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Palaeobotanical studies on Late Glacial and Holocene vegetation development and transformations of the 'Wielkie Błoto' mire near Gołdap (north-eastern Poland)

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ABSTRACT. This paper presents the results of palynological, macrofossil and peat analyses that were conducted on deposits from a profile collected from the Wielkie Błoto mire near Bałupiany (north eastern Poland). The investigation revealed that the recorded changes of vegetation span the period from the decline of the Younger Dryas (ca 9600 cal. yr BC) to the late Subboreal or early Subatlantic chronozone, but due to a 40 cm long sediment gap a complete reconstruction was not possible. At the beginning, the area was occupied by steppe and tundra communities together with abundant *Juniperus* stands. A subsequent expansion of birch (*Betula*) woodlands with pine (*Pinus sylvestris*) took place in the Preboreal chronozone in which a rise in the water level and/or basin deepening was recorded at the site as well. The domination of such woodlands lasted to the end of the Boreal chronozone when *Corylus avellana* expanded rapidly. In the Atlantic chronozone multispecies deciduous forests developed with *Tilia cordata* and *Quercus*, while *Ulmus* together with *Alnus* spread in damp habitats. During this chronozone, traces of the occurrence of *Carpinus betulus* were detected in the macrofossil analysis, while the pollen analysis failed to record its presence. The expansion of *Carpinus betulus* and *Picea abies* was characteristic of the Subboreal chronozone when both taxa presented antagonistic optima. Alone in north-eastern Poland, there was a re-expansion of deciduous forest in the younger part of the Subboreal chronozone caused probably by low human impact, which is reflected in the whole profile. The first probable traces of human activity were noticed in the Atlantic chronozone and attributed to peoples of the Mesolithic or Early Neolithic cultures, while the first evidence of cultivation was correlated to the Bronze Age. However, the low resolution of the radiocarbon dates did not allow a more precise reconstruction of the chronology. The analysis of macrofossils and tissues indicated two episodes of oligotrophication of the mire. The first one took place during the Boreal chronozone, while the second fall in trophy was triggered by spruce expansion in the Subboreal chronozone. On the other hand, a rise in human impact during the first *Carpinus betulus* maximum caused eutrophication of the mire.

KEYWORDS: palynological analysis, macroscopic plant remains, Late Glacial, Holocene, north-eastern Poland

INTRODUCTION

The Bałupiany site, according to Kondracki (2002) is located in the geographical area called Pagórki Rogalskie (Rogalskie Hills, within the Węgorapa District) that is to the north-east of the Mazury Lake District (Fig. 1). However, unlike the latter it is poorly palynologically and archaeologically recognized (e.g. Ralska-Jasiewiczowa et al. 2004a). While, the first reconstructions of vegetation changes from the Mazury Lake District were done in the 1930's (Groß 1935, 1936, 1939) and later (Ralska-Jasiewiczowa 1966, Pawlikowski

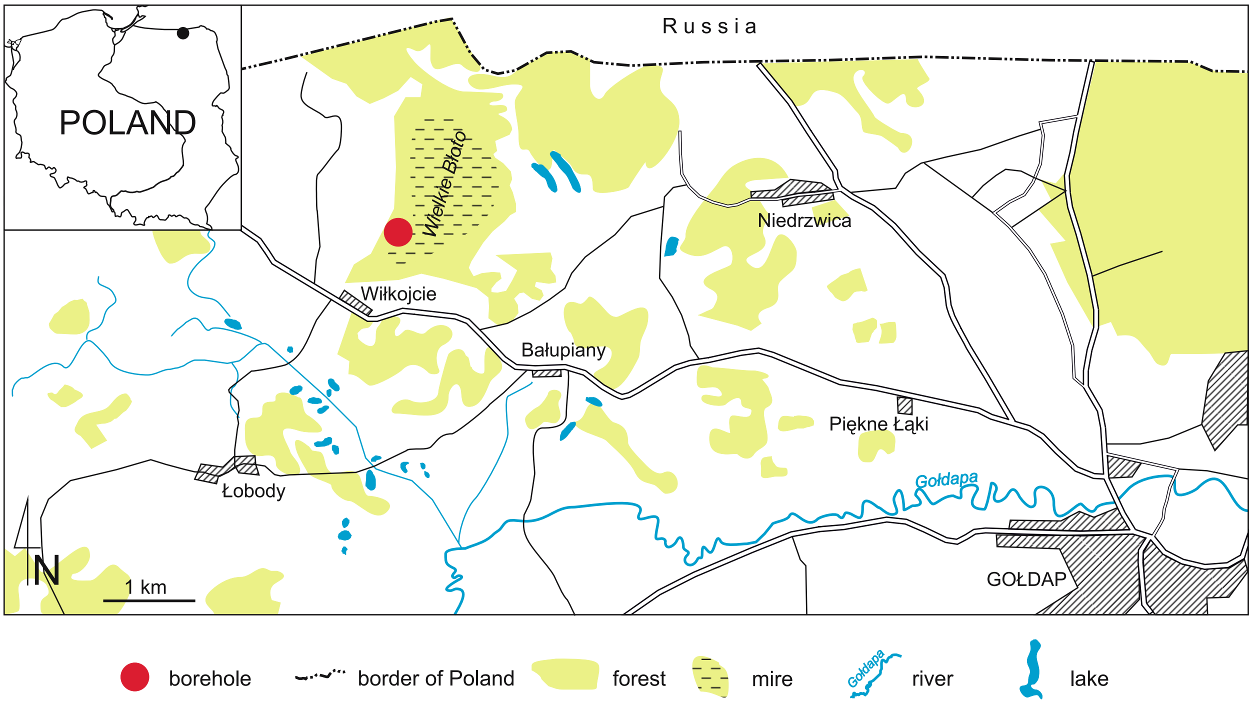

Fig. 1. Location of the Bałupiany site

et al. 1982, Filbrandt-Czaja 2000, Kuprjanowicz 2002, Wacnik 2009a, b), before the research in the Skaliska Basin (Stachowicz-Rybka et al. 2009) there have been no modern palaeobotanical investigations within the Węgorapa District. Hence, research conducted in this area may significantly contribute to the knowledge of migration patterns in northeastern Poland and provide new information about vegetation development in the Late Glacial and Holocene.

The main aim of this research was a reconstruction of the vegetation history in the Pagórki Rogalskie region during the Late Glacial and the Holocene based on pollen analysis, sediment analysis and macroscopic remains analysis supported by radiocarbon dating. The palynological analysis presented in this paper is mainly based on an MSc thesis (Karpińska-Kołaczek 2008).

CHARACTERISTICS OF THE STUDIED AREA

GEOLOGY AND GEOMORPHOLOGY

The site is located ca16 km east of the Skaliska Basin within a vast peat land called 'Wielkie Błoto'. It is limited in the south and east by sandy-gravel hills of terminal moraines, while kames form the northern boundary of the peat bog. This depression (kettle?) probably originated during the Pomeranian phase retreat (ca 13 250 yr BC following Marks 2002), a stade of the ice sheet. The ice sheet stagnation was marked by terminal moraine zones running from SW to NE in the direction of Węgorzewo – Piłackie Wzgórza – Audyniskie Góry – Gołdap (Pochocka-Szwarc 2003, 2009, 2010).

SOILS

In the Rogalskie Hills region, the dominant types of soil are cambisols and luvisols mostly formed on glacial till, with the former on clayey sands and loam as well (Bednarek & Prusinkiewicz 1999, Uggla 1956). In the landscape the soil falls into characteristic groups connected with the land relief. On the moraine hills cambiosols and luvisols occur, on the slopes mostly gleysols (planosols), and in the depressions between moraines, along rivers, and lakes semihydrogenic and hydrogenic soils developed, which are connected with a shallow water table, among them being histosols, gleysols, gyttjas and fluvisols (Uggla & Ferczyńska 1975, Bednarek & Prusinkiewicz 1999, Bednarek et al. 2004).

