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# The vegetation changes recorded in sediments of Kładkowe Bagno peat bog in Puszcza Knyszyńska Forest, north-eastern Poland*

MIROSŁAWA KUPRYJANOWICZ

Department of Botany, Institute of Biology, University of Białystok, 15-950 Białystok, Świerkowa 20b, Poland;
e-mail: kuprbot@uwb.edu.pl

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ABSTRACT. Material for the palynological study comes from the Kładkowe Bagno peat bog in the north-eastern part of the Puszcza Knyszyńska Forest (Białystok Upland, north-eastern Poland). Nine local pollen assemblage zones (L PAZ) have been distinguished in the pollen diagram produced from this site. The results were used to reconstruct the succession of vegetation during the Late Glacial form the Vistulian and Holocene. It is shown in different aspects: (1) as changes in the surroundings of the studied site, (2) as changes caused by human activity and (3) as changes in a water level and mire plant communities.

KEY WORDS: pollen analysis, pollen assemblage zones, human impact, Late Glacial, Holocene, Puszcza Knyszyńska Forest, Białystok Upland, Poland

## INTRODUCTION

Since 1999, palaeobotanical investigations for reconstruction of the late Glacial and Holocene succession of the local peat bog vegetation in various hydrological conditions have been made in the Puszcza Knyszyńska Forest in north-eastern Poland (Drzymulska 2001, 2003). The main study, based on analyses of macroscopic plant remains and of botanical composition of peat, has been prepared by Drzymulska (2001, 2003). It is complementary to pollen analysis of selected investigated profiles, of which main goal has been the description of vegetation changes in the studied peat bogs and their vicinity.

Pollen analysis results from the first of the examined profiles – KBVII profile from the Kładkowe Bagno peat bog – are presented in this paper. Preliminary palynological study of this profile was the subject of a Master of Science Thesis (Brzostowska 2001). In 2002 its results were included to a scientific project "Late Glacial and Holocene history of vegetation in Poland based on isopollen maps" (Ralska-Jasiewiczowa et al. 2004). Obtained pollen data suggested that this pollen profile, in the contrast to other profiles from the Puszcza Knyszyńska Forest (Kupryjanowicz 1991, 1995, 2000), may present the full record of Holocene vegetation history and, after the precise analysis and $^{14}C$ dating, it will become the stratotype profile for this part of Poland.

## SHORT CHARACTERISTIC OF THE PRESENT-DAY NATURAL ENVIRONMENT OF THE PUSZCZA KNYSZYŃSKA FOREST

According to the regional division of Poland made for palaeobotanical studies, the Puszcza Knyszyńska Forest belongs to the Białystok Upland and the Biebrza Basin region (P-o),

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which is the part of the larger unit – the Mazovia-Podlasie Lowlands (Ralska-Jasiewiczowa 1989a). In the physical-geographical division it is assigned to two mezoregions – a larger region comprising the Białystok Upland and a smaller region north-eastern fragment to Sokólskie Hills – that are the parts of the North-Podlasie Lowland (Kondracki 1994). This macroregion is an old-glacial area located in an immediate neighbourhood of the Vistula glaciation (e.g. Marks 2002). The glacial relief of the area was modelled by the Warta glaciation (Musiał 1992).

The Puszcza Knyszyńska Forest is one of the coldest regions of Poland (Chrzanowski 1991). The mean annual temperature is relatively low, +7°C. The difference between mean temperature of coldest and warmest month is very high, 22°C, and indicates continental character of climate of this part of Poland. The mean annual precipitation oscillates around 610 mm. Snow covers the ground for 85–90 days and its maximum thickness fluctuates from 8 to 80 cm. The growing season is short, begins in the first half of April and lasts about 200 days (Sasinowski 1995). There is a prevalence of westerly (27.9%) and southerly (26.3%) winds (Górniak 2000).

The soils of Puszcza Knyszyńska Forest are generally rather poor. Large areas are covered with loose, slightly clayey podzols formed in sand (Czerwiński 1995).

Forests cover about 70% of the area of Puszcza Knyszyńska Forest. Their characteristic feature is the presence of numerous species and communities with a northern range type. *Pinus sylvestris* is the dominant tree (71.4%). The very important component is *Picea abies* (13.3%), growing in all forest associations.

## PREHISTORIC HUMAN SETTLEMENT IN THE PUSZCZA KNYSZYŃSKA FOREST

The archaeological information on the prehistoric settlement development in the Puszcza Knyszyńska Forest is very poor (Sałaciński & Zalewski 1995). This area has never been systematically explored and data come chiefly from surface investigations undertaken by the Archaeological Surface Survey of Poland (ASS; in Polish: Archeologiczne Zdjęcie Polski – AZP). They are very unsuccessful in this region which is mostly covered by dense woodland.

Due to favourable natural conditions, the area of the Puszcza Knyszyńska Forest was probably penetrated or periodically inhabited by man from the earliest prehistory. Archaeological data on the oldest settlement are very scarce and concern very few localities of the Late Palaeolithic age (ASS data). The main part of them is connected with the Świder culture.

During the Mesolithic the Puszcza Knyszyńska Forest area, similarly to the whole central and eastern Poland, was under the influence of the Janisławice culture (Godłowski & Kozłowski 1983, Kozłowski 1989). Its presence at the Supraśl river is documented by detached findings at three sites (ASS data). They are located, similarly to all other Mesolithic localities, in rather dry and fairly high areas, mainly at the kame hills (Ryżyk 1986).

The Neolithic settlement was associated chiefly with the Neman culture (ASS data), which is connected with a circle of para-Neolithic forest cultures (Kempisty 1989). It was characterized by the dominance of adopting economy and a considerable role for hunting, fishing and collecting. At the beginning of the Neolithic areas of Puszcza Knyszyńska Forest were also under the influence of the eastern group of the Funnel Beaker culture and later of the Globular Amphorae culture (ASS data). In the Late Neolithic the Corded Ware culture developed and gradually replaced previous cultures (Godłowski & Kozłowski 1983). It is very probably that in the same time flint deposits were exploited at the lower Sokołda in the north-western part of the Puszcza Knyszyńska Forest (Sałaciński & Zalewski 1995).

The main phase of the prehistoric settlement in the region of the Puszcza Knyszyńska Forest was placed on the early Bronze Age (ASS data). Settlement of this period was firstly connected with the Trzciniec culture (Gardawski 1959, Zalewski 1991, Dąbrowski 1997), which appeared in north-eastern Poland in the second half of the 1st period of the Bronze Age. Simultaneously the Neman culture still remained (Kempisty 1989). Such coexistence of post-Neolithic cultures and the Trzciniec culture was characteristic for the first two and even three periods of the Bronze Age though the whole north-east of Poland (Dąbrowski 1997).

The early Bronze Age was probably turning stage of the settlement development in the region of Puszcza Knyszyńska Forest. Then clear stagnation of settlement took place. Unfortunately, its reasons are not known (Miśkiewicz 1978).

At the late Bronze Age the separate culture unit from the Masovian circle of the Lusatian culture was formed in the region between Bug and Narew (Dąbrowski 1997). It is defined as the Suraż group. Its traces were discovered at only three sites in Puszcza Knyszyńska Forest (ASS data). Process of disappearance of this culture finished about 620 years BC, at the Hallstatt C to Hallstatt D transition (Dąbrowski 1997).

During the late Bronze Age a development of flint exploitation has succeeded in the Puszcza Knyszyńska Forest. Its scale considerably surpassed the necessity of human groups inhabiting this region. The remains of flint mines from before 3000 years were discovered near the village of Rybniki (Sałaciński & Zalewski 1995).

Very few sites represent the Iron Age settlement in the Puszcza Knyszyńska Forest (ASS data). One of them is defined as Hallstatt and other as Roman Period. According to archaeologists this was probably the time of the so-called settlement emptiness, which remained till early middle Ages (Sałaciński & Zalewski 1995).

## SITE DESCRIPTION

The Kładkowe Bagno peat bog is located in the north-eastern part of the Puszcza Knyszyńska Forest. It is 40 ha in area and consists of two depressions (Fig. 1). The deeper depression in the southern part (ca. 5 m depth) is separated from the shallower one in the northern part (ca. 2.5 m depth) by a distinct shallow of 0.3 m (Drzymulska, personal information). Both depressions originated as melt forms. Their genesis is connected with the end of the Warta glaciation (Musiał 1992).

