Acta Palaeobotanica 50(1): 17–54, 2010

History of vegetation and climate of the Mazovian (Holsteinian) interglacial and the Liviecian (Saalian) glaciation on the basis of pollen analysis of palaeolake sediments from Nowiny Żukowskie, SE Poland

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Received 4 August 2009; accepted for publication 26 May 2010

ABSTRACT. The aim of this paper was to present changes in vegetation and climate which occurred during the late Sanian 2 (Elsterian) glaciation, the Mazovian (Holsteinian) interglacial and the early Liviecian (Saalian) glaciation. The reconstruction was based on results of palynological studies of the palaeolake sediments of the Nowiny Żukowskie site. The analysis covered two profiles: $NŻ_{05}$ (drilled in 2005) and $NŻ_{50\text{-}4}$ (drilled in 1950 from borehole 4 and examined repeatedly). The analysis revealed that the late Sanian 2 glaciation was marked by the presence of steppe-tundra that was in the Mazovian (Holsteinian) interglacial replaced by boreal birch forests, riparian forests dominated by *Fraxinus*, spruce forests with a zone of yew (43%), an intra-interglacial oscillation with pine and birch, an alternating dominance of *Abies* and *Carpinus*, and finally by boreal pine forests with larch and juniper. The early Liviecian (Saalian) glaciation was characterized by the development of shrub tundra with *Betula nana* and steppe-like communities. The abundance of taxa identified in both examined profiles allowed not only for a detailed description of changes in vegetation in the Nowiny Żukowskie area, but also for an accurate reconstruction of changes in climate conditions characterizing this part of Pleistocene, and a reinterpretation of its palynostratigraphy when compared with results obtained by Dyakowska (1952). Pollen succession recorded at Nowiny Żukowskie was compared with several other sites representing the Mazovian (Holsteinian) interglacial in Poland. Differences observed between them indicate that the large variability of flora resulted from changes in climate affecting this area, passing from continental into an oceanic one.

KEYWORDS: pollen analysis, vegetation history, palaeoclimate, Sanian 2 (Elsterian) glaciation, Mazovian (Holsteinian) interglacial, Liviecian (Saalian) glaciation, Poland

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INTRODUCTION

Nowiny Żukowskie (51°04′20″N, 22°45′12″E) is situated in the northern part of the Lublin Upland (Fig. 1). Pleistocene organic sediments are abundant in its vicinity that includes the Polesie Region, surrounding Nowiny Żukowskie in the north, and the Central Polish Lowlands in the west.

For many years the sediments have been subject to both geological and palaeobotanical studies (Dyakowska 1952, Brem 1953, Sobolewska 1956, Janczyk-Kopikowa 1981, 1983, Pidek 2003). Nowiny Żukowskie was one of the earliest sites located and examined in this area, with the first boreholes drilled in 1950 (Rühle 1952). Material obtained from these boreholes was examined by means of pollen analysis and plant macroremains analysis carried out by Dyakowska (1952). On the basis of these studies, the relative age of sediments from Nowiny Żukowskie was determined as the Mazovian (Holsteinian) interglacial, and Szafer (1953) considered the site to be a stratotype for this interglacial due to the presence of a complete and undisturbed sequence of lacustrine sediments and perfectly preserved fossil plant material.

Within the last 60 years significant progress has been made in the improvement of research methods applied for palynological analysis with these being essential for the interpretation of results. Due to these circumstances, a new drilling was carried out in the Nowiny Żukowskie area in 2005, in a site adjacent to the borehole drilled in 1950. The sampled material was subjected to studies aiming to identify the palynostratigraphic zones. The examined drill core was denoted as $NŻ_{05}$.

REGIONAL SETTING

The Lublin Upland is part of the Lublin Province, a geographical region covering the area between the middle Vistula river and the Bug river. The geographic location of this area

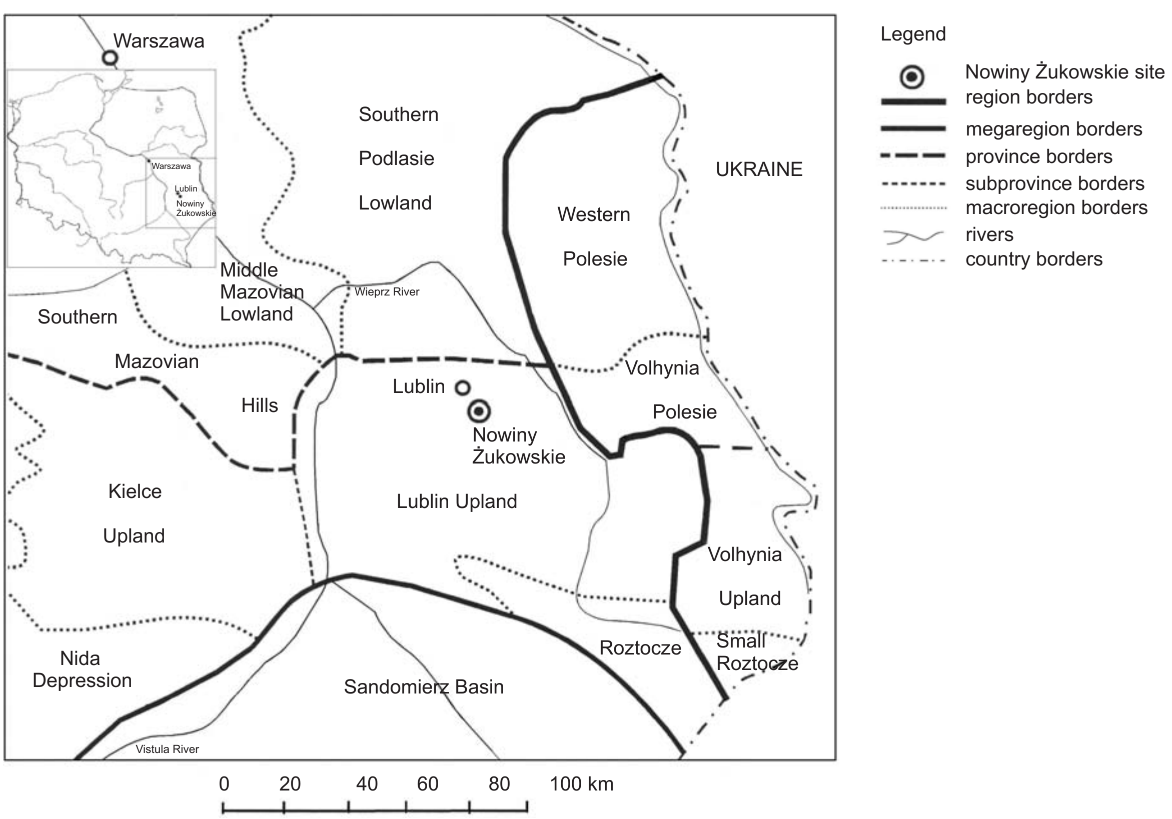

Fig. 1. Locality of Nowiny Żukowskie site (geographical regions after Kondracki (2000)

is of a remarkable character in Poland and Europe and is situated at the intersection of physiographic boundaries of the highest rank. The north-eastern boundary, though poorly visible in the field, is of high geographic importance as it separates the Polesie Region and the Volhynia Upland, representing the Eastern Europe, from the areas belonging to Western Europe. The northern boundary is marked by the 20 m plus high edge of the Lublin Upland. It separates the latitudinal belts of the Central Polish Lowlands that belong to the European Lowland from the southern area of European uplands and mountains. The upland area of this geographical region, elevated above its surrounding, with a steep edge of the Roztocze Region, slopes down to the south towards the area of foreland lowlands. The north-eastern part of the low belongs to the Lublin Upland (Kondracki 2000).

Nowiny Żukowskie is located ca. 23 km to the south-east of Lublin, in the northern part of the Lublin Upland (Fig. 1) and within the area of the Krzczonowski Landscape Park. The locality is situated in lowland and its eastern periphery is marked by a flat valley extending from south-east to north-west (Rühle 1952). Quaternary sediments of the lowland attain an even thickness of 30 m and are underlain by Tertiary limestone and siliclastic rocks (Fig. 2).

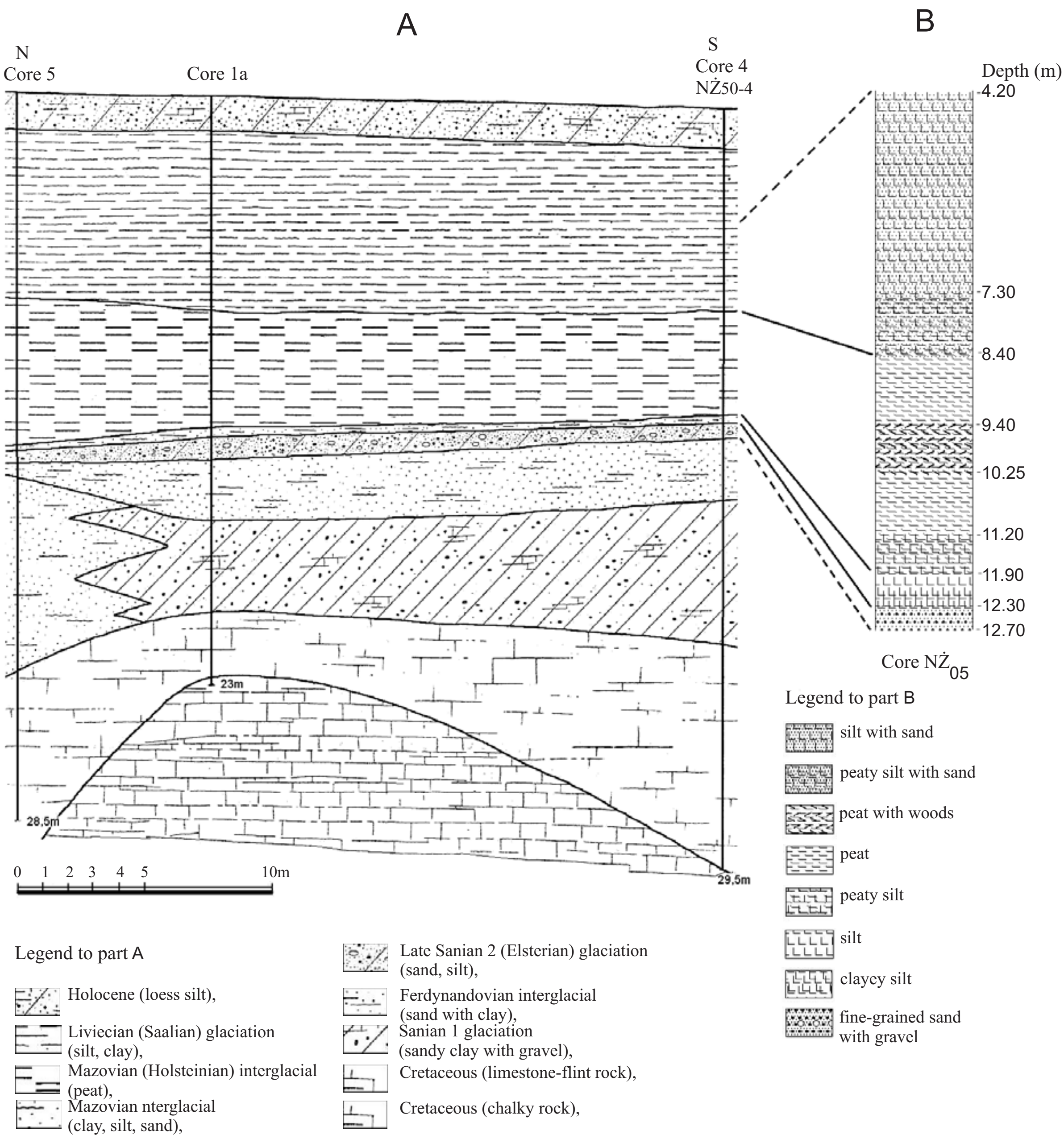

Fig. 2. Geological section of Nowiny Żukowskie: **A** – profile $NŻ_{50\text{-}4}$ after Rühle (1952); **B** – lithology of $NŻ_{05}$ profile

Studies carried out as part of the Detailed Geological Map of Poland at the scale of 1: 50 000 (Harasimiuk et al. 1987, 1988) revealed that the Nowiny Żukowskie area is built of Tertiary deposits forming sandstone outcrops of the Sarmat Stage (Miocene, the Szabatowa Mt. – 282.8 m a.s.l.) and gaizes with interbedded chalky limestone, lying directly below the Pleistocene sediments recorded by Rühle (1952). The Tertiary sediments are underlain by limestone and siliclasic rocks of the Dan Stage (Rühle 1952), which are currently considered as Palaeogene (Harasimiuk et al. 1987, 1988). Moreover, the surrounding is also typified by the presence of outcrops of marls and chalks, often overlain by sandy silts and loess-like silty sands. The Pleistocene sediments from Nowiny Żukowskie overlying the Tertiary deposits according to Rühle (1952), in their basal part represent the oldest glaciation of this area (Sanian 1 glaciation = part of the Cromerian Complex), marked by the presence of sandy loam with sandstone cobbles and gravels (Fig. 2). Sediments recorded in the upper part of section comprise sand with layers of clay and silt, being devoid of organic remains and classified into the interglacial (Ferdynandovian interglacial = part of the Cromerian Complex). The overlying stratum, 0.9 m in thickness, contains sand with gravels and cobbles of crystalline rocks (Sanian 2 glaciation = Elsterian). It is overlain by lacustrine sediments with silt and peat (ca. 6 m in thickness) representing the Mazovian (Holsteinian) interglacial. The last stratum of a lacustrine origin is composed of silts and sand, cobbles and fragments of sandstones (Liviecian glaciation = Saalian, ca. 7 m in thickness). The surface layer bears loamy sands and loess silt, probably deriving from Holocene.

MATERIAL AND METHODS

GEOLOGICAL LOCATION OF ORGANIC DEPOSITS

Section $NŻ_{05}$ was drilled in Nowiny Żukowskie in 2005, ca. 1 m to the north-east of the archival borehole 4, drilled in 1950 (Rühle 1952) and denoted as $NŻ_{50-4}$. The new borehole was drilled by Szadkor Company from Krosno with the use of the URB 2.5 A drill rig, 132 mm in diameter. The drilled log was 15 m long and each recovered segment obtained from the core was 1.5 m long.

The sediment (Tab. 1) is composed of loose sands passing from coarse-grained into fine-grained ones, containing many horizons of iron and a bed of gravels, up to 8 mm in diameter, overlain by a series of clays and silts. Their last layer contains a large amount of an organic admixture. The depth of 11.20 m is marked by the presence of highly compacted organic lacustrine sediments – peat of ca. 3 m in thickness. The stratum is overlain by a bed of silts, ca. 7.3 m thick, and a bed of loam, over 1 m thick.

SAMPLING AND POLLEN ANALYSIS

All together 400 samples were taken from a core deriving from the depth of 1.30–13.00 m. Mineral sediments (clay, silt and sand) were sampled every 5 cm with 3 cm^3 taken for analysis, while for highly compacted peat sediments samples were taken every 2.5 cm with 1 cm^3 taken. All samples meant for pollen analysis were acetolized according to the Erdtman's method (1960). Before acetolysis, one tablet containing a *Lycopodium* indicator was added per 1 cm^3 of each sample (Stockmar 1971, Berglund & Ralska-Jasiewiczowa 1986), in order to determine the absolute concentration of sporomorphs.

The pollen and spores were identified with the use of the Amplival Zeiss-Jena light microscope.

Sporomorphs were determined with the use of key by Faegri and Iversen (1989a) and Moor et al. (1991), papers by Faegri and Iversen (1989b), Punt (1976), Punt & Clarke (1980, 1981, 1984), Punt & Hoen (1995), Punt et al. (1991, 1994, 2006), Stix (1960), and Erdtman et al. (1961), atlases by Reille (1992), Beug (2004), and Stuchlik et al. (2001), as well as with the use of the reference pollen collection kept at the Department of Palaeobotany, W. Szafer Institute of Botany, Polish Academy of Sciences in Kraków.

Pollen spectra for each sample were counted on two slides of a surface area of 20 × 20 mm. If the frequency of pollen grains was high, the counting was carried out up to ca. 1000 grains. Only in case of samples taken from the mineral part of the drill core, originating from the late glacial and early glacial sediments where the frequency of sporomorphs was very poor, the counting was carried out up to ca. 200–300 pollen grains and spores, usually on three slides.

POLLEN DIAGRAM

Pollen data obtained from pollen analysis from 119 samples were presented graphically in a pollen diagram showing the percentage of particular taxa found in the analysed spectra and ordered stratigraphically. The diagram was plotted using POLPAL software (Walanus & Nalepka 1999, Nalepka & Walanus 2003). Percentage calculations were based on the basic sum which included pollen grains of trees and shrubs (AP) and terrestrial herbaceous plants and dwarf shrubs (NAP). The percentage proportion of aquatic plants, spores of Pteridophyta and Bryales, colonies of algae, and of rebedded and non-determined sporomorphs was calculated in relation to the basal sum added to the basic sum.

In the percentage pollen diagrams taxa are ordered in accordance with their habitat requirements (i.e. humidity), on the basis of the „Ecological indicator values of vascular plants of Poland" (Zarzycki et al. 2002).

Table 1. Lithology of the profile $N\dot{Z}_{05}$.

Depth (m)	Sdiment description
1.00–1.25	yellowish brown clayey silt, with sand, gravel and stones (to 5 cm Ø)
1.25–2.60	light gray clayey silt, with small amount of sand and with small ferriferous concretions in floor of layer
2.60–4.00	light brownish gray silt, with small amount of clay, sand and gravel
4.00–4.20	light grayish brown clayey and sandy silt, with gravel and moluscs
4.20–5.50	light grayish brown silt, with small amount of clay and sand
5.50–7.35	dark grayish brown clayey and sandy silt, with interlayers of dark brown humus
7.35–8.10	dark gray clayey and peaty silt, with small amount of sand
8.10–8.455	dark gray clayey and sandy silt, with small amount of peat, with interlayers of humus
8.455–9.40	dark brown peat, with small amount of sand, strongly decomposed
9.40–10.30	dark brown peat, very hard and compact with interlayers of wood
10.30–10.80	dark brown peat, weakly decomposed
10.80–11.20	dark grayish brown peat, weakly clayey, with vegetation remains
11.20–11.90	dark grayish brown silt, with small amount of clay, peat, sand, with a lot of humus and macroremains
11.90–12.12	olive gray clayey silt, weakly sandy in the top of layer
12.12–12.30	grayish brown clay, with small amount of sand
12.30–12.31	dark reddish brown fine-grained sand, very hard ferriferous layer
12.31–12.56	dark brownish yellow fine-grained sand
12.56–12.80	olive gravel (to 8 mm Ø), with fine-grained sand
12.80–13.07	light olive small-grained clayey sand, with small ferriferous interlayers
13.07–13.08	reddish brown fine-grained sand, ferriferous layer
13.08–15.00	dark yellowish brown small-grained clayey sand, with gravel

The order in which the curves are arranged conforms with the appearance of particular taxa within habitat groups.

The separated lower part of pollen diagram showing the late Sanian 2 glaciation was modified by exclusion of rebedded sporomorphs, and pollen grains of *Pinus sylvestris* t. and *Betula alba* t., large amounts of which originate from a long-distance transport.

The concentration of sporomorphs in section $N\dot{Z}_{05}$ was calculated with the POLPAL software (Walanus & Nalepka 1999, 2007).

NUMERICAL ANALYSIS

In order to distinguish significant parts of the sections and to confirm the distinction of zones in profile $N\dot{Z}_{05}$, standard numerical analyses, including the Constrained Single Link, Principal Components Analysis (Birks 1986b, Prentice 1986, Walanus 1995, Walanus & Nalepka 1999, 2007, Nalepka & Walanus 2003, Nalepka 2005) and Rarefaction Analysis (Rarefacted number of taxa, Hurlbert 1971, Krebs 1989), were carried out.

