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The Late Glacial and Holocene development of vegetation in the area of a fossil lake in the Skaliska Basin (north-eastern Poland) inferred from pollen analysis and radiocarbon dating

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ABSTRACT. The development of vegetation in the Skaliska Basin has been reconstructed on the basis of palynological analysis and radiocarbon dating (AMS technique) of 6 sites from the late phase of the Bølling-Allerød interstadial complex to modern times. Although the area covers 90 km^2, the mosaic character of habitats led to the development of different patterns of vegetation changes during the Late Glacial and Holocene. Only one site located in the eastern part of the Skaliska Basin reflected the 'pine phase' of Allerød, and this is the oldest data on vegetation in the Skaliska Basin. Interesting discrepancies were recorded during the Younger Dryas when patches of shrublands with *Juniperus* were distinct around some of the sites, while steppe with *Artemisia* was common in others. The beginning of the Holocene brought an expansion of birch-pine forest, but around 9600 cal. BC a cold oscillation took place which was reflected in an increase in birch in the woodlands in the western and eastern part of the Skaliska Basin. In the Preboreal chronozone elm (*Ulmus*) also expanded in the area but its appearance was non-synchronous. The vegetation of the Boreal chronozone was similar in the whole area and the most characteristic feature was the rapid expansion of hazel (*Corylus avellana*) which displaced *Betula* from the most of its sites. At that time a distinct redeposition of pollen material in the Parchatka river valley was detected which was probably the effect of an increase in fluvial activity of the river (humid oscillation). The following stage of vegetation development was climax woodlands with *Tilia cordata*, *Ulmus*, *Quercus*, *Corylus avellana*, and *Alnus* in damp places. At the beginning of the Subboreal chronozone the expansion of *Quercus* took place, which was subsequently replaced by *Picea abi*es and partly *Carpinus betulus*. The pattern of *Picea abies* expansion distinctly presents two maxima which is characteristic of many sites in the north-eastern Poland. The Subatlantic chronozone is represented only by the profile from the Skaliski Forest, where, because of sandy ground, *Pinus sylvestris* was the dominant element. Human impact was poorly reflected through the rare occurrence of pollen grains of Cerealia type in the pollen profiles spanning the time from the Subboreal chronozone to modern times. In most profiles AMS dating produced age discrepancies, which limited the possibility of establishment of a detailed chronology. However, dates obtained from the material contaminated by mixture of glycerine, thymol and ethyl alcohol, pretreated by alcohol, showed reliable results in most cases.

KEYWORDS: pollen analysis, AMS dating, Holocene, Late Glacial, Preboreal oscillation, north-eastern Poland

INTRODUCTION

The variety of sites suitable for carrying out pollen analysis in the area of north-eastern Poland (Fig. 1) encouraged several palynologists to do research as early as in 1930's and 1940's (Bremówna & Sobolewska 1934, Groß 1935a, b, 1936, 1938, 1939a, b, 1940, 1941a, b, Paszewski 1937, Paszewski & Poznański 1936, Ołtuszewski 1937). The next important stage in the palynological research of area was the study of Lake Mikołajki (Ralska-Jasiewiczowa 1966). It was the first analysis conducted in accordance with modern palynological principles. In the 1960's and 1970's a few profiles were also investigated, e.g. Lake Mamry and Lake Jegocin (Stasiak 1967), Lake Mikołajskie (Stasiak 1966, 1967, 1971) Lake Śniardwy and Tałty from the Mazury Lake District (Stasiak 1971) and from the Suwalszczyzna region (Stasiak 1961, 1963, 1965, 1971, 1979).

In the first synthetic palaeoecological studies devoted to vegetation changes during the last 13000 years, edited by Ralska-Jasiewiczowa in 1989, two reference sites were selected for north-eastern Poland i.e. Lake Mikołajki for the Mazury Lake District (Ralska-Jasiewiczowa 1989) and Woryty for the Dobrzyńsko-Olsztyńskie Lakeland (Noryśkiewicz & Ralska-Jasiewiczowa 1989).

The 1990's and the beginning of the 21st century brought other palynological studies from Dudka (Nalepka 1995), Lake Dgał Wielki (Filbrandt-Czaja 2000), Lake Miłkowskie (Wacnik 2009a, b), Nietlice Wetland (Kupryjanowicz 2002), in the Augustowska Forest (Milecka 1997) and other sites (Kupryjanowicz 2004, 2008, Szwarczewski & Kupryjanowicz 2008, Wacnik & Ralska-Jasiewiczowa 2008, Kupryjanowicz & Jurochnik 2009, Drzymulska & Kupryjanowicz 2010, Lauterbach et al. 2011, Wacnik et al. 2012).

Even though several detailed palynological studies have been carried out in north-eastern Poland, there is still a deficiency of synthetic multi-proxy studies. Up until now, only Lake Wigry (Kupryjanowicz 2007, Rutkowski et al. 2007, Zawisza & Szeroczyńska 2007) and Lake Hańcza (Lauterbach et al. 2011) have been studied in this way. However, most profiles are deficient in radiocarbon dates, which makes a precise correlation between them extremely difficult.

These problems encouraged the formation of a research group (including authors of the present paper) to initiate palaeoecological multi-proxy studies, and to focus on the reconstruction of palaeoecosystems that existed in the area of the Skaliska Basin in the past (see Gąsiorowski 2013, Mirosław-Grabowska 2013, Pochocka-Szwarc unpubl.a, b, Sienkiewicz 2013, Stachowicz-Rybka & Obidowicz 2013, Woronko & Pochocka-Szwarc 2013). This paper summarizes the results of the research considering the vegetation development based on palynological analysis, and discusses the problem of the age of the deposits in the light of pollen analysis and AMS radiocarbon dating.

CHARACTERISTICS OF THE AREA

GEOMORPHOLOGY AND GEOLOGY

The Skaliska Basin is located in the northern part of the Mazury Lake District. It is part of the belt of East-Baltic Lakelands and is a microregion belonging to the Węgorapa District (Kondracki 2002) with the Polish-Russian border running across it. This geographical unit is a broad plain originating in the area of the palaeolake and covers 90 km^2 extending between altitudes of 90 and 92 m a.s.l. It adjoins the morainic hills called the Kruckie and Klewińskie mountains, which reach altitude of 200 m a.s.l. Those hills are polygenetic forms originating as ice-pushed moraines during the transgression of the Fennoscandian ice sheet and both could have been nunataks during this period (Pochocka-Szwarc 2003).

From the south and west, the Skaliska Basin is surrounded by an undulating morainic upland whose altitude ranges between 117–130 m a.s.l. Their slopes are covered by glaciofluvial deposits and kame terraces, which developed in a sandy-gravel facies. Ice-pushed moraines were also detected in the south-eastern part of the upland (Pochocka-Szwarc 2005). The zone of deglaciation in the Skaliska Basin is 20 km wide and contains flat ice-cored moraine ridges separating damp depressions. The topographic height of these moraine ridges reaches 100–110 m.

The south-eastern and eastern part of the area is built of sand with loam intercalations, on the surface of which several peat bogs are located as well as relatively large depressions filled with gyttja.

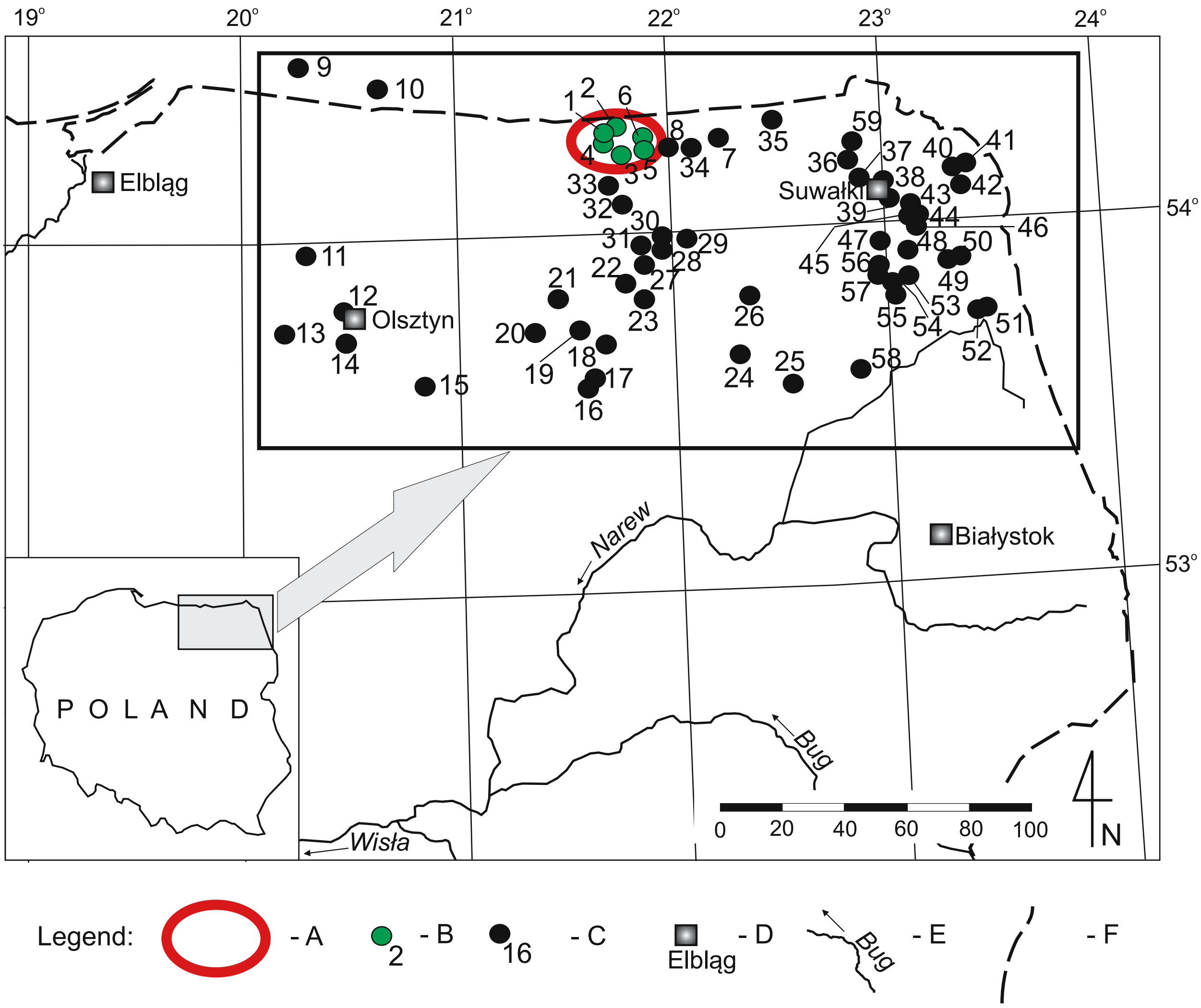

Fig. 1. Location of the sites under investigation and of sites studied by means of pollen analysis in north-eastern Poland and the border area of Kaliningrad Oblast, Russia (amended from Kupryjanowicz 2008). **A**. Study area; **B**. Location of analysed sites: **1** – Piotrowo Ławniki (in this article), **2** – Sąkieły Małe (in this article), **3** – Skaliski Forest (in this article), **4** – Budzewo (in this article), **5** – Rapa (in this article), **6** – Parchatka valley (in this article); **C**. Location of other sites investigated palynologically: **7** – Bałupiany (Karpińska-Kołaczek et al. 2011), **8** – Czarne Lake (Karpińska-Kołaczek 2011), **9** – Zinten, at present Kornevo (Groß 1941b), **10** – Korniten, at present Ljublino (Groß 1941a), **11** – Lingenau, at present Łęgno (Groß 1939b), **12** – Allenstein, at present Olsztyn (Groß 1938), **13** – Woryty (Dąbrowski et al. 1982, Pawlikowski et al. 1982, Noryśkiewicz & Ralska-Jasiewiczowa 1989), **14** – Steinberg, at present Kamienna Góra (Groß 1936), **15** – Grammen, at present Grom (Groß 1936), **16** – Szeroki Bór (Breitenfeld & Mothes 1940), **17** – Lake Jegocin (Stasiak 1967), **18** – Lake Śniardwy (Stasiak 1971), **19** – Lake Mikołajki (Stasiak 1966, 1967, 1971, Ralska-Jasiewiczowa 1966, 1989a), **20** – Lake Wągiel (Stasiak 1971), **21** – Lake Tałty (Stasiak 1971), **22** – Nietlice mire (Kupryjanowicz 2002b), **23** – Lake Łazduny (Wacnik, personal comm.), **24** – Borken, at present Borki (Groß 1936), **25** – Kuwasy (Maksimow et al. 1953, Żurek 1968, 1970), **26** – Miłuki (Milecka 1997), **27** – Lake Miłki (Wacnik 2009a, b), **28** – Szczepanki (Ralska-Jasiewiczowa & Wacnik 2006), **29** – Masuchowken, at present Mazuchówka (Groß 1935a), **30** – Dudka (Nalepka 1995), **31** – Eisermüller Wiesen/Stasswinner See, at present Łąki Staświńskie (Groß 1935b, Groß 1940), **32** – Lake Dgał Wielki (Filbrant-Czaja 2000), **33** – Lake Mamry (Stasiak 1967), **34** – Sappalen, at present Sapałówka (Groß 1939b), **35** – small no name lake in Puszcza Romincka (Groß 1935a), **36** – Lake Hańcza (Lauterbach et al. 2011), **37** – Osowa (Stasiak 1965), **38** – Osinki 1 i Osinki 2 (Ołtuszewski 1937), **39** – small dystrophic lake near Lake Krzywe (Ołtuszewski 1937), **40** – Sejny (Szwarczewski & Kupryjanowicz 2006), **41** – Gajlik (Żurek et al. 2006), **42** – Malona (Żurek et al. 2006), **43** – Lake Suchar Dembowskich (Ołtuszewski 1937), **44** – Lake Wigry (Kupryjanowicz 2007, Kupryjanowicz & Jurochnik 2009), **45** – Suchar Wielki (Drzymulska & Kupryjanowicz 2010), **46** – Zakąty (Ołtuszewski 1937), **47** – Olszanka (Bremówna & Sobolewska 1934), **48** – Busznica (Ołtuszewski 1937), **49** – Paniewo (Ołtuszewski 1937), **50** – Płaska (Ołtuszewski 1937), **51** – Skieblewo (Ołtuszewski 1937), **52** – Biebrza Upper Basin BZC (de Klerk et al. 2007), **53** – Studzieniczna (Ołtuszewski 1937), **54** – Augustów (Ołtuszewski 1937), **55** – Lake Sajno (Bremówna & Sobolewska 1934), **56** – Szczebra (Bremówna & Sobolewska 1934), **57** – Rospuda (Bremówna & Sobolewska 1934, Stasiak 1968), **58** – Czerwone Bagno (Stasiak 1979, Kupryjanowicz & Fiłoc in press), **59** – Lake Linówek (Gałka et al. in press); **D**. Towns; **E**. Rivers; **F** – Border of Poland

The sediments which built the delta (also called an alluvial fan in the text) contain gravel and sand, whose thickness diminishes in a distal direction (from the east to the south). The bottom part of these deposits contains silt and lacustrine loam (Pochocka-Szwarc & Lisicki 2001). In the northern part, the Skaliska Basin is filled with peat.

The Węgorapa and its tributary the Gołdapa, two strongly meandering rivers, run through the area of the Skaliska Basin. Only some sections of both valleys have well-developed floodplain terraces. The surface of the alluvial fan has been dissected by several watercourses (e.g. the Parchatka – the largest one) and superimposed by peat bogs (Pochocka-Szwarc 2005).

SOILS

The soils of north-eastern Poland developed mainly on a substratum of glacial origin. Podzolic soils, the prevailing soil type, developed on sands accumulated under glaciofluvial conditions. Brown podzolic and loess soils originated on till and both are common in the northern part of the area (Uggla 1956). Additionally, in the area of the Mazury Lake District different subtypes of wetland soils developed (Uggla 1969a, b) which are connected with peat bogs, dried-out water bodies and areas of stagnant water (Bednarek et al. 2004).

CLIMATE

Taking into consideration the climatic region division made by Woś (1999), the Skaliska Basin belongs to the Mazury-Podlasie region, which is characterized by the highest number of days with freezing and severe freezing weather (Woś 1999). The mean annual temperature in the period 1996–2000 was 7–7.5°C, the coldest month was January with a mean temperature of –3°C to –4°C, whereas the mean temperature of July, the warmest month, reached 17–17.5°C. During the period 1971–2000, the annual precipitation was 600 mm, and the highest values, reaching 80 mm in average, were recorded in June. The length of periods with snow cover fluctuates between 70 and 80 days (Lorenc 2005).

RECENT VEGETATION

The description below of plant communities was prepared on the basis of the Local Development Plan of the Gołdap District (Zarząd Powiatu w Gołdapi 2004) and Czajkowski et al. (2004).

The dominant woodland type is *Tilio-Carpinetum* association (subboreal type with boreal elements) distributed mainly on soil developed on morainic till and sandy-clayey deposits (Matuszkiewicz 2001). German, and subsequently Polish, forest management transformed the composition of forests toward domination of spruce. Where the surface sediments are predominantly sandy, they are covered by the *Peucedano-Pinetum* and *Querco roboris-Pinetum* associations, with patches of communities from the *Serratulo-Pinetum* association. In moist/damp depressions marshland forest communities developed (mixed deciduous, mixed coniferous and coniferous marshland forests). Among them, the largest area is covered by woodlands from the *Sphagno-Piceetum* association and less frequently *Ribo nigri-Alnetum*, *Sphagno-Alnetum*, and *Vaccinio uliginosi-Pinetum* forests. A transitional zone between damp and dry habitats is occupied by deciduous forests from the *Tilio-Carpinetum* association, damp forests from the *Querco-Piceetum* association and *Molinio-Pinetum* forests. River valleys, areas along streams and other water-courses are dominated by several communities from riparian woodlands and thickets belonging to the *Fraxino-Alnetum*, *Ficario-Ulmentum*, *Carici remotae-Fraxinetum*, *Salicetum albo-fragilis*, and *Salicetum triandro-viminalis* associations.

Different types of peatland occur within the whole area of the Gołdap District. Their area is partly exploited as mown meadows and pastures (*Calthion* and *Arrhenatherion elatioris* alliances), which after discontinuation of use were transformed into tall herb communities (e.g. *Filipendulo-Geranietum* association), secondary willow communities (*Salicetum pentandro-cinereae* association), and communities with shrubs and reeds (*Phragmites australis*).

MATERIAL AND METHODS

Material from the Skaliska Basin was collected using a Więckowski sampler (piston corer) in 2005.

Subsamples numbering of 314 (1 cm^3 volume) from all profiles were selected and prepared using the standard preparation procedure and then acetolysis was applied (Berglund & Ralska-Jasiewiczowa 1986). To every sample a weighed *Lycopodium* tablet was added for further calculations of pollen concentration (Stockmarr 1971) with the exception of profiles from Sąkieły Małe and Budzewo, where the addition of tablets was skipped. More than 500 arboreal pollen grains (occasionally 200–500 in samples with a low pollen frequency) per sample were counted at 400× and 1000× magnification.

The pollen taxa were determined with the assistance of keys and atlases (Punt 1976, Faegri & Iversen 1989, Moore et al. 1991, Reille 1992, Beug 2004) and the modern pollen slide collection of the Władysław Szafer Institute of Botany, Polish Academy of Sciences. Additionally, in the Piotrowo-Ławniki, Saliski Forest 1 and 2 and Parchatka profiles, green algae from *Pediastrum* and *Coelastrum* genera were identified using atlases and a conference presentation (Komárek & Jankovská 2001, Jankovská & Komárek 2006).

The percentage values of individual taxa were calculated in the ratio of taxon to AP+NAP excluding Cyperaceae, other telmatophytes and limnophytes as well as the spores of cryptogams. The percentages of excluded taxa were calculated in the ratio of taxon to AP+NAP+taxon. Pollen diagrams were plotted using POLPAL software (Nalepka & Walanus 2003). Pollen diagrams were divided into local pollen assemblage zones (L PAZ) following Birks (1986) and Janczyk-Kopikowa (1987) with the support of the ConSLink dendrogram. The diagrams were also divided into chronozones as proposed by Mangerud et al. (1974), and the chronology of the profiles was established on the basis of radiocarbon dates and by comparison with well dated profiles from north-eastern Poland (Kuprjanowicz 2007, Wacnik 2009b, Lauterbach et al. 2011), as well as by mutual comparisons with other profiles from the Skaliska Basin.

