

Late Glacial and Holocene plant cover in Węgliny, Lubsza Plain, south-west Poland, based on pollen analysis

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ABSTRACT. Late Glacial (since Oldest Dryas) and Holocene (to Subatlantic) changes of vegetation at the Węgliny site (south-west Poland) are reconstructed based mainly on pollen analysis of five cores from the palaeobasin (anaerobic sediments). The chronology of the described events is based on palynological comparison with the Lubsza Plain environs, based on LPAZs from several published pollen diagrams on ^{14}C data, and multiple cryptotephra levels determined in the Węgliny profiles. The Węgliny record integrates well into the north European Holocene and Late Glacial biostratigraphic framework. The Węgliny site is the next (fourth) locality in Poland where the Laacher See Tephra (LST) horizon within the Allerød chronozone was identified.

KEYWORDS: palynology, vegetation changes, Late Glacial, Holocene, Laacher See Tephra, Lower Lusatia, Poland

INTRODUCTION

The Lubsza Plain (Lower Lusatia) is poorly investigated in terms of changes in Late Glacial and Holocene vegetation. Archaeological and geomorphological studies have been accompanied by palynological analyses only (Nowaczyk & Okuniewska-Nowaczyk 1992, Kobusiewicz & Kabaciński 1993, Masojć et al. 2006).

The region is situated in the marginal zone of the Vistulian (Weichselian) glaciation (Kozarski 1995), showing young glacial and periglacial landforms in a relatively small area.

The aim of this study was to provide a reconstruction, based on pollen analysis of sections from the Węgliny site, of vegetation changes in this region in the Late Glacial and Holocene, to describe the palaeobasin and changes affecting it, and to reconstruct the habitat conditions prevailing in the study area in the past. The southern part of the Lubsza Plain, including relatively shallow deposits of brown coal, among the largest in Europe, is planned to be the site of an open pit mine in the Brody-Gubin

area, and a power station. Thus the need to investigate this area before it is irreversibly altered.

RESEARCH AREA

GEOLOGICAL SETTING OF THE STUDY AREA IN THE QUATERNARY

The Lubsko Upland (Lubsza Plain), located in the western part of the marginal zone of the Baltic glaciation (Bartkowski 1963, Kozarski 1963, Kondracki 2002), is surrounded by the Bóbr river valley from the east, the Nysa Łużycka river valley from the west (Fig. 1), the Głogów-Baruth ice-marginal valley from the south, and the Warsaw-Berlin ice-marginal valley from the north (Ratajczak-Szczerba 2010). One of the physico-geographical units within the Lubsko Upland is the Lubsza Plain, bordered by the Brody Ridge from the south-west, the Zasięki Basin from the south, the

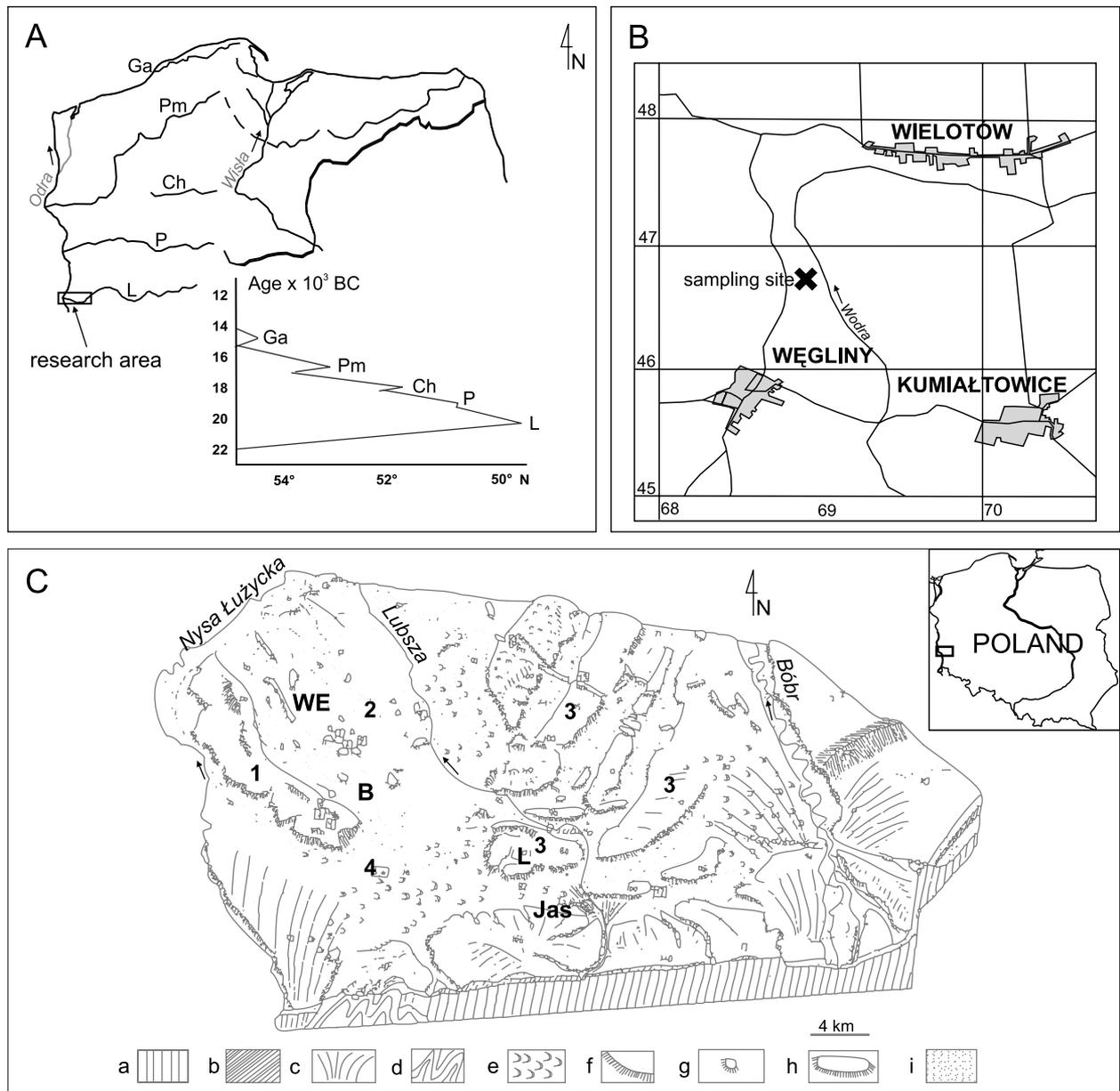


Fig. 1. Map showing the geographical situation of the Węgliny site in Poland. **A:** general extent of the Last Glacial Maximum of the Vistulian glaciation; **L** – Leszno phase, **P** – Poznań phase, **Ch** – Chodzież phase, **Pm** – Pomorze phase, **Ga** – Gardno phase (acc. Kozarski 1995, modified). **B:** Węgliny site; fragment of 1:10000 topographic map (revised). **C:** marginal zone of the Vistula glaciation on the Lubsza Plain (Lubsko Upland); **1** – Brody Ridge, **2** – Lubsza Plain, **3** – Lubsko-Bobrowice Remnants, **4** – Zasięki Basin (acc. Bartkowski, modified); **WE** – Węgliny, **L** – Lubska, **B** – Brody, **Jas** – Jasień; **a** – poznań silt (Pliocene), **b** – loamy moraines (older Pleistocene), **c** – alluvial fans, **d** – glactectonically disturbed deposits (Miocene and older Pleistocene), **e** – dunes, **f** – edges, **g** – kame hills, **h** – esker hills, **i** – sands and gravels (Pleistocene)

Lubsko-Bobrowice Remnants from the east, and the Gubin Heights from the north (Fig. 1; Bartkowski 1961, Kondracki 1988, 2002, Bartczak 2001a, b, Chmal 2001a, b). The study site is in a valley of a subordinate tributary of the Nysa Łużycka river – the Wodra (Wdra) river (Fig. 1). In the Pleistocene the area was repeatedly covered by ice (Mojski 2005). The limit of the last Scandinavian glaciation in the discussed area has not yet been determined unequivocally. Following Bartkowski (1961, 1963, 1967), the ice-sheet reached the Brody-

Drewitz Ridge and at its foot, from the north, formed a glacial channel. During its areal disappearance, the ice-sheet was disintegrated into numerous blocks of dead ice, preserving the above-mentioned channel, while fluvioglacial accumulation resulted in the development of kames and eskers (op. cit.). However, Milewicz (1992) identifies the above-distinguished forms of the Lubsza Plain as end moraines (Fig. 1) of the Leszno phase, which shifts the extent of the Baltic ice-sheet to the north of the Brody-Drewitz Ridge and of the depression already

described as a glacial channel (Głowacki 2006). According to Bartczak (2001a, b), initially, in the anaglacial phase, the area between Brody and Węgliny in the Lubsza Plain was the site of formation of a local ice-dammed lake, most likely originally larger, however, with part of its sediments damaged by the water of the ice-marginal valley. The thrust of the ice-sheet on this site, recorded as end moraines (sands and locally occurring tills), determined the Last Glacial Maximum of the Vistulian glaciation (Leszno phase) to be limited by the northern peripheries of the Brody Ridge, to the west of Węgliny, and to the south of Brody (op. cit.).

The deglaciation of the ice-sheet resulted in the development of numerous positive forms such as pushed moraines (Chmal 2001a, b), end moraines (serving as evidence of a subsequent stage of the ice-sheet stillstand), kames, eskers, and sandurs, as well as concave forms (remains of buried blocks of dead ice). Subglacial channels were also formed (due to subglacial erosion of the stagnant or retreating ice-sheet which dissected the pre-Quaternary sediments (Milewicz 1992) and became filled with fluvio-glacial and biogenic sediments (plains of biogenic accumulation). The channels were most frequently oriented NW-SE and subordinately oriented SW-NE. One of them, meridionally oriented, passed to the west of Strzegów through Węgliny (where it branched) to Brodzkie Lake (op. cit.). This was also the time of origin of alluvial fans by the accumulative activity of rivers flowing into the Głogów-Baruth ice-marginal valley from the south (op. cit.). The north-central part of the Lubsza Plain, located within the Baltic glaciation, is typified by young-glacial landscape (hilly postglacial lakelands, morainic plains, sandur hills) and valley landscape (flood valleys, terraces with dunes), while the southern part is typified by plain landscape (accumulation and denudation plains) with easily recognised hills (kames, eskers), hill-shaped moraines (end moraines) and a well developed river system (Kondracki 1988, 1994, 2002). The relief of the area includes clearly diversified forms not differing greatly in height. Many of them are of still-undiscovered origin and age, and the above-presented hypotheses are still being verified in ongoing studies (Nowaczyk 1996, 1998, Nowaczyk & Okuniewska-Nowaczyk 1992, 1999, Nowaczyk et al. 2002, Ratajczak & Tomczyk 2006, Głowacki 2006,

Ratajczak-Szczerba 2010). Nor is the genesis of the channel from the Lubsza Plain known precisely, and two hypotheses are considered. The first, formulated by Bartkowski (1963, 1967) suggests that the area was developed by erosive activity at the front or lobe of the advancing ice-sheet, which overlaid the Brody-Drewitz Ridge with sediments exarated from the basement. The second, by Milewicz (1992), posits that the ice-sheet stopped at the Biecz-Datyń-Węgliny line and that the concave form developed in consequence of outflow of proglacial water from the stagnant or retreating ice-sheet. The water penetrated the near vicinity of the Brody-Drewitz Ridge and, at its foot, eroded a depression (subglacial channel). Biogenic depressions formed within it likely originated from melting or burying of blocks of dead ice. This thesis is in part supported by Głowacki (2006) and his studies in the Brody channel. At the end of the Vistulian, after the retreat of the Baltic ice-sheet from the Lubsza Plain, the stadials were dominated by weathering processes (formation of frost cracks) and by dune-forming and denudation processes. Warmer periods initiated melting of the buried ice and accumulation of biogenic sediments. Following Alexandrowicz and Nowaczyk (1982), the melting of blocks of dead ice in the Wielkopolska (Greater Poland) area falls in the Allerød, while Wojciechowski (2000) dates the beginning of this process to the Bølling; the issue is still under discussion. Possibly the palaeolake examined in the present study is of similar origin. The basin is located in the Wodra valley, so the effect of this river on the developing lake should be considered. During the Bølling, most likely the block of dead ice melted out completely, initiating sedimentation of biogenic sediments. The presence of fluvial sands in the sections, possibly originating from the Oldest Dryas, may indicate fluvial activity affecting the study site in this period.

SOILS

The Lubsza Plain is dominated by podsols and pseudopodsols that developed on loose, sandy or slightly loamy deposits and are found on sandurs, alluvial fans, dunes, and some moraines. Small areas, mainly at lower altitudes, are covered by brown and black soils. Ice-marginal and river valleys comprise fluvisols as

well as (mostly in endorheic depressions) bog and peat soils (Kończak-Konarkowska 2005).

CLIMATE

The Lubsza Plain is controlled by transitional climate, strongly affected by oceanic climate (Wiszniewski 1973). The region is considered to be the warmest part of Poland, typified by a low temperature amplitude, relatively mild winters with brief snow cover, and slightly cooler summers marked by higher rainfall than in other parts of the country (Matuszkiewicz 2006). Mean annual temperature is 8°C, and annual rainfall is in the range of 500–600 mm (Lorenc 2005).

VEGETATION COVER

In the Lubsza Plain, most habitats are overgrown by forest complexes extending over 50% of the land, with pine (*Pinus sylvestris*) as the dominant species (ca 90%) (Demidowicz & Konopczyński 2011). Forests cover mainly the poorest types of soils, podsols (op. cit.). Pine forest (*Leucobryo-Pinetum*, Pomeranian-Silesian variant) and mixed coniferous forest (*Pino-Quercetum*) are the most frequent associations. Uplands and chains of end moraines

are overgrown by fresh mixed coniferous forest (*Quercu-Pinetum*, *Calamagrostio-Quercetum*) and acidophilous beech forest (*Luzulo pilosae-Fagetum*). Riverbanks are the site of ash-alder riparian forest (*Fraxino-Alnetum*), while more distant valleys and depressions have humid mixed coniferous forest associations (*Fago-Quercetum petraeae*) (Szafer 1972, Matuszkiewicz 2008). Many depressions and wetlands are covered by alder forest of the *Carici elongatae-Alnetum* association (Medwecka-Kornaś 1977). Blowouts and other endorheic depressions are overgrown by raised bogs (*Scheuchzerio-Caricetea nigrae*). Open and strongly insolated areas are covered by xerothermic grasslands of the *Festuco-Brometea* class (Tobolski 2000, Matuszkiewicz 2008, Jermaczek 2011).

HISTORY OF PALYNOLOGICAL STUDIES IN THE LUBSZA PLAIN

The palynological studies done in the area most frequently have accompanied archaeological research. The fortified settlement in Wicina (Fig. 2), built at the close of the Bronze Age, was inhabited by a population representing the Lusatian culture (Kołodziejki 1984).

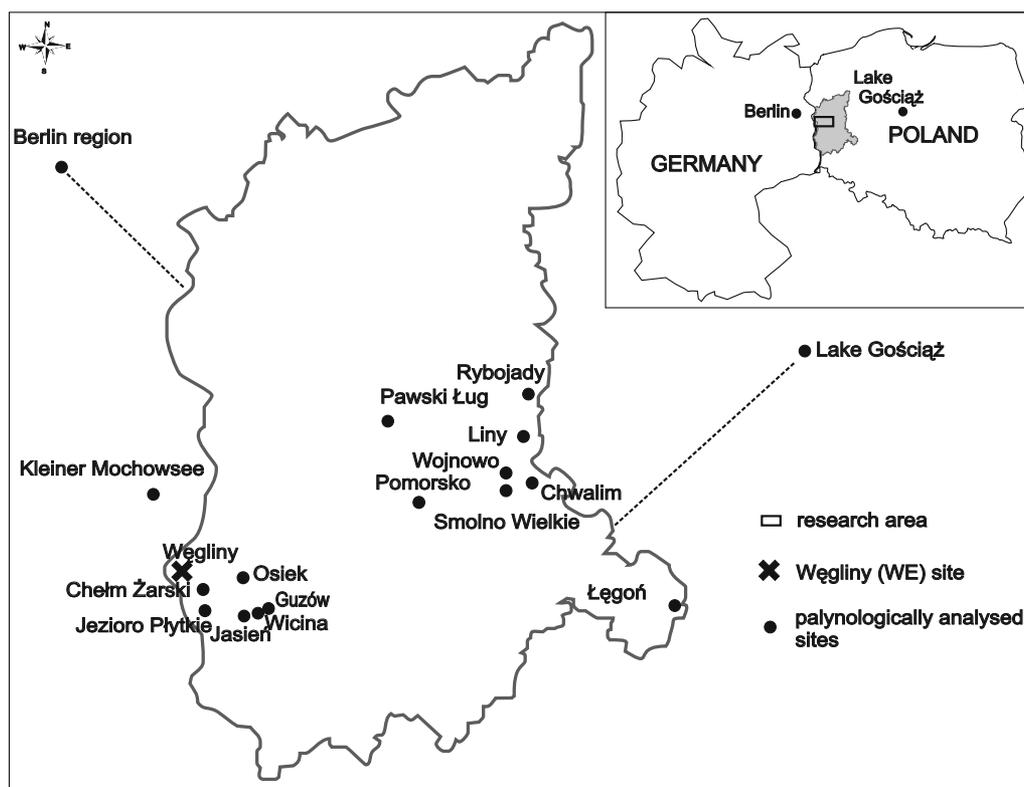


Fig. 2. Location of the Węgliny site, other palynologically analysed sites on the Lubsza Plain and adjacent German area, and reference sites (Lake Gościąż in central Poland) and in Berlin region

Palynological studies indicate that humans appeared on this land several thousands of years earlier (Nowaczyk & Okuniewska-Nowaczyk 1992, Nowaczyk et al. 2002). Studies of the archaeological excavation site at Chwalim (Fig. 2), where palaeo-, meso-, and para-Neolithic artefacts were found (Kobusiewicz & Kabaciński 1993), included reconstruction of the history of vegetation. Palynological and carpological analyses enabled a description of the history of vegetation from the Preboreal to the Subatlantic (Wasylikowa 1993). The Lubsza Plain has been studied by geologists and geomorphologists, among them Professor B. Nowaczyk, whose cooperation with palynologists provided comprehensive descriptions of 10 sites (Fig. 2) located within the Lubsza Plain and representing dunes (Guzów, Jasień, Pomorsko, Chełm Żarski), blowouts (Osiek), lake bottom sediments (Płytkie Lake), archaeological excavation sites or their close surroundings (Wicina, Liny), as well as peat bogs and basins affected by deposition of biogenic sediments (Smolno Wielkie, Wojnowo), analysed palynologically by I. Okuniewska-Nowaczyk (2005). Some of the above-mentioned materials have not yet been published. Studies of sections from Liny, Guzów, Jasień, and Wicina sites, bearing a record of vegetation history from the Late Glacial and early Holocene (to the Subboreal in Wicina), have been published only fragmentarily (Okuniewska 1986, Nowaczyk & Okuniewska-Nowaczyk 1992, Kowalkowski et al. 1999, Okuniewska-Nowaczyk 1996, 1998, Kobusiewicz et al. 2001). Archaeological investigations carried out in the Węgliny area (Florek 1976, Burdukiewicz 1976, Bagniewski 1995) yielded the discovery of an exceptionally rare artefact, a uniseriably barbed bone harpoon from the close of the Palaeolithic (Domański & Burdukiewicz 1994). The archaeological research was restarted in 2004 and involved a palynological examination of the Węgliny section (Figs 1, 2), performed by M. Malkiewicz (Masojć et al. 2006). Pollen analysis provided a general description of the natural environment inhabited by humans during late Pleistocene and early Holocene. Artefacts found by archaeologists evidenced the local presence of people representing two Palaeolithic cultures, the Ahrensburg and the Federmesser. Infrequent findings also indicated the presence of Younger Mesolithic populations (Cziesla & Masojć 2007). Palynological

analyses were also performed for sections from Łęgoń (Fig. 2) as part of archaeological studies in 2001–2002 in the Kopanica valley by J. Burdukiewicz (Malkiewicz 2002, Burdukiewicz et al. 2003, 2007). The research resulted in the discovery of new remains of settlement originating from the Hamburg, Federmesser, and late Mesolithic cultures, and reconstruction of the natural environment (Burdukiewicz et al. 2003). In 2004, as part of doctoral thesis work, palynological analyses were made (Herking 2004) for sections of Rybojady and Pawski Ług (Fig. 2), which became the first sites in the Lubsza Plain examined only for the purpose of reconstructing the vegetation history.

MATERIAL AND METHODS

FIELDWORK AND SAMPLED MATERIALS

The Węgliny study site (51°49'55"N, 14°43'31"E) is located in the north-eastern part of Węgliny village in the Wodra valley (Fig. 1) and covers an area ca 1 km in length and maximally 124 m in width. It is presently a boggy meadow serving as pasture and drained due to the high level of groundwater and the presence of a small watercourse, the Wodra river, flowing in an artificial river bed (http://adamwalanus.pl/wegliny_pej.html). The site for core taking was chosen by Professor B. Nowaczyk on the basis of his long fieldwork experience (Nowaczyk & Okuniewska-Nowaczyk 1992, 1999, Nowaczyk 1996, 1998). The research continued in 2008–2011 and included geological mapping (B. Nowaczyk, A. Jarzynka, A. Jurochnik) and demarcation of 12 E-W and N-S transects, subjected to 40 geological soundings. Figures 3, 4, and 5 show a schematic drawing and sections of the basin. Between 2008 and 2010, five cores were taken for palaeobotanical analyses (Tab. 1). The material (anaerobic sediments) was collected from one site (low-lying basin), but represented four separate, complete sections (WE'08, WE'09, WE'10, WE'10/2); the fifth one (WE'10/3) comprised only the basal part of the section and was identical to WE'10/2. The cores were taken by different research groups, at distances ranging from a few tens of centimetres to a few metres between boreholes (Tab. 1; see Housley et al. 2013, tab. 1), over a three-year period (2008–2010).

