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Late Vistulian and Holocene changes in the Ner river valley in light of geological and palaeoecological data from the Ner-Zawada peatland

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The Ner-Zawada peatland is located in the valley of the Ner River in Central Poland. It is a small fen peatland that was formed in the Alleröd Period. In the Younger Dryas, it was transformed into a lake and became a peatland again in the Holocene. Within the peatland and around it, geological and archaeological research was carried out. A sediment core collected in the central part of the peatland was subjected to the analysis of pollen, fossil Cladocera, and absolute dating. This study allows a reconstruction of palaeoecological changes in the peatland and drawing conclusions about the palaeogeography of the middle section of the Ner River valley during the past 13 000 years.

Key words: peatland, pollen, cladoceran, palaeoecology, Late Vistulian, Holocene, the Ner River valley, Central Poland

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INTRODUCTION

Lakes and peatlands are archives of the past, therefore, investigations of their settings in different aspects (palaeoecological, archeological, geological, etc,) make the basis for the reconstruction of palaeo-conditions. In Central Poland, fen peatlands dominate (Żurek, 1987). Some of them have been investigated, but generally those were unidirectional studies. The present paper describes the Late Vistulian and Holocene environmental history of the Ner River valley, based on lithological, pollen, Cladocera and archeological data from the small Ner-Zawada peatland. The aim of this palaeoecological investigation was to document the record of human impact. The results allowed a palaeogeographical reconstruction of the Ner River valley.

The Ner-Zawada peatland is located in the central part of the Polish Lowland, in the outer part of the Ner River valley floor (Fig. 1), in its middle section. The Ner River valley in the study area is linked with an extensive east–west oriented landform (the so-called Warsaw–Berlin Spillway). The current Ner River channel has been regulated and protected by flood embankments. The peatland is located ca. 1 km away from the channel and covers ca. 5 ha. The peatland is located in an oval depression whose ordinate is similar to the Ner River valley-floor. The valley bottom, in the area in question, is composed mostly of Late Vistulian sediments which in the Holocene were dissected by active river channels. Outside the river channel, the Holocene sediments form a thin layer on older elements of the flood plain.

MATERIALS AND METHODS

Geological investigations included mechanical and hand drilling in the peatland and around it (Fig. 1). With the use of a soil sampler and a peat sampler (Eijkelkamp Agrisearch Equipment, the Netherlands) we documented the biogenic sediments within the peatland and collected the well NZ-1 core for detailed analyses. The grain-size distribution analyses (Folk, Ward, 1957; after Mycielska-Dowgiałło, 1995) and quartz-grain abrasion (according to the method of Cailleux (1942) modified by Manikowska (1993) were undertaken for sediments of the mineral substratum of the peatland. We also made use of some geological materials collected earlier, and of geomorphological mapping (Fig. 1).

The scope of the study was extended to include the analysis of Cladocera (commonly known as water fleas). Cladocera are small crustaceans that live mostly in lakes. Their ecological preferences are well known, so cladoceran species are good proxies for reconstruction of palaeoenvironment conditions (e. g., trophic status, fluctuations of water level, as well as pH in lakes). The analysis of Cladocera was based on 53 samples from the well NZ-1 core (depth 0–475 cm). Samples, 1 cm^3 each, were processed according to the standard procedure (Frey, 1986). The taxonomy of cladoceran remains in this paper follows that presented by Szeroczyńska and Sarmaja-Korjonen (2007).

Pollen analysis shows the development of local vegetation around the basin over time. Pollen was prepared and analyzed using standard methods according to Berglund and Ralska-Jasiewiczowa (1986). All sporomorphs were identified until a minimum of 500 pollen grains of trees and bushes (arboreal pollen, AP) were counted. Pollen grains of all herbaceous species (except the local aquatic and telmatic plants) were counted as NAP, and the sum of AP and NAP was considered as 100%. The zonation is confirmed by CONISS (Grimm, 1987). The CONISS dendrogram and diagram illustrating pollen distribution were plotted stratigraphically by means of Tilia2 and Tilia-Graph (Grimm, 1992).

We made basic chemical analyses of biogenic sediments, i. e. pH, calcium carbonate content, ash content (after Tobolski, 2000) and also radiocarbon dating of depostis from the NZ-1 core at the Poznan Radiocarbon Laboratory.

In the course of archaeological research, we compiled archival information on sites identified by means of the archaeological surface survey in the section of the Ner River valley under study.

RESULTS

Geological features

The Mesozoic bedrock in the study area, composed of limestones and marls dating back to the Late Cretaceous (Maastricht), is characterized by a great variation in altitude (Dutkiewicz, 1989; 1992). South of the Ner-Zawada peatland, the top of the Cretaceous rocks is relatively high and covered with a thin layer of Quaternary deposits (1.5 m to 6 m). The Cretaceous top is sloping down to the north and east (ca. 1.5 km away from the peatland it lies at a depth of 52 m (Dutkiewicz, 1989). Within the studied part of the valley, the Maastricht limestones and marls are covered with glacigenic deposits. These include fluvioglacial sands and gravels (Figs. 2, 3). It was not possible to date those sediments precisely on the basis of their arrangement. They are covered by till the origin of which is associated with the Wartanian (Saalian) glaciation

