

Younger Dryas Cladocera assemblages from two valley mires in central Poland and their potential significance for climate reconstructions

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Abstract

Two sections of sediment from small oxbow-lake infillings located in different river valleys in central Poland were studied by cladoceran analysis in order to examine the response of aquatic ecosystems to the Younger Dryas. Lithological and geochemical records, as well as chydorid (Chydoridae) ephippia analysis were also used to reconstruct Younger Dryas climate trends. A high concentration of cladocerans, as well as the presence of Cladocera taxa preferring warmer water, was found. It is likely that local processes in the oxbow lakes were important, because the presence of warm-preferring taxa was also related to their habitats and their development. Yet local environmental forces, such as the influence of the rivers, habitat modification, macrophyte abundance, and eutrophication, were not only major factors to affect the Cladocera diversity in the Younger Dryas. The observation of changes in the composition and concentration of Cladocera in oxbow-lake infillings indicates that most of the changes occurred in response to climate changes.

Keywords: Younger Dryas, Cladocera, oxbow-lake deposits, valley mires, climate and local conditions

1. Introduction

The Younger Dryas (YD) has received much attention from terrestrial and marine geology, as well as from oceanography, palaeoecology and palaeoclimatology (e.g. Isarin et al., 1998; Isarin & Bohncke, 1999; Isarin & Rensen, 1999; Mojski, 2005). Researchers have emphasised the climatic distinctness of the YD. The interval was very short (Björck, 2006; Lowe et al., 2008; Steffensen et al., 2008; Walanus & Nalepka, 2010), and its beginning and end, as well as its duration, have yielded various datings, depending on the place of collection of samples. The duration of the YD in Poland was approxi-

mately 1100–1300 years (Ralska-Jasiewiczowa et al., 1998, 2003; Goslar et al., 1998, 1999; Litt et al., 2001).

The YD can, however, not be treated as a uniform, continuously cold episode (Bohncke et al., 1993; Berglund et al., 1994; Isarin & Bohncke, 1999), as it was interrupted by phases of relatively better (wet) conditions, followed again by the recurrence of cold (dry) conditions (Bohncke et al., 1993; Walker, 1995). A good tool for such reconstructions, especially in terrestrial sediments, is the palaeobotanical record (pollen and plant macrofossils), as well as the record of animal remains (beetles, chironomids, and crustaceans). The analysis

of Cladocera ehippia, based on changes in reproduction and usually dependent on the length of the open-water season, is a very useful technique for reconstructing climate trends (Sarmaja-Korjonen, 2003; Sarmaja-Korjonen & Seppä, 2007; Nevalainen et al., 2011).

The pollen record in the YD are dominated by arctic (subalpine) and cold-tolerant taxa (Bohncke, 1993; Böttger et al., 1998; Mortensen et al., 2011). A similar situation exists in the records of macro- and micro-invertebrates. Certain taxa, such as flying insects and even cladocerans, however, will react more rapidly to climate changes than do other proxies, such as tree pollen (Płóciennik et al., 2011; Pawłowski, 2012). This is manifested by the appearance of taxa that prefer better (warmer, wet) conditions. This has been recognised for the subfossil remains of Cladocera: species preferring warmer conditions occurred sometimes during the YD (Szeroczyńska, 2006). These temperature fluctuations have also been recorded from other sites in Europe (Szeroczyńska, 1998a; Hofmann, 2000; Lotter et al., 1997, 2000; Benike et al., 2004). This may indicate that, during the YD, there were short phases of milder climate conditions. The reconstructed YD palaeotemperatures from central Poland suggest that the mean July temperature was about 13°C (Coope et al., 1998; Isarin et al., 1998; Isarin & Renssen, 1999), or even approx. 15–16°C (Dobrowolski et al., 2001; Lorenc, 2008; Płóciennik et al., 2011).

Most of the Cladocera data come from the sediments of lakes and bogs. Sediments from abandoned palaeochannels (oxbow lakes), also those from the YD, may contain good climate indicators in the form of fossils. In the Bölling, rivers changed their regimes and channel patterns from braided to large meanders in response to the spreading of forest vegetation and the rapid reduction of sediment load (Kozarski, 1991; Starkel, 1990), and filled these lakes with mineral/organic sediments, mostly during the YD (Rotnicki & Młynarczyk, 1989; Starkel et al., 2007). This happened although the cooling of the YD caused an increase in bedload and also in spite of a tendency towards braiding of the rivers (Starkel et al., 2007). Oxbow infillings may thus be valuable archives for palaeoenvironmental reconstructions; they might also be an archive of climate changes.