Palynological examination of the first section (WE'08) marked the beginning of cooperation with Dr. R. Housley and Dr. A. MacLeod (Royal Holloway, University of London), who independently took core WE'09 at the study area in search of Laacher See volcanic tephra (Riede 2008) under the RESET (Response of Humans to Abrupt Environmental Transitions) research project. After both cores were analysed, subsequent ones (WE'10 and WE'10/2) were taken and thoroughly examined. Collaboration with the geomorphologist was aimed at making a detailed lithological study of section WE'10/3. In order to correlate the

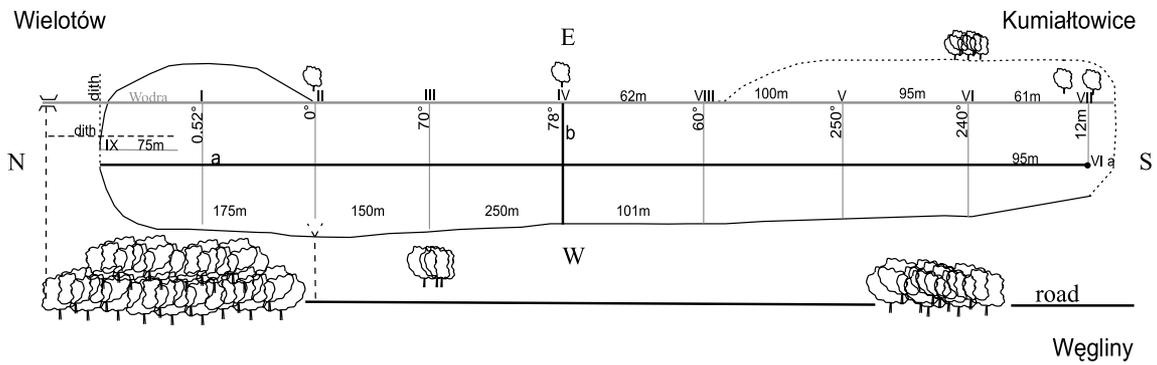


Fig. 3. Schematic drawing of Węgliny site (B. Nowaczyk, A. Jurochnik). a - longitudinal transect b - transverse transect

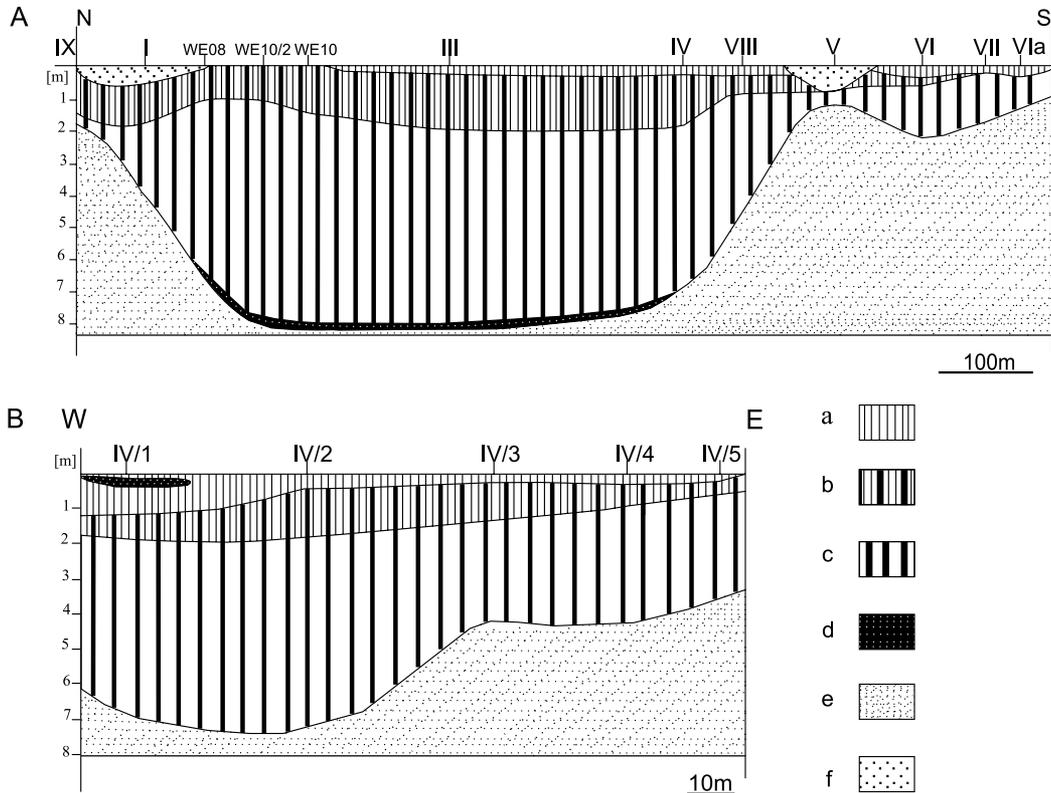
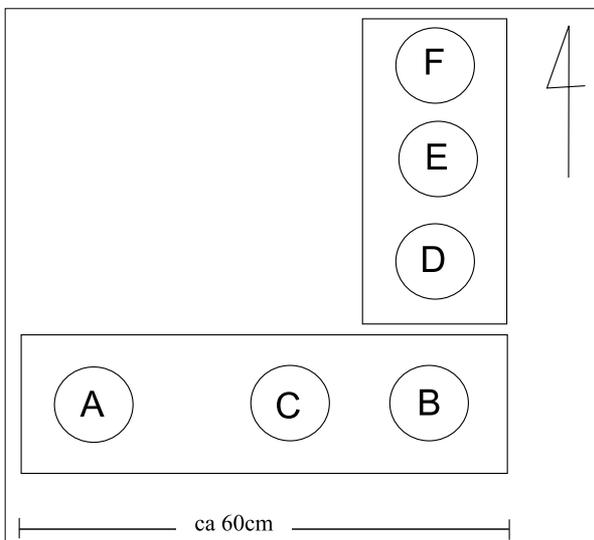


Fig. 4. Geological sections across reservoir of biogenic accumulation at Węgliny site. A - longitudinal, B - transverse (Nowaczyk B. & Jurochnik A.); a - peat, b - detritus gyttja, c - gyttja, d - sandy silt/clay (or sandy gyttja), e - fluvial/glaciofluvial sand, f - sand from embankment



palynological and lithological data, pollen from several samples taken from the basal part of section WE'10/3 was analysed. The sediments from all cores were very similar and homogenous, and the correlation of sections was based on pollen analysis. This paper presents the three most important sections: WE08, WE10, and WE10/2.

WE'08 - segments of the core were taken with an Instorf probe (chambered Russian peat corer) 5 cm in diameter; the first 0.5 m of sediment was not obtained due to technical problems. The core described in the laboratory following the method of Troels-Smith (1955) is presented in Table 2. Segments of the core were cut longitudinally into two halves, one meant for



Fig. 5. Boreholes of WE'10 (A, B, C) and WE'10/2 (D, E, F) core locations

Table 1. Węgliny site. Collection of cores for analyses. * – Jurochnik A. & Stachowicz K. in prep.,** – see Housley et al. 2013

Core code	Year of collection	Scientific team taking the cores	Transported to lab and samples taken for analysis in:	Analyses in Poland	Analyses in UK	Profiles	Device
WE'08	2008	D. Nalepka, B. Nowaczyk, I. Okuniewska-Nowaczyk, A. Walanus	W. Szafer Institute of Botany PAS, Kraków, Poland	Palynology – expertise only, Algae*, NPP, LOI		Complete profile 50–600 cm	Russian chamber (Instorf)
WE'09	2009	R. Housley with team	Royal Holloway, University of London, UK	Palynology – expertise only	Tephra**, LOI	Complete profile 30–580 cm	Russian chamber (Instorf)
WE'10	2010 April	R. Housley, A. MacLeod, P. Masojć, M. Morgan, D. Nalepka, B. Nowaczyk, I. Okuniewska-Nowaczyk, A. Walanus http://adamwalanus.pl/weglidy.html	W. Szafer Institute of Botany PAS, Kraków, Poland	Palynology – full, A, B, C	Tephra** D, E, F, LOI	Complete profiles A, B, C (see Tab. 4) D, E, F	Russian chamber (Instorf) (see tab. 3)
WE'10/2	2010 October	A. Jurochnik, D. Nalepka, B. Nowaczyk, A. Walanus and technical team from PAS, Toruń http://adamwalanus.pl/weglidy10ib.html http://adamwalanus.pl/weglidy_2010_10_23.html	W. Szafer Institute of Botany PAS, Kraków, Poland	Palynology – full – the main core, Macrofossils*, AMS ¹⁴ C	Tephra**, LOI	Complete profile 0–840cm (see Tab. 4)	Więkowski corer
WE'10/3	2010 October	A. Jurochnik, D. Nalepka, B. Nowaczyk, A. Walanus and technical team from PAS, Toruń	Adam Mickiewicz University, Poznań, Poland	Palynology – expertise basal part only, Sedimentology		Complete profile 0–840 cm	Więkowski corer

Table 2. Lithological description of the Węgliny WE'08 profile. Described according to Troels-Smith (1955) in the Laboratory of the Department of Palaeobotany, W. Szafer Institute of Botany, Polish Academy of Sciences

Depth (cm)	Description of sediments	Physical properties	Formula
50–65	Peat strongly decomposed	nig.3, strf.0, elas.2, sicc.2, lim. sup.?.; col. 2.5Y 2/0 blackish brown	Th ³ 4 Ga+
65–133	Peat strongly decomposed	nig.3, strf.0, elas.2, sicc.2, lim. sup.0; col. 2.5Y 2/0 blackish brown	Th ³ 4
133–206	Gyttja	nig.2, strf.0, elas.3, sicc.2, lim. sup.1; col. 2.5Y 3/2 dark green to black	Ld4
206–278	Gyttja	nig.1, strf.0, elas.2, sicc.3, lim. sup.0; col. 5Y 6/2 dark olive to black	Ld4
278–450	Gyttja	nig.3, strf.0, elas.2, sicc.2, lim. sup.1; dark green to black, col. 5Y 3/2-darker 5Y 5/2-lighter; 5Y 2/1-black inserts (Ld ⁴ 3, Sh1)	Ld4; Ld ⁴ 3, Sh1 (black inserts)
450–500	Gyttja with silt	nig.3, strf.0, elas.2, sicc.2, lim. sup.1; olive grey with dark inserts; col. 5Y 6/2 olive grey; col. 5Y 2/1 black	Ld3, Sh1; As/Ag+
500–518	Gyttja with silt	nig.3, strf.0, elas.2, sicc.2, lim. sup.1; col. 2.5Y 3/2 dark green	Ld ³ 3, As/Ag1
518–564	Silty mud	nig.2, strf.0, elas.1, sicc.2, lim. sup.1; col. 5Y 5/1 olive grey	As/Ag 4
564–600	Silty sand	nig.1, strf.0, elas.1, sicc.2, lim. sup.3; col. 5Y 6/1 light grey	Ga3, As/Ag 1

pollen analysis and the other for loss on ignition (LOI) analysis.

WE'10 – the core (Tab. 3) was taken with an Instorf probe (chambered Russian peat corer) 5 cm in diameter from two boreholes, A and B (Fig. 5, Tab. 4). Then 0.5 m long segments of the core were collected with a 10 cm overlap. Due to technical problems, one segment from 280–330 cm depth was taken from borehole C. Also the topmost 2 m were not collected. Other cores from boreholes D, E, and F, and a segment

from 6.90–7.90 m depth in borehole C were taken (<http://adamwalanus.pl/weglidy.html>) for the RESET research project (Fig. 5, Tab. 4).

WE'10/2 – the core (Tab. 5) was taken with a Więkowski probe (modified version of Livingstone core) 5 cm in diameter from boreholes WE'10/2 and WE'10/2a with an overlap of several cm. Metre-long segments were subjected to palynological analysis (<http://adamwalanus.pl/weglidy10ib.html>, http://adamwalanus.pl/weglidy_2010_10_23.html).

Table 3. Lithological description of the Węgliny WE'10 profile

Depth (cm)	Description of sediments	Signature of the borehole
200–250	brown-grey detrituosus gyttja	A
280–330	brown-grey, detrituosus gyttja including irregular black and light beige layers	C
360–410	dark-grey to light grey gyttja including beige layers, which disappeared in the upper part	A
440–490	brown-dark grey gyttja	A
520–570	brown-dark grey gyttja	A
600–650	light grey gyttja	A
640–690	light grey gyttja	B
680–730	light grey gyttja; in the upper part passing to dark-grey, and in the lower part passing to the brown-dark-gray gyttja	A
760–810	brown-dark-gray gyttja in the upper part, passing to sandy silt and sand in the bottom	A

Table 4. Collected segments of WE10 profile (see Fig. 5)

A (cm)	C (cm)	B (cm)
200–250		240–290
	280–330	
		320–370
360–410		400–450
440–490		480–530
520–570		560–610
600–650		640–690
680–730	690–790	720–770
760–810		750–800

POLLEN ANALYSIS

Pollen analyses used 237 samples (volume 1 cm³) taken every 5, 10, 15 or 20 cm, locally every 1 or 2 cm, and varying in number between cores. Samples were macerated and acetolised following the standard procedure using hydrofluoric acid (HF) and an indicator (Erdtman 1960, Stockmarr 1971, Berglund & Ralska-Jasiewiczowa 1986). After preparation, the material was immersed in glycerine. Palynological analysis was carried out in the Department of Palaeobotany, W. Szafer Institute of Botany, Polish Academy of Sciences in Kraków, using light microscopes (Nikon and Carl Zeiss Jena), keys, literature (Erdtman et al. 1961, Faegri & Iversen 1978, 1989, Moor et al. 1991, Reille 1992, Beug 2004, Punt et al. 2006) and the reference pollen collection housed in the Department of Palaeobotany. Pollen grains were counted on 1–3 slides up to the sum of at least 500 grains of trees and shrubs (AP) per sample. Samples of mineral sediment in which pollen frequency did not exceed 200–300 AP and NAP grains were always counted on three slides. Percentage calculations are based on the sum of pollen grains of trees and shrubs (AP) and dwarf shrubs and terrestrial herbaceous plants (NAP). The pollen analysis results are presented in pollen diagrams (Figs 6, 7, 8) plotted with POLPAL

software (Nalepka & Walanus 2003, POLPAL) and including the local pollen assemblage zones (L PAZ, Tabs 6, 7, 8). The division into L PAZs was supported by PCA, ConSLink, rarefaction analysis, a sample similarity matrix (Fig. 9) and basic numerical analyses (Nalepka & Walanus 1995, 2003, Nalepka 2005). Analyses were carried out for all profiles and involved selected sets of taxa regarded as climatic or ecological indicators.

DESCRIPTION OF LOCAL POLLEN ASSEMBLAGE ZONES

Core WE'10/2 (Tab. 8, Figs 4, 8), bearing a record of a complete vegetation succession, was considered the benchmark (reference profile) and was subjected to examination of plant macroremains (not discussed in this article), radiocarbon dating and a detailed tephrochronological analysis of the basal part. In order to provide a unified and comprehensive description of the material, the corresponding L PAZs of particular profiles were distinguished on the basis of the same boundaries and annotated with the same names, but with different numbers. In the paper, all paragraphs on palaeoenvironmental reconstructions pertain to compiled zones, for example WE-1 including WE'08-1, WE'10-1, and WE'10/2-1, or WE'-1. The study presents complete descriptions of L PAZs from sections enabling reconstruction of changes in vegetation. Descriptions of other L PAZs were abridged (simplified) but may be found in complete form in the manuscript of the original doctoral thesis kept at the archives (library) of the W. Szafer Institute of Botany, Polish Academy of Sciences in Kraków (Jurochnik 2012).

The location of section WE'08 (Tab. 6, Fig. 6), most likely representing the marginal, shallower part of the palaeobasin (Fig. 4), was the main argument for examining the section with additional analyses, that is, loss on ignition analysis (LOI, Tab. 9), and expert analysis of *Pediastrum* algae and of non-pollen palynomorphs (NPP), performed for selected zones. Numerical analyses indicate clear similarity between sections WE'08 and WE'10/2, considered the benchmark.

Table 5. Lithological description of the Węgliny WE'10/2 profile

Depth (cm)	Description of sediments
0–110	Coarse detrituosus gyttja / black peat
110–220	Black detrituosus gyttja
220–320	Brown gyttja
320–430	Light brown gyttja to brown gyttja, black-brown in the section
430–540	Light brown gyttja to brown gyttja, black-brown in the section with light beige inserted layers, which seem to be remains of malacofauna. These layers disappeared at the top
540–640	Light brown gyttja, black in the section, including distributed malacofauna
640–750	Light brown gyttja, black in the section
750–840	Light-brown – grey gyttja or mud, sandy, brown grey in the section, grey silty sand in the bottom, including black layers of mud

Table 6. Węgliny site, WE'08 core. Description of local pollen assemblage zones (L PAZ) (Fig. 6)

L PAZ	Name of L PAZ	depth (cm)	Description
WE'08 ₉	<i>Pinus-Picea-Tilia</i>	50–68	Increase of <i>Pinus sylvestris</i> (from 44.5% to 48%), low amount of <i>Betula</i> undiff. (between 2.8% and 3.3%), decrease of <i>Corylus avellana</i> (down to 0.9%), <i>Ulmus</i> (down to 0.4%), <i>Quercus</i> (down to 2%), and <i>Alnus</i> (down to 9%), significant increase of <i>Picea abies</i> (up to 3.6%) and <i>Salix</i> undiff. (up to 8.5%), presence of <i>Taxus baccata</i> , <i>Rubus</i> , and <i>Ligustrum vulgare</i> , small decrease of Ericaceae and <i>Calluna vulgaris</i> , increase of Poaceae (up to 16%), low amount of <i>Artemisia</i> , increase of Cyperaceae (up to 8.5%), single pollen grain of <i>Erica tetralix</i>
WE'08 ₈	<i>Corylus-Alnus-Quercus-Ulmus</i>	68–140	Further decrease of <i>Pinus sylvestris</i> (down to 14.5%), <i>Betula</i> undiff. (below 14%), increase of <i>Corylus avellana</i> (from 8.4% to 18.5%), <i>Ulmus</i> (up to 4.1%), <i>Quercus</i> (up to 10.9%), <i>Tilia</i> (up to 2%), <i>Fraxinus excelsior</i> (up to 2.2%), and <i>Alnus</i> (35%, maximum); <i>Picea abies</i> , <i>Salix</i> undiff., and <i>Taxus baccata</i> not exceeding 1%, a few pollen grains of <i>Carpinus betulus</i> , <i>Abies alba</i> , <i>Fagus sylvatica</i> , <i>Hedera helix</i> , <i>Ilex aquifolium</i> , <i>Cornus mas</i> , and <i>Empetrum</i> , small increase of Ericaceae, Poaceae below 8%, <i>Artemisia</i> below 0.5%, <i>Calluna vulgaris</i> and Cyperaceae below 1.5%. Upper zone boundary: increase of <i>Pinus sylvestris</i> , significant decrease of <i>Corylus</i> , <i>Betula</i> , and <i>Ulmus</i>
WE'08 ₇	<i>Corylus-Pinus-Quercus</i>	140–210	Slow decrease of <i>Pinus sylvestris</i> (down to 39%) and <i>Betula</i> undiff. (down to 8%), increase of <i>Corylus avellana</i> (from 7.5% to 20%), <i>Ulmus</i> (from 0.6% to 3.57%), and <i>Quercus</i> (from 0.1% to 9%), increase of <i>Alnus</i> (up to 25.5%); <i>Tilia cordata</i> , <i>Fraxinus excelsior</i> , <i>Picea abies</i> , and <i>Salix</i> undiff. below 1%, a few pollen grains of <i>Betula nana</i> (ca 1%), <i>Taxus baccata</i> not exceeding 0.5%, Ericaceae, <i>Calluna vulgaris</i> , and Poaceae not exceeding 8.5%, Cyperaceae and <i>Artemisia</i> unchanged, a few pollen grains of <i>Erica tetralix</i> and <i>Empetrum</i> . Upper zone boundary: increase of <i>Alnus</i> , <i>Quercus</i> , and <i>Ulmus</i> , followed shortly by decrease of <i>Corylus avellana</i>
WE'08 ₆	<i>Pinus-Betula-Corylus</i>	210–230	Decrease of <i>Pinus sylvestris</i> (down to 54%), increase of <i>Betula</i> undiff. (up to 34%), start of continuous curve of <i>Corylus avellana</i> (exceeding 1.5%); <i>Ulmus</i> and <i>Alnus</i> oscillating at ca 1%, a few pollen grains of <i>Betula nana</i> t., <i>Quercus</i> , <i>Fraxinus excelsior</i> , and <i>Picea abies</i> , constant amount of Poaceae, <i>Artemisia</i> , and Ericaceae (below 1%). Upper zone boundary: rise of <i>Corylus avellana</i> , decrease of <i>Betula</i> undiff.
WE'08 ₅	<i>Betula-Pinus-Poaceae</i>	230–285	Increase of <i>Pinus sylvestris</i> (from 44% to 79.5%) and <i>Betula</i> undiff. (from 3% to 45%), <i>Corylus avellana</i> , <i>Ulmus</i> , and <i>Alnus</i> below 1%, <i>Salix</i> undiff. (below 2%), a few pollen grains of <i>Juniperus communis</i> and <i>Betula nana</i> t., low amount of <i>Fraxinus excelsior</i> , <i>Picea abies</i> (below 0.5%), Poaceae (from 3.5% to 8.74%), and <i>Artemisia</i> (below 0.5%), Ericaceae and <i>Calluna vulgaris</i> below 0.5%, Cyperaceae below 1%. Upper zone boundary: increase of <i>Betula</i> undiff, start of continuous curve of <i>Corylus</i>
WE'08 ₄	<i>Poaceae-Artemisia</i>	285–371	Fluctuating amounts of <i>Betula</i> undiff. (between 16.5% and 31%), and <i>Pinus sylvestris</i> (between 48 and 66%), low amount of <i>Salix</i> undiff. (below 2%), a few pollen grains of <i>Betula nana</i> t., <i>Juniperus communis</i> (below 1%), <i>Corylus avellana</i> (below 1.5%), <i>Ulmus</i> , <i>Quercus</i> , and <i>Alnus</i> (below 1%), <i>Picea abies</i> , Ericaceae, <i>Calluna vulgaris</i> , and Cyperaceae at ca 1%, increase of Poaceae (up to 18%) and <i>Artemisia</i> (up to ca 2%), final disappearance of redeposited (Rebedded) sporomorphs, presence of single Dinophyceae. Upper zone boundary: decrease of Poaceae and <i>Artemisia</i> , increase of <i>Pinus sylvestris</i>
WE'08 ₃	<i>Pinus-Betula</i>	371–485	<i>Pinus sylvestris</i> exceeding 44% (up to 65%) and <i>Betula</i> undiff. exceeding 25% (up to 46.5%), low amount of <i>Juniperus communis</i> (below 1%), <i>Salix</i> undiff. (below 2%), single pollen grains of <i>Betula nana</i> t. and <i>Vaccinium</i> t., Ericaceae, <i>Calluna vulgaris</i> and <i>Erica tetralix</i> below 1%, low amount of <i>Artemisia</i> (below 0.5%) and Poaceae (between 3% and 7%), Cyperaceae below 1.5%, increase of redeposited (Rebedded) sporomorphs (from 7.5% to 43%)
WE'08 _{3a}	NAP	445–465	Decrease of <i>Pinus sylvestris</i> (down to 47%), small increase of <i>Betula</i> undiff. (up to ca 33%), a few pollen grains of <i>Betula nana</i> t., substantial increase of NAP including Poaceae (from 3.5% to 18.5%), <i>Artemisia</i> below 1%, Cyperaceae exceeding 1%, substantial increase of redeposited (Rebedded) sporomorphs (from 7.5% to 35%). Upper zone boundary: increase of Poaceae and <i>Artemisia</i>
WE'08 ₂	<i>Poaceae-Betula-Hippophaë</i>	485–520	Decrease of <i>Pinus sylvestris</i> (down to 16%) simultaneous with increase of <i>Betula</i> undiff. (up to 46%), increase of <i>Hippophaë rhamnoides</i> (up to 2%), decrease of <i>Juniperus communis</i> (down to 0.1%), increase of <i>Salix</i> undiff. (up to 6%, highest at bottom of profile), a few pollen grains of Ericaceae and <i>Calluna vulgaris</i> , Poaceae continuous (ca 30%), redeposited (Rebedded) sporomorphs present (up to 9%). Upper zone boundary: substantial decrease of Poaceae, increase of <i>Pinus sylvestris</i>
WE'08 ₁	<i>Poaceae-Juniperus</i>	520–559	High amount of <i>Pinus sylvestris</i> (ca 50%) and decrease of <i>Betula</i> undiff. (below 15%), appearance of <i>Juniperus communis</i> (up to 2%), <i>Salix</i> undiff. (from 1% to 5%), Poaceae continuous (ca 31%), increase of <i>Artemisia</i> (up to 6%) at top of zone, appearance of <i>Hippophaë rhamnoides</i> (ca 1%), increase of Cyperaceae (up to 2%), <i>Helianthemum nummularium</i> t. present (1%), a few pollen grains of Ericaceae, <i>Calluna vulgaris</i> , and <i>Ledum palustre</i> , redeposited (Rebedded) sporomorphs fluctuating (between 6% and 19%), presence of Dinophyceae (between 1% and 3%). Upper zone boundary: decrease of <i>Pinus sylvestris</i> and <i>Juniperus communis</i> , increase of <i>Betula</i> undiff. and Poaceae