DESCRIPTION OF PROFILES

The sediment and peat description from all profiles follows Tobolski (2000) and it is based on a paper by Stachowicz-Rybka & Obidowicz (2013), in which this subject is broadly described and discussed. The abbreviations of profiles were established on the basis of a name of the nearest village, town or other geographical points. In other papers presenting preliminary results of the research those names were expressed as working names e.g. Piotrowo-Ławniki in our article = W1 in previous papers, Sąkieły Małe = W2, Skaliski Forest = W3, Budzewo = W4, Rapa = W5, and Parchatka valley = W6 (Karpińska-Kołaczek et al. 2009, Pochocka-Szwarc & Kołaczek 2009, Pochocka-Szwarc & Winter 2009, Pochocka-Szwarc et al. 2006, Pochocka-Szwarc et al. 2008, Stachowicz-Rybka et al. 2009)

PIOTROWO-ŁAWNIKI (W1)

The site of the Piotrowo-Ławniki (PiotŁ) profile drilling is at an altitude of 93.1 m a.s.l. (54°18′7″N, 21°51′44″E), within a strongly drained peat bog located on the flat surface of a post-glacial stagnant lake plain, relatively close to the slopes of the adjacent upland (about 0.5 km). The profile was collected about 200 m north of Węgorapa and about 1 km from the confluence of the Węgorapa and Gołdapa rivers (Fig. 2).

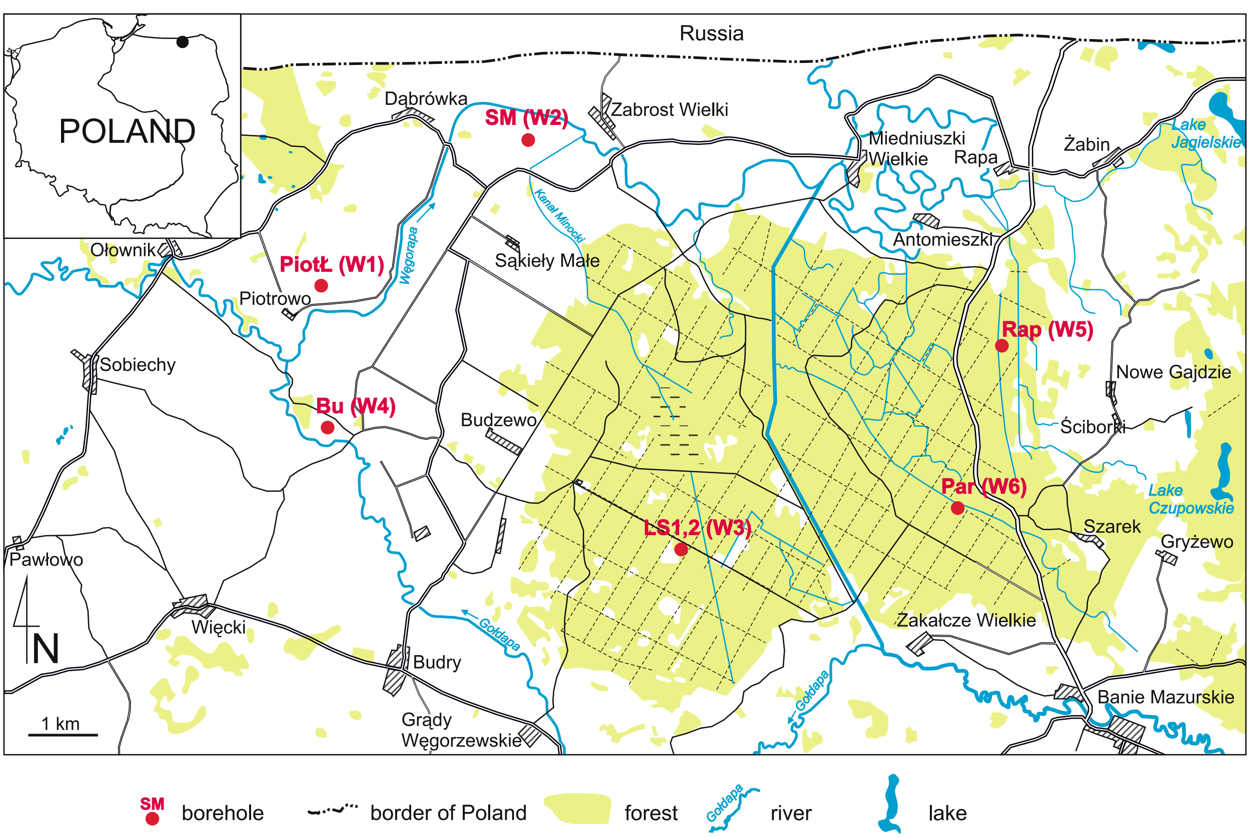

Fig. 2. Map of the Skaliska Basin and adjacent area with location of analysed sites

L i t h o l o g y (depth in cm):

20–40	peat humus
40–60	sedge-reed peat (Cariceti-Phragmiteti)
60–120	sedge peat (Cariceti)
120–150	detrital gyttja
150–170	Potamioni peat
170–210	coarse detrital gyttja
210–350	dy (>80% of humus)
350–460	minerogenic deposits mainly sand with silt intercalations

SĄKIEŁY MAŁE (W2)

The site of the Sąkieły Małe (SM) profile drilling is situated at an altitude of 91.1 m a.s.l. (54°19′20″N, 21°54′31″E), within a drained peat bog located on the flat surface of the post-glacial stagnant lake plain, in the vicinity of the Węgorapa riverbed. The profile was collected 1.2 km from the Polish-Russian border and 400 m north of the road linking Dąbrówka with Zabrost. Unfortunately, the material was accidentally destroyed before the lithology was established.

SKALISKI FOREST (W3)

The site of the Skaliski Forest (LS; originally Las Skaliski) profile collection was at an altitude of 99.6 m a.s.l. (54°16′09″N, 21°56′38″E), within a peat bog located on a sandy fan. The site is situated about 1 km south of 'Minta' forest range, between dikes, along which drainage ditches were dug in the middle of the 19th century to drain a damp area of forest. Two profiles were collected from this site, the first one, named LS1 is short because of a mechanical obstacle (probably roots) which prevented further coring; the second profile LS2 reached the minerogenic base of the depression.

Skaliski Forest (LS1 profile)

L i t h o l o g y (depth in cm):

20–95	sedge peat (Cariceti)

Skaliski Forest (LS2 profile)

L i t h o l o g y (depth in cm):

60–210	sedge peat (Cariceti)
210–220	willow peat (Saliceti)
220–245	sedge peat (Cariceti)
245–260	silt with the admixture of detritus
260–280	sedge peat (Cariceti)

BUDZEWO (W4)

The site of the Budzewo (Bu) profile drilling was at an altitude of 93.7 m a.s.l. (54°17′06″N, 21°55′55″E), within a drained peat bog located on the flat surface of the post-glacial stagnant lake plain at the foot of a small sandy hill, on the right of Węgorapa.

L i t h o l o g y (depth in cm):

20–150	sedge-reed peat (Carici-Phragmitieti)
150–180	rush peat (Limno-Phragmitieti)
180–230	Potamioni peat
230–270	rush peat (Limno-Phragmiteti)
270–1010	detrital gyttja with dy

RAPA (W5)

The site of the Rapa (Ra) borehole was at an altitude of 95 m a.s.l. (54°17′47″N, 22°00′42″E), within a longitudinally directed depression of about 3 km length and 700–800 m width which probably originated from the melting of a dead ice block. The depression is located in the boundary zone between the sandy fan and the adjacent morainic hills to the east.

L i t h o l o g y (depth in cm):

20–50	sedge peat (Cariceti)
50–70	alder swamp forest peat (Alneti)
70–90	reed peat (Phragmiteti)
90–150	rush peat (Limno-Phragmiteti)
150–190	bulrush peat (Scirpo-Typheti)
190–230	alder swamp forest peat (Alneti)
230–240	bulrush peat (Scirpo-Typheti)
240–430	detrital gyttja
370–430	sand with the admixture of silt and peat

PARCHATKA (W6)

The site of the profile retrieval in the Parchatka valley (Pa) was at an altitude of 101 m a.s.l. (54°17′47″N, 22°00′42″E), within a peat bog in the south-eastern part of a sandy fan.

L i t h o l o g y (depth in cm):

20–90	moss peat (*Sphagnum centrale*)
90–110	sedge peat (Cariceti)
110–150	sedge-moss peat (Bryalo-Parvocaricioni)
150–440	sedge peat (Cariceti)
440–450	alder swamp forest peat (Alneti)
450–480	detrital gyttja

480–490 alder swamp forest peat (Alneti)
490–520 detrital gyttja
520–675 sandy detrital gyttja

RADIOCARBON DATING

Material for AMS radiocarbon dating (Tab. 1) was selected from the depths with distinct changes of pollen spectra. However, not every selected sample contained a sufficient weight of carbon, so macrofossils treated with glycerine-thymol-ethyl alcohol mixture (1:1:1 proportion) were incorporated in these samples as well. AMS radiocarbon dating was carried out in the Poznań Radiocarbon Laboratory (Laboratory code – Poz) and the dates were calibrated using the OxCal v 4.10 program (Bronk Ramsey 2009), according to the calibration curve IntCal 09 (Reimer et. al 2009). Samples contaminated with glycerine-thymol-ethyl alcohol mixture were rinsed in alcohol before the procedure of age measurement in the radiocarbon laboratory.

Table 1. Radiocarbon dates from the profiles from the Skaliska Basin

Depth [cm]	Lab. code	Age ^{14}C BP	Callibrated age (BC/AD)	Dated material	Remarks
Piotrowo-Ławniki					
30–40	Poz-41016	4265±35	68.2% 2910BC (68.2%) 2878BC 95.4% 3004BC (0.9%) 2992BC 2930BC (83.2%) 2861BC 2808BC (10.0%) 2756BC 2720BC (1.3%) 2705BC	Peat	
55–60	Poz-37991	5420±40	68.2% 4332 BC (68.2%) 4258 BC 95.4% 4352 BC (90.2%) 4228 BC 4200 BC (4.5%) 4170 BC 4090 BC (0.8%) 4080 BC	*Carex* sp. fruits	
295–300	Poz-37992	1000±30	68.2% 992 AD (64.2%) 1040 AD 1110 AD (4.0%) 1116 AD 95.4% 982 AD (70.1%) 1052 AD 1081 AD (19.2%) 1128 AD 1134 AD (6.1%) 1153 AD	*Betula* sect. *Albae* fruits, *Schoenoplectus lacustris* fruits	Excluded from interpretation
430–440	Poz-37993	6570±100	68.2% 5624 BC (68.2%) 5469 BC 95.4% 5665 BC (95.4%) 5327 BC	*Betula humilis* fruits and plant tissues	Very small 0.07 mg C, excluded from interpretation
450–460	Poz-40013	9790±100	68.2% 9386 BC (65.2%) 9139 BC 8970 BC (3.0%) 8946 BC 95.4% 9656 BC (3.0%) 9577 BC 9551 BC (76.9%) 9112 BC 9085 BC (1.9%) 9038 BC 9029 BC (13.6%) 8836 BC	Plant detritus	0.15 mg C, thymol, rinsed in alcohol
Skaliski Forest 1					
43–46	Poz-41018	2190±30	68.2% 356 BC (46.5%) 286 BC 234 BC (21.7%) 198 BC 95.4% 364 BC (95.4%) 176 BC	Unidentified leaves	Thymol, rinsed in alcohol
Skaliski Forest 2					
60–70	Poz-41019	2460±30	68.2% 750BC (25.4%) 686BC 666BC (10.1%) 640BC 593BC (28.6%) 509BC 437BC (4.2%) 422BC 95.4% 756BC (26.6%) 684BC 670BC (68.8%) 414BC	*Menyanthes trifoliata* fruits, *Carex elata* fruit, *Carex acuta* fruit	Thymol, rinsed in alcohol

Table 1. Continued

Depth [cm]	Lab. code	Age ^{14}C BP	Callibrated age (BC/AD)	Dated material	Remarks
190–200	Poz-41020	4110±40	68.2% 2854BC (17.2%) 2812BC 2746BC (7.8%) 2725BC 2697BC (33.1%) 2618BC 2610BC (10.0%) 2581BC 95.4% 2872BC (23.5%) 2801BC 2792BC (0.7%) 2786BC 2780BC (70.1%) 2572BC 2512BC (1.1%) 2504BC	*Betula* sect. *Albae* scales, *Betula* sect. *Albae* fruits	Thymol, rinsed in alcohol
220–230	Poz-41022	5300±50	68.2% 4229BC (14.0%) 4197BC 4172BC (54.2%) 4048BC 95.4% 4311BC (0.8%) 4303BC 4260BC (94.6%) 3989BC	Fragments of wood	Excluded from interpretation
Budzewo					
240–245	Poz-37983	4770±40	68.2% 3636 BC (8.9%) 3623 BC 3604 BC (59.3%) 3523 BC 95.4% 3644 BC (85.2%) 3507 BC 3426 BC (10.2%) 3381 BC	*Betula* sect. *Albae* fruits and plant tissues	
345–350	Poz-37984	5560±50	68.2% 4448 BC (27.7%) 4414 BC 4405 BC (40.5%) 4355 BC 95.4% 4492 BC (95.4%) 4334 BC	Fragments of wood and plant tissues	Small sample, 0.4 mg C
450–460	Poz-41017	7020±80	68.2% 5991 BC (65.5%) 5836 BC 5822 BC (2.7%) 5814 BC 95.4% probability 6026 BC (95.4%) 5736 BC	*Betula* sect. *Albae* fruits, *Cicuta virosa* fruit, *Stachys palustris* fruit, *Cristatella mucedo*	Small sample, thymol, rinsed in alcohol
620–650	Poz-41012	7170±70	68.2% 6200 BC (1.3%) 6195 BC 6100 BC (63.3%) 5982 BC 5942 BC (3.6%) 5928 BC 95.4% 6216 BC (87.3%) 5971BC 5954 BC (8.1%) 5910 BC	Poaceae, *Typha* sp. *Juncus* sp., *Cristatella mucedo*	Thymol, rinsed in alcohol
800–810	Poz-41008	6730±110	68.2% 5728 BC (68.2%) 5550 BC 95.4% 5870 BC (0.2%) 5865 BC 5846 BC (95.2%) 5476 BC	Poaceae undiff. fruit, *Betula* sect. *Albae* fruits	Small sample
900–910	Poz-41005	2880±60	68.2% 1189 BC (2.4%) 1180 BC 1156 BC (3.1%) 1145 BC 1130 BC (59.7%) 974 BC 954 BC (3.0%) 943 BC 95.4% 1260 BC (95.4%) 910 BC	Mosses stems, *Betula* sect. *Albae* fruits	Thymol, rinsed in alcohol excluded from interpretation
970–975	Poz-37987	9660±60	68.2% 9244 BC (42.0%) 9121 BC 9002 BC (24.4%) 8918 BC 8890 BC (1.9%) 8880 BC 95.4% 9259 BC (45.9%) 9106 BC 9090 BC (49.5%) 8830 BC	*Betula* sect. *Albae* fruits, *Schoenoplectus lacustris* fruits	
980–990	Poz-38016	9570±60	68.2% 9131 BC (38.5%) 8982 BC 8929 BC (29.7%) 8814 BC 95.4% 9194 BC (95.4%) 8761 BC	fragments of wood and plant tissues	

Table 1. Continued

Depth [cm]	Lab. code	Age ^{14}C BP	Callibrated age (BC/AD)	Dated material	Remarks
980–990	Poz-38017	9540±50	68.2% 9120 BC (36.7%) 9003 BC 8918 BC (6.8%) 8894 BC 8871BC (24.7%) 8786 BC 95.4% 9148 BC (95.4%) 8748 BC	Fragments of wood and plant tissues	Thymol, rinsed in alcohol
Rapa					
250–255	Poz-41023	7300±50	68.2% 6218 BC (68.2%) 6101BC 95.4% 6326BC (0.3%) 6321BC 6251BC (95.1%) 6050 BC	*Betula* sect. *Albae* scales, *Schoenoplectus lacustris* fruits, *Solanum dulcamara* fruits	Small sample, 0.6 mg C, thymol, rinsed in alcohol
360	Poz-33502	9000±60	68.2% 8296 BC (41.1%) 8170 BC 8115 BC (6.6%) 8086 BC 8081 BC (5.5%) 8055 BC 8046 BC (15.0%) 7982 BC 95.4% 8436 BC (2.9%) 8367 BC 8352 BC (89.0%) 7934 BC 7929 BC (0.7%) 7911 BC 7901 BC (2.8%) 7831 BC	fragments of wood and plant tissues	Small sample, 0.5 mg C
441	Poz-35684	11330±60	68.2% 11326 BC (68.2%) 11201 BC 95.4% 11388 BC (95.4%) 11152 BC	Fragments of plant tissues	Very small sample
Parchatka valley					
550–560	Poz-37988	8400±60	68.2% 7542BC (53.9%) 7451 BC 7406 BC (14.3%) 7370 BC 95.4% 7579 BC (95.4%) 7336 BC	*Schoenoplectus lacustris* fruits	Small sample, 0.6 mg C
610–620	Poz-38065	9410±60	68.2% 8765 BC (68.2%) 8620 BC 95.4% 9113 BC (1.4%) 9082 BC 9050 BC (1.2%) 9023 BC 8840 BC (92.1%) 8542 BC 8506 BC (0.7%) 8490 BC	Fragments of plant tissues	
665–670	Poz-37989	8700±50	68.2% 7750 BC (68.2%) 7606 BC 95.4% 7938 BC (1.3%) 7924 BC 7918 BC (2.1%) 7897 BC 7870 BC (92.0%) 7594 BC	*Schoenoplectus lacustris* fruits	

RESULTS AND DISCUSSION

THE LATE GLACIAL AND HOLOCENE VEGETATION OF THE SKALISKA BASIN AND THE DEVELOPMENT OF MIRES AND WITH REFERENCE TO HUMAN IMPACTS

The results of pollen analysis are presented as pollen diagrams (Figs 3–8) and a concise description in Tables 2–8. The nomenclature and chronology of the Late Glacial and the Holocene are consistent with the division made by Mangerud et al. (1974) and calibrations of chronozones boundaries made by Walanus & Nalepka (2010).

Ra-1 *Pinus-Betula* L PAZ; ca until 11 000 cal. yr BC, Younger part of Allerød

The vicinity of the Rapa site was occupied by pine and/or pine-birch forest. These types of woodland communities were widespread in the lowlands of Poland during the younger phase of the Allerød chronozone (Latałowa 2004). In north-eastern Poland this period is represented at Lake Mikołajki (Ralska-Jasiewiczowa & Latałowa 1996), Lake Wigry (Kupryjanowicz 2007), Lake Miłkowskie (Wacnik 2009b), Lake Linówek (Gałka et al. in press), and Lake Czarne located in the adjacent Rogalskie

Table 2. Piotrowo-Ławniki – the description of the local pollen assemblage zones (L PAZs)

L PAZ	Depth [cm]	Description of pollen spectra	Top boundary description
PiotŁ-1 *Betula-Juniperus*	460–435	Domination of *Betula* undiff., maximum of *Juniperus* (20%) and *Betula nana* type (1%). High values of *Pinus sylvestris* type, *Salix* undiff. and *Salix pentandra* type. Regular percentages of *Artemisia* (max 2.8%), Poaceae undiff., and Chenopodiaceae. Among cryptogams domination of *Equisetum* and *Sphagnum*. Maxima of *Pediastrum boryanum* var. *cornutum* (1.1%) and *Pediastrum subgranulatum* (1.3%), regular occurrence of *Tetraedron*	Decrease in *Juniperus*
PiotŁ-2 *Betula-Pinus*	435–297.5	Maximum of *Betula* undiff. (62.5%), fall in *Juniperus* and its disappearance in the upper part of the zone, simultaneous with rise in *Ulmus*, stable values of *Salix* undiff. Decrease in *Artemisia* and Chenopodiaceae. Increase in *Filipendula* and Filicales monolete. Fall in *Equisetum*. Fluctuation of *Tetraedron* (max. 16.5%), rise and fall in *Pediastrum boryanum* var. *boryanum*, increase in *P. integrum*, *P. boryanum* var. *longicorne*, and *P. duplex* var. *rugulosum*	Fall in *Betula* undiff., rise in *Corylus avellana*
PiotŁ-3 *Corylus*	297.5–235	Sharp decline of *Betula* undiff. curve coincided with rapid rise in *Corylus avellana* (from 10.5 to 44%). Increase in *Alnus* undiff. Gradual decrease in *Pinus sylvestris* type. Stable values of *Ulmus*, appearance of *Tilia cordata* type. Fall in *Filipendula*, stable occurrence of Poaceae undiff. Continuous curve of *Nymphaea alba*. Regular findings of Filicales monolete, rise in *Thelypteris palustris*. Fall in *Pediastrum duplex* var. *rugulosum* more numerous *P. kawraiskyi*. Maximum of pollen concetration in the profile: 470×10^3/cm^3	Fall in *Corylus avellana*, rise in *Tilia cordata* type
PiotŁ-4 *Alnus-Ulmus-Tilia*	235–55	Domination of *Alnus* undiff., rise in *Tilia cordata* type, *Quercus*, *Fraxinus excelsior*. Increase in herb frequency	Fall in *Quercus*, rise in *Pinus sylvestris* type
PiotŁ-4a *Alnus-Ulmus-Tilia* (*Alnus*)	235–95	Gradual rise in *Alnus* undiff. (max. 34%). The highest values in profile of *Tilia cordata* type (7.5%), fall in *Corylus avellana*. More abundant *Typha angustifolia*. The appearance of *P. simplex* var. *echinulatum* in the lower part of subzone, rise in *P. integrum* and *Tetraedron* in the upper part	
PiotŁ-4b *Alnus-Ulmus-Tilia* (*Quercus*)	95–55	Rise in *Quercus* (max. 9.5%), fall in *Alnus* undiff. and *Corylus avellana*. Increase in Poaceae undiff. (max. 23%), Cyperaceae undiff. (max. 29.5%), and *Typha latifolia*. Maxima of *Nymphaea alba* (1.1%) and *Lemna* type (1.5%). Gradual increase in Filicales monolete. Disappearance of *Tetraedron*	
PiotŁ-5 *Pinus*	55–20	Rapid rise and domination of *Pinus sylvestris* type, increase in *Picea abies*, fall in *Quercus*. Fluctuations of NAP and Filicales monolete. Disappearance of prevailing number of algae taxa	
PiotŁ-5a *Pinus* (*Fraxinus*)	55–35	Maximum of *Pinus sylvestris* type (71.5%), fall in *Quercus*, *Alnus* undiff., *Ulmus*, *Fraxinus excelsior*, and *Corylus avellana*. Presence of *Vitis*. The highest values of Filicales monolete in the whole profile (74%)	
PiotŁ-5b *Pinus* (*Alnus*)	35–20	Rise in *Alnus* undiff., fall in *Pinus sylvestris* type but it still dominates. Fall in Filicales monolete	

hills (Karpińska-Kołaczek 2011). Percentages of *Pinus sylvestris* type recorded in the zone exceed those presented in isopollen maps in which 40–60% is the average value for this period (cf. Latałowa et al. 2004).

