ACTA PALAEOBOTANICA
27 (1): 283—304, 1987

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HISTORY OF VEGETATION DURING THE LATE-GLACIAL AND HOLOCENE IN THE BRODNICA LAKE DISTRICT IN THE LIGHT OF POLLEN ANALYSIS OF LAKE STRAŻYM DEPOSITS

Późnoglacjalna i holoceńska historia roślinności Pojezierza Brodnickiego w świetle analizy pyłkowej osadów jeziora Strażym

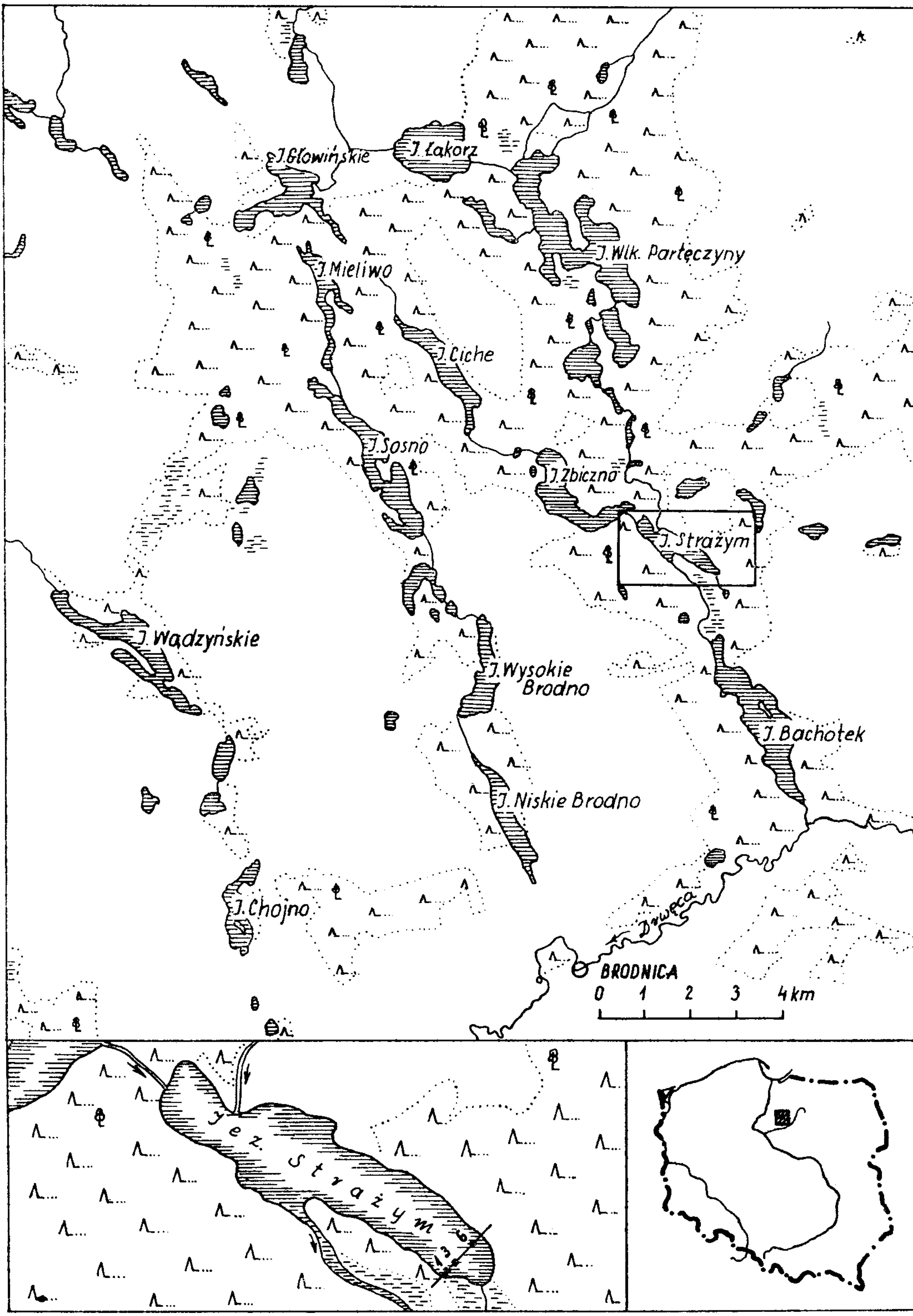
ABSTRACT. Palynological studies on bottom deposits from Lake Strażym were carried out on the material from 3 profiles collected from places of varying depths. The main profile from the deepest place was divided into 10 biostratigraphic units (PAZ) which were correlated to chronozones distinguished on the basis of six radiocarbon datings and published diagrams of Northern Poland which have a greater number of radiocarbon datings. Development of vegetation in the area discussed here was reconstructed from the Alleröd to modern time. During the younger part of the Holocene 6 settlement phases were distinguished on the basis of pollen diagram and then correlated with archaeological data.

INTRODUCTION

Pollen analysis of Lake Strażym sediments was initiated by Prof. W. Niewiarowski who was conducting morphological studies on water level changes in the lakes of the Brodnica Lake District.

Lake Strażym was designated as reference site for IGCP Project 158 B: Palaeohydrological changes in the temperate zone in the last 15000 years: lake and mire environments. The lake is situated in the Brodnica Lake District mesoregion which belongs to the Chełmno—Dobrzyń Lake District macroregion (Kondracki 1978). A detailed physiographic characteristic is given by Niewiarowski (this volume).

Palynological studies were performed on material from three cores collected along the cross-section in the southern part of the lake (Fig. 1). Apart from pollen analysis the sediments were examined for macrofossils by Boińska, *Cladocera* by Błędzki, oxygen ^{18}O and carbon-^{13}C isotopes by Różański, physical-chemical properties by Lankauf and radiocarbon dating by Pazdur (all in this volume). The results obtained permitted to reconstruct the history


J. Głowińskie
J. Łakorz
J. Wlk. Partęczyny
J. Mieliwo
J. Ciche
J. Sosno
J. Zbiczno
J. Strażym
J. Wądzyńskie
J. Wysokie Brodno
J. Bachotek
J. Niskie Brodno
J. Chojno
Drwęca
BRODNICA
0 1 2 3 4 km
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of the lake and its water level fluctuations during the Late-Glacial and Holocene (Niewiarowski, this volume).

Pollen analysis and ^{14}C datings proved that in profile 1 there exists a sedimentation hiatus synchronous with Sub-Boreal and Younger Sub-Atlantic chronozones, while the main profile shows undisturbed sedimentation sequence from the Alleröd to the Subatlantic chronozone inclusively.

RECENT VEGETATION OF THE BRODNICA LAKE DISTRICT

The young glacial relief of the Brodnica Lake District and the diversity of habitats enabled the development of rich flora represented by a greater number of species (over 600) then in the neighbouring areas. The natural vegetation were deciduous forests and mixed forests and aquatic, swamp and peatbog plant communities related directly to lakes of this area. The forest area decreased as settlement and farming developed. However, to the present time the mesoregion has a far greater forestation than the entire macroregion of the Dobrzyń—Chełmno Lake District. In forestry the preference for pine growing is observed. The pine had been introduced into the habitats of deciduous forests which in turn caused the declining vitality of forests and also degradation of soil.

The forest communities occurring in this area belong to three syntaxonomic classes. *Alnetea glutinosae* class is represented by stands of *Salicetum pentandro-cinereae* and *Carici elongatae-Alnetum* developing in several variants. They develop most often on peat soils along lake shores, in the shallow parts of subglacial channels and on the edges of forest peatbogs (Zielski 1978).