Table 7. Węgliny site, WE'10 core. Description of local pollen assemblage zones (L PAZ) (Fig. 7)

L PAZ	Name of L PAZ	Depth (cm)	Description
WE'10 ₈	<i>Corylus-Alnus-Quercus-Ulmus</i>	200.5–220.5	<i>Pinus sylvestris</i> continuous (ca 47%), slight decrease of <i>Betula</i> undiff. (9.5%, minimum), increase of <i>Corylus avellana</i> (up to 22%), <i>Quercus</i> (up to 4.7%), <i>Alnus</i> (up to 18.5%), <i>Ulmus</i> (up to 3%); <i>Tilia cordata</i> , <i>Fraxinus excelsior</i> , and <i>Picea abies</i> oscillating around 1%, low amount of Poaceae (ca 3.5%); <i>Artemisia</i> and <i>Calluna vulgaris</i> below 0.5%, Cyperaceae increased (up to 3%)
WE'10 ₇	<i>Corylus-Pinus-Quercus</i>	220.5–290.5	Slight decrease of <i>Pinus sylvestris</i> (from 59% to 48.5%) and <i>Betula</i> undiff. (down to 19.5%), increase of <i>Corylus avellana</i> (up to 17%, maximum), <i>Ulmus</i> (up to 2%), <i>Quercus</i> (up to 3%), and <i>Alnus</i> (up to 4%), <i>Salix</i> undiff., <i>Tilia cordata</i> , <i>Fraxinus excelsior</i> , and <i>Picea abies</i> below 1%, single grains of <i>Juniperus communis</i> , <i>Viburnum opulus</i> t., <i>Sambucus nigra</i> t., <i>Rubus</i> , and <i>Ligustrum vulgare</i> , Poaceae below 5%, Ericaceae below 0.5%, <i>Artemisia</i> and Cyperaceae below 1%. Upper zone boundary: increase of <i>Alnus</i> , <i>Quercus</i> , and <i>Ulmus</i> , decrease of <i>Corylus avellana</i>
WE'10 ₆	<i>Pinus-Betula-Corylus</i>	290.5–350.5	<i>Pinus sylvestris</i> continuous (between 51% and 63%), <i>Betula</i> undiff. fluctuating (between 24.5% and 40%); increase of <i>Corylus avellana</i> (up to 3.5%) and <i>Alnus</i> (up to 3%), <i>Ulmus</i> and <i>Quercus</i> not exceeding 1.5%, <i>Tilia cordata</i> , <i>Fraxinus excelsior</i> , and <i>Salix</i> undiff. below 1%, single grains of <i>Juniperus communis</i> , <i>Picea abies</i> , <i>Hedera helix</i> , <i>Viburnum opulus</i> t., <i>Vitis vinifera</i> , and <i>Sambucus nigra</i> t., continuous curves of <i>Artemisia</i> and Poaceae. Upper zone boundary: increase of <i>Corylus avellana</i> , decrease of <i>Betula</i> undiff.
WE'10 ₅	<i>Betula-Pinus-Poaceae</i>	350.5–460.5	Increase of <i>Pinus sylvestris</i> (from 44% to 69%), increase of <i>Betula</i> undiff. (from 21% to 48%); <i>Salix</i> undiff., <i>Alnus</i> , <i>Corylus avellana</i> , and <i>Artemisia</i> ca 1%, single grains of <i>Juniperus communis</i> , <i>Ulmus</i> , <i>Quercus</i> , <i>Ephedra distachya</i> , <i>Helianthemum nummularium</i> t., <i>Picea abies</i> , and <i>Viburnum</i> t., increase of Poaceae (up to 9%, maximum), Cyperaceae and Ericaceae below 1.5%. Upper zone boundary: increase of <i>Betula</i> undiff, beginning of continuous curve of <i>Corylus avellana</i>
WE'10 ₄ cm	Poaceae- <i>Artemisia</i>	460.5–510.5	Initial decrease of <i>Pinus sylvestris</i> (down to 11%, minimum), then increase (up to 30%), increase of <i>Betula</i> undiff. (up to 62%), <i>Juniperus communis</i> and <i>Salix</i> undiff. oscillating (ca 1%). Decrease of Poaceae (from 15% to 7.5%), increase of <i>Artemisia</i> (up to 5.6%, maximum), single grains of <i>Corylus avellana</i> , <i>Ulmus</i> , <i>Quercus</i> , <i>Alnus</i> (probably redeposited), <i>Helianthemum nummularium</i> t., decrease of Cyperaceae (down to 0.5%), slight increase of Ericaceae. Upper zone boundary: decrease of Poaceae and <i>Artemisia</i> , increase of <i>Pinus sylvestris</i>
WE'10 ₃	<i>Pinus-Betula</i>	510.5–700.5	High amounts of <i>Pinus sylvestris</i> (up to 68%) and <i>Betula</i> undiff. (up to 61%), <i>Juniperus communis</i> , <i>Salix polaris</i> , and <i>Salix</i> undiff. below 1%, <i>Artemisia</i> below 2%, increase of Poaceae (up to 10%, maximum), single grains of <i>Helianthemum nummularium</i> t., <i>Ledum palustre</i> , <i>Calluna vulgaris</i> , and <i>Empetrum</i> , Ericaceae at 0.5%, Cyperaceae not exceeding 2.5%, redeposited (Rebedded) sporomorphs disappeared. Upper zone boundary: increase of Poaceae and <i>Artemisia</i>
WE'10 ₂	Poaceae- <i>Betula-Hippophaë</i>	700.5–760.5	High amounts of <i>Pinus sylvestris</i> (ca 55%), increase of <i>Betula</i> undiff. (ca 48%), <i>Juniperus communis</i> near 1%, <i>Salix</i> undiff. below 2%, Poaceae fluctuating (between 5.7% and 19%), <i>Artemisia</i> ca 2.3%, single grains of <i>Hippophaë rhamnoides</i> , <i>Salix polaris</i> , <i>Ephedra distachya</i> , <i>Helianthemum nummularium</i> t., and Ericaceae. Cyperaceae ca 1.5%, redeposited (Rebedded) sporomorphs below 1%. Upper zone boundary: decrease of Poaceae and <i>Pinus sylvestris</i>
WE' 10 ₁	Poaceae- <i>Juniperus</i>	760.5–809.5	High <i>Pinus sylvestris</i> (up to 88%), low <i>Betula</i> undiff. (from 0.4% to 19.5%), increase of <i>Juniperus communis</i> (up to 3%), <i>Salix</i> undiff. (up to 6.4%), <i>Hippophaë rhamnoides</i> (up to 4%), <i>Helianthemum nummularium</i> t. (up to 2.5%), <i>Artemisia</i> (up to 4%), and Poaceae (up to 25%), single grains of <i>Larix</i> , maximum of Ericaceae (10%) and Cyperaceae (3.5%), very high amounts of redeposited (Rebedded) sporomorphs: <i>Sequoia</i> (up to 3.5%), <i>Nyssa</i> (up to 1.5%), <i>Juglans</i> (up to 1%), other Rebedded (up to 12%), and Dinophyceae (8.5%, maximum). Upper zone boundary: decrease of <i>Pinus sylvestris</i> and <i>Juniperus communis</i> , increase of <i>Betula</i> undiff. and Poaceae

WEGLINY WE'08

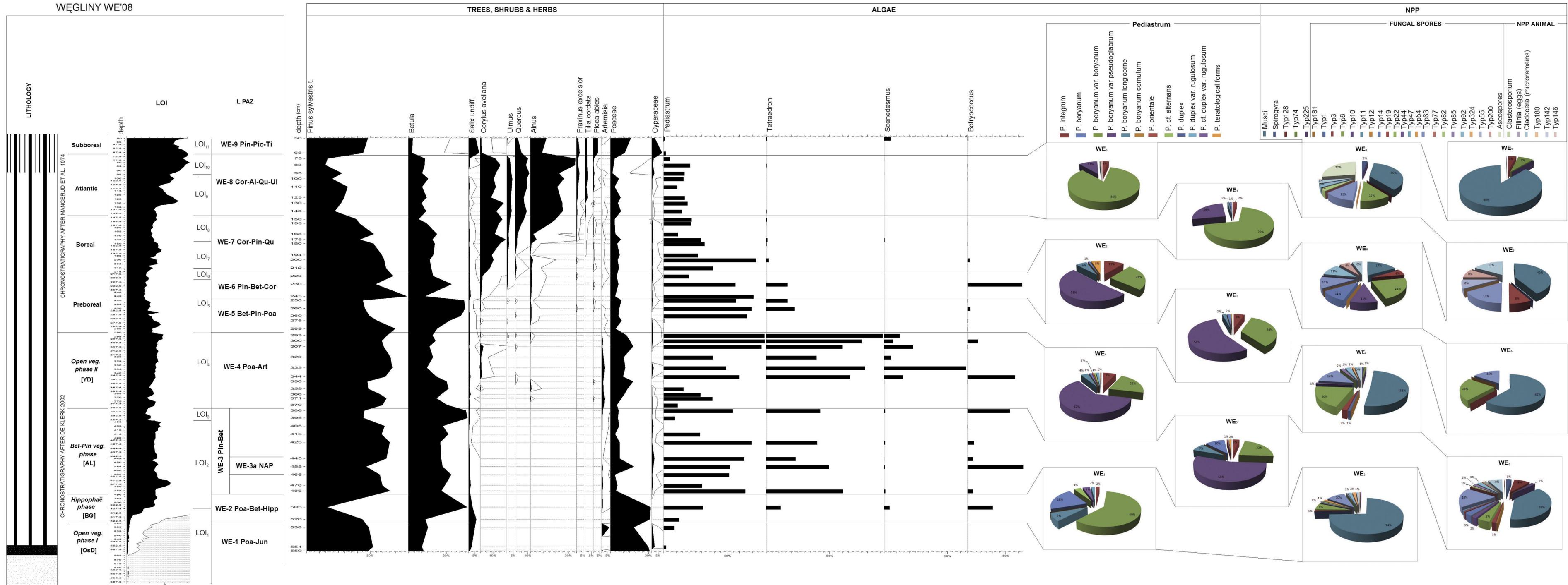


Fig. 6. Simplified pollen diagram of the WE'08 profile with results for loss of ignition (LOI), algae and non-pollen palynomorphs (NPP) analyses

WĘGLINY WE'10

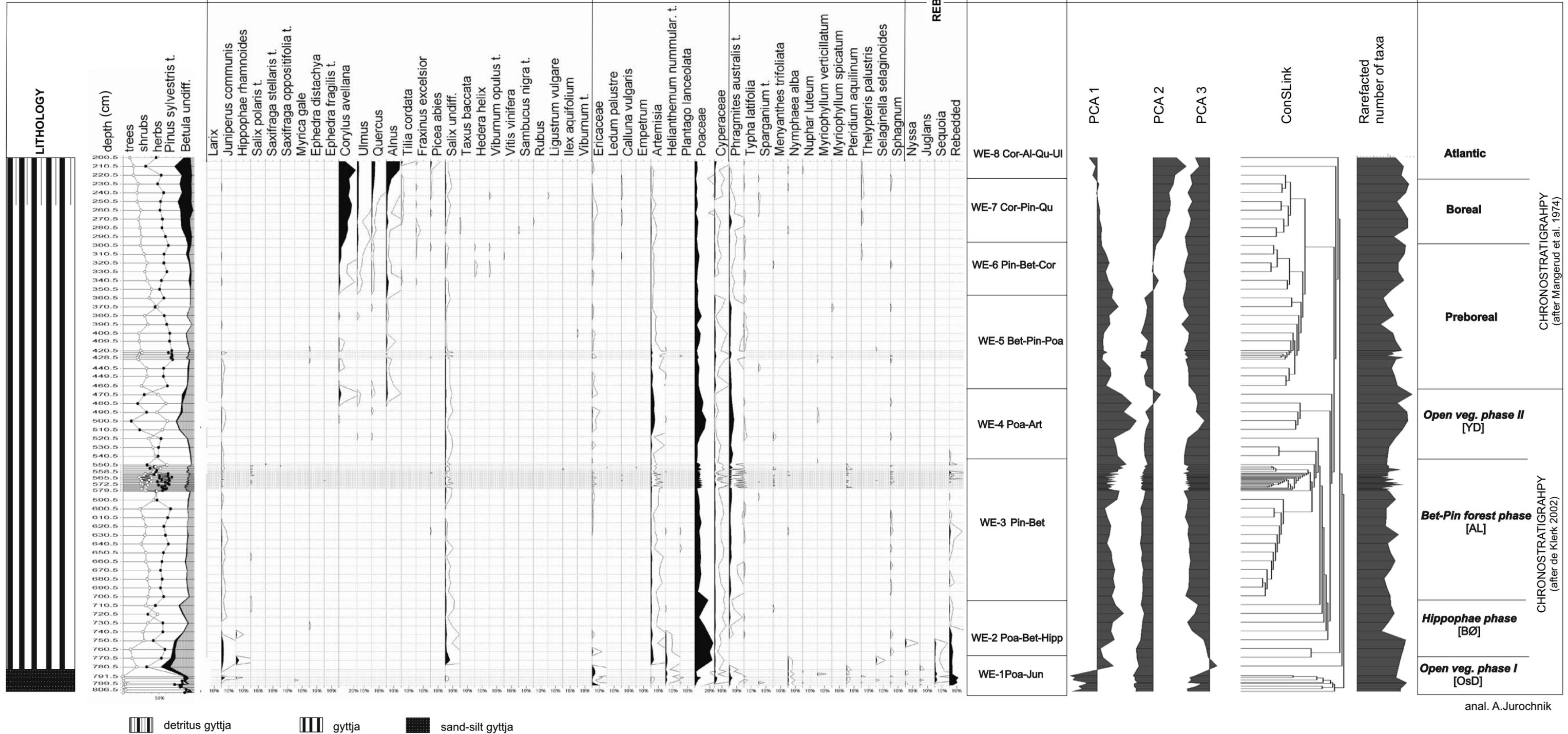


Fig. 7. Percentage pollen diagram of the Węgliny WE'10 profile with results of numerical analyses

Table 8. Węgliny site, WE'10/2 core Description of local pollen assemblage zones (L PAZ) (Fig. 8)

L PAZ	Name of L PAZ	Depth (cm)	Description
WE'10/2 ₁₀	NAP- <i>Alnus</i>	5.5–20.5	Decrease of <i>Pinus sylvestris</i> (down to 30.5%), increase of <i>Betula</i> undiff. (up to 7.9%), <i>Alnus</i> (up to 39%), slight increase of <i>Corylus avellana</i> and <i>Quercus</i> (up to 2.5%), decrease of <i>Picea abies</i> (down to 2%); <i>Ulmus</i> , <i>Tilia cordata</i> , <i>Fraxinus excelsior</i> , <i>Carpinus betulus</i> , <i>Fagus sylvatica</i> , Ericaceae, and <i>Calluna vulgaris</i> below 0.5%, increase of Poaceae (up to 17.5%, maximum), and Cyperaceae (up to 5.2%). <i>Artemisia</i> above 1% at top of zone. Single grains of <i>Ligustrum vulgare</i> , Cerealia undiff., <i>Secale cereale</i> , and <i>Hordeum</i> t.
WE'10/2 ₉	<i>Pinus-Picea-Tilia</i>	20.5–100.5	Increase of <i>Pinus sylvestris</i> (up to 74%), decrease of <i>Betula</i> undiff. (down to 1.1%), <i>Corylus avellana</i> (down to 0.4%), <i>Ulmus</i> (down to 0.4%), <i>Quercus</i> (down to 0.5%), and <i>Fraxinus excelsior</i> (down to 0.5%), <i>Alnus</i> initially decreasing (down to 10%), then increasing (up to 26%), slight increase of <i>Tilia cordata</i> (up to 3.2%), <i>Picea abies</i> (up to 4.8%), and <i>Salix</i> undiff. (up to 6.5%), first appearance of <i>Fagus sylvatica</i> (up to 2.3%), <i>Taxus baccata</i> , <i>Viburnum</i> t., <i>Calluna vulgaris</i> (below 0.5%), Ericaceae, and <i>Artemisia</i> (below 1%), increase of Poaceae (up to 12.5%) and Cyperaceae (up to 4.5%). Upper zone boundary: decrease of <i>Pinus sylvestris</i> , decrease of <i>Alnus</i> and Poaceae, appearance of Cerealia undiff.
WE'10/2 ₈	<i>Corylus-Alnus-Quercus-Ulmus</i>	100.5–210.5	Slight decrease of <i>Pinus sylvestris</i> (down to 23%), <i>Betula</i> undiff. (down to 12%), and <i>Corylus avellana</i> (down to 6.5%), <i>Alnus</i> fluctuating (between 20% and 31%), increase of <i>Quercus</i> (up to 8.5%) and <i>Ulmus</i> (up to 4.4%), <i>Tilia cordata</i> and <i>Fraxinus excelsior</i> exceeding 1%, <i>Picea abies</i> , Ericaceae, <i>Artemisia</i> , and Cyperaceae oscillating at ca 1%, increase of Poaceae (up to 5.8%), single grains of <i>Carpinus betulus</i> , <i>Hedera helix</i> , <i>Calluna vulgaris</i> , and <i>Ledum palustre</i> . Upper zone boundary: decrease of <i>Pinus sylvestris</i> , substantial decrease of <i>Corylus avellana</i> , <i>Betula</i> undiff., and <i>Ulmus</i>
WE'10/2 ₇	<i>Corylus-Pinus-Quercus</i>	210.5–260.5	Increase of <i>Pinus sylvestris</i> (up to 54%), decrease of <i>Betula</i> undiff. (down to 12.5%), increase of <i>Corylus avellana</i> (up to 18%, maximum), <i>Quercus</i> (up to 6%), <i>Ulmus</i> (up to 2%), and <i>Alnus</i> (up to 14%), single grains of <i>Fraxinus excelsior</i> and <i>Ledum palustre</i> ; <i>Tilia cordata</i> , <i>Picea abies</i> and <i>Salix</i> undiff. below 1%, <i>Artemisia</i> , Ericaceae and <i>Calluna vulgaris</i> below 0.5%, decrease of Poaceae (down to 1%) after fluctuation, Cyperaceae at low level (ca 1%). Upper zone boundary: decrease of <i>Alnus</i> , <i>Quercus</i> , <i>Ulmus</i> , and <i>Corylus avellana</i>
WE'10/2 ₆	<i>Pinus-Betula-Corylus</i>	260.5–340.5	At zone bottom, decrease of <i>Pinus sylvestris</i> (down to 48.5%), increase of <i>Betula</i> undiff. (up to 39.5%) and <i>Corylus avellana</i> (up to 9%); <i>Alnus</i> and <i>Ulmus</i> oscillating (between 0.5% and 1.5%), increase of <i>Quercus</i> and <i>Salix</i> undiff. (up to 0.5%), single grains of <i>Picea abies</i> , fluctuation of <i>Calluna vulgaris</i> , <i>Artemisia</i> , Ericaceae, and Cyperaceae. Poaceae (between 6% and 3.5%). Upper zone boundary: decrease of <i>Corylus avellana</i> and <i>Betula</i> undiff.
WE'10/2 ₅	<i>Betula-Pinus-Poaceae</i>	340.5–420.5	Increase of <i>Pinus sylvestris</i> (up to 77%, maximum), <i>Betula</i> undiff. (between 39% and 42%), fluctuation of <i>Juniperus communis</i> , <i>Alnus</i> and <i>Salix</i> undiff. (ca. 1%), single grains of <i>Salix polaris</i> , <i>Corylus avellana</i> and <i>Ulmus</i> , low amount of Ericaceae, decrease of Poaceae (down to 3%), and <i>Artemisia</i> (down to 0.5%). Cyperaceae low (ca 1%). Upper zone boundary: increase of <i>Betula</i> undiff, start of continuous curve of <i>Corylus avellana</i>
WE'10/2 ₄	Poaceae- <i>Artemisia</i>	420.5–519.5	Slight decrease of <i>Pinus sylvestris</i> (down to 46%), increase of <i>Betula</i> undiff. (up to 33.5%); <i>Juniperus communis</i> and <i>Salix</i> undiff. at ca 1%, single grains of <i>Hippophaë rhamnoides</i> , <i>Salix polaris</i> , and <i>Helianthemum nummularium</i> t., low amount of Ericaceae, <i>Calluna vulgaris</i> , and <i>Vaccinium</i> t., increase of <i>Artemisia</i> (up to 3%) and Poaceae (up to 11%), Cyperaceae oscillating (between 1% and 2%), redeposited (Rebedded) sporomorphs absent in middle of zone. Upper zone boundary: decrease of Poaceae, <i>Artemisia</i> , and <i>Pinus</i>
WE'10/2 ₃	<i>Pinus-Betula</i>	519.5–710	Fluctuation of <i>Pinus sylvestris</i> (maximum up 64.5%) and <i>Betula</i> undiff. (at ca 51%); <i>Salix polaris</i> , <i>Salix</i> undiff., and <i>Juniperus communis</i> below 1%, single grains of Ericaceae, <i>Calluna vulgaris</i> , <i>Helianthemum nummularium</i> t., and <i>Ephedra fragilis</i> t., increase of Poaceae (up to 15%), Cyperaceae not exceeding 2.7%, increase of redeposited (Rebedded) sporomorphs (up to 14%, maximum), single Dinophyceae (0.1%)
WE'10/2 _{3a}	NAP	610–645.5	Increase of <i>Betula</i> undiff. (up to 52%) and <i>Pinus sylvestris</i> (up to 32%), <i>Juniperus communis</i> , <i>Salix polaris</i> , and <i>Salix</i> undiff. do not exceed 0.5%, increase of NAP including increase of Poaceae (up to 12%), <i>Artemisia</i> continuous (ca 1%), slight decrease of Cyperaceae (down to 1%). Fluctuation of redeposited (Rebedded) sporomorphs (between 0.5% and 14%). Upper zone boundary: decrease of pollen of Poaceae and <i>Artemisia</i>

Table 8. Continued

L PAZ	Name of L PAZ	Depth (cm)	Description
WE'10/2 ₂	Poaceae- <i>Betula</i> - <i>Hippophaë</i>	710–750	Decrease of <i>Pinus sylvestris</i> (down to 2.1%) followed by an increase (up to 59%), increase of <i>Betula</i> undiff. (up to 55%) and <i>Hippophaë rhamnoides</i> (up to 23%), decrease of <i>Juniperus communis</i> (down to 0.2%) and <i>Betula nana</i> t. (down to 1.5%), <i>Salix</i> undiff. and <i>Salix polaris</i> oscillating around 1%, <i>Artemisia</i> around 2%, Ericaceae below 0.5%, decrease of <i>Helianthemum nummularium</i> (down to 2%), high amount of Poaceae (up to 32%), increase of Cyperaceae (up to 4.5%), redeposited (Rebedded) sporomorphs not exceeding 5.5%, <i>Pterocarya</i> present. Upper zone boundary: decrease of Poaceae and <i>Pinus sylvestris</i>
WE'10/2 ₁	Poaceae- <i>Juniperus</i>	750–790	Decrease of <i>Pinus sylvestris</i> (from 80% to 39.5%), low amount of <i>Betula</i> undiff. (up to 16%, minimum), presence of <i>Juniperus communis</i> (up to 4.5%), <i>Hippophaë rhamnoides</i> (up to 3%), <i>Betula nana</i> t. (up to 2.5%), <i>Salix</i> undiff. (up to 1.3%), Poaceae (up to 23%), <i>Helianthemum nummularium</i> t. (up to 2%), Ericaceae (up to 3%), and Cyperaceae (ca 3%, maximum), redeposited (Rebedded) sporomorphs (6%) include <i>Sequoia</i> (up to 1%) and single Dinophyceae. Upper zone boundary: decrease of <i>Pinus sylvestris</i> and <i>Juniperus communis</i> , increase of <i>Betula</i> undiff. and Poaceae

In section WE'10 (Tab. 7, Figs 4, 7), microtephra horizons were identified (Housley et al. 2013). In order to observe potential vegetational changes in these intervals, the density of sampling for pollen analysis was increased to 2 cm and 1 cm in the first and second segments, respectively. Numerical analyses were also carried out for the discussed section. ConSLink and PCA analyses provided the basis for distinguishing several potentially important parts of the diagram corresponding to depths of 520.5/510 cm, 470.5/460.5 cm, 300.5/290 cm, 360/350 cm, and 230.5/220.5 cm, and indicating pollen assemblage zone boundaries (see Tab. 7). The 720.5/710 cm boundary is relatively clear and separates the oldest pollen assemblage zone into

two parts (Fig. 7). The results from SSM analysis (Fig. 9) suggest that the discussed section is most similar to WE'09 and WE'10/2).

