proportion of *Betula nana* t. – up to 3.2% and *Juniperus* – up to 4.3% in the lower part of the zone. *Ephedra fragilis* t. and *E. distachya* t. pollen occur. NAP percentages are high and fall towards the upper part of the zone; in it Poaceae up to19.8%, *Artemisia* and Cyperaceae up to 8.5% each, Chenopodiaceae pollen forms continuous curve (values range from 0.5 to 2.3%), *Rumex acetosella* t. forms continuous pollen curve with max. of 2.5%. Pollen taxa of dry grasslands occur: *Rumex acetosella* t., *Aster* t., *Dianthus* t., *Gypsophila fastigiata*, *Saussurea* t. Frequently found are taxa of wet meadows: *Filipendula*, *Mentha* t., *Peucedanum palustre* t., *Ranunculus acris* t., *Urtica*, and *Cirsium/Carduus*. Proportion of Musci spores is high in the lower part of the zone (41.5%), and decreases in the upper part as well as percentages of *Sphagnum* and Filicales. *Pediastrum* coenobia reach 80.5%, *Ceratophyllum* hairs are frequent, continuous curve of *Myriophyllum spicatum* pollen occurs and sporadic is pollen of *M. verticillatum*
Ł 13 *Pinus-Ulmus-Quercus*	28.75–28.85 m 3 samples	*Pinus* pollen dominates (59.0–69.0%); *Betula* undiff. percentages fall to ca 15%; *Picea* pollen grains appear sporadically, continuous curve of *Alnus* occurs with quickly rising values up to 2.5%, pollen of *Ulmus* and *Quercus* appear again and rise considerably (up to 4.1% and 7.8%, respectively); continuous pollen curve of *Carpinus* forms; sporadically occur *Fraxinus* and *Tilia*. *Corylus* pollen is more frequent again and forms continuous curve up to 1.1% in the upper sample; values of NAP, *Salix*, *Juniperus*, and *Betula nana* t. fall. Among NAP the highest percentages reach Poaceae – up to 2.1% and Chenopodiaceae – 1.3%, those of *Artemisia* and Cyperaceae are lower than 1%. Frequent occurrence of *Filipendula*, *Urtica*, sporadic of *Aster* t., *Silene* t. Pollen curve of *Humulus* appears again. Among reedswamp taxa *Typha latifolia* t., *Sparganium*, *Phragmites* are frequent, *Ceratophyllum* hairs occur continuously, *Nymphaea alba* and *N. candida* pollen is present as well as the fragment of *Salvinia* mikrosporangium tissue
Ł 14 *Carpinus-Quercus-Alnus*	28.45–28.70 m 6 samples	Distinct decrease of pine and birch pollen values up to 20% and 9% respectively; simultaneous increase of *Alnus* (up to 24.5%) and *Carpinus* (up to 33.5%); percentages of *Ulmus*, *Fraxinus* and *Quercus* pollen – similar to the previous zone; pollen of *Tilia* forms continuous curve up to 1%, *Tilia platyphyllos* and *Acer* occur, *Corylus* percentages rise very sharply and reach 11.0%, *Humulus* is frequent, and in the upper part also *Calluna* and Ericaceae undiff. Poaceae decrease to 0.8–2.0%, *Artemisia* and Chenopodiaceae are sporadic, Cyperaceae reach 1.1–1.8%. Pollen of *Valeriana officinals* t., *Thalictrum*, Apiaceae undiff, *Aster* t., *Ranunculus acris* t., Rosaceae undiff., Cichoriaceae occur. Very frequent is *Typha latifolia* t. pollen – up to 10%, values of Musci and Filicales monolete increase slightly, pollen of *Nymphaea* occurs mikrosporangium tissue of *Salvinia* is still present, coenobia of *Pediastrum* are less frequent
Ł 15 *Pinus*	28.00–28.40 m 8 samples	*Pinus* pollen again reach very high values up to 78.5%; those of *Betula* range from 7–15.5%, continuous curve of *Picea* percentages increase towards the upper part of the zone up to 4.9%; almost continuous curve forms *Abies* pollen (up to 3.5%); sporadically found are *Taxus* pollen grains, percentages of *Alnus* decrease to 0.2–5.1%, those of *Ulmus* to 0.9%, *Quercus* ranges between 0.6 and 3.2% and *Carpinus* between 0.8 and 4.4%, less frequent is *Tilia*, although it reaches its maximum in the lower part of the zone (1.1%), proportion of *Corylus* decreaeses, pollen of Ericaceae appears again (especially *Calluna*, *Vaccinium* t., *Ledum* as well as single pollen grain of *Bruckenthalia* cf. *spiculifolia*), Poaceae, and Cyperaceae are more frequent up to 3.6 and 6%, respectively, more frequent are also Chenopodiaceae and *Artemisa*, pollen of wet meadows occur: *Comarum palustre*, *Lythrum*, *Filipendula*, *Humulus*, *Ranunculus acris* t., *Thalictrum*, *Rumex acetosa* t., Rosaceae undiff., and Apiaceae undiff. Musci spores are quite frequent, *Sphagnum* again forms continuous curve up to 6.5%, more frequent are *Equisetum* spores, but the proportion of Filicales monolete is smaller, sporadic are *Pteridium aquilinum* spores. Among pollen of aquatics presence of *Trapa natans* is worth stressing, idioblasts of Nymphaeaceae and mikrosporangium of *Salvinia*. *Pediastrum* is not frequent at the beginning of the zone, however in the upper part it reaches 17.5%

Table 1. Continued

Local pollen assemblage zone	Sample depth/ Number of samples	Characteristics of pollen spectra
Ł 16 *Betula-Pinus*-NAP	26.30–27.90 m 20 samples	*Pinus* pollen values decrease to 17.5–26.5% in the upper part of the zone, sporadically *Pinus cembra* t. occur, percentages of *Betula* increase quickly in the upper part of the zone to 28–34.5%, pollen of *Larix* reaches max. 1.3%, sporadically found is *Sorbus*, proportion of *Alnus* decreases to 0.8–1.9%. In the younger part of the zone *Corylus*, *Quercus*, *Ulmus* pollen occur regularly. Less frequent are *Tilia*, *Fraxinus*, and *Abies*. *Salix* values increase considerably to 2.5% and those of *Betula nana* to 9%. Continuous pollen curve of *Juniperus* forms with max of 2.4%. *Ephedra fragilis* t. pollen is present. NAP percentages decrease sharply; Poaceaeup to 22%, *Artemisi*a to 12%, Cyperaceae to 13%. Pollen of Chenopodiaceae forms continuous curve with values up to 2.5%, pollen of *Anthemis* t., *Aster* t., *Thalictrum*, *Rumex acetosella* t., *Comarum* t., *Ranunculus acris* t. occurs regularly. *Dianthus* t., *Bupleurum*, *Scleranthus perennis*, *Rumex aquaticus*, *Helianthemum*, *Armeria maritima*, *Valeriana officinali*s t., *Lythrum*, and *Menyanthes trifoliate* are also present. Musci spores range from 11 to 75%, those of *Sphagnum* are less frequent, sporadically found are *Myriophyllum spicatum* pollen grains
Ł 17 *Betula-B. nana*-NAP	25.90–26.20 m 7 samples	Proportion of *Betula* pollen increaees up to 62%, values of *Pinus* range from 10 to 23%, pollen of *Picea*, *Alnus*, *Larix* occurs regularly with values not exceeding 1% (with the exception of the lowermost sample), sporadically found are *Fraxinus*, *Carpinus*, *Tilia*, *Corylus* pollen. *Salix* has continuous pollen curve up to 2.4% *Betula nana* t. achieves to 5%, values of NAP are similar to previous zone. More frequent is the pollen of *Rumex acetosella* t., *Anthemis* t., *Aster* t., *Thalictrum* t., Cichoriodeae, Apiaceae, and *Comarum palustre.* Pollen of reedswamp taxa *Phragmites*, *Typha latifolia* t., *Myriophyllum spicatum* occurs only in the lower part of the zone, percentages of Musci excl. *Sphagnum* range between 14 and 48%, *Sphagnum* is less frequent and Filicales monolete spores are lacking. Frequency of the sporomorphs decreases significantly from ca 26.1 m upwards
Ł 18 *Pinus-Picea*-Ericaceae	25.05–25.85 m 16 samples	*Pinus* pollen reaches max (79.5%), proportion of *Picea* also increases significantly to 3.7%, as well as *Alnus* (to 2.2%). *Ulmus*, *Quercus*, *Carpinus*, *Tilia*, and *Corylus* pollen grains are frequent, values of *Betula* pollen decrease, *Larix* occurs regularly. Less frequent are *Salix* undiff., *Betula nana* t., *Juniperus*. Among shrubs pollen *Ephedra fragilis* t.,occurs and among dwarf shrubs numerous *Calluna* pollen, *Bruckenthalia* cf. *spiculifolia*, V*accinium* t., *Ledum*, and *Empetrum.* Values of NAP are lower than in the previous zone. Poaceae and Cyperaceae drop to 1–2%, *Artemisia* to 0.1%, pollen of Chenopodiaceae is sporadic, in the lower part of the zone more frequently found is pollen of *Thalictrum*, Apiaceae undiff. Among herb pollen *Helianthemum nummularium* t., *Peucedanum palustre*, *Polygonum aviculare* t., Liliaceae, P*otentill*a t., and *Menyanthes trifoliata* occur. Proportion of Musci spores is reduced significantly, but *Sphagnum* spore values increased. Filicales monolete spores form continuous curve (to1%), frequent are *Equisetum* spores as well as idioblasts of Nymphaeaecae, sporadically found are *Myriophyllum spicatum* and *M. verticillatum*, *Nymphoides peltata*, *Nuphar*, *Alisma plantago/aquatica*, and *Sparganium* t., *Typha latifolia* t., pollen is more frequent, sporadic are *Ceratophyllum* hairs
Ł 19 *Pinus*-NAP	25.00–24.48 m 10 samples	Percentages of *Pinus* decrease but range from 53 to 69%, values of *Betula* – 10–24.5%, percentages of *Picea* and *Alnus* decrease too, especially in the younger part of the zone. *Larix*, *Pinus cembra* t., *Ulmus*, *Quercus*, *Corylus* occur sporadically. Pollen of *Ephedra fragilis* t., is present and Ericaceae have still significant pollen values. Percentages of *Betula nana* t. increase as well as Poaceae (to 11%), Cyperaceae (to 14%), and *Artemisia*. More frequent is pollen of *Galium* t., Cichorioideae, *Comarum* t., *Ranunculus acris* t. and Apiaceae undiff. NAP taxa are very differentated. Among other things there occur: *Saxifraga* spp. (*S. granulata*, *S. hirculus*), *Valeriana officinali* t., *Gypsophila fastigiata*, *Aster* t., *Dianthus* t., *Helianthemum nummularium*, *Polygonum bistorta/ viviparum*, *Prunella*, *Trifolium*, and *Menyanthges trifoliata.* Pollen of *Typha latifolia* t. is still frequent and the share of Musci and *Sphaganum* spores increase to 32% and 9%, respectively