The *Querco-Fagetea* class is represented by stands of *Circaeo-Alnetum* growing on habitats similar to those of alder woods, but characterized by a lower level of ground water. *Fraxino-Ulmetum* is found in the valley of the Lutryna River. The most common association of deciduous forests in the region is *Tilio-Carpinetum*. Its stands develop on the edges of the subglacial channels (Zielski 1978), within undulating morainic plateau and on the valley slopes of the Drwęca River and of small erosional incisions. This association is represented by subassociations and a number of lower units whose formation was influenced by habitat diversity and sometimes by human interference. Relatively small areas are occupied by stands of *Potentillo albae-Quercetum*. The *Vaccinio-Piceetea* class is represented by *Querco roboris-Pinetum* and pine forests occupying quite large areas. Pine forests are located mainly near the villages Ryte Błota, Ciche, Łąkorz and Partęczyny and belong mainly to *Peucedano-Pinetum* and *Leucobryo-Pinetum* associations. On the western shore of Lake Bachotek the stands of *Vaccinio uliginosi-Pinetum* with *Ledum palustre* and *Vaccinium uliginosum* occur. A strong human influence is visible in the forests communities of the Brodnica Lake District, connected mostly with tourism.

Fig. 1. Skech map showing the vegetation of the study area and the position of the localities

Recent vegetation of the Brodnica Lake District has preserved a number of rare species and associations protected in reserves. The communities of raised bogs and intermediate fens are protected in the reserves: Kociołek, Łabędź, Żurawie Bagno, Okonek and Stręszek. There are rich stands of *Cladium mariscus* in the Bachotek reserve, *Cypripedium calceolus* in the "Island" reserve on the Lake Partęczyny Wielkie, and forest communities in the reserves of Mieliwo and Partęczyny.

In appreciation of natural values of the area, the Brodnica Landscape Park has been set up to protect the most interesting parts of the Lake District. In this area with forest coverage up to 60%, there are several deep channel lakes. The distribution limits of *Larix polonica* Rac., *Acer campestre* L., *Acer pseudoplatanus* L., *Sorbus torminalis* (L.) Cranth. run through the park.

SITE DESCRIPTION

Lake Strażym lies in a 14 km long, narrow and deep subglacial channel that also holds lakes: Ciche, Zbiczno, and Bachotek. The differences between the levels of moraine plateau and of lake surface reach 50 m. Lake area is 73.4 ha, total shoreline length 5050 m, maximum depth 9 m. The lake has an in — and outflow and its bottom is very diversified, with elevations and deepenings. Prevailing sediment is calcareous gyttja with the thickness up to 10 m. In the upper parts of cores from the shallower part of the lake peats and sandy deposits were found. At the base of sediments a thin layer of Alleröd peat occurs.

According to its physical and chemical properties, Lake Strażym is classified as a shallow lake, with a rather low water transparency and displaying no thermal either oxygen stratification. Lake water is poor in iron, phosphates, ammonia, nitrates and somewhat richer in silica, potassium. The content of calcium, magnesium and sodium is relatively high (Bednarek 1972).

Lake Strażym is surrounded by woods (85% of area), mostly pine forests. The channel slopes and its bottom around the lake are occupied by deciduous forests and shrubs, and a peatbog. The morainic plateau to the north-east of the lake is covered with fields where rye, barley and potatoes are mostly grown.

The vegetation directly connected with the lake reveals a typical zonation of plant communities belonging to 5 syntaxonomic classes: *Lemnetea*, *Potamogetonetea*, *Phragmitetea*, *Alnetea glutinosae* and *Querco-Fagetea*, most of them typically developed.

The lake bottom is covered by *Ceratophylletum demersi* occupying large areas in places to the depth of 3 m. Stands of *Myriophylletum spicati*, *Elodeetum canadensis*, *Potamogetonetum lucentis* and *Potamogetonetum perfoliati* form small patches. In shallow places protected from wind there develop phytocenoses of *Hydrocharitetum morsus-ranae*, the largest areas occupied by this association being found in northern and southern part of the lake. They frequently border on stands of *Nupharo-Nymphaeetum albae* and *Potamogetonetum natantis*.

Small patches of *Ranunculetum circinati* were found at the outlet of the Skarlanka River from the lake. Among the subaquatic meadows of *Potamogetonetea*, small patches of *Lemno-Spirodeletum polyrrhizae* and *Lemnetum gibbae* were observed.

Along the lake shores there develop the reed-swamp associations of the class *Phragmitetea*: *Eleocharitetum communis*, *Scirpetum lacustris*, *Oenantho-Rorippetum*, *Glycerietum maximae*, *Acoretum calami*, *Iridetum pseudoacori*, *Caricetum gracilis*, *Caricetum paniculatae* and *Thelypteridi-Phragmitetum*. On the bottom of abandoned fish ponds stands of *Eleocharitetum acicularis* were found.

In the southern part of the basin along the section of the Skarlanka River joining together lakes Strażym and Bachotek, there occurs a fen divided by an esker. On this area of 18.75 ha the Bachotek reserve was set up to protect patches of *Cladietum marisci* and phytocenoses of *Glycerietum maximae*, *Caricetum elatae*, *Caricetum paniculatae*, *Caricetum rostratae*, *Caricetum acutiformis*, *Thelypteridi-Phragmitetum*, *Salicetum pentandro-cinereae*, *Carici elongatae-Alnetum* and *Circaeo-Alnetum* (Kępczyński & Zielski 1981).

PALAEOECOLOGICAL STUDIES

Methods

The cores for palynological studies were collected from ice with Więckowski's (1961) piston corer, in March of 1984 and 1985. The samples for pollen analysis were collected with 1 cm^3 volumetric sampler at 5 cm intervals in the Late Glacial part, and at 10 cm intervals in the Holocene part. Prior to acetolysis and in order to remove organic substance the material was boiled in 10% KOH, then calcium carbonate was removed with 10% HCl and finally the material was treated with hydrofluoric acid, decanted and rinsed with 10% HCl to remove silica from the mineral deposit. The pollen concentration was measured by use of tablets containing *Lycopodium* spores (Stockmarr 1971).

The results of pollen analysis are presented in pollen diagrams (Figs. 2, 3, 4). Pollen percentages have been calculated from the sum AP+NAP, without including into the 100% pollen of aquatics and spores. The high content of calcium carbonate in gyttja restricted possibilities of dating only to peat deposits. For Lake Strażym, 7 radiocarbon datings were carried out at the Silesian Technical University in Gliwice:

1.	Gd 1915	Strażym 1	120—125 cm	4750± 50 BP
2.	Gd 2266	Strażym 3	5—10 cm	3960±120 BP
3.	Gd 2417	Strażym 3	55—60 cm	4990±150 BP
4.	Gd 2419	Strażym 3	210—215 cm	5920±130 BP
5.	Gd 2265	Strażym 3	240—246 cm	5890±140 BP
6.	Gd 1786	Strażym 4	60—65 cm	9530±100 BP
7.	Gd 2418	Strażym 6	1040—1045 cm	11910±210 BP