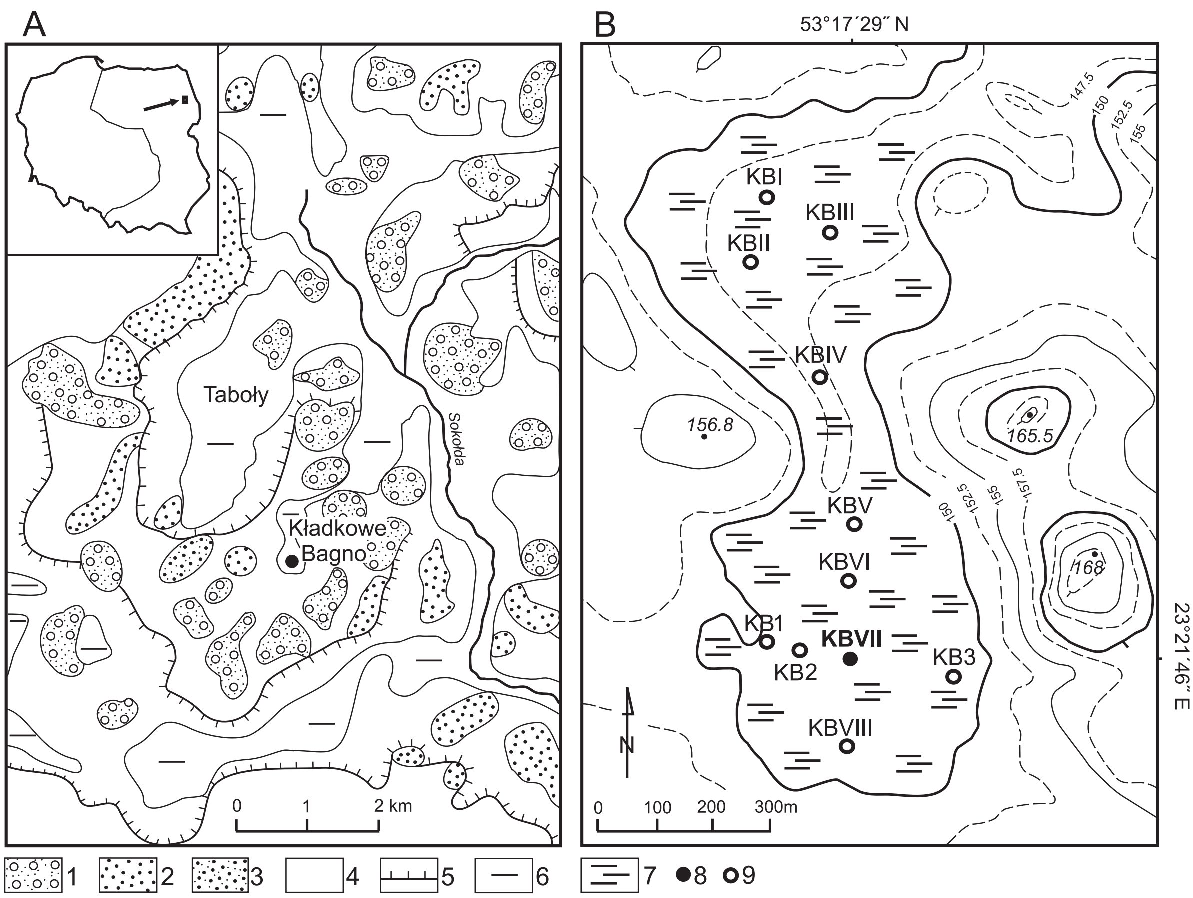


**Fig. 1**. Maps of the Kładkowe Bagno surroundings. **A** – Surface relief (according to Musiał 1992): **1** – kame hills, **2** – kame ridges, **3** – glaciofluvial-ablational ridges, **4** – ground moraine, **5** – melt holes, **6** – melt depressions. **B** – Topography: **7** – peat, **8** – location of the profile investigated using pollen analysis, **9** – locations of profiles investigated using other palaeobotanical analyses

The peat bog Kładkowe Bagno is preserved in its natural form as it has not meliorated and peat-mining has not previously been carried out. Vegetation which covered the Kładkowe Bagno peat bog is very homogeneous. *Pinus sylvestris* and *Betula pubescens* grow on the whole area of peat bog and forms only one plant association, *Vaccinio uliginosi-Pinetum*. In the undergrowth layer of the forest *Eriophorum vaginatum*, *Vaccinium uliginosum*, *Oxycoccus quadripetalus*, and *Ledum palustre* are predominants. *Andromeda polifolia*, *Vaccinium myrtillus*, and *V. vitis-idaea* are present in smaller amounts. *Sphagnum magellanicum* and *Polytrichum strictum* are the most common Bryales.

The edge of the peat bog is minerogenic (Fig. 1). Soils surrounding the site are poor, formed mostly in sands or clayey sands and in tills. They are overgrown by *Myceli-Piceetum*, *Querco-Piceetum*, *Serratulo-Piceetum*, *Tilio-Carpinetum*, and *Meliti-Carpinetum* (Czerwiński 1995 – map of forest ecosystems in Puszcza Knyszyńska Forest). In about 400 m distance from the north-western boundary of the Kładkowe Bagno the large peat bog Toboły (other name: Wały) is situated. It is overgrown by *Carici chordorrhizae-Pinetum*, *Sphagno-Piceetum*, *Thelypteri-Betuletum*, and *Carici elongatae-Alnetum*.

## MATERIAL AND METHODS

A series of eleven borings were performed along the shorter and longer axis of the peat bog in 1999–2002 years (Drzymulska 2001, 2003). The KBVII core for pollen analysis was taken from the deepest place (53°17′29″ N, 23°21′46″ E) – 200 m away from the southern edge of the peat bog and 230 m from its eastern edge (Fig. 1). The nearest trees were located in about 5 m distance from the drilling place.

A 5 metre core of deposits was collected with a 5 cm diameter Russian sampler. The sediments were briefly described in the field and in more detail way in the laboratory, using Troels-Smith's system (Troels-Smith 1955). From the 11 obtained segments about 200 samples (1 $cm^3$ in volume) were taken for pollen analysis. The sampling intervals were 2.5, 5 or 10 cm. A total of 107 samples have been studied.

Pollen samples were prepared using the Erdtman's acetolysis method (Erdtman 1943). The samples containing mineral material were pre-treated with hydrofluoric acid (Moore et al. 1991).

Pollen sums from over 500 to over 2000 (most often about 1000) pollen grains per sample were counted. Samples which previously were analysed by Brzostowska (2001) and in which those sums were lower, are now added.

Some non-pollen microfossils, important for palaeoecological reconstructions, were determined and counted during pollen analysis: Nymphaeaceae idioblasts (127 type, Pals et al. 1980), algae (*Botryococcus braunii*, *Pediastrum* ssp. – Jankovská & Komárek 2000, *Tetraedron* cf. *minimum* -371 type, van Geel et al. 1981), fungi (*Tilletia sphagni* -27 type, van Geel 1978) and Rhizopods (*Amphitrema flavum* -31A type, van Geel 1978).

The content of microscopic charcoal fragments in the sediment was determined in each sample by means of 3-grade scale, taking into account the degree to which the surface of microscopic slide has been covered.

The obtained results were presented as pollen diagrams, constructed in accordance with recommendations made by Berglund and Ralska-Jasiewiczowa (1986). The percentage values were calculated on the basis of the total sum including trees and shrubs (AP) and herbs (NAP), and excluding pollen of aquatic and mire plants, spores and no-pollen remains. The diagrams were drawn using the POLPAL programme (Walanus & Nalepka 1999).

Seven samples were chosen for $^{14}C$ dating by accelerator method and dated at Poznań Radiocarbon Laboratory (Tab. 1).

**Table 1**. Kładkowe Bagno. Results of $^{14}C$ dates from samples collected in the KBVII profile. All dates given are in uncalibrated radiocarbon years BP

| No. | Sediment type | Depth (m) | Age BP | Remarks |
|---|---|---|---|---|
| 1 | *Eriophorum-Sphagnum* peat | 0.70 | 575 ± 25 | |
| 2 | *Eriophorum-Sphagnum* peat | 1.35 | 2190 ± 30<br>2240 ± 40 | |
| 3 | *Eriophorum-Sphagnum* peat | 2.10 | 1815 ± 30 | date is unreliable |
| 4 | *Eriophorum-Sphagnum* peat | 2.95 | 8340 ± 50 | date is unreliable |
| 5 | Moss-sedge peat | 3.95 | 8110 ± 40 | |
| 6 | Fine detritus gyttja | 4.45 | 9750 ± 40 | date is inexact |
| 7 | Detritus-sandy gyttja | 4.85 | 10 460 ± 40 | |

SEDIMENT DESCRIPTION

Depth (m)