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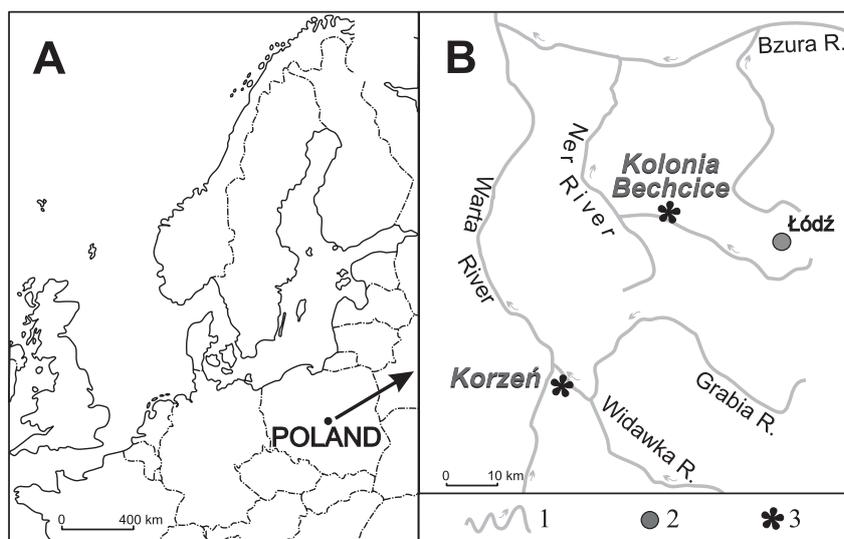
The present contribution discusses the results of an analysis of subfossil Cladocera from two valley mire sediments, from the Ner and Widawka river valleys, which accumulated during the YD. These are among the few rare sites in central Poland suited to palaeoclimate studies, and particularly to the analysis of subfossil cladocerans, because of (1) the evidence for YD oxbow cladoceran communities, (2) the evidence for short-lived oscillations in the cladoceran records, and (3) the sparse knowledge concerning cladoceran successions from the central part of Poland (in contrast to the existing knowledge concerning the northern part of the country). The objective of this contribution is thus to answer the questions of: (1) how the changes in the Cladocera succession accumulated in oxbow lakes can be used for climate-change studies (for the example of the YD), and (2) whether the presence of warm-preferring taxa and their climate response was directly related to the temperature fluctuations, or, alternatively, to their habitats and to the oxbow development. In addition, Cladocera analysis from these mires provides data on the environmental evolution of the YD lakes and the oxbow lakes under changing conditions, and helps to reconstruct the palaeoenvironmental changes which then took place in central Poland.

2. Materials and methods

2.1. Study sites

The sites selected for analysis are located in central Poland (Fig. 1 A, B), in the area of the Warthian (Late Saalian) ice sheet, which was the last to cover this part of the country. The Korzeń and Kolonia Behcice sites are valley mires in the valleys of the Ner and Widawka rivers, which flow into the Warta river. These mires are approx. 30 km apart from each other (Fig. 1B); they had the same (transitional) climate, with similar ranges of mean annual rainfall, annual temperature, snow cover, etc. (Woś, 1999; Kłysik, 2001). All study sites are situated at the surface of a higher fluvio-glacial

Fig. 1. Location in Europe (A) and Poland (B) of the Korzeń and Kolonia Behcice mires. **1:** Main rivers and their current directions. **2:** Towns. **3:** Location of the mires under study.



terrace built of sandy/gravelly sediments (Kittel et al., 2010; Borówka et al., 2011). Analyses of sediments from these fens using multiproxy methods and radiocarbon datings have been presented by Kittel et al. (2010), Borówka et al. (2011), Borówka & Tomkowiak (2011) and Stachowicz-Rybka et al. (2011).

2.1.1. Korzeń

The Korzeń site is located in the estuary of the Widawka river (Fig. 1B), and is the deepest palaeochannel along the edge of the high terrace of this valley. The basal part of the sediment has been dated as late Vistulian, and the upper part as Holocene (Borówka et al., 2011).

An organic succession of 200 cm thick is present in the deepest part of the palaeochannel (geographical coordinates 51°28'44.0"N; 18°53'25.8"E). The YD is represented by non-calcareous, detritus/clay (gyttja) and the beginning of reed/sedge peat accumulations (Fig. 2). The sediments contain large amounts of mineral matter (on average about 84%), as well as the highest concentrations of lithophile elements, such as sodium, potassium, and magnesium (Fig. 2). The sediments from the end of the YD contain increasing amounts of organic matter, from about 20% to 70%, and decreasing amounts of lithophile elements (Borówka et al., 2011).

2.1.2. Kolonia Behcice

The Kolonia Behcice site (51°45'12.12"N; 19°14'27.13"E) was part of a large palaeochannel in the Ner river valley (Fig. 1B). The accu-

mulation of the fluvial infilling started most probably during the late Vistulian, and continued throughout the Holocene (Kittel et al., 2010).