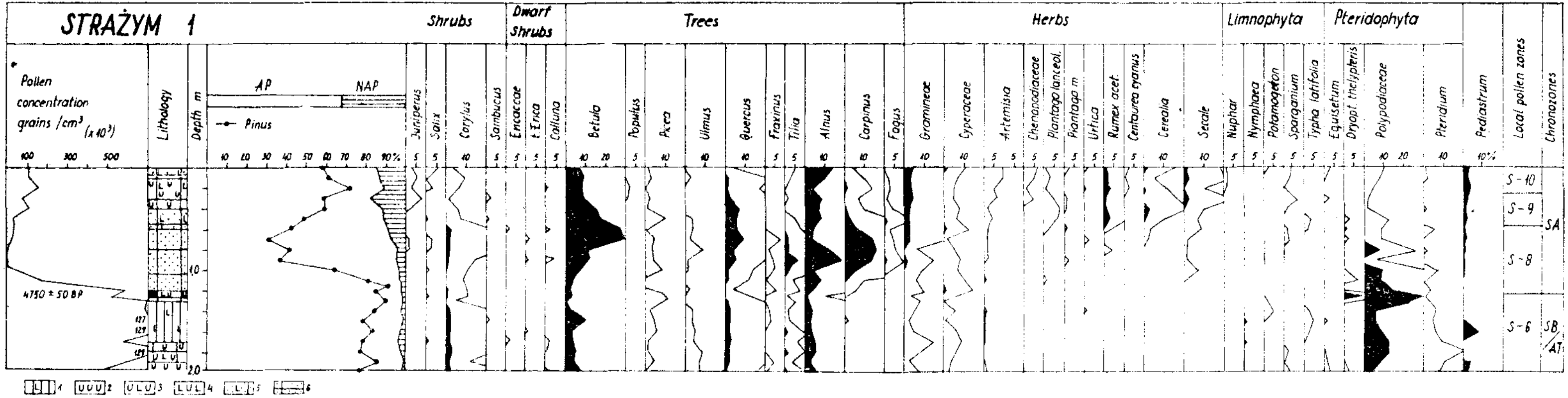


Fig. 4. Simplified pollen diagram from the Lake Strażym profile 1, selected pollen taxa. 1 — peat with clay, 2 — calcareous gyttja, 3 — clayey gyttja, clayey — calcareous gyttja, 5 — sand with organic matter, 6 — sand

Stratigraphy of the lake deposits

The sediments have been described according to the Troels-Smith (1955) system. Depth was measured from the present bottom of the lake.

Table 1

Sediment stratigraphy of profile 6, water depth 575 cm

Layer No.	Depth (cm)	Description
1	0—10	clayey gyttja, black grey, (Ga+Gs) 2, Ag+, Dl+, Dh+, Dg+, Ld+, nig 1, elas 1, strf 0, sicc 3,
2	10—90	clayey — calcareous gyttja, grey, Lc 2, As 1, Ld 1, nig 1, elas 0, strf 0, sicc 1,
3	90—1020	calcareous gyttja, light grey, Lc 4, As+, nig 1, elas 1, strf 1, sicc 2,
4	1020—1040	silty sand with organic matter, grey, Gs 2, Ga 1, As 1, nig 2, elas 0, strf 0, sicc 2,
5	1040—1045	peat, dark brown, Th^2 3, Tb^3 1, nig 3, elas 1, strf 1, sicc 2,
6	1045—1050	fine sand, light grey, nig 1, elas 0, strf 0, sicc 2

Table 2

Sediment stratigraphy of profile 3, water depth 175 cm

Layer No.	Depth (cm)	Description
1	0—100	not collected
2	100—245	peat, dark brown with numerous mollusc shells in deeper part Th^4, Dh+, As+, (test. moll.+) nig 3, elas 2, strf 0, sicc 2,
3	245—445	calcareous gyttja, light grey, Lc 4, As+, nig 1, elas 1, strf 1, sicc 2,
4	445—490	silty — calcareous gyttja, grey, Lc 3, Ag 1, nig 1, elas 1, strf 1, sicc 2,
5	490—540	calcareous gyttja, light grey, Lc 4, Ag+, nig 1, elas 0, strf 0, sicc 0,
6	540—575	clayey — calcareous gyttja, grey, Lc 2, Ag 2, nig 2, elas 0, strf 0, sicc 2,
7	575—628	fine sand with organic matter, Gs 1, As 1, Th+, nig 2, elas 0, strf 0, sicc 2,
8	628—633	peat, dark brown, $Th^2$3, $Tb^3$1, nig 3, elas 1, strf 1, sicc 2,
9	633—640	fine sand, light grey, Gs 3, As 1, Th+, nig 1, elas 0, strf 0, sicc 2

Table 3

Sediment stratigraphy of profile 1, water depth 165 cm

Layer No.	Depth (cm)	Description
1	0—10	clayey gyttja, dark grey, (Ga+Gs) 1, Ag 1, Ld 1, Dl+, Dh+, nig 1, elas 1, strf 0, sicc 3,
2	10—40	clayey gyttja, grey, Lc 2, Ld 1 (As+Ag) 1, nig 2, elas 0, strf 0, sicc 2,
4	60—120	fine and medium sand, light grey, Gs 3, Ld 1, nig 1, elas 0, strf 0, sicc 2,
5	120—130	clayey — calcareous gyttja, grey, Lc 2, Ld 1, As 1, nig 2, elas 0, strf 0, sicc 2,
6	130—170	peat, dark brown, Th⁴3, As 1, nig 3, elas 2, strf 0, sicc 2,
7	170—190	clayey — calcareous gyttja, grey, Lc 2, Ld 1, As 1, nig 2, elas 0, strf 0, sicc 2,
8	190—460	calcareous gyttja, light grey, Lc 4, nig 1, elas 1, strf 1, sicc 2,
9	460—558	fine sand, Gs 3, Ag 1, nig 1, elas 1, strf 0, sicc 3,
10	558—564	silty gyttja, dark grey, Ld 2, Lc 1, Ag 1, Dl+, Dh+, nig 1, elas 1, strf 1, sicc 2,
11	564—589	fine sand, light grey, (Ga+Gs) 2, Ag 1, Ld 1, nig 1, elas 1, strf 0, sicc 3,
12	589—595	silty gyttja, Ld 2, Lc 1, Ag 1, Dl+, Dh+, nig 1, elas 1, strf 1, sicc 2,
13	595—615	fine sand, light grey, (Ga+Gs+Gg) 4, Ld+, nig 1, elas 1, strf 1, sicc 2

Pollen analysis — division of diagrams into pollen assemblage zones (PAZ)

In the profile 6 ten local pollen zones were distinguished; similar course of tree curves in profiles 1 and 3 enabled to divide them into identical zones. Differences in percentage values, especially of aquatics and telmatophytes are the consequence of location of profiles 1 and 3 closer to the lake shore. Because of the lack of radiocarbon datings from calcareous gyttja sediments, each zone was correlated with corresponding chronozone in the profiles which had a greater number of ^{14}C datings and displayed a similar course of plant successions. Sites Woryty (Pawlikowski et al. 1982) located to the north — east of Lake Strażym and Wielkie Gacno (Hjelmroos—Ericsson 1981) 140 km away to the north-west were used for correlations. The Late Glacial from Lake Strażym may be well correlated with profiles from Lake Rudnik (Drozdowski & Berglund 1976) and Lake Steklin (Noryśkiewicz 1982).

Pinus — *Betula* pollen assemblage zone (1)

Pinus (74—91%) and *Betula* (5—18%) play an important role, and NAP values are 2—8%. Pollen grains of *Alnus* and *Corylus* found here are undoubtedly rebedded. Pollen concentration increases from 105 to 428 thousand grains in 1 cm^3.

Juniperus — *Artemisia* pollen assemblage zone (2)

The *Pinus* pollen curve falls rapidly to 36%. *Juniperus* pollen is found in the entire zone, reaching 17%. *Salix* pollen averages above 1% (0.5—2.5%); *Artemisia* (3—10%) dominates in NAP. Pollen grains of *Saxifragaceae*, *Epilobium*, *Dryas*, *Polygonum bistorta/viviparum*, *Scleranthus*, *Helianthemum*, *Arctostaphylos*, *Empetrum* as well as of other heliophilous plants are found here. Pollen concentration is the lowest of all the diagram (1412—160000 grains/cm^3). The lower limit is marked by a rapid decline of *Pinus* pollen and increase of *Juniperus* and NAP. Subzones were distinguished to denote culmination of *Juniperus* pollen in the older part of the zone.