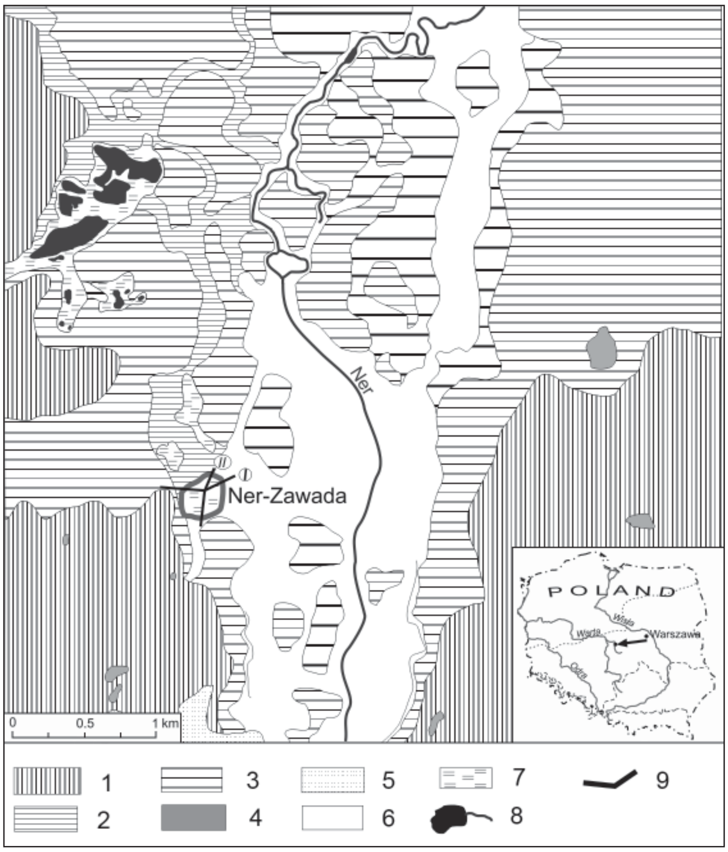

Fig. 1. Geomorphological map of the studied part of the Ner River valley (with location of study area):
1 – morainic plains, *2* – alluvial high terrace, *3* – alluvial low terrace, *4* – depressions, *5* – aeolian plains, *6* – river valley bottom, *7* – peatlands, *8* – rivers and artificial water bodies, *9* – cross-sections (Figs. 2 and 4)

1 pav. Tirtos Nero upės slėnio dalies geomorfologinis žemėlapis:
1 – moreninė lyguma, *2* – viršutinė aliuvinė terasa, *3* – žemutinė aliuvinė terasa, *4* – įdubos, *5* – eolinė lyguma, *6* – upės slėnio dugnas, *7* – pelkynas, *8* – upės ir dirbtinės vandens arterijos, *9* – pjūvių linijos (2 ir 4 pav.)

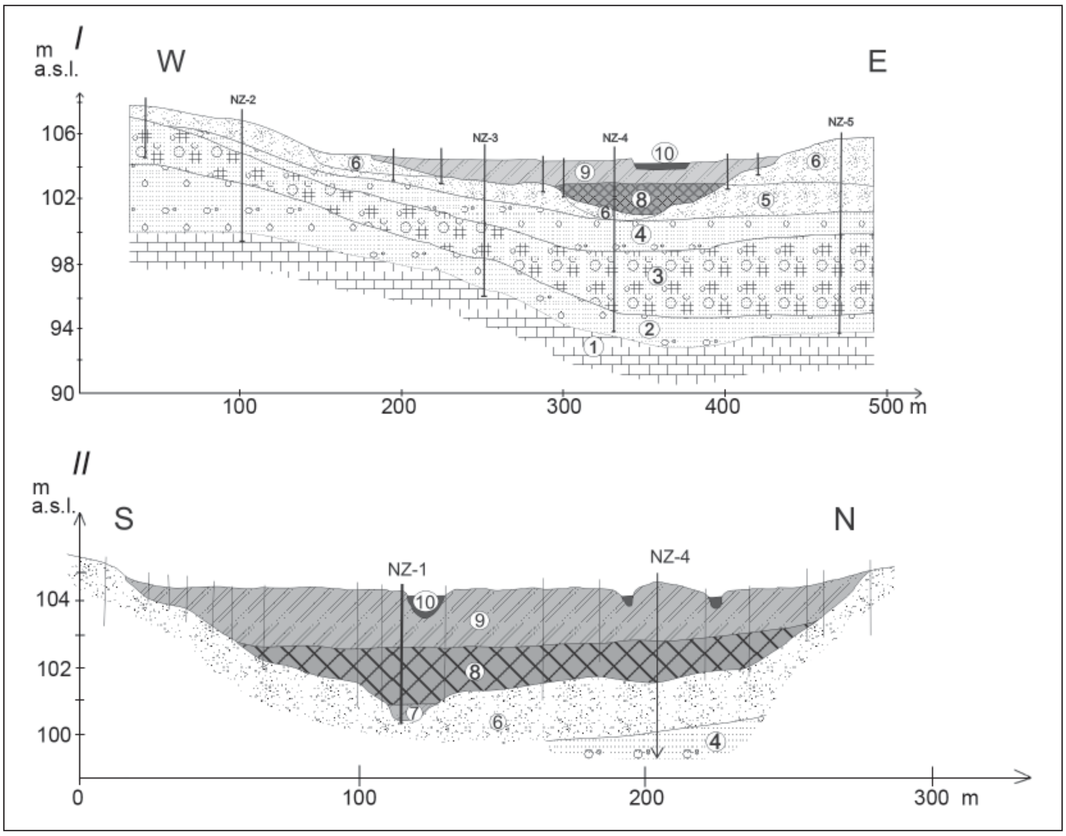

Fig. 2. Geological cross-sections WE of the Ner-Zawada peatland:
1 – marl and limestone (Cretaceous); *2–7* – quaternary: *2* – fluvioglacial sand and gravel, *3* – till (Wartanian / Saalian), *4* – fluvioglacial sand and gravel (Wartanian / Saalian), *5* – fluvial sand (Plenivistulian), *6* – fluvial sand (Late Vistulian), *7* – gyttja (Late Vistulian); *8* – peat (Holocene); *9* – water