An organic succession of 140 cm thick from this site was chosen for analysis (Fig. 3). The basal part of the sediment, consisting of mineral/organic deposits underlying peats, has been dated as YD (Stachowicz-Rybka et al., 2011). This basal part contains up to 10% organic matter and a considerable fraction of the lithophilic elements such as sodium, potassium, and magnesium (Borówka & Tomkowiak, 2011: see Fig. 3).

2.2. Cladocera analysis

The samples from each core were collected in 5-cm intervals. Samples of 1 cm³ each were processed according to the standard procedure of Frey (1986). All remains were counted: head shields, shells, postabdomens, postabdominal claws, and ephippia. The most abundant body part was chosen for each taxon to represent the number of individuals, and percentages were calculated from the sum of individuals. Because the frequency of Cladocera was low, 5–8 slides were counted per sediment sample. The taxonomy of cladoceran remains follows in the present contribution that of Szeroczyńska & Sarmaja-Korjonen (2007).

The presence of Cladocera species and their frequencies were used for a reconstruction of

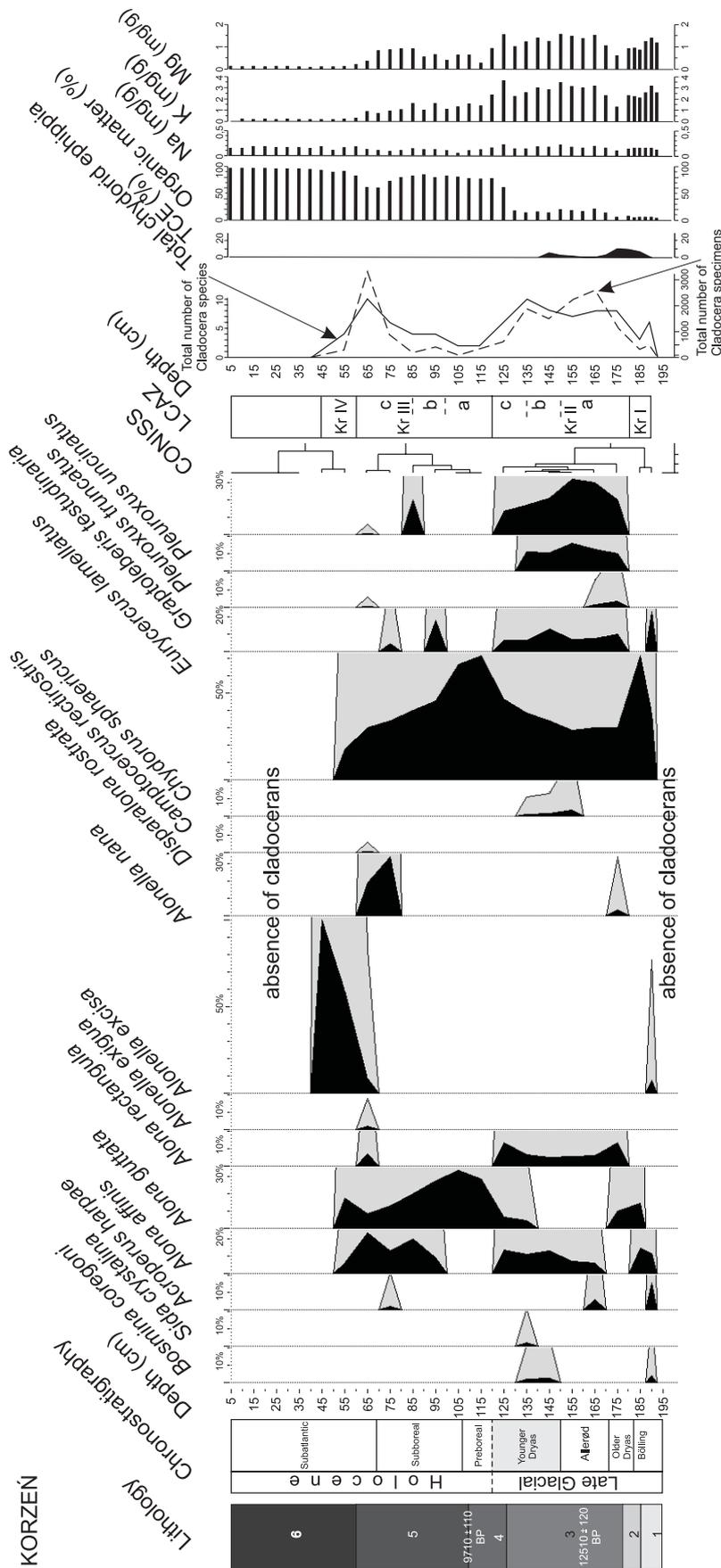


Fig. 2. Chronostratigraphy, radiocarbon dates, percentages of Cladocera, simple numerical analyses of cladoceran data (cluster analysis diagram, CONISS), total number of species, specimens per 1 cm³ of sediment, total chydorid ephippia, organic matter and elemental components from the Korzeń mire. LCAZ: Local Cladocera assemblage zones. The grey color in the chronology column shows the range of YD. TCE: Total chydorid ephippia. Major geochemical components after Borówka et al. (2011).