CLIMATE

The Rogalskie Hills region is under the influence of oceanic and continental climates. The vicinity of the Baltic Sea as well as the numerous lakes and peat bogs cause greater humidity, which negatively influences the level of heat and make this region the coldest in the Polish lowlands (after Ralska-Jasiewiczowa 1966). The mean annual temperature in the years 1996–2000 was 7–7.5°C (on average ca 6.5°C), the coldest month is January with a mean temperature of –3°C to –4°C and the warmest is July with a mean temperature of 17–17.5°C. Mean annual rainfall ranges from 550 to 600 mm and locally even up to 700 mm (Starkel 1999, Woś 1999). Snow cover lasts 70–80 days and the growing period lasts for ca 190 days (Lorenc 2005).

RECENT VEGETATION

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

A dominant forest community in this area is *Tilio-Carpinetum* (a subboreal variant with boreal elements) which occurs on moraine clays and sandy-clayey deposits (Matuszkiewicz 2001). However, German and more recent forest management mean that coniferous trees dominate in such forests, mainly spruce. Moreover, the domination and the expansion of lime mean a reduction of other typical taxa such as *Quercus robur* and *Carpinus betulus*, thus a new community *Tilio-Piceetum* (Czerwiński 1976) was distinguished.

On sandy deposits and on kames *Peucedano-Pinetum*, *Querco roboris-Pinetum*, and locally *Serratulo-Pinetum* developed, which are also present in the vicinity of Gołdap and in the Skaliska Basin.

In depressions and places of water stagnation swampy forest communities occur; the most common is *Sphagno-Piceetum*, while *Ribeso nigri-Alnetum*, *Sphagno-Alnetum*, and *Vaccinio uliginosi-Pinetum* are rather rare.

In the river valleys and along streams riparian forests *Fraxino-Alnetum* and *Ficario-Ulmetum* developed, along with small patches of *Carici remotae-Fraxinetum* and *Salicetum albo-fragilis*, and a community of riverside willows *Salicetum triandro-viminalis* (Matuszkiewicz 2005).

In the woods and in open areas several types of peat bogs occur. Raised bogs are represented by communities from the *Sphagnion magellanici* alliance e.g. *Ledo-Sphagnetum*. Poor fens belong to communities from the *Scheucerio-Caricetea fuscae* class. Under the influence of human activity (deforestation, drainage, mowing, pasture), fens transformed into communities of swampy and reed vegetation from the *Magnocaricion* and *Phragmition* alliances. Some of them are used as meadows and pastures (*Calthion* and *Arrhenaterion elatioris* alliances), which after use change into tall herb communities e.g. *Filipendulo-Geranietum*, reed beds with *Phragmites australis* and *Salix*, secondary willow carr *Salicetum pentandro-cinereae*, and riparian forest-like communities.

In old river beds and natural water bodies plant communities from the *Nymphaeion* and *Potamogetonion* alliances developed, on the flooded riversides communities belonging to the *Bidentetalia tripartiti* order and on the river and stream beds hydrophytes from the *Ranunculion fluitantis* alliance occur.

SETTLEMENT HISTORY

The oldest traces of settlement in this area come from the Stone Age, but due to the character of these findings (single stone tools and waste from their production) it is hard to determine the density of settlement in this area. Only the site in Niedrzwica, located in the river valley on the west outskirts of the town, has traces of a small Neolithic settlement attributed to the Corded Ware culture and dating back to the 3rd millennium BC (Iwanicki pers. comm.).

From the Bronze Age there is known only a bronze axe found in Gołdap. The early Iron Age is more evident. To that time belongs a settlement complex located close to Łobody in the Gołdapa valley, to the west of Bałupiany. It consists of a fortified settlement (Bałupiany, site I) and a settlement placed on the opposite side of the river (Kośmidry, site I). The fortified settlement has not been investigated yet thus, it is difficult to ascertain the date of its establishment, but the settlement is probably from the last three centuries BC. Traces of intensive settlement from the last century BC and the first AD were also discovered in the above-mentioned settlement in Niedrzwica (Iwanicki pers. comm.).

Visible settlement development in this area took place in the period of Romans influence

(1st–4th centuries AD) and in the Migration Period. In the neighbourhood of the existing settlement in Niedrzwica, new ones were found in the Gołdapa valley (Niedrzwica, sites XIII and XV), on the hills to the north of it (Kujki Dolne), and in the northern part of the Szeskie Hills. This settlement ceased ca 5th – 6th century AD, which is evident from the abandonment of settlements and the disuse of field graves in the Gołdapa valley. Settlement continuity was observed only in the area of the Szeskie Hills (P. Iwanicki pers. comm.).

Since the 7th century, the only settlement that has been recorded was a settlement complex in Konikowo-Rostek that consisted of a settlement established at the end of the 2nd century AD and a fortified settlement that was constructed in the 10th century AD. Probably, at the end of the 11th century this complex of buildings was abandoned. The settlement break in this area probably lasted until the establishment of Gołdap town in the 16th century (Iwanicki pers. comm.).

MATERIAL AND METHODS

The profile was collected in 2005 using a Więckowski sampler (piston corer) during sediment research within the project 2 PO4D 02429 supported by the Ministry of Science and Higher Education and was included in the preparation of the 'Detailed Geological Map of Poland 1: 50000, Budry sheet' (Pochocka-Szwarc & Lisicki 2001).

All together 37 samples for pollen analysis, 1 cm^3 in volume, were collected from previously selected depths and prepared by the standard preparation procedure followed by acetolysis (Berglund & Ralska-Jasiewiczowa 1986). To every sample a weighed *Lycopodium* tablet was added for further calculations of pollen concentration (Stockmarr 1971). More than 500 pollen grains of arboreal taxa (occasionally 200–500 in samples with low pollen concentration) per sample were counted at 400× and 1000× magnification. The pollen taxa were determined with the assistance of the modern pollen slide collection of the Władysław Szafer Institute of Botany, Polish Academy of Sciences, and special keys and atlases (Punt 1976, Faegri & Iversen 1989, Moore et al. 1991, Reille 1992, Beug 2004). The taxa were identified to the highest possible taxonomical level. The percentage values of individual taxa were calculated in the ratio to AP+NAP excluding telmatophytes (including Cyperaceae) and limnophytes as well as spores of cryptogams. The percentages of excluded taxa were calculated in the ratio to AP+NAP+excluded taxa. Samples for macroscopic remains analysis were macerated. After a 24-hour soak the sediment was boiled with the addition of potassium hydroxide (KOH) and then sifted with a sieve with 0.2 mm diameter meshes. The material remaining in the sieve was sorted in order to select all identifiable plant remains which were put in a mixture of glycerine, water, and ethyl alcohol (prepared in a 1:1:1 ratio with added thymol). The results of the pollen analysis are presented as a percentage and concentration diagram (Fig. 2), whereas the analysis of macroscopic remains is shown in a diagram of raw data (Fig. 3). Both of them were plotted using POLPAL software (Nalepka & Walanus 2003). The results of the plant tissue analysis supplemented the macrofossil analysis and they were presented in a 0/1 diagram of the occurrence of plant remains in which dominant and peat-forming taxa were outlined (Fig. 4). Additionally, a dendrogram of similarities between pollen spectra prepared using the ConSLink method was also plotted using a program within POLPAL software. The material for radiocarbon dating was selected from the depths corresponding with the main palynological events. Dating was carried out in the Poznań Radiocarbon Laboratory (Laboratory code – Poz).