interglacial riverine communities. In spite of the low pollen values (up to 1.1%) in this zone *Quercus* (?*Q. robur*) forms a continuous pollen curve. Granoszewski (2003) stressed high affinity of *Quercus robur* for riparian habitats and was of opinion that high proportion of oak pollen at the beginning of Eemian interglacial in southern Podlasie region should be mainly associated with floodplain woods, which might have resembled the modern *Ulmo-Quercetum* association known from western Europe. Based on the high proportion of *Ulmus* and *Quercus* pollen at the beginning of the F1 interglacial one can conclude that similar community type may have developed around Łuków at the onset of the first interglacial (F1) in the Ferdynandovian pollen succession.

Frequent pollen of *Alnus* and *Salix* may testify to the presence of alder and willow patches in wet but poorer habitats.

Fig. 3. Percentage pollen diagram from the Łuków-3a profile. L PAZs = local pollen assemblages zones; Stratigraphic units according to Lindner et al. (2004)

Ł3 *Pinus-Betula-Quercus* L PAZ. Pine trees were still predominant in the forests but oak, elm and alder were more and more frequent. Rising values of *Quercus* up to 8.5% indicate that oak may have encroached not only riverine woods, but various communities. Its percentages in modern pollen spectra from the Roztocze region range from 1.6 to 3.1%. At the beginning of the F1 interglacial in pine dominated forests oak may have participated in the development of mixed communities of various types, but communities similar to thermophilous oak woods may also have started to form. It may be assumed that both *Quercus robur* and *Q. petraea* were present in these oak woods. Pollen of *Tilia cordata* t. composes over 90% of *Tilia* undiff. pollen curve thus it can be supposed that *Tilia cordata* and *Ulmus* sp. may have occurred as admixture in the tree layer. *Corylus* probably formed the understorey of oak woods and spread in more lightened places. Higher values of *Ulmus* (up to 4.0%), increasing those of *Alnus* (up to 3.1%), and low but continuous curve of *Fraxinus* pollen (0.1%) indicate that various types of riverine forests spread. In alder woods *Alnus glutinosa* may have been accompanied by *Fraxinus*. Scattered trees of *Fraxinus excelsior* in the vegetation of the Roztocze region are reflected by 0.5–0.9% pollen values in the Tauber-style traps. It may be doubtful if the continuous pollen curve with only 0.1% *Fraxinus* pollen value in the fossil samples from the Ł3 zone might potentially indicate rare ash trees scattered in the regional vegetation, but it must be considered that the *Fraxinus* pollen curve rises significantly in the next zone (up to 1.9% in the Ł4 L PAZ) together with *Alnus* and *Ulmus* pollen curves thus suggesting increasing proportion of ash in the forests (Fig. 3). It may have encroached both into elm-oak riverine forests and alder woods. *Frangula* may have appeared at forest margins together with *Humulus* (continuous pollen curve) and plants associated with wet communities. Littoral zone of the lake was occupied by *Typha latifolia*, *Sparganium* sp., *Phragmites* sp. among other things (Fig. 3).

Ł4 *Quercus-Ulmus-Alnus-/Corylus/* L PAZ. Boreal elements (*Larix*, *Picea Betula*, *Pinus*) decreased considerably and open areas were reduced. Very high values of *Quercus* (up to 26.5%), *Ulmus*, and *Alnus* in pollen spectra (up to 17.0% and 19.5%, respectively) testify to the domination of fertile riverine forests around Łuków at that time. Various elm species, ash, oak, maple-tree (? *Acer campestre*), two species of lime, and also alder may have been components of these communities. Two pollen groups of oak and two – of ash and elm provide one more evidence of the close proximity of oak, ash, and elm trees to the lake shores. Other types of deciduous thermophilous forests were also widely distributed. Their main components were oaks, limes, maples. *Corylus* shrubs developed in more open places. It may have partly replaced heliophilous birch on more fertile soils rich in calcium carbonate. In these forests also thermophilous creepers (*Hedera*, *Vitis*, and *Humulus*) as well as *Urtica* and *Filipendula* occurred (Fig. 3). Sporadic pollen grains of *Celtis* and *Pterocarya* found in this zone suggest that these trees – alien to the contemporary Polish flora – may have occurred in riverine communities at that time. *Celtis* was related by Janczyk-Kopikowa (1975) to the *Celtis australis* L. – species that nowadays occurs, among others, in southern Europe and northern Africa. Pollen of *Pterocarya*, most frequently found in the Mazovian interglacial deposits is related to *Pterocarya fraxinifolia* (Środoń 1955, Krupiński 1995). Pollen groups of alder in the deposits may indicate that alder woods with dominant *Alnus glutinosa* and possibly small admixture of *Pinus* and *Picea* may also have spread in less fertile, swampy areas.

Various species of Chlorophyta were abundant in the lake (*Tetraedron*, *Pediastrum boryanum*, *Coelastrum reticulatum*, and others). Sporadic idioblasts of Nymphaeaceae suggest that the lake at Łuków was big and mezo- to eutrophic at that time.