In the lake representatives of *Potamogeton* subgen. *Eupotamogeton* grew and it was surrounded by a belt with Cyperaceae, *Equisetum*, and *Typha latifolia*, whose occurrence is considered as indicative of a minimum mean June temperature of 13°C (Isarin & Bohncke 1999).

PiotŁ-1 L PAZ *Betula-Juniperus*; SM-1 L PAZ *Pinus-Betula*-NAP; Ra-2 L PAZ *Pinus-Betula*-NAP; ca 11 000–9500 cal. yr BC, Younger Dryas

Climatic deterioration during the Younger Dryas brought contrasting patterns of vegetation response. The decrease of woodland cover allowed the spread of *Juniperus* thickets in the vicinity of the Piotrowo-Ławniki site, whereas, near Sąkieły Małe and Rapa the open area was dominated by herb steppe with *Artemisia*, Poaceae, and Chenopodiaceae. This second pattern is unique in the area of north-eastern Poland, where *Juniperus* was a dominant taxon in the Younger Dryas (Okuniewska-Nowaczyk et al. 2004). Inflorescences of this taxon are very delicate and they easily fall down even before they release their pollen (A. & B. Noryśkiewicz pers. comm.). Hence, the representation of its grains in deposits might have depended on the intensity of downwash and the topography i.e. the more steep slopes surrounding the sedimenatary basin, the higher frequency of juniper grains.

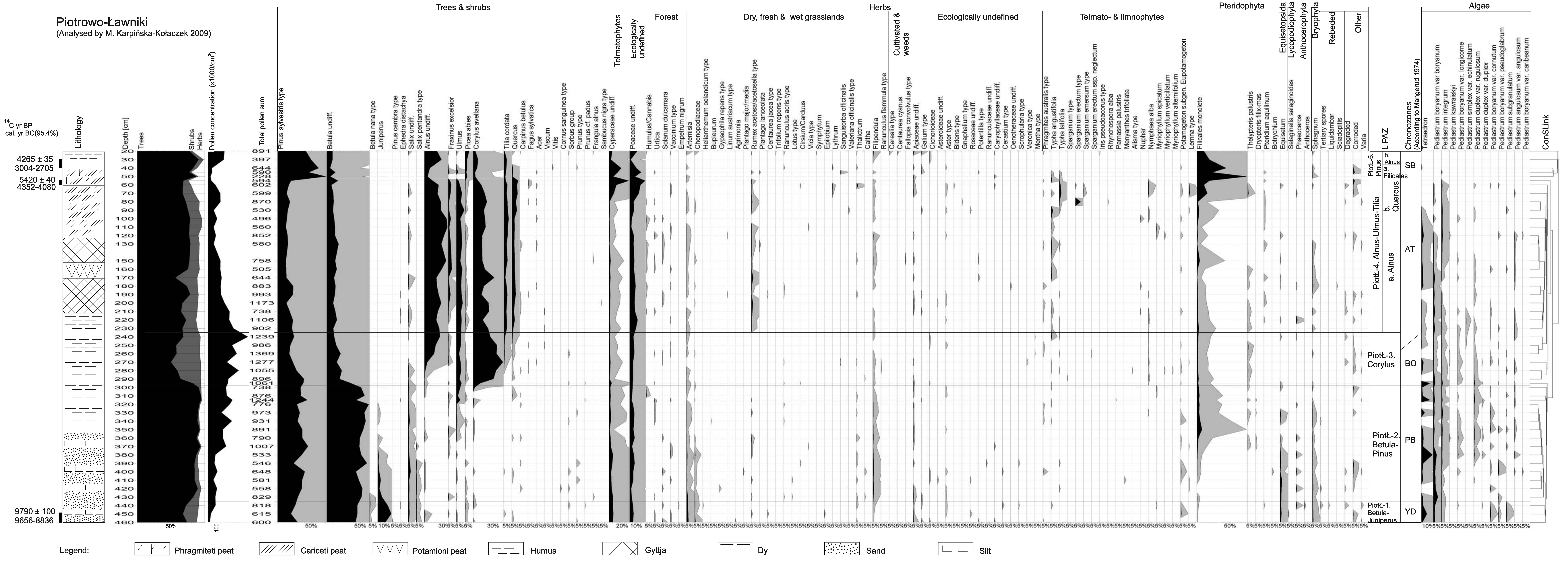

Fig. 3. Percentage pollen diagram of the Piotrowo-Ławniki site

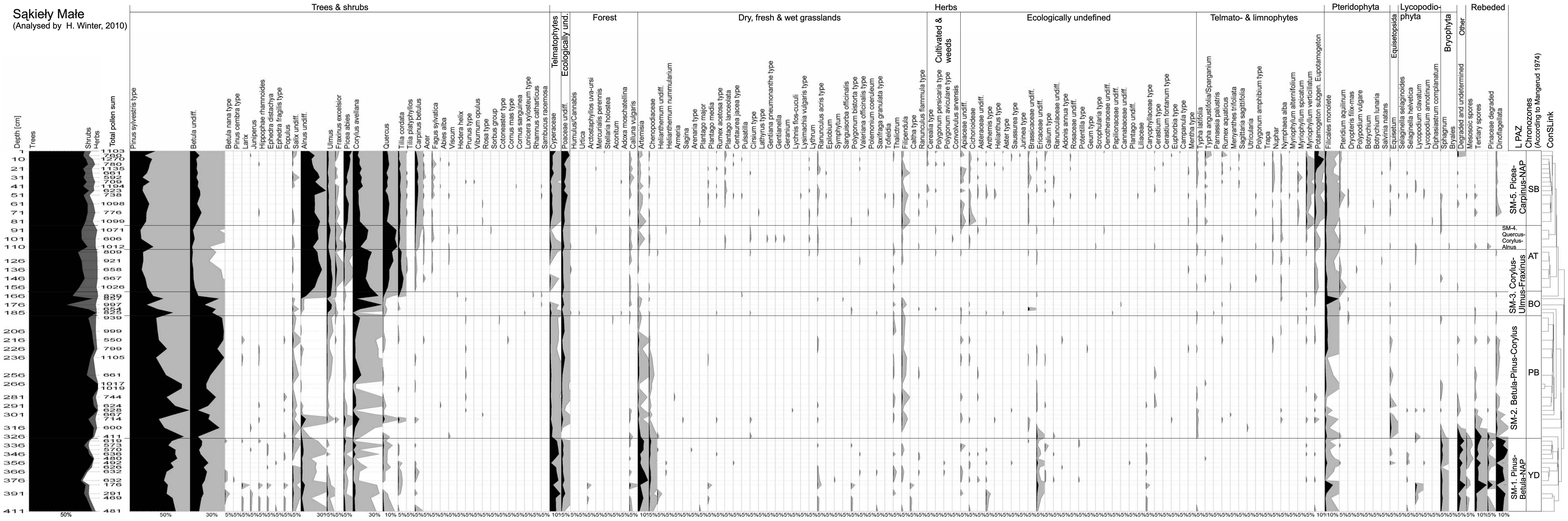

Fig. 4. Percentage pollen diagram of the Sąkiełу Małe site

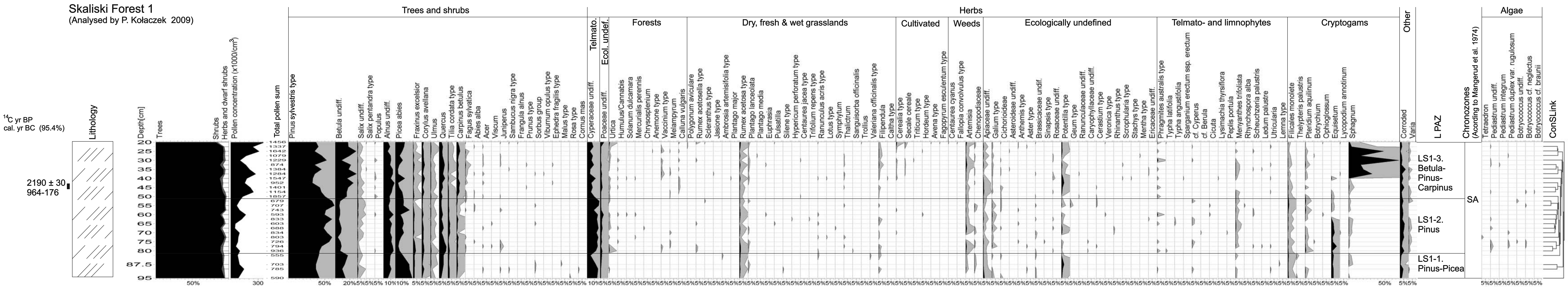

Fig. 5a. Percentage pollen diagrams of the Skaliski Forest 1

Fig. 5b. Percentage pollen diagrams of the Skaliski Forest 2

Fig. 6. Percentage pollen diagram of the Budzewo site

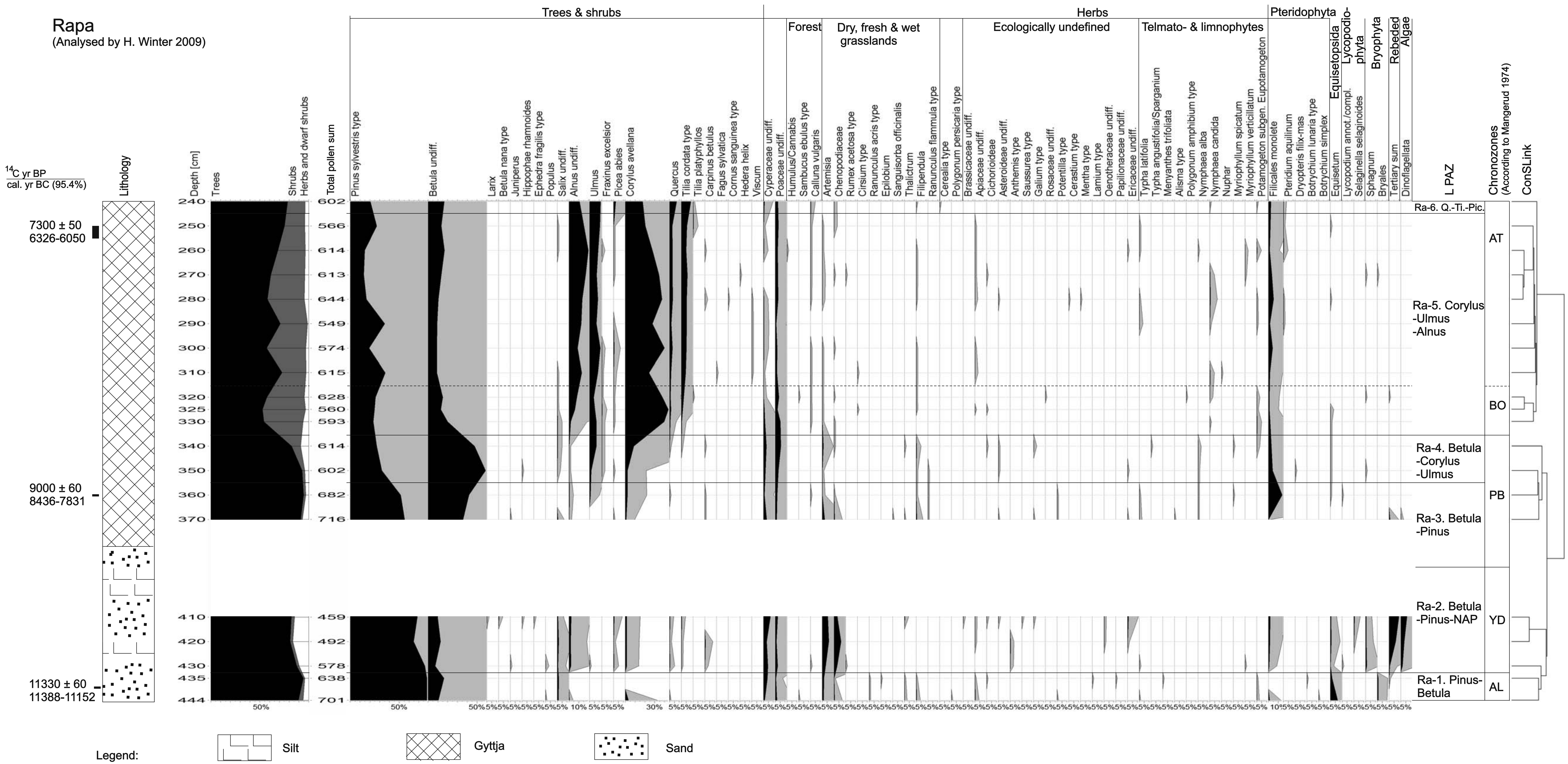

Fig. 7. Percentage pollen diagram of the Rapa site

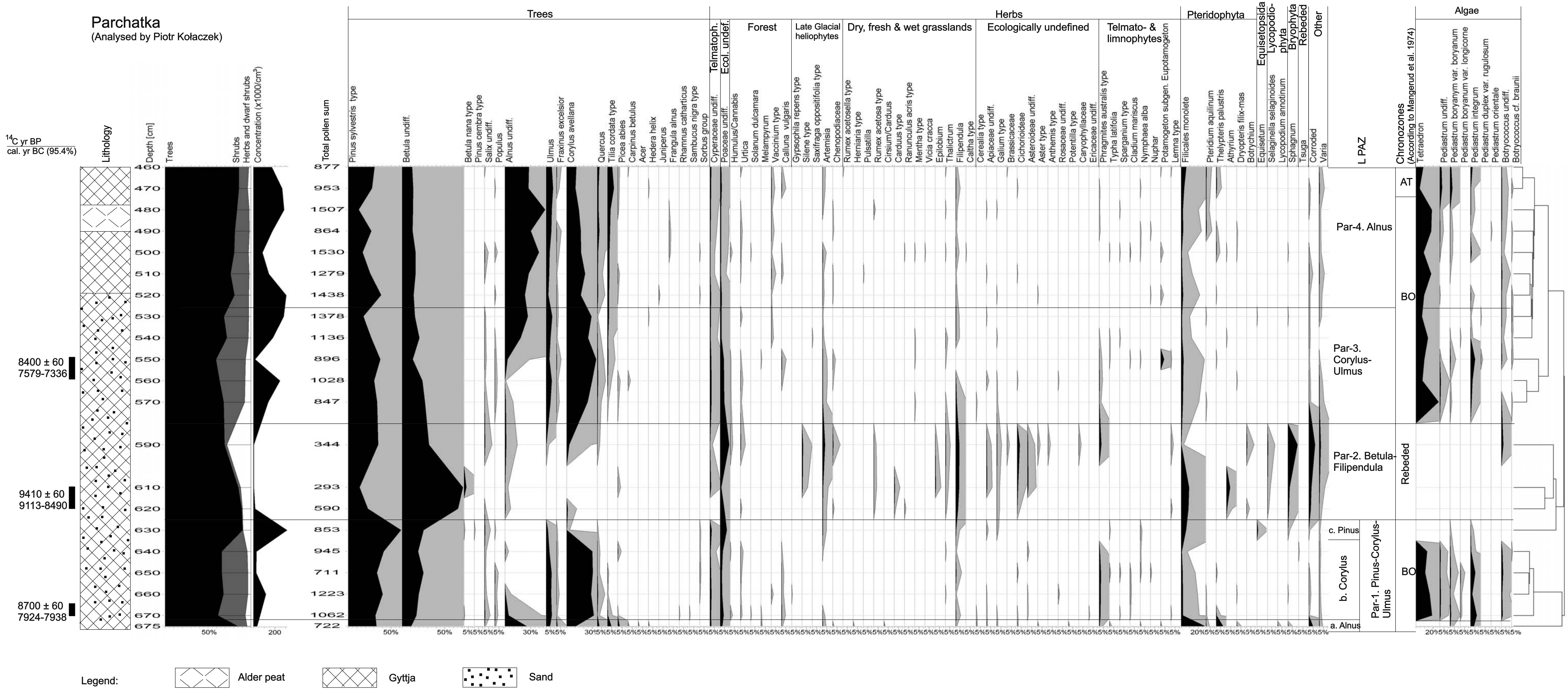

Fig. 8. Percentage pollen diagram of the Parchatka valley site

Table 3. Sąkieły Małe – the description of the local pollen assemblage zones (L PAZs)

L PAZ	Depth [cm]	Description of pollen spectra	Top boundary description
SM-1. *Pinus -Betula*-NAP	411–328.5	AP values up to 90%. Proportions of *Pinus sylvestris* type from 44.3 to 74.3%. Continuous curve of *Betula* undiff. pollen has continuous curve reaching 25.5%. The proportions of *Salix* undiff not exceeding 1.5%. Presence of pollen of *Juniperus*, *Hippophae rhamnoides*, *Betula nana* type and *Pinus cembra* type. Values of Ericaceae undiff. less than 2.7%, and *Calluna vulgaris* less than 1.6%. Among NAP (max. 28%) the highest values are those of *Artemisia* (12.8%), Poaceae undiff. (4.7%) and Chenopodiaceae (2.9%). Presence of Brassicaceae undiff., *Ranunculus acris* type, *Anthemis* type, *Polygonum bistorta* type, *Thalictrum*, *Filipendula*, and Apiaceae undiff. Single grains of *Helianthemum* undiff., *H. nummularium*, and *Potentilla* type. Maximum of Cyperaceae undiff. (15.2%)	Decrease in *Pinus sylvestris* type and NAP, increase in *Betula* undiff. values
SM-2. *Betula-Pinus-Corylus*	328.5–188	Increase in AP percentages. Fall in the values of *Pinus sylvestris* type. Maximum of *Betula* undiff. pollen (47.4%). Continuous curves of *Corylus avellana* and *Ulmus* (respectively up to 11.7%, and up to 0.9%). Fall in NAP values to ca 5%	Below an increase in *Betula* undiff. and decrease in NAP values
SM-3. *Corylus-Ulmus-Fraxinus*	188–113	The zone with maximum percentages of *Corylus* (40.9%), *Ulmus* (8%), *Tilia cordata* type (5.6%), and *Fraxinus excelsior* (1.8%). Frequencies of pollen of *Alnus* undiff. reach 30%. Decrease in the proportions of *Betula* undiff. Beginning of a continuous curve of *Picea abies* and *Carpinus betulus.* Presence of *Acer*, *Fagus sylvatica* and *Viscum*	Decrease in *Corylus avellana* values
SM-4. *Quercus-Corylus-Alnus*	113–86	Domination of AP. Maximum of *Quercus* (19.5%), and *Picea abies* (3.2%). *Alnus* undiff. pollen between 16.7–25.2%. The values of *Ulmus* between 1.9% and 3.2%. Very low values of *Carpinus betulus*. Fall in the percentages of *Corylus avellana* and *Tilia cordata* type. Slight rise in the proportions of NAP. *Potamogeton* subgen. *Eupotamogeton* and *Nymphaea alba* pollen among aquatic plants	Decrease in *Quercus* and *Corylus avellana* pollen and an increase of *Picea abies* values
SM-5. *Picea-Carpinus*-NAP	86–1	Fall in the values of AP. The maxima of percentages of *Picea abies* and *Carpinus betulus* pollen (respectively 10.6% and 4.6%). Increase and sligh fall in the proportions of *Alnus* undiff. (max. 35.1%). Rise in the proportions of *Betula* undiff.pollen. The fluctuations of *Corylus avellana* (from 6.8 to 13.9%), and those of *Quercus* (from 4.8 to 9%). The frequencies of *Tilia cordata* type pollen not exceeding 3.6%. Slight decrease in *Ulmus* values. Continuous curve of *Fagus sylvatica* up to 0.6%. NAP values (not exceeding 15%), with the highest proportions of Poaceae undiff. and Cyperaceae undiff. Among other NAP taxa presence of Cichoroideae, *Artemisia*, Brassicaceae undiff., Apiaceae undiff., *Filipendula*, and *Ranunculus acris*. Presence of pollen of *Potamogeton* subgen. *Eupotamogeton* and *Myriophyllum verticillatum* (respectively max. 13.1% and max. 1.6%)	

Blocks of dead ice located in the western and north-western part of the fossil lake (Piotrowo-Ławniki and Sąkieły Małe sites) were melting down (or already melted down) and formed lakes overgrown by macrophytes of *Potamogeton* genus (PiotŁ-1, SM-1) and *Myriophyllum verticillatum* (SM-1). The most plentiful and variable algal flora of this period was detected in the Piotrowo-Ławniki palaeolake and contained *Tetraedron* and several taxa of *Pediastrum* of which *P. subgranulatum* was the most abundant in the whole profile. This species, according to Komárek and Jankovská (2001), is indicative of mesotrophic or slightly eutrophic water bodies and sometimes coexists with submerged vegetation. The occurrence of *Typha latifolia* in the younger part of the PiotŁ-1 L PAZ and in the older part of Ra-2 L PAZ indicates that the mean June temperature was not lower than 13°C. This fact suggests a northward shift of the 13°C isotherm during the older part of the Younger Dryas (10 950–10 550 ^{14}C yr BP, 10 979–10 480 yr cal BC; 95.4%) to the Skaliska Basin (cf. Isarin & Bohncke 1999). A visible increase in the frequency of Tertiary spores, dinoflagellate cysts, as well as degraded sporomorphs in the Sąkieły Małe and Rapa profiles point to an intensification of surface run-off, being a consequence of the loose vegetation cover.