2 pav. Ner-Zavados pelkyno geologinis pjūvis:
1 – kreidos mergelis ir klintis; *2–7* – kvartero: *2* – fliuvioglacialinis smėlis ir žvirgždas, *3* – morena (Vartos / Salio), *4* – fliuvioglacialinis smėlis ir žvirgždas (Vartos / Salio), *5* – fliuvialinis smėlis (Plenivyslos), *6* – fliuvialinis smėlis (vėlyvosios Vyslos), *7* – gitija (vėlyvosios Vyslos); *8* – dirvožemis (holocenas); *9* – vanduo

(according to Dutkiewicz, 1989; 1992) when the study area was glaciated for the last time. The till layer is continuous and 2–4 m thick at a plateau situated within the buried slope of the Ner valley, west of the peatland (Fig. 2), but in the valley axis it is dissected (Dutkiewicz, 1989; 1992). Glacial till is characterized by a poor sorting and the texture typical of basal tills in this region, with calcium carbonate content about 10%, while quartz-grain abrasion indicates that most grains are of RM and EL types (Fig. 3).

The Wartanian till is covered by another layer of fluvioglacial sands and gravels (Figs. 2, 3) which form the substratum for fluvial sediments accumulated as early as in the Vistulian (i. e. in the last glacial period). The Vistulian fluvial sediments are characterized by predominance of sand. They are better sorted than fluvioglacial and have a low calcium carbonate content. Also, quartz-grain abrasion indicates that most grains were shaped in the aeolian environment (40–56%, Fig. 3). This is characteristic of Plenivistulian (= Middle Vistulian) sediments which build the high river terraces in Central Poland (e. g., Turkowska, 1988; 2006; Goździk, 1995). These fluvial sands directly underlie the biogenic sediments of the Ner-Zawada peatland.

Its substratum is composed of well-sorted, decalcified sands and gravels. Most of quartz grains have been shaped by wind (aeolian abrasion), so they seem to originate from the aeolian environment of an Upper Plenivistulian river.

The mean thickness of the biogenic sediments that fill the oval depression is about 200 cm (Fig. 2). However, in the central part, a deeper place is located, where the profile of peats and gyttia deposits is 470 cm deep (well NZ-1, Fig. 2). At the bottom of the deposits filling the depression, a peat series was documented, lying at a depth of 395–470 cm. Above, to the depth of ca. 220 cm, detritous and carbonate gyttia is located. It is covered with yet another peat series which forms the top of the deposits. The sediments from the NZ-1 core were analysed, and the results are presented below.

Pollen analysis

The pollen diagram is divided into five local pollen assemblage zones (LPAZ) on the basis of AP and NAP percentage curves. Only major trees and selected taxa used in the discussion are shown.