1: Medium-grained fluvial sands. 2: Sands with fragment of wood. 3: Detritus-clay gyttja. 4: Reed/sedge peat. 5: Willow (*Salix* spp.) peat. 6: *Sphagnum* moss peat.

KOLONIA BECHCICE

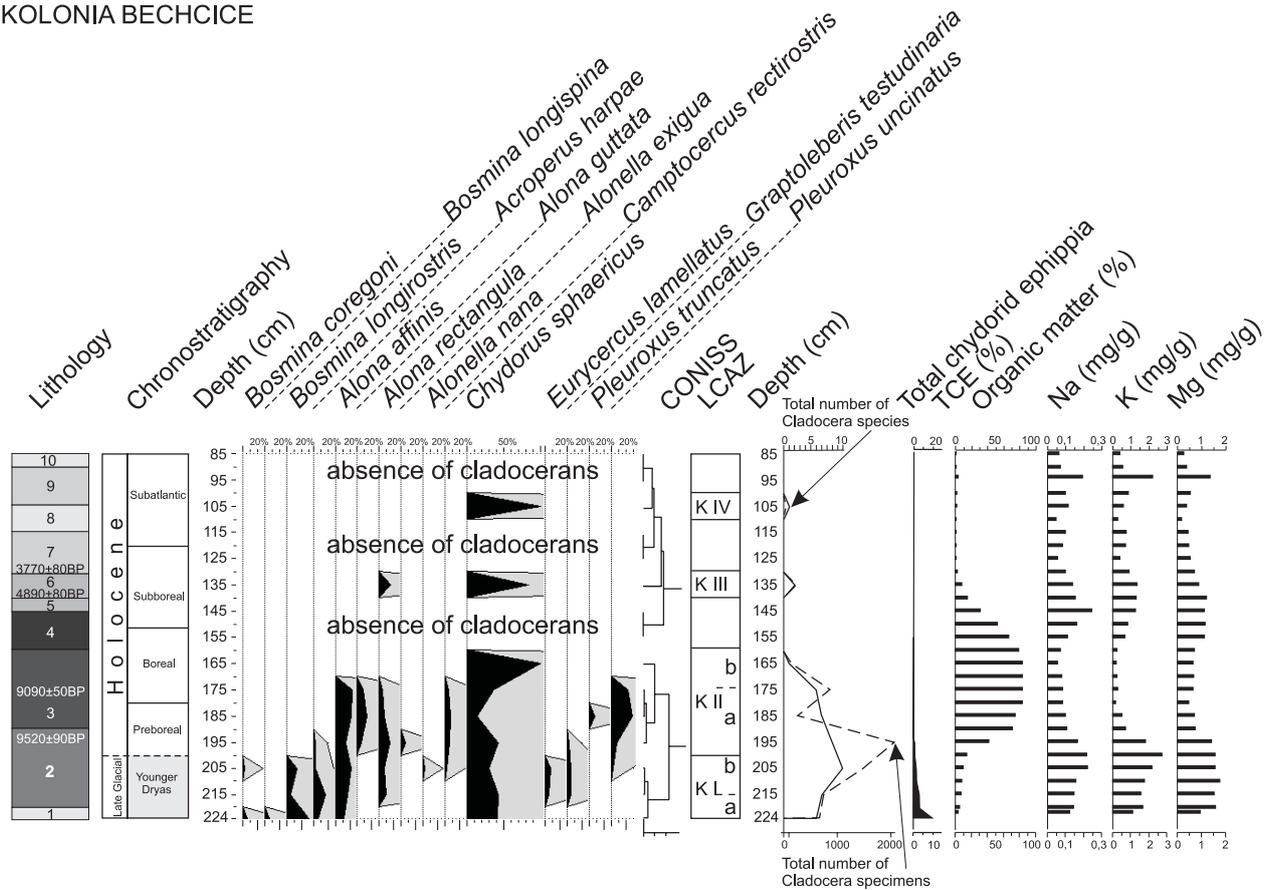


Fig. 3. Chronostratigraphy, radiocarbon dates, percentages of Cladocera, simple numerical analyses of cladoceran data (cluster analysis diagram, CONISS), total number of species, specimens per 1 cm³ of sediment, total chydorid ephippia, organic matter and elemental components from the Kolonia Bechcice mire. LCAZ: Local Cladocera assemblage zones. TCE: Total chydorid ephippia. The grey color in the chronology column shows the range of YD. Major geochemical components after Borówka & Tomkowiak (2011).