- 0–0.50 light brown *Sphagnum* peat with small admixture of Ericaceae roots; Tb$^{1}$(Sphag.)4, Tl$^{1}$(Ericac)+++, Gs++, nig2, elas1, strf0, sicc3, humo1 (H$_{3}$);
- 0.50–3.00 brown *Eriophorum-Sphagnum* peat with small admixture of Ericaceae roots and *Pinus* bark; Th$^{2-3}$(Erioph)2-3, Tb$^{2-3}$(Sphag.)1-2, Tl$^{2-3}$(Ericac)+++, Dl$^{2}$(*Pinus*)++, Gs+, nig3, elas1, strf0, sicc3, humo2-3 (H$_{5-8}$), lim. sup. 0;
- 3.00–3.37 brown *Sphagnum*-Ericaceae peat with small admixture of *Eriophorum*; Tb$^{2}$(Sphag.)2-3, Tl$^{2}$(Ericac)1-2, Th$^{2}$(Erioph)+++, Gs+, nig3, elas1, strf0, sicc3, humo2 (H$_{5}$), lim. sup. 0;
- 3.37–3.60 brown *Sphagnum-Eriophorum* peat with admixture of Ericaceae, Bryales and *Carex*; Tb$^{2}$(Sphag.)3, Th$^{2}$(Erioph)1, Tl$^{2}$(Ericac)+++, Th$^{2}$(radic.)+, Tb$^{2}$(hypn.)+, Gs+, nig3, elas1, strf0, sicc3, humo2 (H$_{5}$), lim. sup. 0;
- 3.60–4.00 light brown moss-sedge peat with small admixture of *Sphagnum* peat and *Pinus* bark; Tb$^{1-2}$(hypn.)2-3, Th$^{1-2}$(radic.)1-2, Tb$^{1-2}$(Sphag.)++, Dl$^{1}$(*Pinus*)+, Gs+, nig3, elas1, strf0, sicc3, humo1-2 (H$_{4-5}$), lim. sup. 0;
- 4.00–4.50 brown fine detritus gyttja with sand; Ld$^{1}$3-4, Ga&Gs1, As&Ag1, nig3, elas1-2, strf0, sicc3, lim. Sup. 1;
- 4.50–4.90 grey-brown detritus-calcareous gyttja with sand, clay and silt; Ld$^{1}$1-2, Ga&Gs1-2, Lc1-2, As&Ag1, nig3, elas1-2, strf0, sicc3, lim. sup. 1;
- 4.90–5.05 dark brown *Eriophorum-Sphagnum* peat with small admixture of Bryales, sand, silt and clay; Th$^{1}$(Erioph)3, Tb$^{1}$(Sphag.)1, Tb$^{1-2}$(hypn.)+, Ga&Gs+, As&Ag+, nig3, elas2, strf0, sicc3, humo1 (H$_{3}$), lim. sup. 1;
- 5.05–5.10 dark brown sand with humus, silt and clay; Ga&Gs3, Sh1, As&Ag+++, nig3, elas0, strf0, sicc2, lim. sup. 0.

## VEGETATION HISTORY

### LOCAL POLLEN ASSEMBLAGE ZONES

Nine local pollen assemblage zones (L PAZ) and eight subzones (L PASZ) were distinguished in the main pollen diagram (Fig. 2). Their short descriptions are presented in Table 2.

Seven sections of the KBVII core, in which the most important changes in local vegetation are recorded, were dated by the accelerator method (Drzymulska 2004). Results of this research are shown in Table 1. Unfortunately, some obtained $^{14}$C dates do not correspond either to the pollen record nor to the $^{14}$C data for similar changes recorded in profiles from other sites in eastern and northern Poland. On the one hand this may be effect of the drilling method – Russian samplers often pull sediments off upper layers of peat in the process of sample extraction. On the other hand this may be result from the dating of deposit samples, and non single remains of *Sphagnum*. Radiocarbon data for samples of peat with admixture of *Pinus* bark may be "rejuvenated" by deep penetration of pine roots, whereas for samples of peat with *Eriophorum* they may be "made to look older than it is" by sediments disturbance owing to upwards overgrowth of cotton-grass shoots. For this reason the age of local pollen assemblage zones distinguished in the Kładkowe Bagno peat bog have been determined on the basis of both the $^{14}$C dating and correlation of these zones with analogue zones in other profiles from this part of country (Fig. 3).

## DEVELOPMENT OF VEGETATION IN THE KŁADKOWE BAGNO SURROUNDINGS

Pollen records shows that the general scheme of the Late Glacial and Holocene development of vegetation in the region of the Kładkowe Bagno peat bog is very similar to that described for other sites both from the Puszcza Knyszyńska Forest (Kupryjanowicz 1991, 1995, 2000) and from whole of north-eastern Poland (e.g. Ralska-Jasiewiczowa 1989b, Wacnik 2003). Therefore description of vegetation changes will be briefly presented with regard to their specific features only.

### KBVII-1 *Artemisia-Juniperus-Betula nana* L PAZ

The oldest stage of vegetation development corresponds to the Younger Dryas. High proportion of NAP, especially of *Artemisia* and Chenopodiaceae, provides evidence for the occurrence of open plant communities and a cold continental climate. Loose patches of steppe-like vegetation with *Artemisia*, Chenopodiaceae, *Helianthemum nummularium*, *Armeria maritima* and *Jasione*, and shrub vegetation with *Juniperus* dominated in dry and sandy habitats. *Betula nana* accompanied by different *Salix* species and numerous herbs such as *Thalictrum*, *Filipendula*, *Botrychium*, *Selaginella selaginoides*, *Sanguisorba officinalis* and, probably, *Polygonum persicaria* occupied lower and more humid places.

Subzone KBVII-1a *Juniperus*-Cyperaceae

**Table 2**. Kładkowe Bagno. Description of local pollen assemblage zones and subzones distinguished in the pollen diagram from the KBVII profile

| Symbol | Name | Depth (m) | Main features of pollen spectra | Top boundary description |
|---|---|---|---|---|
| KBVII-1 | *Artemisia-Juniperus-Betula nana* | 5.10–4.45 | Very high proportions of NAP (mean 20%, max. 25%), mainly *Artemisia*, Cyperaceae, Gramineae undiff., Chenopodiaceae, *Anthemis* type, and *Polygonum persicaria* type; high frequency of shrubs (ca. 5%), chiefly *Juniperus*, *Betula nana* type, and *Salix* | Decrease of NAP and shrubs; rapid rise of *Pinus sylvestris* type |
| KBVII-1a | *Juniperus*-Cyperaceae | 5.10–4.85 | Maximal percentages of *Juniperus* (4%) and Cyperaceae (11%); low frequency of *Betula alba* type (below 20%) | |
| KBVII-1b | *Betula-Artemisia* | 4.80–4.45 | Maximum of *Artemisia* (10%); gradual rise of *Betula alba* type curve (to ca. 30%) | |
| KBVII-2 | *Pinus-Betula-Ulmus* | 4.40–4.30 | First culmination of *Pinus sylvestris* type (64%); maximum of *Betula alba* type (34%); relatively high values of *Ulmus* (mean %); continuous curve of *Corylus avellana* | Increase of *Corylus avellana* and *Ulmus*; beginning of *Alnus* and *Quercus* continuous curves |
| KBVII-3 | *Pinus-Corylus-Ulmus* | 4.25–4.00 | Increase of *Corylus avellana* curve to 10%; *Ulmus* values slightly higher that previously (mean %); slow rise of *Alnus* proportion to 2%; low curve *Betula alba* type (ca. 20%) | Increase of *Alnus* |
| KBVII-4 | *Pinus-Corylus-Ulmus-Alnus* | 3.95–3.60 | Culminations of *Corylus avellana* (17%) and *Pinus sylvestris* type (60%); decline of *Betula alba* type curve (min. 12%); gradual rise of *Alnus* proportion to up 10% | Rise of *Alnus*; small increases of *Tilia cordata*, *Quercus*, and *Ulmus* |
| KBVII-5 | *Alnus-Ulmus-Tilia* | 3.55–3.05 | Nadal dominated role *Pinus sylvestris* type (mean 60%); relatively high values of *Ulmus* (mean 3%), *Tilia cordata* (mean 2%) and *Alnus* (mean 10%); fall of *Corylus avellana* proportion to below 10%; continuous *Fraxinus* curve | Rises of *Tilia cordata*, *Fraxinus, Ulmus*, *Alnus*, and *Quercus*; decrease of *Pinus sylvestris* type |
| KBVII-6 | *Ulmus-Tilia-Quercus* | 3.00–2.20 | Maximal values of *Tilia cordata*type (%), *Fraxinus* (%) and *Ulmus* (%); relatively high proportion of *Quercus* (mean %); gradual decrease in percentages of *Pinus sylvestris* type; very slow rise of *Corylus avellana* and *Picea abies* curves | Rise of *Quercus*; decrease of *Ulmus* and *Tilia cordata*, beginning of *Carpinus betulus* continuous curve |
| KBVII-6a | *Pinus* | 3.00–2.40 | High values of *Pinus sylvestris* type (mean 50%). | |
| KBVII-6b | *Quercus-Betula* | 2.35–2.20 | Clear increase of *Quercus* curve to 4%; culmination of *Betula alba* type (max. 20%); the lowest at entire profile percentages of *Pinus sylvestris* type (min. 30%) | |
| KBVII-7 | *Quercus-Pinus-Carpinus* | 2.15–1.45 | The highest at whole profile values of *Quercus* (max. 5%); increased curves of *Carpinus betulus* (to 3%), *Picea abies* (to 4%) and *Pinus sylvestris* type (to 45%); gradual fall of *Corylus avellana* (to 4%) and *Ulmus*, *Tilia cordata* and *Fraxinus* (each to below 1%) values | Decrease of *Quercus*; increase of *Betula alba* type and *Carpinus betulus* |
| KBVII-8 | *Carpinus-Betula* | 1.40–0.60 | Maximal values of *Carpinus betulus* (mean %, max. 5%); relatively high proportion of *Betula alba* type (mean %) and *Pinus sylvestris* type (mean %); increased percentages of *Picea abies*; continuous curve of *Fagus sylvatica* | Rapid increase of *Pinus sylvestris* type and NAP; decrease of *Alnus*, *Carpinus betulus* and, *Quercus* |
| KBVII-9 | *Pinus-Picea*-Cerealia | 0.55–0.00 | Very high values of *Pinus sylvestris* type (mean %) and *Picea alba* (mean %); low pollen curves of all other trees; among NAP (mean %, max. %) relatively high values of anthropogenic indicators | |
| KBVII-9a | *Pinus-Carpinus* | 0.55–0.35 | Peak of *Pinus sylvestris* type (68%); relativelly high proportion of *Carpinus betulus* | |
| KBVII-9b | *Picea*–Cerealia | 0.30–0.10 | Maximum of *Picea abies* (20%) | |
| KBVII-9c | *Pinus* | 0.05–0.00 | Maximal values of *Pinus sylvestris* type (73%) | |