DESCRIPTION OF PROFILE

The profile from the Bałupiany was collected from the surface of the mire called 'Wielkie Błoto' situated at an altitude of 153 m a.s.l. (54°19′40.27″N, 22°12′56.73″E). The site is located in the vast peatland near Wiłkajcie, which is partly exploited.

Lithology (depth in cm):

30–50 Betuleti-Pineti, moderately decomposed
50–60 Subsecunda peat, moderately decomposed
60–90 *Sphagnum-Phragmites* peat (Sphagno-Phragmiteti)
90–100 Sedge-moss peat (Carici-Bryaleti)
140–150 *Sphagnum* peat with admixture of silt (Minero-Sphagnioni)
150–180 Birch peat (Betuleti)
180–240 Sedge peat (Cariceti)
240–250 Cotton sedge peat (Eriophoreti)
250–270 *Sphagnum angustifolium* peat (Sphagnioni)
270–290 Moss peat (Bryaleti)
290–300 Moss peat (*Drepanocladus*)
300–310 Betuleti, highly decomposed (>40%)

RESULTS

RADIOCARBON DATINGS

Five radiocarbon dates were calibrated using the OxCal v 4.10 program (Bronk Ramsey 2009), according to the calibration curve IntCal 09 (Reimer et al 2009), are presented

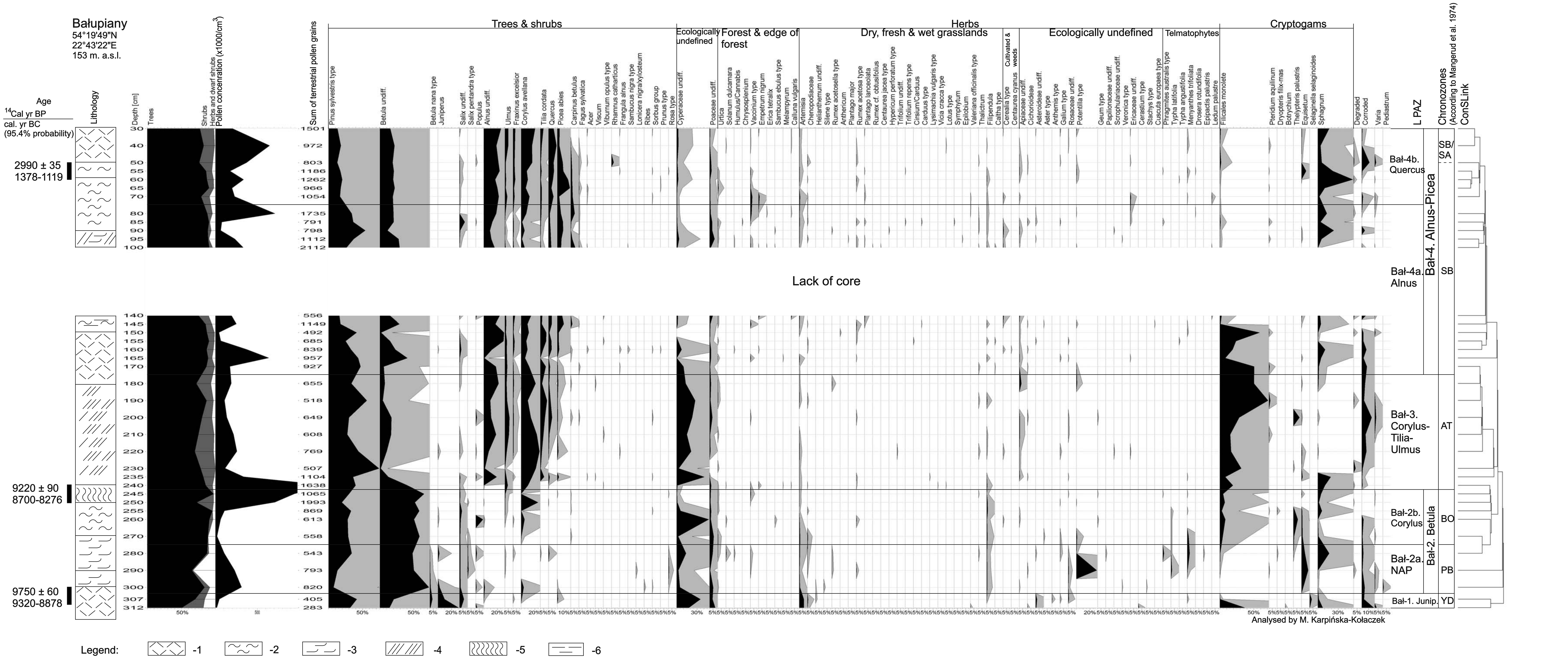

Fig. 2. Palynological diagram from the Bałupiany site; callibrated data are presented in the range of 95.4% probability.
1 – Betuleti and/or Pineti peat, 2 – Sphagnioni peat, 3 – Bryaleti peat, 4 – Cariceti peat, 5 – Eriophoreti peat, 6 – silt

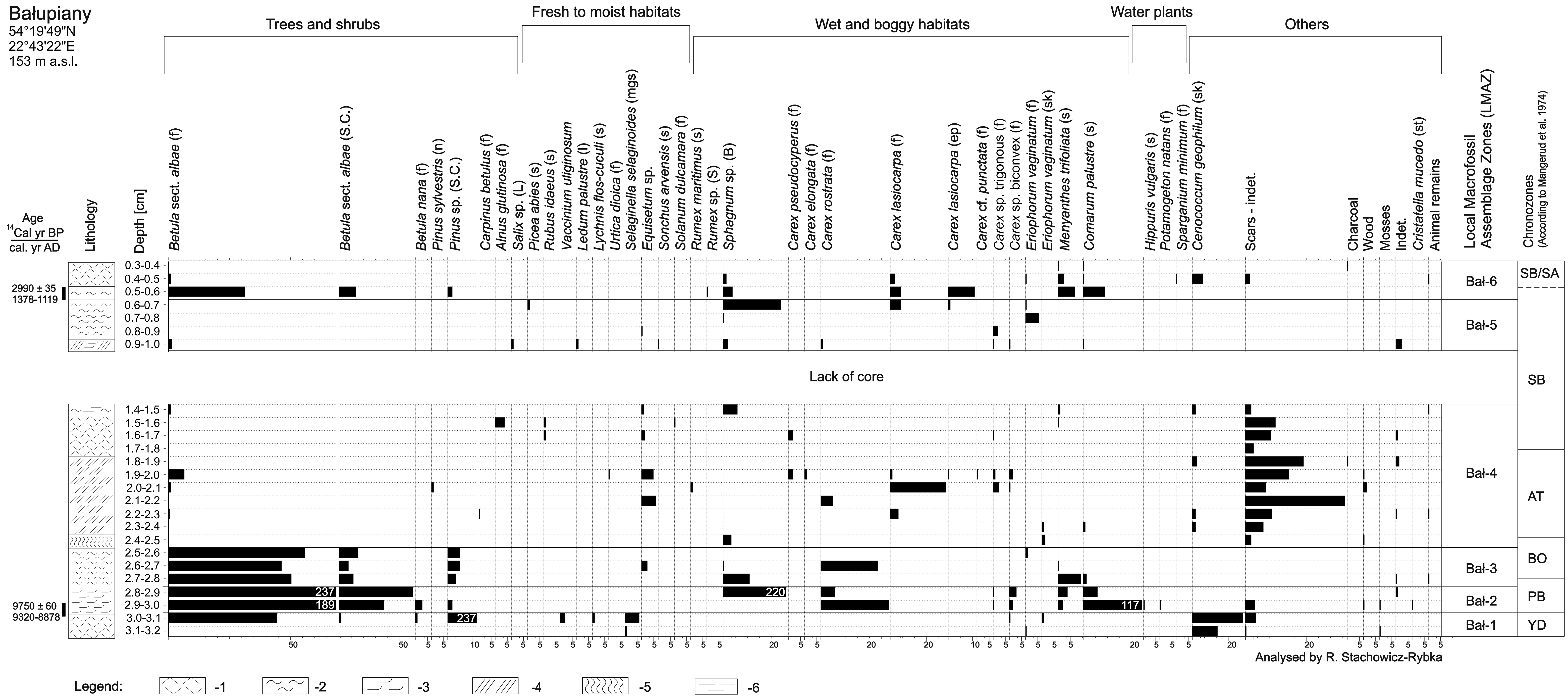

Fig. 3. Macrofossil diagram from the Bałupiany site; callibrated data are presented in the range of 95.4% probability.
1 – Betuleti and/or Pineti peat, **2** – Sphagnioni peat, **3** – Bryaleti peat, **4** – Cariceti peat, **5** – Eriophoreti peat, **6** – silt