LS2-1 L PAZ *Pinus-Selaginella-Helianthemum*; Younger Dryas/Preboreal chronozone

This zone is difficult to classify due to the relatively high proportion of arboreal pollen and lack of *Juniperus*, but also an *Artemisia* maximum, which indicates the Late Glacial origin of this part of the profile. Nevertheless, the regular occurrence of *Selaginella selaginoides*,

Table 4. The Skaliski Forest 1 – the description of the local pollen assemblage zones (L PAZs)

L PAZ	Depth [cm]	Description of pollen spectra	Top boundary description
LS1-1. *Pinus-Picea*	95–81.75	Domination of *Pinus sylvestris* type, maximum and constant decrease in *Picea abies* (max. 23%). Stable presence of *Betula* undiff., *Alnus* undiff., *Quercus*, *Corylus avellana*, *Fraxinus excelsior*, *Salix* undiff., *Ulmus*, and *Carpinus betulus*. Among herbs domination of Cypreaceae undiff. Continuous curve of *Rumex acetosa* type, *Potentilla* type, *Galium* type, and Apiaceae undiff. Constant values of *Equisetum* and Filicales monolete. At the depth of 87.5 cm the highest concentration of charcoal paricles (9.3×10^3 particles/cm^3)	Decrease in *Picea abies* and *Betula* undiff.
LS1-2. *Pinus*	81.75–51.75	Rise in *Pinus sylvestris* type (max. 63 %) after decline in *Picea abies* and *Betula* undiff. Constant presence of *Alnus* undiff., *Corylus avellana*, *Quercus*, *Ulmus*, *Tilia cordata* type, *Carpinus betulus*, *Fraxinus excelsior*, and *Salix* undiff. Relatively high values of Cyperaceae undiff., continuous curves of Poaceae undiff., *Rumex acetosa* type, and Apiaceae undiff.; increase in *Galium* type. Single grains of Cerealia type and *Hordeum* type. Rise in *Pteridium aquilinum* frequency, decline in *Equisetum* in the upper part of the zone, stable presence of Filicales monolete. Among algae presence of *Pediastrum* undiff., *P. duplex* var. *rugulosum*, *Botryococcus* undiff., *B. neglectus*, and *Tetraedron*	Decrease in *Pinus sylvestris* type, increase in *Betula* undiff.
LS1-3. *Betula-Pinus-Carpinus*	51.75–20	Decline in *Pinus sylvestris* type coincides with rise in *Betula* undiff. (max. 28.5 %) and *Carpinus betulus* (max.4.9 %). More frequent grains of *Fagus sylvatica*. Fall in Cyperaceae undiff. and *Galium* type. Regular findings of *Artemisia*, Apiaceae undiff., and Filicales monolete. Rise in *Urtica* undiff. and *Potentilla* type. *Rumex acetosa* type still regular in spectra. More frequent findings of Cerealia type, *Secale cereale*, and *Plantago lanceolata*. Single grains of *Hordeum* type, *Avena* type, *Triticum* type, *Fagopyrum esculentum* type, and *Centaurea cyanus*. Rapid rise in *Sphagnum* in the upper part of the zone (max. 69.5 %). Scattered presence of algae: *Pediastrum* undiff., *Pediastrum integrum*, *P. duplex* var. *rugulosum*, *Botryococcus neglectus*, and *B. brauni*	

Helianthemum, and *Ephedra distachya* suggests well-developed tundra and steppe patches. Taking into consideration the high proportion of *Pinus sylvestris* type, which points to the existence of woodland near the site, it is possible that the LS2-1 L PAZ records a small basin and its subsequent deepening caused by dead ice melting. Its surroundings might have been occupied by plants with preferences for higher moisture, associated with tundra communities e.g. *Selaginella selaginoides* (cf. Pawłowski 1959), whereas, the higher parts with drier conditions might have been covered by plants with higher tolerance to water deficiency, such as *Ephedra distachya* and *Helianthemum* (cf. Granoszewski & Nalepka 2004, Noryśkiewicz et al. 2004).

The relatively high proportions of *Alnus* undiff. and *Corylus avellana* might have resulted from pollen redeposition, perhaps linked to intensification of surface run-off and/or from long distant transport. Moreover, these processes could have led to the redeposition of other pollen taxa.

PiotŁ-2 L PAZ *Betula-Pinus*; Bu-1 L PAZ *Pinus-Betula*; Bu-2 L PAZ *Pinus-Betula-Ulmus*, Ra-3 L PAZ *Betula-Pinus*, Ra-4 L PAZ *Betula-Corylus-Ulmus*; ca 9500–8200 cal. yr BC, Preboreal chronozone

The improvement of climatic conditions triggered a forest expansion, which rapidly displaced shade-intolerant juniper thickets surrounding the Piotrowo-Ławniki site. Patches of this community probably still existed during the older part of this period in the driest parts of morainic hills adjacent to the palaeolake.

The vicinity of lakes in the northern part of the Skaliska Basin was dominated by pioneer birch-pine forest revealing two patterns of development. The first one was recorded in the Sąkieły Małe and Budry and shows a shift from pine-dominated forests in the older part of the Preboreal chronozone to predominantly birch forest in its younger part. The second pattern shown in the Piotrowo-Ławniki profile reflects a continuous domination of birch in this kind of woodland. The re-expansion of birch was probably caused by the Preboreal oscilation an event of climate deterioration. This phenomenon is well documented in a few pollen profiles from northern and north-eastern Poland and is witnessed by a well-defined rise in *Betula* (Latałowa 1982, 1988, Pawlikowski et al. 1982, de Klerk et al. 2007, Wacnik 2009b). This event has also been detected at several sites in the northern hemisphere by different proxy-analyses e.g. in eastern France (Björck et al. 1997), The Netherlands (Bos et al. 2007), Switzerland

Table 5. The Skaliski Forest 2 – the description of the local pollen assemblage zones (L PAZs)

L PAZ	Depth [cm]	Description of pollen spectra	Top boundary description
LS2-1. *Pinus-Selaginella-Helianthemum*	280–265	Gradual increase in *Pinus sylvestris* type, fall in *Betula* undiff. and *Alnus* undiff. Stable presence of *Picea abies*, *Salix* undiff. and *Corylus avellana*. The highest values of *Helianhemum* undiff. (0.8%) *Veronica* type (0.8%) and *Silene* type (0.8%) in the pollen profile, constant occurrence of Cyperaceae undiff., Poaceae undiff., and Apiaceae undiff. The highest values of *Selaginella selaginoides* (1.5%), continuous curves of Filicales monolete and *Equisetum*. The highest values of *Sphagnum* (6%). Algae represented by *Tetraedron* and *Pediastrum* undiff. The lowest concentration of pollen in the whole profile (ca 2–4 × 10^3 grains/cm^3)	Fall in *Selaginella selaginoides* and *Helianhemum* undiff.
LS2-2. *Pinus-Betula*	265–237.5	Maximum and gradual decrease in *Pinus sylvestris* type (max. 74.5%), slight fall in *Betula* undiff. Constant presence of *Alnus* undiff. (fall in values), *Ulmus*, and *Populus*. Grains of *Betula nana* type determined in the upper part of zone as well as maximum of *Salix* undiff. (2.6%). Rapid rise in Poaceae undiff and Filicales monolete as well as higher values of Phragmites *australis* type and *Typha latifolia* in the upper part of the zone. Presence of *Selaginella selaginoides* and *Helianthemum* undiff. only in single spectrum. Algae represented by *Tetraedron* and *Pediastrum* undiff.	Decline of *Betula* undiff., rise in *Alnus* undiff.
LS2-3. *Alnus-Tilia*	237.5–205	Rapid rise in *Alnus* undiff. (max. 55%), increase in *Tilia cordata* type (max. 16%). Rise in *Quercus*, *Fraxinus excelsior*, and *Corylus avellana*. Decrease in *Pinus sylvestris* type, *Betula* undiff., *Salix* undiff., and *Populus*. Sharp fall in Poaceae undiff. and Filicales monolete. Continuous curve and maximum of *Pteridum aquilinum* (1.1%). At depth 225 cm numerous colonies of *Botryococcus pila* (max. 25.5%)	Decrease in *Tilia cordata* type
LS2-4. *Quercus*	205–117.5	Gradual decrease in *Alnus* undiff., stable rise and later fall in *Quercus* values. Constant presence of *Salix* undiff., *Fraxinus excelsior*, *Picea abies*, *Corylus avellana*, *Tilia cordata* type, and *Ulmus*. Fluctuations of *Pinus sylvestris* type and *Betula* undiff. curve. Rise in herbs frequency	Rapid increase in *Picea abies*
LS2-4a. *Quercus* (*Alnus-Betula*)	205–177.5	Rise in *Betula* undiff. and *Quercus* simultaneous with fall in *Pinus sylvestris* type. Increase in Cyperaceae, *Filipendula*, Filicales monolete, and *Thelypteris palustris*. Maximum of Apiaceae undiff. (1.9%) Stable occurrence of *Equisetum* and *Urtica*. Single *Tetraedron* and *Pediastrum* undiff. in the lower part of the zone	
LS2-4b. *Quercus* (*Corylus*)	177.5–167.5	Distinct peak of *Corylus avellana* curve (max. 24.5%, fall in the upper part of the subzone). Values of *Betula* undiff, and *Salix* undiff. similar to the W3a-4a subzone. Increase in *Quercus*, fall in *Pinus sylvestris* type and *Alnus* undiff. Rise in Poaceae undiff., *Urtica*, and *Equisetum*, decrease in Filicales monolete and *Filipendula*. In the upper part of the subzone maxima of *Thelypteris palustris* (2.5%) and *Menyanthes trifoliate* (2.3%)	
LS2-4c. *Quercus* (*Pinus-Picea*)	167.5–117.5	Rise in *Pinus sylvestris* type, constant increase in *Picea abies*, maximum and subsequent fall in curve of *Quercus* (from 19% to 11%). After decline in *Corylus avellana* curve, stable values. Appearance of a low percentage curve of *Carpinus betulus*. Increase in *Rumex acetosa* type and *Galium* type; single Cerealia type grains. Constant presence of *Urtica* and *Equisetum*. *Phragmites australis* type and *Utricularia* more frequent	
LS2-5. *Picea-Pinus*	117.5–77.5	Rapid increase in *Picea abies* (curve with two maxima: 28.5% and 27.5%), together with rise in *Pinus sylvestris* type and *Carpinus betulus*. Constant decline in *Quercus* and *Corylus avellana*. Decrease in *Ulmus*. *Equisetum*, *Plantago lanceolata*, and *Thalictrum* more frequent. Single grain of Cerealia type. Fall in values of Filicales monolete and *Potentilla* type. *Phragmites australis* type less frequent than in the W3a-4c subzone. Occurrence of single grains of *Potamogeton* subgen. *Eupotamogeton* in a few spectra as well as a single coenobium of *Pediastrum* undiff. In the upper part of the zone rise in charcoal concentration up to ca 3100 particles/cm^3	Fall in *Pinus sylvestris* type
LS2-6. *Betula*	77.5–60	Rise in *Betula* undiff. especially in the upper part very distinct (max. 38.5%). Decline in *Pinus sylvestris* type. Rise and subsequent fall in *Alnus* undiff., *Picea abies*, and *Quercus*. Increase in Poaceae undiff. and *Artemisia*. Cerealia type and *Secale cereale* in single spectra. Constant presence of *Pteridium aquilinum*, Chenopodiaceae, and *Menyanhes trifoliata*; rise in *Sphagnum*. At the depth of 75 cm a presence of not numerous colonies of *Pediastrum* undiff., *Pediastrum boryanum* var. *boryanum*, *P. argentiniense* type, *P. angulosum*, *Botryococcus neglectus*, and *B. brauni*	

(Haas et al. 1998, Magny & Bégeot 2004), Germany (ca 8950–8800 cal. yr BC; ca 8950–8400 cal. yr BC; Bos & Urz 2003), and Central North America (Yu & Eicher 1998, Fisher et al. 2002). In the profiles from the Skaliska Basin this phenomenon is most distinct in the Budzewo profile and is dated at 9258–8830 cal. yr BC (95.4%; 9660±60 yr ^{14}C BP). Additionally, the expansion of birch in this profile coincided with a return to more open conditions. Diatom

Table 6. Budzewo – the description of the local pollen assemblage zones (L PAZs)

L PAZ	Depth [cm]	Description of pollen spectra	Top boundary description
Bu-1 *Pinus-Betula*	1010–977.5	High percentages of *Pinus sylvestris* type (45.2–69.1%) and *Betula* undiff. (10.6–52.6%). Stable presence of single pollen grains of *Alnus*, *Corylus avellana*, *Picea abies*, *Quercus*, and *Salix*. Constant occurrence of *Artemisia*, Cyperaceae undiff., Poaceae undiff., and Apiaceae undiff. Very high values of Filicales monolete (max. 68.2%). Regular presence of *Sphagnum*, *Potamogeton*, and *Typha angustifolia/Sparganium*. Single remains of Dinnoflagellata and Tertiary sporomorphs	Fall in *Pinus sylvestris* type, rise in *Betula* undiff.
Bu-2 *Pinus-Betula-Ulmus*	977.5–905	Maximum and then gradual decrease in *Betula* undiff. (63%). Fall and rise in values of *Pinus sylvestris* type. Constant presence of *Ulmus* (3.9–6.6%), *Corylus avellana*, *Populus*, and *Salix* undiff. Rapid rise in Poaceae undiff. Regular occurrence of *Filipendula*. Fall in Filicales monolete. Start of continuous high-value curve of Bryales. First appearance of pollen of *Myriophyllum spicatum*, *M. verticillatum*, *Nuphar luteum*, *Nymphaea alba*, and *Typha latifolia* as well as idioblasts of Nymphaeaceae. Algae represented by *Tetraedron* and *Pediastrum* undiff.	Rise in *Corylus avellana*
Bu-3 *Corylus-Ulmus*	905–825	Very high values of *Corylus avellana* (max. 29.6%). High percentages of *Ulmus* (3.9-6.6%). Presence of *Alnus*, *Quercus*, *Tilia cordata* type, *Picea abies*, and *Salix*. Decrease in *Betula* undiff. (min. 11.5%). First appearance of *Pteridium aquilinum* spores	Increase in *Alnus*
Bu-4 *Corylus-Ulmus-Alnus*	825–665	Very high values of *Corylus avellana* (max. 33.9%). Gradual rise in *Alnus* to 15.4%. Increase in *Ulmus*, *Quercus*, and *Tilia cordata* type. Continuing presence of *Picea abies*, *Salix*, and *Fraxinus excelsior*. Relatively low values of *Pinus sylvestris* type and *Betula* undiff.	Rise in *Ulmus*, *Quercus* and *Tilia cordata* type
Bu-5 *Ulmus-Tilia-Quercus-Alnus*	665–265	Relatively high values of *Ulmus* (max. 12.0%), *Tilia cordata* type (max. 5.7%), and *Quercus* (max. 6.4%). Depression in pollen curve of *Corylus avellana*. Continuous presence of *Fraxinus excelsior*, *Picea abies*, and *Salix*. Relatively low values of *Pinus sylvestris* type (to 60%) and *Betula* undiff. (to 30%). Continuous presence of *Pteridum aquilinum*	Increase in *Corylus avellana* and *Fraxinus excelsior*
Bu-6 *Quercus-Corylus-Tilia-Alnus*	265–190	Gradual decrease in *Pinus sylvestris* type to ca. 6%. Visible maxima of *Corylus avellana* (max. 23.2%), *Alnus* (max. 26.2%), *Quercus* (max. 11.6%), *Fraxinus excelsior* (max. 3.9%), and *Tilia cordata* type (max. 7.3%). Constant presence of *Carpinus betulus* and *Picea abies*. Rise in frequency of herbs. Relatively numerous spores of *Lycopodium annotinum*. Maximum of *Nymphaea alba* (max. 2.3%). Occurrence of *Nymphaea candida* pollen	

analysis revealed unstable physical and/or chemical conditions in the water basin during this time interval; this conclusion was inferred from the domination of benthic diatoms and the occurrence of small *Fragillaria* spp. (Sienkiewicz 2013). Simultaneously the values of $\delta^{18}O$ suggest cooling and/or an increase in humidity (Mirosław-Grabowska 2013). A different situation was observed in the area of the alluvial fan at the Rapa site where the regeneration of *Betula* woodlands was observed after 9000±60 ^{14}C yr BP (95.4%; 8300–7967 cal. yr BC). Nevertheless, in the light of the fact that southern and eastern sites from north-eastern Poland failed to register the occurrence of a Boreal maximum in the *Betula* pollen curve (Kupryjanowicz 2007, Wacnik 2009b, Lauterbach et al. 2011), this raises concerns about the consistency of the radiocarbon date with the pollen analytical results.

Another phenomenon simultaneous with the probable Preboreal oscillation was the appearance of elm (*Ulmus*) in the surroundings of the Budzewo palaeolake (Figs 6, 9). This fact suggests that the onset of the expansion of this genus took place earlier than 8300–7500 cal. yr BC in north-eastern Poland (cf. Zachowicz et al. 2004). Similarly, a new set of palynological data obtained from Lake Hańcza and Lake Wigry seem to confirm the earlier expansion of elm. The beginning of this phenomenon in the first site took place around 8750–8650 cal. yr BC (Lauerbach et al. 2011) whereas, in the second one elm appeared about 8719–8512 cal. yr BC (Kupryjanowicz 2007). Neither is Lake Linówek an exception and clearly points to the period before 9510±60 ^{14}C yr BP (95.4%, 9120–8642 cal. yr BC) as the beginning of this taxon's expansion (Gałka et al. in press).

On the other hand, the onset of elm expansion was non-synchronous (Fig. 9), which is shown at the Piotrowo Ławniki site where in the declining phase of the Preboreal chronozone the values reached by *Ulmus* exceed 2% (according to Huntley & Birks (1983) a reliable indicator of its occurrence in situ).