1: Medium-grained fluvial sands. 2: Detritus gyttja. 3: Reed peat, decomposed. 4: Moss peat, well decomposed. 5: Organic-rich silts. 6: Organic-rich silt intercalating with sands. 7: Silty sands. 8: Fine-grained sands. 9: Sands with silts. 10: Medium-grained sand.

the development of the mires under study. Based on species composition and their abundances, Cladocera developmental zones were distinguished. CONISS software (Grimm, 1987) confirmed that the assigned Cladocera zones (Local Cladocera Assemblage Zones: LCAZ) were correct.

The ecological preferences of cladoceran taxa were determined following Whiteside (1970) and Szeroczyńska (1998b). The results (Figs 2, 3) have been plotted on a percentage diagram using the POLPAL program (Walanus & Nalpeka, 1999). When the Cladocera were counted, chydorid carapaces (representing asexual reproduction) and ephippia (representing sexual reproduction) were also enumerated. The total chydorid ephippia (TCE) was calculated

from the sum of chydorid shells and chydorid ephippia (Sarmaja-Korjonen, 2003).

3. Results

3.1. Korzeń

Sixteen Cladocera species have been identified from the Korzeń sediments, and four zones (Kr I–Kr IV) of Cladocera development have been distinguished (Fig. 2). These zones can be correlated with pollen assemblage zones (Borówka et al., 2011). Cladocera subphases Kr IIb and Kr IIc correlate with the YD (Fig. 2).

This time-span contains 10 species, belonging to 3 families (the Bosminidae, Chydoridae

and Sididae families), and over 1,500 specimens in total per cm³ of sediment (Fig. 2). Most numerous are the littoral species of the Chydoridae family. The planktonic form (*Bosmina* (*Eubosmina*) *coregoni*) does not even account for 10% of all individuals (Fig. 2). The described subphases Kr IIb and Kr IIc are characterized by the dominance of cold-tolerant taxa, such as *Chydorus sphaericus*, *Alona affinis*, and *Eurycerus lamellatus*, but also by the appearance of species preferring warm waters (*Camptocercus rectirostris*, *Pleuroxus truncatus*, and *Pleuroxus uncinatus*). Some of these, such as *Pleuroxus uncinatus*, are abundant and exceed 20% of all individuals (Fig. 2). Ehippia of 4 chydorid species were found (*Alona affinis*, *Alona rectangularis*, *Chydorus sphaericus* (sensu lato), and *Pleuroxus uncinatus*), although carapaces of 14 species were identified (Fig. 2).

The highest proportion of total chydorid ehippia (TCE) occurs at a depth of 175 cm (Older Dryas), where the TCE increased to 10.7%. The last considerable maximum (5.6%) was found at a depth of 145 cm (Younger Dryas) where the TCE suddenly increased after a phase during which they maintained a value of some 0.4% (Fig. 2). In the younger part of the YD sediments, no ehippia were found.

3.2. Kolonia Bechcice

The sediments of the Kolonia Bechcice site contain 15 Cladocera species (Fig. 3), belonging to 2 families (Bosminidae and Chydoridae). Four Cladocera developmental zones (K I-K IV) are distinguished, which correlate with pollen assemblage zones (Stachowicz-Rybka et al., 2011). Cladocera phase K I correlates with the YD (Fig. 3). In samples from the end of the YD, more than 1,900 specimens are present, with 11 species per cm³. The most numerous are littoral species of the Chydoridae family. The number of pelagic individuals (from the Bosminidae family) do not exceed 40%, but *Bosmina longirostris* – a species usually inhabiting fertile, shallow zones of lakes (Szeroczyńska, 1998b) – is abundant in the initial phase of lake sedimentation and exceeds 30% of all individuals (Fig. 3).

The most significant feature of the YD sub-fossil Cladocera assemblage is the clear dominance of cold-tolerant taxa such as *Chydorus sphaericus*, *Alona affinis*, and *Acroperus harpae*. Despite their dominance, taxa preferring warm waters and high trophic states as well as plant-associated taxa (*Graptoleberis testudinaria*, *Alona rectangularis*, *Bosmina longirostris*, *Pleuroxus uncinatus*, and *Camptocercus rectirostris*) are also numerous. The ehippia of only 3 chydorid species have been identified (*Alona affinis*, *Alona rectangularis*, *Pleuroxus uncinatus*). The highest TCE occurs at a depth of 224 cm (Younger Dryas) where it increases to 10%. After this maximum, the proportion of total chydorid ehippia decreases (Fig. 3).