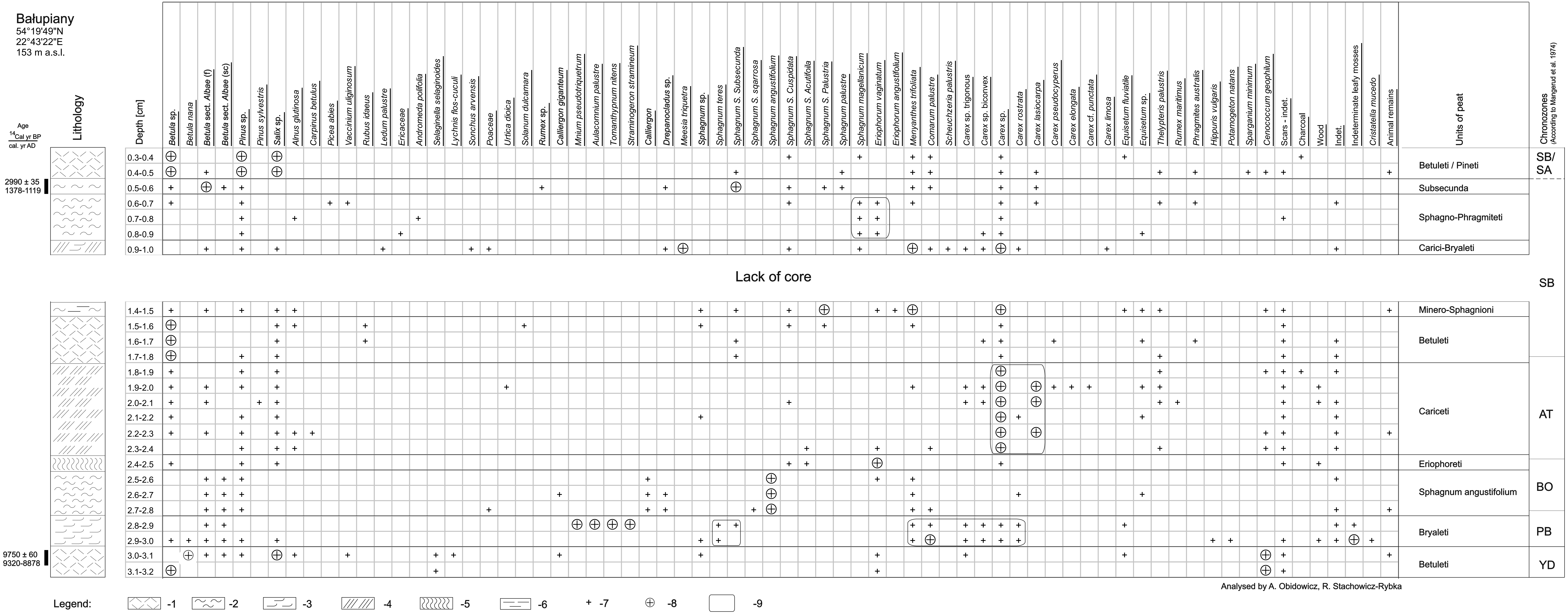

Fig. 4. Plant tissues and additional macrofossils diagram from the Bałupiany site; callibrated data are presented in the range of 95.4% probability. **1** – Betuleti and/or Pineti peat, **2** – Sphagnioni peat, **3** – Bryaleti peat, **4** – Cariceti peat, **5** – Eriophoreti peat, **6** – silt, **7** – presence of the taxon, **8** – dominant taxon, **9** – peat forming taxa

in Table 1. The dates obtained from a depth of 95–100 cm (Poz-37981) and a depth of 260 cm (Poz-35501) yielded ages too young to be compatible with the results of the palynological analysis. Thus, they were rejected. These age-inconsistencies are difficult to explain because the material selected for datings came from terrestrial plants i.e. was the best possible to carry out the measurement of ^{14}C content. Hence the explanation might be rejuvenation caused by humic acids which infiltrate the ground, saturate macroremains and increase the proportion of ^{14}C in them (Björck & Wohlfarth 2001). Nevertheless, the radiocarbon date from the upper part (Poz-37979) of the profile seems to be reliable in the light of pollen analysis and the macroremains selected for this dating should be those most exposed to such acids. The influence of humic acids, therefore, fails to entirely explain the cause of these inversions, which are similar to those in sites from the nearby Skaliska Basin (Kołaczek et al. 2013). The second explanation might be contamination of samples by microorganisms during the storage. The profile was collected at the same time as profiles from the Skaliska Basin, and the whole procedure of sample collection and selection of macroremains for AMS dating was the same in both cases (see Kołaczek et al. 2013). So then, the conditions of storage might have had a negative influence on the dating results. Moreover, material selected for Poz-37981 and Poz-35501 dates had a small content of carbon (in dry weight < 1.4 mg) and those kinds of samples are more susceptible to contamination and subsequent rejuvenation than larger ones (Wohlfarth et al. 1998).

PALAEOBOTANICAL ANALYSES

The pollen diagram (Fig. 2) was divided into 4 local pollen assemblage zones (L PAZs) and 4 subzones (L PASZs) with the support of the ConSLink dendrogram, following the instructions provided by Birks (1986) and Janczyk-Kopikowa (1987). Two L PAZs were divided into local pollen assemblage subzones (L PASZs). The diagram was also divided into chronozones, as proposed by Mangerud et al. (1974), on the

Table 1. Radiocarbon dates from the Bałupiany profile

Depth [cm]	Lab. code	Age ^{14}C BP	Callibrated age	Dated material	Remarks
50–60	Poz-37979	2990±35	68.2% probability 1300 BC (57.3%) 1192 BC 1176 BC (5.7%) 1162 BC 1143 BC (5.3%) 1132 BC 95.4% probability 1378 BC (6.8%) 1336 BC 1322 BC (88.6%) 1118 BC	*Betula* sect. *Albae* fruits, *Menyanthes trifoliata*	
95–100	Poz-37981	1125±30	68.2% probability 890 AD (12.8%) 904 AD 912 AD (55.4%) 970 AD 95.4% probability 783 AD (0.5%) 788 AD 818 AD (3.1%) 842 AD 860 AD (91.7%) 991 AD	*Betula* sect. *Albae* fruits, Poaceae	small, 0.5 mgC, excluded from interpretation
240–250	Poz-41024	9220±90	68.2% probability 8546BC (13.3%) 8502BC 8494BC (54.9%) 8316BC 95.4% probability 8700BC (1.5%) 8676BC 8644BC (93.9%) 8276BC	*Eriophorum vaginatum* spindles, a piece of wood	Tymol, rinsed in alcohol, excluded from interpretation
260	Poz-35501	1970±35	68.2% probability 19 BC (3.7%) 13 BC 0 AD (64.5%) 72 AD 95.4% probability 46 BC (92.5%) 87 AD 104 AD (2.9%) 120 AD	*Betula* sect. *Albae* fruits, *Pinus sylvestris* scales	small, 0.5 mgC, excluded from interpretation
300–310	Poz-37982	9750±60	68.2% probability 9287 BC (68.2%) 9190 BC 95.4% probability 9320 BC (87.5%) 9122 BC 9002 BC (7.7%) 8919 BC 8883 BC (0.2%) 8878 BC	*Betula* sect. *Albae* scales and fruits	

basis of radiocarbon dates and pollen successions in well dated profiles from north-eastern Poland (Wacnik 2009a, b, Lauterbach et al. 2011, Kołaczek et al. 2013). The results of the palynological analysis are presented in Table 2 and Figure 2. The results of macrofossil analysis (Tab. 3, Fig. 3) pointed to the presence of 6 macrofossil assemblage zones (MAZ), whereas the analysis of plant tissues distinguished 11 zones with 10 units of peat (Fig. 4).