RESULTS OF POLLEN ANALYSIS

In the both profiles a total of 201 taxa have been identified: 74 determined to the rank of species, 57 to genus, 51 to order and 16 to family. Two taxa within the *Potamogeton* genus were determined as sections: *Eupotamogeton* and *Coleogeton* while a single taxon within the *Osmunda* genus included two species: *O. regalis* and *O. claytoniana.*

The examination of 119 samples from the core $N\dot{Z}_{05}$ enabled the identification of 199 taxa, represented by 45 trees and shrubs (AP), 8 dwarf shrubs, 105 terrestrial herbaceous plants (NAP), 24 aquatic and reedswamp plants, 13 Pteridophyta, 2 Bryophyta, 2 algae, 22 plant taxa considered to be rebedded, 4 Tertiary sporomorphs (*Tsuga*, *Ilex aquifolium*, *Celtis* and *Nyssa*) and also cysts of Dinophyceae.

Names of vascular plants determined to species follow Mirek et al. (2002), and determined to order or family follow Beug (2004), and Moore et al. (1991). Taxonomy of algae was adopted from Kadłubowska (1975) and Komarek & Jankovská (2001).

REBEDDED SPOROMORPHS

The stage of damage and corrosion of sporomorphs, found in mineral sediments of sections $N\dot{Z}_{05}$ and $N\dot{Z}_{50\text{-}4}$, most likely indicates their water transport. Such sporomorphs were considered to be rebedded in a secondary bed.

The rebedded sporomorphs represent Tertiary taxa (*Tsuga*, *Ilex aquifolium*, *Celtis*, and *Nyssa*), and all were included in a common group of the "Rebedded sporomorphs". The group covered also pollen grains of trees and shrubs of higher climatic requirements, found in mineral sediments of cool periods, and most likely originating from earlier Quaternary periods (*Abies*, *Picea abies, Taxus baccata*, *Acer*, *Hedera helix*, *Alnus glutinosa* t., *Buxus*, *Sambucus nigra*, *Viburnum* t., *Carpinus betulus*, *Corylus*, *Fagus sylvatica*, *Quercus*, *Juglans*, *Pterocarya*, *Fraxinus excelsior*, *Tilia cordata* t., *Ulmus*, and *Vitis*). The rebedded sporomorphs were found in the base of section $N\dot{Z}_{05}$, at the depth of 12.700–11.605 m, and in section $N\dot{Z}_{50\text{-}4}$, at the depth of 13.000–12.350 m.

DESCRIPTION OF LOCAL POLLEN ASSEMBLAGE ZONES (L PAZ)

In the examined profiles of Nowiny Żukowskie, the distinction of Local Pollen Assemblage Zones (L PAZ) was carried out in accordance with criteria stated by West (1970), Birks (1973) and Janczyk-Kopikowa (1987, 1988) and pollen period by Szafer (1953). The zones were numbered from the base to top of the profile. Local Pollen Assemblage Zones have been described on the basis of pollen diagrams (Figs 3, 4) and were denoted as $NŻ_{05}$ for the profile drilled in Nowiny Żukowskie in 2005, (Tab. 2) and $NŻ_{50\text{-}4}$ for the profile 4 drilled in Nowiny Żukowskie in 1950, (Tab. 3). The upper boundary of a given zone is also the lower boundary of the overlying one.

HISTORY OF VEGETATION

In the descrtption of vegetation, two equivalent pollen zones, from profile $NŻ_{05}$ and $NŻ_{50\text{-}4,}$ were correlated.

LATE SANIAN 2 (ELSTERIAN) GLACIATION

$NŻ_{05}$1 *Betula nana-Juniperus-*(*Larix*)-NAP L PAZ

$NŻ_{50\text{-}4}$1 *Betula nana-Juniperus-*(*Larix*)-NAP L PAZ

During the late Sanian 2 glaciation the landscape was dominated by a diversified mosaic of open, steppe-tundra communities (Figs 5, 6). Birches and pines occurred infrequently as single trees or in small clusters. Pollen of *Pinus sylvestris* and *Betula alba* were not frequent, and presumably originated in part from long-distance transport. Taxa of herbaceous plants were found abundantly (Fig. 6 – increase in pollen values up to 90%). *Betula nana* and *Juniperus* also attained high values, up to 40% and 20%, respectively.

The area was marked by the occurrence of larch (*Larix*), found in pollen spectra in a frequency amounting to even 2%. Clumps of trees were likely to include green alder (*Alnus viridis*) and stone pine (*Pinus cembra*). However, pollen grains of stone pine were found infrequently suggesting that the trees grew at a distance from the basin investigated. Patches of woody vegetation found in drier habitats could have included *Lycopodium annotinum*.

The end of this period was characterized by a considerable increase in the proportion of pine (*Pinus sylvestris*), most likely resulting from an intensified long-distance transport of its pollen from areas intensively overgrown by the trees. However, it was a short-term event, followed by a rapid decrease in pollen values for *Pinus*. It is possible a lack of sediments.

Dry habitats were presumably covered by steppe-like grassy communities with admixtures of wormwood (*Artemisia*), juniper (*Juniperus*), and *Hippophaë rhamnoides* that is usually found on sandy, poor soils, also.

On humid areas communities were predominated by sedges (Cyperaceae), with *Thalictrum*, *Filipendula*, *Caltha*, *Trollius europaeus*, *Mentha*, and tundra-like communities with a high proportion of *Betula nana* accompanied by infrequent dwarf willows (*Salix herbacea*), *Polygonum viviparum*, *Equisetum*, and mosses.

The belt of littoral reed-swamps surrounding the lake was most likely overgrown by communities dominated by Cyperaceae and *Phragmites* accompanied by *Equisetum*, some species of Ranunculaceae, Brassicaceae, and Apiaceae. *Sphagnum* and other mosses occurred abundantly. In standing water within lakes, *Botryococcus* was present.

Rebedded Tertiary sporomorphs, particularly common for both the Tertiary and Quaternary, were very numerous. Among the Quaternary sporomorphs a lot of thermophylous trees occur, i.e. *Picea abies* (even 12%), *Abies* (8%), *Carpinus* (8%), their pollen grains are corroded. Cysts of Dinophyceae were also recorded, what may serve as an additional evidence of unstable soil conditions and erosive processes resulting from the lack of a dense plant cover. The open type of vegetation may be also evidenced by a very low concentration of sporomorphs found in the discussed zone.

MAZOVIAN (HOLSTEINIAN) INTERGLACIAL

Pollen Period I

$NŻ_{05}$2 *Betula-Larix-*(*Pinus*)-NAP L PAZ

$NŻ_{50\text{-}4}$2 *Betula-Larix-*(*Pinus*)-NAP L PAZ

Forest cover typical for the initial phase of the Mazovian (Holsteinian) interglacial was still of a poor density and was predominated

Fig. 3. Percentage pollen diagram of the Nowiny Żukowskie NZ_{05} profile

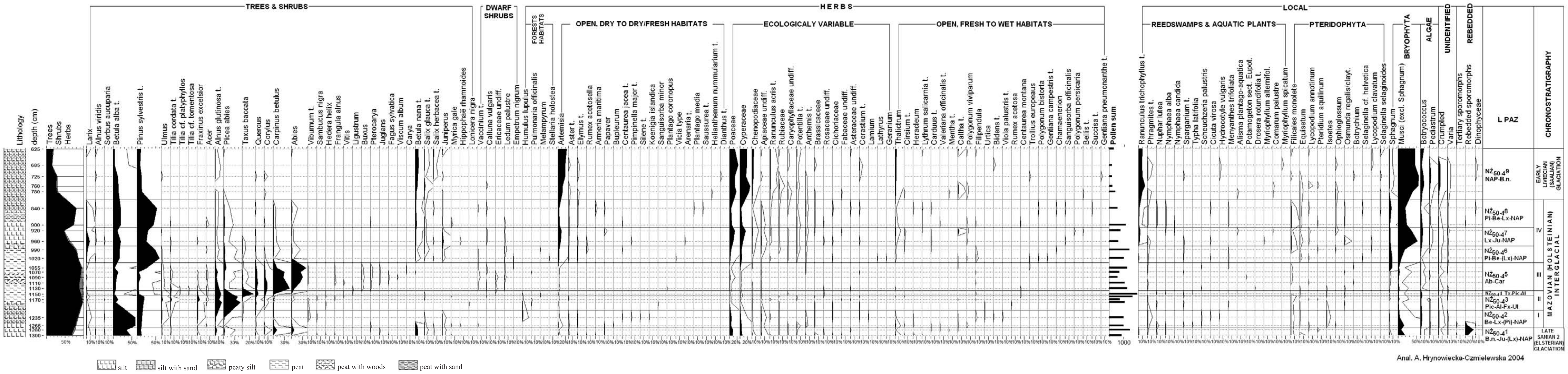

Fig. 4. Percentage pollen diagram of the Nowiny Żukowskie NŻ$_{50\text{-}4}$ profile

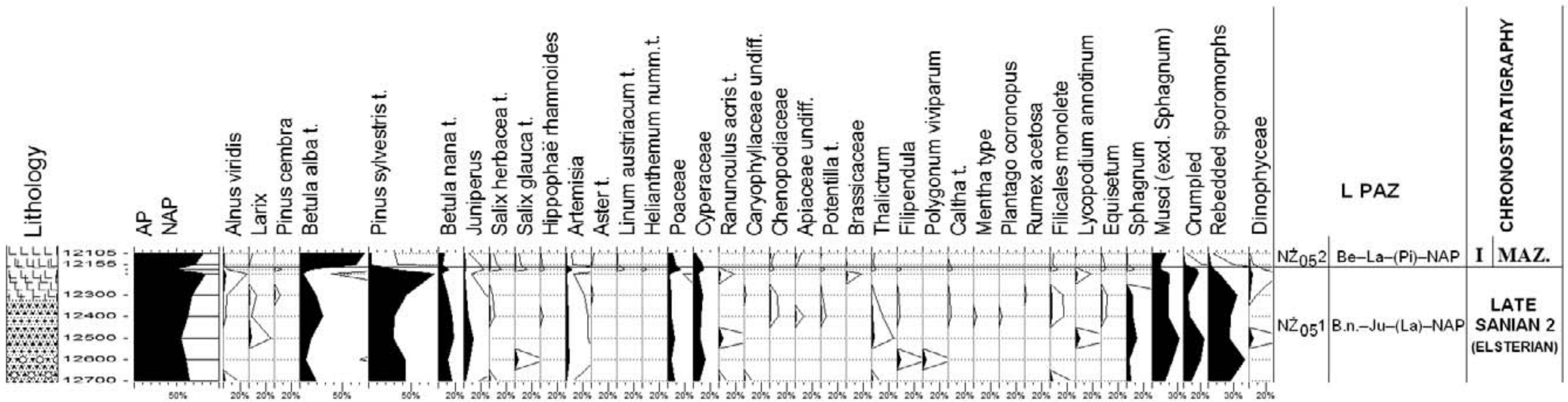

Fig. 5. Modified percentage pollen diagram of late Sanian 2 (Elsterian) glaciation of the Nowiny Żukowskie (profile $NŻ_{05}$) excluding in pollen sum (AP+NAP) rebedded sporomorphs

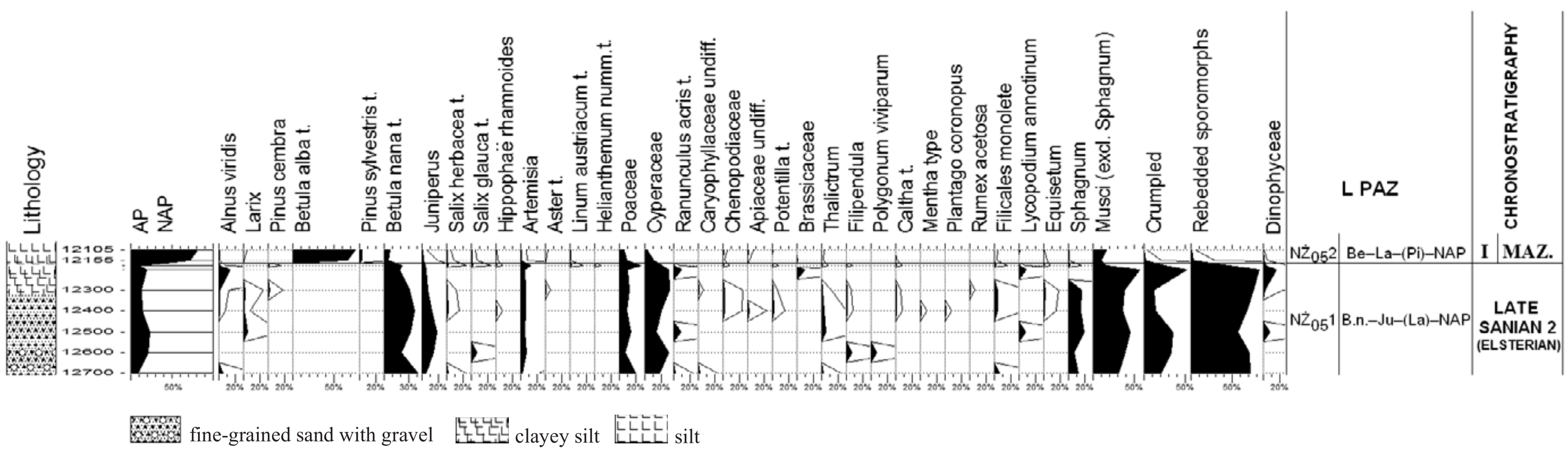

Fig. 6. Modified percentage pollen diagram of late Sanian 2 (Elsterian) glaciation of the Nowiny Żukowskie (profile $NŻ_{05}$) excluding in pollen sum (AP+NAP), rebedded sporomorphs and pollen of *Pinus sylvestris* t. and *Betula alba* t.

Table 2. Profile NŻ$_{05}$. Description of local pollen assemblage zones (L PAZ)

Symbol	Name	Depth (m)	Description (numerical analysis and concentration – Fig. 7)
			Late Sanian (Elsterian) 2 glaciation
NŻ$_{05}$1	*Betula nana-Juniperus-(Larix)*-NAP	12.700–12.180	Sporomorphs are found in low or very low concentrations. Values of AP vary from 50.1% to 86%. Values of the sum of AP + NAP, after excluding the rebedded sporomorphs, vary from 36.5% to 73.3%. Pollen of *Pinus* attains its highest proportions, ca. 25%, increasing to 67% at the top of layer. *Betula* reaches values between 3% and 19.5%, *Juniperus* – of 8%, *Alnus viridis* – of 2.5%, and *Larix* – of 2%. *Betula nana* attains a high frequency of 14%. Presence of *Hippophaë rhamnoides* is recorded. Pollen values of Poaceae increase from ca. 3.4% to 13.5%, of Cyperaceae – from ca. 6% to 10.5%, and of *Artemisia* – from 2% to 6%. Rebedded sporomorphs attain a high frequency of ca. 30%, crumpled sporomorphs – of 19.5% and Dinophyceae – of 4%. The upper boundary of the zone is marked by a decrease in values of *Pinus* (from 67% to 3.2%), *Betula nana*, and *Juniperus*, and by an increase in the amount of *Betula* (from 10% to 62%). Proportions of rebedded sporomorphs decrease. Results of numerical analysis (ConSlink) confirm the inclusion of these spectra into the given L PAZ
			Mazovian (Holsteinian) interglacial Pollen Period I
NŻ$_{05}$2	*Betula-Larix-(Pinus)*-NAP	12.180–11.605	Sporomorphs are found in high concentrations. Values of AP amount to 81.5%. High proportion (between 51.5% and 71%) is recorded of *Betula*. Frequency of *Pinus* gradually increases from ca. 3% to 18.5%. *Larix* attains a value of ca. 1%. Values of *Betula nana* and *Juniperus* decrease from 6.5% to 1% and from 1.7% to 0.3%, respectively. Pollen of *Hippophaë rhamnoides*, *Ephedra distachya* t., and *Ribes alpinum* recorded. Values of Poaceae and Cyperaceae fluctuate between 8.2% and 5.3%, and between 10% and 3%, respectively. Values of Apiaceae increase from 0.2% to 2.4%. Rebedded sporomorphs and Dinophyceae are infrequent and corroded. Their values do not exceed 2%. The upper boundary of the zone is marked by a decrease in values of NAP and a slight increase in the amount of pollen of trees, mainly *Ulmus*, *Alnus*, and *Picea*. Results of numerical analyses (ConSlink and PCA) confirm the distinction of this L PAZ
NŻ$_{05}$3	*Betula-Larix-(Pinus)*	11.605–11.255	Sporomorphs are found in high concentrations. The AP curve attains a value of 91%. The highest values are reached by *Betula* – 61% and *Pinus* – 20.5%. Values of *Larix* increases to 2.9%. An increase is observed in curves plotted of trees: *Ulmus* – up to 3.4%, *Fraxinus* – up to 7.6%, *Picea* – up to 5.7%, and *Alnus* – up to 3.7%. *Viburnum* and *Sambucus nigra* appear. Proportions of Poaceae and Cyperaceae decrease (from 4.9% to 1.8%, and from 3.5% to 1.1%, respectively). Apiaceae attain a value of 2%. Proportion of *Humulus lupulus* increases up to 1.9%. The upper boundary of the zone is marked by a decline of the *Betula* curve, a nearly complete disappearance of the NAP curve, and a continued increase in the amounts of *Ulmus*, *Fraxinus*, *Picea*, *Alnus*, and *Tilia*. Results of numerical analysis (ConSlink) suggest a similarity with the lower L PAZ
			Pollen Period II
NŻ$_{05}$4	*Fraxinus–Ulmus-Tilia*	11.255–11.105	Sporomorphs are found in high concentrations. Values of AP amount to 95.6%. Pollen of *Fraxinus* is dominant – its proportion increases from 15.2% and attains its maximum value of 22.5%. It is accompanied by pollen of *Ulmus* (5.9%) and *Tilia* (8.7%). Curves of *Picea* and *Alnus* rise, from 7.9% to 21% and from 7% to 13.5%, respectively. Curves of pine and birch decline from 25% to 14% and from 20% to 6.4%, respectively. *Tilia* cf. *tomentosa*, *T.* cf. *platyphyllos*, *Frangula alnus*, *Viburnum* t. occur. Poaceae and Cyperaceae attain the proportion of ca. 1%, while *Artemisia* – below 1%. The upper boundary of the zone is marked by an increase in the amount of *Picea* and decrease in values of *Fraxinus*, *Ulmus*, and *Tilia*. Results of numerical analyses (ConSlink and PCA) confirm the distinction of this L PAZ
NŻ$_{05}$5	*Picea-Alnus*	11.105–10.955	Sporomorphs are found in high concentrations. Values of AP increase to 98.4%. Spruce attains the proportion of 48%. *Alnus* reaches its maximum value of 14.9%. In the middle part of the zone, values of *Betula* pollen increase to 24.5%. The continuous curve of *Carpinus* begins. *Quercus* attains the proportion of 3.4%, and *Corylus* – of ca. 1.4%. Values of *Ulmus*, *Fraxinus*, and *Tilia* show a decrease from 2.1% to 0.8%, from 10.2% to 1.9% and from 2.1% to 1.4%, respectively. Pollen of *Hedera helix*, *Viscum*, and *Sambucus nigra* appear. Proportions of Cyperaceae and Poaceae do not exceed 1%. The upper boundary of the zone is marked by a decrease in the amount of *Picea* and *Alnus* and an increase in the proportion of *Taxus*. Results of numerical analyses (ConSlink and PCA) allow the distinction of pollen spectra within this L PAZ