Ł5 *Corylus* L PAZ. Very high percentages of hazel pollen (up to 37%) tesify to its wide distribution in the landscape. *Corylus* encroached probably upon different habitats. It was not only represented in the understorey of widespread dry-ground and riverine forests but may have formed its own thermophilous thickets resembling modern *Peucedano cervariae–Coryletum* (cf. Matuszkiewicz 2001). Such an opinion referring to climatic optimum of the Eemian interglacial was published by Mamakowa (1989). Granoszewski (2003) considered the phase of maximum *Corylus* spread as the beginning of climatic optimum and stressed that in the Eemian interglacial hazel arrives after elm, ash, and oak and before the expansion

Table 2. Total area occupied by different forest communities of the Roztocze National Park according to Izdebski et al. (1992)

Plant community	Dominating trees in the upper tree layer	Percentage share in the total area of the Park
Dentario glandulosae – Fagetum	*Fagus sylvatica* small admixture of *Abies alba*	25.2
Substitutre communities from *Querco-Fagetea* Class	*Pinus sylvestris* considerable admixture of *Fagus sylvatica*, *Abies alba*, *Quercus robur*	23.7
Leucobryo-Pinetum	*Pinus sylvestris*	18.2
Abietetum polonicum	*Abies alba*	8.3
Substitute communities from *Vaccinio-Piceetea* Class	*Pinus sylvestris* sometimes admixture of *Abies alba*	7.1
Querco roboris–Pinetum + Querco roboris–Pinetum fagetosum	*Pinus sylvestris, Quercus robur*, *Abies alba*, *Fagus sylvatica*, *Picea abies*	4.0
Vaccinio uliginosi–Pinetum	*Pinus sylvestris*	1.9
Tilio-Carpinetum	*Carpinus betulus*, *Abies alba*, *Fagus sylvatica*, *Quercus robur*, *Tilia cordata*	1.8
Young forest	*Pinus sylvestris*, *Betula pendula*	1.5
Ribeso nigri–Alnetum + Circaeo-Alnetum	*Alnus glutinosa*	1.8
Querco-Piceetum	*Picea abies*, *Quercus robur*	1.2

of lime and hornbeam. These conclusions may be true also for the Ferdynandovian vegetation succession during the first interglacial (F1). The appearance of *Ligustrum*, *Buxus*, *Ilex*, and *Viburnum* pollen indicate that these thermophilous shrubs may have been components of hazel thickets or understorey of rich riverine communities. Creepers were represented by *Hedera* and *Humulus*. Presence of *Viscum* was one more indicator of warm climate (cf. Iversen 1944). In the younger part of the zone continuous pollen curve of *Taxus* appeared and still abundantly represented were herbal taxa associated with wet habitats. Decreasing *Pteridium aquilinum* and Filicales monolete values suggest more dense forest canopy layer and occupation of all available open habitats by forests and shrubs. Aquatic plants composition was enriched in thermophilous *Trapa natans* and water fern *Salvinia natans*. The community of green algae was also rich and diversified. All these features confirm further eutrophication of the water.

Ł6 *Quercus-Tilia-Abies-/Taxus/* L PAZ. Thermophilous oak forests expanded in drier and rather fertile habitats. They could have partly replaced hazel thickets as evidenced by the maximum of *Quercus* values and falling percentages of *Corylus* in pollen spectra. *Tilia cordata* was an important component there. Composition of elm riverine forests was still very rich (presence of *T. platyphyllos* and frequent *Acer* pollen). According to Granoszewski (2003) in the Eemian the co-ocurrence of *Tilia platyphyllos*, *Acer*, and *Ulmus* may be associated with the presence of *Aceri-Tilietum* thermophilous forest which today occurs in the south of Poland on hillsides with moist soils. Together with *Quercus* these trees may also have occurred in multispecies communities on more fertile, drier soils. Maximum values of several thermophilous trees in the Ł6 zone and the presence of *Celtis*, *Ilex*, *Ligustrum* indicate that most favourable climatic conditions were still keeping up. Continuous rise in the pollen values of *Taxus* and *Abies* to the maxima of 3.7% and 2.7%, respectively, the rise in *Picea* percentages provide evidence of increasing proportions of yew, fir, and spruce in forest communities. *Taxus* may have been significant component of dry-ground forests. The 3.7% value must be considered high in the light of modern pollen records reported by Noryśkiewicz (2009) from the Wierzchlas Reserve. *Taxus baccata* is there the main component of *Tilio-Carpinetum* community, however, growing in the lower tree layer has limited chance to spread its pollen over greater distances. This fact probably resulted in strong underrepresentation of yew (up to 2.8% in the AP sum) in surface lake deposits from the neighbouring Lake Mukrz (Noryśkiewicz 2009). In case of *Abies* its very low pollen dispersal ability is confirmed by the modelling approach conducted in the Roztocze by Poska and Pidek (2010). These pollen dispersal and deposition characteristics of *Abies alba* in the Roztocze showed that major proportion of its pollen is deposited within 100 m of the sampling site mainly due to high fall speed of heavy fir pollen grains. *Abies* pollen values 3.1–5.3% in the Roztocze pollen spectra (Tab. 5) seem to suggest that *Abies* is slightly underrepresented in the pollen rain as the proportion of pure fir forest stands in the vegetation composition is ca 8.3% (Tab. 2). Underrepresentation is observable especially in the Tauber trap placed in the centre of *Abietetum polonicum* community, which on average registers only 21% of fir pollen even if *Abies* trees predominate in the surrounding vegetation. The pollen deposition value of 1.3% has beed recorded in the traps distant of ca 1.5 km from *Abietetum polonicum* forest, where only scattered fir trees are present in the lower tree layer. Based on these findings, the values of 2.7% in the Ł6 L PAZ may indicate significant admixture of *Abies* in the forests around Łuków. It implies that not only mixed spruce-fir forest with oak may have formed on fertile habitats, but an expansion of fir in fertile mixed forests could also be possible as well. However, if fir woodland was distant from the lake, *Abies* pollen values would remain quite low.

In the Roztocze landscape *Picea* pollen grains, that are heavier than that of *Pinus*, are not transported in huge quantities by air currents. The vast majority is probably deposited within 1 km of the source trees (Pidek et al. 2010a). *Picea* is a component of several forest associations (Tabs 2, 3) however, mainly as scattered trees and frequently in the lower tree layer. Spruce pollen percentages (0.3–0.6%) in the modern pollen spectra from Tauber-style traps in the Roztocze when compared to the ones in the upper part of the Ł6 zone (3.8–8.8%) seem low. Thus the 8.8% value in the uppermost sample of Ł6 may testify to the very high representation of spruce trees around the lake. Latałowa and van der Knaap (2006) tested the 2% pollen threshold as the value that tracks the advance of main spruce front in the Holocene expansion but finally concluded that the 2% value may have failed to detect small populations. The PMP data from the Roztocze region strongly support this statement. It must be borne in mind that the increasing proportion of *Picea* in forest communities may indicate also some hydrological changes. It is suggested also by steep rise in the *Alnus* percentages. These features may indicate further expansion of spruce into riverine forests but also in spreading alder forests.

Low share of NAP throughout the zone testifies to the occupation of all the suitable habitats by forest communities. *Myrica gale*, pollen of whose occurs in this zone, may have appeared on the mires connected to alder communities. It is an ecological indicator of warm, mild, oceanic climate (Zarzycki et al. 2002).

Rich algae community, *Salvinia natans* microsporangium tissue, and the occurrence of reedswamp taxa (*Phragmites*, *Typha latifolia*, *Equisetum*) may suggest further eutrophization of the lake water and wide littoral zone.

Ł7 *Pinus-Betula* L PAZ. Sharp increase in pine pollen values, and simultaneous fall of all thermophilous trees evidence a considerable change in climate conditions, which resulted in withdrawal of *Quercus*, *Ulmus*, *Fraxinus*, *Corylus*, and all the thermophilous shrubs and creepers. Pine dominated communities encroached the habitats of dry-ground oak forests and partly also riverine forests. However,

Table 3. Percentage share of main forest communities in the Guciów village according to Grądziel et al. (2006)

Plant community	Dominant trees in the upper tree layer	Percentage share in the total area of the village
Ribeso nigri-Alnetum, *Circaeo-Alnetum*, *Salicetum pentandro-cinereae*	*Alnus glutinosa*, *Salix pentandra*	2.5
Leucobryo-Pinetum	*Pinus sylvestris*	11.7
Abietetum polonicum, *Querco-Piceetum*	*Abies alba*, partly also *Picea abies* and *Quercus robur*	9.7
Querco roboris-Pinetum	*Pinus sylvestris*, *Quercus robur*	4.6
Dentario glandulosae-Fagetum	*Fagus sylvatica*	4.7
Tilio-Carpinetum	*Tilia cordata*, *Carpinus betulus*, *Quercus robur*	4.0
Substitute communities from *Vaccino-Piceetea* Class	*Pinus sylvestris*, *Betula pendula*, partly also *Abies alba*, *Picea abies*, and *Quercus robur*	3.5
Substitute communities from *Querco-Fagetea* Class	*Fagus sylvatica*, *Carpinus betulus*, *Tilia cordata*	4.7
Young forest	*Pinus sylvestris*, *Betula pendula*	6.4