4. Discussion

The YD is defined as a cold phase that is generally characterised by a low biodiversity with a few cold-tolerant Cladocera species such as *Acroperus harpae*, *Alona affinis*, and *Chydorus sphaericus* (Lotter et al., 2000; Szeroczyńska, 2006). It is not surprising that such taxa persisted in the YD, because these species are known to occur over a wide range of conditions, and they are tolerant of environmental stress (Duggan & Birks, 2000); they are also common in northern and in European mountain lakes (Kamenik et al., 2007; Bjerring et al., 2009). These species were often found to be pioneer taxa, i.e., early immigrants following the retreat of the ice (Szeroczyńska, 1998a). Additionally, in a cold climate, a higher proportion of chydorid ehippia is expected in lake sediments, because when the open-water season is shorter, the relative duration of the asexual reproduction period is limited, compared to that of the sexual reproduction period (Sarmaja-Korjonen & Seppä, 2007).

The cladoceran-inferred reconstruction suggests a drop to 9–10°C at the beginning of the Younger Dryas (Lotter et al., 2000). Yet, during the YD, there was also a short warmer episode with a high diversity of cladocerans and the presence of species preferring warm water, such as *Camptocercus rectirostris*, *Pleuroxus* spp., and *Alonella nana* (Szeroczyńska, 1998a; Hoff-

man, 2000; Lotter et al., 2000; Bennike et al., 2004). A rapid warming occurred over the final 300 years of the late YD, reflected by a rise in the July temperatures of the order of 5°C (from 10–13°C to 16°C; Ralska-Jasiewiczowa et al., 1998; Starkel, 2002).

At both of the studied oxbow-lake infillings, the presence of forms preferring warm water (*Camptocercus rectirostris*, *Pleuroxus* spp. – especially *Pleuroxus truncatus* – and sporadically *Graptoleberis testudinaria*: see Figs 2, 3; Poulsen, 1928) and an increase in Cladocera biodiversity and frequency was found for the YD (Figs 2, 3). It seems possible that the above-mentioned warmer or milder environmental conditions during this interval gave rise to the observed changes in the valley mires. However, environmental changes can hamper Cladocera-based climate reconstructions (Korhola, 1999; Duigan & Birks, 2000; Bjerring et al., 2009). Additionally, some of these species belong to typical southern fauna of Fennoscandia, according to their latitudinal affinities (Harmsworth, 1968), but the ecology of some species is not yet clear (e.g. *Camptocercus rectirostris* has also been noted from deeper and colder sites in northern Fennoscandia: Korhola, 1999). Therefore, two factors – the local and the global climate – must be taken into consideration.

The first of these factors – local changes – might be connected (directly or indirectly) with the influence of the river (water-level changes), habitat modification, macrophyte abundance, eutrophication, nutrient concentrations, or fish abundance. The developments of the oxbow lakes show some characteristics in common. Both sites are located within river valleys in lowlands; the rivers have similar hydrological characteristics; and the sites were oxbow lakes during the YD. During the YD, accumulation of sediment took place on some valley floors in the Łódź region, and water levels increased (high discharge, floodwaters with high sediment loads: Turkowska, 1988; Forysiak et al., 2010). It is possible that this was also the case in the section of the river valleys studied here. The oxbow lakes were fed by rivers and by groundwater. This can be deduced from the lithological and geochemical components (Borówka et al., 2011;

Borówka & Tomkowiak, 2011): at the Korzeń site from the large, homogeneous content of mineral matter and lithophilic items (Fig. 2), and at the Kolonia Behcice site from the lower content of mineral matter in the marsh sediments (Fig. 3). This suggests that the sediments at the Korzeń site were deposited in a small oxbow-lake landscape, which was probably frequently inundated by floodwaters, or – more likely – the gyttja layer was deposited quickly, at the time when a then existing meander was cut-off (Borówka et al., 2011). In the case of the Kolonia Behcice site, accumulation in the oxbow lake took place in far-reaching isolation with restricted influence from river and floodwaters (Borówka & Tomkowiak, 2011). The Cladocera assemblage in sediments from the initial period of the oxbow is rich and is much more diverse than typical pioneer assemblages (Duigan & Birks, 2000). Also the slightly higher frequency of Cladocera at this site at the end of the YD (Fig. 3) could be explained by its position: this lake was isolated from direct fluvial influence. A similar situation has been reported from Dutch lakes formed after breaching of river dikes (Krilova et al., 2010).