Pinus — *Betula* pollen assemblage zone (3)

Pinus and *Betula* pollen frequencies are high: 49—63% and 47—12%, respectively. NAP values — still high in the older part of the zone — decrease in its younger part. Among NAP, *Gramineae* dominate, and *Artemisia*, *Chenopodiaceae*, *Filipendula* are present. Pollen concentration increases to 700000 in 1 cm^3. The lower limit is marked by rapid decrease of *Juniperus* pollen, NAP, and increase of *Pinus* values.

Pinus — *Betula* — *Corylus* pollen assemblage zone (4)

Pinus and *Betula* pollen values are similar to those in the younger part of the preceding zone. *Corylus* pollen curve increases to 8%, *Ulmus* exceeds slightly 1%, *Quercus* and *Alnus* pollen appear also. Pollen concentration is veiy high — up to 1700000 grains/cm^3. The lower limit was denoted at the increase of *Corylus* pollen values above 1% and *Ulmus* to 1%.

Corylus — *Alnus* — *Quercus* pollen assemblage zone (5)

Pinus pollen frequencies fall below 50%. *Alnus* pollen values increase rapidly (0.3—20%), and those of *Corylus* increase at the beginning of the zone, reaching maximum of 17%, *Quercus* pollen curve increases regularly up to 14% at the depth of 540 cm. At the end of the zone pollen of all deciduous trees is present. NAP maintains the value about 5%. Pollen concentration is slightly lower then in the preceding zone. The lower limit is placed at the increase of pollen curves of *Alnus* and *Quercus*. The zone may be divided into 2 subzones: subzone 1 is characterized by domination of *Alnus* and *Corylus* pollen, and subzone 2 by the *Tilia* pollen exceeding 1%, and an increase of *Ulmus* and *Quercus* pollen values.

Quercus — *Corylus* pollen assemblage zone (6)

The pollen curves of *Pinus* and *Betula* follow a regular course. After a decline at the lower limit of the zone, *Ulmus* curve continues to oscillate, while the curves of *Corylus*, *Quercus* and *Alnus* are stabilized. *Carpinus* pollen appears; at the end of zone its values exceed 1%. From the middle of zone, *Fagus* pollen appears regularly (up to 0.6%). NAP are represented in small quantities. Pollen concentration initially high, falls at the end of the zone. The lower limit was distinguished at the point of another increase of *Corylus* and decrease of *Ulmus* pollen curves.

Pinus — *Carpinus* pollen assemblage zone (7)

Pinus pollen increases in the middle part of the zone from 46 to 55% and again decreases to 34%, *Carpinus* has three subsequently increasing maxima in this zone: 4.2, 6.4 and 10.5%. From the depth of 380 cm *Corylus* pollen curve does not exceed 5%, *Ulmus* pollen is represented by low frequency and irregular curve. A division was made into two subzones: 1 — *Corylus* — *Quercus* — *Tilia* and 2 — *Alnus* — *Quercus* which is justified by the fact that in the older part *Corylus* maintains values close to 5%, while in subzone 2 falls below 5%. The curves of *Tilia* and *Ulmus* are not continuous, while *Alnus* and *Quercus* pollen have not lost their importance.

Carpinus — *Quercus* — *Alnus* — *Fagus* pollen assemblage zone (8)

The *Pinus* pollen curve shows oscillations from 21.2% to 32.3%. *Carpinus* reaches its absolute maximum of 27% at the depth of 180 cm. NAP shows negative correlation to *Carpinus* pollen curve, reaching the highest values where *Carpinus* frequences are at depressions. The lower limit of the zone was placed at the point of rapid increase of *Carpinus* and decrease of *Pinus* pollen values.

Pinus — *Fagus* pollen assemblage zone (9)

Pinus pollen curve increases steadily from 32% to 49% and so does NAP (max. 17%); *Betula* values decline from 20.7% to 12.6%; *Fagus* exceeds 1%. *Ulmus*, *Fraxinus*, *Tilia* and *Salix* values are below 1%. The lower limit was placed at the increase of *Pinus*, *Fagus* and NAP frequencies, and decrease of most other tree pollen.

Pinus — NAP pollen assemblage zone (10)

Pinus pollen dominates in the whole zone with values 48.4% to 56.9%. Declining tendencies show pollen curves of *Corylus* and most deciduous trees — *Ulmus*, *Quercus*, *Tilia*, *Carpinus*. NAP are represented abundantly (from 14.1% to 18.8%), *Picea*, *Fagus*, *Salix* and *Juniperus* occur regularly but are represented by low pollen curves, not exceeding 1%. The lower limit was drawn at the point of increase of *Pinus* and decrease of *Carpinus* and *Fagus* pollen curves.

REGIONAL HISTORY OF VEGETATION

The Late Glacial

Pinus — *Betula* PAZ (1)

This zone is represented by a 5 cm peat layer in the profile 6 and 3. The peat accumulation in both profiles began at the same time and under similar habitat conditions, which is evidenced by the identical sediment thickness and very similar composition of pollen spectra (Tab. 4).

Table 4

Comparison of pollen spectra from profiles 6 and 3

Profile 6 (main)				Profile 3			
PAZ	Depth (cm)	*Pinus* (%)	*Betula* (%)	PAZ	Depth (cm)	*Pinus* (%)	*Betula* (%)
1	1043	73.6	17.8	1	528	78.5	4.6
	1044	85.0	9.6		530	87.7	8.8
	1045	91.9	4.5		535	89.1	8.0

The above data correspond well with the results decribed for the Grudziądz Basin (Lake Rudnik) were the peat layer with a similar pollen composition was dated at 11630±265 BP (Lu — 984, Drozdowski, Berglund 1976). The lower limit of the zone is radiocarbon dated at 11910±210 BP. It may be believed on the basis of pollen analysis that this age is too old, as the zone coresponds to the younger part of the Alleröd chronozone.

The high percentages of *Pinus* pollen and the presence of pine macrofossils may suggest that in the Brodnica Lake District, pine forests with birch admixture dominated during the Alleröd time. The representatives of open plant communities are found sporadically *(Artemisia, Chenopodiaceae, Epilobium)*. During this zone the shallow water basin in the depression of Strażym channel was being gradually overgrown. The following taxons were growing in the lake: *Nuphar*, *Nymphaea*, *Potamogeton*, *Sparganium*, *Menyanthes* and *Typha latifolia*.

Juniperus — *Artemisia* PAZ (2)

In both profiles 6 and 3 the zone is represented by humus sand and in profile 6 also partly by gyttja. Pollen grains are well preserved but in the profile collected nearer the shore (3) a 10 cm layer without pollen was found. It was probably the result of a strong shore abrasion causing a more intensive inflow of mineral matter into the lake. The sudden expansion of *Juniperus* and herbs was caused by the climatic cooling and thus thinning of woodland which in turn enhanced the erosion in the neighbouring areas. Sand grains originating from that period do not show characteristics of any aeolian transportation, hence, there is no ground to believe that the aeolian processes in this area supplied much sand, as is the case in the profiles from north-western Poland (Tobolski 1966, Hjelmroos—Ericsson 1981) and from Central Poland (Wasylikowa 1964). This is also confirmed by the lack of dunes on the neighbouring outwash. The expansion of *Juniperus* during the Younger Dryas is synchronous in many diagrams of Northern Poland (Noryśkiewicz 1982, Hjelmroos—Ericsson 1981).