Table 4. Situation of pollen traps in the Roztocze region

Trap symbol and No.	Geographical coordinates		Elevation	Site description	Size of opening of forest cover in which trap is placed
	Latitude	Longitude			
G 1	50°35,34′N	23°03,51′E	243 m a.s.l.	Small opening within fir woodland *Abietetum polonicum*	10 × 10 m
G 2	50°35,25′N	23°03,33′E	243 m a.s.l.	Large opening within mixed pine-deciduous forest	40 × 120 m
G 3	50°35,16′N	23°03,54′E	247 m a.s.l.	Meadow on edge of mixed forest with pine and fir dominance	Forest edge – distance from nearest trees ca 25 m from eastern side
G 4	50°35,41′N	23°03,28′E	257 m a.s.l.	Large clearing within mixed pine-birch forest with admixture of other tree species	60–120 m
G 5	50°35,13′N	23°03,47′E	279 m a.s.l.	Meadow on edge of beech forest	Forest edge – distance from nearest trees 2m from western side
G 6	50° 34,56′N	23°04,01′E	305 m a.s.l.	Open vegetation – abandoned field overgrowing by birch and willow	Open vegetation
G 7	50°34,57′N	23°04,25′E	246 m a.s.l.	Open vegetation – meadow within cultivated and abandoned fields	Open vegetation, patch pf pine and birch from eastern side at a distance of ca. 15 m
G 8	50°34,21′N	23°03,14′E	348 m a.s.l.	Large clearing within beech forest	80 × 100 m
G 9	50°34,20′N	23°04,07′E	355 m a.s.l.	Under canopy site within beech forest	Under canopy site, distance from nearest trees ca. 8.5m

in these wetter places spruce population was developing. Significant changes were recorded probably in wet forest types with alder domination as *Alnus* percentages in the pollen diagram fall dramatically. Spruce probably partly replaced alder in wetter habitats and may be also fir and yew on more fertile habitats. Feurdean et al. (2011) drew attention to the strong competitive ability of *Picea abies* and resilience of spruce and *Quercus robur* to climate changes and disturbance that enabled fast regeneration. *Carpinus* single pollen grains occur twice in this zone which may indicate that single hornbeam trees may have been growing in the lower tree layer in the last part of climatic optimum and before establishment of the population the climate cooling caused withdrawal of this tree. *Carpinus betulus* is a thermophilous tree (Zarzycki et al. 2002). Macrofossils of this species were found by Stachowicz-Rybka (2011) in the depositis of Augustovian interglacial in the north-eastern Poland, the age of which was correlated with the Cromerian I interglacial by Winter (2006). On the basis of these findings we can assume that *Carpinus* pollen in Łuków-3a also represents *Carpinus betulus*. Boreal elements – *Betula* and *Larix* – appeared as an admixture in pine forests. Forest and mire communities delivered part of the pollen of *Calluna* and other representatns of Ericaceae family.

No more *Salvinia* microsporangium tissue appeared in this zone. More frequent *Pediastrum* coenobia and new occurrence of *Ceratophyllum* hairs seem to reflect higher water level.

Ł8 *Betula-Pinus*-NAP L PAZ. Simultaneous rise in *Betula* undiff. values and fall in *Pinus sylvestris* t. percentages provide evidence of a reconstruction of pine forests in which the role of birch became greater. *Betula pubescens* may have been an admixture in wet places, and also *Picea* and *Larix*. Open herbaceous communities expanded significantly. Increase in Poaceae, Cyperaceae, *Artemisia*, and Chenopodiaceae together with higher values of *Betula nana* t., more frequent *Salix* undiff., *Juniperus*, and Musci evidence the return of steppe-tundra vegetation. Open wet communities of meadow-type spread as well. High values of *Quercus* in the younger part of the zone together with pollen of thermophilous taxa are difficult to interpret in terms of the "in-situ" presence of these trees. The composition of pollen spectra repeats in large extent the upper part of the Ł6 zone which may suggest that pollen of thermophilous taxa may be rather related to reworked or long distance transported material of older deposits, redeposition of which was favoured by increased water level. Probably rebedded is also the only pollen grain of *Fagus* found in this zone. The occurrence of more thermophilous trees in pine-birch forest communities is doubtful. Solifluction processes are evidenced by an admixture of silt in the sediments. On the other hand – the repeated occurrence of higher values of thermophilous trees in Zdany (Zd-8 L PAZ, compare Pidek 2003) may suggest alternative hypothesis of a re-advance of several thermophilous trees. They might have not withdrawn far but possibly persisted in small populations in warmer and more humid conditions somewhere south of the pine forests. Traces of this hypothetical advance may be observed also in the profile from Podgórze (Mamakowa 2003).

F1/2 COOLING/GLACIATION (Ł9–Ł11 L PAZs)

Ł9 NAP-*Betula* L PAZ. Very high NAP values (up to 64%) – especially those of *Artemisia*, Poaceaea, frequent Chenopodiaceae and increase in the *Betula nana* t., *Salix* undiff., and *Juniperus* percentages provide evidence of a dramatic change of plant communities. Forests were replaced by open landscape. Wetlands were occupied by sedge-moss mires as evidenced by the rise in the Cyperaceae pollen values and rising percentages of all moss spores. Dwarf birch and willow shrubs expanded (pollen group of *Salix*) on mires and formed vegetation patches of shrub tundra type. Spruce and alder (?*Alnus incana*) may have survived in waterlogged places. Presence of more thermophilous taxa (pollen of *Quercus*, *Tilia*, *Ulmus*, *Carpinus*, *Corylus*) is doubtful. In the younger part of the zone NAP overdominates. The Ł9 zone marks the first stadial of the F1/2 cooling/glaciation between the two interglacials in the Ferdynandovian succession. Various habitats of wet meadows and steppe grasslands rich in herbaceous species were widespread. Pre-Quaternary rebedded sporomorphs may be connected with erosional processes. Increased values of *Phragmites* t. and presence of *Typha latifolia* pollen may evidence the tendency of the lake to shallow and overgrow.

Ł10 *Pinus-Betula* L PAZ. The drastic change in the composition of pollen spectra marked new expansion of boreal pine–birch forest with small admixture of spruce and larch. Stabilization of the ground was greater so the redeposition of pollen was probably less pronounced (decreasing *Fraxinus*, *Ulmus*, and *Quercus* values). The zone reflects interstadial changes during which dense boreal forest almost entirely replaced the communities of open landscape. However, patches of wet meadow-type communities may have occurred close to the lake. Reduction of mire area is also evidenced by low values of Musci and Cyperaceae pollen. However, pollen of *Betula nana* t. (up to 3.2%) indicates survival of dwarf birch near the lake. Pollen of aquatic and swamp plants is rare in this zone and *Pediastrum* coenobia are sporadic. These features may indicate further overgrowing of the lake.

Table 5. Average percentages of trees in pollen assemblages based on 13 years data (1998–2010) of monitoring pollen deposition into Tauber-style traps in the Roztocze regions. Calculations were made according to AP+NAP sum and according to AP sum. Additionally average percentages of Poaceae was provided (for explanations see text)

Taxon	Average% value in pollen spectra acc to AP+NAP sum	Average% value in pollen spectra acc to AP sum
Ulmus	0.2	0.4
Quercus	1.6	3.1
Fraxinus	0.5	0.9
Carpinus	4.1	7.9
Tilia	0.2	0.4
Alnus	4.2	8.2
Fagus	3.9	6.2
Abies	3.1	5.3
Picea	0.3	0.6
Pinus	19.2	34.5
Betula	15.2	28.1
Poaceae	24.0	

Ł11 NAP-*Salix-Juniperus* L PAZ. New considerable opening of forest cover probably as a result of succesive climate cooling is reflected in the increase of the NAP. Pine-birch forest retreated from many habitats and became less dense. Spruce trees and may be also alder (?*Alnus incana*) may still have occurred as an admixture. Grass communities with *Artemisia* and *Juniperus* may have occupied poor and dry habitats. The diversity of herb communities should have been rather great as indicated by rich composition of the NAP. Widespread wet communities are also reflected by high values of *Salix* undiff. and frequent *Betula nana* t. pollen. Numerous Musci and *Equisetum* spores evidence new expansion of mires. Rapid rise in *Pediastrum boryanum* values and reconstruction of littoral zone (*Phragmites* t. pollen) may indicate that water level may have increased again. Solifluction processes were active at that time as indicated by a silt admixture in the sediments and the presence of *Tsuga* and *Tilia* pollen.