Table 2. Continued

Symbol	Name	Depth (m)	Description (numerical analysis and concentration – Fig. 7)
NŻ$_{05}$6	*Taxus-Picea*	10.955–10.705	Sporomorphs are found in high concentrations. Values of AP amount to 98.9%. Pollen of *Taxus* attains its maximum value of 43%. Values of *Picea* increase from 20% to 34%, of *Quercus* – from 3.1% to 8.3%, and of *Corylus* – from 0.8% to 5.9%. *Alnus* attains a proportion of ca. 11%, *Ulmus* – of 0.7%, *Tilia* – of 0.9%, and *Fraxinus* – of 3%. The continuous curve of *Abies* begins. Presence of *Hedera helix*, *Viscum*, *Ligustrum*, and *Buxus* is recorded. Proportion of *Betula* attains ca. 3.6%, reaching 7.7% only at the top of the zone. Value of *Pinus* amounts to 12%. The upper boundary of the zone is marked by a decline of the *Taxus* curve and an increase in the amount of *Picea*. Results of numerical analyses (ConSlink and PCA) confirm the inclusion of these spectra into the given L PAZ
NŻ$_{05}$7	*Picea*	10.705–10.555	Sporomorphs are found in high concentrations. Values of AP amount to 98.6%. The pollen of *Picea* attains its maximum proportion of 55.5%. Values of *Alnus* amount to ca. 6.8%, of *Quercus* – to ca. 3%, of *Corylus* – to ca. 3.2%, and of *Taxus* – do not exceed 2%. Values of *Carpinus* increase from 2.1% to 5.9%. Proporcion of *Abies* and *Ulmus* do not exceed 1%, while *Fraxinus* attains the value of ca. 1% and *Tilia* – of ca. 1.3%. In the middle part of the zone, *Pinus* attains the proportion 18.5%, followed by a decrease to 12%. The values of *Betula* pollen increase from 4.1% to 6.4%. Pollen of *Hedera helix* and *Ligustrum* is recorded. The upper boundary of the zone is marked by a decline in the amount of *Picea* and increase in the proportion of *Betula* and *Pinus*. Results of numerical analyses (ConSlink and PCA) confirm the distinction of this L PAZ
NŻ$_{05}$8	*Pinus-Betula-Picea-(Larix)*	10.555–10.480	Sporomorphs are found in high concentrations. Values of AP amount to 97.9%. Pollen of *Betula* and *Pinus* attain high frequencies of 36% and 31%, respectively. Values of *Picea* decrease from 38.5% to 19%. At the top of the zone, proportion of *Corylus* increases to 7.5% and of *Abies* – to 7.9%. The values of *Larix* amounts to 1.4%, and of Cyperaceae – to 4%. The upper boundary of the zone is marked by a decrease in the proportions of *Pinus* and *Betula*, and an increase in the amount of *Abies* and *Carpinus*. Results of numerical analysis (ConSlink) allow the distinction of pollen spectra within this L PAZ
Pollen Period III			
NŻ$_{05}$9	*Abies-Carpinus*	10.480–9.705	Sporomorphs are found in high concentrations. Values of AP amount to 99.2%. *Abies* attains its maximum proportion of 53.5%, followed by oscillations between 17%, 50%, 6.2% and 48%. Pollen of *Carpinus* attains the value of 14% and afterwards fluctuates between 38%, 3.8%, 61.5% (being its maximum value) and 30.5%. Finally, at the top of the zone, it decrease to 4.3%. Values of *Picea* decrease from 22.5% to 1%. However, at the top of the zone, they increase to 6.7%. The proportion of *Pinus* decreases from 21.5% to 8.7%, but at the top of the zone it increase to 18.5%. Values of *Alnus* is variable and does not exceed 10%. *Quercus* and *Corylus* gradually increase their values to 11.1% and 25%, respectively. Proportions of *Ulmus*, *Fraxinus*, and *Taxus* do not exceed 1%. Values of *Tilia*, in the central part of the zone, amount to 1.7%. Thermophylous taxa of *Frangula alnus*, *Vitis*, *Hedera helix*, and *Viscum* are recorded. At the upper part of the zone, *Pterocarya* obtains its maximum value of 2.1%. Proportion of *Buxus* attains 1.4%. *Juglans* and *Carya* occur. *Fagus sylvatica* is represented by a continuous, low-percentage curve. The upper boundary of the zone is marked by a decrease in the proportions of *Abies* and *Carpinus* and increase in the amount of *Betula* and *Pinus*. Results of numerical analyses (ConSlink and PCA) confirm the distinction of this L PAZ
Pollen Period IV			
NŻ$_{05}$10	*Pinus-Betula-*(*Larix*)-NAP	9.705–9.155	Sporomorphs are found in high concentrations. However, from the bottom of the zone to its top, values of AP decrease from 94.8% to 76.7%. Proportion of *Pinus* decreases from 61.5% to 40%. Values of *Larix* increases from 0.9 to 1.9%. Proportion of *Betula* reaches ca. 20%, of *Abies* – ca. 5%, of *Carpinus* – ca. 3.6%, of *Picea* – ca. 2.7%, of *Alnus* – ca. 1.5%, of *Quercus* – ca. 1.5%, and of *Corylus* – below 1%. *Fraxinus*, *Ulmus*, and *Tilia* occur infrequently. Values of *Betula nana* attain ca. 1.5% and of *Juniperus* – do not exceed 1%. Among the NAP, Cyperaceae increase their value from 3.5% to 10.3%, Poaceae attain ca. 4% and *Artemisia* – ca. 2.4%. *Buxus*, *Pterocarya*, *Frangula alnus*, *Viscum*, *Vitis*, *Fagus sylvatica*, and *Viburnum* t. are still present. The upper boundary of the zone is marked by an increase in the proportions of *Betula*, *Larix* and Cyperaceae and a decrease in the amount of *Pinus* and other trees, which nearly completely disappear. Results of numerical analyses (ConSlink and PCA) confirm the distinction of this L PAZ

Table 2. Continued

Symbol	Name	Depth (m)	Description (numerical analysis and concentration – Fig. 7)
NŻ$_{05}$10	*Pinus-Betula-*(*Larix*)-NAP	9.155–9.080	"Birch oscillation" Sporomorphs are found in low concentrations. Proportion of AP decreases from 81.8% to 74.8%. Pollen of *Betula* attain a high frequency of 52%. Concentration of *Larix* reaches 9%. Values of pollen of *Pinus* decrease to 3.6%. However, at the top of the zone, they attain 18%. Other pollen of trees, found in the bottom, attain higher values: *Alnus* – 4.6%, *Taxus* – 1.1%, *Quercus* – 2.6%, *Corylus* – 3.7%, *Abies* – 1.6%, *Carpinus* – 4.9%. Values of *Betula nana* decrease from 2% to 1%. *Artemisia* attains the frequency of 2%, Poaceae – of 4.3%. Proportion of Cyperaceae increases from 8.3% to 22.5%, and of *Equisetum* – from 4.6% to 10%. The upper boundary of the zone is marked by an increase in the amount of *Pinus* and a decrease in the values of *Betula*. Results of numerical analyses (ConSlink and PCA) confirm the distinction of this L PAZ
		9.080–8.400	Sporomorphs are found in high concentrations. Proportion of AP decreases from 86.1% to 62.6%. Pollen of *Pinus* is dominant (47%–55.5%). Values of *Betula* decrease from 27.5% to 14% and afterwards slightly increase to 18%. Frequency of *Larix* decreases from 3.2% to ca. 1.3%. Proportion of *Picea* attains 3.7% (at the bottom of the zone) and *Abies* – 3.5% (at the top of the zone). Values of pollen of other trees do not exceed 1%. Values of *Betula nana* fluctuate between 1%, 2.7% and ca. 1.5%. *Juniperus* attains the frequency of 1%. Proportion of *Artemisia* increases from 0.6% to 6%, of Poaceae – from 1.2% to 6%, while values of Cyperaceae decrease from 6.8% to ca. 3% and afterwards increase to 10%. *Buxus* and *Frangula alnus* occur infrequently. Pollen of *Alnus viridis*, *Hippophaë rhamnoides*, and *Ephedra distachya* t. are recorded. The upper boundary of the zone is marked by a decrease in the proportions of *Pinus* and an increase in the amounts of NAP. Results of numerical analyses (ConSlink and PCA) confirm the distinction of this L PAZ and suggest its similarity with the upper L PAZ
NŻ$_{05}$11	*Larix-Juniperus-*NAP	8.400–8.100	At the beginning of the zone sporomorphs are found in low concentrations and next concentration of sporomorphs increases. Values of AP increase from 42.6% to 57.4%. Proportion of *Larix* increases from 1% to 9%. *Juniperus* attains its maximum value of 13%, followed by a decrease to 6%. Values of *Pinus* increases to 23%, and of *Betula* – decreases to 12% and afterwards increases to 16.5%. Pollen of other trees occur infrequently. Proportion of *Betula nana* decreases from 4% to ca. 1.7%. Values of Poaceae fluctuate between 8% and 13.5%, and of Cyperaceae - between 12% and 22%. *Artemisia* attains the frequency of ca. 5.4% (max. 10.5%), *Ranunculus acris* – of ca. 2.2%, Chenopodiaceae – of ca. 2%. Proporcion of *Ranunculus trichophyllus* decreases from 15.5% to ca. 3%. The upper boundary of the zone is marked by an increase in the proportions of *Pinus* and *Betula* and a decrease in the amount of *Larix* and *Juniperus*
NŻ$_{05}$12	*Pinus-Betula-Larix*-NAP	8.100–7.300	Sporomorphs are found in high concentrations. Values of AP increase from 54.6% to 62.8% and afterwards decrease to 46.8%. Maximum values are attained by pollen of *Pinus* (increase from 25% to 34%, followed by a decrease to 20%) and *Betula* (increase from 16% to 21.5%). Proportion of *Larix* decreases from 5.4% to 1%. *Juniperus* attains the value of 2.4%, which decreases to ca. 1.5%. Frequency of other trees usually do not exceed 1%. Only *Abies* attains the value of 2.5% (at the top of the zone), *Picea* – of over 1%, and *Betula nana* – of ca. 1.5%. Pollen of *Pinus cembra*, *Alnus viridis*, and *Ribes alpinum* are present. Values of *Artemisia* increases from ca. 4% to 8%, of Poaceae – from 7.7% to 12.5%, and of Cyperaceae decrease from 18% to ca. 13%. The upper boundary of the zone is marked by a decrease in the amounts of pollen of *Pinus* and *Betula*, and an increase in the proportions of *Betula nana* and NAP. Results of numerical analyses (ConSlink and PCA) confirm the classification of the distinguished spectra into the Early Liviecian glaciation
			Early Liviecian (Saalian) glaciation
NŻ$_{05}$13 NAP-*Betula nana* L PAZ NŻ$_{05}$13a	NAP-*Betula nana*	7.300–5.400	Sporomorphs are found in very low concentrations. Proportion of AP decreases from 33.7% to below 30% in the middle part of the zone, and 18.2% in the top of zone. Among trees, the highest values are attained by *Betula* (15.5% decreasing to 5.5% and afterwards increasing to about 12%). Values of *Pinus* fluctuate about below 10%. Other trees occur infrequently. Proportions of *Pinus cembra* and *Larix* do not exceed 1%. Pollen of *Ribes alpinum* is recorded. *Alnus viridis* attains the frequency of 1.4%. Values of *Juniperus* oscillate around 2% and decrease below 1%, and values of *Salix herbacea* – around 1.5%, and of *Betula nana* fluctuates between 8.5%, about 4% in middle part of zone, and 10.5% in top part of zone. Among NAP, the highest proportions are attained by Cyperaceae (from 17.5% to 28.5% and decrease to 12%), Poaceae (from 17% to 27.5%), *Artemisia* (from 8% to

Table 2. Continued

Symbol		Name	Depth (m)	Description (numerical analysis and concentration – Fig. 7)
NŻ$_{05}$13 NAP-*Betula nana* L PAZ	NŻ$_{05}$13a	NAP-*Betula nana*	7.300–5.400	17.5%), Chenopodiaceae (ca. 2%), and *Thalictrum* (4.5%). Values of *Ranunculus trichophyllus* attained 11%, decrease to about 5% in middle part of zone, and decrease to 35% in top part of zone. The upper boundary of the zone is marked by a slight increase in the proportions of *Betula nana* accompanied by constant, high amounts of NAP
NŻ$_{05}$13 NAP-*Betula nana* L PAZ	NŻ$_{05}$13b	*Betula nana*-NAP-*Juniperus*	5.400–4.200	Sporomorphs are found in low or very low concentrations. The AP values decrease from 20% to 5% and only in the middle part of the zone attain 33.5%. Proportion of *Betula* fluctuates between 13% and 1%. Frequency of *Pinus* increases to 8% and afterwards decreases to ca. 4%. The course of curve of *Alnus viridis* is nearly continuous. Values of *Juniperus* decreases from 8.5% to ca. 1% and afterwards increases to 4%. *Betula nana* attains three maximum values of 20.5%, 16% and 17% and a minimum value of 4.5%. Proportion of Poaceae increases from 26% to 48%. Values of Cyperaceae decrease from ca. 7.3% to a minimum of 1%, in the top part of the layer, and afterwards increase to 5.5%. Frequency of *Ranunculus acris* attains 20.5% in the middle part of the subzone. Values of *Artemisia* increases from 15% to 25.5%. Proportion of *Ranunuculus trichophyllus* amounts to 60%, in the middle part of the layer, and ca. 30%, in the whole subzone. Values of *Thalictrum* attain 6% in the bottom part of the layer. Damaged sporomorphs are found in high values from 6% to 28%. No upper boundary can be distinguished as the subzone closes the succession of Nowiny Żukowskie. Results of numerical analyses (ConSlink and PCA) confirm the similarity of spectra classified into this L PAZ

Table 3. NŻ$_{50\text{-}4}$. Description of local pollen assemblage zones (L PAZ)

Symbol	Name	Depth (m)	Description
			Late Sanian 2 (Elstarian) glaciation
NŻ$_{50\text{-}4}$ 1	*Betula nana*-*Juniperus*-(*Larix*)-NAP	13.000–12.800	Values of AP amount to 77%. Among AP, the highest proportions are attained by *Betula* (46.5%) and *Pinus* (12%). Frequency of *Betula nana* amounts to 6.8%, and of *Juniperus* – to 1.1%. Among NAP, highest values are attained by Poaceae (8.7%), Cyperaceae (6.3%), and *Artemisia* (0.6%). Rebedded sporomotphs are found in high values. Cysts of Dinophyceae are recorded. The upper boundary of the zone is marked by an increase in the amount of *Betula* and a decrease in the proportion of NAP
			Mazovian (Holsteinian) interglacial Pollen Period I
NŻ$_{50\text{-}4}$ 2	*Betula*-*Larix*-(*Pinus*)-NAP	12.800–12.350	Values of AP increase to 84.4%. Pollen of *Betula* is dominant (58%). Pollen of *Pinus* attains the frequency of 12.5%, and of *Larix* of 1.4%. Proportions of *Ulmus*, *Fraxinus*, *Alnus*, and *Picea* show a slight increase to ca. 2.2%. Values of NAP fluctuate between 13.6% and 20.3%. Poaceae attain the proporcion of 4.4%, Cyperaceae of 4%, and Apiaceae of 1.5%. Proportion of *Betula nana* amounts to 4.8%. The upper boundary of the zone is marked by a decrease in the amount of *Betula*, a nearly complete decline of the NAP curve, and an increase in the proportions of *Picea* and *Alnus*
			Pollen Period II
NŻ$_{50\text{-}4}$ 3	*Picea*-*Alnus*-*Fraxinus*-*Ulmus*	12.350–11.600	Values of AP increase to 97.7%. Pollen of *Picea* attains its maximum value of 45.5%. Proportion of *Alnus* fluctuates between 11% and 18.5%. In the middle part of the zone, *Fraxinus*, *Ulmus*, and *Tilia* reach their maximum values of 6.9%, 4.1% and 3.6%, respectively, while the values of *Quercus* attains 3%. Frequency of *Betula* decreases to 6.8%, and of *Pinus* – remains constant at ca. 18%. Proportion of *Taxus* attains 2.5%. Continuous curves of *Abies*, *Carpinus*, and *Corylus* begin. Appearance of *Viburnum* t., *Sambucus nigra*, *Frangula alnus*, *Hedera helix*, and *Vitis* is recorded. The upper boundary of the zone is marked by an increase in the amount of *Taxus*, a slight increase in proportions of *Quercus* and *Corylus*, and a decrease in frequency of *Picea*, *Betula*, and *Pinus*

Table 3. Continued

Symbol	Name	Depth (m)	Description
NŻ$_{50-4}$ 4	*Taxus-Picea-Alnus*	11.600–11.500	Values of AP increase to 98%. Pollen of *Taxus* is dominant and attains its maximum value of 30.5%. Proportion of *Picea* decreases to 22.4% and of *Alnus* – attains 16.4%. Frequency of *Quercus* and *Corylus* increase to 7.5% and 3.9%, respectively, while values of *Pinus* and *Betula* decrease to 4.6% and 2.9%, respectively. Pollen of *Hedera helix*, *Sambucus nigra*, *Tilia* cf. *tomentosa*, *T.* cf. *platyphyllos*, and *Ligustrum* appear. The upper boundary of the zone is marked by a decrease in the amounts of *Taxus*, *Picea*, and *Alnus*, and an increase in the proportions of *Carpinus* and *Abies*
Pollen Period III			
NŻ$_{50-4}$ 5	*Abies-Carpinus*	11.500–10.550	Values of AP remain at a constant level of about 97%. Proportion of *Carpinus* initially attains 44.5%, making it the dominant pollen. However, in the middle part of zone, its values decrease to 26.5%, afterwards increase to 30.5%, and finally decrease to 10%. Proporcion of *Abies*, at the bottom of zone, amounts to 8.4%. However, it gradually increases to 30%, than decreases to 25.5% and finally attains its maximum value of 39%, making the pollen of *Abies* dominant. Proportion of *Quercus* remains at a constant level of 5%. Values of *Picea* increases from 2.5% to 6.6%, and of *Corylus* – attains ca. 8% and then decreases to ca. 1.5%. Curve of *Alnus* fluctuates between 10.5% and 3.7%. Values of *Taxus* decrease from 2.9% to 1.4%. Proportions of *Ulmus* and *Fraxinus* do not exceed 1%, similarly as of *Tilia*, attaining only 2.5% in the middle part of the zone. Proporcion of *Betula* slightly increases to 12.5%, and of *Pinus* is retained at a constant level of ca. 5%, later increasing to 25.5%. Continuous curves of *Pterocarya*, *Buxus*, *Juglans*, and *Fagus sylvatica* begin. *Viburnum* t., *Frangula alnus*, *Vitis*, *Tilia*. cf. *tomentosa*, *T.* cf. *platyphyllos*, *Ligustrum*, *Viscum*, and *Carya* appear infrequently. The upper boundary of the zone is marked by a decrease in proportions of *Abies* and *Carpinus* and a continued increase in amounts of *Pinus* and *Betula*
Pollen Period IV			
NŻ$_{50-4}$ 6	*Pinus-Betula-*(*Larix*)-NAP	10.550–9.900	Values of AP decrease to 85.2%. The maximum values of *Pinus* amount to 60%, and of *Betula* 17.5%. Proporcion of *Larix* increases from 1% to 3.3%. Pollen of other trees are found in small amounts. Frequency of *Picea* attains 3.7%, *Carpinus* 1.9%, *Abies* 2.4%, *Juniperus* ca. 0.7%, and *Betula nana* 1.4%, in the bottom part of layer. Among NAP, proportion of Poaceae increases to 4%, of Cyperaceae to ca. 4.5%, and of *Artemisia* to ca. 3%. The upper boundary of the zone is marked by a decrease in the amount of *Pinus* and *Betula*, and an increase in the proportion of NAP
NŻ$_{50-4}$ 7	*Larix-Juniperus-*NAP	9.900–9.200	Proportions of AP decrease from 64% to 47.2%. Values of *Pinus* decreases to ca. 27%. *Betula,* at the bottom of the zone, attains a value of 20%, and at the top of the zone – of 11%. Frequency of *Larix* initially reaches even 8.5%, and of *Juniperus* 4.3%. *Betula nana* retains a constant value of ca. 1.9%. The NAP curve rises. Poaceae increase their proportion from 9.5% to 13.5%, Cyperaceae from 8.5% to 15.5%, *Artemisia* from 7% to 8.5%, and *Ranunculus trichophyllus* t. from 3.4% to 4.3%. Pollen of *Hippophaë rhamnoides* appears. The upper boundary of the zone is marked by an increase in the amounts of *Pinus* and *Betula* and a decrease in the concentration of NAP
NŻ$_{50-4}$ 8	*Pinus-Betula-Larix-*NAP	9.200–8.400	Values of AP amount to 79.8%. The maximum proportion of *Pinus* reaches 52.5%, at the top of the zone, *Betula* 19.5%, and *Larix* 2.4%. Other trees occur infrequently. *Picea* attains the values of 2.6%, *Abies* of 1.7%, and *Betula nana* of 3.6%. Values of *Juniperus* do not exceed 1%. Among NAP, frequency of Poaceae decreases from 6.2% to 4.2%, and of Cyperaceae from 6% to 3.5%. Proportion of *Artemisia* remains at a constant level of ca. 3.7%, and of *Ranunuculus trichophyllus* at ca. 1.2%. The upper boundary of the zone is marked by a decrease in the amounts of *Pinus* and *Betula*, and an increase in the proportions of Poaceae, Cyperaceae, and *Artemisia*
Early Liviecian (Saalian) glaciation			
NŻ$_{50-4}$ 9	NAP-*Betula nana*	8.400–6.250	Values of AP fluctuate between 30% and 16%. The maximum proportion of *Betula* amounts to 14.5% and decrease to 3.5%. Propoecion of *Pinus* decreases from 13% to 8.5%. Frequency of *Salix glauca* attains 3% and *Betula nana* 2.5% to 9.5%. Among NAP, the highest values are attained by Cyperaceae (27%). Poaceae reach the values of 18.5%, *Artemisia* 23%, Chenopodiaceae increase to 5.5%, *Ranunculus trichophyllus* attains maximally 17%, and *Thalictrum* – of 2.4%. Cysts of Dinophyceae are found. No upper boundary can be distinguished as the subzone closes the pollen succession of section NŻ$_{50-4}$