At both sites, the abundant littoral cladoceran taxa provide evidence for a shallow-water setting, although the water level was sufficiently high for planktonic cladoceran forms (*Bosmina* (*Eubosmina*) *coregoni*, *B. (E.) longispina*, and *B. longirostris*: see Figs 2, 3). Their appearance might, however, also be related to floodings (Pawłowski et al., 2012). The hydrological regime of these YD oxbow lakes (e.g. the influence of floodwaters and the rise of groundwater levels in the valley) was slightly different from that in closed-lake depressions from this time. Moreover, the local changes resulting from geological and geomorphological positions that differed from those of more typical lakes may have affected the hydrological conditions in the abandoned meanders (Korzeń is located in the estuary of the river, whereas Kolonia Behcice is in the middle section of the river). The additional fluvial regime and sediment load affected the infilling of the meanders. For example, the rates of shift from bedload to suspended load during the Younger Dryas/Preboreal transition varied, and depended on the size of

the river valley, the position in the longitudinal profile, and the location of the headwaters in mountains or in lowlands (Starkel, 2002). These hydrological and sedimentological changes did not occur in closed-lake depressions.

Other environmental factors, such as the pattern of the habitat (structures such as plant-growth forms) and substrate types are likely to have played significant roles at these sites: chydorids live in littoral regions and depend largely on the habitats provided by aquatic vegetation (Duigan & Birks, 2000; Bjerring et al., 2009). The development of these lakes is reflected by the accumulation of mineral/organic sediments (at the Korzeń site) or by the accumulation of mineral deposits (at the Kolonia Behcice site). Therefore, most of the species from the YD found in these oxbow-lake deposits are littoral, macrophyte/sediment-associated taxa, which were common in European lakes (Bjerring et al., 2009). Chydorid species as *Pleuroxus* spp., *Graptoleberis testudinaria*, and *Camptocercus rectirostris* live in warm water, but they are also primarily associated with vegetation. Some of these taxa are commonly found in small ponds (Korhola, 1999).

The high frequency of *Pleuroxus uncinatus* could, however, also be explained by the extensive mineral substrates in the oxbow lakes (Bjerring et al., 2009), and the presence of *Camptocercus rectirostris* may be due to its existence on benthic substrates created by the macrophyte decline (Duigan & Birks, 2000). On the other hand, the presence of more phytophilous species such as *Graptoleberis testudinaria*, *Eurycercus lamellatus*, and *Alonella nana* – which are usually associated with, or live between, submerged macrophytes (Duigan & Birks, 2000; Bjerring et al., 2009) – point to a well-developed vegetation. Additionally, this situation developed due to the decrease in the water level in the oxbow lakes: the number of planktonic species dropped temporarily, while the number of benthic and phytophilous littoral species increased. It seems that this situation resulted from the rich macrovegetation that covered the littoral zone, allowing an increase in the number of macrophyte-associated species. Similar changes in cladoceran assemblages were reported by Illyova & Nemethova (2005) from the Danube floodplain area. An

increase in macrophyte abundance has a large impact on cladoceran communities (Sweetman et al., 2010); it supports an increase in phytophilous cladocerans. The development of the littoral vegetation most likely proceeded once the annual and summer temperatures had risen, as suggested by Nevalianen et al. (2011). Bjerring et al. (2009) have also suggested that a shallow water depth and a high temperature may favour macrophyte growth, and that it can result in increased taxon richness of cladocerans as an indirect climate response through increases in macrophyte cover and water-filled volume. This thus suggests an important influence of climate on cladoceran assemblages during the YD at both sites.

Moreover, the increase in nitrification concentrations and eutrophication may influence Cladocera diversity. The habitat conditions for cladocerans improved during the YD. This is documented by the occurrence of pelagic species such as *Bosmina longirostris*, as well as of littoral forms such as *Alona rectangularis*, and *Chydorus sphaericus* (Figs 2, 3), which are considered by most researchers to be trophy indicators, as they are abundant in nutrient-rich temperate lakes (Whiteside, 1970; Szeroczyńska, 1998a,b). The increase in pelagic species during the YD was connected with the evolution of the lacustrine conditions, a higher productivity, a possible increase in food for cladocerans, the abundance of macrophytes and, probably, warm waters. The impoverishment of the Cladocera frequency at the end of this stage at the Korzeń site (Fig. 2) could be due to overgrowth, the transition of the oxbow lake to a fen, and the reduction of the water level.

Biotic interactions with fish within the food web may be more pronounced in structuring Cladocera communities, as demonstrated by Davidson et al. (2007). However no predator communities of fish (or of other invertebrates, such as *Chaoborus* larvae) have been identified from these oxbow deposits during these times. Additionally, the presence of large cladocerans (e.g. *Eurycercus lamellatus*) suggests a decrease in predation pressure by fish, but not the total absence of fish predation.