DISCUSSION

THE VEGETATION HISTORY OF THE ROGALSKIE HILLS AND THE DEVELOPMENT OF THE MIRE IN BAŁUPIANY

The profile was obtained from the southern part of the mire, at its edge, so the reconstruction of the local vegetation changes reflects only the vicinity of the drilling site (Fig. 1).

Bał-1 MAZ; Bał-1 *Juniperus* L PAZ, (depth 312–303.5 cm) Younger Dryas

The vegetation at that time had a character of park tundra with stands of birches, probably *Betula pubescens* (occurrence of fruits of *Betula* sect. *Albae*), and *Pinus sylvestris*.

Patches of tundra vegetation were represented by dwarf birch (*Betula nana*), a species typical of this period in the region (comp. Gałka & Sznel 2013). Another taxon characteristic of open-communities was *Selaginella selaginoides*. In dry places *Juniperus* thickets may have occurred, which distinctly expanded at that time in this part of Poland as well as in neighbouring countries (e.g. Odgaard 1994, Litt et al. 2001, Staničkaite et al. 2002, Okuniewska-Nowaczyk et al. 2004, Berglund et al. 2008). However, its percentage values considerably exceed those presented in isopollen maps for Poland (Okuniewska-Nowaczyk et al. 2004) and are similar to these recorded by Wacnik (2009a). The sparsely wooded slopes surrounding the lake probably favoured xeric vegetation and juniper (*Juniperus*) might have found suitable conditions for growth there. Single specimens of *Ephedra distachya* could have occurred there as well, but long distance transport, as a potential reason of the appearance of *Ephedra* pollen, cannot be rejected (Granoszewski & Nalepka 2004). Open areas were mainly occupied by communities of steppe herbs with *Artemisia*, Chenopodiaceae, and Poaceae, together with *Helianthemum* (*Helianthemum oelandicum* type) and members of Asteraceae, Apiaceae and Rosaceae. *Lychnis flos-cuculi* and *Valeriana* were growing in places with good moisture conditions.

At the beginning of peat accumulation on the mire surface *Betula*, *Alnus*, and *Salix* were present. The main moss taxa were *Sphagnum* sp. and *Caliergon giganteum*. The presence of *Eriophorum vaginatum* there might have contributed to the preservation of seeds of *Betula* sp. from deterioration by protecting seeds lying underneath its tufts, as Daniels (2001) showed in the case of *B. pubescens*. Birch was the most important peat forming taxon during this period (Betuleti peat). In the depression and probably in other damp areas patches of dwarf tundra with *Betula nana*, *Salix*, and *Vaccinium uliginosum* occurred. In this period *Cenococcum geophilum*, a ubiquitous ectomycorrhizal fungus living on, in, or just below the litter horizon (Thormann et al. 1999, Wurzburger et al. 2004), has been detected in great numbers. So the record of its sclerotia could be evidence that organic matter in the surface soil (i.e., litter horizon) eroded and was deposited into the peat bog (cf. Wick et al. 2003, Tinner et al. 2008). This kind of origin may be confirmed by sites located east of Bałupiany e.g. the Skaliska Basin (Stachowicz-Rybka & Obidowicz 2013) and Lake Czarne (Karpińska-Kołaczek 2011), in which this fungus occurred frequently during the Younger Dryas and early Preboreal chronozone in the initial phases of the basin's development. *Cenococcum geophilum* is also associated with transient or chronic environmental stress (e.g. winter frost injuries; Webb et al. 1993). Hence its rise in frequency during the cold period might have been induced by more severe winters and early springs as well.

Bał-2 MAZ; Bał-2a *Betula* – NAP L PASZ, (depth 303.5–242.5 cm) Preboreal chronozone

The expansion of pioneer birch woodlands with birch points to climate amelioration. *Betula* reached a maximum of occurrence which was common for the entire Mazury Lake District in the Preboreal chronozone (Ralska-Jasiewiczowa et al. 2004b). *Populus* and *Pinus sylvestris* also featured in those forests. Despite the presence of *Corylus avellana* and *Ulmus* in north-eastern Poland at the end of

Table 2. Bałupiany – description of the local pollen assemblage zones (L PAZ's)

L PAZ	Depth [cm]	Description of pollen spectra	Top boundary description
Bał-1. *Juniperus*	312–303.5	Domination of *Juniperus* (max. 30.7%). High percentages of *Pinus sylvestris* type and *Salix* undiff. A maximum of *Betula nana* type (4.1%), *Artemisia* (9.8%), Poaceae undiff. (11.9%), *Selaginnella selaginoides* (3.3%), and Asteroideae undiff. (2.3%). The highest frequency of corroded sporomorphes. A distinct peak of Cyperaceae undiff. Very high values of Filicales monolete in the bottom part. Low pollen concentration: 17–48 sporomorphs/cm^3	A fall in *Juniperus* a rise in *Betula* undiff.
Bał-2. *Betula*	303.5–242.5	Domination of *Betula* undiff. and its maximum in the profile, a continuous curve of *Filipendula*	A decline of *Betula* undiff. curve
Bał-2a. *Betula* (NAP)	303.5–275	A rapid rise in *Betula* undiff. (max. 78.4%), a gradual increase in *Pinus sylvestris* type. A sharp rise and a fall in *Potentilla* type, a decrease in Cyperaceae undiff., Poaceae undiff., *Artemisia*, and *Selaginella selaginoides*. The highest values of *Equisetum* in the profile (9.8%) as well as of *Menyanhes trifoliata* (3.5%)	
Bał-2b. *Betula* (*Corylus*)	275–242.5	A continuous curve with fluctuations and the first maximum (24.5%) of *Corylus avellana* appears. The irregular occurrence of *Populus* with the maximum at the depth of 260 cm (10.5%), the beginning of the *Fraxinus excelsior* curve. Fluctuation and a maximum of Cyperaceae undiff. (47.5%). A rise and a fall in *Thelypteris palustris*	
Bał-3. *Corylus-Tilia-Ulmus*	242.5–175	A rapid fall in *Betula* undiff., an increase and fluctuation in *Pinus sylvestris* type (max. 74.5%). An increase and flucuation in *Corylus avellana* values (second maximum – 27%). Continuous curves of *Alnus* undiff., *Tilia cordata* type, *Ulmus*, *Quercus*, and *Picea abies* appear. A rise and fluctuation in Cyperaceae undiff. An abrupt rise in Filicales monolete (max. 71%) in the upper part of the zone. An increase in corroded sporomorphs. The highest concentration of pollen at the beginning of the zone: 1341.9×10^3 sporomorphs/cm^3	A decrease in *Corylus avellana*
Bał-4. *Alnus-Picea*	175–30	The highest values of *Alnus* undiff., *Picea abies*, *Carpinus betulus*	
Bał-4a. *Alnus-Picea* (*Alnus*)	175–75	A decline in *Pinus sylvestris* type and a subsequent rise in the upper part of the profile. A maximum of *Carpinus betulus* (6.4%). A rise and fluctuation of *Betula* undiff. A fall and a rise in *Alnus* undiff. which reach its maximum in the profile. The beginning of the continuous curve of *Fagus sylvatica*. After a rapid increase, an abrupt fall in Filicales monolete, a rise in *Sphagnum*	
Bał-4b. *Alnus-Picea* (*Quercus*)	75–30	After a maximum, *Picea abies* (18.5%) curve presents a decreasing trend, stable values of *Pinus sylvestris* type and *Betula* undiff. A slight rise in *Ulmus*, *Fraxinus excelsior*, *Tilia cordata* type, and *Quercus* (max. 11.5%). A gradual increase in *Corylus avellana*. Fluctuations and a distinct maximum of *Sphagnum* (51%)	