Section WE'10/2 (Tab. 8, Figs 4, 8) records a complete vegetation succession from the Late Glacial to the Holocene (Fig. 8) and also includes an LS tephra horizon identified at WE-3 L PAZ. The occurrence of a zone with tephra justified radiocarbon dating (Housley et al., 2013). Numerical analyses greatly helped distinguish the pollen boundaries. Figure 10 shows the correlation of local pollen assemblage zones (LPAZs) of all Węgliny profiles.

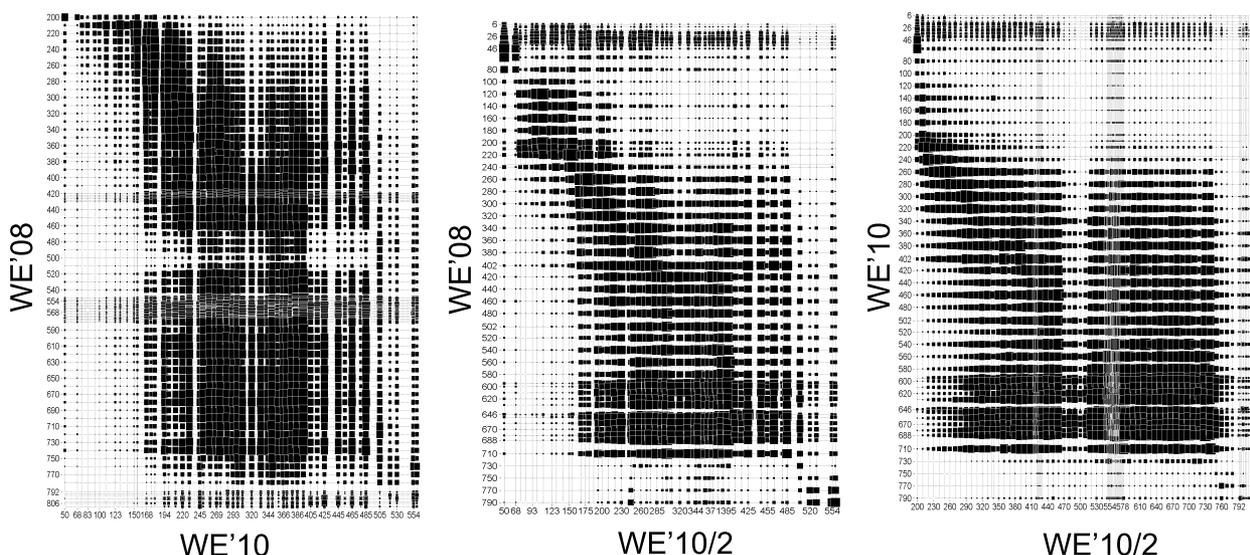


Fig. 9. Results of sample similarity matrix (SSM) comparison (POLPAL) between percentage values for pairs of Węgliny WE profiles

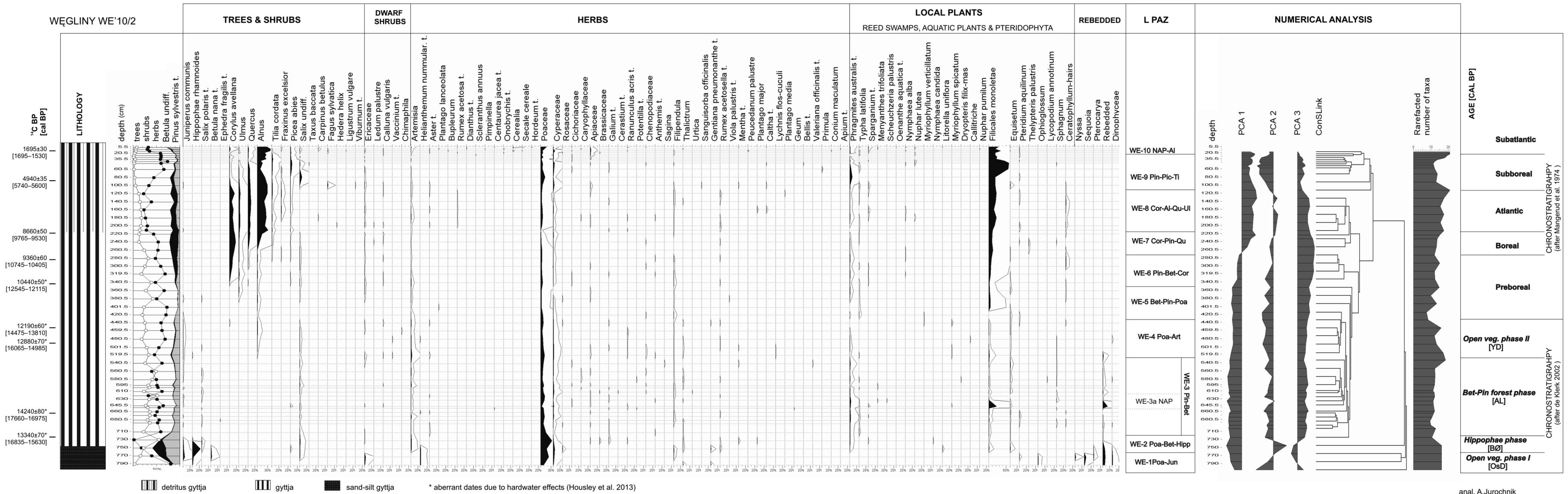


Fig. 8. Percentage pollen diagram of the Wegliny WE'10/2 profile with results of numerical analyses

L PAZ WE				WE'10/2		
WE-10 NAP-AI	WE' 08			WE'10/2 ₁₀		
WE-9 Pin-Pic-Ti	WE'08 ₉	WE' 09	WE' 10	WE'10/2 ₉		
WE-8 Cor-AI-Qu-UI	WE'08 ₈	WE'09 ₅	WE'10 ₈	WE'10/2 ₈		
WE-7 Cor-Pin-Qu	WE08 ₇	WE'09 ₄	WE'10 ₇	WE'10/2 ₇		
WE-6 Pin-Bet-Cor	WE'08 ₆	WE'09 ₃	WE'10 ₆	WE'10/2 ₆		
WE-5 Bet-Pin-Poa	WE'08 ₅	WE'09 ₂	WE'10 ₅	WE'10/2 ₅		
WE-4 Poa-Art	WE'08 ₄	WE'09 ₁	WE'10 ₄	WE'10/2 ₄	WE'10/3	
WE-3 Pin-Bet	WE'08 ₃	WE'08 _{3a}	WE'10 ₃	WE'10/2 ₃	WE'10/2 _{3a}	WE'10/2 ₃
WE-2 Poa-Bet-Hipp	WE'08 ₂		WE'10 ₂	WE'10/2 ₂		WE'10/2 ₂
WE-1 Poa-Jun	WE'08 ₁		WE'10 ₁	WE'10/2 ₁		WE'10/2 ₁

Fig. 10. Correlation of local pollen assemblage zones (L PAZs) of all Węgliny profiles

COMPLEMENTARY ANALYSES

Loss On Ignition (LOI) Analysis

Loss on ignition analysis was performed for core WE'08 (Tab. 9). The entire section was cut into segments 2.5 cm long, and those samples were dried at 105°C for ca 12 hours and then ground in a mortar and sieved through 1 mm mesh. The obtained dust was placed in ceramic crucibles of a defined volume, re-dried for ca 12 hours in an oven and weighed.

The final stage included ignition at 550°C for 4 hours and another weighing. This procedure was carried out under the supervision of Professor W. Margielewski in the laboratory of the Institute of Nature Conservation, Polish Academy of Sciences. The data collected were processed following an algorithm by Heiri et al. (2001) with Excel software and are presented in a diagram (Fig. 6). The shape of the LOI curve provided the basis for distinguishing 11 segments characteristic for the examined material. The distribution of organic matter (LOI) in section WE'08 is relatively well correlated the determined pollen assemblage zones.

Table 9. Characterization of Loss of ignition (LOI) segments for the WE'08 profile and their correlation with local pollen assemblage zones of WE'08 profile

No. LOI	Description of loss on ignition (LOI)	Correlation to L PAZ
LOI-1	Lowest content/amount of organic matter; up to 20%	WE'08 ₁ and part of WE'08 ₂
LOI-2	Constant content/amount of organic matter; ca 40%, with one exceptional maximum of ca 55%	part of WE'08 ₂ and part of WE'08 ₃
LOI-3	Sharp decrease down to 25%	WE'08 ₃
LOI-4	Gradual rise of organic matter to 45%	WE'08 ₄ and WE'08 ₅
LOI-5	Decrease to ca 25%	WE'08 ₄ and WE'08 ₅
LOI-6	Rise to ca 30%	WE'08 ₆
LOI-7	Initial rise to ca 45%, then fall to ca 35%	WE'08 ₇
LOI-8	Slight rise of organic matter to ca 40%	WE'08 ₇
LOI-9	Unstable curve. High percentages of ca 68% with temporary drop	WE'08 ₈
LOI-10	Unstable curve. Highest percentage, more than 80%	WE'08 ₈
LOI-11	Decrease of organic matter content to ca 60%	WE'08 ₉

Radiocarbon Dating

Nine radiocarbon determinations from profile WE10/2 at the Węgliny site are available (Tab. 10). Four samples consist of peat with gyttja, and five consist of gyttja. The examined material did not contain any organic macroremains suitable for radiocarbon dating. All determinations were made by the Poznań Radiocarbon Laboratory using AMS technique. The dates are uncalibrated in radiocarbon years BP (before present – AD 1950) using the half-life of 5568 years. Calibration is by the IntCal09 (Reimer et al., 2009) and OxCal v4.1 calibration programs (Bronk Ramsey 2010). Housley et al. (2013) exhaustively describe the detailed procedure for depth/age model construction and discuss sediment age.

SUCCESSION OF VEGETATION AND CHANGES IN CLIMATE DURING THE LATE GLACIAL AND HOLOCENE

RECONSTRUCTION OF VEGETATION CHANGES IN THE WĘGLINY AREA DURING THE LATE GLACIAL

Open Vegetation phase (I) – Oldest Dryas OsD

**WE-1 Poaceae-*Juniperus* L PAZ; WE'08-1,
WE'10-1, WE'10/2-1**

The landscape reconstructed on the basis of palynological analysis shows a mosaic of open communities overgrown by grasses (Poaceae) and heliophytes such as *Artemisia*, *Helianthemum* (pollen of *H. nummularium* t.), aster (*Aster* t.), and heather (*Calluna vulgaris*), accompanied by infrequent brushwood with the pioneer species juniper (*Juniperus communis*), and sea buckthorn (*Hippophaë rhamnoides*). Larch (*Larix*) probably occurred as single trees or formed, together with pine (*Pinus sylvestris*) and birch (*Betula*), clusters

of forest communities with *Pteridium aquilinum* fern in the ground layer. Tundra-type habitat is indicated by the presence of dwarf birch (pollen of *Betula nana* t.), willow (*Salix*) including polar willow (pollen of *Salix polaris* t.), dwarf shrubs of the heather family (Ericaceae), and by humid communities with sedges (Cyperaceae), clubmoss (*Selaginella selaginoides*), horsetail (*Equisetum*), and peatmoss (*Sphagnum*). The floral composition of meadows was diversified and determined by edaphic conditions. Steppe-like grasslands extending on heights were represented by *Sanguisorba officinalis*, *Bupleurum*, *Solanum nigrum* t., taxa of the Plantaginaceae family (including *Plantago media*), *Rumex acetosa* t., *R. acetosella* t., *Anthemis* t., and plants of the Brassicaceae family. Boggy areas supported hygrophilic communities with *Filipendula*, *Ranunculus arvensis*, *Urtica*, *Caltha* t., *Hydrocotyle vulgaris*, and *Thalictrum*. There also were sites of development of ferns such as *Botrychium* and *Ophioglossum*. Reedswamp communities surrounding the lake comprised *Phragmites australis*, *Littorella uniflora* developed in shallow oligotrophic water, and *Myriophyllum verticillatum* in shallow and stagnant water.

Most likely the palynological pattern presented in the pollen diagrams is slightly distorted by the high proportion (overrepresentation) of pine and birch pollen in the basal part of the section. Large amounts of this pollen originated from long-distance transport or were redeposited from older basement sediments, as confirmed by the high numbers of sporomorphs typical of Neogene sediments, such as *Nyssa*, *Juglans*, *Sequoia*, and *Pterocarya*, as well as by abundant Dinophyceae cysts (Tab. 11). For this reason, pine and birch were considered taxa of minor importance in interpretations of zones WE-1 and WE-2.

Table 10. AMS ¹⁴C age determinations and calibrated ranges for dated samples from Węgliny core WE'10/2. * aberrant dates due to hardwater effects

No.	Profile and depth (cm)	Dated material	Lab. no.	Date ¹⁴ C BP	Age cal BP (95.4%) Housley et al. 2013
1.	WE'10/2 14–15	peat	Poz-43984	1695±30	1695–1530
2.	WE'10/2 89–90	peat	Poz-42400	4940±35	5740–5600
3.	WE'10/2 218–219	peat	Poz-42397	8660±50	9765–9530
4.	WE'10/2 285–286	peat	Poz-42398	9360±60	10745–10405
5.	WE'10/2 345–346	gyttja	Poz-43985	10440±50*	12545–12115
6.	WE'10/2 455–456	gyttja	Poz-42399	12190±60*	14475–13810
7.	WE'10/2 491–492	gyttja	Poz-44103	12880±70*	16065–14985
8.	WE'10/2 665–666	gyttja	Poz-43987	14240±80*	17660–16975
9.	WE'10/2 724–725	gyttja	Poz-43989	13340±70*	16835–15630

Table 11. Presence of redeposited sporomorphs in the Węgliny profiles

Profile	Rebedded	Pleistocene taxa	Neogene taxa	Dinophyceae
WE'08	WE'08 ₁ to WE'08 ₄	lack	lack	WE'08 ₁ , WE'08 ₄
WE'09	WE'09 ₁ to WE'09 ₃	lack	lack	lack
WE'10	WE'10 ₁ to WE'10 ₃	WE'10 ₁	WE'10 ₁	WE'10 ₁
WE'10/2	WE'10/2 ₁ to WE'10/2 ₄	WE'10/2 ₁ to WE'10/2 ₂	WE'10/2 ₁	WE'10/2 ₁ to WE'10/2 ₃
WE'10/3	WE'10/3 ₁ to WE'10/3 ₃	WE'10/3 ₁ to WE'10/3 ₂	WE'10/3 ₁	WE'10/3 ₁ to WE'10/3 ₂

Hippophaë phase – Bølling Bø

WE-2 Poaceae-Betula-Hippophaë L PAZ; WE'08-2, WE'10-2, WE'10/2-2

The landscape was still dominated by open, steppe-like communities overgrown mainly by grasses (Poaceae). Single assemblages of trees and brushwood with the heliophilous *Juniperus* were also found, and locally formed communities resembling park tundra in which trees such as *Betula* (pollen of *Betula*, fruits and seed scales of *Betula* sect. *Albae*) and *Pinus sylvestris* likely gained importance. Patches of dwarf shrub tundra with *Betula nana* (pollen of *Betula nana* t. and fruits of *Betula* cf. *nana*) and *Salix polaris* occurred locally. Dry, poorly developed soils of convex postglacial forms (dunes) had abundant sea buckthorn, *Hippophaë rhamnoides*, possibly accompanied by shrubs of *Ephedra distachya*. Most likely the active hydrological processes shaping the ground surface hindered the development of dense plant cover. The area was rather dominated by meadows including grasses, *Artemisia*, *Helianthemum*, and plants of the Chenopodiaceae and Rosaceae families. Sites along watercourses and the vicinity of shores of the developing lake were inhabited by assemblages with *Filipendula*, *Thalictrum*, *Mentha*, *Potentilla*, and plants of the Apiaceae and Ranunculaceae families. Boggy areas were occupied by sedge fens composed of sedges (Cyperaceae), *Equisetum*, *Peucedanum palustre*, and *Sphagnum*, as well as swamp vegetation with *Phragmites australis*.

The palynological record of the history of this area begins with the formation of the basin. The initial stage of its development is indicated by sandy and sandy-clayey sediments found in basal parts of sections WE-1 and WE-2, and by the occurrence of Characeae algae, commonly observed in this type of sediment (Wacnik 2009, Stachowicz-Rybka 2011) and considered to be the first coloniser

species in lakes (Pełechaty & Susek 2008). Algae of the genera *Pediastrum*, *Tetraedron*, and *Scenedesmus* were also present. The occurrence of bryozoans *Cristatella mucedo* (in macrofossil analysis) permitted an estimation of the physicochemical conditions dominant in the basin, most likely typified by a high or moderate concentration of calcium carbonate, moderate amounts of magnesium, and slightly acidic, clear water (Økland & Økland 2000). *Cristatella mucedo* prefers regions with mean July temperatures reaching ca 10°C (Birks & Birks 2000, 2006). According to Økland and Økland (2000) the species is not found in cold lakes with water temperature falling below 11–16°C in the summer. The occurrence of algae such as *Pediastrum integrum*, *P. boryanum* var. *longicorne*, and *P. cf. alternans*, known to prefer clean, cold, oligo- and dystrophic water, indicates periods of rather boreal climatic conditions (Pokorný & Jankovská 2000, Komárek & Jankovská 2001, Tell 2004). Spores of *Selaginella selaginoides* provide evidence for maximum July temperatures close to 17°C (optimum mean temperature 10–14°C), while pollen of dwarf birch (*Betula nana*) indicates maximum January temperature not exceeding 0°C (Kolstrup 1979, 1980, Tobolski 1991, Mamakowa 1997). On the basis of the present-day environmental preferences of *Juniperus*, minimum July temperature may be assessed as exceeding 10°C (Iversen 1954, Isarin et al. 1998). These zones were also marked by abundant pollen of *Hippophaë rhamnoides* shrubs, suggesting mean annual temperatures ranging from 4.7°C to 15.6°C (Basistha et al. 2010). High amounts of this pollen in zone WE-1, in the diagrams plotted for WE'08 (2%), WE'10/2 (23%) and WE'10/3 (5%), indicate that the species was widespread in the study area. According to de Klerk (2008), shares of *Hippophaë* pollen amounting to 5–8% show dominance of the shrub. The occurrence of *Selaginella* spores and pollen of *Juniperus*, *Betula nana*, and other heliophytes, accompanied by the highest

shares for *Hippophaë*, Poaceae, and *Helianthemum*, as well as one of the highest percentages recorded in the diagrams for Cyperaceae, all serve as indicators of a rather cool period.

Betula/Pinus forest phase – Allerød AI

WE-3 *Pinus-Betula* L PAZ; WE'08-3, WE'10-3, WE'10/2-3

The vegetation surrounding the basin changed markedly. Open communities, so far dominant, were replaced by intensively developing tree vegetation forming forest complexes with birch as the most frequent taxon (fruits and fruit scales of *Betula* sect. *Albae* and *Betula* sp.). High pollen values for *Pinus sylvestris* recorded in the examined material suggest that pine was also one of the main components of the forest, most likely including numerous grasses and mosses in their ground layer. Park tundra and tundra with dwarf shrubs of *Salix polaris* and *Betula nana* (pollen of *Salix polaris* t. and *Betula nana* t.) formed a mosaic with steppe communities, comprising Poaceae, *Artemisia*, and *Rumex acetosella* t., as well as plants of the Chenopodiaceae and Asteraceae (*Aster* t.) families. Insolated heights were covered by dwarf shrubs of the Ericaceae family including *Calluna vulgaris*, and by *Juniperus* shrubs. Humid depressions were occupied by Cyperaceae, *Filipendula*, *Thalictrum*, and *Equisetum*, while overflow areas were sites of the development of swamps with *Phragmites*, *Typha*, *Sparganium*, and ferns (Filicales monoete). Patches of peat bogs with *Menyanthes trifoliata* and *Sphagnum* occurred locally, as confirmed by the presence of fungal ascospores, for example Type 3, Type 6, and Type 63 (Fig. 6), indicating a boggy and peaty habitat (Van Geel 1978, Van Geel & Aptroot 2006). The bottom of the basin was covered by bryozoan (*Cristatella mucedo*) and stonewort (Characeae family) meadows, serving as indicators of high carbonate (CaCO₃) content. The littoral was overgrown by *Myriophyllum verticillatum* and *M. spicatum*. The fauna of the zone was represented by *Daphnia* floating in the water body, and abundant malacofauna, remains of which were observed in the sediment during sampling. Lake plankton included algae of *Tetraedron*, *Botryococcus*, *Spirogyra*, and *Pediastrum*. *Pediastrum boryanum* var. *boryanum*, dominant in the previous period,

was gradually displaced by *P. boryanum* var. *pseudoglabrum*, infrequently found in the profiles and known to prefer mesotrophic basins (Komárek & Jankovská 2001). However, water trophy probably did not noticeably change as *P. integrum* and *P. boryanum* var. *longicorne*, preferring oligotrophic water, were recorded (Kowalska 2011).