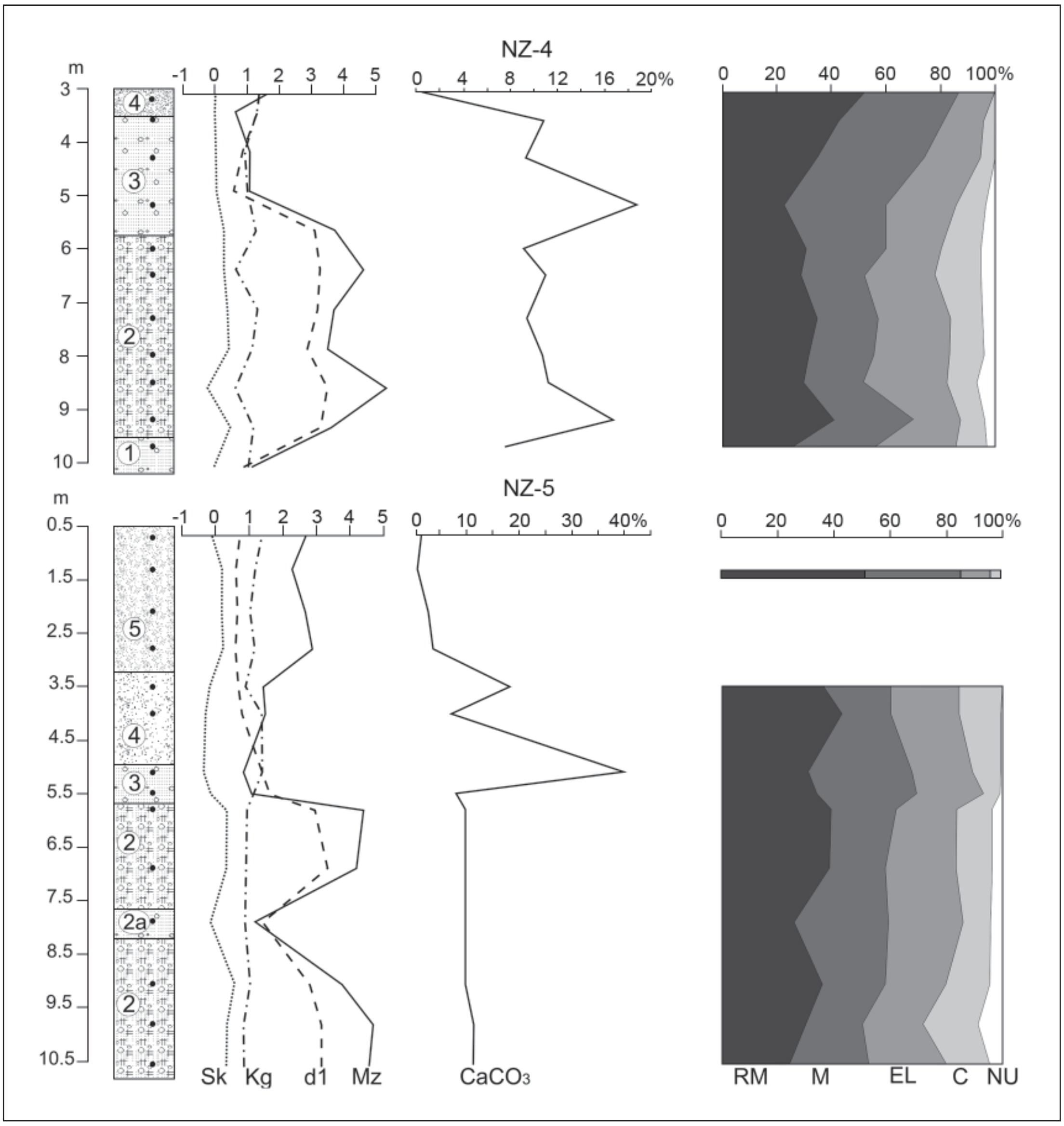

Fig. 3. Lithology of NZ-4 and NZ-5 drillcores. The grain-size coefficients (Folk, Ward, 1957; after Mycielska-Dowgiałło, 1995): Mz – mean size, d1 – standard deviation, Sk – skewness, Kg – curtosis. Quartz-grain abrasion by the Cailleux method (Cailleux, 1942; Manikowska, 1993): RM – round mat, M – intermediate, EL – shiny, C – crushed, NU – unabraded (fresh). Lithology: *1* – sand and gravel, *2* – till, *2a* – coarse sand (insertion), *3* – sand and gravel, *4* – sand, *5* – sand with silt

3 pav. NZ-4 ir NZ-5 gręžinių litologija. Granuliometriniai koeficientai (Folk & Ward, 1957; pagal Mycielska-Dowgiałło, 1995): MZ – vidurkinis dydis, d1 – standartinis nuokrypis, Sk – asimetriškumas, Kg – išrūšiavimas. Kvarco grūdelių abrazija pagal Cailleux metodą (Cailleux, 1942; Manikowska, 1993): RM – matinis, M – vidutinis, EL – atsispindintis, C – trupintas, NU – neabraduotas. Litologiniai ženklai: *1* – smėlis ir žvirgždas, *2* – morena, *2a* – stambus smėlis (intarpas), *3* – smėlis ir žvirgždas, *4* – smėlis, *5* – smėlis su aleuritu

Table 1. **Characteristics of distinguished local pollen assemblage zones (LPAZ, see Fig. 4)**
1 lentelė. **Žiedadulkių zonos ir jų apibūdinimas (4 pav.)**

LPAZ symbol	LPAZ name	Depth, cm	Description
Ner-5	Pinus-NAP-Alnus	0–87	Growth of NAP and human activity indicators. Decrease in *Pinus*. *Alnus* appears and achieves a very high percentage. Increase in telmatophytes
Ner-4	Pinus-Corylus-Ulmus	87–212	*Pinus* dominates. *Corylus* and *Ulmus* present. Aqautic plants disappear. Low percentages of telmatophytes
Ner-3	Betula	212–277	Peak of *Betula*, with absolute maximum 57.8% at 250 cm. Decrease in *Pediastrum* and telmatic plants
Ner-2	NAP-Juniperus	277–415	Peak of NAP (with maximum 25%), high but lowering share of *Pinus*. *Juniperus* present. Increase in *Pediastrum,* up to over 50%
Ner-1	Pinus	415–475	Peak of *Pinus*, followed by a decline. Single coenobia of *Pediastrum*

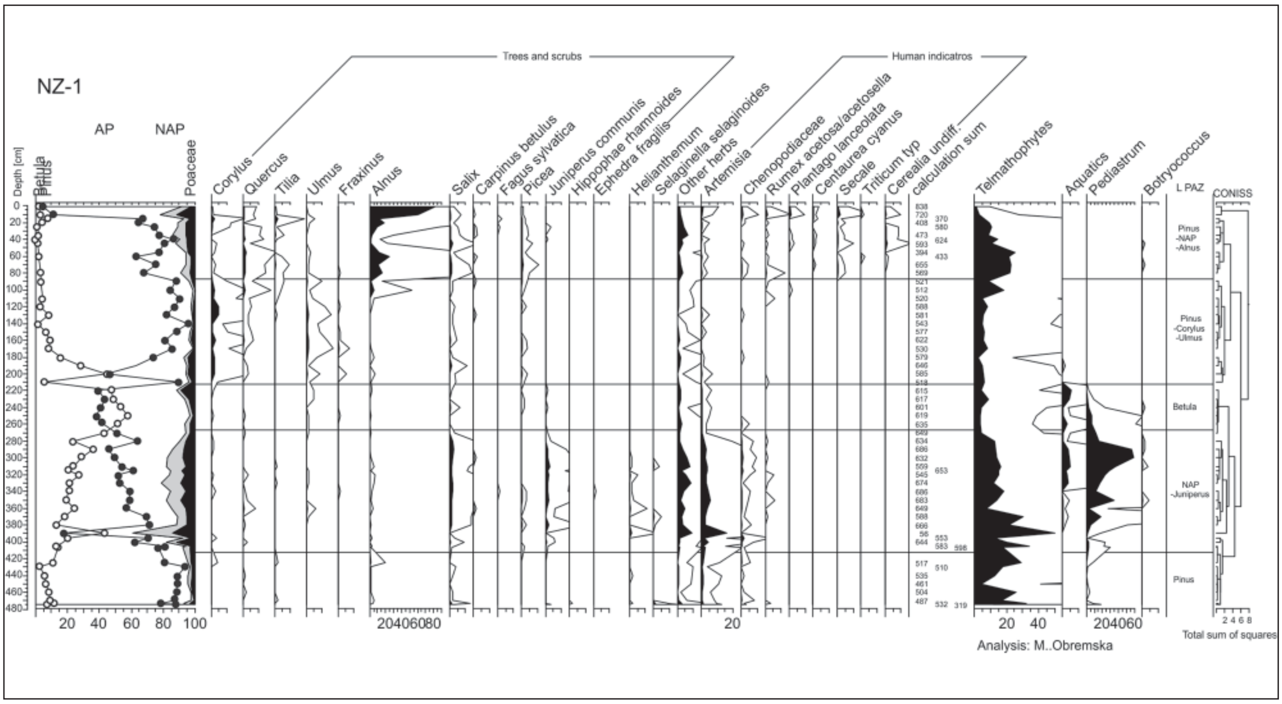

Fig. 4. Percentage pollen diagram of core NZ-1 (selected taxa)