INTERGLACIAL F2 (Ł12–Ł15 L PAZs)

Ł12 *Betula-Pinus-Artemisia* L PAZ. Re-expansion of pioneer birch boreal forest with small admixture of larch, spruce and stone-pine marks the beginning of a new warm period. Pine probably encroached quickly over open habitats and formation of pine–birch forests started. *Sorbus* and *Populus* (?*P. tremula*) trees may have been an admixture in these communities. Single pollen grains of *Abies*, *Ulmus*, *Quercus*, *Corylus*, and *Fraxinus* are probably rebedded. Shrubs were represented by willow and juniper. Still high NAP values (up to 40%), abundant *Artemisia* and Poaceae pollen, and *Pteridium aquilinum* spores indicate that forests were not dense. Herb communities were differentiated as evidenced by pollen of various taxa connected to wet meadows. Sedge and sedge-moss taxa are also abundantly represented but considerable reduction of areas occupied by shrub tundra is noticable. *Myriophyllum spicatum* and *M. verticillatum* together with *Ceratophyllum* were present in the lake as well as abundant *Pediastrum* coenobia, which testify to an increase in the water level.

Ł13 *Pinus-Ulmus-Quercus* L PAZ. In spite of still abundant pine and birch pollen, a considerable rise in the percentages of many thermophilous taxa evidence simultaneous formation of different types of deciduous forests. These were probably elm dominated riverine communities with admixture of oak (?*Quercus robur*). The continuous curve of *Ulmus* (up to 4.1%) indicates that elm colonised more fertile wetlands. New expansion of alder is visible in quickly rising values of *Alnus* pollen curve. Alder may have occured as admixture in elm dominated riverine forests and could have formed its own communities. Pine domination in pollen spectra evidences wide-spread pine forests in which oak trees probably began to appear. The existence of clearings in pine and pine-oak forests is confirmed by the high values of *Pteridium aquilinum* spores. Start of the continuous pollen curves of *Carpinus* and *Corylus*, in the upper sample of the Ł13 zone (Fig. 3), indicates their encroachment into the forests. Hornbeam may have entered dry-ground forests on more fertile soils together with oak, lime and admixture of ash and elm. The role of oak in mixed pine forests increased as indicated by the rise in *Quercus* values up to 7.8% in this zone. The encroachment of hazel was again simultaneous with decrease of pioneer tree birch and open herbaceous communities. At the same time boreal shrubby communities dominated by willow, juniper, and dwarf birch withdrew forced by forest expansion. *Typha latifolia* grew vigorously in the reservoir. Simulatneous presence of Nymphaeaceae and water fern *Salvinia natans* indicate warm, eutrophic lake.

Ł14 *Carpinus-Quercus-Alnus* L PAZ. This zone represents the climatic optimum of the second interglacial period (F2). Rich, multispecies deciduous forests developed, in which *Quercus* and *Carpinus* dominated. The role of pine was reduced, and mixed pine-oak forest was transformed into deciduous oak-hornbeam forest probably of the modern *Querco-Carpinetum* type. Presence of two oak species (*Q. robur* and *Q. petraea*) is probable at that time. *Carpinus* may have formed at the first a lower tree layer in the pine-oak communities. In the opinion of Faliński and Pawlaczyk (1993) hornbeam combines several types of biological strategies gaining the advantage over other trees in *Querco-Carpinetum*. The rapid rise in the pollen values of *Carpinus* in Łuków, up to the maximum of 33.5% provides evidence of its extremely dynamic expansion. The proportion of *Carpinus* in modern pollen spectra from the Roztocze region ranges from 4.1 to 7.9% (Tab. 5). When compared to quite small representation of forests in which *Carpinus* is a main tree (e.g. 4% of *Tilio-Carpinetum* association in the Guciów village vegetation and only 1.8% – in the Roztocze National Park forest composition) we can conclude that the values exceeding 33% in the fossil pollen spectra from Łuków indicate dominant role of hornbeam in the dry-ground forests formation. Probably in a short time hornbeam became dominant in mixed forest, and formed various types of oak-hornbeam communities. *Tilia cordata* belonged to the communities occupying more fertile, drier soils as indicated by the continuous curve of *Tilia* undiff. up to 1%. *Tilia platyphyllos*, maple-tree (?*Acer campestre* or *A. pseudoplatanus*), and elm (?*Ulmus glabra*) most probably also occurred there. The significant rise in the *Alnus* pollen values indicates that alder forests played an important role in wetlands throughout the zone. *Taxus* may have occurred sporadically in the expanding riverine forests. The continuous curve of

Picea rising towards the end of the zone may indicate that spruce entered into forest communities of many types. In the upper part of the zone the tree canopy may have been looser as *Humulus* pollen is more frequent together with *Calluna* and Ericaceae undiff. Wide littoral zone of the lake is refleced by maximum of *Typha latifolia* pollen. The lake must have been eutrophic with representants of Nymphaeaceae overgrowing water surface together with *Salvinia natans.*

Ł15 *Pinus* L PAZ. High percentages of *Pinus* reflect great transformation, which again took place in the area near Łuków as a result of climate change. Expanding boreal pine communities could have encroached upon habitats of dry-ground forests (dramatic fall in *Carpinus* pollen values accompanied by *Quercus* and *Tilia* decrease in the pollen curves), although in the lower part of the zone *Tilia cordata* has still its local maximum of 1.1%. Decrease of thermophilous elements is accompanied by an increase in *Abies* percentages followed by high *Picea* values. Both the taxa form continuous pollen curves up to 3.5% and 4.9%, respectively. *Abies* pollen percentages, similar to the modern pollen values in the Roztocze (Tab. 5), suggest that fir constituted a considerable admixture in the mixed spruce-fir communities. *Abies* could have potentially encroached habitats previously occupied by oak-hornbeam communities, which subsequently might have been replaced by spruce. In the corresponding zone of the Zdany profile (Pidek 2003) similar values of fir were observed followed by higher proportion of spruce. However, at other sites with the deposits from the Ferdynandowian interglacial F2 Ferdynandów (Janczyk-Kopikowa 1975), Białobrzegi (Janczyk-Kopikowa 1991), Podgórze (Mamakowa 2003) the values of *Abies* are then very low. These differences may result from local conditions and the greater distance of fir community from the lake shores. In the younger part of the zone the forest with *Abies* and *Picea* gradually withdrew may be in response to drier and cooler climate.

Decrease in alder population was also significant, but probably part of alder woods with admixture of spruce still survived. *Larix* appeared again as an admixture in pine forests. New occurrence of *Betula nana* is observed at that time simultaneously with indicators of mire expansion. In the lake the presence of *Trapa natans* pollen is worth stressing as it can testify to eutrophic warm water in the summer.

SANIAN 2 (= ELSTERIAN 2) EARLY GLACIAL (Ł16–Ł19 L PAZs)

Ł16 *Betula-Pinus*-NAP L PAZ. Sharp increase of NAP simultaneous with higher values of *Betula* undiff. and fall in *Pinus sylvestris* t. pollen percentages indicate more open forest cover in which tree birch began to gain dominance and new expansion of herbaceous communities occurred. This zone marks the first stadial of the Sanian 2 glaciation. Part of *Betula* undiff. pollen may belong to *B. humilis* shrubs. Larch began to play an important role in the forests, as its pollen values rise up to 1.3%. The landscape resembled forest-tundra. In spite of the fact that pollen percentages of *Alnus* fall, it is probable that at least *Alnus incana* may have persisted in boreal conditions and *Alnus viridis* shrubs occurred in the vicinity of lake shores. The proportion of *Salix* undiff. pollen increased considerably together with *Betula nana* t. which suggests more areas occupied by shrubby tundra. Pollen of thermophilous taxa (*Carpinus*, *Quercus*, *Ulmus*, *Corylus*), more frequent in the lower part of the zone, may be referred to redeposition from older deposits as their taxonomic composition resembles the one from the previous zone (Ł15). Presence of *Ceratophyllum* hairs and very frequent *Pediastrum* coenobia seem to support the hyphothesis of the outwash of the older deposits from the lake shores due to increased water level. Regional landscape must have been quite open as evidenced by frequent juniper, presence of *Ephedra* and numerous pollen of Ericaceae family. More widespread were steppe-like grass communities with abundant representants of *Artemisia*, *Anthemis*, *Aster*, and Chenopodiaceae, various mires (reflected by abundant pollen of Cyperaceae undiff., *Comarum palustre*, *Menyathes trifoliata* and frequent spores of Musci and *Spaghnum*), and wet meadow-like communities (pollen of *Thalictrum*, *Ranunculus acris* t., *Filipendula*, *Valeriana officinalis* t., *Polygonum bistorta*/*viviparum*, *Armeria maritima* B-type, and others).