Presumably the basin was filled with dystrophic water and supplied with redeposited material (constant occurrence of interglacial sporomorphs) originating from a river flowing into the lake. The zone does not contain many indicators of a noticeable improvement in temperature conditions. Changes in the ecosystem are evidenced mainly by the development of tree vegetation including birch and pine, favouring mean July temperature of 12–13°C (Kolstrup 1980, Wasylkova 1964, Mamakowa 1989), and by a constant proportion of pollen of *Filipendula*, requiring minimum mean July temperature of 8°C (Brinkkemper et al. 1987). The presence of *Typha latifolia* pollen and *Typha* sp. macroremains serves as evidence of mean July temperature reaching at least 13–14°C (Iversen 1954). Improvement in temperature conditions is also suggested by the appearance of cyanobacteria (Type 146), being the first coloniser species in warm periods of the Late Glacial (Van Geel 2001) in the fossil record. Moreover, the continued presence of Filicales spores implies an increase in both temperature and humidity during this period (Smith et al. 2006).

The depth interval of WE-3 L PAZ in sections WE'10 and WE'10/2 is marked by the Laacher See Tephra horizon, dating the investigated sediment to the latter stages of the Allerød interstadial, ca 200 years before the onset of the Younger Dryas stadial (Housley et al. 2013). During the interstadial, a brief increase in the frequency of grasses and birches was accompanied by a noticeable rise in NAP amounts and a decrease in pine values (WE'10/2 and WE'08 – subzone WE'3a) (Fig. 6), probably indicating temporary cooling. However, as no such change was displayed in the palynological record of other sections, it was not assigned to a distinct zone.

Within the LOI curve (Fig. 6) plotted for section WE'08, a fragment close to the WE-3/WE-4 boundary shows a clear brief decrease in the amount of organic matter in the basin and provides evidence for supply of mineral

material (interval LOI₃). Sediment of the zone was described as gytjtja, while the above-mentioned interval most likely differed from the over- and underlying deposits only by the higher percentages noted for the mineral fraction. Such an observation is recorded for slow, gradual deposition of fine fraction in the material. As it was difficult to identify this change without further detailed studies, the zone was not distinguished in the lithological description. To the end of the Allerød, for example in the section from Meerfelder Maar, it is marked by a change in sediment showing an increase in content of mineral matter, interpreted as activation of fluvial erosion or weathering processes in the surroundings of the basin and demonstrating deterioration of abiotic conditions (Brauer et al. 1999). Presumably the vicinity of the Węgliny site was affected by similar events.

Open Vegetation phase (III)
– Younger Dryas YD

WE-4 Poaceae-Artemisia L PAZ; WE'08-4, WE'10-4, WE'10/2-4

Cooling of climate in this period is indicated by, for example, the reoccurrence of dwarf birch (pollen of *Betula nana* t. in section WE'08) and *Hippophaë rhamnoides* (in section WE'10/2), most likely growing on the slopes of dunes or moraines adjacent to the basin. The landscape was marked by the appearance of clumps and loose patches of birch and pine, accompanied by juniper in the shrub layer and by *Vaccinium* and mosses (Musci spores) in the ground layer. Dwarf shrubs of the Ericaceae family, including *Calluna vulgaris*, formed steppe-like communities with *Artemisia*, *Helianthemum nummularium*, *Aster* t., *Rumex acetosella* t., and grasses (Poaceae). The high frequency of grasses, sedges and other herbaceous plants, representing families such as Plantaginaceae, Caryophyllaceae, Fabaceae, Asteraceae, Cichoriaceae, and Chenopodiaceae, indicates the prevalence of open areas. Those taxa most likely developed in extensive sandy grasslands typical of inland dunes. The slopes of moraines may have been covered by *Ephedra distachya*, and fresh soils by *Selaginella selaginoides*, serving as indicators of open areas and cool climate (Granoszewski et al. 2004). Heights and areas of higher insolation alternated with

humid tundra inhabited by *Betula nana* and *Salix polaris*. Sites close to the basin were overgrown by willow (*Salix*) and tall herb communities with *Filipendula*, and presumably *Urtica dioica* (as indicated by carpological macroremains), *Sanguisorba officinalis*, *Lychnis flos-cuculi*, and *Geum*. Scrubs with *Valeriana officinalis*, mint (*Mentha* t.), and *Thalictrum* may have occurred locally.

The communities of the basin were slightly altered. Species such as *Oenanthe aquatica*, *Cicuta virosa*, and *Cladium mariscus* appeared in the shores and swamps, accompanied by the so-far dominant *Phragmites*, *Typha latifolia*, *Sparganium*, and *Equisetum*. Nearby wetlands were marked by the reoccurrence of *Mentha aquatica* and *Lycopus europaeus*. Among the aquatic plants, *Najas marina* and *Callitriche* were most numerous. The shallower part of the basin, closer to its shore, probably was covered by patches of peat bog including peatmosses (*Sphagnum*). This suggestion is confirmed by the presence of fungi (Type 3, Type 6, Type 63) known to prefer boggy and peaty environments (Fig. 6) in the zone. The water surface was covered by floating leaves and flowers of *Hydrocharis morsus-ranae*, while the water bodies and bottom were occupied by *Ceratophyllum*, *Batrachium*, *Myriophyllum spicatum*, and *M. verticillatum*. The increasing biodiversity of swamp and aquatic vegetation found in the coves most likely resulted from lowering of the water level and successive increases in the trophy of the littoral and smaller coves. Such conditions promoted the abundant development of chlorophytes of the genera *Botryococcus*, *Scenedesmus*, and *Tetraedron* (Fig. 6), the frequency of which markedly increased in the pollen diagram. Increases were also noted for the values of *Pediastrum* taxa such as *P. boryanum* var. *boryanum*, *P. boryanum* var. *pseudoglabrum*, and *P. duplex* var. *rugulosum*, preferring meso- to eutrophic water (Komárek & Jankovská 2001, Kowalska 2010). Zone WE-4 is characterised by the highest shares of *Pediastrum*, *Scenedesmus* and *Tetraedron* chlorophytes. The main lake basin was locally still overgrown by bryozoan meadows with *Cristatella mucedo*. Floating *Pediastrum integrum*, *P. boryanum* var. *longicorne*, and *P. cf. alternans* in the water bodies (Fig. 6) evidences oligo- to dystrophic conditions in this part of the basin (op. cit). Moreover, the noticeable increase in the amounts of *P. integrum* and the

reoccurrence of *P. cf. alternans* and *P. boryanum* var. *longicorne* indicates cooling of the climate (Komárek & Jankovská 2001).

Carpological analysis identified remains of *Potamogeton friesii*, typical of the Vistulian. The occurrence of this taxon confirms the stadial type of climatic conditions (Velichkevich & Zastawniak 2006). The reappearance of numerous indicators of cool climate, such as *Hippophaë rhamnoides*, *Betula nana*, *Juniperus*, *Ephedra distachya*, and *Selaginella selaginoides*, suggesting mean July temperature of ca 10°C (Wasylikowa 1964, Isarin & Bohnacke 1999), unequivocally shows deterioration of temperature conditions in this period.

LATE GLACIAL CHRONOSTRATIGRAPHY IN THE WĘGLINY AREA

The chronostratigraphy of the Late Glacial part of the examined sections from the Węgliny site was not determined in full. The applied chronostratigraphic division, regarded as optimal, follows de Klerk (2008) and is based on a correlation incorporating the palynostratigraphy of numerous sites from NE Germany as well as the record of climatic changes in Greenland ice cores (GRIP and GISP II).

Open Vegetation phase (I) – as the radiocarbon dating results for zone WE'10/2₂ and partly for zone WE'10/2₃ are over-aged estimates, the stratigraphy of the basal part of the cores was inferred only from palynological analysis, which indicates tundra-type vegetation typical of stadial successions.

Hippophaë phase – the maximum values of *Hippophaë rhamnoides* pollen in the examined material as well as in many other pollen diagrams from Poland and Europe fall within the period immediately preceding the appearance of forest communities in Late Glacial profiles. This observation was assigned to the Meindorf phase in sections from Löddigsee (Jahns 2006) and Miłkowskie Lake (Wacnik 2009) and to the Oldest Dryas for sections of Witów (Wasylikowa 1964) and Łęgoń (Malkiewicz 2002). In sections from Gościąż Lake (Ralska-Jasiewiczowa et al. 1998a) and Imiołki Lake (Tobolski 1998) this event falls within the Oldest Dryas and Bølling, in Vorpommern (de Klerk 2002) and Guzów within the Bølling (Nowaczyk & Okuniewska-Nowaczyk 1999), in sediments of the Łukcze Lake within the

Older Dryas (Bałaga 1990), in sediments of Stare Biele (Kupryjanowicz 2000) and Osłonki (Nalepka 2005) within the Older Dryas, and in Cedynia and Jasień (Okuniewska-Nowaczyk 1998, Kowalkowski et al. 1999) most likely within the pre-Allerød. As analysis of isopollen maps indicates the greatest distribution of sea buckthorn in the Bølling (Krupiński et al. 2004), the phase of *Hippophaë* was assigned to this period.

The description of vegetation from the *Betula/Pinus* forest phase in the Węgliny area corresponds to the Allerød succession. However, for Węgliny we did not record the occurrence of a birch phase preceding the pine phase, an observation typical of this period (Mamakowa 2003, Latałowa 2004), nor did we find a tripartite division of this interval, noted for sites in Germany and Switzerland (e.g. Gerzensee, Meerfelder Maar, Hämelsee) (Merkt & Müller 1999, Litt et al. 2003). Subzone WE'08_{3a}, corresponding to the brief cooling that preceded the record of the LST (Laacher See Tephra, dated to the latter stages of the Allerød interstadial located ca 200 years before the onset of the Younger Dryas stadial (Housley et al. 2013), was distinguished in zones WE'08₃ and WE'10/2₃, but from palynological analyses alone it is difficult to correlate this subzone with the Gerzensee oscillation, especially as it was not recorded in all sections from the investigated site.

The second Open Vegetation phase (III) corresponds to the Younger Dryas in terms of its palynology and chronology (Tab. 10). The close of the Late Glacial has been under discussion for many years. Palynological analyses provided the basis for proposing three phases within the Younger Dryas, but in recent years it has been divided rather into two parts in view of its temperature and humidity conditions. The first part displays extremely low temperature, while the second shows a milder climate (see conclusions in Dzieduszyńska 2011). The area of Europe is marked by two trends. In north-western Europe and the Alps, the first, cooler period, despite the lower temperature, was typified by a more humid climate which became drier and milder in the second period. These observations are supported by pollen diagrams showing the proportion between pollen of herbaceous plants (NAP) and pollen of trees (AP) as well as high amounts of grasses and heliophytes (mainly *Artemisia*) in west

European and Alpine profiles (Dzieduszyńska 2011). Poland and Norway demonstrate a different trend, however. The older period was characterised by drying and harshening of the climate, and the younger one by a slight warming and increase in humidity (op. cit.), as recorded, for example, at Gościąg (Ralska-Jasiewiczowa et al. 1998b) and Witów (Wasylikowa 1964, 1999–2001). The Węgliny site rather displays the “Polish-Norwegian” trend, evidenced by a decrease in the frequency of Poaceae, *Artemisia*, and *Juniperus*, accompanied by an increase in pollen values for trees, particularly *Betula* and *Pinus*, visible in the pollen diagram for the second phase of the Younger Dryas, represented by the upper part of zones WE’10-4 and WE’10/2-4.

LATE GLACIAL CLIMATE IN THE WĘGLINY AREA

Table 12 presents a suggested palaeoclimatic reconstruction prepared using published results from multidisciplinary research involving thermal and environmental indicators from different fields of study (e.g. Walker 1995, Isarin & Renssen 1999, Behre et al. 2005, Szeroczyńska & Zawisza 2007, Płóciennik et al. 2011, Aarnes et al. 2012). These results provide a complete description of climatic changes in the late Vistulian and may serve as a reference for interpreting climatic changes affecting a microregion and recorded at a single site (Tab. 12). At the Węgliny site no clear differences in temperature were noted between particular periods of the Late Glacial, probably the result of the delayed response of plants to climatic changes (Coope 2002). Presumably the taxa identified in pollen analysis

have greater thermal tolerance than the animals used in the climatic reconstruction (Chironomideae, Ostracoda, Coleoptera, Aves; Tab. 12) (Van Geel et al. 1989, Walker et al. 1993, Walker 1995, Walker et al. 2003, Płóciennik et al. 2011).

The flora composition is more affected by local habitat conditions than by ambient temperature; therefore the vegetation succession does not provide a complete record of global climatic changes (Blockley et al. 2006). The most recent studies carried out in Germany on plant thermal climatic indicators such as *Betula*, *Pinus*, *Juniperus*, *Salix* (including *S. polaris*), and Ericaceae (Theuerkauf & Joosten 2012) indicate that the presence of taxa significantly depends on temperature, soil and latitude. In the period preceding the Younger Dryas the growth of taxa was determined more by their soil than by temperature or landform features (op. cit.). Two trees dominant in the period, pine and birch, show different ranges of occurrence. The percentage shares of pine pollen increased southwards and eastwards. *Betula*, *Juniperus*, and *Salix* displayed the opposite trend and a northwards increase in percentage shares. Sandy soils had intensive growth of *Pinus* while *Betula* inhabited areas with better-developed soils, periodically flooded. Dense pine-birch forest, typical of the Allerød, slightly changed its extent in the Younger Dryas, when temperature had a much greater effect on the distribution of vegetation. South of 53°N latitude, *Pinus* occupied almost all habitats and displaced *Betula*. The range of birch was therefore limited to the mountains and river valleys, where the snow layer protected vegetation from frost. Pine, though very tolerant of severe frost, generally was not found above 53°N latitude, most likely due to the presence of permafrost

Table 12. Comparison of the microclimate of the Węgliny location with the palaeoclimate of Europe (Płóciennik et al. 2011, changed). * for reconstruction of palaeotemperature in Europe we used Chironomideae data from Polish, Russian, Swedish, and Norwegian databases, and Ostracoda, Coleoptera, and Aves databases. ** Level absent

chronostratigraphy	Europe		Węgliny
	Temperature reconstruction based on various quantitative methods*		Temperature reconstruction based on plant bioindicators
	mean July temperature		
	minimum	maximum	mean July temperature
Younger Dryas	7°C	17°C	10–14°C
Allerød	10°C	19°C	12–14°C
Older Dryas	8°C	15.5°C	–**
Bølling	10°C	19°C	10–14°C
Late pleni-Glacial – Oldest Dryas	6°C	16°C	10–14°C

preventing the trees from rooting properly there (Theuerkauf & Joosten 2012). The valleys of large rivers, dominated by conditions in which permafrost could not form, served as the only pine refugia (op. cit.). During this period in Europe, permafrost persisted up to 54–55°N following Isarin (1997), or only up to 50°N according to Renssen and Vandenberghe (2003). While snowless conditions prevailed in western areas, Poland in the Younger Dryas most likely was covered with a snow layer, strongly or even completely constraining the development of permafrost (Kozarski 1993). Kozarski and Nowaczyk (1999) stated that the permafrost retreated from Poland in the Bølling or Allerød, but Błaszkiwicz (2011) maintained that in favourable conditions it may have remained locally until the end of the Preboreal. The landform features of the study area probably supported the persistence of the snow layer in this period, enabling pine-birch forest refugia to develop and leaving a rather uniform pattern of late Vistulian vegetation.

RECONSTRUCTION OF VEGETATION CHANGES IN THE WĘGLINY AREA DURING THE HOLOCENE

THE PREBOREAL

WE-5 *Betula-Pinus-Poaceae* L PAZ; WE'08-5, WE'10-5, WE'10/2-5

The Preboreal period of the Holocene began with a brief rapid increase in mean annual temperature, by several degrees (Jin & Chen 2008, for basic literature see Dzeduszyńska 2011). Although vegetation shows a delayed response to climatic changes, subtle indications of the upcoming warming of climate may be gleaned from the pollen diagram. In all sections the Younger Dryas/Preboreal transition was marked by single counts of pollen of *Corylus avellana*, *Quercus*, *Ulmus*, and *Alnus*. Such an observation is likely to indicate mildening of the climate and the gradual approach of these trees to areas of western Poland.

Analysis of the isopollen maps showing those taxa indicates a trend similar to the one already recorded in sections from western and central Poland (Milecka et al. 2004, Miotk-Szpiganowicz et al. 2004, Szczepanek et al.

2004, Zachowicz et al. 2004). The trees are characteristic of warmer periods and generally do not appear before the early Holocene. Their low shares, mostly below 2%, suggest that they did not occur *in situ* close to the basin (Huntley & Birks 1983). This was a time of gradual changes in landscape. Communities passed into park tundra dominated by birch and pine, and mainly ferns in the ground layer (*Dryopteris filix-mas*, *Thelypteris palustris*, *Osmunda regalis*, *Pteridium aquilinum*) along with mosses (Musci spores). High shares of Filicales monolete spores in the pollen diagrams demonstrate its increasing importance in the ecosystem. It was accompanied by tall herb communities with *Urtica*, *Filipendula*, *Bidens*, *Ranunculus acris*, *Rumex acetosa*, *Solanum dulcamara*, *Viola palustris* t., and *Sanguisorba officinalis*. Decreasing amounts of grasses and sedges and single occurrences of heliophytes in the pollen spectra of all diagrams may suggest increasing restriction of their open habitat, which was being overgrown by numerous plants of the Plantaginaceae, Rosaceae, Ranunculaceae, Cichoriaceae, and Apiaceae families, as well as by *Rumex acetosella* and *Galium*. Among the bog and swamp plants, *Phragmites*, *Typha*, and *Equisetum* were dominant. The shores of the basin supported patches of peat bog with *Sphagnum* and fungi, most likely developing on peat-forming or boggy vegetation (spores of Type 6 and Type 63, Fig. 6). Shallow lake coves were inhabited by *Nuphar lutea*, *Hydrocharis morsus-ranae*, and *Myriophyllum spicatum*. *Pediastrum* chlorophytes still dominated the water, while the values for *Tetraedron* and *Botryococcus* decreased markedly and *Scenedesmus* was no longer recorded. The bottom of the basin was covered by meadows of *Ceratophyllum* and Characeae. An increasing supply of nutrients washed in from adjacent areas resulted in eutrophication of the lake water, particularly in the shallow coves, as observed in zone WE-4. In zone WE-5 the decrease in the amounts of *Tetraedron* and *Botryococcus* chlorophytes and the disappearance of *Scenedesmus* and *Pediastrum duplex* var. *rugulosum* likely reflect changes in lacustrine trophy. The decline or absence of thermal plant indicators of cool climate and the presence of *Solanum dulcamara* (indicating mean July temperature of 13°C) may suggest an improvement in temperature conditions in the zone (Granoszewski 2003).

WE-6 *Pinus-Betula-Corylus* L PAZ;
WE'08-6, WE'10-6, WE'10/2-6

In this period, tree stand structure in the Lubsza Plain underwent changes. Open forests were still dominated by birch and pine. The shrub layer was formed by the heliophilous *Corylus avellana*, proceeding with its intensive growth, while the ground layer was formed by ferns (spores of Filicales monoete) and mosses. Trees such as *Ulmus*, *Quercus*, and *Picea abies* occurred in or near the region. Single grains of *Fraxinus excelsior* probably originate from long-distance transport but still indicate an improvement in temperature conditions. Depressions, most likely periodically flooded, were the sites of gradual expansion of riparian forest with *Alnus* and *Salix* accompanied by clumps of *Filipendula*, *Urtica*, *Circaea*, and the ferns *Thelypteris* and *Osmunda*. Forest glades were overgrown by Poaceae, *Artemisia*, *Aster*, *Rumex acetosella*, *Rosa*, *Anthemis*, and plants of the Ranunculaceae, Cichoriaceae, Apiaceae, Caryophyllaceae, and Chenopodiaceae families. Insolated exposed heights were covered by dense assemblages of Ericaceae dwarf shrubs with *Calluna vulgaris*.

Small waterlogged boggy valleys supported saprophytes (Type 3, Type 6, Type 63) developing on dead trees (Fig. 6). The littoral zone of the basin was also affected by changes. Swamp continued to be comprised of *Typha*, *Spartanium*, and *Phragmites*. Fungi (Type 200) typical of such habitats appeared as well. The growth of the peat-forming plants *Sphagnum*, *Scheuchzeria palustris*, and *Cladium mariscus* on the shores likely was the result of lowering of the water level, additionally evidenced by the occurrence of *Najas marina* and *Stratiotes aloides* known from shallow basins. Aquatic floating-leaf plants included nymphaeids with *Nymphaea candida* and *N. alba*, ceratophyllids with *Ceratophyllum*, and lemnids with *Lemna*. Shallow lake water supported *Botryococcus* and *Tetraedron* algae. In the genus *Pediastrum*, *Pediastrum boryanum* var. *boryanum*, and *P. boryanum* var. *pseudoglabrum* were the dominant taxa, presently found in clean meso- and eutrophic water (Kowalska 2011). However, the presence of *P. integrum* and *P. boryanum* var. *longicorne* likely indicates oligotrophic conditions in the open water of the basin (Komárek & Jankovská 2001). The main indicators of a climatic improvement in

this period include aquatic and swamp plants, which respond earlier to temperature changes. The occurrence of *Typha latifolia* and *Nymphaea alba* indicates conditions advantageous to the growth of these plants, which at present are known to prefer minimum mean July temperature between 13°C and 14°C (Iversen 1954, Kolstrup 1980). A high amount of seeds of *Najas marina*, typified by slightly higher temperature requirements (17°C), suggests temperature higher by even 3°C (Granoszewski 2003). Other indicators are *Corylus avellana*, showing optimum development at an annual temperature of 9°C (Zarzycki et al. 2002), and *Ulmus*. *Ulmus scabra* is not now found beyond the 16°C July isotherm, and two other *Ulmus* species prefer even higher temperature (Kanterva 1956, Szczepanek 1971). The noticeable increase in the percentage shares recorded in the pollen diagram for spores of ferns, formerly known as Filicales and according to modern terminology assigned to Polypodiales (Smith et al. 2006), indicates an improvement in temperature conditions, and primarily increasing humidity.

THE BOREAL

WE-7 *Corylus-Pinus-Quercus* L PAZ;
WE'08-7, WE'10-7, WE'10/2-7

The vegetation changed noticeably. Mixed forest with hazel (*Corylus avellana*), accompanied by elm and oak, became dominant on the landscape. Fertile soils adjacent to the basin supported the development of lime (*Tilia cordata*). The appearance of single pollen grains of *Taxus baccata* on the diagrams plotted for WE'10 and WE'09 betokens the occurrence of yew in the region (Noryśkiewicz 2006). Multispecies riparian forest was abundant and included *Alnus*, *Fraxinus excelsior*, and *Salix*, as well as *Urtica*, *Thalictrum*, *Humulus lupulus*, and *Filipendula* in the ground layer. There was a simultaneous decrease in the area of open, loose pine-birch forest, with *Picea abies* likely to be found as an admixture, and *Calluna vulgaris* and dwarf shrubs *Erica tetralix* and *Empetrum* covering the ground layer.