4 pav. NZ-1 kerno žiedadulkių procentinė diagrama (pasirinktos rūšys)

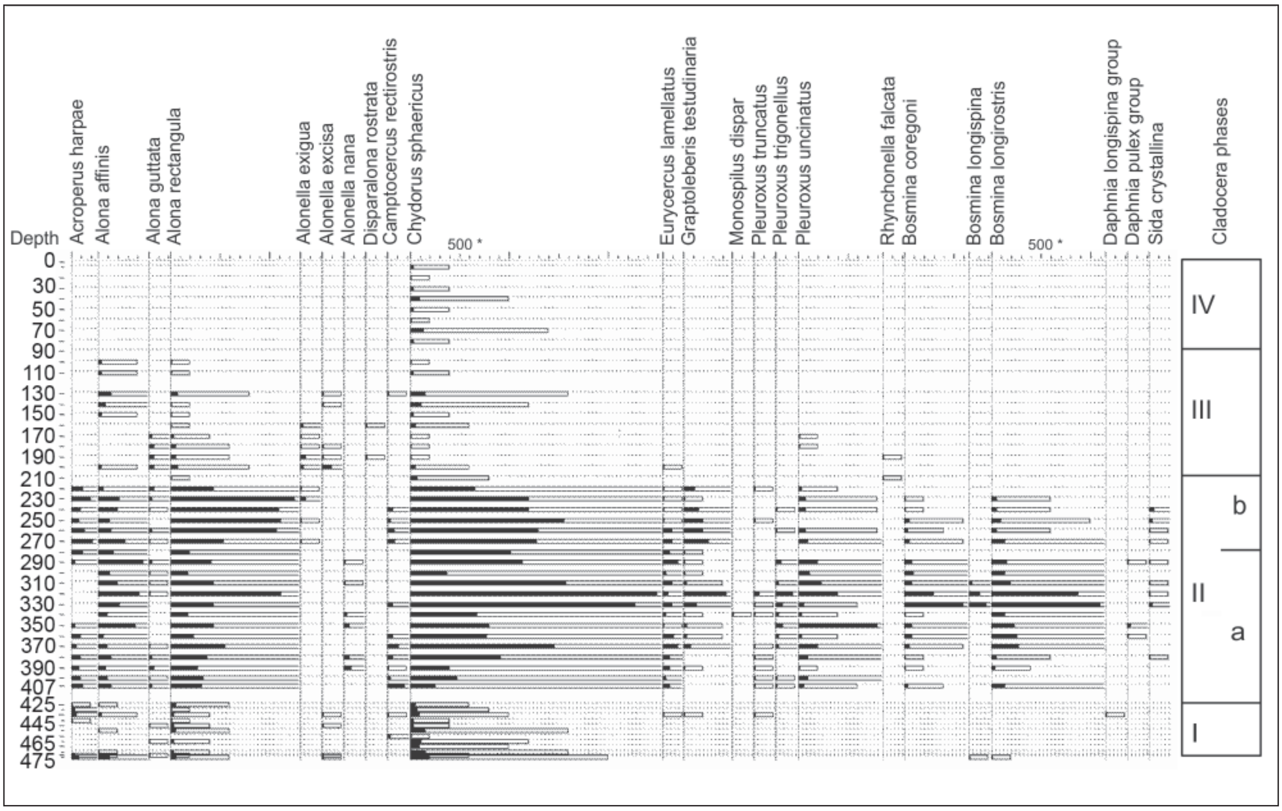

Fig. 5. Diagram of the absolute number of Cladocera individuals in sediments of the Ner-Zawada peatland. Lithology explanations:
1 – gyttja, *2* – peats. Scale on diagram shows specimens in 1 cm^3 of fresh sediments

5 pav. *Cladocera* radinių kiekis mėginyje iš Ner-Zavados pelkyno. Litologiniai ženklai:
1 – gitija, *2* – dirvožemis. Mastelis diagramoje rodo 1 cm^3 radinius nuoguloje

Cladocera communities

In sediments of the Ner-Zawada peatland, 23 cladoceran species (Fig. 5) were recognized. Most numerous were littoral species. On the basis of the communities of Cladocera and changes in the frequency of different species, four phases of the development of cladoceran communities were distinguished (Table 2 and Fig. 5).

Archaeological evidences

In the immediate vicinity of the Ner-Zawada peatland (i. e. within a distance of 1.0 km from the mire – Fig. 6), an ensemble of 16 archaeological sites was discovered during the nationwide archaeological survey of Poland ("Archeologiczne Zdjęcie Polski", abbreviated AZP). Those 16 sites have been subdivided into 31 archaeological cultural horizons (so-called "archaeo-

