Lake Wierzchoń, where a belt of Tilio-Carpinetum woods is preserved today (Kępczyński & Noryśkiewicz, Chapter 3.7). Around the lake *Carpinus* populations were probably not so well developed: the maximum pollen percentages of *Carpinus* are then 16 % in the centre of Tobyłka Bay (T1/90, Fig. 8.26) and only ca. 5% in the adjacent kettle-hole mire (Demske 1995).

The structure of *Carpinus* forests at that time might have been of the type proposed by Tobolski (1990, 1991) as the historical primeval form of hornbeam woods growing in Greater Poland between ca. 3400 to 1650 ^{14}C BP, but not occurring in Poland anymore: in such woods *Carpinus* would form the highest tree layer and canopy, the contribution of other deciduous trees would be insignificant, and, particularly, very few *Corylus* would be in the wood understory.

During this whole transformation time the *Quercus* pollen percentages remain very stable at slightly over 10%, suggesting the occurrence of scattered old oak trees, exposed and well flowering. They produced pollen in rather even amounts over a large area and were rather independent from local vegetation changes. A fairly high and stable influx of *Quercus* pollen (Fig. 8.23) speaks for such an explanation too. It seems clear that the pollen record obtained from the central lake core reflects the regional changes in forest composition.

The disappearance of any limnophyte taxa except for *Potamogeton* S. *Eupotamogeton* from ca. 3500 cal BP until the end of zone and then the reduced frequencies of telmatophytes from ca. 3000 cal BP observed in the profile from the lake centre, may suggest some rise of water level. The increase in the pelagial taxa of Cladocera between 3000 and 2000 cal BP (Szeroczyńska, Chapter 8.4) speaks also for a rather high lake level. The following gradual lowering of water level, rising eutrophication and changes in sediment chemical composition (Więckowski et al., Chapter 5.1, Łącka et al., Chapter 8.2, Szeroczyńska, Chapter 8.4) did not find any expression in the record of limnophyte/telmatophyte vegetation at the lake centre. Also the sedimentation rates, rising distinctly in the Tobyłka Bay (T1/90 core) already from the decline of subzone 10a (ca. 4000 cal BP, Fig. 8.28), in the core from the lake centre remain stable till the end of zone.

***Pinus*-NAP (G1/87-10; 1075(820) – -35 cal BP), (TB-13b – TB-14a,b; 975 – -35 cal BP)**

The top pollen zone, covering approximately the last 1000 yr, records the drastic environmental changes progressing in the study region governed main by human activity. The sediment accumulation rates rise then also significantly in the G1/87 profile from the central lake deep (Figs 8.27, 8.28). The economic development of the area generally increased after the foundation of Polish State in AD 966, but later it oscillated in connection with the progress of historical events and changing settlement. Unfortunately this uppermost part of profile G1/87 suffers from deficient sampling resolution. Still two main stages of environmental history in the Lake Gościąż area can be roughly seen in the record of the last ca. 1000 yr.

The lower spectra of subzone G1/87–10a (ca. AD (875) 1130–1490), register the end of a rather short (a couple of hundred yr) episode of animated economic activities in the region including *Carpinus* felling and increase of acreage of open land used by man and then left abandoned and exposed to the secondary succession (increase of *Pteridium, Calluna, Betula*), (see Chapter 9.1.3). This episode was probably followed by a time (ca. 150 yr) of a more reduced settlement, when the still remaining hornbeam woods stabilized or even slightly regenerated (*Carpinus* ca. 7%), and *Populus tremula* and *Alnus* regained their habitats on wetter abandoned grounds around the lake. The lands used economically shrank then (NAP around 10%). Percentages of *Quercus* pollen remained stable for more than 1600 yr at a level slightly exceeding 10%, expressing the presence and good flowering of oak trees probably protected in the lake region. The other deciduous trees (*Fraxinus, Tilia, Ulmus*) were scattered as minor contribution to the existing deciduous wood fragments and include also single *Fagus* specimens. *Taxus* and *Hedera* reappear in their understory.