the Preboreal chronozone (Miotk-Szpiganowicz et al. 2004, Zachowicz et al. 2004, Kupryjanowicz & Jurochnik 2009), their presence in the surroundings of the mire cannot be confirmed on the basis of palynological data. In the open places and at the edges of the forest there may still have been juniper thickets, which gradually disappeared from this area. Willows (*Salix*) and birches overgrew depressions and sites with intermittent stagnant water, where, in the understorey, *Urtica* and *Solanum dulcamara* might have occurred. However, at the beginning of the Preboreal chronozone steppe communities still played an important role in this region, the principal taxa being Poaceae, Chenopodiaceae, *Artemisia*, and small amounts of *Rumex acetosa*/*acetosella*, *Helianthemum*, and *Silene*.

In the Preboreal chronozone a water body appeared in the area of the mire and was colonized by species of *Potamogeton* and *Pediastrum*. The shallow character of this pool (max. 2 m depth) may be confirmed by the occurrence of *Cristatella mucedo* (Økland & Økland 2000). In the vicinity of the new water body moderately rich fen with characteristic *Sphagnum teres* occurred, which is also confirmed by the domination of moss species such as *Mnium pseudotriquetrum*, *Aulacomnium palustre*, *Tomenthypnum nitens*, and *Straminergon stramineum* (Vitt & Wieder 2008). Additionally the presence of *Aulacomnium palustre* may indicate open, sun-exposed but constantly moist habitat (Proctor 2008). The main vascular plants that grew on the surface of the mire were *Menyanthes trifoliata*, *Epipactis palustris*, and *Carex* spp. In the belt of rushes *Phragmites australis*, *Typha latifolia*, *Hippuris vulgaris*, *Equisetum fluviatile*, and *Comarum palustre* (*Potentilla* type) grew. The abundant occurrence of *Carex rostrata* may indicate the presence of *Caricetum rostratae* communities, which are pioneers on the surface of gradually terrestrializing water bodies (see Matuszkiewicz 2005). The rise in the water table at the beginning of the Preboreal chronozone could have been a reaction to the rapid but relatively short climate deterioration called the Preboreal oscillation, which has been evidenced in e.g. the Skaliska Basin (about 9660±60 ^{14}C BP; Kołaczek et al. 2013, Mirosław-Grabowska 2013, Sienkiewicz 2013), Lake Miłkowskie (Wacnik 2009a, b) and Lake Hańcza (Lauterbach et al. 2011). On the other hand, the origin of the water body could have been the effect of a deepening of the basin by the final melting of dead ice block(s) and/or permafrost remains. Tall-herb communities with *Filipendula* and *Thalictrum* occupied the more eutrophic habitats on the mire. During the Preboreal chronozone *Betula nana* probably became extinct on the mire, as in the vicinity of Lake Czarne (Karpińska-Kołaczek 2011).

The water body probably became completely overgrown and ceased to exist in the older part of this chronozone.

Bał-2b *Corylus* LPASZ; Bał-3, Bał-4 MAZ, (under the depth of 245 cm), Boreal chronozone

In the open understorey of woodlands dominated by *Betula*, *Corylus avellana* expanded rapidly. This process was typical of north-eastern Poland in the Boreal chronozone and was simultaneous across the whole area (see Miotk-Szpiganowicz et al. 2004). A component of those forests, located on moist soils, was elm (*Ulmus*) which migrated from its stands in the region. These may have been located to the west in the Skaliska Basin where its presence was dated at 9258–8830 cal. BC (9660±60 yr ^{14}C BP, Kołaczek et al. 2013) and/or east where it appeared in the vicinity of Lake Linówek at ca 9120–8642 cal. yr BC (95.4%, 9510±60 ^{14}C yr BP, Gałka et al. in press). The herb layer in woodlands consisted of ferns and *Vaccinium* spp., while at the forest edges single *Juniperus communis* and *Sambucus ebulus* specimens might have grown. Damp places may have been occupied by a carr with *Salix* and *Populus* where an overgrowth of *Solanum dulcamara* and *Urtica* formed the groundcover. At that time open area communities lost their importance in the landscape. Their existence was marked by the presence of Poaceae, *Artemisia*, Chenopodiaceae, *Rumex acetosa*, and Apiaceae. Moist habitats were occupied by *Filipendula* (probably *F. ulmaria*).

The domination of *Sphagnum angustifolium* on the mire indicates a fall in trophy because this type of peat, known from an immense area of boreal zone peatlands, develops under ombrotrophic conditions (Obidowicz 1990). The presence of this species may also have indicated the presence of poor fen (Vitt & Wieder 2008). Representatives of *Caliergon* and *Drepanocladus* genera were co-occurring moss taxa. At the beginning there was also present *Menyanthes trifoliata* in great numbers, so this peat community may be compared to the west Siberian mesotrophic association *Menyanthes trifoliata* + *Carex limosa* + *Sphagnum angustifolium* (Liss & Bieriezina 1981). A further fall in trophy led to the spread of *Eriophorum vaginatum* on the mire surface. Moreover, the highest values of *Thelypteris palustris* combined with *Betula* sect. *Albae* fruits may signify the presence of subboreal birch woodland (*Betula pubescens-Thelypteris palustris*) which exists nowadays on poor fens (Matuszkiewicz 2005).

The time span of this subzone is unclear in the light of the radiocarbon date (9220±90 ^{14}C BP) which seems to classify it within the Preboreal chronozone. However, the first maximum of *Corylus avellana* and values of other taxa suggest that the layer originated in the Boreal chronozone.