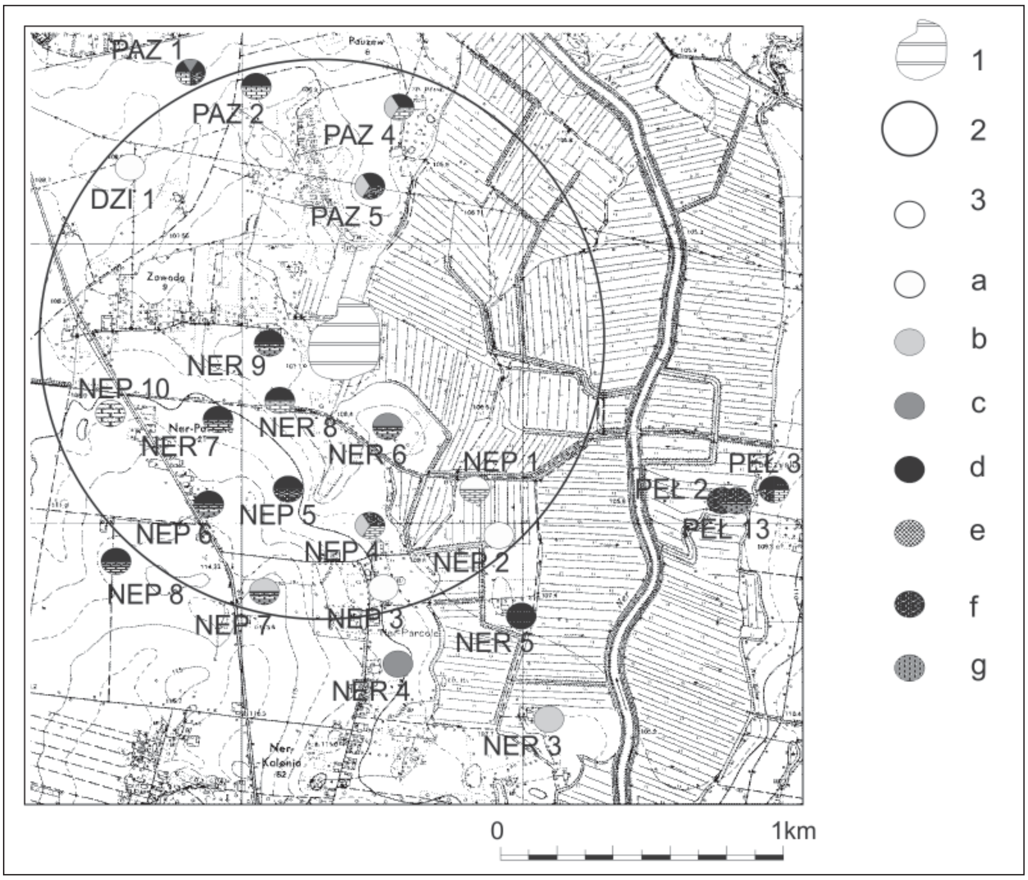

Fig. 6. Location of archaeological sites in the vicinity of the Ner-Zawada peatland:
1 – location of the Ner-Zawada peatland, *2* – range of the 1.0 km equidistant of Ner-Zawada peatland, *3* – archaeological sites (according to the materials of AZP): DZI – Dzierżawy; site no. 1; NEP – Ner-Parcele; 1, 2, 3, 4, 5, 6, 7, 8, 10; NER – Ner; 3, 4, 5, 6, 7, 8, 9; PAZ – Pauzew; 1, 2, 4, 5; PEŁ – Pełczyska; 2; 3; 13; *a* – unidentified prehistoric sites, *b* – Lusatian Culture, Bronze Age and Hallstatt Period of Early Iron Age, *c* – Pomeranian Culture, Early Le Tene Period of Early Iron Age, *d* – Przeworsk Culture, Roman Period, *e* – Early Middle Ages, *f* – Late Middle Ages, *g* – Modern Times

6 pav. Archeologinės radimvietės Ner-Zavados pelkyne:
1 – Ner-Zavados pelkyno vieta, *2* – 1 km apskritimas, *3* – archeologinės radimvietės (AZP duomenimis): DZI – Dzieržavų vieta Nr. 1; NEP – Nera Parcele; 1, 2, 3, 4, 5, 6, 7, 8, 10; NER – Nera; 3, 4, 5, 6, 7, 8, 9; PAZ – Pauzevas; 1, 2, 4, 5; PEŁ – Pelčiska; 2; 3; 13; *a* – nediferencijuotos priešistorinės radimvietės, *b* – Lusatos kultūra, bronzos amžius ir ankstyvosios geležies amžiaus Halštato periodas, *c* – Pomeranijos kultūra, *d* – Prevorsko kultūra, Romos periodas, *e* – ankstyvieji viduramžiai, *f* – vėlyvieji viduramžiai, *g* – Naujieji laikai

Table 2. **Characteristics of phases defined in the development of cladoceran communities**
2 lentelė. ***Cladoceran* grupės vystymosi fazių bruožai**

Phase	Depth [cm]	Description
IV	0–80	Only *Chydorus sphaericus* dominates
III	80–210	Only a few littoral species present, e. g., *Alona affinis*, *A. rectangula*, *A. gutata*, *Alonella excisa*, *Al. exigua* and *Ch. sphaericus*. At a depth of 90 cm no cladocerans remain
II	210–425	Peak of Cladocera: 19 species. Predominant planktonic species: *Bosmina longirostris* and *Bosmina (E.) coregoni*. Littoral species represented mainly by: *Acroperus harpae*, *Alona affinis*, *A. rectangula*, *Camptocercus rectirostris*, *Ch. sphaericus*, *Eurycercus lamellatus*, *Graptoleberis testudinaria* and *Pleuroxus* spp.
I	425–475	Low frequency of Cladocera. Several littoral species, e. g. *Alona affinis*, *A. rectangula*, *Acroperus harpae*, *Ch. sphaericus*). Planktonic species sporadic