Wklejka, Fig. 2, po str. 180

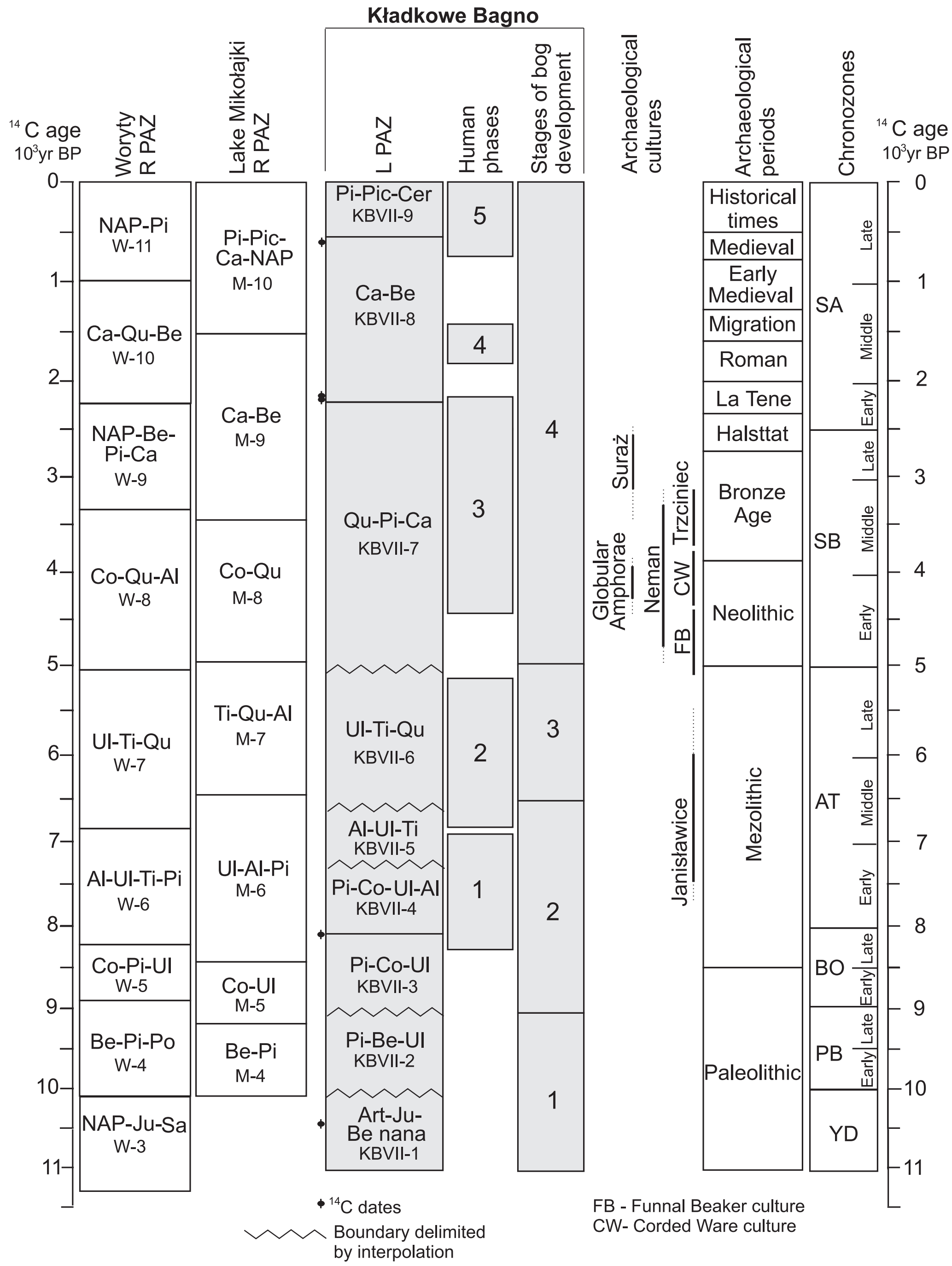


**Fig. 3**. Comparison of local pollen assemblage zones, anthropogenic phases and stages of development of aquatic-mire vegetation distinguished at the Kładkowe Bagno peat bog. Regional pollen zones from Woryty (Noryśkiewicz & Ralska-Jasiewiczowa 1989) and Lake Mikołajki (Ralska-Jasiewiczowa 1989c), chronozones (Mangerud et al. 1974) and archaeological cultures; the archaeological chronology according to Jażdżewski (1968) modified by Kozłowski (1989) for the Late Paleolithic and Mesolithic, by Dąbrowski (1997) for the Bronze Age and by Kowalski (1991) for Migration period

represents the older part of the Younger Dryas. This was the time of the maximum development of *Juniperus* that expanded on drier and more exposed habitats. However, its participation in plant communities around the Kładkowe Bagno peat bog was in that period distinctly lower than in the majority of other sites from central and northern Poland (e.g. Ralska-Jasiewiczowa 1966, 1989c, Latałowa 1982, 1989a, 1989b, Noryśkiewicz 1982, Pawlikowski et al. 1982, Bińka & Szeroczyńska 1989, Noryśkiewicz & Ralska-Jasiewiczowa 1989, Miotk-Szpiganowicz 1992, Ralska-Jasiewiczowa et al. 2001a). Low values of *Juniperus* pollen are noted only in profiles from the Puszcza Knyszyńska Forest (Kupryjanowicz 1991, 1995, 2000) and Lake Łukcze (Bałaga 1990). According to Bałaga (1990) it seems to evidence the drier and more continental climate of eastern part of the country. High proportion of sand in sediments of the section of the KBVII profile, representing this subzone, points out the considerable opening of vegetation and intensive dune-formation processes. The role of woods, particularly of birch (*Betula pendula* and/or *B. pubescens*) and pine (*Pinus sylvestris*), was marginal. The reduction of pine population is not very distinctly reflected by pollen of *Pinus sylvestris* type, which was probably produced more abundantly and freely dispersed in an open landscape (Ralska-Jasiewiczowa et al. 2001a).

The $^{14}C$ date suggests that subzone KBVII-1a was over about 10 460 ± 40 years BP. This date is very similar to dates that record a decline of the older part of Younger Dryas at profiles from some other sites both in eastern (10 680 ± 190 and 10 660 ± 210 in Lake Łukcze – Bałaga 1990) and northern Poland (10 430 ± 300 in Woryty – Pawlikowski et al. 1982; ca. 10 400 $^{14}C$ BP (12 100 cal BP) in Lake Gościąż – Ralska-Jasiewiczowa et al. 2001a).

Subzone KBVII-1b *Betula-Artemisia* is characterized by maximum spread of grasslands with dominant *Artemisia*. The presence of single Cerealia type pollen grains, may represent the wild grass (e.g. wild species of *Hordeum* or *Avena*) and, for this reason, may be connected with these communities. Pollen of *Hordeum* type was sporadically noted also in the Younger Dryas part of the profile from Lake Gościąż (Ralska-Jasiewiczowa et al. 2001a). On the other hand at Kładkowe Bagno it is conceivable that pollen of Cerealia type, similarly as single pollen grains of some trees (e.g. *Alnus*, *Tilia cordata*, *Ulmus*), entered Late Glacial sediments from the youngest Holocene deposits during drilling.