The top zone of the diagram subzone G1/87–10b (AD 1490–1985), from the Late Medieval Period to recent time records the final devastation of natural pattern of forest communities in the region. The pine woods were left as the only meaningful forest community, deciduous woods with hornbeam were reduced to small fragments, and alderwoods were heavily destroyed. Oak remained as the only deciduous tree of any importance. The anthropogenic changes of vegetation during this time are described in details in Chapter 9.2.4.

8.4. THE HOLOCENE CLADOCERAN SUCCESSION IN THE LAMINATED SEDIMENTS OF LAKE GOŚCIĄŻ

Krystyna Szeroczyńska

In Poland an analysis of Cladocera from sediments accumulated during the Holocene was made for lowland lakes, such as Wigry and Wiżajny (Czeczuga et al. 1970, Czeczuga & Kosacka 1977), Jeziorak and Gopło (Bilska & Mikulski 1979, Mikulski 1977), Strażym (Błędzki 1987), Woryty, Błędowo, Skrzetuszewskie, Suszek (Bińka et al. 1991, Szeroczyńska 1985, 1991), Biskupin (Szeroczyńska 1995), and for mountain lakes, such as Przedni and Zadni Staw in the Tatra Mts. and Mały and Wielki Staw in the Karkonosze Mts. (Szeroczyńska 1984, 1993a). Studies are now being carried out on lakes Kortowo (Z. Niewiadomski), Giecz, Tłokowo (I. Polcyn), to