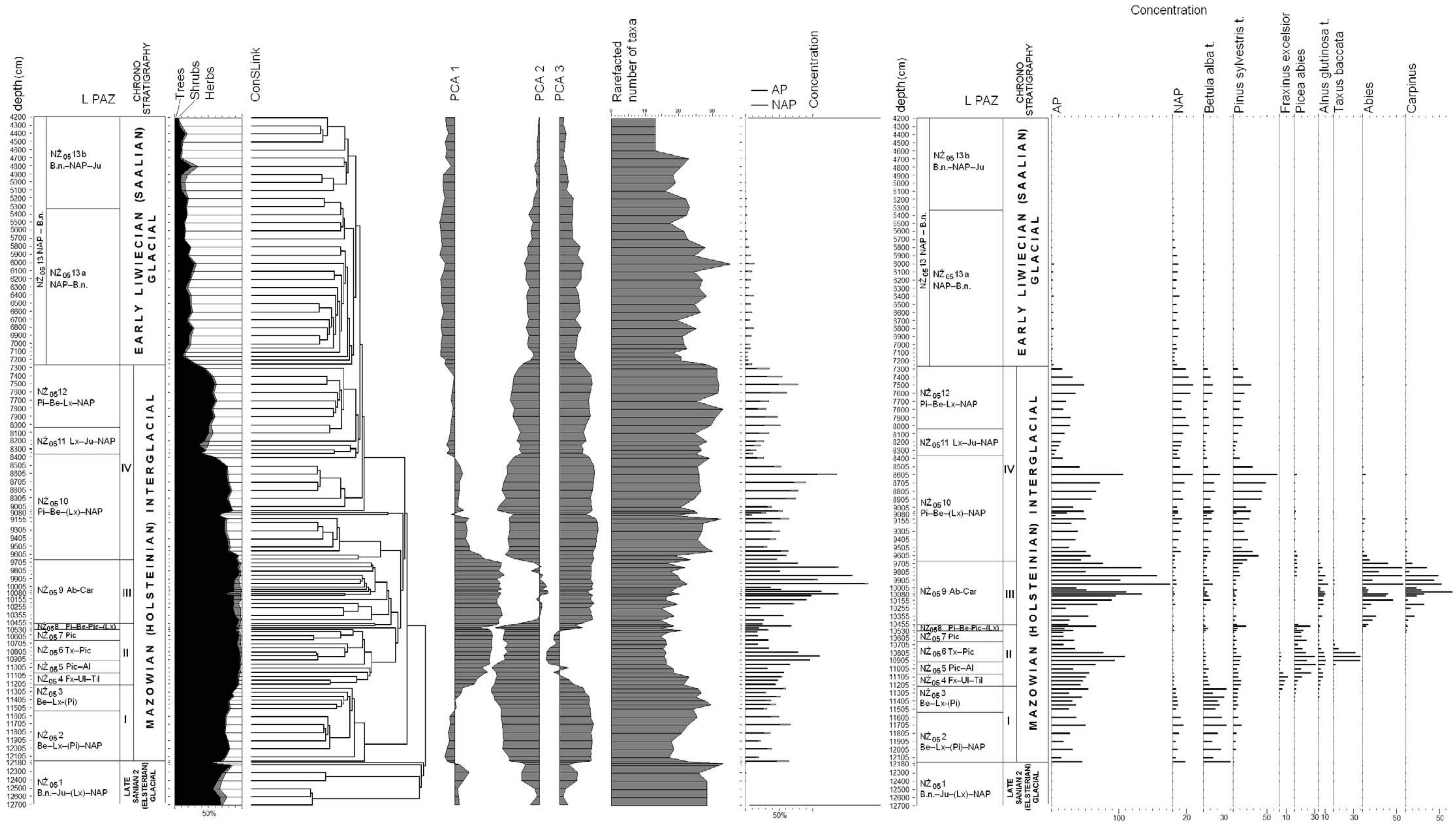

Fig. 7. Numerical analysis and concentration diagrams of the Nowiny Żukowskie NŻ$_{05}$ profile

by an open birch forest (pollen values of *Betula alba* amounting to 50–70%). Dry and fresh habitats were overgrown by *B. pendula*, whereas boggy habitats – by *B. pubescens*. Forest communities including pines were not an important part of landscape, but *Larix* was still present.

Open plant communities with *Hippophaë rhamnoides* and *Ephedra distachya* were retained, and *Alnus viridis* was present along watercourses.

Fertile and humid soils surrounding the lake in Nowiny Żukowskie were gradually entered by *Alnus glutinosa*, *Populus*, and *Fraxinus excelsior*, forming small clusters of a riparian type.

Most likely, the forest cover did not attain a high density, as the proportion of pollen of herbaceous plants amounted to ca. 19%. Open communities with *Juniperus* and *Artemisia* growing on poor, sandy and dry soils, together with Chenopodiaceae, Cichorioideae, Asteraceae, *Potentilla*, and Apiaceae were still important in the vegetation.

On humid habitats surrounding the lake were still dominated by communities with Cyperaceae, accompanied by *Equisetum*, *Thalictrum*, *Filipendula*, and some reed-swamp plants (*Phragmites*). Tundra-like communities with *Betula nana*, *Salix glauca*, and *S. herbacea* were still present.

In the lake *Nuphar lutea*, *Nymphaea alba* and *N. candida*, were present, accompanied by *Lemna* on the water surface and *Botryococcus* and *Pediastrum* in the water.

NŻ$_{05}$3 *Betula-Larix-(Pinus)* L PAZ

The landscape was predominated by dense birch-pine forest accompanied by *Larix*. In the ground cover *Pteridium aquilinum* and *Lycopodium annotinum* were present. *Tilia cordata*, *Acer*, *Ulmus*, and *Fraxinus*, appeared in humid parts of forests with *Viburnum*, *Humulus lupulus*, *Sambucus nigra*, and *Frangula alnus* as undergrowth. *Myrica gale*, indicating the influence of oceanic climate, was also likely to be found.

Tundra-like communities existed on a peat bog as relicts and were represented by pollen of dwarf shrubs like *Betula nana* and *Salix herbacea.*

Vegetation on humid and boggy as well as drier habitats was similar as in the preceding zone.

Humid and boggy meadows with Cyperaceae, *Filipendula*, *Potentilla*, *Pleurospermum austriacum*, *Valeriana officinalis*, *Cirsium*, Asteraceae, Rubiaceae, Rosaceae, and Apiaceae, were poorly developed. Poaceae and *Artemisia* were growing in drier habitats. Low water trophy is indicated by continuous curves of *Isoetës* spores. *Nuphar lutea* and *Nymphaea alba* are still present, and *Botryococcus* colonies are relatively abundant.

Pollen Period II

NŻ$_{05}$4 *Fraxinus-Ulmus-Tilia* L PAZ

A large part of birch forests with an admixture of pine, so far being dominant, was replaced by communities predominated by *Fraxinus*, *Ulmus*, *Tilia cordata*, *Alnus glutinosa*, and *Picea abies*, indicating climate warming. Communities including ash were a very important part of the landscape (frequency of *Fraxinus excelsior* amounting to 22.5%). Due to the fact, that values of *Fraxinus* are usually considerably underestimated in pollen spectra (Tobolski & Nalepka 2004), data obtained in pollen analysis were recalculated with the use of correction coefficients (Andersen 1970, 1973). After the conversion of data (Fig. 8), the proportion of *Fraxinus excelsior* in the tree stand was estimated at 56%. This evidences that the initial phase of Pollen Period II was marked by an intensive spreading of riparian forests with a high frequency of *Fraxinus*, *Ulmus*, and *Alnus glutinosa* accompanied by *Acer*, *Betula*, and *Picea abies* with *Humulus*, *Frangula alnus*, *Sorbus aucuparia*, and *Viburnum* in undergrowth and *Filipendula*, *Equisetum*, and *Osmunda* in the ground cover.

Linden (*Tilia cordata, T. platyphyllos, T. tomentosa*), occurred quite frequently in forest on drier areas accompanied by *Quercus*, *Acer*, *Picea abies*, *Carpinus*, and *Corylus*. Values for linden increase to 22.5% (Fig. 8) after being converted with the use of correction coefficients (Andersen 1970, 1973).

Spruce (*Picea abies*) was initially only as admixture in various forest communities, later the increasing frequency has shown a beginning of dominating spruce forest.

The density of forests was high, what is shown mostly by low values of pollen of herbaceous plants. Plant communities of open parts of forest were similar as in NŻ$_{05}$3 Local Assamblage Zone.

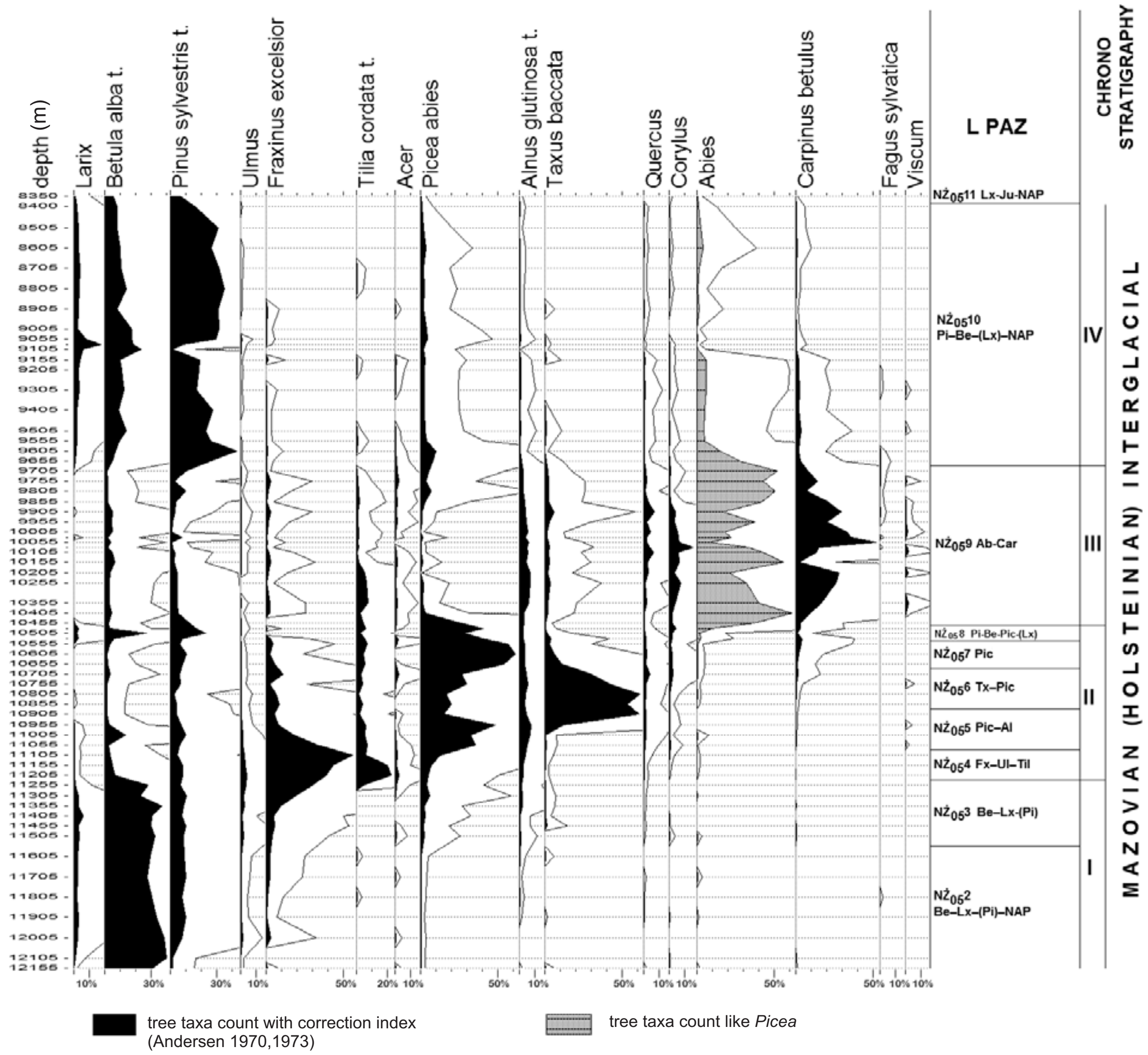

Fig. 8. Selected tree taxa from profile $NŻ_{05}$ count with correction index by Andersen (1970, 1973)

Infrequent occurrence of *Betula nana* pollen indicates the relict character of the taxon, of that time remaining on a peat bog together with *Salix herbacea*, *Ribes alpinum*, and *Lonicera nigra*.

Waterside reed-swamps gradually decreased their area as evidenced by small amounts of pollen of *Phragmites*, Cyperaceae, and *Typha latifolia*. Lake water was still marked by the presence of *Nuphar lutea* and *Nymphaea alba*, accompanied by *Lemna* occurring on the surface. The continuous curve for *Isoëtes* spores indicates oligotrophic conditions in the lake.

$NŻ_{05}$5 *Picea-Alnus* L PAZ
$NŻ_{50\text{-}4}$3 *Picea-Alnus-Fraxinus-Ulmus* L PAZ

Structure of forest communities considerably changed. *Picea abies* became the dominant tree in the landscape, forming forests accompanied by *Quercus*, *Alnus*, and *Betula*. Pollen curve of *Betula alba* rises up to 24.5% and evidences the return of this species to the surroundings of the basin. Elm-ash and ash-alder forests, dominant in the preceding zone, decreased in this zone although an increase was recorded in the amount of *Taxus baccata*.

Forest communities covered nearly the entire area surrounding the discussed site as evidenced by the proportion of AP that amount to 98%. Pollen of herbaceous plants were infrequent and derived mostly from the ground cover of forests and some open areas with small paches of humid meadows. Remains of aquatic and reed-swamp plants were found in minor amounts. *Nuphar lutea* and *Nymphaea alba* still occurred in the basin, accompanied by *Lemna*. Spores of *Isoëtes* were an indicator of poor water trophy.

NŻ$_{05}$6 *Taxus-Picea* L PAZ
NŻ$_{50-4}$4 *Taxus-Picea-Alnus* L PAZ

The tree stand was dominated by *Taxus baccata* that is indicated by a rapid increase in its pollen values, attaining a maximum frequency of 43%. Yew is known to prefer the oceanic climate (Król 1975). According to Noryśkiewicz (1998, 2006), pollen grains of the yew have a low capability of spreading, growing in lower forest floors, usually cooler than the higher parts due to a temperature inversion, therefore the free fall of pollen of yew is limited (Allison 1990, Noryśkiewicz 2006). Additionally, spreading of yew may be constrained by dense crown of higher trees. Due to the above-mentioned facts, it is considered that high amounts of pollen grains of *Taxus baccata* typify only sites overgrown by the tree. Pollen values recorded for yew in the Mazovian (Holsteinian) interglacial (Janczyk-Kopikowa 1981, Krupiński 1995b, Nita 1999, Pidek 2003, and other) are so high (amounting even to 62%, Nita 1999), that they appear to evidence the occurrence of monotypic yew forests. At present, such forests cover only small areas, e.g. in the Caucasus Mountains or in Ireland (Noryśkiewicz 2006). *Taxus* probably formed also the undergrowth of spruce and mixed forests, dominant in this period of the Mazovian (Holsteinian) interglacial. Yew is known to prefer calciferous, humid and deep soils (Tomanek 1994) as well as boggy soils. Together with alder, it could have formed riparian forests and humid alder forests surrounding the lake (Krupiński 1995b). Expansion of *Taxus* in eastern Poland could have been associated with an increase in the level of underground water, providing conditions particularly advantageous for the growth of this tree (Nitychoruk et al. 2005). However, such an intensive development could not be long-lasting, as the tree stand of communities predominated by yew is gradually reduced due to overdensity and overshadowing, making the growth of young trees impossible (Noryśkiewicz 2006).

The role of spruce (*Picea abies*) was most likely as an important component of forests was not strongly limited. Curve showing its concentration (Fig. 7) was not marked by a visible decline, considering the increase in values for yew.

Picea was presumably still dominant in tree stands, forming mixed coniferous forests together with *Quercus* and *Taxus baccata*, and some paches of mixed forest with *Tilia*, *Carpinus*, accompanied by *Corylus*.

Aquatic vegetation and reed-swamps were similar to that in the preceding zones.

NŻ$_{05}$7 *Picea* L PAZ

Nearly the total amount of yew was withdrawn from sites it covered. However, spruce forests have dominated boggy habitats with admixture of *Alnus*, forming alder forests and riparian forests, with some admixture of. *Quercus*, *Carpinus*, *Corylus*, *Tilia*, *Acer*, and *Ulmus* on derier habitats. Yew could have still occurred in humid habitats as an admixture found in minor amounts. Water-bodies of the basin were marked by the occurrence of *Botryococcus* colonies.

NŻ$_{05}$8 *Pinus-Betula-Picea-*(*Larix*) L PAZ

At this time forest destruction connected with a strong eruption phase (Diehl & Sirocko 2006) ocurred. Pine and pine-birch forests with larch began their dominance in the landscape that is marked by both the rapid increase in pollen values for *Pinus sylvestris* and *Betula alba*, and is accompanied by a decrease in the amount of rainfall. Such conditions were most likely the reason, for which nearly the total amount of *Taxus baccata* was withdrawn from the area. However, the temperature may not have decreased as this may be caused by climatic drying (Müller 1974, Bińka & Nitychoruk 1995, 1996, Janczyk-Kopikowa 1996, Thomas 2001). Nevertheless, pollen values of *Picea abies* decreased only slightly, though the tree prefers a humid and moderately cool climate. No increase was recorded in the proportion of NAP. Bińka and Nitychoruk (1995) suggest that the zone is of a transitory character, and describe it as an intra-interglacial climatic oscillation (Fig. 9).

Littoral reed-swamps were poorly developed and an absence of pollen from aquatic plants indicates that the basin was completely overgrown by a peat bog.