The enriched taxonomic composition and diversity of the forest undoubtedly contributed to the decrease in the area of open communities, but forest glades and margins were inhabited by grass and sedge fens with Cypereaceae, Poaceae, *Artemisia*, *Aster*, and *Rumex*

acetosella. Sandy heights were inhabited by *Jasione montana* and *Helianthemum*, fresh meadows by *Dianthus*, *Valerianella dentata*, *Mentha*, and *Plantago media*. There were changes in the basin as well. In the littoral, constant components of reedswamp such as *Phragmites australis*, *Typha latifolia*, *Spartanium*, and *Equisetum* were accompanied by *Thelypteris palustris*. *Ledum palustre*, *Sphagnum*, and possibly *Scheuchzeria palustris* formed peat patches, which most likely supported fungi. Shallow coves were occupied by *Ceratophyllum* and nymphaeids with *Nymphaea alba* and *Nuphar lutea*. This pollen assemblage zone, falling within the central part of zone WE'10/2₅ (L MAZ), is very poor in taxa. Among the aquatic and swamp plants were single remains of *Stratiotes aloides*, *Menyanthes trifoliata*, *Cladium mariscus*, and *Typha* sp., exclusively at the base of the section. The remains of terrestrial plants comprised only grasses, pine and birch. These observations suggest rising water level and decreasing trophy of the basin, also confirmed by the nearly complete disappearance of *Tetraedron*, *Botryococcus*, and *Scenedesmus* chlorophytes. The period was also marked by a decrease in the frequency of *Pediastrum*. Among the recorded species, *P. boryanum* var. *boryanum* and *P. boryanum* var. *pseudoglabrum* were dominant. *P. integrum* occurred as well, indicating oligo- or mesotrophic water (Tell 2004).

An improvement in habitat conditions, including increased temperature, were also confirmed by the high and rising amounts of biomass in zone LOI₇, corresponding to the early Boreal. A decrease in organic matter content recorded in the LOI curve for the late Boreal (close of the Boreal, zone LOI₈) may result from the reduced frequency of *Pediastrum* and the disappearance of aquatic and swamp plants, probably also indicating rising water level. A successive improvement in temperature conditions is indicated by the presence of *Humulus lupulus* and *Tilia cordata*, preferring mean July temperature of at least 15°C (Hulten 1950) or even 17°C (Zagwijn 1996). Additionally, the regional appearance of *Taxus baccata* and shrubs of *Vitis vinifera*, presently native to southern European areas typified by warm humid summers (Hegi 1965), also indicates a climate of increasing humidity (Hrynowiecka-Czmielewska 2010). Sections WE'10/2 and WE'08 bear a record of

the highest percentage values of *Corylus avellana* in the Boreal, 18% and 20% respectively. In other two sections, hazel reaches 17.5% (WE'10) and 19% (WE'09); its maximum percentages fall within the early Atlantic close to its lower boundary: 22% and 21% respectively. Such high values for *Corylus* pollen may suggest the dominance of this shrub in the shrub layer or forest glades. A hazel pollen frequency reaching $\geq 25\%$ is thought to indicate its forest-forming function and the development of hazel forest, not represented by a present-day equivalent (Huntley & Birks 1983, Gardner 1999).

THE ATLANTIC

WE-8 *Corylus-Alnus-Quercus-Ulmus* L PAZ; WE'08-8, WE'10-8, WE'10/2-8

In the Boreal, hazel was one of the most important components in tree stands. Its maximum occurrence preceded the entrance of mesophilous deciduous forest into the basin's surroundings. *Corylus* attained high frequency values throughout the Atlantic, confirming the strong influence of this taxon on the ecosystem. On the Atlantic landscape, depressions and basins with soils of greater fertility were the sites of development of climax forest, possibly riparian elm-ash forest including large proportions of oak. On the pollen diagrams the pollen of trees and shrubs having higher temperature requirements, such as *Ilex aquifolium*, *Hedera helix*, *Vitis vinifera*, and *Acer*, is infrequent, most likely because the pollen of some of these trees is produced in low amounts and is masked by taxa producing pollen intensively (mainly pine) or by dense forest cover surrounding the basin.

That is why deposition of pollen grains of trees and other plants growing in further parts of the forest was limited (Göransson 1986), distorting the description of vegetation on the Lubsza Plain. Presumably the area near the basin was still overgrown by well-developed loose pine-birch forest with an admixture of spruce and ground layer covered by dwarf shrubs of Ericaceae, with *Calluna vulgaris* and *Empetrum*, as well as by *Lycopodium annotinum* and mosses. Distant areas may have been occupied by forest with oak, lime, hornbeam, maple, and spruce (Matuszkiewicz 2006).

Periodically flooded boggy sites around the lake supported the intensive growth of bog alder forest dominated by *Alnus glutinosa* and

Salix, accompanied by *Viburnum opulus* (pollen of *Viburnum opulus* t.). In the ground layer were communities including *Urtica dioica* (fruits) and *Mentha*. Sedge fens with Cyperaceae and *Thelypteris palustris*, and (at humid sites) clumps of tall herbs with *Filipendula*, *Urtica*, *Caltha*, and *Galium*, were also formed, accompanied by *Rumex maritimus* and *Ranunculus repens*, as indicated by their macroscopic remains recorded in the sediment. Ferns, represented by species such as *Pteridium aquilinum*, were also an important component of the ground layer. Insolated dune slopes were the sites of development of brushwood with privet (*Ligustrum vulgare*). Fir (*Abies alba*) possibly appeared in the region, as evidenced by infrequent pollen grains of it found in section WE'08.

The great variability of herbaceous taxa and the high values of grasses, regularly observed in the pollen spectra, suggest that the forest surrounding the lake was not very dense. Open areas within the forest and sites adjacent to the lake most likely had patches of meadow forming a mosaic of grasses and herbaceous plants of the Apiaceae, Rosaceae, Chenopodiaceae, Asteraceae (e.g. *Artemisia*, *Aster*, *Anthemis* t.), Polygonaceae (e.g. *Rumex acetosella* t.), and Caryophyllaceae (e.g. *Scleranthus annuus*) families. Humid soils of the ground layer supported herbaceous plants, the source of pollen of *Rumex acetosa* t., *Ranunculus acris* t., *Valeriana officinalis*, and *Bidens* t., gradually passing into a belt of swamp, still locally found in peaty lake coves. Muddy ground favoured the development of nymphaeids and *Littorella uniflora*.

Pollen assemblage zone WE-8 corresponds to two carpological zones, the upper part of the WE'10/2₅ (L MAZ) and the entire WE'10/2₆ (L MAZ) zones (Jurochnik 2012). In shallow lake coves, nymphaeids and *Littorella uniflora* were accompanied by the *Najas* plants *N. marina* and *N. minor*. Swamps were composed of *Typha*, *Eleocharis*, and *Carex pseudocyperus*. *Scheuchzeria palustris*, considered to be a component of peat bogs, was observed as well (Tobolski 2000). Subsequent zones provide evidence for changes proceeding in the basin. The taxonomic composition of zone WE'10/2₆ (L MAZ) shows gradual lowering of the water level followed by shoreline retreat. The entry of plants typical of swamps but also forming patches of peat bogs was marked by

the appearance of *Ledum palustre* and *Menyanthes trifoliata* and by a noticeable increase in the proportions of *Cladium mariscus* and *Carex* sedges. In deeper parts of the lake, chlorophytes of the Characeae family and the genera *Spirogyra* and *Pediastrum*, including *P. boryanum* var. *boryanum*, *P. boryanum* var. *pseudoglabrum*, and *P. integrum*, may have occurred. Water bodies had floating *Daphnia* and *Lemna minor* developing on the surface. Fruits of *Cladium mariscus*, very numerous in the carpological diagram, indicate optimum conditions for the growth of this species: warm summers, with mean temperature above 15°C, and mild winters (Lamb 1977). Saw-sedge is generally considered a heliophyte preferring habitats abundant in calcium carbonate and characteristic peat bogs growing on chalk (Herbichowa & Wołejko 2004, Kaczmarek 1960, 1962). However, recent studies have shown that the occurrence of *Cladium* depends more on specific environmental conditions than on calcareous soil. Fruits and pollen of that taxon are found in fine-grained sands and non-calcareous detritus gyttja (Gałka & Tobolski 2006, 2011, Tobolski & Gałka 2008). *C. mariscus* is known to prefer rather extreme conditions, and grows in periodically flooded areas with stagnant anaerobic water and in habitats with large amounts of organic and mineral (particularly) calcareous matter, devoid of nutrients such as phosphates. It is not observed on fertile, nutrient-rich soils (Pokorný et al. 2010).

The humid phase distinguished in the early Atlantic (Margielewski 1997) probably corresponds to the first noticeable increase in organic matter recorded in zone LOI₉ (Fig. 6). The next rise in biomass in the zone initiates the increasing trend of the LOI curve, the maximum of which (80%) falls within the close of the Atlantic in zone LOI₁₀. Such high LOI values in that zone indicate that during the late Atlantic the study site was dominated by conditions optimal for intensive development of vegetation.

The climate was oceanic, as demonstrated by the occurrence of elm-ash riparian forest, presently developing most intensively in the southern and south-eastern parts of Central Europe (Matuszkiewicz & Borowik 1957). The presence of *Hedera helix* and *Ilex aquifolium* additionally confirms the prevalence of humid and mild climate. Ivy has fixed temperature requirements and does not flower if the

temperature of the coldest month falls below -1.7°C or -2°C (Iversen 1944, Zagwijn 1994) but survives at temperature down to -5°C (Paszyński & Niedźwiedź 1991). Its optimum growth is recorded at a mean warmest-month temperature of 15°C (Aalbersberg & Litt 1998), while *Ilex aquifolium* prefers temperatures of at least 0°C in the coldest month of the year (Iversen 1944, Zagwijn 1996). Both taxa serve as indicators of mild winters and increasing air humidity in the period (Brud & Mamakowa 2001).

THE SUBBOREAL

WE-9 *Pinus-Picea-Tilia* L PAZ; WE'08-9, WE'10/2-9

The structure of the landscape changed. Climax deciduous forest was replaced by mixed deciduous-coniferous forest with *Tilia*, *Fraxinus excelsior*, *Picea abies*, and *Pinus sylvestris*. Forest margins or glades were inhabited by infrequent shrubs of hazel, *Ligustrum vulgare*, and raspberry (seeds of *Rubus idaeus*). Single trees of *Carpinus betulus* and *Fagus sylvatica* most likely grew in the close surroundings of the basin. Waterlogged bog alder forest developed intensively, as indicated by numerous macroremains of *Alnus glutinosa*, *Urtica dioica*, *Mentha aquatica*, *Rumex maritimus*, and *Ranunculus sceleratus*. Willow increased in frequency and may have partly dominated wetlands close to watercourses. It was accompanied by *Urtica dioica* (fruits), *Caltha*, *Filipendula*, *Mentha*, and *Ranunculus acris*. In their ground layer, the communities also included abundant ferns such as *Pteridium aquilinum* and *Polypodium vulgare*. The dominance of *Pinus* and the occurrence of Ericaceae dwarf shrubs represented by *Calluna vulgaris*, *Erica tetralix*, and *Ledum palustre*, and of the dystrophic *Drosera intermedia*, may be evidence of the appearance of boggy pine forest near the basin. Pollen of *Ulmus* was no longer recorded.

The withdrawal of elm from habitats having humidity and temperature favourable for its growth is commonly observed in this period in Europe and is associated with elm disease (Huntley & Birks 1983) and regional expansion of human settlement in the Neolithic (Zachowicz et al. 2004). The rising content of pollen of grasses and sedges indicates an increase in the size of open areas inhabited

by heliophytes such as *Artemisia*, *Hedysarum*, *Primula*, and herbaceous plants of the Cichoriaceae, Apiaceae, Brassicaceae, and Chenopodiaceae families.

The disappearance of thermophilous trees and shrubs, such as *Ilex aquifolium*, *Hedera helix*, and *Vitis vinifera*, serves as evidence of a slight deterioration of temperature conditions in this period. The late Subboreal most likely was marked by increased rainfall, as indicated by the percentage values (highest) for pollen grains of *Picea abies* and *Salix* and for spores of Filicales monoete in the diagrams plotted for Węgliny. The minimum annual rainfall optimal for spruce is 500 mm (Granoszewski 2003). *Phragmites australis* clearly gained importance. The belt of swamp developed intensively. Apart from reed, it comprised mainly *Lycopus europaeus*, *Oenanthë aquatica*, *Cicuta virosa*, *Schoenoplectus lacustris*, *Alisma plantago-aquatica*, *Rorippa palustris*, and numerous *Carex* species including *C. vesicaria*, *C. elata*, *C. rostrata*, *C. diandra*, *C. cf. pseudocyperus*, and *C. acutiformis*. Swamp communities greatly increased their area, which probably confirms a fall of the water level in the basin. Hardly any aquatic plants were recorded, except for the occurrence of *Myriophyllum verticillatum* and the development of *Lemna trisulca* on the surface. The presence of spores of the *Scenedesmus*, *Tetraedron*, *Botryococcus*, and *Pediastrum* chlorophytes as well as Type 128 spores (Fig. 6) indicates meso- or eutrophic conditions in the basin (Van Geel et al. 1989). At the end of this period probably the whole basin became shallow and overgrown by communities of boggy and swamp vegetation. A few depressions were still inhabited by aquatic and swamp vegetation but the greater part of it was already occupied by fens overgrown by boggy spruce forest, pine forest and bog willow-alder forest. Ferns and horsetails were abundant in the ground layer. High content of plant biomass is attested by the LOI curve, rising in the top part of zone LOI₁₁.

THE SUBATLANTIC

WE-10 NAP-*Alnus* L PAZ; WE'10/2-10

The vegetation most likely followed a pattern similar to the one we see today. Pine forest with admixture of birch, oak, spruce, and hazel was dominant. Elm reappeared. The farther

neighbourhood of the site most likely was inhabited by beech-hornbeam tree stands. The diversity of heliophilous herbaceous vegetation, known to prefer dry or fresh soils, increased noticeably. Together with grasses it formed vast meadows, originating pollen of *Artemisia*, *Aster* t., *Bupleurum*, *Dianthus* t., *Pimpinella*, *Onobrychis* t., *Agrostemma githago*, *Alchemilla* t., and other plants of the Rosaceae, Cichoriaceae, Caryophyllaceae, and Apiaceae families. Slopes of dunes and moraines probably were inhabited by Ericaceae dwarf shrubs such as *Calluna vulgaris*. Thermophilous shrub communities with *Ligustrum vulgare* probably occurred as well.

Human use of grassland might account for the presence of *Plantago lanceolata*, *Centaurea jacea* t. and plants of the Chenopodiaceae family, accompanied by grasses (seeds, pollen) found in high amounts. Human presence in the study area is confirmed mainly by the record of cereal pollen (Cerealia undiff.), including *Secale cereale*, *Hordeum* t., and the *Agrostemma githago* weed in the pollen diagram.

The disappearing lake was the site of development of bog alder forest with *Alnus*, *Caltha* t., *Filipendula*, *Thalictrum*, *Mentha* t., *Peucedanum palustre*, *Conium maculatum*, *Apium* t., *Juncus* sp. (seeds), *Glyceria fluitans* (seeds), and *Lychnis flos-cuculi* (seeds). Small shallow ponds inhabited by nymphaeids such as *Nymphaea alba* and *Nuphar lutea*, swamps with *Phragmites australis*, *Typha latifolia*, *Sparganium*, *Equisetum*, and *Pteridium aquilinum*, as well as Characeae chlorophytes (oospores), gradually became completely devoid of water and were overgrown.

HOLOCENE CHRONOSTRATIGRAPHY IN THE WĘGLINY AREA

Presently there are two main approaches to the chronostratigraphy of the Holocene. The first is based on chronozones defined by Mangerud et al. (1974, Walanus & Nalepka 2010) and corresponds to the classification of climate and vegetation by Blytt-Sernander (Dyakowska 1959). According to the second approach, referring to proxy data and used mainly in climatic reconstructions, the Holocene is divided into three phases: Eoholocene/Early Holocene/moderate period, Mesoholocene/Middle Holocene/warm period, and Neoholocene/late Holocene/cold period (Swindles et al. 2007, Jin & Chen

2008, Debret et al. 2009, Wanner et al. 2011). The classification provided by Starkel joins both approaches (Starkel 1999, Starkel et al. 2013). For the sections described in the paper, the Holocene phases are distinguished following the stratigraphy by Mangerud et al. (1974), as the data from western Poland were insufficient for comparisons.

HOLOCENE CLIMATE IN THE WĘGLINY AREA

The general climatic changes characteristic for the European Late Glacial and Holocene are also observed at the Węgliny site. The transition of the early Holocene to the climatic optimum is typified by an increase in the amount of trees having higher temperature requirements, such as *Tilia*, *Ulmus*, *Quercus*, and *Fraxinus excelsior*, and by the occurrence of pollen of *Hedera helix* and *Vitis vinifera* in the pollen diagrams (Figs 6, 7, 8). High proportions of *Alnus*, forming riparian forest together with *Fraxinus excelsior* and *Ulmus*, reflect increasing humidity. This pattern is observed particularly when applying the correlation coefficient for the pollen production of selected trees, following Andersen (1979). If the diagram shown in Figure 8 was plotted for the relative content of trees in the forest (using the correlation of pollen production), it would demonstrate enlarged curves for under-represented trees, such as *Tilia* and *Fraxinus excelsior*, and lowered proportions of other trees, mostly the overrepresented *Pinus* and *Betula*. These results should provide a more reliable description of the forest growing in the period discussed (Nalepka & Walanus 1995, Nalepka 1999). The rapid decline in the curve for *Tilia* and the falling curves of *Ulmus*, *Fraxinus excelsior*, and *Quercus* suggest brief cooling of the climate. Moreover, the simultaneous rise in the *Salix* curve indicates the beginning of a cool humid phase in the early Subboreal. The later increase in the curve for *Tilia* and the maximum values attained by *Picea abies* imply an improvement in temperature conditions. The maximum shares of Filicales spores in the sections additionally show an increase in humidity. The decreasing content of trees, except for *Alnus*, accompanied by an increase in *Betula* and Poaceae in the Subatlantic, may be evidence of another cooling of climate. The

continued presence, already from the Younger Dryas, of curves for *Alnus* and Filicales indicates a specific humid microclimate in the Wodra valley. Such a description of vegetation confirms the dominant impact of local habitat conditions on successive vegetation changes in the Węgliny area.

COMPARISON OF THE STUDY SITE WITH OTHER REGIONS DURING THE LATE GLACIAL AND HOLOCENE

COMPARISON OF SECTIONS WITHIN THE WĘGLINY SITE

The first palynological description of the Węgliny site in the Wodra (Werdawa) valley was given by M. Malkiewicz (Masojć et al. 2006). Her preliminary palynological analysis of the Węgliny section was done as part of archaeological studies in the area. She did not assign a specific annotation to the section, so hereafter it will be denoted “Węgliny” to distinguish it from the sections labelled “WE”, given numbers, and described in Table 1. The Węgliny section is represented by 250 cm of sediment, gyttja and peat. According to M. Malkiewicz, the lake sedimentation began in the late Allerød (spectra from 250 cm depth) and ended in the Atlantic. The results of her study provided the basis for detailed palynological examinations in the Wodra valley (Fig. 1). The sections (WE’08, WE’10, WE’10/2) were taken up to sands directly underlying lacustrine sediments.

Lithological sections begin at the base with silts with admixture of sand, pass into gyttja, and end with peat of variable thickness identified at the top. In the Węgliny section (Masojć et al. 2006) the first distinguished period is the Allerød. The similar outline of the curves (increasing content of Poaceae, Cyperaceae, and *Artemisia* at the Allerød/Younger Dryas boundary in the Węgliny and WE (WE’08, WE’10, WE’10/2) sections indicates that the identified period corresponds to the top part of zone WE-3 *Pinus-Betula* (Allerød). The high percentage values for Poaceae, *Artemisia*, and *Juniperus* in the next period (Younger Dryas) in the Węgliny section correspond to the description of taxa in zone WE-4 Poaceae-*Artemisia*. Further correlations show that the Preboreal vegetation described for the Węgliny

section may correspond to zones WE-5 *Betula-Pinus-Poaceae* and WE-6 *Pinus-Betula-Corylus* (Preboreal). The shape of the curves plotted for *Ulmus*, *Quercus*, *Alnus*, *Pinus*, and *Betula* trees in the next two periods of the Węgliny section generally matches the pattern shown by these curves in zones WE’08 and WE’10/2. In the Węgliny section the Boreal falls within zone WE-7 *Corylus-Pinus-Quercus*. The last interval defined in the section studied by Malkiewicz (Masojć et al. 2006) is the Atlantic, basically corresponding to the lower part of zone WE-8 *Corylus-Alnus-Quercus-Ulmus* (sections WE’10/2 and WE’08). Only the curve plotted for *Corylus avellana* shows a slightly different outline than in the above-mentioned zone.

COMPARISON OF THE WĘGLINY STUDY SITE WITH SELECTED SITES OF THE LUBSZA PLAIN AND VICINITY DURING THE LATE GLACIAL AND HOLOCENE

The examined site was compared with selected sections of the Lubrza Plain and its immediate surroundings: Jasień, Wicina, Guzów, Pawski Ług (Nature Reserve), Rybojady, Łęgoń (Koponica valley), and Kleiner Mochowsee (Fig. 2), and more distant sites important as benchmarks: Gościąż Lake in central Poland and Pechsee and Tegeler See near Berlin, Germany. Being located in western Poland, the Lubrza Plain is under a stronger influence of oceanic climate than are areas of central Poland. Comparing the Węgliny site with Gościąż Lake and the Berlin area should point up the similarities and differences between the analysed vegetation successions.

Jasień

Two sections from the Jasień site were described: Jas-12 (Ja-12) (Okuniewska-Nowaczyk 1996, 1998) and Jas-N (Ja-N) (Okuniewska-Nowaczyk 1998, Kowalkowski et al. 1999). The sections represent dune sediments marked by layers of palaeosols. In both sections the palynological record begins in the late Vistulian (pre-Allerød in Ja-12, Allerød in Jas-N) and ends in the Boreal (Ja-12) and Preboreal (Jas-N; Okuniewska-Nowaczyk 2005). In section Ja-12, Okuniewska-Nowaczyk (1998) distinguished two zones corresponding to the pre-Allerød: Ja-12₁ (*Salix-Artemisia-Cyperaceae*) and Ja-12₂ (*Betula-Salix*). Zone Ja-12₁ probably corresponds in age to WE-1. In terms of

taxonomy, both zones are characterised by the occurrence of indicators of harsh climate such as *Selaginella* and *Hippophaë* (information from the zone description, not the diagram) and high amounts of *Juniperus*, *Artemisia*, and Cyperaceae. The main differences between the zones relate to the *Pinus* and Poaceae curves. In section Ja-12 the taxa showed low percentages but in the diagrams plotted for Węgliny they reached high values. The similar shapes of the *Betula* and *Pinus* curves in both diagrams (Ja-12 and WE'10/2), showing a rapid increase in birch pollen content, a simultaneous decrease in pine pollen and a rise in *Poaceae* and *Artemisia*, provides the basis for correlating zones Ja-12₂ and WE-2 (phase of *Hippophaë*). For this zone the diagram description for Ja-12 does not include *Hippophaë*, which most likely disappeared, but in the WE sections it reaches its maximum values (from 2% to 23%). Increasing amounts of *Betula* and *Pinus* pollen, typical of the Allerød, are recorded both in section Ja-12 (zones Ja-12₃ and Ja-12₄) and in Jas-N (zone Jas-N₁: Jas-N_{1a} and Jas-N_{1b}) as well as in WE (zone WE-3). In this period the Jasień sections show dichotomy demonstrated by increasing pine pollen accompanied by high proportions of sedge pollen (in the first part of the period) and a decrease in the frequency of birch (in the second part). The subsequent cool period is recorded in the top part of zone Ja-12₅ in section Ja-12, zone Jas-N₂ in section Jas-N, and zone WE-4 in the WE sections. All the above-mentioned zones show high content of *Artemisia* and Cyperaceae. In this period, sections Jas-N and WE are typified by rising amounts of *Juniperus* and Poaceae. Section Ja-12, with only single pollen grains of juniper and a low curve for grasses, displays a different trend. Section Jas-N₂ bears a record of the highest (up to 20%) frequency of Cyperaceae. The essential difference between the sections from Jasień and Węgliny is the content of *Sphagnum*, observed in high amounts in Jasień but as single spores, in the Younger Dryas, in the diagrams for Węgliny.