Ł17 *Betula–B. nana*–NAP L PAZ. Significant increase in the *Betula* undiff. values indicates that pioneer birches expanded again.

Larch, spruce and some pine were probably in admixture. It cannot be excluded that also *Alnus incana* may have been sparcely distributed in wetter places together with spruce. Birch forest did not encroach on all areas of the tundra and steppe-like communities. Pollen group of *Artemisia* confirms its abundant local presence. Simultaneously willow species, dwarf birch and *Alnus viridis* still formed shrub communities on peatbogs. Pollen diagram (Fig. 3) shows that the diversity of herb communities was similar to the one in the previous zone. High values of NAP, especially in the lower part of the zone, an admixture of silt in the deposit, loose character of pioneer birch forest, and vast areas covered by the mixture of open dry habitats and peatbogs suggest that pollen of thermophilous taxa (*Fraxinus*, *Carpinus*, *Tilia*, *Quercus*, *Ulmus*) could have been atributed to redeposition (partly destroyed pollen grains) similar to the previous zone.

Ł18 *Pinus-Picea*-Ericaceae L PAZ. Birch woodland was replaced by pine forests with admixture of spruce and larch. Spruce and alder (?*Alnus incana*) may have formed their own communities in waterlogged habitats as indicated by considerable amount of *Picea* pollen grains. Part of Filicales monolete and *Equisetum* spores could have come from these communities. The continuous presence of *Ulmus* and *Quercus* pollen is difficult to interpret as the new spread of riverine communities. It can not be excluded, however, that single trees of these two genera might have been scattered among alder or spruce-alder forests on wet habitats, as both these trees can tolerate lower temperature to some extent and appear as first trees following boreal taxa in the Holocene pollen succession. Alternatively the populations of elm and oak might have been not very distant to the south from the region of Łuków. Low values of NAP indicate that herb communities were replaced by pine forests in most of habitats. It can be assumed that Poaceae-*Artemisia* steppe-like communities were taken over by advancing pine woods and tundra communities were partly overgrown by spruce. Grass communities again started to spread in dry and sandy areas in the upper part of the zone. Decrease in the *Pediastrum* values simultaneous with the increase in the number of *Sphagnum* spores together with the presence of pollen of *Menyanthes trifoliata*, *Peucedanum palustre* t., *Comarum palustre*, and other taxa associated with transitional peatbogs and wet meadow-like communities may testify to shallowing and overgrowing of the lake. This is also confirmed by *Sparganium* t. and *Typha latifolia* pollen which indicate that reedswamps may again have been more widespread in the lake shore zone.

Ł19 *Pinus*-NAP L PAZ. The development of pine forest was restricted rather quickly, probably by a new cold wave that marked the end of the interstadial. *Salix*, Poaceae, and Cyperaceae became again more frequent and forests were replaced by herb and shrub vegetation. Composition of herb vegetation was similar to the previous zone but percentage values of herb taxa (mainly *Galium* t., *Ranunculus acris* t., Apiaceae undiff.) and of Musci spores were higher evidencing the increased role of open habitats. The return of tundra communities is observable also in the rise of *Betula nana* t. pollen curve. Sporadic occurrence of thermophilous trees is probably associated with the reworked pollen material. This assumption is supported by a sand admixture in gyttja deposits.

CLIMATIC CHANGES REFLECTED IN POLLEN SPECTRA

F1 interglacial. The start of pioneer tree birches expansion evidences the rise in temperatures at the beginning of the interglacial warming and suggests that the mean July temperature must have exceeded 10°C and –5°C in January (Zagwijn 1996b, Kupryjanowicz 2008). As the forest cover became denser the solifluction processes became weaker which is reflected by rapid fall in the values of redeposited pre-Quaternary sporomorphs in the Ł1 L PAZ. The presence of *Ceratophyllum* (? *C. demersum*) and *Typha latifolia* in the lake since the beginning of the integlacial allows to estimate that the mean July temperature was not lower than 13–14°C at that time. Mamakowa (1989) considered similar temperature for the beginning of the Eemian interglacial. Formation of pine communities during the Ł2 zone, and probably just then the encroachment of *Quercus* and *Alnus* provided evidence of a rapid increase in temperatures which enabled the expansion of more thermophilous trees. Riverine components (*Ulmus* and *Fraxinus*) started their expansion almost simultaneously with *Quercus* and *Alnus*. This early appearance of *Alnus*, and above all the continuous pollen curves of thermophilous deciduous trees (*Fraxinus*, *Ulmus*, *Quercus*) provide also the evidence of enhanced climate humidity. The rise in the mean annual temperature during the period from the pollen zone with the high *Betula* values was estimated at 7.5°C on the basis of $\delta^{18}O$ measurements in the Ferdynandowian deposits from the Wola Grzymalina Central Poland (Krzyszkowski et al. 1996). The early occurrence of *Tilia* continuous pollen curve (in the Ł3 L PAZ) may additionally testify to warm climate conditions. Thermal optimum is well reflected throughout the Ł4-Ł5 zones by the culminations of *Quercus* and *Ulmus* pollen curves evidencing the major expansion of riverine forests, and by the subsequent high culmination of *Corylus* in the Ł5 zone. Mamakowa (1989) pointed out to the rapid expansion of *Corylus* in the Eemian interglacial in response to marine transgression and stressed the sensitivity of this shrub to the oceanic climate. Giesecke et al. (2008), when exploring Holocene continentality changes in Fennoscandia, drew attention to the fact that *Ulmus glabra* and *Corylus avellana* belong to the most oceanic from among 5 taxa studied in the early Holocene tree succession (elm, hazel, oak, lime, spruce). The exceptionally abundant occurrence of *Ulmus* (?*U. glabra*) at the very beginning of the F1 interglacial implies that the mean July temperature could have been at least 16°C (Granoszewski 2003). Strong expansion of riverine elm-oak communities with ash admixture confirms the increasing oceanic character of the climate. The overall pattern of trees expansion seems to resemble the one observed at the beginning of Eemian interglacial in the Podlasie region (see Granoszewski 2003, Kupryjanowicz 2008). The subsequent rapid spread of *Corylus* additionally confirms further oceanicity of the climate. Other thermophilous trees, i.e. *Celtis*, *Tilia platyphyllos*, *Acer*, *Pterocarya*, and *Taxus*, which occurred in the rich, multispecies riverine forests, appeared soon before the culmination of *Corylus*. Towards the close of the Ł5 zone, *Abies* spread, too. Increasing climate oceanicity is reflected also by the appearance of *Hedera* at the beginning of the Ł4 zone. Based on the now classical paper by Iversen (1944) it can be supposed that as early as this part of the F1 interglacial the temperature of the coldest month did not fall below −1.5°C. *Viscum*, the second classic indicator of warm climate, testifies to the mean temperature of the warmest month not lower than 17°C (Iversen 1944). Several other taxa pointing to the warm and humid climate (*Vitis*, *Ilex*, *Buxus*, *Ligustrum*) were also present in these thermophilous forest communities of the F1 thermal optimum. At present *Ligustrum* occurs under oceanic-submediterranean climatic conditions, and in Poland is found only in scattered sites in the south (Browicz, Gostyńska 1965), while *Vitis vinifera* L. subsp. *sylvestris* grows in southern Europe, but its isolated sites are found along the valleys of large rivers in Austria, southern Germany, and south-western Switzerland (Granoszewski 2003, after Hegi 1965). Similar conclusions can be derived from the presence of *Buxus* (?*B. sempervirens*) – the shrub with strong affinity to warm, ocenic climate with annual precipitation of 800–1000 mm. Yew, which expanded in the younger part of the Ł5 zone, can be also good oceanicity indicator as the present distribution of *Taxus baccata* coincides with the one of *Hedera helix* (cf. Kupryjanowicz 2008). The same conclusion can be derived from the occurrence of *Myrica gale* in the Ł5 and Ł6 zones. The highest frequency of *Celtis* pollen was recorded in the lower part of the Ł5 zone in which the pollen diagram reflects the maximum spread of rich multispecies riverine forests. *Trapa natans* that occurred at that time in the lake indicates even higher July temperature of ca 18°C (cf. Litt et al. 1996). *Tilia cordata* pollen is the most abundant throughout the Ł6 zone. Its higher values might indicate that winter temperatures slightly rise. Giesecke et al. (2008) drew attention to the fact that *T. cordata* in its northern distribution limit seems to require several days of July temperature exceeding 20°C followed by a warm August and mild September. They also considered more continental character of this species compared to *Ulmus glabra*, *Corylus avellana*, and *Quercus robur* as *T. cordata* is more resistant to cold winters. *Tilia platyphyllos*, is one more indicator of mean July temparature not lower than 17.5°C (Granoszewski 2003, Litt et al. 1996). The expansion of *Abies* from the beginning of the Ł6 zone evidences still high air moisture. Ecological requirements of *Abies alba* in respect to minimum annual rainfall (650 mm) are similar to that for *Picea abies* (cf. Granoszewski 2003, Kupryjanowicz 2008).