Pollen Period III

NŻ$_{05}$9 *Abies-Carpinus* L PAZ
NŻ$_{50-4}$5 *Abies-Carpinus* L PAZ

During this period *Abies* and *Carpinus* began their dominance in the landscape. Expansion of the species was likely to occur

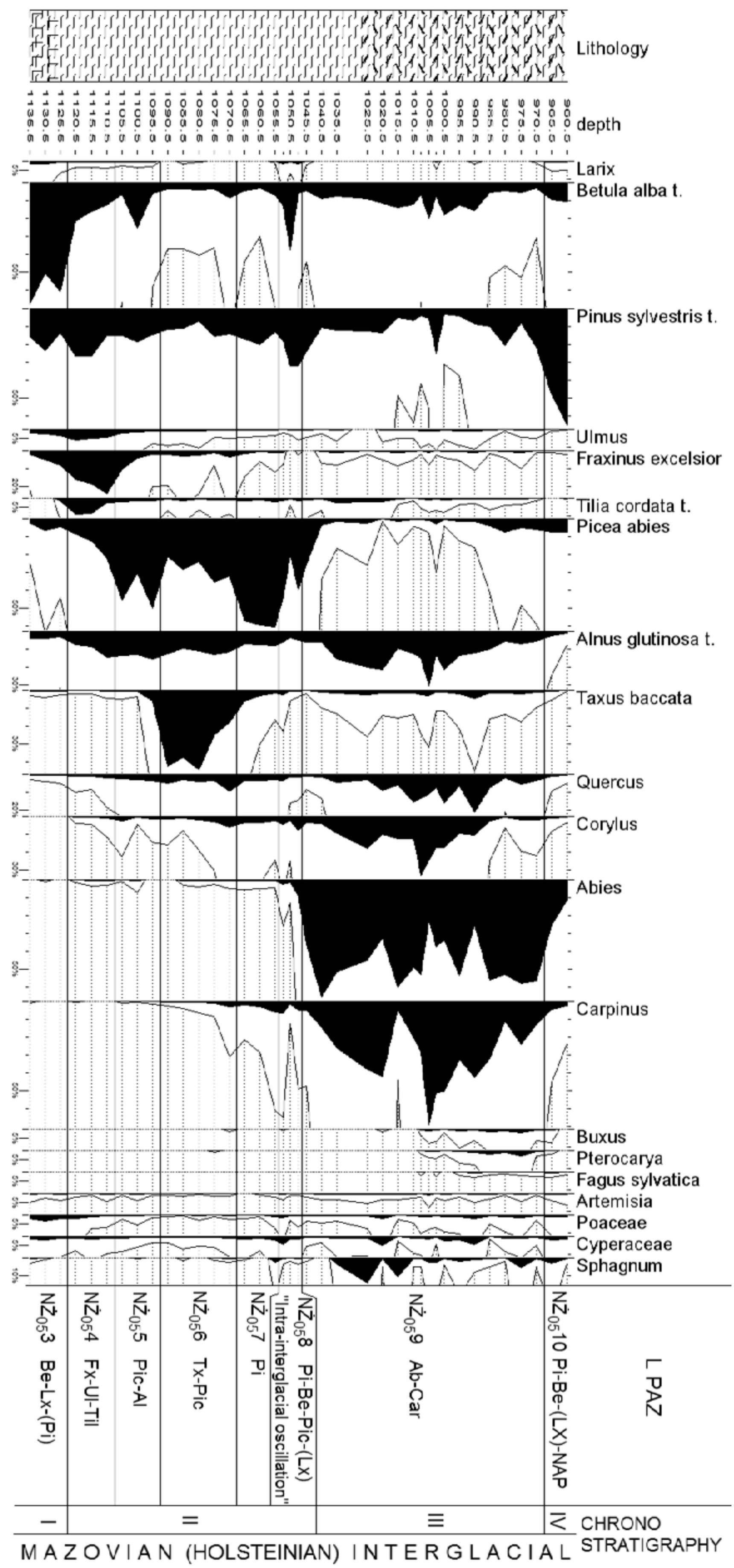

Fig. 9. Shorted percentage pollen diagram of the Mazovian interglacial (pollen periods II and III) climatic optimum showing the "intra-interglacial oscillation" in the NŻ$_{05}$ profile. Lithology like on Fig. 3

at the expense of *Picea abies*, displaced from areas it formerly covered. This may have been caused by an improvement in climatic conditions (increase in mean temperatures of summer), being advantageous for the spreading of *Abies* and adverse for the further development of *Picea*. To estimate the presumable proportion of fir in the tree stand (Fig. 8), data for the species were recalculated with the use of a correction coefficient previously identified for *Picea* (Andersen 1970, 1973). Amounts of pollen produced by fir and spruce were similar (Poska & Pidek 2007) but after conversion of the data the frequency of fir increased to 61.5%.

The Mazovian (Holsteinian) interglacial was described as the "time of fir" in the Quaternary history of trees (Środoń 1983). This is evidenced by the dominance of fir. It is likely that on poorer soils *Abies* formed fir forests with an admixture of *Picea abies* and *Pinus sylvestris*. Such forests were characterized by a poor ground cover, in which Pteridophyta, lycopods and abundant mosses were found.

Alterations in the structure of forests are evidenced by a rapid increase in *Carpinus* pollen. Multispecies mixed forests, predominated by hornbeam, became the dominant forest communities in the area of Nowiny Żukowskie, due to a decrease in humidity (Faliński & Pawelczuk 1993, Bińka & Nitychoruk 1995). Tree stands of hornbeam (*Carpinus betulus*) were nearly pure. This species, together with *Quercus* and *Corylus*, was also abundant in the undergrowth, and have formed oak-hornbeam forests accompanied by *Viscum* and *Hedera*.

Mixed oak-pine forests, as communities of lower habitat requirements, were retained on dry poor, and degraded soils. In the ground cover of such forests grew *Vaccinium*, *Calluna vulgaris* and Poaceae, as well as mosses, Pteridophyta and lycopods.

In the top of this zone, the structure of forests was fragmentarily changed. Mixed deciduous forests were now predominated by *Abies* and *Carpinus*, accompanied by *Quercus*, *Fagus sylvatica*, and *Juglans* that are collectively characteristic for the Mazovien (Holsteinian) interglacial.

Relatively high amounts of *Corylus*, increasing pollen values of *Quercus*, as well as the continuous curve for the Mediterranean element *Buxus*, provides evidence for the occurrence of thermophilic, light forests. Boxwood is an evergreen, insect-pollinated shrub, requiring insolation (Krupiński 1995a). Relatively high pollen values of *Buxus* (presumably *Buxus sempervirens*) confirm the occurrence of this species in the area of the Lublin Upland.

On humid and boggy soils alder forests, with *Fraxinus, Ulmus*, *Salix glauca*, and *Pterocarya* developed. In the undergrowth *Hedera helix*, *Vitis*, and *Humulus lupulus* grew. The occurrence of *Pterocarya,* an exotic taxon, presumably could have resulted from climatic drying (Müller 1974, Bińka & Nitychoruk 1995, 1996, Janczyk-Kopikowa 1996, Thomas 2001).

Littoral reed-swamps were very poor, and on peat bogs *Drosera rotundifolia* and *Ledum palustre* grew. *Pediastrum* colonies were infrequent, while *Botryococcus* algae were quite abundant.

Pollen Period IV

NŻ$_{05}$10 *Pinus-Betula-*(*Larix*)-NAP L PAZ
NŻ$_{50\text{-}4}$6 *Pinus-Betula-*(*Larix*)-NAP L PAZ

The cooling of climate was most likely the reason for radical changes in the structure of forest communities, evidenced by an increase in pollen values of *Pinus sylvestris*, attaining 61.5%, and a decrease in the proportion of *Abies*. Pine became dominant in the landscape and formed boreal pine forests with a minor proportion of *Betula alba* and *Larix*, accompanied by *Abies* and *Picea*. *Vaccinium*, *Calluna vulgaris*, grasses, pteridophytes, and mosses were important ground cover components within this forest. The density of tree crowns was slightly decreased, what is evidenced by a slight increase in the values of NAP.

Pollen values of *Abies* and *Picea abies*, still attaining sufficiently high amounts, indicate that the withdrawal of both species from formerly covered sites was very slow, and that the trees still have formed fir forests with an admixture of *Pinus sylvestris* and *Picea abies*.

Decreasing pollen values of *Carpinus*, *Quercus*, and *Corylus*, and only occasional occurrences of *Tilia* and *Acer* evidence the withdrawal of mixed forests from the areas of Nowiny Żukowskie.

The closest surroundings of the lake were overgrown by boggy and periodically flooded paches of alder and riparian forests, what is indicated by the occurrence of *Alnus glutinosa*, *Salix glauca*, *Populus*, *Fraxinus excelsior*, *Ulmus*, *Pterocarya*, *Frangula alnus*, *Viburnum*, *Vitis*, Cyperaceae, *Equisetum*, and *Osmunda regalis*. Such communities covered small areas, giving place to boreal pine forests.

Juniperus and *Buxus* were growing on open dry habitats, and *Vaccinium*, *Calluna vulgaris*, Ericaceae, *Ledum palustre*, *Menyanthes*, on more humid areas.

A slight rise of *Betula nana* in the pollen curve, as well as the appearance of *Salix herbacea*, serves as evidence for greater changes in climate and flora.

Littoral vegetation is similar to the previous zones and in law trophy water of the lake *Botryococcus* and *Isoëtes* were present.

In the middle part of this zone a short local change in vegetation is marked. According to the pollen diagram, the zone was marked by an alteration in the structure of forests. Forest covers slightly decreased in their density, due to the spreading of birch and larch at the expense of pine (decrease in pine pollen values to 3.6%). The lake shallowed, while the littoral belt probably became broader and habitats were dominated by reedswamp communities with Cyperaceae and *Equisetum*. However, the range of this event is not so large if discussed on the basis of low concentration curves (Fig. 7) as their decline is recorded for both *Pinus sylvestris* and *Betula alba*, though in case of birch the decrease is not as rapid as for pine. Generally, pollen found in the zone occurred in low concentration. Presumably, such a situation resulted from a short-lasting oscillation of hydrological changes. This episode can be recognized only as a local "birch oscillation" (Fig. 10).

NŻ$_{05}$11 *Larix-Juniperus*-NAP L PAZ
NŻ$_{50\text{-}4}$7 *Larix-Juniperus*-NAP L PAZ

Notable climatic cooling resulted in the withdrawal of pine and birches. Pollen values for the above-mentioned taxa, not exceeding 25%, are likely to indicate the prevalence of long-distance transport (Birks 1986a). During that beginning this period the landscape was marked by the dominance of communities of herbaceous plants, mainly Poaceae, Cyperaceae, and *Artemisia*. In the surroundings of the basin in Nowiny Żukowskie, the vegetation was characterized by a high variability of communities.

Most likely, *Pinus sylvestris* and *Betula alba*, accompanied by *Larix*, *Juniperus*, *Hippophaë rhamnoides*, and *Alnus viridis* formed only clumps of trees, dispersed in the mosaic landscape of the steppe-tundra. Pollen of thermophylous trees originated from long-distance transport.

A slight improvement in climatic conditions resulted in an increase in the density of forests, dominated by larch with an admixture of pine and birches. However, the forests did not regain their boreal character and a great part of landscape remained open, with the pioneer juniper as an important component. A well marked increase in the occurrence of pollen of *Larix* and *Juniperus* evidences a noticeable continentalization of climate. Such loose forests were marked by the presence of *Alnus viridis*, *Lonicera nigra*, and *Pinus cembra*, likely to occur in a long distance from the basin. Their ground cover included *Lycopodium annotinum*, *Pteridium aquilinum*, *Dryopteris filix-mas*, *Botrychium*, acidophylous dwarf shrubs (pollen of *Vaccinium*, *Empetrum nigrum*, *Bruckenthalia spikulifolia*, and other Ericaceae), grasses, and abundant mosses. Pollen of other thermophylous trees, as well as part of pollen of *Pinus sylvestris* and *Betula alba*, were likely to originate from long-distance transport.

Vast surroundings of Nowiny Żukowskie were overgrown by a dwarf shrub tundra composed of *Betula nana*, *Salix herbacea*, and some Ericaceae accompanied by herbaceous plants like *Thalictrum*, *Saxifraga hirculus*, *S. stellaris*, and numerous Cyperaceae, Poaceae, and mosses. In humid habitats *Filipendula*, *Ranunculus acris*, *Polygonum bistorta*, *Caltha*, *Gentiana pneumonanthe*, *Valeriana officinalis* and *Sanguisorba officinalis* grew. Peat bogs were still being developed including *Sphagnum*, *Ledum palustre*, and *Bruckenthalia spiculifolia*. At present *B. spiculifolia* grows in the mountains of the Balkan Peninsula, on peat bogs and is an indicator of continental climate (Whittington 1994, Granoszewski 2003). Up to now, this species has only been recorded only in two sites representing the Mazovian (Holsteinian) interglacial – Woskrzenice and Kaliłów (Bińka & Nitychoruk 1995, 1996). Musci were abundant in various plant communities. Dry steppe-like habitats were an important part of the landscape as evidenced by an increase in pollen values of Poaceae and *Artemisia*, as well as by the appearance of pollen of *Bupleurum*, Chenopodiaceae, *Anthemis*, and Caryophyllaceae.

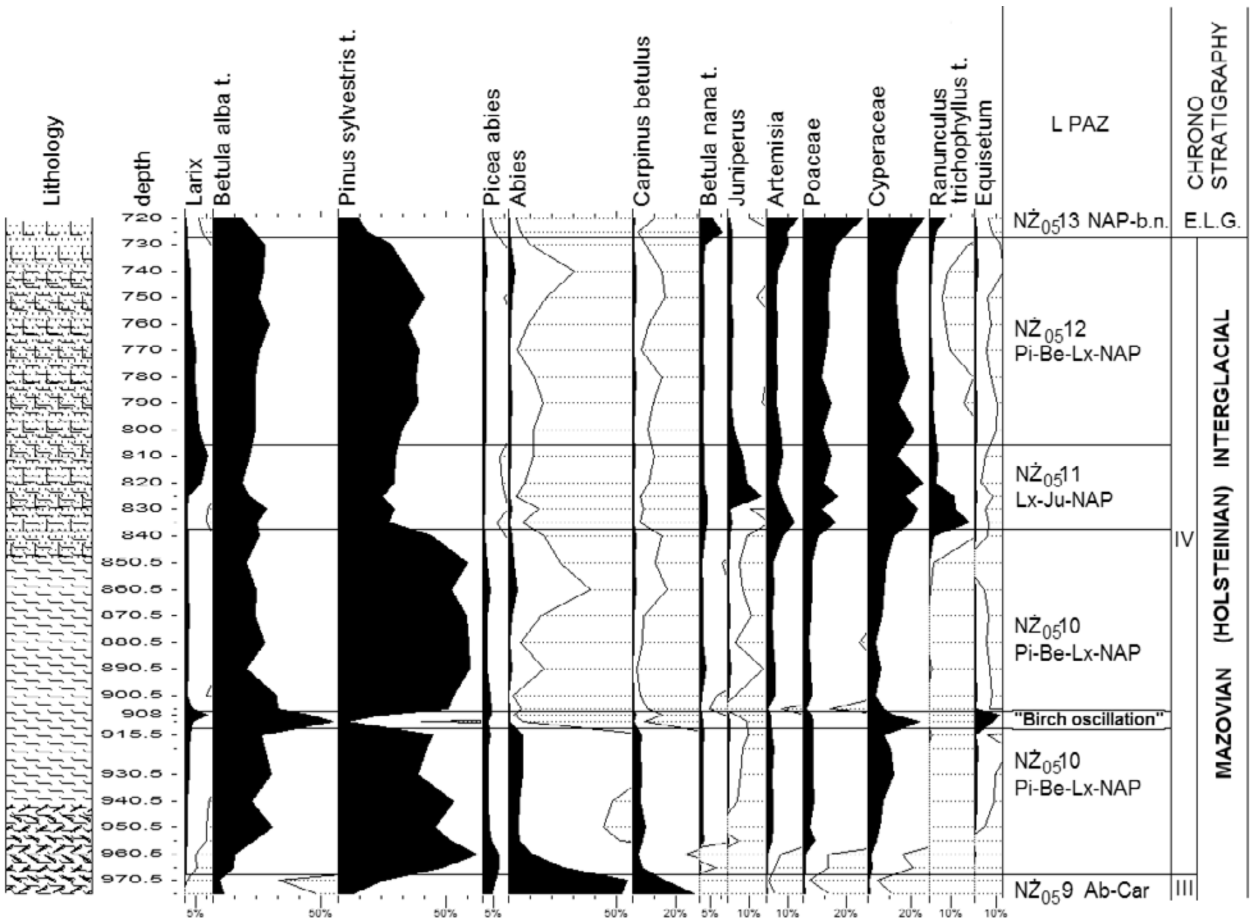

Fig. 10. Shorted percentage pollen diagram of telocratic period on the Mazovian interglacial (pollen period IV) showing the "birch oscillation" in the NŻ$_{05}$ profile. E.L.G. – Early Liviecian glaciation. Lithology like on Fig. 3

The change in climate also affected the composition of the aquatic flora. A decrease was observed in both variability and frequency of aquatic plant taxa. However, a first rise was recorded in *Ranunculus trichophyllus*, a pollen taxon including several species formerly classified into *Batrachium*. Such an abundant occurrence of this taxon may indicate its overrepresentation. At present, the plants are characterized by a broad range of ecological settings concerning trophy, temperature and rate of water flow. Some taxa of Cyperaceae, *Phragmites*, *Menyanthes trifoliata*, *Hydrocotyle vulgaris*, and *Equisetum* have formed reed-swamps. Trophic conditions of the lake were likely to improve by a continuous curve for *Pediastrum* and an increase in the amount of *Botryococcus* algae.

NŻ$_{05}$12 *Pinus-Betula-Larix*-NAP L PAZ
NŻ$_{50\text{-}4}$8 *Pinus-Betula-Larix*-NAP L PAZ

Pine forests with birch and larch extended their cover in the areas surrounding the lake. Preceding improvement in climatic conditions resulted in an increase in AP values up to ca. 63%. Sporomorphs were found in considerable higher concentrations. However, the above mentioned forests did not regain dominance. Changes in vegetation resulted in a slight increase in the density of forest cover. Surroundings of the basin were marked by the occurrence of *Juniperus*, found infrequently, accompanied by *Alnus viridis* and *Pinus cembra*. Pollen of other tree taxa, as well as part of *Pinus sylvestris* and *Betula alba* pollen, was likely to originate from long-distance transport. The ground cover of these open forests was overgrown by dwarf shrubs representing Ericaceae (*Vaccinium*, *Calluna vulgaris*, and *Bruckenthalia spiculifolia*), accompanied by Poaceae, Cyperaceae, Musci, *Sphagnum*, and *Botrychium.* Occurrence of *Bruckenthalia spiculifolia* pollen is particularly worth consideration.

Other vegetation types as step-like communities on dry habitats, dwarf shrub tundra and humid meadows, as well as reed-swamps, were very similar to the respective vegetation types from the preceding zone.

EARLY LIVIECIAN (SAALIAN) GLACIATION

N$\dot{Z}_{05}$13 NAP-*Betula nana* L PAZ

N$\dot{Z}_{05}$13a NAP-*Betula nana* subzone

N$\dot{Z}_{50\text{-}4}$9 NAP-*Betula nana* L PAZ

Almost the entire Nowiny Żukowskie area was deforested. Only single trees, dispersed in the steppe-tundra mosaic, existed in the landscape. Apart from birch and pine, taxa like *Alnus viridis*, *Larix*, and *Pinus cembra*, have been found occasionally. On poor and sandy areas *Juniperus*, *Hippophaë rhamnoides*, *Ephedra distachya*, and *E. fragilis* grew locally. Progressive changes in conditions controlling the area, towards a continental, arctic climate, resulted in the drying and stepping of the landscape.

Steppe vegetation, known to prefer sandy, dry soils with low fertility, was broadly spread as evidenced by high pollen values of Poaceae, *Artemisia*, and Chenopodiaceae, as well as by the occurrence of *Aster*, *Helianthemum nummularium*, *H. alpestre*, *Silene*, *Jasione*, *Elymus, Pulsatilla*, *Anthemis*, *Cerastium*, Cichorioideae, Rubiaceae, and Caryophyllaceae.

Patches of heathland with *Calluna vulgaris* and other Ericaceae, most likely accompanied by *Lycopodium annotinum*, *L. clavatum*, and Pteridophyta (spores of Filicales monolete), were retained locally.