Table 7. Rapa – the description of the local pollen assemblage zones (L PAZs)

L PAZ	Depth [cm]	Description of pollen spectra	Top boundary description
Ra-1 *Pinus-Betula*	444–432.5	High percentages of AP (up to 95%). Proportions of *Pinus sylvestris* type pollen ca 77%, *Betula* undiff. pollen – ca 15.6%, and *Salix* undiff. – ca 1.5%. The low proportion of NAP. Herbaceous plants represented by Cyperaceae undiff., Poaceae undiff., *Artemisia*, and Chenopodiaceae pollen. Among spores presence of *Equisetum*	Decrease in values of *Pinus sylvestris* type and an increase in NAP values
Ra-2 *Betula-Pinus*-NAP	432.5–390	Slight decrease in AP percentages. In the lower part oh the zone high values of *Pinus sylvestris* type. Increase in NAP. Rise in the values of Cyperaceae undiff., *Artemisia*, Chenopodiaceae, and Poaceae undiff pollen. Single grain of *Juniperus*, *Hippophae rhamnoides*, *Betula nana* type, and *Ephedra fragilis* type. In the upper part of the zone increase in the percentage values of *Betula* undiff. up to 34.6%., and fall in *Pinus sylvestris* type	Below an increase in *Betula* undiff and decrease in NAP values
Ra-3 *Betula-Pinus*	390–355	The zone with maximum percentages of *Betula* undiff. pollen (57.7%). The increase in proportions of *Ulmus* and *Corylus avellana*. Among aquatic plants presence of *Nymphaea alba*. A maximum values of Filicales monolete	Increase in *Corylus avellana* values and a decline of *Betula* undiff. and *Pinus sylvestris* type values
Ra-4 *Betula-Corylus-Ulmus*	355–335	Domination of AP. Fall in percentages of *Betula* undiff. Increase in the proportions of *Ulmus* and *Corylus avellana* pollen. Rise in *Ulmus* pollen values up to 7%, and *Corylus avellana* 8.5%. Very low NAP values with Poaceae undiff. reaching 5.5%	Decrease in *Betula* undiff. values and increase in *Corylus avellana* and *Ulmus*
Ra-5 *Corylus-Ulmus-Alnus*	335–245	Maximum of AP values (99%). The highest values of *Corylus avellana* (43.5%), *Alnus* undiff. (22%), and *Ulmus* (11.2%). Continuous curves of *Quercus* and *Tilia cordata* type. Single grains of *Viscum* and *Hedera helix*	Decrease in *Corylus avellana* and *Alnus* undiff.values, and increase in values of *Quercus* and *Tilia cordata* pollen
Ra-6 *Quercus-Tilia-Picea*	245–240	Decrease in the percentages of *Corylus avellana* and *Alnus* undiff. (respectively to 10.7% and to 17.6%). Rise in the values of *Quercus* and *Tilia cordata* type pollen to 7.2% and 9.5%. The maximum of *Ulmus* (11.2%). *Picea abies* values below 2%	

A different pattern of vegetation development was observed on the southern part of the alluvial fan in the Skaliska Basin, where *Pinus sylvestris* rapidly dominated the area and probably prevented other tree taxa from expanding.

An important component of damp thickets close to water bodies was willow (*Salix*), whose palynological imprint is most clearly recorded in the PiotŁ-2 L PAZ. The range of the percentage values of *Salix* is typical of the Preboreal chronozone in north eastern Poland (cf. Balwierz et al. 2004). In the drier parts of slopes, hazel (*Corylus avellana*) appeared in the understorey of pine-birch forests, and its population was probably the most numerous near the Sąkieły Małe site.

Filipendula spread in damp places around palaeolakes in the western and northern part of the Saliska Basin, where it coexisted with Cyperaceae, *Typha latifolia*, *T. angustifolia*, and/or *Sparganium*. The highest diversity of submerged macrophytes, which consisted of Nympheaceae (*Nymphaea alba* and *Nuphar*), *Myriophyllum* and *Potamogeton* subgen. *Eupotamogeton* was typical of the Budzewo profile. More numerous blooms of *Pediastrum duplex* var. *rugulosum*, *P. integrum*, and *P. boryanum* var. *longicorne*, together with a reliable frequency of *Tetraedron* and *Pediastrum boryanum* var. *boryanum* suggest eutrophic conditions in the younger part of the period in the lake located in Piotrowo-Ławniki. The occurrence of *P. integrum* and *P. boryanum* var. *longicorne* is typical of the early Holocene in pollen diagrams, and the presence of the latter is indicative of peaty water (Komárek & Jankovská 2001). Algae assemblages reflect the fact that this palaeolake was relatively small which enabled water to warm up sufficiently for algae to bloom during the summer.

A rise in the woodland cover caused by climatic amelioration at the beginning of the Holocene probably improved water retention and subsequently limited the role of run-off in pollen sedimentation in the Sąkieły Małe and Rapa water bodies. These processes were demonstrated by a reduction in the accumulation of Tertiary spores, dinoflagellate cysts and degraded sporomorphs.

Table 8. The Parchatka valley – the description of the local pollen assemblage zones (L PAZs)

L PAZ	Depth [cm]	Description of pollen spectra	Top boundary description
Par-1 *Pinus-Corylus-Ulmus*	675–625	Domination of *Corylus avellana*, *Pinus sylvestris* type, *Betula* undiff., and *Ulmus*. Presence of *Salix* undiff., *Tilia cordata* type, and *Fraxinus excelsior* in each spectrum. Among herbs constant occurrence of Poaceae undiff., Cyperaceae undiff., *Filipendula*, and *Phragmites australis* type. Continuous curve of Filicales monolete	Rise in *Betula* undiff.
Par-1a *Pinus-Corylus-Ulmus* (*Alnus*)	675–672.5	The subzone is represented by a single spectrum. Relatively high values of *Alnus*, undiff. (33 %), *Fraxinus excelsior* (1.2%), *Tilia cordata* type (4.6%), and *Picea abies* (2.3%). Maxima of Filicales monolete (27.5%) and *Thelypteris palustris* (8%) in the profile. Occurrence of coenobia of *Pediastrum integrum* and *P. boryanum* var. *boryanum*	
W6-1b *Pinus-Corylus-Ulmus* (*Corylus*	672.5–635	Rapid increase in *Corylus avellana* (28.5–31.5%); rise in *Ulmus*; strong fall in *Alnus* undiff. (between 4.3 and 0%). Decrease in *Quercus*, *Fraxinus excelsior*, *Tilia cordata* type, *Picea abies* as well as Filicales monolete, and *Thelypteris palustris*. Continuous low-percentage curve of *Urtica*. *Cladium mariscus* detected in most spectra. High diversity of algae, among them predominance of *Tetraedron*, *Pediastrum* undiff., *P. integrum*, *P. boryanum* var. *boryanum*, *P. boryanum* var. *longicorne*, and *Botryococcus* undiff.	
Par-1c *Pinus-Corylus-Ulmus* (*Pinus*)	635-–625	The subzone is represented by a single spectrum. Rapid fall in *Corylus avellana* and decrease in *Ulmus* coincided with rise in *Pinus sylvestris* type (max. 61.5%). Increase in Poaceae undiff. and Filicales monolete. Algae represented by *Pediastrum integrum* and *P. boryanum* var. *boryanum*	
Par-2 *Betula-Filipendula*	625–580	Visible rise and after decrease in *Betula* undiff. (max. 71.5%), an opposite trend of *Pinus sylvestris* type. Low percentage curve of *Alnus* undiff. At depth of 610 cm presence of *Betula nana* type (max. 2.7%). Increase in percentages of herbs, among which maxima of Poaceae undiff. (10.5 %), *Filipendula* (4.5%), *Artemisia* (3%), Apiaceae undiff. (0.7%), *Aster* type (1%), *Thalictrum* (0.6%), and *Galium* type. Additionally more numerous presence of *Silene* type, *Botrychium*, and *Selaginella selaginoides*. Rising trend of *Sphagnum* curve (max. 11.5%). Corroded sporomorphs the most frequent in the whole profile (2.3–7.5%). The lowest concentration of pollen: ca 3–15 $\times 10^3$ grains/cm^3	Increase in *Corylus avellana* and *Ulmus*
Par-3 *Corylus-Ulmus*	580–525	Sharp rise in *Corylus avellana* (max. 34.5%) as well as *Alnus* undiff., but in the upper part. Increase in *Ulmus*, *Quercus*, *Tilia cordata* type, and *Fraxinus excelsior*. Decrease in *Betula* undiff. Constant fall in herb taxa. *Phragmites australis* type in almost every spectrum. At a depth of 550 cm maximum of *Potamogeton* subgen. *Eupotamogeton* (4%). The highest percentages of *Tetraedron* (26.5%)	Fall in *Corylus avellana* and *Ulmus*; domination of *Alnus* undiff.
Par-4 *Alnus*	525–460	Rise in *Alnus* undiff. (23–47%), *Tilia cordata* type (max. 20%), and *Quercus* (max. 2.8%) simultaneous with gradual fall in *Corylus avellana* (to 10.5 %). After decrease, rise in *Ulmus*. Fluctuation of *Pinus sylvestris* type and constant values of *Betula* undiff and *Filipendula*. Higher frequency of *Vaccinium* type and spores of *Thelypteris palustris*. Increasing trend of Filicales monolete. In the upper part of the zone low percentage curve of *Pteridium aquilinum*. Regular occurrence of *Tetraedron* and *Botryococcus* undiff.; *Pediastrum* undiff., *P. boryanum* var. *boryanum*, and *P. integrum* in almost every spectrum	

PiotŁ-3 L PAZ *Corylus*, below a depth of 255 cm; **SM-3 L PAZ *Corylus-Ulmus-Fraxinus***, below a depth of 161 cm; **LS2-2 L PAZ *Pinus-Betula*; Bu-5 L PAZ *Corylus-Ulmus-Alnus***, below a depth of 725 cm, **Ra-5 L PAZ *Corylus-Ulmus-Alnus***, below a depth of 315 cm; **Par-1 L PAZ *Pinus-Corylus-Ulmus***; **Par-3 L PAZ *Corylus-Ulmus*; Par-4 *Alnus***, below a depth of 475 cm; ca 8200–7000 cal. yr BC, Boreal chronozone

Rapid spread of hazel probably prevented the development of birch seedlings and restricted the occurrence of *Betula* in pine-birch forests. This phenomenon was observed in the area of north-eastern Poland in the Boreal chronozone and the time of this event was approximately 7500–6700 cal. yr BC (Miotk-Szpiganowicz et al. 2004). A more abundant component of woodlands was lime (*Tilia cordata*) with trees probably occupying more fertile soils. In the older part of this period alder (*Alnus*) started to expand in the wetter habitats and probably formed alder carrs there. This taxon was probably the most important component of riparian forest and co-existed with elm. A unique pattern was reflected in the profile from the Parchatka valley, where the first maximum of alder, a reliable indicator of its local occurrence, was detected before 7937–7593 cal. yr BC (95.4%, 8700±50 ^{14}C yr BP). After this event, a sudden disappearance of alder took place, which might have been caused by an increase in the water level of the Parchatka stream up to the level intolerable to *Alnus*. Temporary natural deforestation, in the lowest terraces of the valley caused a rapid increase in pollen frequency of *Corylus avellana*, which occupied higher elevations. Probably the consequence of this climatic disturbance is intercalation of allochthonous sediment overlying the Par-1b LPASZ (see: Discontinuities in profiles from the Skaliska Basin versus climatic oscillations). Relatively stable hydrological conditions after 7578–7336 cal. yr BC (95.4%; 8400±60 ^{14}C yr BP) brought about a re-expansion of alder on the flooded terrace. Generally, the beginning of *Alnus* expansion in the area of north-eastern Poland took place in the late Boreal chronozone, but the onset of this phenomenon was

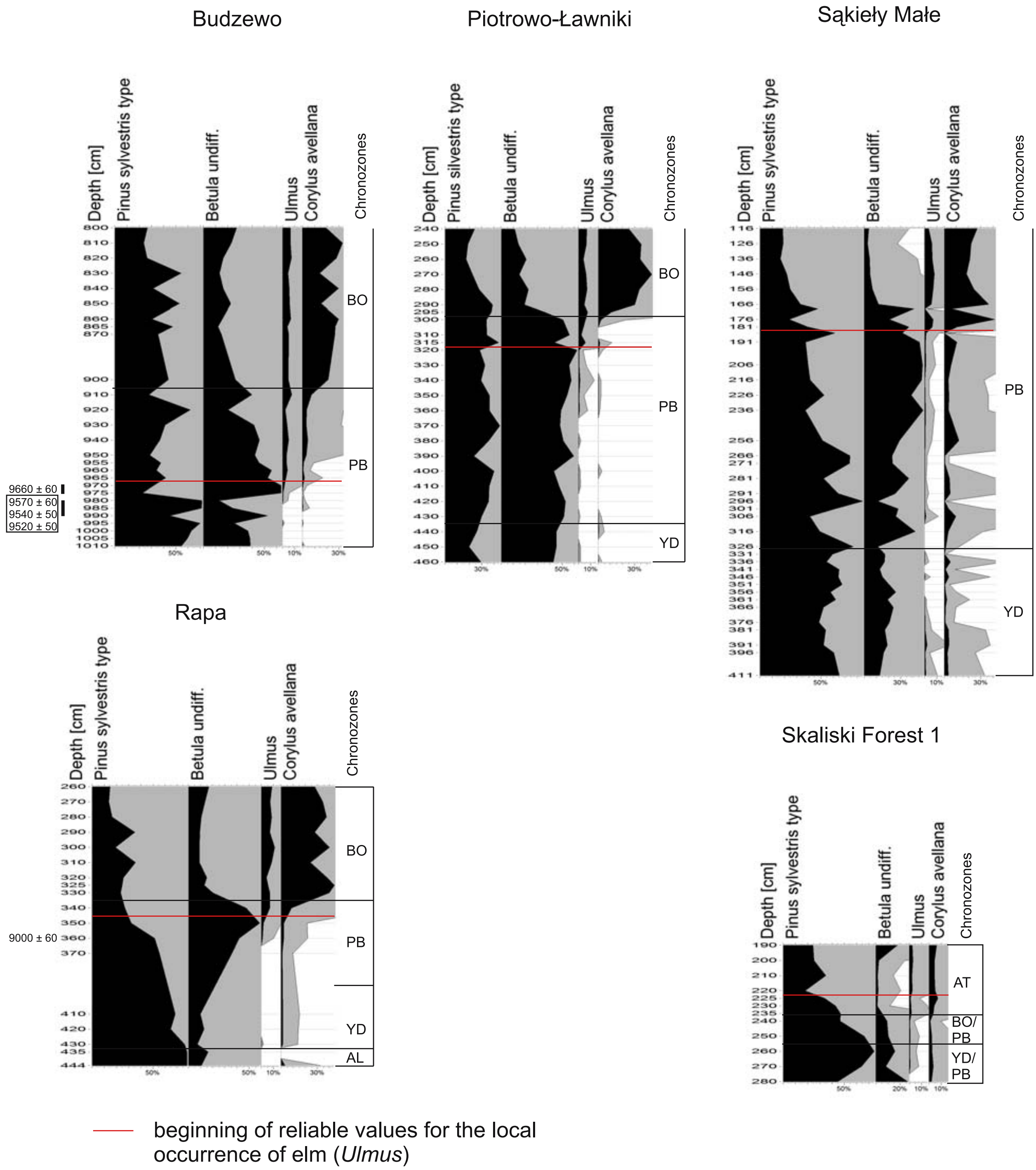

Fig. 9. Timing of appearance and expansion of elm (*Ulmus*), pine (*Pinus*), birch (*Betula*) and hazel (*Corylus avellana*) at sites in the Skaliska Basin in the early Holocene

not synchronous. This event was dated at ca 7796 cal. yr BC in Lake Wigry (Kupryjanowicz 2008), ca 7150 cal. yr BC in Lake Miłkowskie (Wacnik 2009a, b) and ca 7050 cal. yr BC in Lake Hańcza (Lauterbach et al. 2011). Improvement of thermal conditions enabled ivy (*Hedera helix*) and mistletoe (*Viscum*) to occur in the woodlands surrounding each site, with the exception of the Skaliski Forest. Both taxa require a minimum June mean temperature of 16°C, but the former taxon will not tolerate either a January mean temperature below –2°C in a more oceanic climate (Iversen 1944) or one below –3.3°C in a continental climate (Jasiewicz 1951).

In the belt of rushes that adjoined the water body in the Parchatka valley, saw-sedge (*Cladium mariscus*) occurred regularly between ca 7937 and 7336 cal. yr BC and this is the only site in the Skaliska Basin where this species was recorded. Another identification of pollen of saw-sedge from the Boreal chronozone in north-eastern Poland was made in Lake Miłkowskie (Wacnik 2009a, b). The composition of the algal flora, where *Tetraedron* distinctly dominated, points to eutrophic conditions and probably the small size of this basin.

During the Boreal chronozone, a palaeolake at the Piotrowo-Ławniki site failed to show visible changes in the composition of green algae in comparison with the previous chronozone, but an interesting fact was the occurrence of *Pediastrum kawraiskyi*. This species is attributed to clear stenothermic water bodies, mainly slightly eutrophic (Komárek & Jankovská 2001). However, it was not found in the Late Glacial sediments in this palaeolake. In contrast, together with the appearance of *P. kawraiskyi* a slight rise in *P. boryanum* var. *longicorne*, a taxon preferring peaty water, took place and this might suggest a fall in the water table. Additionally, a simultaneous noticeable rise in the $\delta^{18}O$ curve may confirm this process in the water body (Mirosław-Grabowska 2013). In addition, the expansion of *Nymphaea alba* may suggest highly eutrophic conditions (Matuszkiewicz 2005). In the depression in the Skaliski Forest a water body with *Myriophyllum spicatum* and Lemnaceae existed, and *Pediastrum* undiff. also bloomed there. The composition of other telmatophytes and limnophytes at other sites was similar to the Preboreal chronozone.

PiotŁ-3 L PAZ *Corylus*, above a depth of 255 cm; **PiotŁ-4 L PAZ *Alnus-Ulmus-Tilia*; LS2-3 L PAZ Alnus-Tilia; Bu-4 L PAZ *Corylus-Ulmus-Alnus***, above a depth of 725 cm; **Bu-5 L PAZ *Ulmus-Tilia-Quercus-Alnus***, **Ra-5 L PAZ *Corylus-Ulmus-Alnus*** above a depth of 315 cm; **Ra-6 L PAZ *Quercus-Tilia-Picea*; Par-4 L PAZ *Alnus***, above a depth of 475 cm; ca 7000–3800 cal. yr BC, Atlantic chronozone

The climatic conditions of the Holocene climatic optimum supported the development of multispecies deciduous and mixed woodlands. Likewise, an improvement in edaphic conditions enabled *Tilia cordata* to spread over the whole area of the Skaliska Basin. Moreover, the second native species to Poland – broad leaved lime (*Tilia platyphyllos*) probably appeared then as isolated specimens, as was recorded in the profiles from Sąkieły Małe, Budzewo, and Skaliski Forest. Nowadays, the north-eastern limit of this species occurs in the southern part of Poland up to the latitude 52° (Boratyńska & Dolatowski 1991, Zając & Zając eds 2001), so that data obtained from the Skaliska Basin suggest a wider distribution in Central Europe. Other well-dated profiles, carried out from north-eastern Poland failed to detect the occurrence of broad-leaved lime in the Holocene climatic optimum (Lake Wigry – Kupryjanowicz 2007, Lake Miłkowskie – Wacnik 2009a, b, Lake Hańcza – Milecka, pers. comm.). Oak (*Quercus*) gradually increased its numbers in woodlands and might have started to form, together with Scotch pine (*Pinus sylvestris*), communities similar to modern ones from the *Pino-Quercetum* association. The development of climax woodlands shaded the understorey and probably led to a slight reduction in hazel. Ivy expanded in the groundcover, whereas mistletoe was a common taxon in the canopy level. Alder (*Alnus*) probably still dominated in the damp niches and surroundings of palaeolakes and mires, but elm (*Ulmus*) and ash (*Fraxinus excelsior*) were also a significant component in these areas. The last taxon reached its highest distribution (2–3% of pollen values) in Holocene around 5550–4730 cal. yr BC in north-eastern Poland (Tobolski & Nalepka 2004). All sites, except for Budzewo and Rapa, recorded a similar or higher pollen frequency of ash. Alder carrs were probably best developed in the area of the southern part of the Skaliski Forest (LS2-3 and Par-4 LPAZs), where both species *Alnus incana* and *A. glutinosa* occurred together (Stachowicz-Rybka & Obidowicz 2013). In that habitat, spruce might have been present as individual trees. Even though pollen spectra showed the development of woodland communities, traces of open vegetation increased, as shown by a distinct maximum of *Rumex acetosa/acetosella*, were recorded in the Piotrowo-Ławniki profile. This phenomenon might have two explanations; first, that it was caused by activity of Mesolithic humans who burnt patches of forest to simplify hunting game, the second explanation postulates the spread of one of the *Rumex* species in the belt of reeds. The activity of forest clearance might be confirmed by the more frequent occurrence of bracken (*Pteridium aquilinum*) over the whole area of the Skaliska Basin. This fern according to Emmingham (1971) requires high light intensity, and young plants appear abundantly on soils enriched by wood-ash (Oberdorfer 1990, following Madeja et al. 2004). What is more, the acidification of soil resulting from fire facilitates the germination of spores (Page 1986). Burning was a typical method of clearing woodlands then, as has been described by Stančikaitė et al. (2002) and Bos and Urz (2003). Moreover, detailed archaeological investigations carried out in nearby Dudka (Gumiński 1995, 1999) and Szczepanki (Gumiński 2003) as well as pollen researches from Nietlice (Kupryjanowicz 2002) and Szczepanki (Wacnik & Ralska-Jasiewiczowa 2008) point to local intentional fire clearances induced by human activity at this period. This activity could have positively affected the maintenance of hazel in the understorey of woodlands where the increasing shade should have affected negatively the growth and germination of this species (cf. Miotk-Szpiganowicz et al. 2004). Additionally, morphological features of *Corylus avellana* such as its relatively deep rooting system make this species fire-resistant and enable fast regeneration (Behre 1981). The occurrence of local fires, but assigned to the Boreal chronozone, was also detected in the Bałupiany site located east of the Skaliska Basin and this phenomenon also had a positive impact on the increase in pollen frequency of hazel (Karpińska-Kołaczek et al. 2013).