The more open pine forests than in the previous zone, enbled birch to develop. Pollen of such plants of pioneer and heliophilous communities as e.g. *Helianthemun*, *Scleranthus perennis*, *Saxifraga*, *Epilobium*, *Cerastium*, *Armeria*, *Sedum* and *Arctostaphylos* was found. Pollen of *Cornus suecica*, *Papaver*, *Sedum* and spores of *Lycopodium selago* indicate communities of forest tundra representing cold climate. In the close vicinity of the lake grew *Empetrum*. This Arctic — Boreal — Alpine plant has survived in the Brodnica Lake District to the present day and its single stands were described from the peatbogs of this area by Kępczyński (1965). *Filipendula*, connected with tall herb communities reaches its maximum in this zone. Aquatics did not respond as dramatically as pine to the Younger Dryas cooling: *Nymphaea*, *Nuphar* and *Menyanthes* continued to grow in the lake and *Pediastrum* reaches high values. In the middle of zone, percentage values of *Juniperus* pollen and NAP decline, while frequencies first of *Betula* and then also of *Pinus* pollen increase. This change of vegetation is synchronous with the increase of ^{18}O isotope content indicating rise of temperature (Różański, this volume). Berglund et al. (1984) mention a warmer oscillation during the Younger Dryas evidenced by identified beetle assemblage typical for the temperate zone. These authors date the warming at 10500 BP, making a reservation based on pollen diagrams from Southern Sweden that the vegetation responds to the temperature rise with 300 years delay. Zone 2 is synchronous to the Younger Dryas chronozone.

Holocene

Pinus — *Betula* PAZ (3)

The sediment of that zone is calcareous gyttja. At that time, birch and willow woodland occupied most probably the humid habitats. *Ulmus* and *Corylus* appeared sporadically. Herb communities pressed by developing forests lose the area. The consistent occurrence of *Filipendula* pollen and sporadic occurrence of *Humulus* and *Thalictrum* pollen indicate a significant role of those taxa in herb layer of woodland on humid habitats.

The increased content of organic matter in sediment of profile 6 simultaneous with the peat formation in profiles 2 and 3, permit a conclusion that lake water level decreased (Niewiarowski, this volume, Fig. 5). The swamp communities were formed by *Cladium mariscus*, *Typha latifolia* and *Dryopteris thelypteris*. The occurrence of pollen and fruits of *Cladium mariscus* in the deposit — a species which had arrived in the Brodnica Lake District from the west through the Drwęca River valley, suggests July temperature being at last 17°C. The appearance of *Cladium mariscus* as early as the beginning of the Holocene is a proof of quick rise of temperature, after the Younger Dryas cooling. Similar conclusions may be drawn from the observation of $\gamma^{18}O$ curve (Różański, this volume). Zone 3 may be correlated with the older part of the Pre-Boreal chronozone.

Pinus — *Betula* — *Corylus* PAZ (4)

The vegetation of this zone is characterised by further development of pine — birch forests. The pollen concentration reaches its highest values during the Holocene. In the forests on drier soils *Juniperus* continued to grow. *Corylus*, a thermophilous species, increased its range, spreading in the understory of pine forests on more fertile soils. Elm grew im more humid places. The low frequences of *Quercus* and *Alnus* pollen are probably the result of long distance transport. Among herbs *Gramineae* are most abundant and, besides, the plants of humid habitats — *Filipendula*, *Thalictrum* and *Dryopteris thelypteris* were found. This zone corresponds to the younger part of the Pre-Boreal chronozone.

Corylus — *Alnus* — *Quercus* PAZ (5)

A characteristic feature of this zone is spreading of thermophilous deciduous trees occupying the most fertile soils. *Pinus* is most likely confined to poor soils on outwash. This zone has been divided into two subzones based on the spread of particular trees.

Alnus — *Ulmus* PASZ (5a)

Pinus woods are gradually reduced by hazel shrub communities spreading on channel slopes exposed to the south. The oak becomes a component of pine woods. The expansion of alder coinciding with oak expansion was possible because of different habitat pereferences of these trees. Alder grew on humid depressions, and along the stream and lake shores. *Melampyrum* pollen and *Pteridium aquilinum* spores found in the deposit come from open pine — oak forest. Spores of *Polypodiaceae* and *Dryopteris thelypteris*, already found in the previous zone, but now in smaller amounts, prove permanent occurrence of damp habitats in the lake shore zone.

Tilia — *Fraxinus* PASZ (5b)

During the second subzone, the forest composition in the Brodnica Lake District undergoes distinct changes. *Corylus* restricts its occurrence to the understory of forests. Linden, oak, elm and ash spread remarkably and then reach stables proportions in forest composition. On poor soils pine forests with birch and oak contribution dominate, with *Calluna* and *Pteridium* growing in herb layer. The more fertile soils especially on morainic plateau were occupied by oak woodlands with developed undergrowth. However their herb layer formed mostly by entomophilous species is poorly represented in the lake deposit, because of dense growth of trees and shrubs on the slopes of subglacial channel. A new forest community in this zone is the pine — oak — linden forest. The fertile places with a high ground water level, especially in the vicinity of the lake and in the wet depressions were occupied by the riparian forests composed of alder, ash, elm and probably birch. The stable and high birch pollen values (average 20%) suggest the presence of *Betula pubescens* growing together with alder on swampy lake shore. Birch peak at 630 cm level of profile 6, and even more distinct in profile 3 at 340 cm occurs in both pollen and macrofossil diagrams, after the decrease of pine pollen values and is parallel to *Ulmus* decrease. This suggests the spread of *Betula pendula* as a result of forest fire. The pollen of culture indicators — *Artemisia* and *Rumex acetosa* — appear simultaneously. At the end of the zone a continuous *Carpinus* pollen curve begins, accompanied by sporadic *Fagus* pollen grains. These trees did not as yet grow in close vicinity of the lake and their pollen comes from a long distance transport.

Cladium mariscus pollen and macrofossils occurs since zone 3 (Pre-Boreal) but a distinct rise and maximum occurrence takes place in zone 5. The older part of this zone may be correlated with the Boreal chronozone, while the younger with the Atlantic chronozone. Remarkable spread of *Cladium mariscus* and occurrence of *Viscum* and *Hedera* seem to indicate the Holocene climate optimum. The conclusion is confirmed by the $\gamma^{18}O$ isotope curve.

Quercus — *Corylus* PAZ (6)

As a whole, zone 6 is represented only in profile 6, while in pıofile 3 only its youngest part is represented, in which elm and linden decrease. During the younger part of the zone, these trees again recover their pollen values. Pine — oak forests with linden played a predominant role on the Brodnica Lake District at that time. Hazel probably grew on forest edges and within the forest communities it formed a part of understory. At the end of this zone the hornbeam starts spreading on fertile soils. At this stage of its succession the hornbeam was not competitive to pine what is proved by *Pinus* stable percentage values. Small pollen percentage of spruce (below 0.5%) prove that the area of the Brodnica Lake District lay outside the range of *Picea* continuous distribution which is also the case today. Its pollen grains found in profile come from a long distance from the areas to the north — east and south — west, or from single stands of spruce on humid sites (Środoń 1967, Ralska-Jasiewiczowa 1983). NAP curve falls to its minimum in this zone. In addition to *Gramineae* and *Cyperaceae* pollen also *Lysimachia thyrsiflora* pollen was found. Zone 6 represents decline of the Atlantic and older part of the Sub-Boreal chronozones.

Pinus — *Carpinus* PAZ (7)

Hornbeam, continuously occurring in pollen spectra from the Atlantic period through the older part of the Sub-Boreal, clearly increases its percentage pollen values in zone 7. Together with oak, linden and maple it forms deciduous forest communities. Along with increasing frequency of hornbeam constant presence of *Plantago lanceolata*, *Urtica*, *Rumex* and *Artemisia* is marked which is indicative of intensified human activity.

Corylus — *Quercus* — *Tilia* PASZ (7a)

Hazel shows tendencies to decline but its pollen curve holds between 7 and 4%. On moraine plateau grow *Tilio* — *Carpinetum* forests. Low percentages of beech pollen come mainly from long distance transport.