However, thermal limit for winter temperature for *Abies alba* is –4°C, which implies that unlike continental tree-*Picea abies*, fir cannot tolerate extreme winter temperatures (Zagwijn 1996b). In the uppermost part of the climatic optimum the expansion of communities with spruce, pine and birch provided evidence of the beginning of cooling and increased continentality. However, a fall in temperature did not affect the thermophilous water fern *Salvinia natans*, which still persisted in the lake. Cool, boreal climate prevailed not before the Ł7 zone when pinewood spread. However, quite abundant presence of *Picea*, frequent *Calluna* and periodical ocurrence of pollen of alder and some other thermophilous trees may be the evidence of increased precipitation. Presence of *Quercus robur* is also possible. Open communities gradually expanded during the Ł8 zone, among them tundra communities with dwarf birch, which is evidenced by the continuous curve of *Betula nana* t. pollen starting at the end of the Ł7 zone. This succession, typical of the last parts of the interglacials, developed in response to the decrease of mean July temperature. Persistence of *Typha latifolia* may have indicated that the mean temperature of the warmest month was still not lower than 14°C.

F1/2 cooling/glaciation. Strong climatic cooling resulted in the replacement of forest by herbaceous vegetation of tundra, steppe and swamp types as indicated by the very high values of NAP. In Scandinavia the modern boundary of birch-pine forest runs along the January isotherm of −10°C (Cheddadi et al.1998). Areas occurring northwards of it are covered by herbaceous and dwarf shrub vegetation. The development of steppe-like communities with heliophytes (*Ephedra*, *Helianthemum*) provides evidence of strong seasonality, considerable dryness, which testify to climate continentality. Climate during this glacial period was not uniformely cold. Pollen succession indicates small-rank climate oscillations of variable temperature. The first very strong cooling of a stadial nature (Ł9 zone) was followed by the return of boreal birch-pine forest (Ł10) typical of interstadial or early interglacial warmings which must have resulted from a rise in the mean July temperature to ca 12°C. The subsequent climatic oscillation, is represented by the Ł-11 zone, in which the values of NAP and Musci spores considerably increase. The rise in the pollen values of *Artemisia*, *Juniperus*, and *Betula nana* t. and the reappearance of heliophyte taxa (*Bruckenthalia spiculifolia*, *Juniperus*) are especially important for climatic interpretations providing evidence of repeated cooling and drying of the climate. Granoszewski (2003) pointed out to significance of *Bruckenthalia spiculifolia* as an indicator of the continental climate. This conclusion is confirmed by presence of two *Ephedra* species at the onset of the next pollen zone (Ł12).

F2 interglacial. At the beginning of the second warm period the area was colonized by pioneer birches, and then by pine-birch and pine forests (Ł13 zone). The continuous curve of *Typha latifolia* indicate a considerable warming of the lake water. Air temperature was still increasing gradually, and the continuous pollen curves of *Alnus* and some thermophilous trees (*Ulmus*, *Quercus*, *Carpinus*) appear. Climatic optimum of this warm period is best expressed in the Ł14 zone, in which pollen of *Carpinus* reaches its maximum of 33.5%. Simultaneously pollen values of *Quercus*, *Ulmus*, *Corylus*, and *Alnus* considerably rise. Worth stressing is also the continuous curve of *Tilia* undiff. pollen and appearance of *T. platyphyllos*, *Acer*, *Fraxinus*, and *Taxus*. The total composition of pollen spectra in the Ł14 zone provides evidence of warm and wet climate in which the temperature of the warmest month was not lower than 17°C. Based on the investigations on the Eemian interglacial climate (Cheddadi et al. 1998) it can be supposed that during the phase of hornbeam domination the mean January temperature was not lower than –4°C. The occurrence of *Humulus* in forest communities and continuous pollen curve starting as early as the onset of the Ł13 zone provided also evidence of oceanic, mild climate, just as the presence of *Salvinia natans* and Nymphaeaceae in the lake. The same climatic significance have both the development of alder forests and the spread of fir and spruce, which was favoured by climate humidity, additionally confirmed by presence of *Taxus*. Considerable rise of the pine curve in the Ł15 zone, being the first signal of the approaching climate deterioration, indicates that mean temperature of the warmest month was then much lower. Overgrowing of alder woods and other types of wet forests by spruce or pine-spruce communities with frequent representants of Ericaceae family might be the evidence of still humid climate, which enabled development of mire habitats. The same climatic interpretation can be derived from constant presence of *Humulus*. The summers could initially have been warm enough for persistence of *Salvinia natans* in the lake. It can support the theory that aquatics may survive in water bodies longer in spite of the withdrawal of terrestrial thermophilous vegetation in response to the deterioration in air temperature (cf. Granoszewski 2003 and reference therein).

Sanian 2 Early Glacial. The Ł16 zone opens the sequence of stadial/interstadial changes at the onset of the Sanian 2 glaciation. The transition from boreal to subarctic climate is reflected in the first stadial zone (Ł16) by the high pollen values of *Artemisia* nad Poaceae, the continuous curve of *Betula nana* t., *Salix* undiff., and *Juniperus* and the occurrence of *Ephedra fragilis* t. However, the climate prevailing was not very severe because pine-birch forest patches with larch and spruce still persisted. Presence of stone-pine in the tree layer is also probable. The continental climatic tendency seems to increase during the younger part of the Ł16 zone in which forest was replaced by herbaceous vegetation. The successive two zones reflect a warm climatic oscillation of an interstadial rank with the return of boreal forests. During the Ł17 zone tundra and mire communities were partly replaced by birch and pine dominated communities indicating increase in the mean July temperature probably to about 12°C. Surprisingly *Typha latifolia* was still present in the reservoir thus seems to indicate that summer temperatures may have been even warmer (at least 13–14°C). Another possible explanation is that *Typha* pollen was washed out into the lake together with pollen grains of several thermophilous trees from the older deposits on the lake shores. During the Ł18 zone several indicators suggesting increase in climate humidity occurred. These were high values of *Picea* pollen, almost continuous curves of Filicales and *Equisetum* spores, numerous taxa associated with wet meadow-like communities and transitional bogs. At the same time an increase in continentality is expressesd by frequent occurrence of *Bruckenthalia* cf. *spiculifolia* pollen The rise in the NAP values in the Ł19 zone is conditioned by high frequeny of Cyperaceae, Poaceae, more frequent *Artemisia* and Chenopodiaceae, and the maximum percentages of *Sphagnum* spores evidencing a new cooling which resulted in the reduction of trees and the spread of tundra sedge-moss mires.