The palaeolake at the Piotrowo-Ławniki site recorded the occurrence of a new taxon – *Pediastrum simplex* var. *echinulatum*. This species, according to Komárek & Jankovská (2001) is a component of freshwater plankton under various eutrophic conditions with neutral to alkaline water. This episode is correlated with a decrease in $\delta^{18}O$ and $\delta^{13}C$ content in the water body, which may suggest a rise in the water level caused by an increase in precipitation (Mirosław-Grabowska 2013). A rise in the number of *Botryococcus* undiff. colonies in the palaeolake in Budzewo in the younger part of the Atlantic chronozone points to its eutrophication (cf. Jankovská & Komárek 2000). A fall in the water level was also demonstrated in the expansion of *Typha angustifolia* and *T. latifolia* in the belt of reeds as well as in the more frequent occurrence of *Nymphaea alba* within the lake.

On the surface of the former water body in the Parchatka valley alder carr probably developed and caused a rapid deterioration of pollen preservation, which is typical of peat accumulated in the area of alder carrs (Barthelmes et al. 2006). This fact is confirmed by peat analysis which pointed to the beginning of alder peat accumulation from a depth of 450 cm (Stachowicz-Rybka & Obidowicz 2013).

PiotŁ-5 L PAZ *Pinus*; SM-5 L PAZ *Picea-Carpinus*-NAP; LS1-1 L PAZ *Pinus-Picea*; LS1-2 L PAZ *Pinus*; LS 2-4 L PAZ *Quercus*; LS2-5 L PAZ *Picea-Pinus*; LS2-6 L PAZ *Betula*; Bu-6 L PAZ *Quercus-Corylus-Tilia-Alnus* Subboreal chronozone; ca 3800–600 cal. yr BC, early Subatlantic chronozone

At the beginning of this period oak (*Quercus*) continued its expansion and was probably a main component of the then equivalent of *Pino-Quercetum* woodlands, which may have reduced the area of the Skaliska Basin, occupied by alder. Climate deterioration might have led to the revival of the birch population, which maintained a stable level during the whole Subboreal chronozone in the surroundings of Sąkiełу Małe, whereas in the area of the Skaliski Forest birch was displaced by rapidly expanding hazel. However, this episode was short-lived.

The change in climatic conditions favoured the expansion of spruce, which probably had sparsely occupied more damp areas up until this period. Probably this species displaced oak and hazel from its habitat and together with

Pinus sylvestris started to form coniferous forest similar to those which nowadays occupy the boreal zone. These processes are best highlighted in the profiles from the Skaliski Forest and Sąkiełу Małe, where during the period of the spruce domination in woodlands, a sudden decline in its frequency was recorded (more visible in the Skaliski Forest). The pattern of spruce expansion showing two optima of occurrence is repeated elsewhere and was recorded in eastern located sites e.g. Lake Czarne located in the Rogalskie Hills (Karpińska-Kołaczek 2011), Bałupiany in the Węgorapa District (Karpińska-Kołaczek et al. 2013). The results of radiocarbon dating obtained from Lake Hańcza point to ca 3050 cal. yr BC as the beginning of spruce expansion and ca 2450 cal. yr BC as its first maximum (Lauterbach et al. 2011). The results of pollen analysis and radiocarbon dating from Lake Wigry showed that the first maximum of this taxon took place ca 2020 cal. yr BC and the second one was estimated at 340 cal. yr BC (Kupryjanowicz 2007). On the other hand, Lake Linówek revealed a pattern of spruce expansion without distinct maxima, and the beginning of that expansion was dated at 2471–2153 cal. yr BC (95.4%; 3860±50 ^{14}C yr BP; Gałka et al. in press). Isopollen maps estimate the age of the optimum of spruce occurrence at ca 2650–1050 cal. yr BC in north-eastern Poland (Obidowicz et al. 2004).

Almost every profile from the Skaliska Basin failed to reflect a distinct retreat of elm at the beginning of the Subboreal chronozone (cf. Ralska-Jasiewiczowa 2004, Zachowicz et al. 2004). The profile from Sąkiełу Małe is the only one which demonstrates a decline in the elm curve, but the age of this event was approximated only palynologically. Probably the low intensity of Neolithic farming activity in the area of Skaliska Basin and the subsequent lack of pollarding activity retarded the spread of Dutch elm disease (see Moe & Rackham 1992). A similar situation was recorded in the adjacent Lake Czarne (Rogalskie Foothills), where this taxon reached its maximum after the Holocene climatic optimum and this coincided with an increase in human activity (Karpińska-Kołaczek 2011). To summarize, the insignificant human impact at the beginning of the Subboreal chronozone, together with a rise in humidity let elm maintain its sites in the Skaliska Basin and may even have had a positive influence on the development of its population. A similar pattern was observed in Lake Miłkowskie where a distinct fall in *Ulmus* was recorded in 1950 cal. yr BC. However, during the transition between the Atlantic and Subboreal chronozone a small decrease in this taxon's curve was registered (Wacnik 2009a, b). On the other hand, a typical pattern with an early Subboreal elm decline was recognized in easterly located sites like Lake Hańcza (Lauterbach et al. 2011), Lake Wigry (Kupryjanowicz 2007), Lake Dũba and Lake Pelesa in Lithuania (Stančikaitė et al. 2002).

In deciduous and mixed woodlands, hornbeam (*Carpinus betulus*) appeared as a new component. The late Holocene spread of this taxon might have been facilitated by human activity which had left deforested areas which were favourably colonized by relatively fast growing hornbeam specimens (cf. Ralska-Jasiewiczowa & van Geel 1998). The records of Lake Hańcza show the date ca 2450 yr cal. BC as the beginning of the increase in the frequency of *Carpinus betulus* in woodland communities (Lauterbach et al. 2011), whereas, in the vicinity of Lake Miłkowskie the beginning of its regular occurrence was recognized later, in the period 1950–1850 yr cal. BC (Wacnik 2009a, b). The probable appearance of *Carpinus betulus* in the surroundings of Lake Wigry took place about 2022 cal. yr BC, although its local occurrence there was quite uncertain (Kupryjanowicz 2007). The interesting phenomenon is that *Carpinus betulus* maxima are associated with declines of *Picea abies* in the profiles from Sąkiełу Małe and the Skaliski Forest. However, the more frequent presence of ribwort plantain (*Plantago lanceolata*) is coincidental with rises in hornbeam, as well as single occurrences of Cerealia type pollen which seems to confirm a human role in these processes. Generally, pollen spectra related to the Subboreal chronozone in each profile reflect only slightly a fall in woodland cover, which may also be a reflection of the weak activity of Neolithic tribes. Unfortunately, there is no available archaeological data from the area of the Skaliska Basin.

The phenomenon of spruce-hornbeam interaction has not been identified in north-eastern Poland before, and the presence of both taxa was generally considered as promoted by human disturbance of forests (Wacnik 2009a, b).

A different reaction of vegetation at the beginning of the Subboreal chronozone was recorded in the profiles from Piotrowo-Ławniki and Budzewo. In the former, there was a rapid expansion of pine with a simultaneous regression of oak, but there is also the possibility of a hiatus in deposition with the layer assigned to the Subboreal period being much younger. In the latter profile, arboreal taxa traditionally linked with the Holocene climatic optimum, such as *Fraxinus excelsior*, *Corylus avellana*, and *Tilia cordata*, seemed to extend their distribution by a rapid restriction of the occurrence of *Pinus sylvestris*.

A probable rise in the water level caused a re-expansion of submerged macrophytes like *Myriophyllum verticillatum* and *Potamogeton* subgen. *Eupotamogeton* in the palaeolake located in Sąkiely Małe. The higher number of dinoflagellate cysts may suggest an increase in the role of run-off in pollen and other palynomorph sedimentation. During this period at the site in the Skaliski Forest there was a peat bog with small eutrophic pond(s) occupied by *Utricularia*, whereas the surroundings were covered by *Phragmites australis*, *Menyanthes trifoliata*, telmatic representatives of *Equisetum*, and probably *Comarum palustre* (*Potentilla* type).

LS1-3 L PAZ *Betula-Pinus-Carpinus*; Subatlantic chronozone younger than ca 500 cal. yr BC

A slight intensification of human activity was recorded in more numerous occurrences of cereal pollen. The spread of rye (*Secale cereale*) reflected in the upper part of the L PAZ may have been the effect of the agricultural practice of tribes dating back to the Iron Age or of humans who occupied this area in the Early Mediaeval Period. Isopollen maps point to an increase in rye percentages during the last millennium in north-eastern Poland (Okuniewska-Nowaczyk et al. 2004). Human impact could have led to nitrification of habitats, which enabled *Urtica* to spread. The expansion of *Betula* as well as of *Carpinus betulus*, which coincide with this phenomenon, was probably due to the easier colonisation by these taxa of fallow lands. The first optimum of hornbeam, however, demonstrated by relatively low percentages (ca 5%) was dated at 964–176 cal. yr BP (95.4%, 2190±30 ^{14}C BP) and could have been connected with forest regeneration before the rise in activity of the Iron Age tribes. On the other hand, the rise in *Betula* values could have been because of its expansion at the surface of the peat bog, which might have been brought about by a fall in the water level. However, periods with a temporary higher water level were present which allowed *Pediastrum* spp. to appear.

DISCONTINUITIES IN PROFILES FROM THE SKALISKA BASIN VERSUS CLIMATIC OSCILLATIONS

The first sediment discontinuity is visible in a distinct sandy lens lying above sediments which originated during the Younger Dryas chronozone in the Rapa profile (Fig. 7). This intercalation of sand might have been caused by a strengthening of the activity of streams that cut into the sandy fan during the late part of the Younger Dryas chronozone. This period was characterized by a higher lake level in middle-Europe (Magny et al. 2003), but at the same time there is no visible intensification of flood episodes in Poland (Macklin et al. 2006). So there is also a possibility that a single catastrophic event was recorded in this profile.

The second visible discontinuity is the injection of older pollen material (Par-2 zone) into sandy detrital gyttja in the Boreal deposits of the profile from the Parchatka valley (Fig. 8). A radiocarbon date obtained from the beginning of this layer showed 9112–8489 yr cal. BC (95.4%; 9410±60 ^{14}C yr BP) and suggests a Preboreal origin. This intercalation probably reflects event(s) with an increase in the activity of streams and subsequent floods, which may have rebedded older material. Taking into consideration the radiocarbon dating carried out under and above this layer, this event took place between 7937 and 7336 cal. yr BC. This time interval spans the period of higher water level in the lakes from the Jura, French Pre-Alps and Swiss Plateau (Magny & Bégeot 2004), and ice rafting debris in the northern Atlantic Ocean (Bond et al. 2001). However, in Poland it coincides with a wet phase on peatbogs (Żurek & Pazdur 1999, Żurek et al. 2002) and flood phases in the Upper Vistula (Starkel et al. 2002). Only the profile from Budzewo reflected two declines in the δ^{18}O, which may suggest increasing humidity of climate (Mirosław-Grabowska 2013). Unfortunately, an attempt to obtain a radiocarbon date from this part of the profile was not successful.

The profile from the Skaliski Forest contained a truncated section deposited probably during the Preboreal and Boreal chronozones. Pollen spectra failed to record the early Holocene maximum of *Corylus avellana* or of *Betula* undiff. However, Stachowicz-Rybka and Obidowicz (2013) detected numerous sclerotia of *Cenococcum geophillum*, which may indicate an event involving strong erosion of organic matter from the surface soil (Wick et al. 2003). Deposition of a silt layer in the zone assigned to the Preboreal and/or Boreal chronozone may also suggest the possibility of water flowing through the depositional basin which could then have ceased during the Atlantic chronozone, when accumulation of peat was able to start.

Profiles located in the area of the basin, outside the sandy fan, are devoid of late Holocene sections. This was probably the result of final infill of the depressions during the Atlantic and Subboreal chronozones. Probably the deposits from the upper part of the Piotrowo-Ławniki profile belong to the Subatlantic chronozone and they overlie deposits from the Atlantic chronozone. This is visible in the sharp rise in the percentages of *Pinus sylvestris* type and the lack of an early Subboreal rise in *Quercus* values.

RADIOCARBON DATE DISCREPANCIES

The strongest radiocarbon inversions took place in the Piotrowo-Ławniki profile. In this profile the radiocarbon date (Poz-37993) from the Younger Dryas/Preboreal chronozone transition which showed 6570±100 yr ^{14}C BP was obtained from unidentified plant tissue, so it may suggest rejuvenation of the sample by roots. Age inversion at the depth of 270–280 cm in the Skaliski Forest site could have an identical explanation. The date Poz-41022 (5300±50 yr ^{14}C BP) was obtained from wood fragments, which were the only material sufficient for radiocarbon dating and they probably were fragments of tree roots colonizing the mire surface in the late Atlantic chronozone. However, the sample selected for the radiocarbon date Poz-37992 from the Piotrowo-Ławniki site comprised fruits of *Betula* sect. *Albae* and *Schoenoplectus lacustris* (Tab. 1), so rejuvenation caused by improper material selection fails to explain this problem, because these plants do not assimilate HCO^- as do submerged plants. Additionally a pollen diagram as well as results of oxygen and carbon isotope analyses (Mirosław-Grabowska 2013) point to subsequent sedimentation without traces of disturbance. Another explanation might be rejuvenation caused by humic acids which infiltrated the ground and saturated the macroremains leading to an increase in the content of ^{14}C in them (Björck & Wohlfarth 2001). Nevertheless, a radiocarbon date from the upper part of the profile (Poz-37991, 5420±40 yr ^{14}C BP) matches palynological analysis well, and these macroremains should have been exposed to the strongest activity of humic acids. The other reason for the dates being too young might have been improper storage. The samples for AMS dating were kept in closed plastic bags in a dark and cool (ca 5°C) place. Samples for radiocarbon dating were ultimately chosen in conjunction with the results of pollen analysis, which allowed us to distinguish the most distinctive events. That fact caused a 24 month delay between the sampling and dating. Wohlfarth et al. (1998) proved that the longer time of sample storage increases the probability of obtaining a younger age in comparison to estimations from other proxies. It was also shown that samples with a low content of carbon (in dry weight smaller than ca 1.4 mg) are more susceptible to contamination than larger ones (Wohlfarth et al. 1998). Those phenomena were explained by the rejuvenating role of fungi and other microorganisms, which are easily incorporated into samples during the retrieval of cores, sampling samples and even during the storage procedures. On the other hand, fungi are heterotrophic organisms so the only 'young' carbon contaminants in material selected for AMS dating should come from modern spores which fall onto the material. A subsequently spreading mycelium incorporates carbon from its substratum i.e. macroremains in the case of the research presented in this paper. So then, dates from the combination of macroremains and mycelium should display an age similar or slightly rejuvenated in comparison to sterile substratum. According to Wohlfarth et al. (1998) CO_2 may be "assimilated by the fungi from the organic-rich medium and from contaminating nutrients in the ambient water during growth". This recent carbon, when added to the sample, may account for the large errors of several hundred to several thousand years encountered in data series (cf. Walker 2005). Geyh et al. (1974) and Colman et al. (1997) also revealed that long-term storage influences obtaining younger ages in bulk sediment radiocarbon dating. In the first case as a main driver of age discrepancies, the terrestrial bacteria were determined. Research carried out by Parkinson et al. (1990, 1991) revealed that cells of the fungus *Fusarium oxysporum* under oligotrophic conditions contain 0.78% of carbon from CO_2 and 99.22% originates from other sources, which include pre-formed cell material and trace organic contaminants in the medium and in the atmosphere. However, O. Constantinescu cited by Wohlfarth et al. (1998) claimed that the fungus *Paecilomyces farinosus* "may easily grow and absorb CO_2 from the remaining air in the glass bottle and from the ambient water".

The interesting fact is that most of the dates from the Skaliska Basin carried out from macrofossils treated by a mixture of glycerine, thymol and ethyl alcohol (but pretreated by rinsing them in alcohol) reflected a reliable age in comparison with that deduced from palynological analysis. The aforementioned observations give a far-reaching possibility of dating profiles investigated in the past, from which macrofossils have already been identified and collected (and thus preserved in glycerine-thymol-ethyl alcohol mixture). However, not all samples pretreated by alcohol revealed reliable dates, as was noted in the Budzewo profile (dates Poz-41008 and Poz-41005), therefore more control tests should be carried out before the introduction of this method. Considering an issue of dates from the Skaliska Basin, it is also possible that the preserving mixture restricted the development of microorganisms in/on macroremains. However, the extraction of macrofossils and their conservation was carried out about 12 month after the collection of the core, so the period of exposure to fungi and bacteria was shorter than in case of samples in storage for AMS dating.

To sum up, several authors have had to face problem of inconsistency of dates with other proxies and even the finest macroremains found in undisturbed deposits have suggested ages that were far from probable (e.g. Beer et al. 2007, Kiage & Liu 2009).

CONCLUSIONS

1. Even though, pollen profiles from the Skaliska Basin reflect vegetation development since the decline of the Bølling-Allerød interstadial up until the present, none of them reveals a complete succession spanning this period.

2. The palynological research proved that the Late Glacial and Holocene vegetation history of this small area could display different patterns. The Younger Dryas was the period when juniper shrublands typical of north-eastern Poland developed as well as patches of steppe with *Artemisia*, more common for the southern part of Poland. A more homogenous vegetation consisting of birch-pine forest was characteristic of the Preboreal chronozone, but in two profiles from Budzewo and Rapa, a definite expansion of *Betula* was reflected. However, the appearance of elm (*Ulmus*) in the forest was non-synchronous and the first reliable amounts of pollen which show its in situ occurrence were dated at 8830–9244 cal. yr BC. The subsequent hazel (*Corylus avellana*) expansion was recorded in a majority of profiles as well as the development of deciduous forests during the Atlantic period. An interesting phenomenon was the simultaneous rise in the values of thermophilous taxa in the Subboreal chronozone in the western part of the area (Budzewo) and the decline of these taxa in the parallel sections of other profiles. Vegetation of the Subboreal chronozone was recorded in the profiles from Sąkieły Małe and the Skaliski Forest. In both sites an initial expansion of oak (*Quercus*) was recorded. However, it was probably displaced in the younger part of the chronozone by Norwegian spruce (*Picea abies*) whose percentages recorded two maxima. Additionally hornbeam (*Carpinus betulus*) started to be a more common element in woodlands. The deposits of the Subatlantic chronozone were detected only in the profile from the Skaliski Forest, where pine forest with an admixture of birch, spruce, and alder dominated.

3. Human impact was detected in the rare occurrences of grains of Cerealia type in the Subboreal and Subatlantic chronozones. This observation as well as the constant low percentages of herbs seems to confirm the low penetration of the Skaliska Basin by human groups.

4. There is no clear explanation for inconsistencies of radiocarbon dates revealed by most of

the profiles. Surprisingly, a good agreement of radiocarbon dates obtained from macrofossils contaminated by a preserving mixture, (pretreated by alcohol before dating) with results of palynological analysis is very promising in terms of chronology for profiles devoid of radiocarbon dates.

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REFERENCES

BALWIERZ Z., FILBRANDT-CZAJA A., NORYŚKIEWICZ A.M., NORYŚKIEWICZ B. & NALEPKA D. 2004. *Salix* L. – Willow: 199–207. In: Ralska-Jasiewiczowa M., Latałowa M., Wasylikowa K., Tobolski K., Madeyska E., Wright H.E., Jr. & Turner C. (eds), Late Glacial and Holocene history of vegetation in Poland based on isopollen maps. W. Szafer Institute of Botany, Polish Academy of Sciences, Kraków.

BARTHELMES A., PRAGER A. & JOOSTEN H. 2006. Palaeoecological analysis of *Alnus* wood peats with special attention to non-pollen palynomorphs. Rev. Palaeobot. Palynol., 141: 33–51.