Alnus — *Quercus* PASZ (7b)

Pollen diagram shows declining values of almost all deciduous trees, which indicates limited areage of deciduous forests and a short-term growth of pine stands with birch. After that stage, hornbeam increases its percentage pollen values, not accompanied by any simultaneous increase of other deciduous trees. This must have been a short — time process because hornbeam pollen values decrease again and then rise for the thirt time simultaneously with the increase of linden and oak pollen values. At the end of subzone 7b pollen curves of deciduous trees decrease while pollen values of plants indicating human activity increase. These are: *Plantego lanceolata*, *Urtica*, *Artemisia* and *Cerealia*. The zone corresponds chronologically to the younger part of the Sub-Boreal and older part of the Sub-Atlantic chronozones.

Carpinus — *Quercus* — *Fagus* — *Alnus* PAZ (8)

Rapid expansion of hornbeam, facilitated by human activity changed the character of the Brodnica Lake District forests. On fertile soils, especially on the moraine plateau, deciduous forests developed in which, depending on habitat conditions, an important element was either beech or pine — along with the hornbeam and linden. The variant *Tilio — Carpinetum* with *Fagus sylvatica* is now found near Lake Mieliwo, about 7 km north-west of Lake Strażym. Some forest communities situated near this basin, relatively little affected by human activity, are protected because of massive occurrence of beech growing near its natural continuous range. This species displays great vitality in all forest layers and great expansiveness especially on compact soils (Zielski 1978). At the end of the zone, as shown by the decrease of hornbeam pollen values, pine entered areas hitherto occupied by that species. This change of forest composition may have been caused by pine-protecting human activity.

Pinus — *Fagus* PAZ (9)

This zone is characterized by increase of pine and NAP percentage values with stable pollen frequency of beech, and distinctly decreasing hornbeam pollen curve. The areas occupied by deciduous forest communities were restricted by pine forests and deforestation activities. Together with dominating *Pinus*, *Fagus*, *Betula*, *Carpinus*, *Tilia* grow in the forests, with *Frangula*, *Juniperus* and *Corylus* in understory. Restructuring of plant communities observed in this zone was caused by the intensified human activity which caused in addition to pine — protection also an increase of NAP percentage values, among which anthropogenic plant species played a significant role.

That is the Late Sub-Atlantic chronozone.

Pinus — NAP PAZ (10)

The destructive influence of man upon natural forests recorded from the beginning of zone 9, intensifies. Further retreat of deciduous trees is marked, only alder growing on lakes shores and along the rivers holds on to its position. Pine pollen reaches high values and herbs find here their Holocene maximum. In NAP composition high percentage is reached by *Cerealia*, *Fagopyrum*, *Centaurea cyanus*, *Papaver*, *Artemisia* and *Chenopodiaceae*. That is the youngest part of the Sub-Atlantic chronozone.

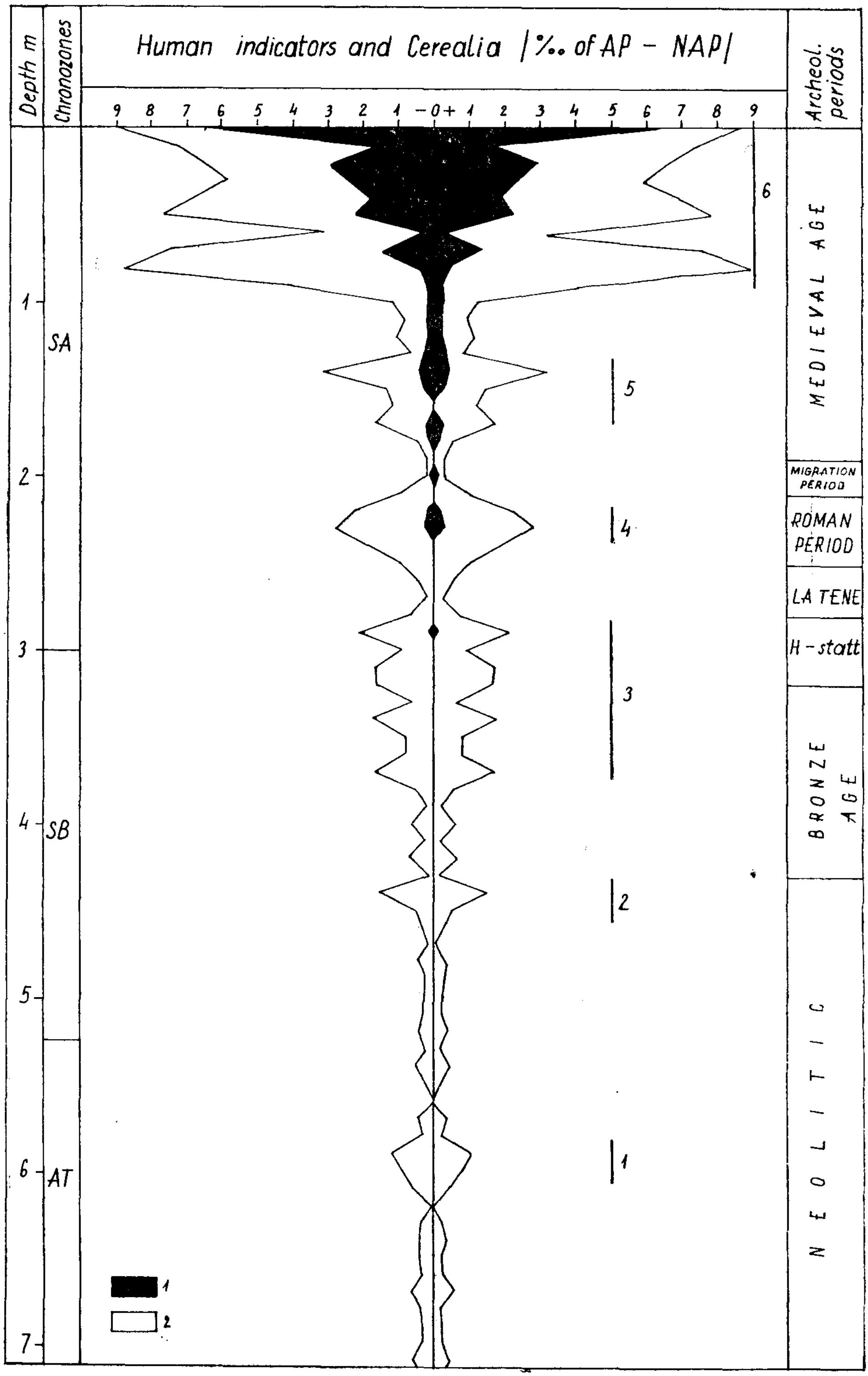
On the basis of changes in the deciduous and pioneer tree curves, and the appearance of plants indicative of human activity 6 settlement phases were distinguished in the younger part of the Holocene (Fig. 5).

The oldest phase is only marked in the diagram by the depressions of *Ulmus* and *Quercus* curves, the increase of *Artemisia* and presence of *Urtica* and *Rumex acetosa* pollen. This phase is better manifested in profile 3 collected in the shallower part of the lake where at 340 cm the distinct peaks of *Betula* pollen and *Pteridium* spores are observed. The character of those changes suggests a fire but there is no evidence of its anthropogenic origin. The fire is also reflected by the intensified erosion processes recorded at 600 cm level in profile 6 by the increased supply of mineral matter into the lake (Lankauf, this volume). The quick regeneration of trees and return of the ignition residue curve to its previous values proves a short — time habitat change. This phase corresponds probably to the period of the Early Neolithic during which the population of Corded Ware culture lived in the Brodnica Lake District, but absence of ^{14}C datings from calcareous gyttja makes the unequivocal synchronization with archaeological data unpossible.