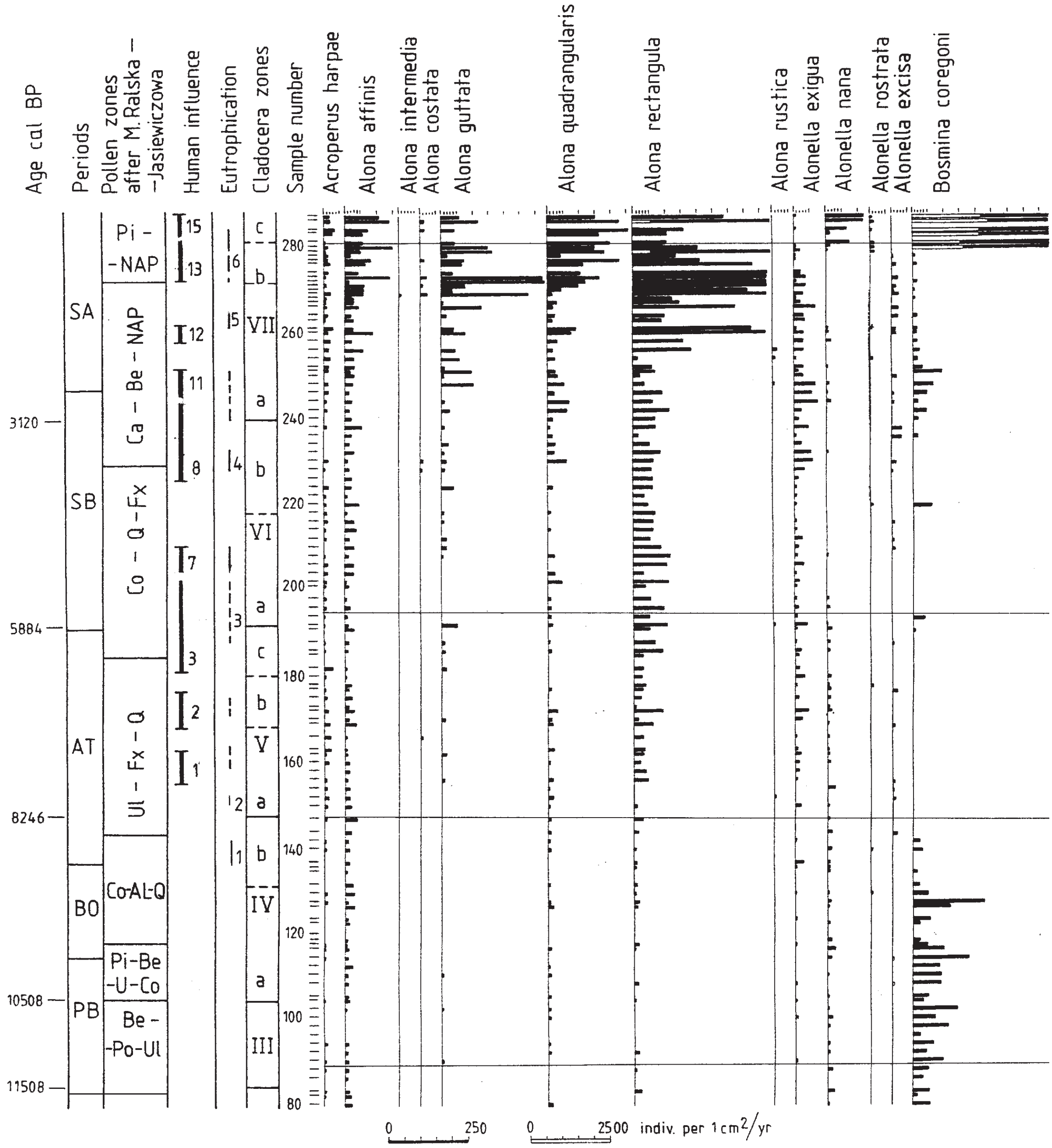


Fig. 8.29. Absolute frequency of Cladocera species in the Holocene part of profile G1/87. Numbers on the right side of the diagram (1–4) indicate.

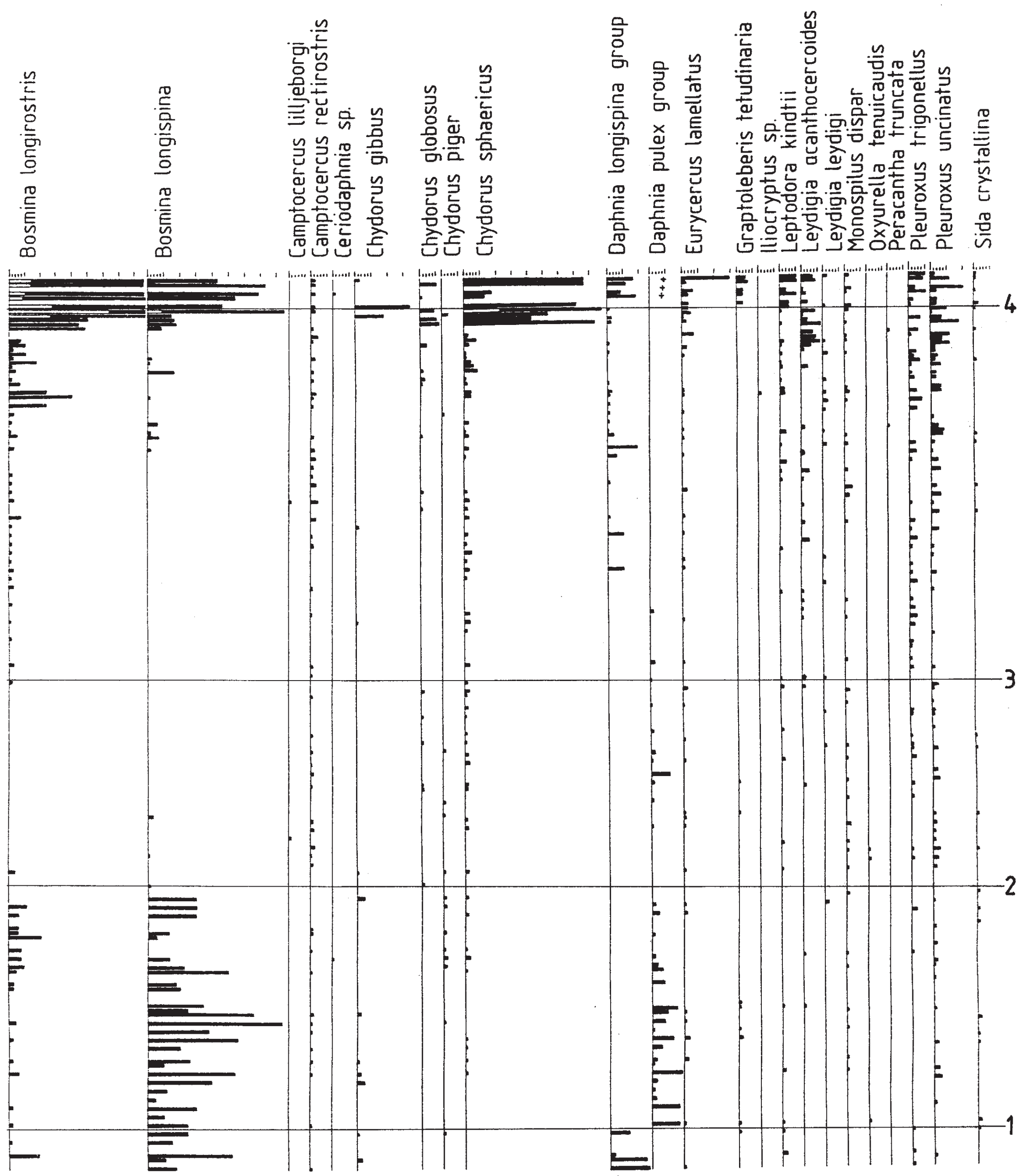
contribute to data about the history of Cladocera during the last 10,000 years.