BEDNAREK R., DZIADOWIEC H., POKOJSKA U. & PRUSINKIEWICZ Z. 2004. Badania ekologiczno-gleboznawcze. Wydawnictwo Naukowe PWN, Warszawa.

BEER R., HEIRI O. & TINNER W. 2007. Vegetation history, fire history and lake development recorded for 6300 years by pollen, charcoal, loss on ignition, and chironomids at a small lake in southern Kyrgyzstan (Alay Range, Central Asia). Holocene, 17(7): 977–985.

BEHRE K.E. 1981. The interpretation of anthropogenic indicators in pollen diagrams. Pollen et Spores, 23: 225–245.

BERGLUND B.E. & RALSKA-JASIEWICZOWA M. 1986. Pollen analysis and pollen diagrams: 455–484. In: Berglund B.E. (ed), Handbook of Holocene Palaeoecology and Palaeohydrology. J. Wiley & Sons, Chichester, New York.

BEUG H.J. 2004. Leitfaden der Pollenbestimmung für Mitteleuropa und angrenzende Gebiete. Verlag Dr. Friedrich Pfeil, München.

BIRKS H.J.B. 1986. Numerical zonation, comparison and correlation of Quaternary pollen-stratigraphical data: 743–774. In: Berglund B.E. (ed), Handbook of Holocene Palaeoecology and Palaeohydrology. J. Wiley & Sons, Chichester, New York.

BJÖRCK S & WOHLFARTH B. 2001. ^{14}C chronostratigraphic techniques in paleolimnology: 205–245. In: Last W.M. & Smol J.P. (eds), Tracking Environmental Change Using Lake Sediments. Volume 1: Basin Analysis, Coring, and Chronological Techniques. Kluwer Academic Publishers, Dordrecht, The Netherlands.

BJÖRCK S., RUNDGREN M., INGÓLFSSON Ó. & FUNDER S. 1997. The Preboreal oscillation around the Nordic Seas: terrestrial and lacustrine responses. J. Quartern. Sci., 12: 455–465.

BOND G., KROMER B., BEER J., MUSCHELER R., EVANS M.N., SHOWERS W., HOFFMANN S., LOTTI-BOND R., HAJDAS I. & BONANI G. 2001. Persistent solar influence on North Atlantic climate during the Holocene. Science, 294: 2130–2136.

BORATYŃSKA K. & DOLATOWSKI J. 1991. Systematic and geographic distribution: 21–55. In: Białobok S. (ed.), Lipy. *Tilia cordata* Mill., *Tilia platyphyllos* Scopp. Monografie popularnonaukowe 15, Wydawnictwo Arkadia, Poznań.

BOS J.A.A. & URZ R. 2003. Late Glacial and early Holocene environment in the middle Lahn river valley (Hessen, central-west Germany) and the local impact of early Mesolithic people – pollen and macrofossil evidence. Veget. Hist. Archaeobot., 12: 19–36.

BOS J.A.A., van GEEL B., van der PLICHT J. & BONCKE S.J.P. 2007. Preboreal climate oscillations in Europe: Wiggle-match dating and synthesis of Dutch high-resolution multi-proxy records. Quatern. Sci. Rev., 26: 1927–1950.

BREITENFELD E. & MOTHES K. 1940. Bestandesgeschichtliche Untersuchungen an Masurischen Wäldern. Schrift. Physical.-Ökonom. Ges. Königsberg, 2.

BREMÓWNA M. & SOBOLEWSKA M. 1934. Podyluwialna historia lasów Puszczy Augustowskiej na podstawie analizy pyłkowej torfowisk. Las Polski: 1–3.

BRONK RAMSEY C. 2009. Bayesian analysis of radiocarbon dates. Radiocarbon, 51(1): 337–360.

COLMAN S.M., JONES G.A., RUBIN M., KING J.W., PECK J.A. & OREM W.H. 1996. AMS radiocarbon analyses from Lake Baikal, Siberia: challenges of dating sediments from a large, oligotrophic lake. Quatern. Sci. Rev., 15: 669–684.

CZAJKOWSKI P., KARWACKI P., OWCZARSKA U., TRĘBIŃSKA E. & POTEMPA W. 2004. Program Ochrony Środowiska Gminy Gołdap na lata 2004–2007 z uwzględnieniem perspektywy na lata 2008–2011. (Available on: http://bip.goldap.pl/files/fck/21/Program_ochrony_srodowiska_gminy_Goldap_na_lata_2004_-_2007_z_uwzglednieniem_perspektywy_na_lata_2008_-_2011.pdf).

DĄBROWSKI J., RALSKA-JASIEWICZOWA M. & STUPNICKA E. 1982. Z problematyki badań zespołu osadniczego kultury Łużyckiej we wsi

Woryty, woj. Olsztyn: 364–369. In: Hensel W. (ed.), Przemiany ludnościowe i kulturowe I tysiąclecia p.n.e. na ziemiach między Odrą i Dnieprem. Wrocław-Warszawa-Kraków.

DRZYMULSKA D. & KUPRYJANOWICZ M. 2010. Palaeobotanical studies of dystrophic lakes of the Wigry National Park – preliminary results. Acta Soc. Bot. Pol., 79, Suppl. 1: 82.

EMMINGHAM W.H. 1972. Conifer growth and plant distribution under different light environment in the Siskiyou Mountains of south-western Oregon. Corvallis, OR. Oregon State University Thesis.

FAEGRI K. & IVERSEN J. 1989. Textbook of Pollen Analysis. Munksgaard, Copenhagen.

FILBRANDT-CZAJA A. 2000. Vegetation changes in the surroundings of Lake Dgał Wielki in the light of pollen analysis: 89–99. In: Kola A. (ed.), Studies in Lake Dwellings of West Baltic Barrow Culture. Wydawnictwa Uniwersytetu Mikołaja Kopernika, Toruń.

FISHER T.G., SMITH D.G. & ANDREWS J.T. 2002. Preboreal oscillation caused by a glacial Lake Agassiz flood. Quatern. Sci. Rev., 21(8/9): 873–878.

GAŁKA M., TOBOLSKI K., ZAWISZA E. & GOSLAR T. in press. Postglacial history of vegetation, human activity, and lake-level changes in the NE Poland (Lake Linówek) based on multi-proxy data. Veget. Hist. Archeobot. DOI 10.1007/s1007/ss00334-013-0401-7

GĄSIOROWSKI M. 2013. Cladocera record from Budzewo (Skaliska Basin, north-eastern Poland). Acta Palaeobot. 53(1): 93–98.

GEYH M.A., KRUMBEIN W.E. & KUDRASS H.-R. 1974. Unreliable ^{14}C dating of long-stored deep-sea sediments due to bacterial activity. Mar. Geol., 17: M45–M50.

GRANOSZEWSKI W. & NALEPKA D. 2004. *Ephedra* L. – Joint-fir: 89–94. In: Ralska-Jasiewiczowa M., Latałowa M., Wasylikowa K., Tobolski K., Madeyska E., Wright H.E., Jr. & Turner C. (eds), Late Glacial and Holocene history of vegetation in Poland based on isopollen maps. W. Szafer Institute of Botany, Polish Academy of Sciences, Kraków.

GROß H. 1935a. Die Steppenheidethorie und die vorgeschichtliche Besiedlung Ostpreußen. Altpreußen, 2(3): 152–168.

GROß H. 1935b. Moorfunde, ihre Bergung, Auswertung und Bedeutung. Altpreußen, 1(1): 47–51.

GROß H. 1936 Die Steppenheidetheorie und die voergeschichtliche Besiedlung Ostpreußen. Altpreußen, 1(4): 193–216.

GROß H. 1938. Die Zeitstellung der Hamburger Stufe des Magdalénien bei Ahrensburg in Holstein. Praehist. Zeitschr., 28–29(1–2): 3–15.

GROß H. 1939a. Die subfossilen Renntierfunde Ostpreußens. Schrift. Physikal.-Ökonom. Ges. Königsberg, 71(1): 79–126.

GROß H. 1939b. Pollenanalitische Untersuchung zweier bemerkenswerter Mittelsteinzeitfunde aus Ospreußen. Nachrichtenblatt für Deutsche Vorzeit, 15(11/12): 286–291.

GROß H. 1940. Der Renngeweih-Dolch von Eisermühl. Altpreußen, 4(4): 81–84.

GROß H. 1941a. Ein frühgeschichtlicher Holztopffund aus dem Samland. Altpreußen, 6(2): 155–162.

GROß H. 1941b. Mittelsteinzeitliche funde aus Zinten. Altpreußen, 6(3): 34–36.

GUMIŃSKI W. 1995. Environment, economy and habitation during the Mesolithic at Dudka, Great Mazurian Lakeland, NE-Poland. Prz. Archeol., 43: 5–46.

GUMIŃSKI W. 1999. Środowisko przyrodnicze a tryb gospodarki i osadnictwa w mezolicie i paraneolicie na stanowisku Dudka w Krainie Wielkich Jezior Mazurskich (summary: Natural environment – and the model of economy and settlement in the Mesolithic and Paraneolithic at the Dudka site in the Masurian Lakeland. Archeol. Pol., 44: 31–74.

GUMIŃSKI W. 2003. Szczepanki 8. Nowe stanowisko torfowe kultury Zedmar na Mazurach (summary: Szczepanki site 8. A new peat-bog site of Zedmar culture in the Great Mazurian Lakes Region, NE Poland). Światowit, B, 46(5): 53–104.

HUNTLEY B. & BIRKS H.J.B. 1983. An Atlas of past and present pollen maps for Europe: 0–13 000 years ago. Cambridge University Press, Cambridge.

ISARIN R.F.B. & BOHNCKE S.J.P. 1999. Mean July temperatures during the Younger Dryas in Northern and Central Europe as inferred from climate indicator plant species. Quatern. Res., 51: 158–173.

IVERSEN J. 1944. *Viscum*, *Hedera* and *Ilex* as climate indicators. A contribution to the study of the Post-Glacial temperate climate. Geol. Förening. Förhandl., 66(3): 463–483.

JANCZYK-KOPIKOWA Z. 1987. Uwagi na temat palinostratygrafii czwartorzędu (summary: Remarks to the palynostratigraphy of Quaternary). Kwart. Geol., 31(1): 155–162.

JANKOVSKÁ V. & KOMÁREK J. 2000. Indicative value of *Pediastrum* and other coccal green algae in palaeocology. Folia Geobot., 35: 59–82.

JANKOVSKÁ V. & KOMÁREK J. 2006. *Pediastrum* and some other algae in pollenslides. International workshop on Non- Pollen- Palynomorphs – NPPs Innsbruck.

JASIEWICZ A. 1951. Bluszcz. Chrońmy Przyrodę Ojczystą, 9/10: 3–11.

HAAS J.N., RICHOZ I., TINNER W. & WICK L. 1998. Synchronous Holocene climatic oscillations recorded on the Swiss Plateau and at the timberline in the Alps. Holocene, 8(3): 301–304.

KARPIŃSKA-KOŁACZEK M. 2011. Przemiany szaty roślinnej w otoczeniu Jeziora Czarnego (Polska NE) na podstawie kompleksowej analizy palinologicznej – wstępne wyniki badań: 61–62. In: Karasiewicz M.T., Noryśkiewicz A.N., Hulisz P. & Winter H. (eds), V Polska Konferencja Paleobotaniki

Czwartorzędu 'Człowiek i jego wpływ na środowisko przyrodnicze w przeszłości i czasach historycznych', Górzno, 13–17 czerwca 2011. Materiały konferencyjne. Państwowy Instytut Geologiczny – Państwowy Instytut Badawczy, Warszawa.

KARPIŃSKA-KOŁACZEK M., KOŁACZEK P., KUPRYJANOWICZ M. & WINTER H. 2009. Późnoglacjalna i holoceńska historia roślinności Niecki Skaliskiej na podstawie analizy pyłkowej: 9–11. In: Pochocka-Szwarc K. & Winter H. (eds), IV Polska Konferencja Paleobotaniki Czwartorzędu „Późnoglacjalne i holoceńskie zmiany środowiska abiotycznego i ich zapis paleobotaniczny", Jeziorowskie, 16–19 czerwca 2009. Materiały konferencyjne. Państwowy Instytut Geologiczny, Warszawa.

KARPIŃSKA-KOŁACZEK M., KOŁACZEK P., STACHOWICZ-RYBKA R. & OBIDOWICZ A. 2013. Palaeobotanical studies on Late Glacial and Holocene vegetation development and transformations of the 'Wielkie Błoto' mire near Gołdap (north-eastern Poland). Acta Palaeobot., 53(1): 53–68.

KIAGE L.M. & LIU K.-B. 2009. Palynological evidence of climate change and land degradation in the Lake Baringo area, Kenya, East Africa, since AD 1650. Palaeogeogr., Palaeoclim., Palaeoecol., 279: 60–72.

de KLERK P., COUWENBERG J. & JOOSTEN H. 2007. Short-lived vegetational and environmental change during the Preboreal in the Biebrza Upper Basin (NE Poland). Quatern. Sci. Rev., 26: 1975–1988.

KOMÁREK J. & JANKOVSKÁ V. 2001. Reviev of the green algal genus *Pediastrum*; Implication for pollen-analytical research. Bibliotheca Phycologica. Berlin-Stuttgart.

KONDRACKI J. 2002. Geografia Polski. Mezoregiony fizyczno-geograficzne. Wydawnictwo Naukowe PWN, Warszawa.

KUPRYJANOWICZ M. 2002. Przemiany roślinności w sąsiedztwie stanowiska 41 w Paprotkach Kolonii na Pojezierzu Mazurskim (zusammenfassung: Der Wandel der Pflanzenwelt in der Nachbarschaft der Fundstelle 41 in Paprotki Kolonia an der Masurischen Seenplatte: 55–76. In: Karczewska M., Karczewski M., Pirożnikow E. (eds), Die Siedlung aus der Römischen Kaiserzeit und der Völkerwanderungszeit in Paprotki Kolonia Fundstelle 41 in der Masurischen Seenplatte. (Band 2. Paläoökologische Analysen). Podlasko-Mazurska Pracownia Archeologiczna, Białystok.

KUPRYJANOWICZ M. 2004. Postglacjalny rozwój roślinności rejonu jeziora Wigry. Wstępne wyniki analizy pyłkowej osadów z Zatoki Słupiańskiej (summary: Postglacial development of the vegetation in the Lake Wigry vicinity. Preliminary results of pollen analysis of sediments from Słupiańska Bay). Rocz. August.-Suwal., 4: 37–44.

KUPRYJANOWICZ M. 2007. Postglacial development of vegetation in the vicinity of Wigry Lake. Geochronometria, 27: 53–66.

KUPRYJANOWICZ M. 2008. Badania palinologiczne w Polsce północno-wschodniej (summary: Palynological studies in north-eastern Poland). In: Madeyska E. & Wacnik A. (eds), Polska północno-wschodnia w holocenie. Przyroda-klimat-człowiek. Bot. Guidebooks, 30: 77–95.

KUPRYJANOWICZ M. & JUROCHNIK A. 2009. Zapis pyłkowy postglacjalnych zmian roślinności zawarty w osadach dennych jeziora Wigry (summary: Pollen record of postglacial vegetation changes as contained in bottom deposits of Wigry Lake): 181–198. In: Rutkowski J. & Krzysztofiak L. (eds), Jezioro Wigry. Historia jeziora w świetle badań geologicznych i paleoekologicznych. Stowarzyszenie 'Człowiek i Przyroda', Suwałki.

LATAŁOWA M. 1982. Postglacial vegetational changes in the eastern Baltic Coastal Zone of Poland. Acta Palaeobot., 22: 179–249.

LATAŁOWA M. 1988. A palaeobotanical study of the peat-bog at Orle in the Reda-Łeba ice-marginal valley. Folia Quatern., 58: 45–58.

LATAŁOWA M. 2004. Late Glacial 14,000–10,000 ^{14}C yr BP (ca 15,500 (16,000)–11,500 cal yr BP): 385–392. In: Ralska-Jasiewiczowa M., Latałowa M., Wasylikowa K., Tobolski K., Madeyska E., Wright H.E., Jr. & Turner C. (eds), Late Glacial and Holocene history of vegetation in Poland based on isopollen maps. W. Szafer Institute of Botany, Polish Academy of Sciences, Kraków.

LATAŁOWA M., TOBOLSKI K. & NALEPKA D. 2004. *Pinus* L. subgenus *Pinus* (subgen. *Diploxylon* (Koehne) Pilger) – Pine: 165–177. In: Ralska-Jasiewiczowa M., Latałowa M., Wasylikowa K., Tobolski K., Madeyska E., Wright H.E., Jr. & Turner C. (eds), Late Glacial and Holocene history of vegetation in Poland based on isopollen maps. W. Szafer Institute of Botany, Polish Academy of Sciences, Kraków.

LAUTERBACH S., BRAUER A., ANDERSEN N., DANIELOPOL D.L., DULSKI P., HÜLS M., MILECKA K., NAMIOTKO T., PLESSEN B., von GRAFENSTEIN U. & DECLAKES PARTICIPANTS. 2011. Multi-proxy evidence for early to mid-Holocene environmental and climatic changes in northeastern Poland. Boreas, 40: 57–72.

LORENC H. (ed.) 2005. Atlas Klimatu Polski. Instytut Melioracji i Gospodarki Wodnej, Warszawa.

MACKLIN M.G., BENITO G., GREGORY K.J., JOHNSTONE E., LEWIN J., MICHCZYŃSKA D.J., SOJA R., STARKEL L. & THORNDYCRAFT V.R. 2006. Past hydrological events reflected in the Holocene fluvial record of Europe. Catena, 66: 145–154.

MADEJA J., BAŁAGA K., HARMATA K. & NALEPKA D. 2004. *Pteridium aquilinum* (L.) Kuhn – Bracken: 327–335. In: Ralska-Jasiewiczowa M., Latałowa M., Wasylikowa K., Tobolski K., Madeyska E., Wright H.E., Jr. & Turner C. (eds), Late Glacial and Holocene history of vegetation in Poland based on isopollen maps. W. Szafer Institute of Botany, Polish Academy of Sciences, Kraków.

MAGNY M. & BÉGEOT C. 2004. Hydrological changes in the European midlatitudes associated with freshwater outburst from Lake Agassiz during the Younger Dryas event and early Holocene. Quatern. Res., 61: 181–192.

MAGNY M., BÉGEOT C., GUIOT J. & PEYRON O. 2003. Contrasting patterns of hydrological changes in Europe in response to Holocene climate cooling phases. Quatern. Sci. Rev., 22: 1589–1596.

MAKSIMOW A., OKRUSZKO H. & LIWSKI S. 1953. Torfowisko Kuwasy. Roczn. Nauk Roln., Ser. A, 68(1): 1–32.

MANGERUD J., ANDERSEN S.T., BERGLUND B.E. & DONNER J.J. 1974. Quaternary stratigraphy of Norden, a proposal for terminology and classification. Boreas, 3(3): 109–128.

MATUSZKIEWICZ J.M. 2001. Zespoły leśne Polski. Wydawnictwo Naukowe PWN, Warszawa.

MATUSZKIEWICZ J.M. 2005. Przewodnik do badań fitosocjologicznych. Wydawnictwo Naukowe PWN, Warszawa.

MILECKA K. 1997 (unpubl.). Miłuki – sprawozdanie z badań osadów biogenicznych metodą analizy pyłkowej w 1997 roku. Manuscript, Adam Mickiewicz University, Department of Biogeography and Palaeoecology.

MIOTK-SZPIGANOWICZ M., ZACHOWICZ J., RALSKA-JASIEWICZOWA M. & NALEPKA D. 2004. *Corylus avellana* L. – Hazel: 79–87. In: Ralska-Jasiewiczowa M., Latałowa M., Wasylikowa K., Tobolski K., Madeyska E., Wright H.E., Jr. & Turner C. (eds), Late Glacial and Holocene history of vegetation in Poland based on isopollen maps. W. Szafer Institute of Botany, Polish Academy of Sciences, Kraków.

MOE D. & RACKHAM O. 1991. Pollarding and a possible explanation of the neolithic elmfall. Veget. Hist. Archaeobot., 1992(1): 63–68.

MOORE P.D., WEEB J.A. & COLLINSON M.E. 1991. Pollen analysis. Blackwell Scientific Publications, Oxford.

NALEPKA D. 1995. Palynological investigations of an archaeological site at Dudka (profile D1-26). Prz. Archeol., 43: 62–64.

NALEPKA D. & WALANUS A. 2003. Data processing in pollen analysis. Acta Palaeobot., 43(1): 125–134.

NORYŚKIEWICZ B. & RALSKA-JASIEWICZOWA M. 1989. Type region P-w: Dobrzyń-Olsztyn Lake District. In: Ralska-Jasiewiczowa M. (ed.), Environmental changes recorded in lakes and mires of Poland during the last 13 000 years. Part three. Acta Palaeobot., 29(2): 85–93.