The next settlement phase is marked by the presence of *Plantago lanceolata*, *Rumex acetosa* and *Artemisia* pollen, while at the same time frequencies of *Ulmus*, *Quercus* and *Tilia* pollen decrease. *Cerealia* are absent while presence of pasture plants suggests the animal husbandry and cattle grazing on deforested areas. Despite absence of ^{14}C datings the phase may be synchronized with the Late Neolithic assuming that hornbeam spread in this area took place about 3700 BP. According to archaeologists (Huszcza 1969) the settlement at the outlet of the Rypienica River is connected with the Beaded Ware Culture.

After the second settlement phase there was a certain decrease of human activity manifested by increase of hornbeam and beech pollen values. The trees spread on the areas abandoned by man, forming together with oak and linden new forest communities in the Lake District. According to archaeological findings (Chudziakowa 1974) this happened during the fall of the Neolithic and I and II phase of the Bronze Age.

The third settlement phase was connected with the Lusatian Culture population. Two depressions of the *Carpinus* curve synchronous with the decline of *Ulmus* and *Quercus* pollen frequencies are recorded in the pollen diagram, coincident with the increase of pine, birch and herb pollen values. *Plantago lanceolata*, *Rumex acetosa*, *Urtica*, *Artemisia* and *Chenopodiaceae* are present. The absence of distinct culmination of culture indicators permits to believe that Lusatian Culture people settled on the area gradually, without reaching the close vicinity of the lake. The conclusions drown from the pollen diagram fit archaeologists' findings (Chudziakowa 1974) assuming that the region limited by rivers Vistula, Drwęca and Osa was uninhabited during the Early Bronze Age. During the later phase of the Bronze Age archaeologists distinguish



Depth m
Chronozones
Human indicators and Cerealia |‰ of AP - NAP|
Archeol. periods
9 8 7 6 5 4 3 2 1 - 0 + 1 2 3 4 5 6 7 8 9
1
2
3
4
5
6
7
SA
SB
AT
6
5
4
3
2
1
MEDIEVAL AGE
MIGRATION PERIOD
ROMAN PERIOD
LA TENE
H-statt
BRONZE AGE
NEOLITHIC
1
2

4 phases of Lusatian Culture development. These phases are synchronous with 3rd settlement phase distinguished in the pollen diagram, and correspond respectively: first to III period of Bronze Age, second to IV and V, third to the older Hallstatt subperiod and fourth to the younger Hallstatt period and Early La Tene.

On the basis of archaeological finds — graveyards used for a short time, minimal number of settlements, scarce ceramics — Chudziakowa (1974) believes that during that period animal breeding prevailed over agriculture. This point of view may be supported by the palynological data — only 1 pollen grain of Cerealia was found in the section of diagram corresponding to this cultural phase.

Looking at the location of Lusatian sites (Chudziakowa 1974) one can easily notice their grouping along the valleys of rivers Vistula and Osa which is probably due to fertile soils as well as water transportation facilities and natural defensive features of sites. The area of moraine plateau together with lake surroundings was poorly populated during all that time which is reflected in relatively low amounts of anthropogenic pollen indicators in the diagram. The very distinctive depressions of hornbeam curve, simultaneous increase of pine, birch and NAP values reflect human activity over larger area. On these grounds the behavior of hornbeam pollen curve during all the younger part of the Holocene may be regarded as representative for a larger region such as Northern Poland (Hjelmroos-Ericsson 1981, Ralska-Jasiewiczowa 1981, Latałowa 1982, Noryśkiewicz 1982, Zachowicz et al. 1982).

The fourth settlement phase has been clearly marked in deposits of Lake Strażym. The pollen diagram evidences the high degree destruction of the orginal forests. The pollen values of hornbeam and linden — components of deciduous forests decrease. Further decline and even disappearance of *Ulmus* and *Fraxinus* pollen curves confirms the intensive utilization of fertile habitats hitherto occupied by riparian forests. The agricultural activites of man are recorded by *Cerealia* pollen including *Secale cereale*. This phase may be correlated with the Roman period from which comes a skeleton grave found in the village of Lembarg about 15 km west of Lake Strażym.

After the fourth settlement phase a period of regeneration of deciduous forests is clearly observed. The tree species typical of forests on fertile soils returned to the land first cultivated and then abandoned by man (oak — hornbeam, elm — ash). The similar changes are registered in the pollen diagram from Woryty, Olsztyn Lake District (Ralska-Jasiewiczowa 1981) where, as in the profile from Lake Strażym they are correlated with the Migration period.

The fifth settlement phase begins with another deforestation expressed by decrease of *Carpinus* and *Tilia* pollen values. This was caused by Early —

←

Fig. 5. Human impact diagram with the local anthropogenous phases. 1 — *Cerealia*, 2 — *Artemisia*, *Centaurea cyanus*, *Chenopodiaceae*, *Fagopyrum*, *Humulus*, *Linum*, *Papaver*, *Plantago lanceolata*, *P. major*, *P. media*, *Polygonum*, *Rumex*, *Urtica*, *Solanum*

Medieval population. The remains of two fortified settlements of that age were found close to the lake. The older of them was dated at X—XII century and considered as a refugial point. The excavations carried on in 1985 proved very scarce settlement traces on this site (personal communications). The phase ends with a short but distinctive break in human activity perhaps due to abandonment of the fortified settlements. The break in settlement was too short for the complete regeneration of deciduous forests but is marked by a spread of birch and some increase of hornbeam contribution.

The last, sixth settlement phase reflects the youngest period of man activities around the lake. It is characterized by highest percentage pollen values of cereals and pasture plants. Pollen grains of typical segetal weeds as, e.g. *Centaurea cyanus* and *Papaver* appear in the diagram. The reduction of deciduous forest area, in favour of farmland is very distinctive. Pine begins to dominate in forests being cultivated by man.

CONCLUSIONS

Palynological studies of the deposits of Lake Strażym provide data on the history of vegetation in the Brodnica Lake District from the Alleröd to modern times. The vegetational development has been described basing on 10 biostratigraphic zones distinguished in pollen diagrams. Zones 1 and 2 represent the Late Glacial vegetation, the others — the Holocene.

The most important features of vegetational development in the Brodnica Lake District are:

— in zone 1 (Alleröd) pine dominates, birch occurs in smaller amounts; there exists already a lake, with typical aquatic vegetation represented by *Nuphar* and *Nymphaea*;

— in zone 2 (Younger Dryas) heliophilous plant communities with *Juniperus* shrubs dominate, pine forests are restricted though pine continues to grow in the Brodnica Lake District. In the middle of the Younger Dryas there was a rise of temperature reflected by the NAP and *Juniperus* decline and spread of *Betula*, confirmed by the oxygen isotope studies;

— the improvement of climate in zone 3 (Pre-Boreal) causes the spread of forest communities with *Pinus* and *Betula*;

— zone 4 begins with the spread of *Corylus* and *Ulmus*;

— in subzone 5a the participation of *Alnus* and *Quercus* in woodlands increases;

— the small amounts of *Picea* pollen prove that the Brodnica Lake District lay outside the range of this tree during the whole Holocene;

— the climatic optimum is recorded in subzone 5b (Atlantic) by the highest values of *Tilia, Quercus, Ulmus* and *Fraxinus* pollen and maximum of pollen and fruits of *Cladium mariscus*, with simultaneous occurrence of *Viscum* and *Hedera*;

— the absolute maximum of *Carpinus* pollen in zone 8 (Sub-Atlantic) indicates its great role in forest communities of the Brodnica Lake District; at the same time *Fagus* increases its range.

On the basis of pollen diagram, six settlement phases were distinguished during the younger part of Holocene and correlated with archaeological data. The first and the least distinctive phase is correlated with the Early Neolithic, the first pollen grain of cereals was found in phase 3 while intensification of human activity falls on 5 and 6 settlement phases (Early Mediaeval and younger historical times).