DISCUSSION

The pollen succession from the Łuków-3a profile shows features typical of the complete Ferdynandovian pollen sequence and can be correlated with the succession from the nearest site of the same age at Zdany (19 km to the north) and with stratotype sequence from Ferdynandów (Janczyk-Kopikowa 1975, Janczyk-Kopikowa et al. 1981) and Podgórze (Mamakowa 2003). The corresponding local pollen assemblage zones in the profiles under discussion and correalations with west and east European palynostratigraphy were presented in Pidek and Małek (2010). Lately, one more bi-partite succession of the same age was described from Latvia (Kalnina et al. 2013). In the latter pollen diagram the percentages of NAP during the cooling/glaciation separating the two interglacials seem lower that in eastern Poland (Łuków and Zdany sites) but the presence of *Betula nana* and *Ephedra* confirms the conditions of cold boreal climate. The other difference is the presence of *Fagus* pollen – a tree with maritime climate affinity – at the close of the first interglacial in Latvia (Kalnina et al. 2013). This may result from stronger oceanicity of climate in Latvia than in eastern Poland at that time.

The present paper focuses mostly on succession of trees showing high thermal demands (*Tilia*, *Quercus*, *Ulmus*) and sensitive to air humidity (*Abies*, *Picea*, *Corylus*, *Ulmus*, *Alnus*, *Taxus*). Based on the 13-years long dataset of monitoring pollen deposition by Tauber-style traps in the Roztocze average pollen percentage values were calculated. These estimations, which relate pollen presence to tree abundance in the surrounding vegetation, were used in the present study and may be used in future interpretations of fossil pollen diagrams. Several forest forming tree species occur in the Roztocze thus it is possible to estimate what pollen percentage value reflect presence and abundance of tree species in several different situations: scattered in the vegetation (*Ulmus*, *Fraxinus*), forming tree stands in this region (e.g. *Abies*, *Fagus*, *Pinus*) or occurring frequently in the lower tree layer (e.g. *Picea*). The modern data from the Roztocze region may potentially contribute to the discussion on the pollen presence/absence threshold values for major forest-forming European trees the estimation of which is essential when interpreting spread of thermophilous trees from glacial refugia and establishing their populations (see Lisytsyna et al. 2011). These modern pollen data can also contribute to understanding climate factors as triggering mechanisms of vegetation changes, especially in terms of oceanicity/continentality of climate conditions. Although pollen percentages are interrelated within pollen assemblage the thresholds from the Roztocze are important as they are the first data from annual pollen traps in the temperate zone in the non-mountainous area, thus problems of pollen transport above timeberline mentioned by Hicks (2001) do not exist here. The calculations of pollen percentages were presented in relation to the two basic sums: (AP+NAP = 100%) and AP = 100% sum. The latter way of calculating averages seems to be more appropriate when interpreting woody landscapes of interglacials. They did not resemble the modern semi-cultural landscapes of the Roztocze. Besides, in Tauber traps in which the opening is positioned at the ground level, frequent overrepresentation of Poaceae pollen has been observed (Pidek et al. 2010a). Average count of Poaceae in Tauber traps from Roztocze equals 24% thus percentages of individual tree taxa in pollen spectra are significantly lower when calculated according to AP+NAP sum.

Percentage values of elm, ash, hazel, fir, spruce, and hornbeam in fossil pollen spectra from the Łuków fossil pollen profile have been compared to modern pollen dataset. This enabled more precise interpretation in terms of palaeoecology and climate. The pollen presence/absence of *Ulmus* 0.2–0.4% obtained in the Roztocze, where elm trees are scattered, are even lower than suggested by Zachowicz et al. (2004). The latter authors were of opinion that pollen values higher than 1% probably indicated scattered presence of *Ulmus* in the region.

Average pollen values of *Quercus* calculated for the Roztocze seem quite low (1.6–3.1%). At present the continental mixed forest composed of oak and pine (*Querco roboris-Pinetum* association) occupies ca 4% of the Roztocze National Park (Tab. 2) and 4.6% of the Guciów village (Tab. 3). Oak trees occur as frequent admixture also in *Tilio-Carpinetum* association and in the substitute communities from *Querco-Fagetea* class. Considering the range of 1.6–3.1% as pollen presence/absence threshold for *Quercus* trees being present in forest communities, this seems to confirm the opinion of Milecka et al. (2004) that 2% threshold should be treated as local presence of oak trees in the vegetation. In the light of the modern pollen data from Roztocze it seems that values as low as 1.6% show significant local presence of oak trees, and sporadic patches of *Quercus* dominated tree stands.

Fraxinus is another example of trees whose pollen production is still the matter of debate.

Andersen (1970) considered *Fraxinus* as one of trees strongly underrepresented in pollen rain. Mamakowa (1989) and Granoszewski (2003) were also of that opinion and based on Andersen's (1970) correction factors interpreted the role of *Fraxinus* in the Eemian riverine communities. However, the present data from Roztocze seem rather to confirm the opinion of Tobolski and Nalepka (2004) that *Fraxinus* can be only slightly underrepresented in the pollen spectra.

In the situations where no macrofossil analysis was applied to a profile or when macrofossils of a particular tree species are absent from the lake deposits, the use of pollen presence/absence threshold values can help to solve the problem of local presence of a tree species or its possible long-distance transport of pollen. The presence/absence thresholds have been based on long series of monitoring modern pollen deposition under known climate conditions thus can support the interpretation not only in terms of forests composition and different types in variable habitas but in terms of climate interpreataions as well.

The middle Pleistocene is so deep in the past that modern pollen analoques are not easy to find. However, some features of the pollen succession of the F1 interglacial seem to indicate its similarity to the Eemian succession in the Podlasie region elaborated by Granoszewski (2003) and Kupryjanowicz (2008). In spite of the fact that both the successions are divided by several hundred thousand years – the Ferdynandovian being correlated with MIS 13–15 (Lindner et al. 2004, Ber et al. 2007) and the Eemian with MIS 5e, it seems probable that widespread elm-oak riverine communities followed by phase of abundant hazel thermophilous shrubs and subsequent development of dry-ground forests may represent similar combination of forest communities in both the F1 and Eemian interglacial. Development of these forests was triggered by enhanced oceanicity of the climate which was becoming more continental only towards the younger part of climate optimum.

The general pattern of climate changes reflected in the Łuków pollen spectra agrees very well with the one obtained from Zdany pollen diagram and both the approaches – the plant indicators one and modern analogues one exhibit great degree of agreement which was the matter of discussion in Pidek and Poska (2013). Even if *Celtis* and *Pterocarya* – are exotic taxa present in the thermal optimum of the F1 interglacial and not occuring in the Eemian pollen diagrams – the overall pattern of rapid rise in temperatures both in July and January and increases air humidity at the beginning of the Eemian interglacial show striking similarities between the F1 and the Eemian. At the same time the differences between the start of the F1 and the Holsteinian interglacials were stressed which were mainly marked by increased humidity not followed by significant increase in temperatures until the second part of the Holsteinian interglacial. Most probably the temperature of the coldest month remained quite low which resulted in high seasonality, enabled long lasting expansion of *Picea* and *Alnus* and stopped more thermophilous trees from further spread until the younger part of the Holsteinian interglacial (Kühl & Litt 2007). The pollen data from Łuków strongly support the oceanic climate features at the beginning of the F1. However, for the rapid spread of *Carpinus* at the onset of the F2 interglacial, the only analogue found between known interglacial pollen successions in Poland, is the second interglacial of the so–called Augustovian pollen succession (Winter & Janczyk-Kopikowa 2006).

The F 1/2 glaciation between two interglacial pollen successions (F 1 and F 2) has typical features of pollen spectra recorded in stadials and interstadials of the Quaternary. Palynostratigraphically it reflects undoubtful glacial climatic conditions, however, according to Lindner et al. (2004) it does not fulfil the criteria of recognizing it as a proper glacial from geological point of view due to the lack of glacial tills representing the F 1/2. The same cooling of a glacial type occurs also in other pollen sequences of the Ferdynandovian age situated not only in Poland (see Mamakowa 2003) but in the north European Lowlands to the east of Łuków, as well. In Byelarus older interglacial corresponding to F 1 is called “Belovezhian interglacial” and the younger one (corresponding to F 2) is called “Mogilevian interglacial” (see Rylova & Savchenko 2005, Pidek & Małek 2010 and discussion therein). This fact confirms wider distribution of the climate phenomenon F 1/2 which reflects the return of steppe-tundra communities (stadial) interrupted by the return of more boreal conditions with the spread of birch-pine forests (interstadial).

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