Bał-3 *Corylus – Tilia – Ulmus* L PASZ; Bał-3 MAZ, (depth 245–175 cm), Atlantic chronozone

Pinus sylvestris with rare specimens of spruce (*Picea abies*) formed the main type of woodland where *Vaccinium* and *Empetrum nigrum* shrubs could find suitable conditions for growth. Hazel (*Corylus avellana*) became abundant in the understorey, in gaps and at the forest margins and its percentage values suggest that at the beginning it was the dominant species forming understorey and/or it formed homogenous thickets (e.g. Huntley & Birks 1983). Taxa traditionally related to the

Table 3. Bałupiany – description of the local macrofossil assemblage zones (L MAZs)

L MAZ	Depth [cm]	Description of L MAZ
Bał-1	320–300	Among trees *Betula* sect. *Albae* and *Pinus sylvestris* dominate. Additionally *Betula nana* was determined. Vegetation of wet habitats is represented by *Selaginella selaginoides* and *Lychnis flos-cuculi*. Mire taxa such as *Eriophorum vaginatum*, *Vaccinium uliginosum*, and *Carex* sp. trigonous were also found. The presence of *Cenococcum geophilum* was detected as numerous sporocarps
Bał-2	290–280	Macrofossils of *Betula* sect. *Albae* are the most numerous within tree taxa; *Pinus sylvestris* and *Betula nana* were also found. More numerous are remains of mire taxa: *Menyanthes trifoliata*, *Comarum palustre*, *Carex rostrata*, and *Carex* sp.2- and 3-sided in relation to the Bał-1 L MAZ. Limnophytes are represented by *Hippuris vulgaris* and *Potamogeton natans*
Bał-3	290–250	The last occurrences of the macrofossils of water plants determine the boundary of the zone. *Betula* sect. *Albae* and *Pinus sylvestris* were the dominant tree taxa. *Equisetum* sp. was also recorded. In the group of mire taxa *Carex rostrata*, *Menyanthes trifoliata*, *Comarum palustre*, *Eriophorum vaginatum*, *Carex* sp.2- and 3-sided, and *Sphagnum* mosses dominate
Bał-4	250–140	The number of *Betula* sect. *Albae* macrofossils rapidly decline. *Pinus sylvestris*, *Carpinus betulus*, *Alnus glutinosa*, and *Rubus idaeus* are present. *Urtica dioica*, *Equisetum* sp., *Solanum dulcamara*, and *Rumex maritimus* were also identified. Mire taxa are represented mainly by *Carex pseudocyperus*, *C. rostrata*, *C. lasiocarpa*, *C. elongata*, *C.* cf. *punctata*, *Carex* sp. biconvex and trigonous, and *Sphagnum* mosses. *Menyanthes trifoliata*, *Comarum palustre*, and *Eriophorum vaginatum* also occur. Scars are abundant. *Cenococcum geophilum* appears more abundantly
Bał-5	100–60	*Betula* sect. *Albae*, *Pinus sylvestris*, *Salix* sp., and *Picea abies* were identified among trees. *Equisetum* sp. and *Sonchus arvensis* were present. Mire vegetation is represented by *Ledum palustre*, *Carex rostrata*, *C. lasiocarpa*, *Carex* sp.2- sided and 3-sided, and *Sphagnum* mosses. *Comarum palustre* and *Eriophorum vaginatum* occur as well
Bał-6	60–30	Macrofossils of *Betula* sect. *Albae* increase in frequency, whilst *Pinus sylvestris* appears again. There is also a rise in the number of mire taxa occurrences, especially *Menyanthes trifoliata*, *Comarum palustre*, and *Carex lasiocarpa*. *Eriophorum vaginatum* and *Sphagnum* mosses were also determined. *Sparganium minimum* and *Cenococcum geophilum* appear

climatic optimum such as *Ulmus*, *Tilia*, and *Quercus* spread in surrounding forests due to favourable climatic and edaphic conditions, so deciduous mixed forests successively became more important communities in the landscape. These processes meant that light-demanding birch was out-competed and retreated from woodlands. Macroremains prove that single specimens of *Carpinus betulus* were present in the vicinity of the mire, despite the lack of any pollen signal. Climate improvement is demonstrated by the appearance of *Viscum*, which indicates that the mean temperature of July must have been higher than 15.8°C (Iversen 1944). In the understorey of these deciduous forests *Viburnum opulus* and *Frangula alnus* grew. The composition of the neighbouring carr gradually changed as the migration of *Alnus* and *Fraxinus excelsior* occurred and a riparian forest developed where *Urtica* and *Solanum dulcamara* might have grown. The first probable presence of peoples of Mesolithic or Early Neolithic cultures was marked in this zone at a depth of 180 cm, where there were macroscopic charcoal particles, which together with *Cenoccocum geophilum* may indicate intentional fire clearance and subsequent soil erosion (Wick et al. 2003, Tinner et al. 2008). Additionally peaks of bracken (*Pteridium aquilinum*) in the zone may signify the expansion of this fern in the fire clearings (see Page 1986, Oberdorfer 1990). Patches of open habitats began to spread in the area and *Artemisia*, *Rumex acetosa*, *R. acetosella* grew there as well as members of Poaceae, Apiaceae, Asteraceae, and Rosaceae. In damp places, along streams communities with *Filipendula*, *Thalictrum*, and *Rumex maritimus* prevailed instead.

Sedges dominated the vegetation of the mire whose basic environmental resources underwent constant changes. The probable association that spread during the Atlantic period was similar to modern *Caricetum lasiocarpae* (abundance of *Carex lasiocarpa* fruits in deposits). Other plants that coexisted on the mire were *Carex rostrata*, *C. pseudocyperus*, *Eriophorum vaginatum*, *Menyanthes trifoliata*, *Comarum palustre*, *Equisetum*, and *Thelypteris palustris*. During this period, patches of birch woodlands occurring on the mire retreated visibly.

Bał-4a *Alnus* L PASZ; Bał-4 MAZ, Bał-5 MAZ, until 85 cm, Subboreal chronozone

Tilia cordata and *Ulmus* gradually retreated from multispecies deciduous woodlands, and on fertile and moist soils *Quercus* expanded instead. Nevertheless, lime (*Tilia cordata*) probably re-expanded in this chronozone before the final retreat. A similar pattern was observed in the Budzewo site in the Skaliska Basin to the west, where the beginning of the Subboreal chronozone was marked by an untypical rise in thermophilous taxa (Kołaczek et al. 2013). The beginning of the late Holocene did not bring the rapid elm decline noticed in several profiles from Poland and other countries of Europe (e.g. Zachowicz et al. 2004, Wacnik 2009a). A similar situation was also observed in the Skaliska Basin (Kołaczek et al. 2013) and in Lake Czarne (Karpińska-Kołaczek 2011), where the fall in *Ulmus* percentages failed to mark the end of the Atlantic chronozone. In both cases this phenomenon was explained by low human impact. Moreover, the density of forest communities led to the spread of taxa generally tolerant of low light conditions, such as *Picea abies*, *Carpinus betulus*, and *Fagus sylvatica*. It is worth pointing out that nowadays beech (*Fagus sylvatica*) does not grow in the region, but its values reached 0.5% then, suggesting the probable presence of its first stands at that time (Woods & Davis 1989). A distinct beginning of the spruce expansion (rise in percentages up to 10%) was dated in southern sites at 2471–2153 cal. yr BC (95.4%, 3860±50 ^{14}C yr BP) in Lake Linówek (Gałka et al. in press) and ca 2350 cal. yr BC in Lake Hańcza (Lauterbach et al. 2011). Insufficient amounts of sunlight also led to the withdrawal of *Corylus avellana* from the understorey of most woodlands, but in slightly open ones hazel, together with *Rubus idaeus* (*Sorbus* group) and *Viburnum opulus*, was probably still present. The herb layer in these forests was quite well developed and contained fern species, Polypodiaceae, and *Sambucus ebulus*, as well as *Melampyrum* and *Calluna* at forestedges. An interesting phenomenon similar to that in the Skaliska Basin is that *Carpinus betulus* maxima correlate with declines in *Picea abies* (Kołaczek et al. 2013). The late Holocene spread of hornbeam (*Carpinus betulus*) there might have been caused by humans leaving deforested areas which were favourably colonized by relatively fast growing hornbeam (see Ralska-Jasiewiczowa & van Geel 1998). Moreover, the presence of ribwort plantain (*Plantago lanceolata*) and sorrel (*Rumex acetosa*), considered as minor ruderals (Poska et al. 2004), coincident with the hornbeam suggests a human role in this phenomenon. Additionally simultaneous with the percentage rise in *Carpinus betulus* (at a depth of 90–100 cm) seeds of *Sonchus arvensis* were found, a weed which nowadays infests all types of crops, and also occurs in fallows, vegetable and fruit gardens (Matuszkiewicz 2005). On the other hand, the occurrence of the highest values of Cerealia type accompanied the spruce maximum. This may point to factors other than anthropogenic also causing the phenomenon of the spread of hornbeam. Those events took place before 1378–1119 cal. yr BC, so they may be traces of the peoples of the Bronze Age. The aforementioned processes were not the first to point to human agricultural activity. The occurrence of cornflower (*Centaurea cyanus*) together with a grain of Cerealia type in the older part of the Subboreal chronozone revealed the presence of cultivated fields in the landscape. The first appearance of this species in the Miłki site was dated at 600–50 cal. yr AD and was correlated to the Migration Period (Madeja et al. 2010). Open areas, more common in the landscape, were occupied by grasslands (pastures and/or meadows) with Poaceae, *Trifolium repens*, and *Carduus*. *Symphytum*, *Epilobium*, *Valeriana*, *Filipendula*, and *Thalictrum* overgrowing wetter habitats.