NORYŚKIEWICZ B., FILBRANDT-CZAJA A., NORYŚKIEWICZ A.M. & NALEPKA D. 2004. *Helianthemum* Mill. – Rock-rose: 305–308. In: Ralska-Jasiewiczowa M., Latałowa M., Wasylikowa K., Tobolski K., Madeyska E., Wright H.E., Jr. & Turner C. (eds), Late Glacial and Holocene history of vegetation in Poland based on isopollen maps. W. Szafer Institute of Botany, Polish Academy of Sciences, Kraków.

OBERDORFER E. 1990. Pflanzensoziologiche Exkursionsflora. 6th ed. Verlag Eugen Ulmer, Stuttgart.

OBIDOWICZ A., RALSKA-JASIEWICZOWA M., KUPRYJANOWICZ M., SZCZEPANEK K., LATAŁOWA M. & NALEPKA D. 2004. *Picea abies* (L.) Karst. – Spruce: 147–157. In: Ralska-Jasiewiczowa M., Latałowa M., Wasylikowa K., Tobolski K., Madeyska E., Wright H.E., Jr. & Turner C. (eds), Late Glacial and Holocene history of vegetation in Poland based on isopollen maps. W. Szafer Institute of Botany, Polish Academy of Sciences, Kraków.

OŁTUSZEWSKI W. 1937. Historia lasów Pojezierza Suwalsko-Augustowskiego w świetle analizy pyłkowej. Poznańskie Towarzystwo Przyjaciół Nauk, Prace Komisji Matematyczno-Przyrodniczej, Seria B, 8(4): 1–65.

OKUNIEWSKA-NOWACZYK I., MILECKA K., MAKOHONIENKO M., HARMATA K., MADEJA J. & NALEPKA D. 2004. *Secale cereale* L. – Rye: 347–353. In: Ralska-Jasiewiczowa M., Latałowa M., Wasylikowa K., Tobolski K., Madeyska E., Wright H.E., Jr. & Turner C. (eds), Late Glacial and Holocene history of vegetation in Poland based on isopollen maps. W. Szafer Institute of Botany, Polish Academy of Sciences, Kraków.

PAGE C.N. 1986. The strategies of bracken as a permanent ecological opportunist: 173–181. In: Smith R.T. & Taylor J.A. (eds), Bracken, ecology, land use and control technology. 1985 July 1– July 5, Leeds, England, Lancs; The Parthenon Publishing Group Limited.

PARKINSON S.M., KILLHAM K. & WAINWRIGHT M. 1990. Assimilation of $^{14}CO_2$ by *Fusarium oxysporum* grown under oligotrophic conditions. Mycol. Res., 94: 959–964.

PARKINSON S.M., JONES R., MEHARG A.A., WAINWRIGHT M. & KILLHAM K. 1991. The quantity and fate of carbon assimilated from $^{14}CO_2$ by *Fusarium oxysporum* grown under oligotrophic and near oligotrophic conditions. Mycol. Res., 95: 1345–1349.

PASZEWSKI A. 1937. Dalsze badania nad historią lasów Puszczy Białowieskiej na podstawie analizy pyłkowej torfowisk. Rocz. Nauk Roln., 41(1): 183–187.

PASZEWSKI A. & POZNAŃSKI F. 1936. Materjały do historji lasów Puszczy Białowieskiej. Rocz. Nauk Roln., 36(1): 59–67.

PAWLIKOWSKI M., RALSKA-JASIEWICZOWA M., SCHONBORN W., STUPNICKA E. & SZEROCZYŃSKA K. 1982. Woryty near Gietrzwałd, Olsztyn Lake District, NE Poland – vegetational history and lake development during the last 12 000 years. Acta Palaeobot., 22(1): 85–116.

PAWŁOWSKI B. 1959. Szata roślinna gór polskich: 189–257. In: Szafer W. (ed.), Szata roślinna Polski, II. Państwowe Wydawnictwo Naukowe, Warszawa.

POCHOCKA-SZWARC K. 2003 (unpubl.). Szczegółowa mapa geologiczna Polski w skali 1: 50 000, ark. Banie Mazurskie i Mażucie z objaśnieniami. Państw. Inst. Geol.

POCHOCKA-SZWARC K. 2005. Zagadka zaniku jeziora skaliskiego w Krainie Wielkich Jezior Mazurskich (summary: Mystery of the ancient Skaliska Lake in the Mazury Lakeland (NE Poland)). Prz. Geol., 53(10): 873–878.

POCHOCKA-SZWARC K. 2013. Some aspects of the last glaciation in the Mazury Lake District (northeastern Poland). Acta Palaeobot. 53(1): 3–8.

POCHOCKA-SZWARC K. & KOŁACZEK P. 2009. Stanowisko 2 – Parchatka W6: 64–65. In: Pochocka K. & Winter H. (eds), IV Polska Konferencja Paleobotaniki Czwartorzędu 'Późnoglacjalne i holoceńskie zmiany środowiska abiotycznego i ich zapis paleobotaniczny', Jeziorowskie, 16–19 czerwca 2009. Materiały konferencyjne. Państwowy Instytut Geologiczny, Warszawa.

POCHOCKA-SZWARC K. & LISICKI S. 2001. Szczegółowa mapa geologiczna Polski w skali 1: 50 000, ark. Budry z objaśnieniami. Centr. Arch. Geol. Państw. Inst. Geol., Warszawa.

POCHOCKA-SZWARC K. & WINTER H. 2009. Stanowisko 3 – Rapa W5: 66–67. In: Pochocka K. & Winter H. (eds), IV Polska Konferencja Paleobotaniki Czwartorzędu „Późnoglacjalne i holoceńskie zmiany środowiska abiotycznego i ich zapis paleobotaniczny", Jeziorowskie, 16–19 czerwca 2009. Materiały konferencyjne, Państwowy Instytut Geologiczny, Warszawa.

POCHOCKA-SZWARC K., STACHOWICZ-RYBKA R., OBIDOWICZ A., KOŁACZEK P. & KARPIŃSKA M. 2006. Wstępne wyniki badań osadów i roślinności z kopalnego zbiornika jeziornego z okolic Węgorzewa: 25–27. In: Wacnik A. & Madeyska E. (eds), Konferencja naukowa 'Polska północno-wschodnia w holocenie. Przyroda-Klimat-Człowiek', 23 czerwca 2006, Streszczenia referatów i posterów, Instytut Botaniki PAN, Kraków.

POCHOCKA-SZWARC K., STACHOWICZ-RYBKA R., OBIDOWICZ A., KOŁACZEK P. & KARPIŃSKA-KOŁACZEK M. 2008. Wstępne wyniki badań sedymentologicznych i paleobotanicznych osadów kopalnego zbiornika jeziornego z okolic Węgorzewa (summary: Preliminary reports of the sedimentological and palaeobotanical research of deposits from fos sil Lake basin in the Węgorzewo area). In: Wacnik A. & Madeyska E. (eds), Polska północno-wschodnia w holocenie. Człowiek i jego środowiska. Bot. Guidebooks, 30: 133–146.

POCHOCKA-SZWARC K., KUPRYJANOWICZ M., STECZKOWSKA M., KARPIŃSKA-KOŁACZEK M., STACHOWICZ-RYBKA R. & MIROSŁAW-GRABOWSKA J. 2009. Stanowisko 4 – Budzewo W4: 68–74. In: Pochocka K. & Winter H. (eds), IV Polska Konferencja Paleobotaniki Czwartorzędu 'Późnoglacjalne i holoceńskie zmiany środowiska abiotycznego i ich zapis paleobotaniczny', Jeziorowskie, 16–19 czerwca 2009. Materiały konferencyjne. Państwowy Instytut Geologiczny, Warszawa.

PUNT W. 1976. Sparganiaceae and Typhaceae: 75–88. In: Punt W., Janssen C.R., Reitsma T. & Clarke G.C.S. (eds), The Northwest European Pollen Flora, I. Elsevier Scientific Publishing Company, Amsterdam–Oxford–New York.

RALSKA-JASIEWICZOWA M. 1966. Osady denne Jeziora Mikołajskiego na Pojezierzu Mazurskim w świetle badań paleobotanicznych (summary: Bottom sediments of the Mikołajki Lake (Masurian Lake District) in the light of palaeobotanical investigations). Acta Palaeobot., 7(2): 1–118.

RALSKA-JASIEWICZOWA M. 1989. Type region P-x: Masurian Great Lakes District. In: Ralska-Jasiewiczowa M. (ed.), Environmental changes recorded in lakes and mires of Poland during the last 13 000 years. Acta Palaeobot., 29(2): 95–100.

RALSKA-JASIEWICZOWA M. 2004. Late Holocene 5000–2500 ^{14}C yr BP (ca. 5700/5800–2550 cal yr BP): 405–409. In: Ralska-Jasiewiczowa M., Latałowa M., Wasylikowa K., Tobolski K., Madeyska E., Wright H.E., Jr. & Turner C. (eds), Late Glacial and Holocene history of vegetation in Poland based on isopollen maps. W. Szafer Institute of Botany, Polish Academy of Sciences, Kraków.

RALSKA-JASIEWICZOWA M. & LATAŁOWA M. 1996. Poland: 403–472. In: Berglund B.E., Birks H.J.B., Ralska-Jasiewiczowa M. & Wright H.E. (eds), Palaeoecological events during the last 15 000 years. Regional synthesis of Palaeoecological Studies of Lakes and Mires in Europe. J. Wiley & Sons Ltd, Chichester, New York.

RALSKA-JASIEWICZOWA M.& van GEEL B. 1998. Pollen record of anthropogenic changes of vegetation in the Lake Gościąż region from AD 1660 until recent times: 318–326. In: Ralska-Jasiewiczowa M., Goslar T., Madeyska T. & Starkel L. (eds.), Lake Gosciąż, Central Poland, a monographic study. W. Szafer Institute of Botany, Polish Academy of Sciences, Kraków.

RALSKA-JASIEWICZOWA M. & WACNIK A. 2006. Kształtowanie się szaty roślinnej w rejonie kopalnego jeziora Staświńskiego i jej związek z lokalnym osadnictwem pradziejowym: 27–29. In: Wacnik A. & Madeyska E. (eds), Konferencja naukowa 'Polska północno-wschodnia w holocenie. Przyroda-Klimat-Człowiek', 23 czerwca 2006. Streszczenia referatów i posterów, Instytut Botaniki im. W. Szafera PAN, Kraków.

REILLE M. 1992. Pollen et spores d'Europe et d'Afrique du Nord. Laboratoire de Botanique Historique et Palynologie, Marseille.

REIMER P.J., BAILLIE M.G.L. BARD E., BAYLISS A., BECK J.W., BLACKWELL P.G., BRONK RAMSEY C., BUCK C.E., BURR G.S., EDWARDS R.L., FRIEDRICH M., GROOTES P.M., GUILDERSON T.P., HAJDAS I., HEATON T.J., HOGG A.G., HUGHEN K.A., KAISER K.F., KROMER B., MCCORMAC G., MANNING S., REIMER R.W., RICHARDS D.A., SOUTHON J.R., TALAMO S., TURNEY C.S.M., van der PLICHT J. & WEYHENMEYER C.E. 2009. IntCal09 and Marine09 radiocarbon age calibration curves, 0–50,000 years cal. BP. Radiocarbon, 51(4): 1111–1150.

RUTKOWSKI J., KRÓL K. & SZCZEPAŃSKA J. 2007. Lithology of the profundal sediments in Słupiańska Bay (Wigry Lake, NE Poland) – introduction to interdisciplinary study. Geochronometria, 27: 47–52.

SIENKIEWICZ E. 2013. Limnological record inferred from diatoms in the sediments of the Skaliska Lake (north-eastern Poland). Acta Palaeobot., 53(1): 99–104.

STACHOWICZ-RYBKA R. & OBIDOWICZ A. 2013. The development and genesis of a small thaw lake filling the Skaliska Basin during the Late Glacial and Holocene. Acta Palaeobot. 53(1): 69–91.

STACHOWICZ-RYBKA R., GĄSIOROWSKI M., KARPIŃSKA-KOŁACZEK M., KOŁACZEK P., KRAWCZYK M., KUPRYJANOWICZ M., MIROSŁAW-GRABOWSKA J., OBIDOWICZ A., POCHOCKA-SZWARC K., SIENKIEWICZ E. & WINTER H. 2009. Późnoglacjalne i holoceńskie zmiany środowiska przyrodniczego w rejonie kopalnego jeziora skaliskiego (Kraina Wielkich Jezior Mazurskich): 35–36 In: Winter H. & Pochocka-Szwarc K. (eds), IV Polska Konferencja Paleobotaniki Czwartorzędu 'Późnoglacjalne i holoceńskie zmiany środowiska abiotycznego i ich zapis paleobotaniczny', Jeziorowskie 16–19 czerwca 2009. Państwowy Instytut Geologiczny, Warszawa.

STANČIKAITÉ M., KABALIENÉ M., OSTRAUSKAUS T. & GUOBYTÉ R. 2002. Environment and man around Lakes Dűba and Pelesa, SE Lithuania, during the Late Glacial and Holocene. Geol, Quart., 46: 391–409.

STARKEL L. 2002. Changes in the frequency of extreme events as the indicator of climate change in the Holocene (in fluvial systems). Quartern. Internat., 91: 25–32.

STASIAK J. 1961. Pieczonki – profile of lacustrine sediments; Allerød, Younger Dryas and Holocene. 6th INQUA Congress Publications, Guide Book of Excursion D: 54–59.

STASIAK J. 1963. Historia jeziora Kruklin w świetle osadów strefy litoralnej (summary: History of Kruklin lake as revealed by the deposits of its littoral zone). Prace Geogr. IG PAN, 42: 1–93.

STASIAK J. 1965. Badania nad starożytnym krajobrazem Pojezierza Suwalskiego w rejonie Szwajcarii. Prace Białostoc. Tow. Nauk., 7: 1–42.

STASIAK J. 1966. History of lakes on the Younger-Glacial areas on the north-eastern Poland. Intern. Hydrol. Decade, 2: 847–851.

STASIAK J. 1967. Age and evolution of meltwater basins in the Masurian Lake District. Baltica, 3: 273–285.

STASIAK J. 1971. Holocen Polski północno-wschodniej. Rozpr. Uniw. Warszaw., 47: 1–105.

STASIAK J. 1979. Wiek Jeziora Maliszewskiego i bagien w Kotlinie Biebrzy (summary: The age of Lake Maliszewskie and of bogs in the Biebrza Valley). Prace i Studia IG UW, 23: 129–172.

STOCKMARR J. 1971. Tablets with spores used in absolute pollen analysis. Pollen et Spores, 13(4): 615–621.

SZWARCZEWSKI P. & KUPRYJANOWICZ M. 2008. Etapy rozwoju zagłębień bezodpływowych w okolic Sejn (summary: The evolutionary stages of local depressions in the Sejny area). In: Wacnik A. & Madeyska E. (eds), Polska północno-wschodnia w holocenie. Człowiek i jego środowiska. Bot. Guidebooks, 30: 195–205.

TOBOLSKI K. 2000. Przewodnik do oznaczania torfów i osadów jeziornych. Wydawnictwo Naukowe PWN, Warszawa.

TOBOLSKI K. & NALEPKA D. 2004. *Fraxinus excelsior* L. – Ash: 105–110. In: Ralska-Jasiewiczowa M., Latałowa M., Wasylikowa K., Tobolski K., Madeyska E., Wright H.E., Jr. & Turner C. (eds), Late Glacial and Holocene history of vegetation in Poland based on isopollen maps. W. Szafer Institute of Botany, Polish Academy of Sciences, Kraków.

UGGLA H. 1956. Ogólna charakterystyka gleb Pojezierza Mazurskiego. Zesz. Nauk. WSR w Olsztynie, 1: 15–54.

UGGLA H. 1969a. Gleby gytiowe Pojezierza Mazurskiego. I. Ogólna charakterystyka gleb gytiowo-bagiennych i gytiowo-murszowych. Zesz. Nauk. WSR, 25. 702: 563–582.

UGGLA H. 1969b. Gleby gytiowe Pojezierza Mazurskiego. II. Właściwości fizyczne, chemiczne i biologiczne gleb gytiowo-bagiennych i gytiowo-murszowych. Zesz. Nauk. WSR, 25. 703: 584–606.

WACNIK A. 2009a. From foraging to farming in the Great Mazurian Lake District: palynological studies on Lake Miłkowskie sediments, northeast Poland. Veget. Hist. Archaeobot., 18: 187–203.

WACNIK A. 2009b. Vegetation development in the Lake Miłkowskie area, north-eastern Poland, from the Plenivistulian to the late Holocene. Acta Palaeobot., 49(2): 287–335.

WACNIK A. & RALSKA-JASIEWICZOWA M. 2008. Przemiany szaty roślinnej w rejonie kopalnego Jeziora Staświńskiego i jej związek z lokalnym osadnictwem pradziejowym (summary: Development of vegetation in relation to local prehistoric settlement in the fossil Lake Staświńskie (NE Poland). In: Wacnik A. & Madeyska E. (eds), Polska północno-wschodnia w holocenie. Człowiek i jego środowiska. Bot. Guidebooks, 30: 207–228.

WACNIK A., GOSLAR T. & CZERNIK J. 2012. Vegetation changes caused by agricultural societies in the Great Mazurian Lake District. Acta Palaeobot., 52(1): 59–104.

WALANUS A. & NALEPKA D. 2010. Calibration of Mangerud's boundaries. Radiocarbon, 52: 1639–1644.

WALKER M. 2005. Quaternary Dating Methods. J. Willey & Sons, Chechester, New York.

WICK L., van LEEUWEN J.F.N., van der KNAAP W.O. & LOTTER A.F. 2003. Holocene vegetation development in the catchment of Sagistalsee (1935 m asl), a small lake in the Swiss Alps. J. Paleolimnol., 30: 261–272.

WOHLFARTH B., SKOG G., POSSNERT G. & HOLMQUIST B. 1998. Pitfalls in the AMS radiocarbondating of terrestrial macrofossils. J. Quater. Sci., 13(2): 137–145.

WORONKO B. & POCHOCKA-SZWARC K. 2013. Depositional environment of a fan delta in a Vistulian proglacial lake (Skaliska Basin, north-eastern Poland). Acta Palaeobot., 53(1): 9–21.

WOŚ A. 1999. Klimat Polski. Wydawnictwo Naukowe PWN. Warszawa: 196–197.

YU Z. & EICHER U. 1998. Abrupt Climate Oscillations During the Last Deglaciation in Central North America. Science, 282: 2235–2238.

ZACHOWICZ J., RALSKA-JASIEWICZOWA M., MIOTK-SZPIGANOWICZ G., NALEPKA D. 2004. *Ulmus* L. – Elm; 225–235. In: Ralska-Jasiewiczowa M., Latałowa M., Wasylikowa K., Tobolski K., Madeyska E., Wright H.E. Jr. & Turner Ch. (eds), Late Glacial and Holocene history of vegetation in Poland based on isopollen maps, W. Szafer Institute of Botany, Polish Academy of Sciences, Kraków.

ZAJĄC A. & ZAJĄC M. (eds) 2001. Distribution Atlas of Vascular Plants in Poland. Pracownia Chorologii Komputerowej Instytutu Botaniki Uniwersytetu Jagiellońskiego, Kraków.

ZAWISZA E. & SZEROCZYŃSKA K. 2007. The development history of Wigry Lake as shown by subfossil Cladocera. Geochronometria, 27: 67–74.

ŻUREK S. 1970. Geneza torfowiska Rolniczego Zakładu Badawczego Biebrza na tle paleogeografii środowiska. Bibl. Wiad. IMUZ, 33: 225–243.

ŻUREK S. & PAZDUR A. 1999. Zapis zmian paleohydrologicznych w rozwoju torfowisk Polski (summary: Palaeohydrological changes in the development of Polish peat-bogs): 215–228. In: Pazdur A., Bluszcz A., Stankowski W. & Starkel L. (eds), Geochronologia górnego czwartorzędu Polski w świetle datowania radiowęglowego i luminescencyjnego. Instytut Fizyki Politechniki Śląskiej, Gliwice.

ŻUREK S., MICHCZYŃSKA D.J. & PAZDUR A. 2002. Time record of palaeohydrologic changes in the development of mires during the Late Glacial and Holocene, North Podlasie Lowland and Holy Cross Mts. Geochronometria, 21: 109–118.

ŻUREK S., BIŃKA K., SZAŃKOWSKI M. & KŁOSOWSKI S. 2006. Overgrowing of lakes exemplified by Gajlik and Malona Mires (Sejny Lake District). Limnol. Rev., 6: 295–304.

ZARZĄD POWIATU W GOŁDAPI 2004. Plan Rozwoju Lokalnego powiatu gołdapskiego. (Available on: http://bip.warmia.mazury.pl/powiat_goldapski/190/36/PLAN_ROZWOJU_LOKALNEGO_POWIATU_GOLDAPSKIEGO/).