Dwarf shrub tundra communities, of an arctic-alpine character, composed of *Betula nana*, *Salix herbacea*, and *Ribes alpinum*, with mosses, and Cyperaceae were quite abundant. *Thalictrum*, *Filipendula*, *Caltha*, *Ranunculus acris*, *R. trichophyllu*s, *Selaginella selaginoides*, and *Botrychium* were also well represented. Development of moss-sedge and moss-meadow communities is also confirmed by the high curve of Cyperaceae and spores of mosses.

Subzone N$\dot{Z}_{05}$13b *Betula nana*-NAP -*Juniperus* L PAsZ

Open habitats, overgrown mainly by steppe-like and tundra communities, predominated the landscape as indicated by the proportion of NAP, amounting to 95% at the top of the subzone. *Juniperus* was the dominant shrub. *Alnus viridis* and *Ephedra distachya* were found occasionally.

A decrease in the variability of plant taxa was still observed. Pollen of Poaceae and *Artemisia* was recorded in high amounts, while of Chenopodiaceae are less frequent. The area was also marked by the occurrence of Asteraceae, Rubiaceae, Caryophyllaceae, and *Elymus*. High values of *Betula nana* (max. 20.5%) evidence an intensive development of dwarf shrub tundra communities, with *Salix herbacea* and Cyperaceae appearing frequently. Also *Thalictrum*, *Caltha*, *Cirsium*, *Saxifraga oppositifolia*, *Ranunculus acris*, Apiaceae, Brassicaceae, and abundant mosses, were frequent. Some plants forming dwarf shrub tundra were also growing in other communities, e.g. in humid meadows located on boggy areas surrounding the basin.

Climatic conditions controlling this phase of glaciation were so adverse, that most herbaceous plants and, presumably, all trees and most shrubs withdrew from the Nowiny Żukowskie area. This is evidenced by a poor variability of taxa observed in the pollen spectra and a very low concentration of sporomorphs (Fig. 7). The only abundant taxa, provided with optimum conditions for development and widely spread in the landscape, were Poaceae, *Artemisia*, *Betula nana*, and *Juniperus*.

In the last zone reed-swamps were formed by *Phragmites* and Cyperaceae, most likely accompanied by *Sparganium*, *Cicuta virosa*, *Hydrocotyle vulgaris*, *Scheuchzeria palustris*, *Osmunda*, and *Equisetum.* Macrophyte communities were predominated by *Ranunculus trichophyllus*, pollen of which was retained at the level of ca. 30% throughout two uppermost subzones, attaining a maximum of 60% in subzone N$\dot{Z}_{05}$13b. *Sphagnum* spores were found only in low quantity, while *Pediastrum* colonies in higher amounts.

RESULTS OF STUDIES OF BOREHOLE 4 DRILLED IN NOWINY ŻUKOWSKIE IN 1950 – A NEW PERSPECTIVE

The first palynological analysis of a profile from Nowiny Żukowskie was carried out by Dyakowska (1952) based on borehole 4 drilled in 1950. The examination covered 49 samples of the sediment and enabled the identification of 39 taxa, including 13 trees: *Pinus*, *Abies*, *Larix*, *Picea*, *Betula*, *Alnus*, *Carpinus*, *Fagus*, *Quercus*, *Ulmus*, *Tilia*, *Acer*, *Salix*, and one common unit – *Quercetum mixtum*, one shrub – *Corylus*, 14 taxa of herbaceous plants:

Gramineae (Poaceae), *Polygonum bistorta*, Chenopodiaceae/Caryophyllaceae, *Ranunculus* sp., *Geranium* sp., Papilionaceae (Fabaceae), *Epilobium* sp., Umbelliferae (Apiaceae), *Armeria* sp., Ericaceae, Labiateae (Lamiaceae), *Scabiosa* sp., Compositeae (Asteraceae) and *Artemisia* sp., 5 taxa of aquatic and reed-swamp plants: *Alisma plantago-aquatica*, *Typha latifolia*, *Nymphaea* sp., *Nuphar* sp., and *Myriophyllum* sp., as well as 5 taxa representing Pteridophyta: Filicales monolete (*Athyrium filix-femina*), *Lycopodium* sp., *L. selago*, *L. clavatum*, and *Selaginella selaginoides*. Spores of mosses and fungi were also identified. Indetermined sporomorphs were included in the group of "Varia".

Results of pollen analysis from Nowiny Żukowskie by Dyakowska (1952) are presented in a pollen diagram re-plotted with POLPAL software (Fig. 11). *Quercetum mixtum* was excluded from the diagram. *Lycopodium* sp., *L. selago* and *L. clavatum* were included in one taxon – *Lycopodium*. In the diagram (Fig. 11) particular phases of the development of vegetation, denoted as A – F, were distinguished following Dyakowska (op. cit.), who classified phases A – E into the Mazovian (Holsteinian) interglacial, and phase F – into the Varsovien glaciation, at present known as the Liviecian (Saalian) glaciation.

According to Dyakowska (1952) the climatic optimum of the Mazovian (Holsteinian) interglacial was controlled by a moderate climate enabling the development of trees with slightly higher temperature requirements in the surroundings of Nowiny Żukowskie. However, in the author's opinion it was a relatively cool variant of the climate, as coniferous trees were dominant in the landscape.

Within the present study, sediments from borehole 4 from Nowiny Żukowskie (profile $NŻ_{50\text{-}4}$, Tab. 3, Fig. 4) were re-examined in detail. The examination covered 24 samples and enabled the identification of 143 plant taxa, including 52 determined to the rank of species. The taxa were represented by 35 trees and shrubs (AP), 7 dwarf shrubs, 67 terrestrial herbaceous plants (NAP), 17 aquatic and reed-swamp plants, 11 Pteridophyta, 2 Bryophyta, 2 algae and 20 rebedded taxa. Such an abundance of taxa allows not only for a more detailed description of changes in vegetation of the Nowiny Żukowskie area, but also for an accurate reconstruction of changes in climatic conditions characterizing this period of Pleistocene, and a reinterpretation of its palynostratigraphy.

Comparison of results obtained for both examined profiles (Fig. 12) indicates their similarity, visible particularly in the Mazovian (Holsteinian) interglacial and the early Liviecian (Saalian) glaciation. However, a detailed comparison reveals numerous differences. Phase A (*Betula-Pinus*) of the Mazovian (Holsteinian) interglacial, controlled by a subarctic climate, represents the late Sanian 2 (Elsterian) gaciation, recorded at the basal part of the section and dominated by Poaceae and *Betula*, most likely including high proportions of *Betula nana*. This taxon was not identified in the 1950s. Sediment bearing a record of this cool period was marked by the presence of numerous rebedded sporomorphs.

Subsequent samples represent Pollen Period I of the Mazovian (Holsteinian) interglacial, predominated by pollen of *Betula* and *Pinus*, frequently accompanied by *Larix*. Phases B (*Alnus-Picea*) and C (*Abies-Carpinus*) are conformable with Pollen Period II and III, with these observations consistent with the interpretations of Dyakowska (1952).

Examination of samples taken from profile $NŻ_{50\text{-}4}$ enabled the identification of pollen of taxa being indicators of marine climate, such as *Viscum*, *Hedera helix*, and *Vitis*, as well as of thermophylous trees and shrubs, *Pterocarya*, *Juglans*, *Carya*, *Ligustrum*, and *Buxus*, accompanied by *Fagus sylvatica*, what allows for a more detailed reconstruction of climatic conditions controlling the Nowiny Żukowskie area. The climatic optimum of the Mazovian (Holsteinian) interglacial was definitely a warm, not a "relatively cool" period (Dyakowska 1952, p. 34).

Other differences are visible in phases D and E, described as "*Pinus*" by Dyakowska. Phase D and E should be considered as Pollen Period IV (*Pinus-Betula*, "*Pi-Be*", Fig. 12) of the Mazovian (Holsteinian) interglacial, dominated by pine forests with an admixture of birch and larch and controlled by a subarctic climate. High pollen values of Poaceae, recorded in the central part of phase E, evidence a visible deforestation that can be associated with the cooling of terminal phase of Mazovian (Holsteinian) interglacial (Poaceae, "Po", Fig. 12). In the top part of phase E, high pollen values of *Pinus* and a decrease in the

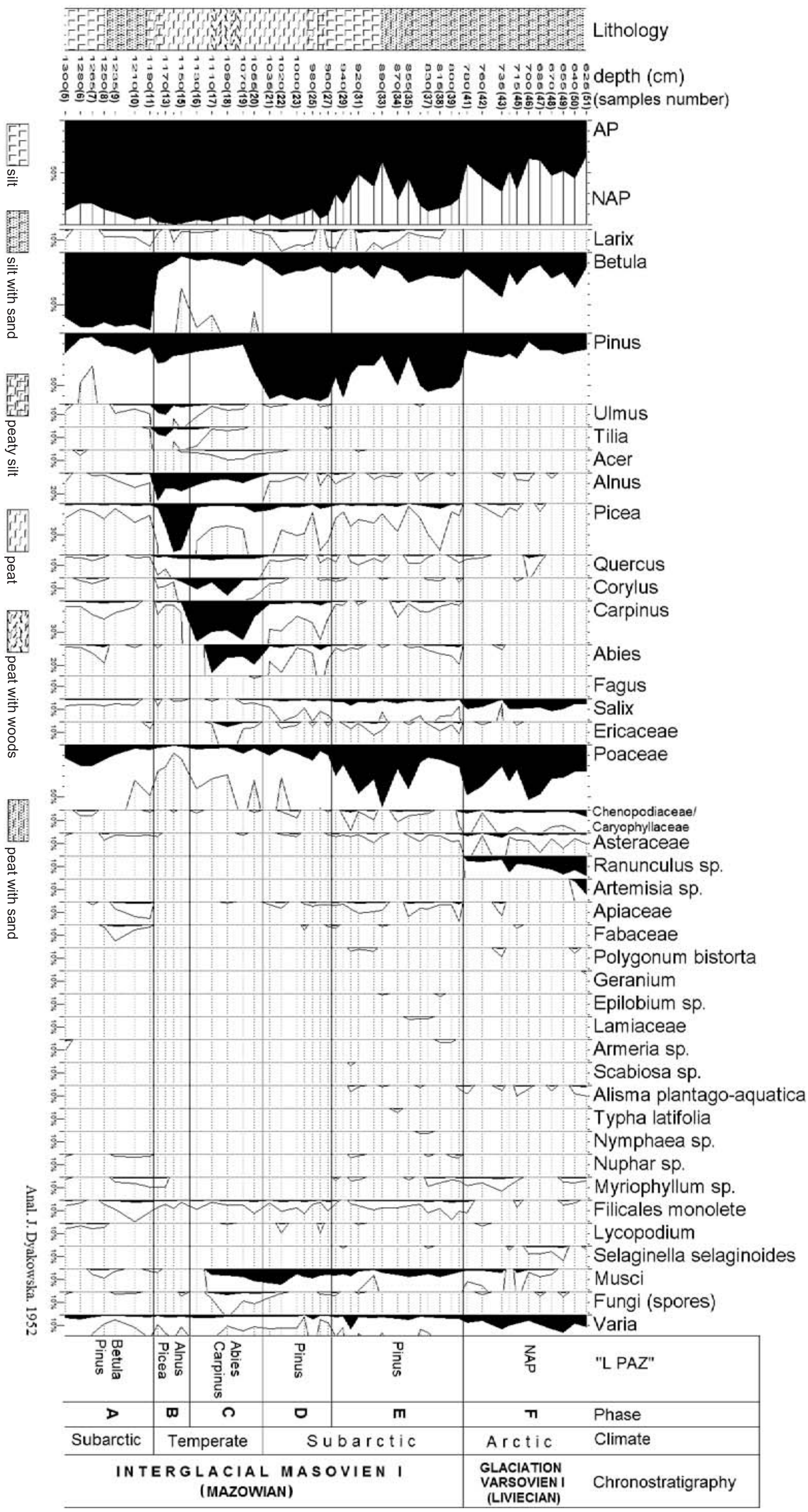

Fig. 11. Percentage pollen diagram of Nowiny Żukowskie by Dyakowska (borehole "4", data from 1952) recalculated and plotted using the POLPAL program (Nalepka & Walanus 2003)

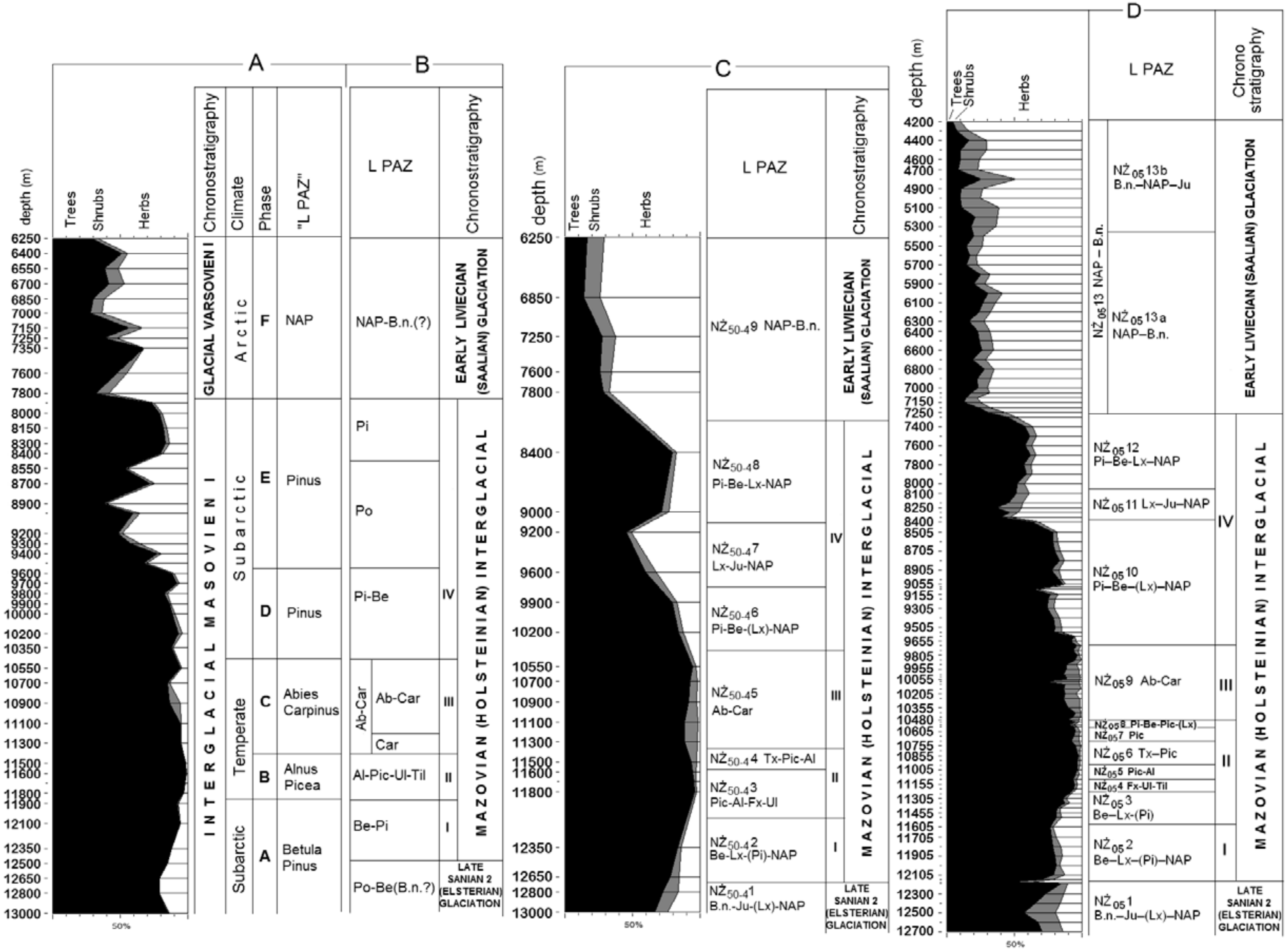

Fig. 12. Comparison the results of researches profiles in 1950 (by Dyakowka 1952), $N\dot{Z}_{50\text{-}4}$ and $N\dot{Z}_{05}$ (by Hrynowiecka-Czmielewska). **A** – Results of pollen analysis by Dyakowska (1952), **B** –Reinterpretation of results of pollen analysis by Dyakowska (1952), **C** – Results of pollen analysis of profile $N\dot{Z}_{50\text{-}4}$, **D** – Results of pollen analysis of $N\dot{Z}_{05}$ profile

proportion of Poaceae were recorded, indicating recovery of climatic conditions (*Pinus*, "*Pi*", Fig. 12). The top segment of the section from Nowiny Żukowskie should be considered to represent the Liviecian (Saalian) early glaciation, marked by the dominance of pollen of herbaceous plants (NAP) and controlled by an arctic climate. Pollen of *Betula*, still recorded in high proportions, should be associated with communities of dwarf shrub tundra with *Betula nana*. Pollen grains of this species, as it was already mentioned, were not formerly identified.

Figure 12 comprises the results obtained by Dyakowska (1952; Fig. 12A), reinterpretation of results of pollen analysis by Dyakowska (Fig. 12B) results of the repeated examination of profile $NŻ_{50-4}$ (Fig. 12B, C), as well as results of analysis carried out for the profile $NŻ_{05}$ (Fig. 12D). Such a comparison shows that frequent sampling of a highly compacted drill core enables a more detailed interpretation of results. It allowed for the distinction of a greater number of L PAZs and for the identification of two climatic oscillations: the intra-interglacial oscillation (Fig. 9) diagnostic for the Mazovian (Holsteinian) interglacial, and the "birch oscillation" (Fig. 10). Moreover, the laboratory preparation of profile $NŻ_{05}$ allowed the analysis of this part of the drill core, which could not be examined in the 1950s, and reached the depth of 4.20 m.

CHRONOSTRATIGRAPHY

Sediments from the Nowiny Żukowskie site are a record of the late Sanian 2 glaciation, complete succession of the Mazovian (Holsteinian) interglacial and the early Liviecian (Saalian) glaciation, preserved very well and attaining a high thickness. It is one of few sites representing the Mazovian (Holsteinian) interglacial, which show changes chactering both glacial-interglacial and interglacial-glacial boundaries. Obtained palynological data enabled the description of history of vegetation, as well as the reconstruction of changes in palaeoclimate characterizing the Nowiny Żukowskie area, visible in periods distinguished in this part of Pleistocene.

The pollen succession of Nowiny Żukowskie was correlated with successions recorded in Krępiec (Janczyk-Kopikowa 1981, succession stratotypical for the Mazovian interglacial), Brus (Pidek 2003), Ciechanki Krzesimowskie (Brem 1953), Syrniki (Sobolewska 1956), areas of Biała Podlaska – Ossówka, Biała Podlaska, Komarno and Grabanów (Krupiński 1984–1985, Krupiński et al. 1988, 1995a, b), Wylezin (Krupiński et al. 2004) as well as Mazovian (Holsteinian) successions from the entire area of Poland (Krupiński 2000).

Characteristic changes in vegetation, observed in particular segments of the profile, allowed for their classification into specific chronostratigraphical units (Tab. 4). The applied stratigraphic perspective followed Lindner et al. (2004), Ber et al. (2007), Lindner & Marks (2008) the most recent stratigraphic division. According to the above-mentioned papers, the Mazovian (Holsteinian) interglacial occurred between the Sanian 2 (Elsterian) glaciation, representing the South-Polish Complex, and the Liviecian (Saalian) glaciation, classified, together with the Mazovian (Holsteinian) interglacial, into the Middle-Polish Complex.