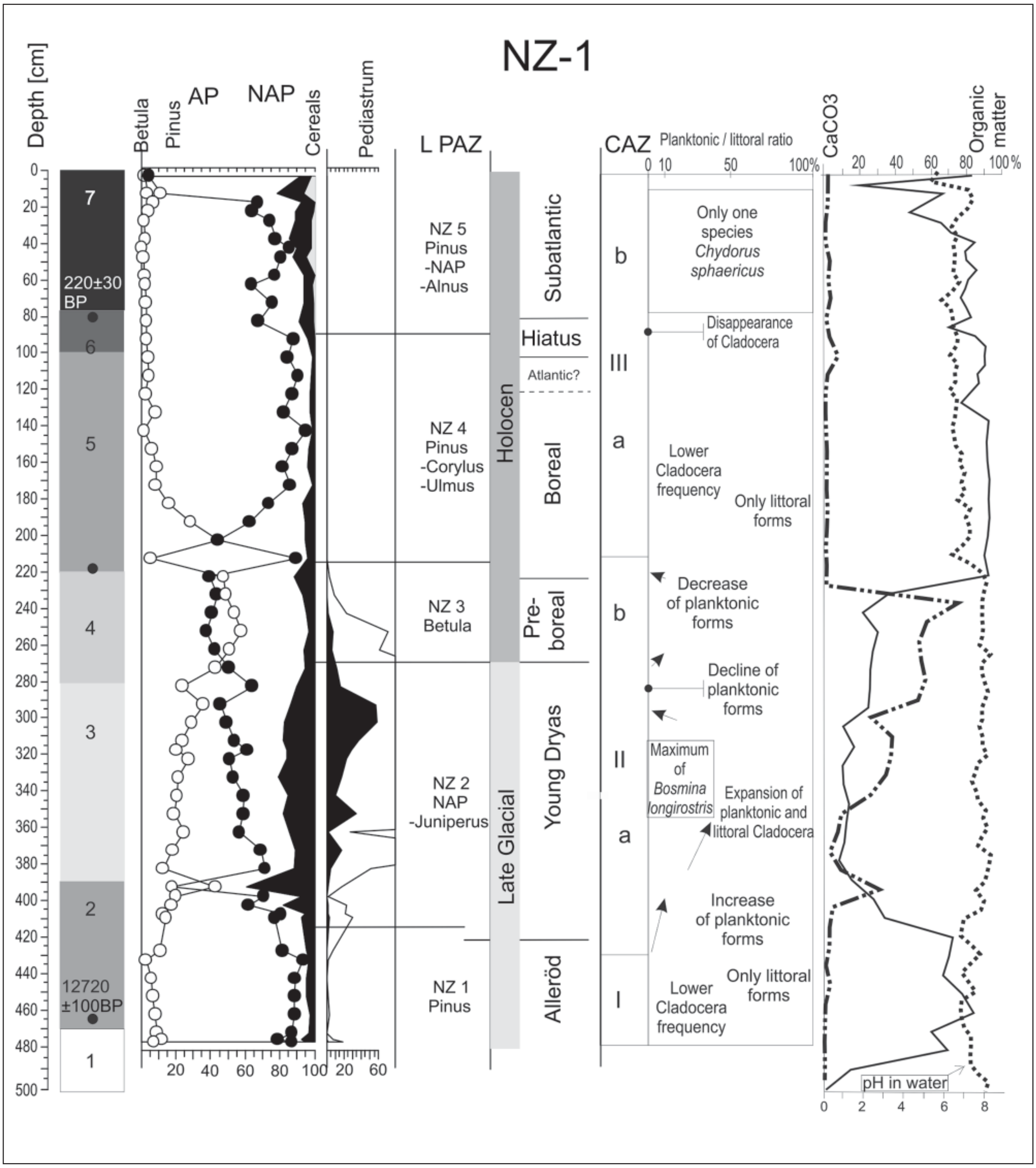

Fig. 7. Stratigraphy of NZ-1 drillcore based on pollen and cladoceran data:
1 – fluvial sand, *2* – herbaceous peat, *3* – calcareous gyttja with silt, *4* – calcareous-detritous gyttja, *5* – herbaceous peat, *6* – herbaceous peat, medium decomposed, *7* – peat, high decomposed

7 pav. NZ-1 kerno stratigrafija remiantis žiedadulkių ir *Cladocera* tyrimų duomenimis:
1 – fliuvialinis smėlis, *2* – žolinės durpės, *3* – karbonatinga gitija su aleuritu, *4* – karbonatinga detritinė gitija, *5* – žolinės durpės, *6* – vidutinės skaidos žolinės durpės, *7* – smulkiaskaidės durpės

logical factors"). Less than half of them (14) are dated to the Late Medieval (3) and to the Modern periods (11). No site has been dated of the Early Medieval period. The remaining 17 prehistoric factors are represented by relicts of settlements of Przeworsk Culture of the Roman Period (9). Four sites are dated to the Bronze Age and / or the Hallstatt Period of the Early Iron Age; they are remains of Lusatian Culture settlements. Only one site is connected with the Pomeranian Culture site dated as the Late La Tène period. Most of the mentioned sites were documented by few archaeological relics.

DISCUSSION AND CONCLUSIONS

The presented geological structure of the peatland and its substratum suggests that the basin of the peatland was originally associated with a river channel. In the Upper Plenivistulian, in the Ner River valley – as in other river valleys of Central Poland – a braided river was formed (e. g., Starkel, 1985; 2001; Turkowska, 1988; 2006; Forysiak, 2005; Kalicki, 2006). At the end of the Upper Plenivistulian and / or Lower Late Vistulian, an erosion phase began in the environment of the meandering rivers, which led to deepening of the river valleys (e. g., Turkowska, 1988). Also the Ner River valley was shaped similarly in the studied section. The elongated and slightly curved shape of the central part of the bottom of the peatland basin seems to indicate that this is part of a palaeomeander, which in Late Vistulian was cut off because of its blockage on the southern and northern sides by sediments accumulated outside the river channel.