The *Juniperus* pollen values are lower than in preceding subzone, which suggests a decrease in its populations.

The climatic change towards more humid conditions is suggested for this time by gradual rise of *Betula alba* type values, which reflects development of birch woodlands. However, the maximum of *Artemisia* pollen curve indicates very cold climate. Only the appearance of *Hippophaë rhamnoides* and gradual disappearance of some heliophilous herbs by the end of this period point out the forest coming and amelioration of climate. Such trend of climatic changes corresponds very well to changes recorded in Lake Gościąż – both stable-isotope and vegetational succession speak for the more humid though rather cold climate at the time between 12 100–11 880 (11 850) cal BP (ca. 10 400–10 210 $^{14}C$ BP), followed by a distinct warming up during at last the ca. 300 years of the Younger Dryas (Ralska-Jasiewiczowa et al. 2001a).

The small rise of *Juniperus* and *Artemisia*, and decline of *Betula alba* type at the very end of subzone KBVII-1b (depth 4.55–4.50 m) may express a short cooling oscillation. The presence of such event in the period 11 600–11 550 cal BP (ca. 10 100 $^{14}C$ BP) was marked by pollen record in the G1/87 profile from Lake Gościąż (Ralska-Jasiewiczowa et al. 2001a).

KBVII-2 *Pinus-Betula-Ulmus* L PAZ

The zone corresponds to the Preboreal chronozone. The $^{14}C$ dating of its lower boundary at about 9750 ± 40 years BP, too young as compared to dates for the Late Glacial/Holocene transition from other northern-Polish sites (e.g. ca. 10 250 BP in Lake Mikołajki – Ralska-Jasiewiczowa 1989a; ca. 10 100 BP in Woryty – Pawlikowski et al. 1982, Noryśkiewicz & Ralska-Jasiewiczowa 1989; 11 510 cal BP (ca. 10 050 $^{14}C$ BP) in Lake Gościąż – Ralska-Jasiewiczowa 2001a, b), probably results from the sampling equipment. Very small thickness of sediment in this layer, representing KBVII-2 L PAZ, indicates the low accumulation rate during this zone. For this reason the dated sample, 1 cm thick, may contain different-age deposits.

A sharp reduction in shrubs and grassland taxa, and the development of forests with contributions of *Pinus sylvestris* and *Betula* evidence climatic warming. The *Ulmus* pollen values over 2% suggest the local presence of this tree (Huntley & Birks 1983). The appearance of *Corylus avellana* pollen indicates it to be approaching the studied area.

KBVII-3 *Pinus-Corylus-Ulmus* L PAZ

The zone probably corresponds to the Boreal chronozone. The birch woods were invaded by extending pine. The forests were being regularly penetrated by the new species – *Ulmus* and *Corylus avellana*. *Ulmus* is assumed to have been presented in the area from the beginning of the preceding zone, while *Corylus* seems to have spread slightly later. The role of herb taxa declined, which can certainly be explained by the *Corylus* shading effect eliminating heliophilous species from the open pinewood understory. The start of continuous pollen curves of *Quercus*, *Fraxinus*, and *Tilia cordata* indicates the approach of the these thermophilous trees into the studied area. During the younger part of the zone *Alnus* arrived in the region of the Kładkowe Bagno peat bog marked by a very slight rise of its population.

KBVII-4 *Pinus-Corylus-Ulmus-Alnus* L PAZ

The zone corresponds to the early Atlantic chronozone. This was the period of successive profound environmental changes in the studied area. The most important event was the expansion of *Alnus* around 8110 ± 40 years BP. Similar, relatively late, spread of *Alnus* has been documented in some sites from north-eastern (7960 ± 180 BP at Maliszewskie Lake – Balwierz & Żurek 1987, 1989, between 8160 ± 60 and 8130 ± 110 BP at Miłkowskie Lake – Wacnik 2003) and eastern Poland (ca. 8000 BP at Łukcze Lake – Bałaga 1989). However, at most sites from the Polish Lake Districts a very fast spread of *Alnus* has been documented earlier, ca. 8900–8500 years BP (e.g. Ralska-Jasiewiczowa 1966, 1989c, Noryśkiewicz 1982, Pawlikowski et al. 1982, Miotk-Szpiganowicz 1992, Ralska-Jasiewiczowa et al. 2001b). It was formerly assumed that ca. 100 years was necessary for such "an explosive *Alnus* invasion" (Ralska-Jasiewiczowa et al. 2001b).

*Alnus* could have spread in the humid habitats on the banks of rivers and lakes. It probably formed forests with the admixture of *Ulmus*, *Fraxinus* and some species of *Salix*. *Pinus sylvestris* was still a dominant element in the composition of these forests, despite its participation decreased by the end of the zone. *Betula* could have constituted a considerable admixture in a pine forest. The gradual extensive spread of *Corylus avellana* was from the beginning of the zone. *Tilia cordata* and *Quercus* could have existed as single trees.

KBVII-5 *Alnus-Ulmus-Tilia* L PAZ

The zone corresponds to the youngest part of the early Atlantic and older part of the middle Atlantic chronozones. In the areas with better habitat conditions the significance of *Ulmus* and *Tilia cordata* was clearly rising. Their continuous pollen curves with peaks of 3–4% suggest that the trees might have formed mixed deciduous forests around Kładkowe Bagno. The role of *Quercus*, though its pollen values also remain above 1%, was rather insignificant. Together with their development the role of *Corylus avellana* decreased.

The increasing shade in the forests and the reduction of the open areas is evidenced by the NAP values, which are the lowest in the entire Holocene by the end of the zone.

On the wettest soils *Alnus* was a main component. *Picea abies* probably occurred in small groups. *Pinus sylvestris* still played a considerable role in the forests at poor soils. However, the strong fluctuations of its pollen curve may suggest destruction of these communities.

The presence of *Viscum* pollen indicates warm summer seasons of this period. *Hedera helix* pollen suggests mild winters and long autumn time.

KBVII-6 *Ulmus-Tilia-Quercus* L PAZ

Due to the pollen record, this zone corresponds to the younger part of the middle Atlantic and entire late Atlantic chronozones (Fig. 3). From the palynological point of view both $^{14}C$ date from this zone – 8340 ± 50 BP from its beginning and 1815 ± 30 BP from its final part – show the incorrect ages for the zone.

Mixed deciduous forests with *Ulmus*, *Tilia cordata*, *Fraxinus*, and some *Acer* attained optimum extent in their Holocene development. The highest pollen percentages of these trees, at the whole profile, indicate that they might have grown in various woodlands near the Kładkowe Bagno peat bog. The *Pinus sylvestris* significance gradually decreases and the role of *Quercus* rises slightly. The high *Alnus* pollen curve underlines the importance of alder woodland swamp communities. The presence of numerous fragments of charcoal suggests that surroundings were constantly visited by man.

The zone shows a clear diversity, which is reflected mainly by fluctuations of pollen curves of *Pinus sylvestris* type, *Betula alba* type and *Quercus*. It is showed by three local pollen subzones.

The older subzone (KBVII-6a *Pinus* L PASZ) was the period of relative stability for forest communities, in spite of the continuous anthropogenic presence in this area. Burning in *Pinus* woods was probably slackened. Pine continued to dominate the light, sandy soils until the end of the subzone after which its proportion rapidly decreased, while that of oak gradually rose.

During the younger subzone (KBVII-6b *Quercus-Betula* L PASZ) the significance of pine in the Kładkowe Bagno surroundings was the lowest in the entire Holocene. Its occurrence was probably limited to areas with sandy soils with the highest elevations. The pine-oak and/or oak-pine woodlands, prevailing in this time, had a rather open structure. Birch was an important component in these forests. Pollen record (continuous presence of *Pteridium aquilinum* and charcoal) suggests anthropogenic origin of this phenomenon (see the next chapter).

KBVII-7 *Quercus-Pinus-Carpinus* L PAZ

The zone corresponds to the Subboreal chronozone and oldest part of the early Subatlantic chronozone. Its lower boundary, on the basis of the *Ulmus* decline, may be dated at around 5100–5000 years BP while the upper boundary was $^{14}$C dated at 2240 ± 40 and 2190 ± 30 BP.