Within Western Europe, the Mazovian (Holsteinian) interglacial is correlated with the Holsteinian interglacial in Germany (Lindner 1991a, Zagwijn 1996), with the Mindel – Riss in the Alps (Lindner 1991b, Mojski 1993), with the Praclaux in France (de Beaulieu et al. 2001) and with the Hoxnian in Britain (Thomas 2001). Within Eastern Europe, the Mazovian (Holsteinian) interglacial is an equivalent of the Likhvinian interglacial in Russia and Ukraine, of the Aleksandrian in Belarus, and of the Butënai in Lithuania (Kondratienë & Seirienë 2003). In North America, the Mazovian (Holsteinian) interglacial is cor-

Table 4. Chronostratigraphy

Chrono-stratigraphical units	Nowiny Żukowskie (SE Poland)	Western Europe, Germany (Lindner et al. 2004, Ber et al. 2007, Lindner & Marks 2008)	The Alps (Lindner 1991b, Mojski 1993)	Eastern Europe, Russia and Ukraine (Lindner et al. 2004, Lindner et al. 2006)
glaciation	Sanian 2	Elsterian	Mindel	Orelian
interglacial	Mazovian	Holsteinian	Mindel – Riss	Likhvinian
glaciation	Liviecian	Saalian	Riss (pre-Riss)	Dnieperian

related with the Yarmouth interglacial (Kapp & Gooding 1974).

Deposits representing the Mazovian (Holsteinian) interglacial are underlayed by sediments bearing the remains of the Sanian 2 (Elsterian) glaciation, therefore indicating its beginning. In Western Europe, the Sanian 2 glaciation is correlated with the Elsterian glaciation and in Eastern Europe with Orelian glaciation. Sediments overlying the Mazovian (Holsteinian) succession are, in Poland, considered to represent the Liviecian (Saalian) glaciation. Initially, they were classified into the Odranian (Saalian) glaciation (Krupiński 2000), which is according to established European stratigraphy an equivalent of the Bargette = Fuhne glaciation (de Beaulieu et al. 2001). In Eastern Europe its correlated with Dnieperian glaciations.

In the most recent studies (Lindner & Marks 1999, Nitychoruk et al. 2005, 2006) the Mazovian (Holsteinian) interglacial was correlated with marine isotopic stage 11. In Central Europe it is often correlated with marine isotopic stage 9 (Zagwijn 1996). It is estimated that the stage was characterized by similar astronomical parameters as marine isotopic stage 1, representing the Holocene. This evidences that the temperature, degree of insolation and humidity attained the same, or at least similar, values in both Mazovian (Holsteinian) interglacial and the Holocene (Nitychoruk et al. 2005, 2006).

CLIMATIC CHANGES RECONSTRUCTED ON THE BASIS OF PALYNOLOGICAL DATA

LATE SANIAN 2 (ELSTERIAN) GLACIATION

Zone NŻ$_{05}$1, *Betula nana-Juniperus-*(*Larix*)-NAP, was marked by a low concentration of sporomorphs, accompanied by relatively high amounts of thermophylous rebedded and Tertiary sporomorphs. Due to that fact, the reconstruction of climatic conditions controlling the late Sanian 2 glaciation was highly hindered.

Dominance of open communities, most important component of which was dwarf shrub tundra with *Betula nana* and *Salix herbacea*, evidences low maximum January temperatures, not exceeding ca. 0°C (Granoszewski 2003). Occurrence of steppe-like communities predominated by Poaceae, Cyperaceae, Chenopodiaceae, heliophites like *Helianthemum nummularium*, as well as by shrubs of *Ephedra* and *Hippophaë rhamnoides*, indicates, that the area was highly affected by continental climate (Iversen 1954). The small proportion of trees in the landscape suggests that the mean July temperature did not exceed 12°C (Iversen 1954, Wasylikowa 1964, Mamakowa 1989). High values for *Juniperus* indicate that the minimum July temperature could have exceeded 10°C, while the appearance of pollen of *Typha latifolia* at the close of the late Sanian 2 (Elsterian) glaciation evidences that the mean July temperature was not lower than 13–14°C (Iversen 1954).

MAZOVIAN (HOLSTEINIAN) INTERGLACIAL

Pollen Period I

Zone NŻ$_{05}$2**,** *Betula-Larix-*(*Pinus*)-NAP, was marked by the development of boreal birch-pine forests and a distinct increase in pollen concentrations, both serving as evidence for the warming of climate. Dominance of birches indicates that the mean July temperature attained at least 12–13°C. Aquatic plants that began to develop in the area are known to have a higher rate of spreading, therefore, their response for changes in thermal conditions is delayed in comparison with terrestrial plants and particularly trees. The development of forest in its protocratic stage was most likely delayed in comparison with changes in climate (Szafer 1954). *Nuphar lutea*, *Nymphaea alba*, and *Typha latifolia*, which require a mean July temperature of ca. 13–14°C (Iversen 1944, Kolstrup 1980) are particularly worth mentioning.

Zone NŻ$_{05}$3, *Betula-Larix-*(*Pinus*) was marked by a decrease in the proportion of pollen of plants associated with open habitats and evidence a lower impact of cool climate.

Pollen Period II

The period was characterized by a proceeding warming of climate, indicated by an intensive development of thermophilic riparian elm-ash forests in zone NŻ$_{05}$4, *Fraxinus-Ulmus-Tilia*. At present, such communities are found mainly in the southern and south-eastern part of Middle Europe, and attain their north-eastern boundary of occurrence in Poland (Matuszkiewicz & Borowik 1957). *Tilia* was as admixture in forests of this kind where *Humulus lupulus* and *Viburnum* were also growing. *Humulus lupulus* is known to prefer mean July temperatures attaining at least 15°C (Hulten 1950), while *Tilia platyphyllos* requires a mean July temperature of at least 17°C (Zagwijn 1996). The mean temperature of the coldest month did not fall below –1.5°C (Iversen 1944). In such a moderate and humid climate, with relatively mild winters, more thermophylous trees, like *Quercus*, *Corylus*, *Acer*, and thermophylous shrubs, like *Buxus* and *Ligustrum*, could develop. *Hedera helix* evidence the proceeding oceanization of climate and *Viscum* indicates summer warmth.

The intensive development of forests with *Picea abies* in zone $NŻ_{05}5$, *Picea-Alnus*, indicates that winters of that period were cool, with a mean January temperature even below –3°C, while summers were not very warm, with a maximum July temperature of 17.7–18°C (Zagwijn 1996). Humid summers were advantageous for the spreading of *Picea* and *Alnus*, known to prefer areas with an annual sum of rainfall amounting to 500–700 mm (Pancer-Kotejowa & Zarzycki 1980).

It is very difficult to determine the climatic requirements of *Taxus baccata*, being one of main components of forests in the “zone of yew”, characteristic for the climatic optimum in the Mazovian (Holsteinian) interglacial (zone $NŻ_{05}6$, *Taxus-Picea*). At present, in the area of Poland, sites overgrown by yew are dispersed. The only factors limiting the development of the species are: minimum January temperatures below –30°C, strong continentalism, long-lasting droughts and high temperature. Yew is a shadow-tolerating tree of a broad ecological tolerance, preferring atlantic climate, rather constant temperatures, high air humidity and rainfall amounts exceeding 800 mm (Król 1975, Ellenberg et al. 1992, Zarzycki et al. 2002). Dominance of *Taxus baccata* in pollen spectra of the zones may indicate a higher impact of marine climate.

The period of maximum occurrence of *Taxus baccata* in Nowiny Żukowskie was followed by a repeated maximum of *Picea abies* (Zone $NŻ_{05}7$ *Picea*). Both trees have a similar ecological amplitude.

Withdrawal of *Taxus baccata* from the surroundings of Nowiny Żukowskie may have been caused by a continentalization of climate, resulting in the drying of ground, enabling *Picea abies*, as a more resistant species, to gain dominance.

In this part of the climatic optimum, the temperature of the warmest month could have amounted to 19–20°C or even 21°C (Krupiński 1995a).

The youngest zone of Pollen Period II, described as the intra-interglacial climatic oscillation (Bińka & Nitychoruk 1995, Krupiński 2000), is characterized by an intensive increase in pollen values of *Pinus sylvestris* and *Betula alba* (Fig. 9, Zone $NŻ_{05}8$ *Pinus-Betula-Picea-*(*Larix*). Alterations in the composition of forests may have resulted from an increasing continentalization of climate, indicated mainly by the frequent occurrence of *Larix*, considered to be an indicator of subcontinental climate. Decreasing pollen values of *Alnus glutinosa* are likely indicate a decrease in the annual amount of rainfall (presumably even to 450 mm) and a decline in the underground water level. However, the temperature of the coolest month was not likely to decrease, or the decrease was only slight (Krupiński 1995a). After Krupiński (1995a) and Nitychoruk (2000) it is concluded that this oscillation lasted for ca. 1500 years as confirmed by isotopic studies.

Pollen Period III

An improvement was observed in climatic conditions, as zone $NŻ_{05}9$, *Abies-Carpinus* was marked by an alternating dominance of deciduous mixed forests, predominated by *Carpinus*, and fir forests, with an admixture of *Quercus*, *Corylus*, and *Picea*, as well as by an increase in values for *Alnus*. The most intensive development of *Abies alba* is recorded in the temperature range between –4°C in January and 17.5–20°C in July (a mean of 15°C, Zagwijn 1996, Jaworski & Zarzycki 1983). Fir is a thermophylous tree, requiring a high humidity of both air and soil, preferring an oceanic-like climate, poorly tolerating frosts and not tolerating high fluctuations of temperature between summer and winter. In the area of Poland, *Abies alba* attains its northern boundary of its occurrence. In the Mazovian (Holsteinian) interglacial, the northern range of occurrence of *Abies* was larger (Kondratienë & Seirienë 2003), indicating much better conditions for the development of this taxon. *Carpinus betulus* is known to prefer habitats affected by continental climate, with a minimum annual rainfall amounting to at least 300 mm (Cheddadi et al. 1998). At present, the range of occurrence of *Carpinus* attains its northern boundary in southern Sweden and Lithuania (Hulten 1950). However, results of palynological studies of the Mazovian (Holsteinian) interglacial from Lithuania (the Butėnai interglacial) indicate, that in that time the boundary was shifted farther to the north (Kondratienė & Seirienė 2003). Alternating oscillations of curves for fir and hornbeam were most likely caused by changes in climate, resulting in an increase in humidity (Nitychoruk et al. 2005). Isotopic $\delta^{18}O$ data indicate that the optimum of this interglacial was controlled by a marine climate (Nitychoruk 2000). Continuous curves for *Buxus*, *Pterocarya*, *Hedera helix*, *Viscum*, *Viburnum*, *Fagus sylvatica*, *Juglans*, and *Vitis* evidence, that this was the warmest period of the Mazovian (Holsteinian) interglacial. *Buxus* requires a minimum mean temperature of 0°C in January and of 17°C in July (Iversen 1944, Zagwijn 1996) or of +1°C in January and of 18°C in July (Aalbersberg & Litt 1998). Spreading of this taxon serves as evidence for an increase in the amount of rainfall and preceding oceanization of climate, as the minimum annual rainfall required by *Buxus* amounts to 650 mm, while its optimum development is provided by amounts exceeding 1000 mm (Zagwijn 1996). At present, the shrub is found in xerothermic communities of submediterranean areas (Ellenberg et al. 1992). *Hedera helix* requires a mean temperature of the coldest month of at least –1.5°C (Iversen 1944) or ranging between –1.7 and –2°C (Zagwijn 1994) to flower. However, flowering plants of *Hedera helix* can be already observed at the mean January temperature of –5°C, in the Roztocze region (Paszyński & Niedźwiedź 1991). Development of this climbing plant is not limited by low mean July temperatures, amounting to ca. 15°C (Aalbersberg & Litt 1998). Occurrence of *Vitis*, most likely *V. sylvestris*, at present found in river valleys of southern Europe and representing the sub-mediterranean - atlantic element (Hegi 1965), indicates that climate controlling the climatic optimum of the Mazovian (Holsteinian) interglacial could have been as warm, or even warmer and of a higher humidity, than climate controlling the areas of present-day north-eastern Europe (Nita 1999). Presence of *Viscum* shows that the mean temperature of the warmest month attained ca. 16°C (Iversen 1944), or even 17°C (Hulten 1950). Appearance of high amounts of pollen of *Pterocarya*, probably *P. fraxinifolia* (Środoń 1955, Krupiński 1995a) as a component of riparian forests, indicates a warm and humid climate. The tree is known to prefer areas with an annual rainfall amounting to even 2000 mm, evenly distributed throughout the year (Berg 1962) but they also grow well with up to 800 mm of rainfall anually.

Palynological data indicate that climate controlling the Nowiny Żukowskie area in the climatic optimum of the Mazovian (Holsteinian) interglacial was presumably humid, warm and milder than the present-day one. Mean temperatures could have been higher than the present-day by 2–4°C. According to Krupiński (1995a), during mild winters the snow layer was not very thick and long-lasting.

Pollen Period IV

The warm and humid mesocratic period was followed by a gradual cooling and increase in continentalism – zone $N\dot{Z}_{05}10$ *Pinus-Betula-(Larix)*-NAP. At the beginning of this period, thermophylous trees were retained although in relatively low proportions. This indicates that initially the climate was still quite mild. However, such trees were eventually withdrawn from the area due to pressure exerted by pine forests with birch and larch spreading in the site. According to Krupiński (1995a) the period was controlled by a boreal climate, with a mean July temperature initially amounting to 15–17°C, and in the later phase from to 14–15°C. January temperatures fluctuated between –3 and –1°C, and at the end of the period between –5 and –4°C. Occasional occurrence of pollen of thermophilic trees and shrub taxa may be associated with local conditions, advantageous enough to provide the development of such species. However, the increase in values of NAP, particularly of Poaceae, Cyperaceae, and *Artemisia*, as well as the appearance of *Betula nana*, indicate the deterioration of climatic conditions and an increase in the proportion of open communities of herbaceous plants in the landscape. Occurrence of *Selaginella selaginoides* may indicate that the maximum July temperature did not exceed 17°C (Tobolski 1991).

Nitychoruk (2000, 2002) suggests that the cooling recorded for Pollen Period IV of the Mazovian (Holsteinian) interglacial was caused by an increase in volcanic activity. The course of $\delta^{18}O$ and $\delta^{13}C$ curves evidences a contamination of atmosphere with volcanic dust contributing to the cooling of climate.

The middle part of this pollen period ("birch oscillation") was probably marked by an interruption in sedimentation (Fig. 10). Pollen values of *Betula alba* and *Larix* indicate, that birch and larch displaced pine. Presumably, hydrological conditions of the area were affected by changes of water conditions. In this segment of the profile sporomorphs were found in low concentrations providing additional evidences for these changes.

Reduction in the area of boreal pine forests, as well as the development of open steppe-tundra communities both indicate a strong cooling of climate and its proceeding continentalization (zone $NŻ_{05}11$, *Larix-Juniperus*-NAP). Most likely, all thermophylous trees were withdrawn at long distances from the area, while *Pinus*, *Betula*, and *Larix* were found only in clumps, including *Pinus cembra* (known to tolerate low temperatures, Obidowicz et al. 2004), *Alnus viridis*, *Juniperus*, and *Hippophaë rhamnoides*. The northern boundary of the forest presumably migrated to the south of Nowiny Żukowskie, or was at least located in a distance from the area; this is likely to indicate that mean July temperatures attained ca. 12–13°C (Wasylikowa 1964, Szczepanek 1971), or even 10–12°C (Krupiński 2000). Appearance of *Typha latifolia* in the end of Mazovian interglacial shows that the mean temperature of the warmest month of this period amounted to ca. 13–14°C (Iversen 1954). High pollen values for *Ranunculus trichophyllus* evidence mean July temperatures attaining at least ca. 13°C (Granoszewski 2003).

Climatic warming is characterized by a slight improvement in climatic conditions that are deduced from an increase in the proportion of AP, exceeding 57%. However, the climate was cool enough to prevent the development of boreal forests. Climatic conditions were affected by preceding continentalization as indicated by an increase in the values for *Larix* and *Juniperus*, and stepping, evidenced by high proportions of Poaceae and *Artemisia*. Communities overgrowing open habitats were still an important part of the landscape, and the northern boundary of forest became only slightly closer to Nowiny Żukowskie shown by high pollen values of Poaceae, Cyperaceae, *Artemisia*, and *Juniperus* as well as by the appearance of *Hippophaë rhamnoides* and *Ephedra distachya*. At that time, *Juniperus* was an important component of the landscape. The mean temperature of the warmest month, being optimum for this taxon, amounts to ca. 8°C (Isarin & Bohncke 1999). *Hippophaë rhamnoides* requires a mean July temperature exceeding 10°C (Kolstrup 1980). Occasional occurrences of *Nuphar lutea* and *Typha latifolia* indicate that mean temperatures recorded during the warmest month must have exceeded 13°C, as both species are not frequently found in cooler areas (Iversen 1944, Kolstrup 1980).

As the slight warming of climate proceeded, an increase was recorded in AP values, attaining nearly 63% in zone $NŻ_{05}12$, *Pinus-Betula-Larix*-NAP. This fact can be explained with a slight increase in the density of forests, accompanying open communities, remaining an important part of landscape. *Hydrocotyle vulgaris*, requiring a mean July temperature of ca. 11.5°C (Aalbersberg & Litt 1998) was also found in the area.

EARLY LIVIECIAN (SAALIAN) GLACIATION

Dominance of open steppe-tundra habitats and dwarf shrub tundra in zone $NŻ_{05}13$, NAP-*Betula nana*, indicates the cooling of climate, passing into a subarctic one, and a shift in the northern boundary of forest to the south of Nowiny Żukowskie. Withdrawal of trees, particularly pine, evidences that the mean July temperature fell below 10°C (Granoszewski 2003). Unequivocally, pollen of thermophylous trees, occurring infrequently, originated from long-distance transport as confirmed by the fact that generally sporomorphs were found in low or very low concentrations. Increase in pollen values for Poaceae, Cyperaceae, *Artemisia*, and Chenopodiaceae indicates a proceeding continentalization of climate. A constant curve of *Betula nana* pollen attaining high percentage values indicates that the maximum temperature of the coldest month amounted to ca. 0°C, while the mean temperature of the warmest month of ca. 10°C (Granoszewski 2003).

At the beginning of the period, July temperatures could have attained even higher values evidenced by the occurrence of spores of *Pteridium aquilinum* – a fern requiring a mean minimum July temperature of ca. 14°C (Tobolski 1991). The presence of spores of *Selaginella selaginoides* and *S.* cf. *helvetica* appears to indicate that the maximum temperature of the warmest month did not exceed 17°C (Tobolski op. cit.). Occurrence of pollen of *Armeria maritima* evidences the dominance of climate similar to the one controlling present-day steppe areas, characterized by minor amounts of snowfall, as the species prefers snow layers of a low thickness (Kolstrup 1980). Appearance of *Dryas octopetala* is an indicator of subarctic climate. Increase in values of Poaceae, accompanied by a gradual decrease in values for Cyperaceae attaining a minimum of 1%, evidences an intensive drying and stepping of climate.

Aquatic plants like *Myriophyllum spicatum* and *M. verticillatum* develop in mean July temperatures of ca. 10–13°C (Kolstrup 1980), as does *Nuphar lutea*. Appearance of *Hydrocotyle vulgaris* indicates, that mean July temperatures amounted to ca. 11.5°C (Aalbersberg & Litt 1998). However, it should be considered, that the response of aquatic plants to fluctuations in temperatures is delayed in comparison with terrestrial plants, as the microclimate of water basins enables the species to withstand thermal conditions perceived as harder in the surrounding. Therefore, such taxa should be regarded as climatic relics (Szafer 1954, Wasylikowa 1964). A visible increase in values of *Ranunculus trichophyllus*, recorded at the close of the period, is likely to indicate a mean July temperature of ca. 13°C (Granoszewski 2003).

The top of the core, considered to represent the early Liviecian (Saalian) glaciation, is marked by relatively high values of *Juniperus* requiring a mean temperature of the warmest month of at least 8°C (Isarin & Bohncke 1999). Occasional occurrences of *Ephedra distachya*, *E. fragilis*, and *Hippophaë rhamnoides* confirm the hypothesis of the dominance of continental climate, with indications of stepping in the surroundings of Nowiny Żukowskie.