The analysis of profiles collected at various water depths in the lake (165 cm, 175 cm, 575 cm) showed significant differences connected with the place of sediment accumulation within lake:
— profile 6 from the deepest part has sediment sequence from the beginning of lake existence to modern times;
— in the profile from the marginal part of the lake the sediment accumulation was disturbed by a hiatus coinciding with a part of the Atlantic and Sub-Boreal chronozones;
— limno — and telmatophytes are represented by higher pollen percentage curves in profiles collected from the shallow part of the lake and generally greater oscillations of pollen values occur in these profiles. The latter refers especially to alder, aquatics and *Polypodiaceae* spores. These profiles represent more distinctly the local vegetation;
— in the main profile (6) from the deepest part of the lake the history of regional vegetation is extensively reflected;
— Late Glacial and Early Holocene zones distinguished in profiles 3 and 6 have a very similar pollen composition.

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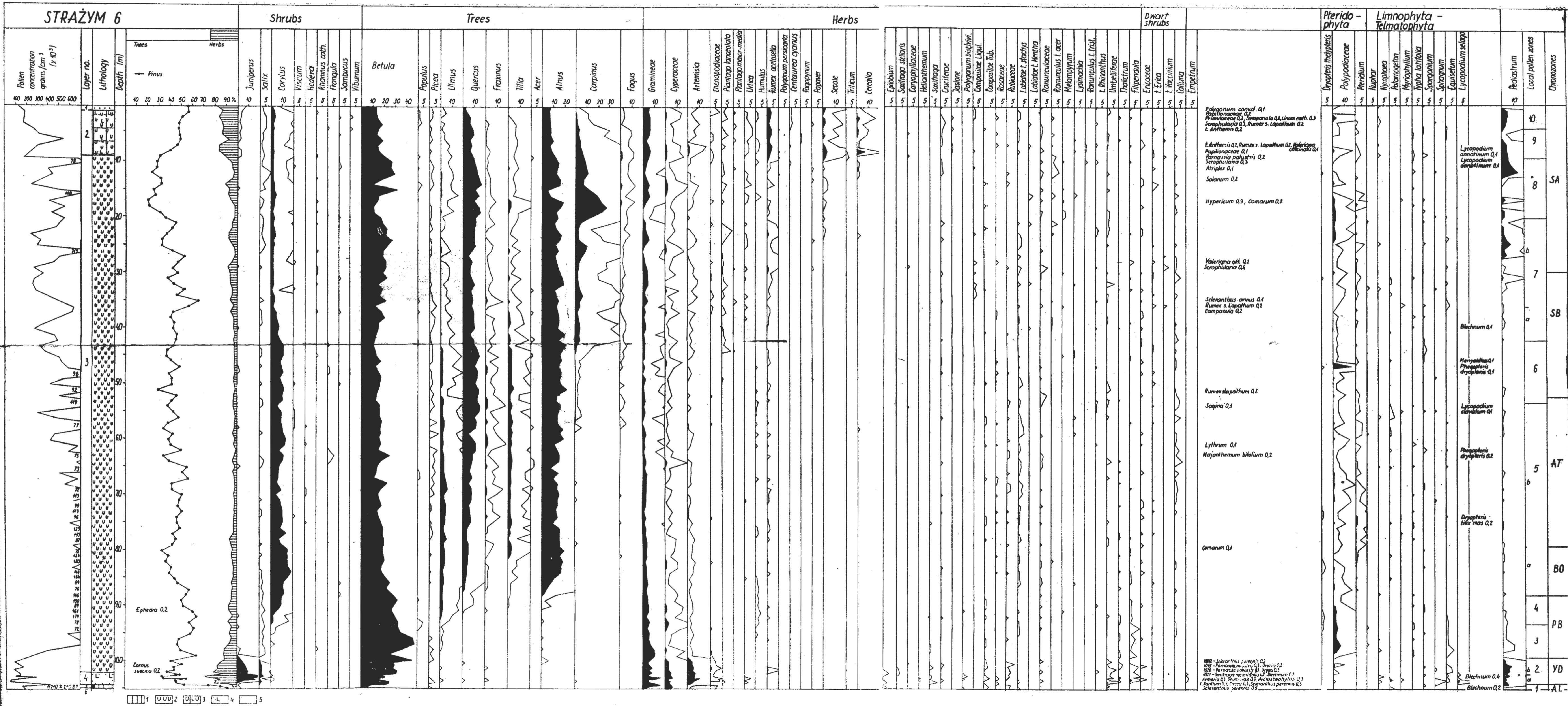

Fig. 2. Pollen diagram from the Lake Strażym profile 6 (main). 1 — peat, 2 — calcareous gyttja, 3 — clayey — calcareous gyttja, 4 — silty sand with organic matter, 5 — sand

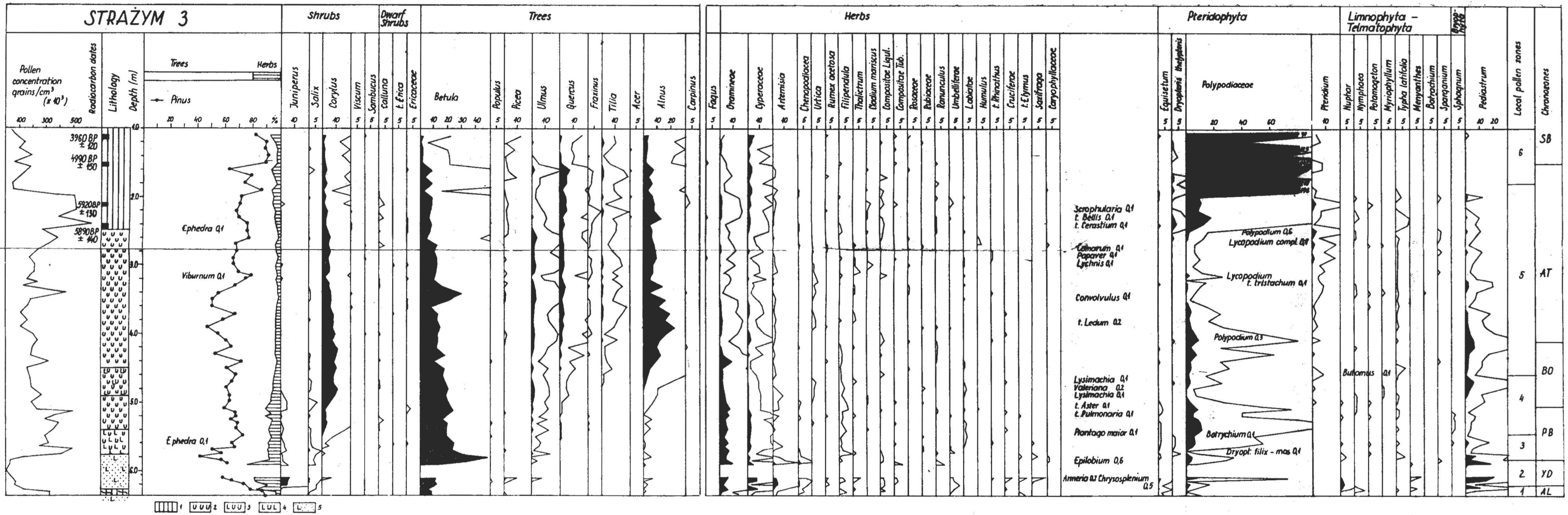

Fig. 3. Pollen diagram from the Lake Strażym profile 3. 1 — peat, 2 — calcareous gyttja, 3 — silty — calcareous gyttja, 4 — clayey — calcareous gyttja, 5 — sand