Important changes in the woodland surrounding the peat bog, mainly in the mixed deciduous forest, started. The proportion of *Tilia*, *Ulmus*, and *Fraxinus* fell abruptly, what might have had connection with human activity (see the next chapter). *Pinus* spread into the disturbed habitats and again played a significant role in the formation of woodland. *Quercus* was the subdominant tree in these forests. At that time it reached the highest pollen values in the Holocene. *Corylus avellana* continued to play an important role in the forest composition, although its proportion gradually decreased. During the younger part of this period *Carpinus betulus* entered region of Kładkowe Bagno and the area occupied by *Picea abies* increased slightly.

KBVII-8 *Carpinus-Betula* L PAZ

$^{14}$C dates for the lower and upper boundaries of the zone suggest that it represent the period, which began by the end of early Subboreal chronozone, about 2200 BP, and continued to the middle part of the late Subatlantic chronozone, about 575 BP. Generally the pollen record confirmed this dating.

The significant development of *Betula* and *Carpinus betulus* populations during the older part of the zone was preceded by short-lasting expansion of *Corylus*. This change clearly coincided with the strong reduction of different deciduous forests with *Ulmus*, *Tilia cordata*, *Fraxinus*, and *Quercus*. Some habitats left by these forests were gradually invaded by *Carpinus* and *Picea abies*. The low pollen values of *Fagus sylvatica* indicate that this tree may merely have been an insignificant admixture in the woodland or else that its pollen is derived from long-distance transport. *Alnus* was still dominant in more humid, fertile habitats, but the area of alder-woods gradually diminished.

During the whole period *Quercus* pollen percentages are very stable and relatively high – still remain slightly above 5%. According to Ralska-Jasiewiczowa et al. (2001b) such a record may suggests the occurrence of scattered old oak trees, exposed and well flowering.

KBVII-9 *Pinus-Picea*-Cerealia L PAZ

The top pollen zone comprises the younger part of late Subatlantic chronozone, from ca. 575 BP to the present day. It demonstrates dramatic environmental change governed primarily by human activity. At this time the vegetation at the areas around the Kładkowe Bagno peat bog took its present character. All deciduous woodlands were destroyed. *Pinus sylvestris* was the absolutely dominating forest component. Mixed woods with hornbeam and oak were reduced to small fragments. Other species of deciduous trees disappeared almost completely. *Betula* occurred in small quantities probably as an admixture of pine forests. Even alder swamp woods strongly diminished.

The expansion of *Pinus* at the beginning of the oldest part of this period (KBVII-9a *Pinus-Carpinus* L PASZ) was probably caused, to a large extent, by human activity (see the next chapter). Pine as a tree settling easily on fire sites, occupied habitats formerly occupied by hornbeam-oak forests and mixed deciduous forests.

The invasion of *Picea abies* was characteristic for the middle phase (KBVII-9b *Picea*-Cerealia L PASZ). The tree appeared in the region not later than 5000 $^{14}$C BP, but only at that time it reached its maximal values. Climatic changes and soil leaching (Iversen 1964, Tobolski 1976) as well as human activity contributed to the spread of species tolerating higher soil acidity. The rapid development of spruce temporary diminished a role of pine in the woodlands.

The *Pinus* re-expansion and rise of the role of cereal cultivation were characteristic for the youngest phase of vegetation changes in the Kładkowe Bagno surroundings (KBVII-9c *Pinus*-Cerealia L PASZ). This phase probably comprised the two last centuries – from the beginning of the 19th century plantation of pine monocultures was very intensive in the Puszcza Knyszyńska Forest (Sokólska 1995), which definitively controlled the present composition of the forests.

## HUMAN IMPACT ON THE VEGETATION

The anthropogenic phases (Fig. 4) are distinguished mainly on the basis of the appearance and disappearance of the pollen taxa accepted as indicators of human activity (Behre 1981, Berglund & Ralska-Jasiewiczowa 1986, Latałowa 1992) and on the basis of changes in the tree pollen curves (Aaby 1986). They form the background to detailed interpretation of local vegetation changes induced by man.

### Phase 1 (depth 4.05–3.30 m)

The earliest changes in the pollen diagram interpreted as evidence of human activity occur within the lower part of KBVII-4 *Pinus-Corylus-Ulmus-Alnus* L PAZ, representing early Atlantic chronozone. The percentage values of human indicators are rather low in this section of the diagram and for this reason distinguishing this phase may be controversial, the more so as some light demanding species, defined as these indicators, might have been natural components of forest communities in the early Holocene. However, the fact that declines of *Pinus sylvestris* type curve occur very regularly and that they are usually synchronised with appearances of *Pteridium aquilinum* and numerous charcoal fragments suggests disturbances in dry mixed pine forests, which may have been caused by man. *Pteridium* expands effectively not only by a good light supply but particularly on soils enriched in ash (Oinonen 1967 after Latałowa 1992). Its presence accompanied by charcoals and charred fragments of plant tissues documents fires. The regularity of their record may indicate anthropogenic origin of this phenomenon (Bennett et al. 1990, Latałowa 1992, Ralska-Jasiewiczowa & van Geel 2001). The occurrence of *Melampyrum* pollen may also represent development of species, which are characteristic of woodland disturbances (Ralska-Jasiewiczowa & van Geel 2001). The slight rise of *Artemisia* illustrates formation of nitrogen-enriched habitats, maybe around human camps.

The palynological record of human phase 1 may register the regular presence around Kładkowe Bagno groups of Mesolithic hunters that penetrated mainly light pine forests. The small scale of the vegetational changes showing by pollen diagram suggests that they were not the result of burning in the woodland but only of local domestic fires. The shapes of pollen curves of taxa such as *Pinus sylvestris* type, *Corylus avellana*, and *Betula alba* type and also of *Pteridium aquilinum* values, suggest the occurrence of several short periods of human activity within this phase. Most likely they are connected with the mobility of nomadic tribes.

The oldest part of phase 1 was $^{14}$C dated at 8110 ± 40 BP (Tab. 1), what confirms correlation of this phase with Mesolithic.

The section of the pollen diagram following phase 1 shows the time of reduced human activity. *Artemisia*, Gramineae undiff., and *Pteridium* frequency decline, charcoals disappear, *Pinus sylvestris type* values rise.

### Phase 2 (depth 3.15–2.10 m)

The new signals of the human presence in the studied area started from the end of KBVII-5 *Alnus-Ulmus-Tilia* L PAZ. Their pollen record is very similar to the record of phase 1, but it is more distinct. Man-made changes are showed by visible increase in *Pteridium aquilinum* values, the reappearance of *Artemisia*, Chenopodiaceae and *Rumex acetosa/acetosella type*, and also by the strong fall of *Pinus sylvestris* type proportion. These changes are accompanied by the continuous and very numerous occurrences of charred tissues, mostly of small wood fragments. The regularity of recorded fires as well as the scale of vegetation changes noted in pollen diagram speaks for their anthropogenic origin. They also indicate burning in the woodland, mainly in poor and sandy habitats, where mixed pine, mostly pine-oak and pine-birch, forests dominated. Latałowa (1992) considers that regular fires on light sandy soils may have produced