POLLEN SUCCESSION OF NOWINY ŻUKOWSKIE IN COMPARISON WITH SELECTED SITES REPRESENTING THE MAZOVIAN (HOLSTEINIAN) INTERGLACIAL

Mazovian (Holsteinian) succession of the Nowiny Żukowskie site was compared with the succession recorded for Krępiec (Janczyk-Kopikowa 1981) as it is considered to be represent the stratotype for the Mazovian (Holsteinian) interglacial in Poland and is closely positioned to Nowiny Żukowskie (Fig. 13). The site of Brus (Pidek 2003) with a complete record of succession of a part of the late Sanian 2 (Elsterian) glaciation, as well as of the entire Mazovian (Holsteinian) interglacial and early glacial of Liviecian (Saalian), is also situated at a relatively close distance. A well preserved record of the early Liviecian glaciation is also found in the profile from Ossówka (Krupiński 1995b), located close to the site of Woskrzenice (Bińka & Nitychoruk 1995) and is marked by a distinct intra-interglacial climatic oscillation. The comparison included also the sites of Gajec (Winter & Urbański 2007), Konieczki (Nita 1999), Krzyżewo (Janczyk-Kopikowa 1996), and other sites situated at a greater distance from Nowiny Żukowskie.

Zones of the Mazovian (Holsteinian) succession, recorded for Nowiny Żukowskie, were distinguished following Janczyk-Kopikowa (1981, 1996). Their comparison with the abovementioned sites was conducted on the basis of a division into Regional Pollen Assemblage Zones (R PAZ), distinguished for the Mazovian (Holsteinian) interglacial in the Podlasie region by Krupiński (2000; Tab. 5).

Views presented by the two authors differ mainly with the location of the boundary separating Pollen Period II and III. According to

Fig. 13. Localities of Mazovian interglacial compare with profile $NŻ_{05}$: Gajec (Winter & Urbański 2007), Konieczki (Nita 1999), Krępiec (Janczyk-Kopikowa 1981), Brus (Pidek 2003), Woskrzenice (Bińka & Nitychoruk 1995), Ossówka (Krupiński 1995b), Przasnysz (Bałuk & Mamakowa 1991), Goleń (Winter & Lisicki 1998), Krzyżewo (Janczyk-Kopikowa 1996)

Table 5. Correlation of local pollen assemblage zones (L PAZ) and pollen periods in profile NŻ$_{05}$ with Regional Pollen Assemblage Zones (R PAZ) and pollen periods after Krupiński (2000)

Regional Pollen Assemblage Zones (R PAZ) and pollen period by Krupiński (2000)			NŻ$_{05}$ Profile			
			Local Pollen Assemblage Zones (NŻ $_{05}$ L PAZ)		Pollen Period	Stages
SAALIAN GLACIATION			13	NAP-*Betula nana* (with two subzones)	EARLY LIVIECIAN (SAALIAN) GLACIATION	
M9	*Pinus*	IV	12	*Pinus-Betula-Larix*-NAP	IV	MAZOVIAN (HOLSTEINIAN) INTERGLACIAL
			11	*Larix-Juniperus*-NAP		
			10	*Pinus-Betula-*(*Larix*)-NAP		
M8	*Carpinus–Quercus-Abies*	III	9	*Abies-Carpinus*	III	
M7	*Abies–Carpinus–Quercus-*(*Corylus*)					
M6	*Pinus–Picea-Alnus*		8	*Pinus-Betula-Picea-*(*Larix*)	II	
M5	*Taxus–Picea-Alnus*		7	*Picea*		
			6	*Taxus-Picea*		
M4	*Picea–Alnus–*(*Taxus*)	II	5	*Picea-Alnus*		
M3	*Picea–Alnus–*(*Pinus*)		4	*Fraxinus-Ulmus-Tilia*		
M2	*Betula–Pinus–*(*Picea–Alnus*)	I	3	*Betula-Larix-*(*Pinus*)	I	
M1	*Betula*-NAP		2	*Betula-Larix-*(*Pinus*)-NAP		
ELSTERIAN GLACIATION			1	*Betula nana-Juniperus-*(*Larix*)-NAP	LATE SANIAN 2 (ELSTERIAN) GLACIATION	

Krupiński (2000), the boundary should be outlined below the records of high values of *Taxus baccata*, therefore the "zone of yew" should be classified into Pollen Period III. However, according to Janczyk-Kopikowa (1987, 1991), the boundary should be marked out above the "zone of yew" and above the repeated maximum of spruce, both of which should be classified into Pollen Period II, dominated by spruce and alder.

LATE SANIAN 2 (ELSTERIAN) GLACIATION AND THE GLACIAL-INTERGLACIAL BOUNDARY

In Nowiny Żukowskie, the late-glacial period was marked by high pollen values of trees with higher climatic requirements, attaining the proportions of even 12% (*Picea abies*). Analogous observations were recorded for sections drilled in Goleń in Mrągowo Lakeland (Winter & Lisicki 1998) and Przasnysz in Ciechanowska Upland (Bałuk & Mamakowa 1991). High frequency of *Picea abies*, *Alnus*, *Abies*, and *Carpinus*, as well as the appearance of *Quercus*, *Corylus*, and *Taxus*, were the basis for the distinction of an interglacial pollen succession described as the Mrongovian interstadial (Lisicki & Winter 1999). Its occurrence was not confirmed in Nowiny Żukowskie, as the above mentioned species were accompanied by high amounts of taxa typical of cool periods, like *Betula nana* (attaining a proportion of even 13.5%), Cyperaceae, Poaceae, and *Artemisia*, while damaged pollen grains of trees with higher temperature requirements were considered to be reworked and deposited in a secondary bed.

Pollen of *Betula nana* L. was identified only in Brus (Pidek 2003) and Nowiny Żukowskie, additionally confirming the late-glacial character of vegetation developing in the areas.

The lower glaciation-interglacial boundary was not noticed in all profiles. In Nowiny Żukowskie, Brus and Woskrzenice it has a specific outline – high values of *Pinus* rapidly pass into high proportions of *Betula*.

MAZOVIAN (HOLSTEINIAN) INTERGLACIAL

At all compared sites, Pollen Period I was marked by similar events and was characterized by the dominance of birch.

The beginning of Pollen Period II, in Nowiny Żukowskie, was marked by high values for *Fraxinus excelsior*, amounting to 22.5%. High pollen values of ash typified also the remaining sites (despite Krępiec, where the species was not recorded), however, they did not exceed 10% and the initial phase of Pollen Period II was indicated rather by high proportions of *Alnus* and *Picea*.

The diagnostic feature of the Mazovian (Holsteinian) interglacial – occurrence of pollen of *Taxus baccata*, was visible at all compared sites. However, the proportions of yew were diversified and varied between 11.4% in Krzyżewo (Janczyk-Kopikowa 1996) and 62.1% in Konieczki (Nita 1999), amounting to 43% in Nowiny Żukowskie. Therefore, it may be assumed that values for yew decreased from west to east as the impact of marine climate was limited.

The intra-interglacial oscillation, characteristic of the Mazovian (Holsteinian) interglacial, was most visibly marked in the profile from Woskrzenice as described by Bińka and Nitychoruk (1995). According to these authors, the oscillation should not be classified neither into the spruce-alder period nor the fir-hornbeam period, as the zone marked by high values of *Pinus*, found in the climatic optimum, is of transitory character and should be distinguished as a separate part of a three-part climatic optimum. This period of time, recorded in the profile from Woskrzenice, was characterized by the occurrence of pine forests (proportion of *Pinus* amounting to ca. 50%), with an admixture of birch (ca. 20%) and larch (ca. 2%), and by a gradual decrease in the frequency of *Picea*.

The nearby site of Ossówka (Krupiński 1995b) was marked by a two-peak increase in values for *Pinus*, attaining a maximum of 57%. At the site of Konieczki the increase in proportion of pine (up to ca. 30%) begins while yew attains a value of ca. 30% (Nita 1999). It seems likely that the spreading of pine could have caused the withdrawal of communities with yew from that area.

In Nowiny Żukowskie the increase in proportions of pine and birch was simultaneous and followed the repeated maximum of spruce. Both *Pinus* and *Betula* attained similar values of 31% and 36%, respectively. This event did not clearly contribute to the decrease in frequency of *Picea*. In the section from Brus (Pidek 2003) a distinct increase was recorded only for proportions of *Pinus sylvestris* (up to ca. 40%), being accompanied by high curves for *Abies* and *Carpinus betulus*.

In the section from Krępiec, no changes likely to indicate a cooling, drying or continentalization of climate were observed in the composition of tree stand (Janczyk-Kopikowa 1996), presumably due to a low density of the analysed samples.

The site of Gajec, located in western Poland (Winter & Urbański 2007), was marked by high proportions of pollen of *Quercus* and *Corylus*, exceeding 20% in Pollen Period II, characteristic of the western Mazovian successions (Müller 1974). The site of Konieczki, also situated in the west was the only area in which an increase was also recorded for curves of oak and hazel, attaining frequency of ca. 10% (Nita 1999).

In Pollen Period II, differences between the compared sites are not clear and concern mainly the order of appearance of particular trees and these appear to be associated with local habitat conditions. Considerable differences are visible between profiles from Nowiny Żukowskie and sites located to the west, being affected by marine climate.

Pollen Period III of the Mazovian interglacial, described as the fir-hornbeam period, was marked by two trends. Sites located in the Lublin province were initially dominated by fir forests, while sites situated in the Podlasie region by oak-hornbeam forests. Further to the west and north the smaller were the areas covered by fir forests, and the lower was the proportion of hornbeam, being displaced by oak, hazel, and yew, in oak-hornbeam forests.

Pollen Period IV was characterized by the dominance of *Pinus*, accompanied by high amounts of *Betula*. Initially in all compared sections the above-mentioned taxa were accompanied by *Abies* in high pollen values and *Picea* and *Carpinus* in lower proportions. The section from Brus was additionally marked by a high frequency of *Alnus* (Pidek 2003), while the section from Gajec by high pollen values of *Quercus* and *Corylus* (Winter & Urbański 2007), confirming the influence of marine climate.

The middle part of Pollen Period IV in Nowiny Żukowskie was characterized by an alteration in the structure of forest. Pine was withdrawn from the area (decrease in percentage values from 37% to 3.6%) and replaced by birch (increase in proportion from 19% to 52%) and larch. All thermophylous trees disappeared, while pollen values of Cyperaceae and *Equisetum* increased. Analogous changes were observed in the section from Gajec, where the withdrawal of *Pinus* and expansion of *Betula* were accompanied by an increase in pollen values of *Larix*, Poaceae, and *Ranunculus flammula* (Winter & Urbański 2007). Additionally, the "birch oscillation" recorded in Gajec was followed by another warming of climate, evidenced by an increase in pollen values for thermophylous trees and shrubs. Very high pollen values of birch (85%) were also recorded in profile from Krzyżewo, at the beginning of the first interstadial preceding the dominance of pine (Janczyk-Kopikowa 1996).

EARLY LIVIECIAN (SAALIAN) GLACIATION

Stadial I

In the early glaciation, the compared profiles were typified by a decrease in AP values, falling to 50% or even lower. The cooling of climate resulted in a distinct decline of the AP curve, to ca. 45% in Nowiny Żukowskie and 44% in Ossówka (Krupiński op. cit.). In the profile from Ossówka four stadials were distinguished (Stadial I, II, III and IV), all characterized by a decrease in values of pine (even to 3%), and increases in the proportion of juniper (attaining a maximum of 65%) and rising curves of *Salix* (5%), Poaceae (attaining a maximum of 25%), Cyperaceae (19%), and *Artemisia* (14%).

In Nowiny Żukowskie the subsequent cooling was considered to represent the Liviecian glaciation, mainly due to a decrease in AP values (attaining 5%) and a high thickness of sediment that are not recorded in any other profile. During this episode of cooling, dwarf birch attains a frequency of up to 20.5% in the top part of the profile and was an important component of flora. *Betula nana* was an infrequently observed taxon, pollen of which hardly ever attained such high proportions. Pollen values for *Ranunculus trichophyllus*, representing aquatic taxa, amounted to even 60%. In no other section being a record of the glacial succession, aquatic taxa (including those mentioned above) attained such high values.

Interstadial I

Interstadial I of the early Liviecian (Saalian) glaciation was recorded in sediments from Ossówka, Krzyżewo and Woźnicko-Wieluńska Upland. In Ossówka located in the Podlasie region (Krupiński 1995b), the warmer periods (Interstadials I, II and III) were marked by an increase in values of *Pinus* (even up to 82%) and *Betula* (up to 27%). Proportions of *Juniperus* and *Larix* were still quite high. Values of herbaceous plants were decreased, while the curve of *Pteridium* spores attained the amount of 23%. In the profile from Krzyżewo (Janczyk-Kopikowa 1996), the interstadial warming was indicated by an increase in the proportion of birch (up to 85%), directly followed by the dominance of pine (ca. 72%). In the two sites situated in Woźnicko-Wieluńska Upland (Raków and Wielki Bór, Nita 2009) the record of succession is closed by Stadial II and III of the Liviecian glaciation.

FINAL REMARKS

The aim of this paper was to reconstruct the development of vegetation and changes in climate of the northern part of the Lublin Upland, on the basis of palynological studies of lacustrine sediments from the Nowiny Żukowskie site (profile $NŻ_{05}$).

Results of pollen analysis indicate, that sediments from the Nowiny Żukowskie site are a record of the late Sanian 2 (Elsterian) glaciation, complete vegetation succession of the Mazovian (Holsteinian) interglacial, and the early Liviecian (Saalian) glaciation.

The history of vegetation, recorded in biogenic sediments from the basin in Nowiny Żukowskie, begins in late Sanian 2 (Elsterian) glaciation in which the landscape was predominated by a mosaic of open communities of dwarf shrub tundra and steppe-tundra communities with *Betula nana*, Poaceae, Cyperaceae, and *Artemisia*.

On the basis of palynological studies the occurrence of the Mrongovian interstadial was excluded. Thermophylous taxa like *Abies*, *Carpinus betulus*, and *Picea abies*, as well as exotic taxa such as *Pterocarya*, *Ilex aquilinum*, and *Juglans*, are rebedded.

The lower boundary of the Mazovian succession of vegetation was indicated by the development of pioneer birch forests with a small proportion of *Larix* and *Pinus sylvestris*. Communities of dwarf shrub tundra were still a part of landscape.

In Nowiny Żukowskie the beginning of the mesocratic period was marked by the dominance of riparian forests with high pollen values for *Fraxinus*, *Ulmus*, and *Tilia cordata*. The climate showed an increase in humidity and warmth. Next followed of mixed forests predominated by *Picea abies* with an admixture of *Quercus*, *Tilia*, and *Corylus*. Intensive spreading of *Taxus baccata*, which became a very important component of various types of forest communities, in which it accompanied spruce. *Picea* was dominated in mixed forests. The intra-interglacial climatic oscillation of the Mazovian (Holsteinian) interglacial - pine forests with an admixture of *Betula* and *Larix* entered areas formerly covered by other forest communities, evidences a climatic drying and also presumably cooling.

The younger period of the climatic optimum marked by fluctuations in values for *Abies* and *Carpinus*. Initially the area was dominated by fir forming forests with a small admixture of *Picea* and *Pinus*. Subsequently, multispecies deciduous forests with *Carpinus*, *Quercus*, *Corylus*, and *Tilia cordata* enlarged their areas. Such forests could have also included *Abies*, however, its proportion was limited due to fluctuations in continental climate. The dominance of fir forests was slightly limited by deciduous forests in which maximum proportions were attained by *Corylus* and *Quercus*, and followed by the widest spreading of *Carpinus* and an expansion of deciduous forests with an admixture of hazel, oak, and linden. The dominance of a warm and humid climate is evidenced by the occurrence of *Juglans*, *Vitis*, *Viscum*, *Hedera helix*, and *Pterocarya*, forming littoral alder forests together with *Alnus*. *Buxus* and *Corylus* were components of thermophilic scrubs. Probably, *Abies* spread again in fir forests with *Picea* and *Pinus*, while *Carpinus* developed in multispecies deciduous forests, however, not as intensively as *Abies*. High values of *Sphagnum* spores are recorded in all subzones and indicate the occurrence of a peat bog.

The first zone representing telocratic period, is a record of proceeding changes towards climate cooling. The landscape was dominated by *Pinus* with an admixture of *Betula* and *Larix*. The “birch oscillation” was characterized by dominance of *Betula* and an increase in the proportion of *Larix*. It is accompanied by a nearly complete disappearance of *Pinus*, observed as a consequence of deep changes in hydrological conditions controlling this part of the telocratic period of the Mazovian (Holsteinian) interglacial. Cyperaceae and *Equisetum* enlarged their areas.

The next cooling brought the steppe-like communities, composed mainly of Poaceae, Cyperaceae, and *Artemisia*. Dwarf shrub tundra with *Betula nana* and *Salix herbacea*, as well as humid meadows, were also recorded. *Ranunculus trichophyllus* was the dominant plant in the water basin. Small clusters of *Pinus* and *Betula*, accompanied by *Larix*, *Juniperus*, and *Alnus viridis*, were retained only locally. Re-entry of trees are associated with a slight improvement in climatic conditions. The tree stands were characterized by a low density and were dominated by larch with an admixture of *Pinus*, *Betula* and frequently *Juniperus*. The proceeding borealization of climate, resulting in an improvement in climatic conditions, enabled the expansion of pine forests with birch and larch represents the end the of the Mazovian interglacial. NAP values, amounting to ca. 50%, indicate a low density of forests.

Due to a proceeding cooling of climate in the early Liviecian (Saalian) glaciation, the northern boundary of the forest was shifted to the south of Nowiny Żukowskie. Trees were found occasionally. The landscape was dominated by dwarf shrub tundra communities with *Betula nana* and *Salix herbacea*, as well as by steppe-like communities of herbaceous plants including *Artemisia*, Chenopodiaceae and many other taxa. The water basin, initially overgrown by a peat-bog, passed into a lake after being deepened. Waters of the lake were marked by an abundant occurrence of *Ranunculus trichophyllus*. The upper part of the zone, is characterized by the occurrence of numerous shrubs of *Juniperus* and ended the pollen succession recorded in the profile from Nowiny Żukowskie.

It should be stated that the part of profile considered to represent the early Liviecian glaciation can be regarded as one of stadials. Pollen values for trees, and evidence the dominance of extremely adverse climatic conditions, typical of the glacial zone, therefore also in a glaciation.

Results of the re-examined profile $NŻ_{50\text{-}4}$ shows that sampling in greater intervals is not given a full view of vegetation and climate changes, especially in very compact deposits.

The next aim is analyses of macroremains, tissues of peat-forming plants, wood and needles, and fungi (actually research). Such comprehensive studies of profile from Nowiny Żukowskie shall enable the completion of pollen analysis, as well as will provide new, interesting data for palaeobotanical, palaeohydrological and palaeoclimatical research, likely to contribute to a better understanding of changes in the present-day climate.

ACKNOWLEDGEMENTS

I am very grateful to Prof. dr hab. Kazimiera Mamakowa (W. Szafer Institute of Botany, Polish Academy of Sciences, Kraków) for introducing me to the subject of Quaternary palaeobotany, for her valuable remarks on palynostratigraphy and all thorough scientific discussions. I would also like to express my gratitude to Prof. dr hab. Magdalena Ralska-Jasiewiczowa for her guidance during the final months of my doctoral studies. Prof. dr hab. Ewa Zastawniak-Birkenmajer, the Head of the Department of Palaeobotany of this Institute, and all of the employees of this Department are warmly thanked for their help and kindness. I am very grateful to Prof. dr hab. Leon Stuchlik for invaluable help in preparing the last version of paper for print. Dr hab. Dorota Nalepka thank very much for enlarged my knowledge on pollen analysis and for supported and valuable advice. I also thank Dr Wojciech Granoszewski, Polish Geological Institute in Kraków, for invaluable help while obtaining sampling material in Nowiny Żukowskie and for important remarks concerning the Pleistocene palynostratigraphy. I also thank mgr Katarzyna Cywa Msc, Małgorzata Zurzycka, Barbara Kurdziel, and Grzegorz Szponder Msc (Department of Palaeobotany, W. Szafer Institute of Botany, Polish Academy of Sciences in Kraków) for their involvement in laboratory works.

For linguistic verification of the text I would like to express my sincerely thanks to Dr Jason Hilton, University Birmingham UK.

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