It is unlikely that the local conditions and the hydrological regime of the oxbow lakes in

the river valleys were the only (or main) factors which influenced Cladocera development (although such a scenario is theoretically possible); rather it is probable that the Cladocera diversity in the oxbow lakes was also subject to changing conditions due to climate fluctuations over many years. Additionally, Engels et al. (2008), on the basis of chironomid assemblages, showed no difference in the temperature inferences for lakes situated on the floodplain, in contrast to those isolated from fluvial influence. This seems to imply that Cladocera records derived from floodplain sediments can be used to reconstruct changes in temperature just as reliably as can records based on cladoceran assemblages from lakes unaffected by fluvial influence. Recent ecological studies also suggest that Cladocera do respond to climate change (Kamenik et al., 2007; Bjerring et al., 2009; Nevalainen et al., 2011) even over a few decades, while their response to temperature is complex and indirect (Kattal et al., 2008).

One of the ways to illustrate the direction and magnitude of climate change, in addition to the presence of species preferring warm water, may be, as suggested by Kamenik et al. (2007), shifts from assemblages with Bosminidae to assemblages without Bosminidae (and vice versa), as well as shifts in Bosminidae, i.e. the replacement of *B. longirostris* with species from the *Eubosmina* group. Similar changes affected the *B. longirostris* frequency at Korzeń and especially at Kolonia Bechcice: initially this species appeared, later it rapidly disappeared, and then the frequency increased again (Fig. 3). This might be a response to YD cooling and environmental changes, as suggested by Sarmaja-Korjonen & Seppa (2007) and by Nevalainen et al. (2011). All the more so, *Bosmina* (*Eubosmina*) *coregoni* and *B. (E.) longispina* have been found in northern Finnish Lapland (Korhola, 1999; Sarmaja-Korjonen et al., 2006), indicating that these forms are tolerant of cold-climate conditions. The cold interval could therefore have resulted in a dramatic decrease and the near extinction of the planktonic Cladocera, especially *Bosmina longirostris*. The decrease of *B. longirostris* in the mires under study may, however, also be related to the general trend of dis-

appearance of all pelagic species, or it might be a response to other factors such as a decrease in the lake-water depth, or the limited influence of floods. Additionally, this situation was connected with a decreasing number of total chydorid eggs (TCE; see Fig. 3), which might suggest a milder climate with a long open-water season when chydorids reproduce asexually, resulting in a high proportion of shells of asexual females and a low proportion of shells of sexual females (ephippia) in the sediments (Sarmaja-Korjonen & Seppa, 2007). Thus these changes may correspond to a warmer phase of the YD. In addition, in both oxbow lakes, along with the appearance of thermophilic species, the frequency of Cladocera increased, and the species associated with macrophytes and requiring a better habitat appeared. This could be a reaction to summers when the water was warmer, with a longer open-water season and slightly more nutrient-rich water, as well as the systematic growth of macrophytes, which ultimately could also be a response to a small climatic amelioration. This situation resembles that known from Lake Gościąż, where a warmer phase can be identified within the YD (Szeroczyńska, 1998a). The same phenomenon was described (Pawłowski, 2012; Forysiak et al., 2010) from other sites in this area: in Żabieniec (nearly 20 km east of Kolonia Bechcice) and at Ner Zawada (in the Ner River valley). It thus seems that the Cladocera analysis indicates only a slight drop in temperature in this region during the YD. These suggestions are close to the results based on chironomid-based reconstructions for this part of Poland (Płóciennik et al., 2011). The warmer part of the YD, the area's distance from the glacier, the milder climatic conditions – characterised by the influence of warmer, wetter oceanic air masses – were more favourable than those in the northern part of Poland, and new ecological niches for colonization (oxbows), favoured cladoceran biodiversity.

Minor climate fluctuations (such as increases in humidity) may have influenced the development of local rivers and oxbow lakes, at least. The filling of the cut-off meanders in Poland started mainly during the YD, or just slightly after, and several meanders were abandoned

during the slight warming of the last 300 years of the YD (Starkel, 2002). The rapid warming and the decline in seasonal fluctuations of runoff and sediment load became recorded in the stabilisation and concentration of river channels, as well as in the narrowing of the active (flood) zone (Starkel, 2002). This probably partly explains the limited influence of floods at the Kolonia Behcice site, because the 'origin' of this oxbow lake took place later, in a warmer phase of the YD. This is confirmed by the increasing diversity of Cladocera and the presence of more species living in warm water at the end of the YD (Fig. 3).

5. Conclusions

Cladocerans appear most useful in reconstructing the climate in the valley mires. The primary factors which affected Cladocera diversity and the presence of taxa preferring warm water in the YD at the Korzeń and Kolonia Behcice sites were the climate and local factors, of which the influence of the river is most important. It seems that this was a response to a small climatic amelioration. This is an additional argument for a rapid response of oxbows/valley mire ecosystems to global climate change.

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