The beginning of the Holocene in sections Jas-N and WE (WE'10/2) is indicated by a decrease in the curves of Poaceae, Cyperaceae, and *Artemisia*. Section Ja-12 is also marked by decreasing proportions of mugwort pollen, while sedges (attaining their maximum frequency in this section) and grasses show increased pollen values. The amounts of

sedges also rise in section WE'10. A common feature of all sections is high content of pine and birch pollen. At the Jasień site, the Boreal, identified exclusively in section Ja-12, was confirmed by high values of pine and relatively low amounts of birch. Similar proportions between these taxa were recorded in the Węgliny sections. The diagrams plotted for both sites also share high frequency of Filicales monolet/Polyodiaceae spores (Okuniewska-Nowaczyk 1996). *Corylus avellana* and trees *Ulmus* and *Quercus* most likely did not appear at the Jasień site before the Boreal. Although section Ja-12, specifically zone Ja-12₇, was described as already containing the taxa (Okuniewska-Nowaczyk 1996, 1998) they were absent from these pollen diagrams. For this reason their range of occurrence could not be determined. In the WE sections, pollen grains of hazel, elm and oak were recorded as early as the close of the Preboreal. Due to the specific type of sedimentation that affected Jasień (dune), even sections Jas-12 and Jas-N from this site differ from each other. They also clearly differ from the Węgliny sections but in particular aspects the two sites show similarities.

Wicina

Palynological profiles from Wicina were obtained from an archaeological excavation site where a fortified settlement of the Lusatian culture is being studied presently. Section Wicina I (Wic I) was taken from an excavation found within the settlement, and section Wicina II (Wic II) was taken from the deepest part of a peat bog ca 200 m away (Nowaczyk & Okuniewska-Nowaczyk 1992). In the pollen diagram, six local pollen assemblage zones were identified in the Wicina II section and four L PAZs in the Wicina I section, but their precise age was not determined. The sections represent vegetation successions from the Allerød (Wic II) and Younger Dryas (Wic I) to the Subboreal (Okuniewska-Nowaczyk 2005).

The main difference between the sections from Wicina and Węgliny is in the content of Cyperaceae pollen, recorded in very high amounts at Wicina (up to 80% in section Wic I, up to 48% in Wic II) and not exceeding 10% in the Węgliny diagrams. Zone Wic II₁ may correspond to zone WE-3, characterised by high values of *Pinus* and *Betula*. The description of the flora in the discussed zones corresponds

to vegetation typical of the Allerød. Subsequent zones, Wic II₂ and Wic I₁, fall within the Younger Dryas (acc. to ¹⁴C date from zone Wic I₁) and are marked by low frequency of *Pinus* pollen, an increase in the proportions of *Juniperus*, *Salix*, and *Artemisia*, and the presence of indicators of open areas, such as *Helianthemum*. The pattern for zone WE-4 is similar. Basically the pollen diagrams from the two sites differ in the proportion between Cyperaceae and Poaceae. The Wicina sections are dominated by sedges while grasses are most frequent in the Węgliny sections.

In the pollen diagrams plotted for Wicina (Wic II₃, Wic I₂) the beginning of the Holocene is indicated by a noticeable rise in the Poaceae curve and a gradual fall of the Cyperaceae curve. The WE diagrams show a different trend, already described for the Jasień section. All diagrams (WE, Wic I, Wic II) display an increasing *Salix* curve, rising most in the Wic I diagram. For this period the Wic II and WE sections include pollen of *Ulmus*, *Corylus avellana*, *Quercus*, and *Quercetum mixtum* (Wic II), but the taxa show higher percentages in the WE diagrams for the late Preboreal. All diagrams for both sites share a high percentage (higher in the sections from Wicina) of fern (Polypodiaceae/Filicales monoete) spores. The Boreal most likely was not recorded in section Wic I or was recorded fragmentarily in the top part of zone Wic I₂ and the base of Wic I₃, represented by only a few samples. In all sections the Boreal was reflected in a decrease in the amount of *Betula* pollen and an increase in the content of *Pinus*, *Corylus avellana*, *Ulmus*, *Quercus*, *Quercetum mixtum* (Wic II₄), *Picea abies*, and *Tilia*. In the WE diagrams the values for those taxa seem higher, except for *Pinus* and *Betula*. In all sections the Atlantic was marked by increasing frequency of *Alnus*, amounting to 73% in Wic II₅ and 59% in Wic I₃. In WE sections the amounts of alder began to rise noticeably as early as the Boreal, and in the Atlantic the proportion of it did not exceed 30%. The period is also characterised by a rise in the curves of trees with higher temperature requirements, a decrease in the *Pinus* and Cyperaceae curves, and low content of *Betula* in all sections. Pollen of *Alnus*, dominant in the topmost (Subboreal) zones of the Wicina sections (Wic II₆ – 73%, Wic I₄ – 77%), shows a decrease in zone WE-9. Similarly, the sections from Wicina bear a record

of the highest *Ulmus* values, while in Węgliny the curve plotted for it falls. Common features of all sections include an increase of *Picea abies*, a decrease of *Corylus avellana*, minor amounts of *Betula*, and the late Boreal rise of *Pinus*.

The discussed sections differ greatly in the frequency of fern spores. The pollen spectra of zone WE-4 have the highest percentages of Filicales/Polypodiaceae spores, the number of which is noticeably reduced in the sections from Wicina.

Guzów

At the Guzów site, the pollen of two cores was analysed: one core from an excavation near a dune (Guz-6) and the second from an accumulation plain of biogenic sediments (Guz-III). The sediments bear a record of the vegetation succession from the pre-Allerød to the Younger Dryas (section Guz-6) or Atlantic (section Guz-III) (Nowaczyk & Okuniewska-Nowaczyk 1999). Section Guz-III, with its more complete succession of vegetation and representing a habitat similar to that of Węgliny, was the main one correlated with WE sections.

The *Pinus* and *Betula* curves from the sections of the two sites have similar patterns and show high pollen values from the oldest periods. In section Guz-6, zones Guz-6₁ and Guz-6₂, *Pinus* reaches 40–79% frequency; in zone WE-1, pine reaches the highest frequency in sections WE'10/2 (40–80%) and WE'10 (80–86%). The main difference between the sites lies in the proportion between Poaceae and Cyperaceae. The proportions from the Węgliny sections seem to be the reverse of those from section Guz-III. At the Guzów site, deposition of lacustrine sediments most likely began in the Bølling. Zone Guz-III₁, with its high content of sedges and low content of grasses, differs slightly from the corresponding zone WE-2 (WE sections), representing the phase of *Hippophaë*. However, both zones give the highest percentage of sea buckthorn in the pollen diagrams plotted for the sites; that is their most characteristic feature. In the next period, section Guz-III includes two phases distinguished by Okuniewska-Nowaczyk (1999): birch (earlier) and pine (later). These phases could not be identified in the sections from Węgliny, as the taxa were recorded in similar percentages. In the Younger Dryas both sites show the

highest percentage values of *Artemisia* pollen and increasing content of Cyperaceae. In diagrams WE'10/2 and WE'08 these changes are accompanied by high amounts of grasses.

In the Preboreal the pollen diagrams from both sites show an increased proportion of *Pinus* pollen and a simultaneous drop in the frequency of *Betula* pollen. At both sites the Boreal is marked by high values of *Corylus avellana* (ca 20%) and trees with higher temperature requirements, such as *Ulmus*, *Quercus*, and *Tilia*. The main difference between the sites is in the pattern of the *Pinus* curve, falling to ca 40% in zone Guz-III₆ and rising to ca 60% in zone WE-7. The Atlantic, the last period determined in section Guz-III, should be assigned to zone Guz-III₇, abundant in *Sphagnum* (up to ca 20%). In the diagrams from Węgliny those spores were found in minimal amounts. In spite of these differences, however, the flora described for the two sites seems similar.

Pawski Ług

The Pawski Ług section was named after the nature reserve containing the ombrogenic peat bog from which the profile was obtained. It represents the vegetation succession from the Atlantic to the Subatlantic (Herking 2004). The Pawski Ług section is characterised mainly by a constant high amount of *Pinus* pollen, reaching as much as 80%, and a relatively low frequency of *Betula*, amounting to 45% only at the top and generally remaining within the 10–20% range. The curves plotted for trees having higher temperature requirements show a pattern rather similar to the corresponding curves from the Węgliny sections, except for *Fagus sylvatica* and *Carpinus betulus*. In the Pawski Ług section, the pollen percentages for beech and hornbeam display constancy from the early Subboreal. The shape of the *Corylus avellana* and *Alnus* curves differs slightly between the Pawski Ług and Węgliny sections. In WE sections the proportion of hazel decreases in the Subboreal and rises slightly in the Subatlantic, while in Pawski Ług there is no noticeable decrease before the Subatlantic. The content of *Alnus* in the Pawski Ług section generally seems stable, with two peaks of increased frequency in the Subboreal and one in the late Subatlantic, reaching up to 30%. In the WE profiles the *Alnus* curve constantly reaches ca 30% in the

Atlantic, followed by a decrease to 10% in the Subboreal and a rise to ca 40% in the Subatlantic. Sections from the two sites also differ in the shape of the *Pinus* curves: in the Atlantic the Pawski Ług section yields high amounts, locally up to 80%, and in WE sections there is a clear decline.

Rybojady

The Rybojady study site is in Pszczew Landscape Park. The section, taken from a peat bog, covers the vegetation succession from the Preboreal to the Subatlantic (Herking 2004). The profile begins with zone R1, recorded before the Preboreal but of uncertain chronostratigraphy. In the Preboreal the floras of the Rybojady and Węgliny sites are of similar description, with the occurrence of *Corylus avellana*, *Ulmus*, *Quercus*, *Alnus*, *Fraxinus excelsior*, and *Tilia*. The Poaceae and Cyperaceae curves show a similar pattern in all sections. The percentage values for *Betula* and *Pinus* in zone R2, which is also marked by the presence of *Hippophaë*, are higher than in the corresponding WE-5 and WE-6 zones. In the Boreal, zones R3 and WE-7 display similar frequency of taxa such as *Corylus avellana*, *Ulmus*, *Quercus*, *Tilia*, *Fraxinus excelsior*, and *Alnus*, and similar curves for *Betula* (decrease) and *Pinus* (increase). The Atlantic shows a tripartite division and covers zones R4 and R5 in the Rybojady section, but is assigned only to one zone in Węgliny. Nevertheless, the curves of trees with higher temperature requirements and of *Corylus avellana*, *Alnus*, and *Betula* display a similar pattern in all sections. The *Pinus* curve rises in zone R5, in contrast to zone WE-8 where it falls. In the Rybojady section the Subboreal is represented by zone R6, including three subzones (R6a, R6b, R6c). The curves plotted for the zone differ noticeably from those for zone WE-9, where decreases are noted for the curves of *Corylus avellana* (clearly decreasing through the entire zone), *Quercus*, *Alnus* (not increasing before the boundary with the next zone), and *Ulmus* (disappearing at the top part). In the Rybojady section the frequency of *Corylus* increases in subzone R6a and falls in subsequent subzones. The proportions of *Ulmus*, *Alnus*, and *Quercus* increase. Oak attains its maximum values in that zone (recorded in the Atlantic for WE sections). Subzones R6b and R6c are typified by constant high amounts of *Fagus sylvatica* and

Carpinus betulus, found occasionally as single pollen grains in zone WE-9. In this period, spruce reaches its maximum values in the WE sections and occurs only as single grains in the Rybojady section. The Subatlantic is divided into early (R7a, R7b, R7c, R7d) and late (R8a, R8b) parts in the Rybojady section; in the sections from Węgliny the period is related to only one zone, WE-10, corresponding very well to subzone R7a. In the two zones (R7a, WE-10) the curves of the above-described taxa are very similar except for late migratory species (*Carpinus betulus* and *Fagus sylvatica*), pollen grains of which are still found occasionally in zone WE-10, and spruce, represented only by single grains in zone R7a.

Łęgoń

At the Łęgoń archaeological excavation site, palynological analysis of two cores, Łęgoń 5 W12 and Łęgoń W14, was performed. They represent a vegetation succession from the late Vistulian (Oldest Dryas – W14, Older Dryas – W12) to the early Holocene (Boreal – W14, Preboreal – W12; Malkiewicz 2002, Burdukiewicz et al. 2007). The sections were taken from a basin identified as a fossil oxbow lake with accumulation of biogenic sediments (Burdukiewicz et al. 2003). At the Łęgoń site the Oldest Dryas falls within zone L14/1, characterised by high content of pollen of Poaceae, Cyperaceae, *Juniperus*, *Betula nana*, *Helianthemum*, and *Artemisia*, and the highest amounts of *Hippophaë*. The description of the flora was similar for zone WE-1 from Węgliny, additionally marked by very high frequency of *Pinus*, most likely originating from redeposition (also recorded in section Łęgoń W14 in the Cor-Quer-Ulm curve). In section Łęgoń W14 the Bølling is typified by an increase in the proportions of *Betula* and *Pinus* and a decrease in Poaceae, Cyperaceae, *Hippophaë*, and *Artemisia*. In the Węgliny sections this period is associated with the phase of *Hippophaë*, with rising values of *Artemisia* and Poaceae and decreasing amounts of *Pinus*. The sections from the two sites differ mainly in the content of *Hippophaë*, which is highest in the Węgliny profiles. The Older Dryas, identified in both sections from Łęgoń, was not distinguished in the Węgliny sections. At both sites the Allerød is characterised by a decrease in NAP values (mainly of grasses), and high frequency of *Pinus* and *Betula*. The sediments from Łęgoń, unlike the

WE sections, record a birch phase (varying in thickness between sections) and a pine phase. All analysed profiles show increasing amounts of Cyperaceae (attaining higher percentage values in Łęgoń) and Poaceae in the Younger Dryas. In sections Łęgoń 5 W12 and Łęgoń W14 a decrease of *Pinus* and *Betula* is also observed. WE sections are marked by lower frequency of birch, in zone WE-4, and the occurrence of an *Alnus* curve. In the Younger Dryas, pollen of *Corylus avellana*, *Ulmus*, and *Quercus* appears in the diagrams plotted for WE (as single counts of particular taxa) and Łęgoń W14 (as the Cor-Quer-Ulm curve).

At the Łęgoń site the Preboreal is typified by a decrease of *Pinus* and a simultaneous increase of *Betula* in zone L14/6 and the top part of zone Łęg5/4. In the other part of zone Łęg5/4, however, pine rises and birch falls. The WE sections also show a decrease of *Betula* accompanied by increasing *Pinus*. Within this zone the main difference between these sites is in the appearance of curves for *Corylus avellana*, *Ulmus*, and *Quercus* in WE-6 (late Preboreal) in Węgliny but only for *Ulmus* in the Łęgoń sections. The presence of the *Populus* curve in zone L14/6 also makes an important difference. All diagrams share an increase in the proportion of Polypodiaceae/Filicales monolete) spores. Within section Łęgoń 5 W12 the taxon attains its highest percentage values (over 60%) in zone Łęg5/3. In section Łęgoń W14 the maximum content of Polypodiaceae falls within the next zone, in the Boreal, while in the WE sections the frequency of Filicales monolete is at maximum in the Subboreal. In the Boreal both diagrams show increasing curves of trees with higher temperature requirements and *Alnus*, which even reaches 30% in zone L14/7. The WE sections show similar values of alder in zone WE-8 (Atlantic). The sites differ in the occurrence of *Carpinus betulus* and *Abies* curves. Both are present in section Łęgoń W14, while in the WE sections hornbeam is found only as single counts, and not before the Atlantic.

Kleiner Mochowsee

Kleiner Mochowsee, the last compared site from the Lubsza Plain area, is west of Gubin. The section was taken from bottom lacustrine sediments and bears a complete record of vegetation succession from the Holocene (Jahns 1999, Jahns & Herking 2002). In the compared

sections the Preboreal is characterised by similar curves for *Pinus* and *Betula* and by the occurrence of curves of *Corylus avellana*, *Quercus*, *Ulmus*, and *Fraxinus excelsior*. The Kleiner Mochowsee section also has a *Fagus* curve, while in the WE sections *Fagus* is recorded only as single counts and does not appear before the Atlantic. At both sites the Boreal shows a pattern with high amounts of pine and gradually decreasing birch. The curves of taxa with higher temperature requirements appear similar in the diagrams; only the *Corylus avellana* and *Alnus* curves differ slightly in shape. In the WE sections, *Corylus* attains its maximum values in the late Boreal and at the onset of the Atlantic, while in the Kleiner Mochowsee section that occurs in the late Atlantic. In this period, *Alnus* shows higher percentages in the WE sections. The Kleiner Mochowsee profile shows curves for *Ilex aquifolium* and *Viscum*, while in the WE sections those two taxa are observed only as single pollen grains, and not until the Atlantic. Although the Atlantic shows a dual division in the Kleiner Mochowsee section, the curves of trees with higher temperature requirements and the curves of *Corylus avellana*, *Alnus*, *Pinus*, and *Betula* are very similar between the two sections. They differ basically in the percentages of *Carpinus betulus* and *Fagus sylvatica*, in Kleiner Mochowsee represented by a constant curve. In the Subboreal the main difference between sections is in *Pinus* content, which decreases in Kleiner Mochowsee and noticeably increases in the WE sections. The sites also differ in the occurrence of *Abies*, which is constant in the Kleiner Mochowsee profile but in the WE sections recorded exclusively in the Atlantic, as a single count. *Picea abies* shows a similar increase in all diagrams. The Subatlantic is divided into early and late parts in Kleiner Mochowsee but section WE'10/2 includes only the early Subatlantic. The latter corresponds to the early Subatlantic in Kleiner Mochowsee.

COMPARISON OF THE STUDY SITE
WITH SELECTED SITES
OF MORE DISTANT REGIONS

Lake Gościąg

Bottom sediments of Lake Gościąg are a benchmark for Poland. Two sections were selected for comparison: G 28/92 (Tobyłka

Bay), representing the Late Glacial and early Holocene, from the Oldest Dryas to the Preboreal, and G1/87 (Lake Gościąg), bearing a record of vegetation succession from the Allerød to the Subatlantic (Ralska-Jasiewiczowa et al. 1998a, b). For the Oldest Dryas, the two sites (G 28/92, WE sections) show similar floras, characterised by high amounts of Poaceae, Cyperaceae, *Helianthemum*, *Salix*, and *Juniperus*, increasing values of *Hippophaë* at the top parts of zones TG-2 (G 28/92) and WE-1, and the presence of *Betula nana* t. The main difference is in the content of *Pinus* and *Betula*. In section G1/87, pine occurs at low frequency (max. 15%) and birch at higher frequency (max. 50%). In the WE sections the pine values are much higher while birch reaches 20% maximally.

The occurrence of a *Larix* curve in the section from Lake Gościąg is another important difference; in the WE sections it is recorded only as a single grain at the basal part of zone WE-1. In section G 28/92 the next layer of sediment is marked by a palynological hiatus, so the Bølling was not identified. In the WE sections the Older Dryas was not distinguished. The next period represented in all sections (G 28/92, G1/87, WE) is the Allerød, typified by high proportions of *Pinus* and decreasing amounts of Poaceae, Cyperaceae, and *Artemisia*. Section G 28/92 shows relatively lower values of *Betula* than in the WE sections. At Lake Gościąg the Younger Dryas is recorded in both sections and in each covers two zones (TG-5a, TG-5b, and G1/87-2, G1/87-3). The curves of the above-mentioned taxa (excluding *Betula nana* t.) are similar in the G28/92 and WE sections, while *Juniperus* and *Betula nana* t. have much higher percentages in section G1/87 than in the WE sections.

The Preboreal is characterised by constant values of *Ulmus*, *Corylus avellana*, and *Quercus* in the G1/87 and WE sections. In both diagrams the taxa display continuous curves in the late Preboreal; only the *Ulmus* curve begins already in the early Preboreal (WE-5 in WE sections). In all sections the Boreal is typified by high amounts of *Corylus avellana* and a slight decrease in *Betula*. The sections differ mainly in the appearance of single pollen grains of *Acer* and *Fagus sylvatica* at Lake Gościąg, while in the WE sections they do not appear before the Atlantic. The Atlantic flora in diagram G1/87, represented by the top

part of zone G1/87-6 and the entire G1/87-7 zone, does not differ much from the vegetation record of zone WE-8. The diagram from Lake Gościąg shows only slightly higher percentages for particular trees with greater temperature requirements, *Tilia* and *Fraxinus excelsior*, and a noticeable decrease of *Corylus avellana*. In subsequent zones there are clearer differences between the G1/87 and WE sections. Zone G1/87-8 (early Subboreal) is marked by increasing content of *Quercus* (reaching its maximum pollen values) and *Corylus avellana*, and by a stable, relatively high frequency of *Alnus* and low frequency of *Pinus*. Zone WE-9 (Subboreal) in the WE sections shows a clear increase in the proportion of pine and a decrease in *Corylus*, *Quercus*, and *Alnus* values; the *Picea abies* curve slightly increases. *Carpinus betulus* and *Fagus sylvatica* display constant curves in the basal part of zone G1/87-9. The early Subatlantic in diagram G1/87 (top part of zone G1/87-9) is clearly marked by a *Carpinus betulus* curve, locally attaining 25% frequency but decreasing in zone G1/87-10. The curve for *Pinus* rises while in zone WE-10 it decreases, another difference between the sites. The amounts of *Betula* decrease in section G1/87, in contrast to the WE sections. The curves plotted for other trees also slightly differ in shape.