The colonization of the depression bottom by peat-forming vegetation, as well as initiation of peat accumulation in the Alleröd are confirmed by the radiocarbon data as 12 720 ± 100 BP (Poz 28986) (Fig. 7). It suggests that the palaeochannel in question has been abandoned by the river by the Alleröd, and the neighbouring active river channel was even deeper at that time. Also, the lack of sandy deposits in this peat series and the low mineral matter content indicate that river waters did not flood the peatland. The peaty pool was very shallow (presence of only littoral species of Cladocera – Figs. 5, 7). The conditions at that time (phase I, Fig. 5) were unfavourable for Cladocera (presence of only a few species tolerating specific conditions), despite warming up. At the end of phase I, the frequency of Cladocera slightly increased, indicating an improvement of living conditions for Cladocera. Pollen analysis shows that the top part of this peat series was accumulated at the beginning of the Younger Dryas (Figs. 4, 7). Such a conclusion can be based on the highest percentage of NAP, including the pollen of light-demanding species (*Helianthemum*, *Artemisia* or *Chenopodiaceae*) and of juniper (*Juniperus*). This peat series has also a higher sand content which suggests that the peatland was flooded then.

In some valleys of the Łódź region, in the Younger Dryas, aggradation at the valley floors took place, and the water level was elevated within them (e. g., Turkowska, 1988; 2006; Forysiak, 2005). Such a tendency is observed also in the study section of the Ner River valley. As a result, a small lake was formed in the depression. It covered a larger area than the former peatland (Fig. 2). The lake was fed by river waters, but also by underground waters with neutral or alkaline pH and a high calcium content (Fig. 7). They originated from groundwater seepage in the immediate neighbourhood, south of the peatland. The lake was shallow, with a well-developed littoral zone which confirms the domination of littoral forms of Cladocera (planktonic forms did not exceed 35% of the total). This is also confirmed by the appearance of numerous coenobia of *Pediastrum*, as well as the development of aquatic vegetation. Probably the environmental conditions in the lake were milder, which is reflected in the presence of species preferring warm waters (*Camptocercus rectirostris, Graptoleberis testudinaria*, *Pleuroxus* spp.). It is possible that seepage water caused the rise of temperature in the lake. In gyttja we observed a high mineral matter content, but there were no traces of a direct influence of the river channel.

At the beginning of the Holocene another erosion phase took place, commonly observed in the valleys of Central Poland (e. g., Starkel, 2001; Turkowska, 1988; 2006; Forysiak, 2005). It caused a deepening of river channels, a lowering of the valley bottoms, and a decrease of the groundwater level within them and in the Ner River valley. Disappearance of most species as well as the low frequency of Cladocera (Figs. 5, 7) indicate a rapid decrease of the water level in the reconstructed lake. Pollen analysis showed that the lake started disappearing in the Preboreal period (Figs. 4, 7). The populations of *Pediastrum* as well as aquatic plant communities decreased. The lake was overgrown, and herbaceous peat was accumulated. The peatland could develop further. Results of pollen analysis suggest that this occurred in the Boreal (*Pinus* domination, presence of pollen grains of elm (*Ulmus*) and hazel (*Corylus*)). The frequency and diversity of Cladocera decreased, indicating that the conditions were unfavourable for Cladocera. In the mire, only a few littoral species were present (e. g., *A. affinis*, *Al. excisa*, *A. guttata*, *Ch. sphaericus*). They tolerate specific conditions, such as low pH and dense aquatic vegetation. The water level was very low then. The mire declined at the end of the Boreal or at the beginning of the Atlantic period (Fig. 7).

The aggradation of the Ner River valley floor started again at the end of the Atlantic period (Turkowska, 1988). The groundwater level in the study section of the Ner River valley was too low to support humid conditions in the peatland. In the Subatlantic period, an aggradation of the valley bottom took place. In river valleys of Central Poland it was due to climatic factors and an increased human impact (e. g., Starkel, 1985; 2001; Turkowska, 1988; Kalicki, 2006; Twardy, 2008). The human impact increased most probably in the Roman period (Fig. 6). The Ner-Zawada peatland reactivated probably much later (about 500 years ago): radiocarbon data 220 ± 30 BP (Poz 28986; cal. 1640–1870 AD, probab. 68.2%), when aggradation in the valley was accelerated. In the pollen profile, NAP content increased in the sediments, and some indicators of human activity appeared (*Rumex acetosa / acetosella, Plantago lanceolata, Centaurea cyanus*), including cereals. In the top part of the core (depth 80–100 cm), only one species (*Ch. sphaericus*) appeared, characterized by a broad ecological tolerance, and it is possible that the frequency of *Ch. sphaericus* was correlated with human activities (exploitation of peat deposits, melioration of areas around the peatland). These changes in the peatland and in the Ner River valley were connected with the progress of settlement in the Middle Ages and in the 18th century (Forysiak et al., 2007).

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VĖLYVOSIOS VYSLOS IR HOLOCENO POKYČIAI PAGAL NER-ZAVADOS PELKYNO NEROS UPĖS SLĖNYJE GEOLOGINIUS IR PALEOEKOLOGINIUS DUOMENIS

Santrauka

Ner-Zavados pelkynas, esantis Nero upės slėnyje (Vidurio Lenkija), susiformavo aleriodo periodu. Ankstyvajame driase pelkynas virto ežeru, tačiau holoceno metu vėl tapo pelke. Pelkyne ir jo apylinkėse buvo atlikti geologiniai ir archeologiniai tyrimai, išanalizuotos žiedadulkės. Iš rankinio gręžimo kerno atrinktos *Cladocera* fosilijos ir nustatytas jų absoliutus amžius. Šie tyrimai padėjo rekonstruoti pelkyno paleoekologinius pokyčius, padaryti išvadas apie Nero upės vidurinės tėkmės slėnio paleogeografiją.

Raktažodžiai: pelkynas, žiedadulkės, paleoekologija, holocenas, Nero upės slėnis, *Cladocera* fosilijos