In damp and periodically inundated places *Alnus* became a most important component of woodlands achieving its maximum of occurrence. Additionally, patches of *Salix* thickets probably overgrew those niches. *Solanum dulcamara* and *Urtica* formed the groundcover of these communities as well as the presence of less damp riparian forest with *Fraxinus excelsior* and *Ulmus*. Although weakly reflected by macrofossils, the evidence of pollen and tissue analysis (Betuleti peat) showed the presence of patches of tree birches on the mire, which together with *Thelypteris palustris* may have built a community similar to subboreal birch forest *Vaccinio uliginosi-Betuletum pubescentis* (Matuszkiewicz 2005) as in the Boreal chronozone. Regularly appearing members of *Spahagnum* sect. *Subsecunda*, *S.* sect. *Cuspidata*, and *S.* sect. *Palustria* may reflect the presence of a moderately rich to poor fen, on which Minero-Sphagnioni peat was deposited. Other important peat-forming taxa were *Menyanthes trifoliata* and *Carex* spp., additional components being *Comarum palustre* and *Equisetum fluviatile*. A rise in human impact together with the first hornbeam maximum coincided with the transformation of peat into Carici-Bryaleti in which the main species was *Meesia triquetra*. This taxon may signify a rise in trophy on the mire (see Vitt & Wieder 2008). During this episode *Sphagnum magellanicum* appeared and afterwards replaced *Meesia* (at a depth of 90 cm) and formed peat with *Eriophorum vaginatum*. *Sphagnum magellanicum* has an ecological scale from peat bog to poor fen (Vitt & Wieder 2008) so its expansion was probably connected with oligotrophication of fen. These processes were triggered by the development of pine forests with spruce which caused an increase in the acidification of soils stimulating a fall in trophy in the mire. A rise in *Vaccinium*, *Erica*, and Ericaceae undiff. percentages seems to confirm this scenario. The interesting fact is that a second wave of hornbeam expansion failed to reflect changes in the mire's composition.

Bał-4b *Quercus – Picea* L PASZ; Bał-5 above 75 cm and **Bał-6 MAZ**, Younger part of the Subboreal chronozone and Subatlantic chronozone

At the beginning of this period, *Carpinus betulus* began to retreat and *Picea abies* achieved the maximum of its occurrence in forests. Spruce, as in the Skaliska Basin (Kołaczek et al. 2013) and Lake Czarne (Karpińska-Kołaczek 2011), showed a pattern of expansion with two maxima (the first was in the Bał-4a subzone). Lime again started to spread in mixed deciduous forests where *Fagus sylvatica* and *Acer* probably grew as individual trees. Expanding *Corylus avellana* together with *Quercus*, which became more common, could have formed patches of shrub-forest communities similar to the *Quercion roboripetraeae* alliance (Ralska-Jasiewiczowa et al. 2003). In drier places, *Quercus* might have also occurred in forests with *Pinus sylvestris*. Forests that belong to the association *Potentillo albae-Quercetum* Libb. 1933 exist nowadays on the southern slopes of morainic hills in the region (Matuszkiewicz 2001). *Rhamnus catharicus* might have occupied some parts of those hills. In forests at lower wetland sites *Alnus* still dominated, but riparian forest with *Ulmus* and *Fraxinus excelsior* also started to expand. The spread of deciduous taxa during this period is a unique phenomenon in the area of north-eastern Poland, and is difficult to explain.

Initially the important role of spruce in acidifying woodlands might have led to the development of mesotrophic poor fens or peat bogs with the domination of *Sphagnum magellanicum* and *Eriophorum vaginatum*. The gradual retreat of spruce induced a decrease in acidification, which limited the occurrence of *Eriophorum vaginatum* at first and induced a subsequent reduction in the role of *Sphagnum* spp. in peat deposition. The area of mire was re-expanded by birch that together with pine started forming Betuleti-Pineti peat in the uppermost layer. Important taxa occupying the fen were also *Menyanthes trifoliata*, *Comarum palustre*, *Phragmites australis*, and *Thelypteris palustris*. Abundant finds of *Carex lasiocarpa* epicarps may point to the existence of a pool(s) which might have been the habitat of *Sparganium minimum*. Human activity detected in the uppermost part of the profile, even if it was poorly recorded in pollen spectra, may have caused the heavier erosion which is reflected in the presence of *Cenococcum geophillum*.

FINAL REMARKS

In the light of the results of palaeobotanical investigation of the profile from Bałupiany the following conclusions can be drawn:

1. Despite the length of the profile, it probably spans the period from at least ca 9600 to 1200 cal. yr BC. However, a 40 cm long sediment gap makes a complete reconstruction of vegetation changes difficult. *Juniperus* thickets dominated the initial plant communities of the Younger Dryas. The beginning of the Preboreal chronozone is marked by the expansion of pioneer birch forest with an admixture of pine. In the declining phase of the Boreal chronozone, *Corylus avellana* expanded rapidly and reached its maximum in the subsequent Atlantic chronozone, which was characterized by a considerable retreat of birch forest. During that time the development of multispecies deciduous woodlands took place, within which *Tilia cordata* and *Quercus* played an important role, while *Ulmus* and *Alnus* occupied damp habitats. During the Atlantic chronozone, pine reached its maximum. Macroscopic

remains confirmed the presence of *Carpinus betulus* in the Atlantic chronozone, despite the lack of evidence in the pollen record. The beginning of the Subboreal chronozone brought the expansion of *Carpinus betulus* and *Picea abies*; the latter also limited the area occupied by deciduous woodlands. Both taxa showed antagonistic optima and spruce presents a pattern with two distinct maxima. In the younger part of the Subboreal chronozone a spread of deciduous forest took place which was a unique pattern for this part of the Holocene in north-eastern Poland. It might be that low human impact at that time, as well as local edaphic conditions, stimulated these processes.

2. Human impact, as mentioned above, was insignificant near the site. The first traces of human activity could have been fires recorded in the Atlantic chronozone, which were probably caused by Mesolithic or Early Neolithic peoples. The first evidence of cultivation can be dated back to the Bronze Age, but unfortunately the low resolution of radiocarbon dating does not allow assigning this event to a specific culture.

3. The analysis of plant tissues and macrofossils pointed to the existence of moderately rich fen in which the temporary existence of a small water body was recorded in the Preboreal chronozone. Two episodes of the mire oligotrophication took place during the Boreal and Subboreal chronozones. In the second case, a fall in trophy was triggered by spruce expansion. A rise in human impact, during the first *Carpinus betulus* maximum, caused eutrophication of the poor fen.

4. AMS radiocarbon dates showed inversion and only two of them were included to the reconstruction of chronology. In general they failed to provide answers to questions about the time and duration of the most important palaeoecological events recorded in the peat sequence.

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