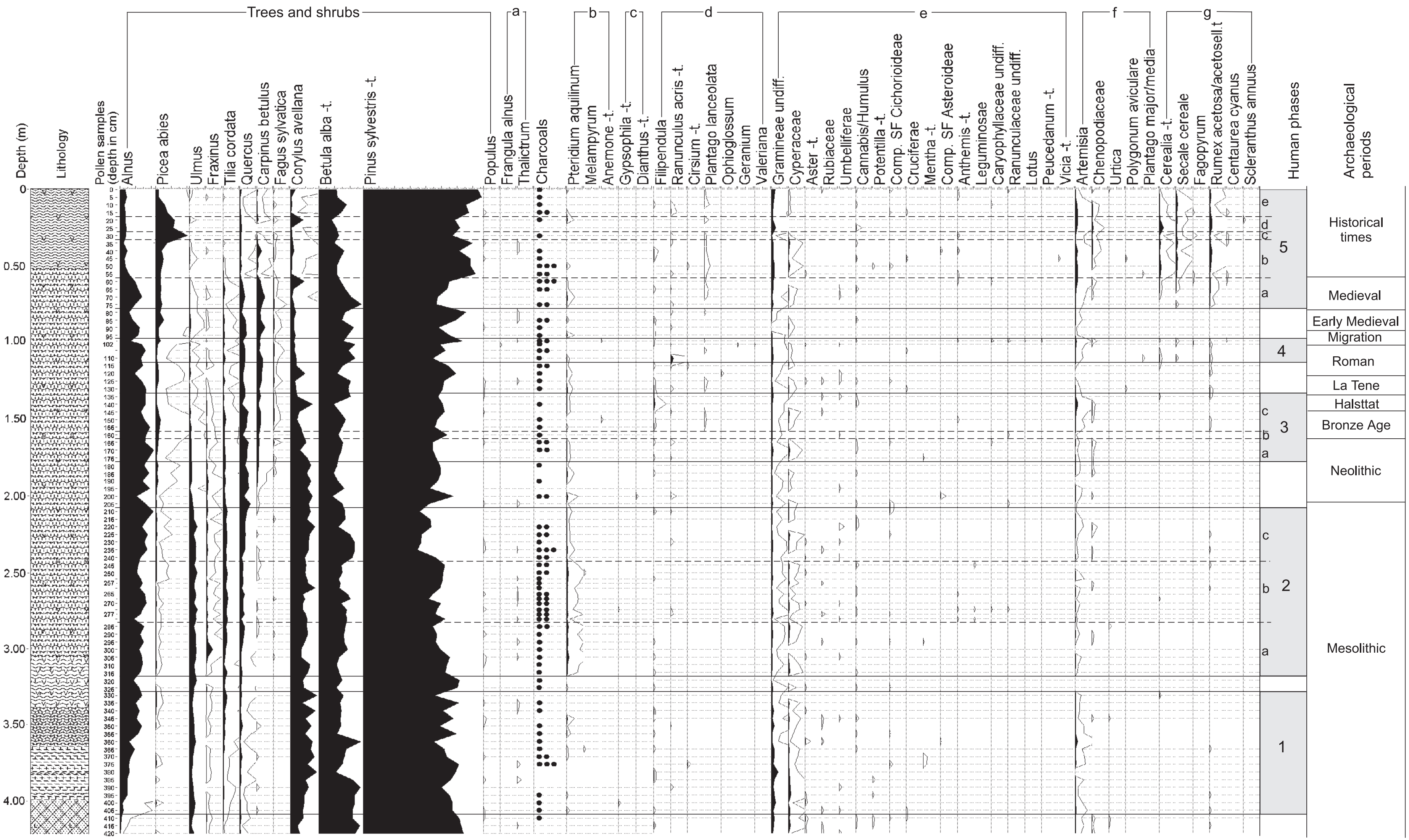


**Fig. 4**. Kładkowe Bagno. Section of the pollen percentage diagram from the KBVII profile showing the human impact on the landscape; curves of herbs related to the economic activity of man have been grouped according to Behre (1981) modified by Berglund and Ralska-Jasiewiczowa (1986) and Latałowa (1992): **a** – mantle/outskirt shrubs, **b** – grazed woodland, **c** – dry grasslands (pastures), **d** – fresh-wet grasslands (meadows), **e** – taxa ecologically undefined (family or genus type rank mostly), but favoured for human use, **f** – ruderals, **g** – cultivated plants and field weeds; charcoals content (black dots) is estimated according to the 3-grade scale: one dot – present, two dots – frequent, three dots – abundant. For other explanations see Figures 2 and 3

favourable conditions for the development of a rich herb layer with dominant *Pteridium aquilinum*, limiting the regeneration of *Pinus* seedlings and favouring the advance of *Quercus*. This interpretation may very well explain the changes in the pollen record observed in phase 2 from Kładkowe Bagno.

Mans activity during anthropogenic phase 2 was varied, as reflected in the distinction of three settlement subphases.

The settlement phase 2 may be connected with the Late Mesolithic. Pollen records register the penetration of areas around Kładkowe Bagno by migratory human groups, perhaps of cattle breeders. The cattle might have been grazed in the forests, mainly in open pinewoods.

Phase 3 (depth 1.75–1.35 m)

It the oldest part of this phase (subphase 3a), as in the previous settlement phase, the undergrowth was burnt and afterwards animals pastured in the poor mixed pine forests. This may have forced people to look for other sources of fodder and led to disturbances in woodlands with *Ulmus*, *Fraxinus*, and *Tilia cordata*. However, during the phase 3 striking anthropogenic changes occurred in the woodland in more fertile habitats first time, as evidenced by fluctuations in the *Ulmus*, *Fraxinus*, and *Tilia cordata* curves. The first *Fraxinus* fall took place in subphase 3a. Towards the end of the subphase 3c there was a second decline of *Fraxinus* which is linked with a drop in the *Ulmus* and *Tilia* curves.

This section of the profile probably illustrates man-made changes in the woodland, which can be linked with increasing animal husbandry. The fluctuation in the tree pollen curves described above might result from the intensive pollarding of elm, ash and lime and from small clearances, which caused pastures to develop. The first single pollen grain of *Plantago lanceolata* appears at the subphase 3c onset, together with an increase of *Filipendula* frequency, but altogether the indicators of all pasturelands are still very poor. Gramineae undiff. curve also remains rather low. Because of the destruction of shade producing species, the better light conditions allowed hazel to flower and spread more rapidly. It may also have been the result of coppicing (Latałowa1992).

Some ruderals, mainly *Artemisia*, clearly increase in subphase 3c. Simultaneously, single pollen grain of Cerealia type appearance. It is the first palynogically documented sign of cereal cultivation in the surroundings of Kładkowe Bagno.

During the middle part of phase (subphase 3b) the indicators of human activity decrease in frequency and a peak of *Pinus sylvestris* type is visible. It may suggest the short-lasting departure of some human groups.

The anthropogenic phase 3 may be connected with the settlement from the Late Neolithic to the beginning of the Iron Age (Halstatt). Subphase 3a probably represents the Neolithic. There are no palynological premises on the development of plants cultivation during this period. The top section of the subphase 3c was $^{14}C$ dated at 2240 ± 40 and 2190 ± 30 years BP. These data makes probable to relate subphase 3c to the activity of the Suraż culture populations, of which development in Puszcza Knyszyńska Forest is dated, on the basis archaeological facts, at the late Bronze Age and oldest part of the Iron Age (Halstatt D and C).

Phase 4 (depth 1.10–0.98 m)

This rapid and brief settlement episode differs distinctly in its pollen record from the earlier phases. A distinct rise of *Betula alba* type and decreases of *Pinus sylvestris* type, *Fraxinus*, *Ulmus*, *Carpinus,* and *Picea* indicate its beginning. The increase in the main human indicators includes: Gramineae undiff., *Artemisia*, *Rumex acetosa/acetosella* type, and Cerealia type. Pollen of *Secale cereale*, *Fagopyrum*, and *Centaurea cyanus* appear for the first time and probably document the first palynological signs of rye and buckwheat cultivation neighbouring the studied site.

According to archaeological chronology, human phase 4 corresponds to the Roman period. Pollen records are clear, in opposition to very scanty archaeological information – in the Puszcza Knyszyńska Forest only one site from this period is noted.

Phase 5 (depth 0.75–0 m)

The youngest settlement phase, lasting to the present day, is marked firstly by decreases of all deciduous trees (declines of *Ulmus*, *Fraxinus*, *Tilia*, *Quercus*, and *Carpinus*) and expansion of *Pinus sylvestris*, *Picea abies*, and anthropogenic communities.

In oldest part of the phase (sub-phase 5a) the frequency of agriculture indicators is low, but gradually rises. Single pollen grains of *Secale cereale*, Cerealia type, *Fagopyrum*, and *Centaurea cyanus* occur. The continuous curve is formed by *Rumex acetosa/acetosella* type, which was a weed within cornfields. A clear rise of ruderals (*Artemisia* and Chenopodiaceae) occurred. The increase in frequencies of fresh-wet meadow taxa (*Plantago lanceolata*, *Ranunculus acris* type) together with taxa undefined ecologically (Gramineae undiff., Cyperaceae) is recorded. Proportion of *Pteridium aquilinum* rise. There is a peak of *Betula alba* type

Sample from sub-phase 5a was $^{14}C$ dated at 575 ± 25 years BP. For this reason, the sub-phase may correlate with a passage from Medieval to historical times and may express Masovian colonisation of the Puszcza Knyszyńska Forest area during the second half of the $15^{th}$ century. (Sokólska 1995). During early Medieval, at the $11^{th}$ century in areas between Biebrza and Narew only small open settlements were found (Sokólska op. cit.). They were mainly steered to the exploitation of forests. The oldest fortified strongholds (Zamczysk, Bachmatowka) are dated to the $12^{th}$ century. At the period from the $13^{th}$ century to the first half of the $15^{th}$ century invasions, firstly by Prussians, Masovians and Russians, and next Lithuanians and Teutonic Knights resulted in almost complete degradation of the settlement at entire region. Its reappearance took place only at the end of the $15^{th}$ century. Intensive colonization remained, with short intervals caused by wars, to the $18^{th}$ century.

In sub-phase 5b the more drastic changes in the forest cover are documented. The deep depressions of *Alnus*, *Betula*, *Ulmus*, *Tilia*, *Carpinus*, *Fagus*, and *Quercus* pollen curves, and the clear increase in *Pinus* proportion express them. Such a record documents total clearing of all still existing fragments of deciduous woods. Human indicators frequencies rise, mainly in groups of cultivated plants and weeds (Cerealia undiff., *Secale cereale*, *Rumex acetosa/acetosella* type), and ruderals (*Artemisia*, Chenopodiaceae). This sub-phase may correspond to the intensive colonisation process of Knyszyńska Forest during $16^{th}$ century, in the Queen Bona and Zygmunt August King times (Wiśniewski 1977, Sokólska 1995).