Vicinity of Berlin: sections from Pechsee and Tegeler See

The analysed sections from Pechsee and Tegeler See are benchmarks for the Berlin region (Behre et al. 1996). The Pechsee section bears a record of the period from the Bølling to the Allerød, and the Tegeler See section shows the vegetation succession from the Allerød to the Subatlantic. The Bølling/Older Dryas is represented by high percentages of *Hippophaë rhamnoides*, *Juniperus* and *Betula*, accompanied by low amounts of *Pinus*. This type of vegetation is similar to the phase of *Hippophaë* in the WE sections. Other important similarities between the Tegeler See and Węgliny sites include the occurrence of *Alnus* already in the Younger Dryas and Preboreal, the shape of the *Quercus* and *Ulmus* curves in the Preboreal, and of *Tilia* and *Fraxinus excelsior* in the Boreal. The pollen spectra in the Boreal display maximum percentage values for *Corylus* in both Tegeler See and Węgliny sections (WE'08 and WE'10/2). In the Atlantic

the sites differ mainly in *Pinus* content, which is constantly high in the Tegeler See section and noticeably decreases in the WE sections. However, the curves for trees with higher temperature requirements and for *Corylus avellana* and *Alnus* show similar patterns in all sections. Important differences are observed in the Subboreal. The percentages of *Corylus avellana*, *Quercus*, and *Alnus* pollen increase in the Tegeler See section and decrease in the WE sections. The sites also differ in their *Pinus* curves, which fall slightly in Tegeler See and clearly rise in the WE sections. Another difference is in the appearance of the *Fagus sylvatica* and *Carpinus betulus* curves in the Tegeler See section, accompanied by a Cerealia curve already in the early Subboreal. In Węgliny the taxa are not observed before the Subatlantic. The Subatlantic is also when rye (*Secale cereale*) pollen appeared at both sites. They are also similar in the increasing frequency of *Betula*, *Quercus*, and *Alnus* and slightly increasing amounts of *Corylus avellana*, but they differ in the proportion of *Pinus*, rising in the early Subatlantic in the WE'10/2 section.

DIFFERENCES BETWEEN THE VEGETATION DESCRIPTIONS OF THE WĘGLINY SITE (WE SECTIONS) AND THE COMPARED SITES DURING THE LATE GLACIAL AND HOLOCENE

Comparisons between Węgliny and the other presented sites revealed several differences in the records of late Vistulian and Holocene vegetation successions (Fig. 11). The Late Glacial description of the flora from Węgliny correlates well with vegetation changes proceeding in the area. Slight differences most likely are due to local habitat conditions and include relatively low values of Cyperaceae, maximum 6% recorded in section WE'10/3, high amounts of Poaceae and *Hippophaë rhamnoides*, maximally 23% in section WE'10/2, and low frequency of *Sphagnum*. In the Węgliny section studied by Malkiewicz (Masojć et al. 2006) the Cyperaceae curve does not exceed 10%. The relatively low values for this taxon in the Węgliny sections analysed in this paper confirm conditions disadvantageous to the luxuriant development of sedges at the study site. This observation is supported by a high proportion of Poaceae, probably reflecting rather dry,



CHRONOZONE	BERLIN REGION TEGELER SEE and PECHSEE	KLEINEN MOCHOWSSE	WĘGLINY [WE]			PAWSKI ŁUG	RYBOJADY	CHWALIM				LAKE GOŚCIAŻ [G1/87]				
SA	15 Pin-Sec-Rum	period of the destruction of forests	WE-10 NAP-AI			P5 Pin-Aln-NBP	R8b Pin-NBP R8a Pin-Qu	Ch-4 P.lan-Cer-Gram			G1/87-10 Pin-NAP					
	14 Pin-Fag-Car-Sec			Xc Pinus ↑	IX Pin-Qu-Car-Fag			WICINA [Wic I]	WICINA [Wic II]	P4b Pin-Car P4a Pin-Fag-Car-Cere	R7d Pin-Qu-NBP R7c Qu-Car R7b Qu-Car-NBP R7a Bet-Car	Ch-3 Pin-Al-Qu	Ch-3b Car-Sal-Cer	G1/87-9 Car-Bet-NAP		
	13 Pin-Bet			Xb Corylus ↑										Xa Corylus ↓	Guz-III, Qu-UI	P3b Pin-Fag-Car-Plan P3a Pin-Fag-Car
SB	12 Pin-Fag-Cor	VIII Pin-Qu	WE-9 Pin-Pic-Ti	WĘGLINY	Wic I, Al-Qu	Wic II, Al-Qu	Guz-III, Qu-UI	P2 Pin-EMW-Fx	R5 EMW-Fx R4 AL-Ti	Ch-2a Art-Pter	ŁĘGOŃ [W14]	G1/87-7 UI-Fx-Qu				
	11 Pin-P.lan-Cere											VII Pin-EMW-Cor	WE-8 Cor-Al-Qu-UI	AT	JASIEŃ [Ja-12]	Wic I, Al-Fx
AT	10 Pin-Fx	VI Pin-Cor-EMW	WE-7 Cor-Pin-Qu	BO	JASIEŃ [Jas-N]	Ja-12, Pin-Cor	Wic I, Pin-Bet-Gram	Guz-III, Cor-Pin	R2 Pin-Bet-UI	Ch-1 Pin-Bet-Gram	L14/6					
	9 Pin-Al-Ti											V Pin-Cor	WE-6 Pin-Bet-Cor WE-5 Bet-Pin-Poa	PB	Jas-N ₁ Pin-Bet-Sph	Ja-12, Pin-Ba-NAP
BO	7 Pin-Cor-Qu	IV Pin-Bet	WE-4 Poa-Art	YD	Jas-N ₂ Pin-Bet-Jun	Ja-12, Bet-Jun	Wic I, Sal-NAP	Guz-6, Bet-Jun	Guz-III, Pin-Jun-Art	L14/4	Łęg 5/2					
	6 Pin-Cor-UI											III Pin-Bet	WE-3 Pin-Bet	AL	Jas-N ₁ Pin-Bet	Ja-12, Pin-Bet
PB	5 Pin-Bet-T.pal	III Pin-Bet	WE-2 Poa-Bet-Hipp	AL	Jas-N ₁ Pin-Bet	Ja-12, Pin-Bet	Wic I, Sal-NAP	Guz-6, Pin-Bet	Guz-6 ₂ Pin-Bet-Sph Guz-6 ₃ Pin-Bet-Cyp	Guz-III, Pin-Bet	L14/2					
	YD											4 Pin-Jun-Art	II Pin-Bet	WE-1 Poa-Bet-Hipp	AL	Jas-N ₁ Pin-Bet
AL		3 Pin-Bet	II Pin-Bet	WE-1 Poa-Bet-Hipp	AL	Jas-N ₁ Pin-Bet	Ja-12, Pin-Bet	Wic I, Sal-NAP	Guz-6, Pin-Bet	Guz-6 ₂ Pin-Bet-Sph Guz-6 ₃ Pin-Bet-Cyp	Guz-III, Pin-Bet	L14/1				
	2 Bet-Jun	I Sal-Hipp-Jun											WE, Poa-Jun	AL	Jas-N ₁ Pin-Bet	Ja-12, Pin-Bet
OD	1Bet-Hipp		I Sal-Hipp-Jun	WE, Poa-Jun	AL	Jas-N ₁ Pin-Bet	Ja-12, Pin-Bet	Wic I, Sal-NAP	Guz-6, Pin-Bet	Guz-6 ₂ Pin-Bet-Sph Guz-6 ₃ Pin-Bet-Cyp	Guz-III, Pin-Bet	L14/1				
		BØ											1Bet-Hipp	I Sal-Hipp-Jun	WE, Poa-Jun	AL
OsD	1Bet-Hipp		I Sal-Hipp-Jun	WE, Poa-Jun	AL	Jas-N ₁ Pin-Bet	Ja-12, Pin-Bet	Wic I, Sal-NAP	Guz-6, Pin-Bet	Guz-6 ₂ Pin-Bet-Sph Guz-6 ₃ Pin-Bet-Cyp	Guz-III, Pin-Bet	L14/1				

Fig. 11. Comparison of local pollen assemblage zones (L PAZs) from Lubsza Plain diagrams with reference localities in central Poland (Lake Gościąg) and in Berlin vicinity (western Germany)

Chronozones acc. to Mangerud et al. 1974; Berlin region: Pechsee and Tegeler See (Behre et al. 1996), Kleiner Mochowsee (Jahns 1999, Jahns & Herking 2002), Węgliny WE (Jurochnik A. 2012), Węgliny (Masojć et al. 2006), Jasień (Okuniewska-Nowaczyk 1996, 1998, 2005, Kowalkowski et al. 1999), Wicina (Nowaczyk & Okuniewska-Nowaczyk 1992, Okuniewska-Nowaczyk 2005), Guzów (Nowaczyk & Okuniewska-Nowaczyk 1999), Pawski Ług (Herking 2004), Rybojady (Herking 2004), Chwalim (Kobusiewicz & Kabaciński 1993, Wasylkowa 1993), Łęgoń (Malkiewicz 2002, Burdukiewicz et al. 2003, 2007), Lake Gościąg (Ralska-Jasiewiczowa et al. 1998a, b).

List of abbreviations: SA – Subatlantic, SB – Subboreal, AT – Atlantic, BO – Boreal, BP – Preboreal, YD – Younger Dryas, AL – Allerød, OD – Older Dryas, BØ – Bølling, OsD – Oldest Dryas; AP – trees and shrubs pollen, Al – *Alnus*, Bet – *Betula*, B. nana – *Betula nana*, Car – *Carpinus*, Cor – *Corylus*, Fag – *Fagus*, Fx – *Fraxinus*, Hipp – *Hippophaë rhamnoides*, Jun – *Juniperus*, Pin – *Pinus sylvestris*, Qu – *Quercus*, Sal – *Salix*, Ti – *Tilia*, Ul – *Ulmus*, EMW – mixed oak forests, Erica – *Ericaceae*, NAP (=NBP) – terrestrial herbs sporomorphs, Art – *Artemisia*, Cere – *Cerealia*, Che – *Chenopodiaceae*, Cyp – *Cyperaceae*, Fil – *Filipendula*, Gram – *Gramineae*, P. lan. – *Plantago lanceolata*, Poa – *Poaceae*, Pter – *Pteridium aquilinum*, Rosa – *Rosaceae*, Rum – *Rumex*, Sec – *Secale cereale*, Sph – *Sphagnum*, T. pal. – *Thelypteris palustris*; 1 – stratigraphical inconsistency; 2 – high amount of taxa in L PAZ, 3 – low amount of taxa in L PAZ

severe habitat conditions, particularly during cool periods. It is also possible that the counts of Cyperaceae in the samples were underestimated. The high amounts of *Hippophaë* in one sample of section WE'10/2 may be an effect of the presence of a sea buckthorn anther in sediment. Nevertheless, the percentage values it attained in other sections, ranging from 2% to 5%, provide evidence for the growth of *Hippophaë* shrubs *in situ* in the Wodra valley. The low frequency of *Sphagnum* in the Węgliny sections confirms the functioning of a lake only locally overgrown by peatmoss patches at the examined site.

Pollen grains of *Ulmus*, *Quercus*, *Corylus avellana*, and *Alnus* appear in the studied sections as early as the Younger Dryas, similarly to the Łęgoń section where the taxa were present in the Cor-Quer-Ulm curve. Their occurrence in the pollen diagrams of zones conformable with the Younger Dryas presumably results from intensive mixing of material within the entire Vistulian (Housley et al. 2013). Other differences are seen in *Pinus* content, noticeably decreasing in the Atlantic and clearly increasing in the Subboreal, and in the decreasing values of *Quercus* and *Corylus avellana* and the very low frequency of *Fagus sylvatica* and *Carpinus betulus* in the Subboreal.

That pattern typical of pine was also recorded in the Guzów and Wicina sections, broadening the range of this observation. The low proportions of late migrants (*Carpinus betulus*, *Fagus sylvatica*) in the Węgliny sections definitely are a local effect. Such a description of the flora most likely reflects deteriorating habitat conditions, indicated also by the disappearance of *Quercus* and *Corylus avellana* and the reexpansion of *Pinus*. Changing trophic conditions are also seen in the highest values of *Picea abies* and *Salix* in the discussed period. Spruce, though requiring habitat conditions similar to those of hornbeam and beech, shows better adaptation to humid areas and most likely occupied potential ecological niches of those taxa.

The description of the flora recorded in the Lubsza Plain for the last 13000 years resembles a vegetation succession typical rather of eastern Germany (vicinities of Berlin) than of central Poland (vicinity of Gościąg Lake), which may be explained by the proximity of the sites and the influence of Atlantic climate.

DISCUSSION

PALAEOBOTANICAL STUDIES AT THE WĘGLINY SITE

Palynology

The main issues requiring explanation are the differences among the WE diagrams that arose although analogous local pollen assemblage zones were distinguished using the same criteria) as well as the same names of local zones.

An essential difference between sections appeared in distinguishing the NAP subzone within zone WE-3 *Pinus-Betula* in diagrams WE'10/2 and WE'08. The subzone reflects brief cooling, in the pollen diagrams marked by an increase in NAP content (particularly of grasses) and a decrease in the frequency of pine. However, as it was not identified in diagram WE10, it was not defined as a distinct zone.

The boundary between zones WE-6 *Pinus-Betula-Corylus* and WE-7 *Corylus-Pinus-Quercus*, consistent with the Preboreal/Boreal transition and determined at the rapid increase in the percentage of *Corylus avellana* and the decrease in *Betula*, was problematic as well. In section WE'10/2 the boundary was recorded at slightly higher percentages (*Corylus* content 9%) than suggested by the isopollen pattern of hazel expansion in the area of Poland, conformable with the PB/BO transition at 9000 ¹⁴C BP (*Corylus* content up to 5%; Miotk-Szpiganowicz et al. 2004). However, the curves for birch and other trees in the section are shaped similarly to those in other diagrams in which hazel shows values below 5%. For this reason the boundary was not lowered. Additionally, the date 9360±60 ¹⁴C BP estimated for a sample representing a period below the boundary suggests that the examined interval still should be assigned to the Preboreal.

Rebedded sporomorphs

Neogene taxa (*Sequoia*, *Tsuga* and *Nyssa*), non-pollen sporomorphs (Dinophyceae) and pre-Quaternary taxa (*Pterocarya*, *Juglans*) not native to these areas in the Quaternary were presented in the pollen diagrams as separate curves. Taxa with higher temperature requirements, observed within the entire Quaternary and found in pollen diagrams of Węgliny in all Late Glacial zones, were summarised and,

together with non-determined sporomorphs from older periods, shown as one curve: Rebedded (Figs 7, 8; Tab. 11). The occurrence of cryophilous taxa typical of open areas (*Salix polaris*, *Hippophaë rhamnoides*, *Betula nana* t.), excludes the presence of thermophilous taxa. From studies of the vegetation succession it was concluded that cryophilous and heliophilous taxa are found *in situ* (Dyakowska 1959).

Pollen grains of *Pinus sylvestris* t. and *Betula*, frequent in the above-mentioned zones, for example in WE-1 (WE'08-1, WE'10-1, WE'10/2-1), caused serious problems in interpretation. All sections were dominated by grains of *Pinus sylvestris* t., up to 80% in WE'10. In this situation it was difficult to unequivocally state how many pollen grains were redeposited from older basement sediments, originated from long-distance transport, or occurred *in situ* at the examined site. The last-mentioned source cannot be excluded, although isopollen maps (Latałowa et al. 2004) show only infrequent sites of *Pinus* in the area of Poland in the discussed period (13 000–12 500 ¹⁴C BP), nearly all located in the central and western parts of the country. A similar issue arose for *Betula* pollen, but the carpological diagram includes macroremains of *Betula* sect. *Albae* already in the second pollen assemblage zone, WE'10/2₂, indicating that tree birches were already a constant component of the regional flora in this period.

AGE OF EXAMINE PROFILES

The next issue is associated with incorrect results obtained for part of the dated material (Tab. 10). The dating of Holocene sediments (4 samples) correlates well with the distinguished palynological zones and is therefore conformable with the Holocene chronostratigraphy defined by Mangerud et al. (1974). However, the dating of the other 5 samples, taken from the older part of the sediment, suggests that the examined material is older than implied by palynological analysis and tephrochronological dating. These over-aged radiocarbon dates may result from the high concentration of calcium carbonate recorded for the lower part of section from CaCO₃ content analysis of the examined sediment (Housley et al. 2013). Such high amounts of calcium carbonate are responsible for the so-called reservoir effect in the basin. Another possible reason for the incorrect dates is intensive redeposition of sporomorphs from

older sediments. Rebedded sporomorphs were observed in all Vistulian pollen assemblage zones and their presence may have affected dating of the sediment to some extent.

TEPHRA AT THE WĘGLINY SITE

Laacher See Tephra (LST) has been recorded in many sections in Europe, from northern Switzerland to northern Germany (Błaszkiwicz 2007, Birks & Lotter 1994, Bittmann 2007, Brauer et al. 1999, de Klerk et al. 2008), but only two sites of it in Poland were previously known, both in north-western Pomerania: Warnowo on Wolin Island, and Niechorze on a cliff near Rewal (Juvigné et al. 1995). New investigations of tephra sediments in Europe have just discovered two more sites: the Trzechowskie palaeolake in central northern Poland (Wulf et al., 2013) and the Węgliny site described in the present paper (Housley et al. 2013). The finding of tephra at Węgliny in WE-3 L PAZ (Housley et al. 2013) extends the range of occurrence of LST to south-western Poland. In order to observe any vegetation changes in intervals including this tephra, the density of sampling for pollen analysis was increased to 2 cm and 1 cm in the first and second segments respectively.

The results enabled us to compare this section with profiles of Neuwied, Meerfelder Maar, Holzmaar, Rotmeer, Rotsee, and Reinberg, analysed by several authors: Bittmann (2007), Brauer et al. (1999), Birks & Lotter (1994), and de Klerk et al. (2008). Although high-resolution pollen analysis was performed it was not possible to detect changes indicating short-term cooling or a direct effect of volcanic eruption on the flora of the Węgliny area. A comparison of the discussed interval with the above-mentioned diagrams suggests that the cooling resulting from the Laacher See eruption was too brief and the examined site was too far from the eruption to make an impact on the vegetation in the pollen record.

SUMMARY AND CONCLUSIONS

1. Palynological analysis of three sections provided the basis for identification of ten local pollen assemblage zones corresponding to climatic-vegetation periods of the Late Glacial and Holocene, and for reconstruction

of changes in vegetation proceeding in these periods at the Węgliny site (Lubsza Plain).

- The Late Glacial includes two phases of vegetation typical of open areas. The first one most likely corresponds to the Oldest Dryas stadial, and the second to the Younger Dryas. Both are characterised by the dominance of vegetation typical of open areas (Poaceae, *Juniperus*, *Helianthemum*, *Artemisia*) and the occurrence of plant indicators of cold climate (e.g. *Betula nana*, *Hippophaë rhamnoides*, *Selaginella selaginoides*).

- In the examined material, interstadial vegetation is represented by the phase of *Hippophaë* and the phase of birch-pine forest. The phase of *Hippophaë* is marked by the highest values of sea buckthorn and an increasing frequency of birch trees (*Betula*), indicating slight improvement of climatic conditions. On the basis of literature data from Germany and Poland and the description of the vegetation succession at the Węgliny site the phase was assigned to the Bølling biozone.

- The phase of birch-pine forest, typified by an increase in the amounts of *Pinus sylvestris* and *Betula* and the disappearance of most indicators of cool climate, falls within the Allerød. This estimation is supported by the occurrence of tephra originating from an eruption of the Laacher See volcano, identified at 580–565 cm depth and dated to the latter stages of the Allerød interstadial ca 200 years before the onset of the Younger Dryas stadial (Housley et al. 2013).

- The description of the flora did not provide a basis for distinguishing the Older Dryas in the examined material. Redeposition of Quaternary sporomorphs recorded in nearly the entire Late Glacial parts of the sections, caused great difficulties in interpreting the pollen analysis results for the late Vistulian.

- The Holocene history of vegetation begins with the Preboreal, characterised by the appearance of *Ulmus* and *Quercus* and an increase in *Corylus avellana* and *Alnus* content.

The Boreal is typified by high values for *Corylus avellana* and increasing amounts of *Alnus*, *Ulmus*, *Quercus*, *Tilia*, and *Fraxinus excelsior*.

- In the Atlantic, well-developed climax forest is accompanied by the appearance of oceanic climate indicators such as *Hedera helix*, *Ilex aquifolium*, and *Vitis vinifera*. The

Subboreal shows a decrease in the frequency of *Ulmus*, an increase of *Picea abies* and *Salix*, and the highest values of the Filicales monolete fern. The Subatlantic is represented by only a few samples from the WE'10/2 section and is marked by a re-increase in the content *Betula*, Poaceae, *Corylus avellana*, *Quercus*, *Alnus*, *Carpinus betulus*, and *Fagus sylvatica*, and the appearance of *Ulmus* and Cerealia, including *Secale cereale* and *Hordeum*.

2. The chronology and stratigraphy of the examined section was determined, but with some difficulties. Nine samples were radiocarbon-dated. Five seemed in conformity with the palynological results and provided dates corresponding to the Younger Dryas, Preboreal, Boreal, Subboreal, and Subatlantic. Additionally, in sections WE'10 and WE'10/2 the Allerød was dated from the presence of the Laacher See Tephra horizon.

3. This work yielded a reconstruction of the palaeobasin and changes affecting it during the Late Glacial and Holocene. The palaeolake, marked by sedimentation of biogenic sediments, possibly developed from the depression of a subglacial channel, most likely preserved with a block of dead ice. The lake was ca 1 km long, 125 m wide and had a maximum depth of ca 8 m. Fluvial sands found in the basal parts of sections and the presence of the Wodra river at the study site may suggest the functioning of a partly flow-through basin.

- The lake developed fully in the Bølling, when accumulation of biogenic sediments was initiated. The basin, originally oligotrophic, changed its trophic status from dystrophic to eutrophic (mainly in coves) with the development of aquatic vegetation and fluctuations in water level. Beginning in the Atlantic, the lake was gradually overgrown, dominated by meso- and eutrophic water and marked by an increase in the number of aquatic and swamp plants characteristic of shallow warm basins. In the Subboreal the lake most likely became entirely shallow and overgrown. Only small, shallow, gradually overgrown ponds were still present in the Subatlantic.

4. Pine was the main plant component as early as the Late Glacial, due to the dominance of sands and then podsol. Periglacial and young-glacial landforms did not favour the development of fertile soils. Early entry and settling of pine as well as the location of the study area in the Wodra river valley were

factors favouring the development of vegetation in the late Vistulian, particularly during the intensive cooling of the Younger Dryas. Although the study site was surrounded by moraines and dunes, aeolian and weathering processes were strongly limited.

5. Throughout the Holocene the investigated area was affected by relatively warm, humid microclimate, as indicated by the constant and increasing content of ferns (spores of Filicales monoletes) and *Alnus*. In the Subboreal the water basin became almost entirely shallow and its area was entered by boggy pine forest with ferns in the ground layer, as evidenced by the highest values attained by *Pinus sylvestris* pollen (in the Holocene) and Filicales monoletes spores. The boggy and marshy type of habitat is also indicated by the amounts of *Picea abies* and *Salix*, increasing in this period.

6. In the Subatlantic the area dried partly, as indicated by the increase in pollen of *Betula*, Poaceae, and *Quercus*, the reappearance of *Carpinus betulus* and *Fagus sylvatica*, and the decrease in *Picea abies* and *Salix*. However, the site was still locally flooded (increasing amounts of *Alnus*).

7. The occurrence of plant indicators of rather humid microclimate in the Wodra valley during the Late Glacial and Holocene most likely results from high groundwater in the study area, presently constantly drained.

8. The Węgliny site integrates well into the northern European Late Glacial biostratigraphic framework of the palyno-stratigraphic frameworks of Poland and northeast Germany. Our comparison of the Węgliny study site with selected sites from the Lubsza Plain and references sites from Germany and central Poland revealed similarities and differences between their floras. The flora recorded in the Węgliny sections resembles rather the profiles from eastern Germany than those of central Poland.

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