Sub-phase 5c is represented by only single pollen spectrum from depth 0.30 m. A fall of human indicators may suggest a short-lasting limitation of agriculture. This sub-phase may be expressed by the settlement limitation resulting from wars in the middle of the $17^{th}$ and at the beginning of the $18^{th}$ centuries (Sokólska 1995).

The pollen record of the sub-phase 5d registers the sharp rise of human activity and following recession possibly in consequence of depopulation and reforestration of this part of the Knyszyńska Forest. Most characteristic, at the beginning of this sub-phase is the rise of cultivation indicators (Cerealia undiff., *Secale cereale*, cf. *Cannabis sativa*, *Rumex acetosa/acetosella* type, single pollen grains of *Centaurea cyanus*, and *Scleranthus annuus*), ruderals (*Artemisia*, Chenopodiaceae) and Gramineae undiff., and a rapid fall of *Picea abies* proportions. This record shows the very fast devastation of spruce woods, which may have been connected, with the robbery exploitation of Knyszyńska Forest during the German occupation after the First World War. During only three years 1915–1918, ca. 10 000 hectares of forest were cut down (Sokólska 1995).

## DEVELOPMENT OF WATER AND MIRE VEGETATION

Changes in the percentage curves of local mire and water plants, and non-pollen microscopic remains enabled specific zonation related exclusively to these taxa (Fig. 2). The evolution of the Kładkowe Bagno palaeo-lake and bog has been reconstructed using this basis.

### Stage 1 *Botryococcus*-Bryales-*Pediastrum* (depth 5.10–4.45 m)

The first stage of the development of water-mire vegetation corresponds to the Younger Dryas. Coenobia of *Botryococcus braunii*, different species of *Pediastrum* and *Tetraedron* cf. *minimum* are dominant among groups of local plants. Percentage values of Bryales spores are high. Single pollen grains of *Nuphar*, *Potamogeton*, *Myriophyllum verticillatum*, *Typha angustifoplia/Sparganium*, *Phragmites* type, and *Menyanthes trifoliata*, and spores of Filicales monolete, *Equisetum*, and *Sphagnum* are present.

Profuse occurrence of *Botryococcus braunii* at the beginning of this stage probably indicates specific lake conditions. It is likely that this taxon dominates in relatively extreme environments, which prevents the mass development of other coccal green algae, e.g. *Pediastrum* (Jankovská & Komárek 2000). The water was very cold, clear and oligotrophic at that time.

The increase of *Pediastrum kawraisky*, *P. boryanum* var. *longicorne*, and *P. duplex* as well as the appearance of *P. integrum* indicate amelioration of environment conditions from the middle part of Younger Dryas. The water in a lake still was clear and rather cold (Jankovská & Komárek 2000).

The gradual warming up of climate in the second half of Younger Dryas is confirmed by better development of *Nymphaea alba*.

Stage 2 *Nymphaea alba-Botryococcus* (depth 4.40–3.65 m)

This stage lasted from the beginning of the Holocene to the early Atlantic chronozone. Pollen records are characterized by very high *Nymphaea alba* values, with maximum of 9%. Nymphaeaceae idioblasts occur mainly in older part of this period. Percentages of *Botryococcus braunii* strongly decrease at the beginning of stage, and rise again. Coenobia of practically all *Pediastrum* species disappear. Single *Amphitrema flavum* remains occur regularly. *Sphagnum* and *Tilletia sphagni* spores are present. This record documents well-developed shallow-water plant communities, mainly with *Nymphaea alba*. Their expansion at the beginning of the Holocene was most probable the joint effect of several factors (Ralska-Jasiewiczowa et al. 2001b). Some temporary lowering of lake level was one of them. However, the climate warming up, the favourable lake-water chemistry, and rising lake trophy with still low competition certainly contributed in a substantial way to the abundant development of this vegetation. The end of gyttja deposition and the start of peat formation evidence the shallowing of the lake in Kładkowe Bagno at the beginning of the Atlantic chronozone, about 8110 years BP. At that time in the central and northern Poland a general decrease of water level took place as a consequence to climate warming and forest development (Ralska-Jasiewiczowa & Starkel 1988).

Stage 3 *Amphitrema* (depth 3.60–3.05 m)

This stage corresponds to the younger part of early Atlantic and the older part of the middle Atlantic chronozones. The maximum values of *Amphitrema flavum* remains are its most characteristic feature. This provides reliable information about local conditions. Van Geel (1978) suggests that *A. flavum* greatly increases in number with increasing humidity, but it probably do not adapt to large bodies of open water and eutrophic conditions. On this basis the beginning of the stage 3 in local succession at Kładkowe Bagno may be related to lake terrestrialization and the transition towards oligotrophic conditions. The disappearance of sporomorphs of water and red-swamp plants, excluding single pollen grain of *Phragmites* type, and a slight increase in percentages of *Sphagnum* confirm this interpretation.

Stage 4 *Sphagnum*-Ericaceae-*Tilletia* (depth 3.00–0.00 m)

This stage has lasted very long, from the middle part of the Atlantic chronozone to the present day. Values of *Sphagnum* and *Tilletia sphagni* spores are generally highest in the entire profile and their percentage curves are said to run parallel. This is a well-known phenomenon (Dickson 1973 after van Geel 1978). van Geel (l.c.) stated that *Tilletia sphagni* infects *Sphagnum cuspidatum* more often than other *Sphagnum* species. This means that during stage 4 *Sphagnum cuspidatum* might have been the important peat-forming species at Kładkowe Bagno. Percentage proportion of *Calluna* type and Ericaceae undiff. is very high. Single pollen grains of *Menyanthes trifoliata* and *Typha angustifolia*/*Sparganium* are present.

The high peak of *Ranunculus* cf. *flammula* in the sample from middle part of the stage 4, in which curves of some peat taxa (*Sphagnum*, *Tilletia sphagni*, *Calluna* type, Ericaceae undiff.) decline, suggests short-lasting changes to the hydrological conditions neighbouring the analysed profile.

## CONCLUSIONS

The pollen data presented in this paper refer to the period from the Younger Dryas to the present day and indicate that general trends of post-glacial changes of vegetation in the surroundings of the Kładkowe Bagno peat bog were similar to those found in north-eastern Poland.

In older part of the Younger Dryas, probably much colder and dryer, this area was covered by treeless tundra. In younger part of the stadial, parkland tundra with single wood birches was formed.

The most characteristic feature of the Holocene succession of vegetation was the constant dominance of pine forests. The proportion of *Carpinus betulus* during the Subboreal and Subatlantic periods were less around Kładkowe Bagno than in western and central Poland. Probably, in spite of a great role of hornbeam in the surrounding of the site, there was a kind of equilibrium between the other tree species like oak, elm, lime, and spruce. Proportions of spruce during the Subatlantic period has been higher in north-eastern Poland than in the other regions of the country. It is the result of the influence of boreal zone. There were only single grains of *Fagus sylvatica* in pollen spectra what can suggest the real absence of beech in Puszcza Knyszyńska Forest.

Unfortunately some of the $^{14}C$ dates recovered are incorrect. Reliable dates were obtained for following changes in vegetation:

– strong decrease in the *Juniperus* proportion, distinguishing the boundary between older and younger part of the Younger Dryas (10 460 ± 40 BP),

– the spread of *Alnus* (8110 ± 40 BP),

– the spread of *Carpinus betulus* and first fall of the *Quercus* significance (2240 ± 40 and 2190 ± 30 B),

– the final disappearance of thermophilous trees connected with the development of anthropogenic vegetation and expansion of pine (575 ± 25 BP).

Human impact on the natural environment is clearly reflected in the pollen diagram only from the Bronze Age. It was probably connected with the development of the Trzciniec culture and then of the Suraż culture. The first palynologically documented signs of cultivations in a neighbouring of the site are evidenced for the Suraż culture.

There is no strong correlation between the boundaries of local pollen assemblage zones and the boundaries of anthropogenic phases, suggesting that human activity has not significantly influenced changes in the vegetation of the Kładkowe Bagno region in a direct fashion.

The pollen record permitted the reconstruction of local changes in water and mire vegetation. In the Younger Dryas the Kładkowe Bagno sedimentary basin was an oligotrophic lake, in which green algae occurred in great numbers. During the Preboreal, Boreal and early Atlantic chronozones the lake was very shallow and in its warmer and eutrophic waters communities with *Nymphaea alba* developed in mass. By the end of early Atlantic the lake terrestrialization process and the transition towards oligotrophic conditions took place and *Sphagnum* peat bog was formed.

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