An analysis of cladoceran assemblages in the Lake Gościąż sediments was carried out with the aim of reconstructing changes in ecological and climatic conditions during the evolution of this lake in the Holocene. Littoral species from the family Chydoridae and planktonic species from the family Bosminidae lived in the great abundance in Lake Gościąż (Figs 8.29, 8.30). This paper presents the results of Cladocera analysis for Holocene sediments. The results of Cladocera analysis for Late-Glacial sediments have already been presented (Szeroczyńska 1993b and Chapter 7.5.2).

Samples of gyttja sediments from profile G1/87 used for analysis of cladoceran remains were prepared according to the methods of Frey (1986a). Each sample consists of cladoceran remains obtained from 1 cm^2 of fresh sediment accumulated during 10 yr (Chapter 4.7).

Species composition and quality of fossil remains in the sediments of Lake Gościąż present a slightly different composition from that in other sites in Poland. The quantity of remains is smaller.

The results of analysis are demonstrated in Table 8.5, in the absolute frequency and in percentage diagrams (Figs 8.29, 8.30 and Fig. 9.19 in Chapter 9.1.4**)**. In the sediments of profile G1/87, 36 cladoceran species be-



the boundaries between the stages of lake development.

longing to 6 families were found; the dominants – except 8 species – are Chydorids.

Planktonic Cladocera

In the Holocene period in Lake Gościąż planktonic species were represented mainly by Bosminidae and Daphnidae (Fig. 8.29), including *Bosmina coregoni*, *B. longispina* and *B. longirostris*, *Daphnia longispina*-group, and *Daphnia pulex*-group. Bosminidae dominated in the Preboreal (75–99%), Boreal (50–90%), early Atlantic (40–80%), and later Subatlantic period (80%). In the Subboreal period their numbers were very low. In the Atlantic period, characterized by a humid climate (Starkel 1977), Bosminidae disappeared. It was for the first time in sediments from Polish lowland lakes that an absence of planktonic forms during the Atlantic period was noted.

Littoral Cladocera

Despite a great number (28) of littoral species present in the sediments of Lake Gościąż, the quantity of specimens was rather low. *Alona*, especially *A. rectangula*, appeared in the greatest abundance. During the Preboreal and Boreal periods *Alona affinis*, *A. quadrangularis*, and *Pleuroxus uncinatus* dominated among Chydoridae.

During the Atlantic period, when planktonic species were absent (Cladocera zone Va, b, c), the abundance of Chydoridae reached 98%. *Alona rectangula*, *Alonella exigua* and *Alona affinis* were predominant. *Camptocercus* and *Pleuroxus* occurred in significant numbers. The Subboreal period was characterized by a domination of *Alona rectangula* and *Pleuroxus trigonellus*. During the Subatlantic period (Cladocera zone VIIa, b) *Alona* species dominated, particularly *A. rectangula* (to 45%), *A. quadrangularis* (to 12%), and *A. guttata* (to 18%). Also *Leydigia* and *Pleuroxus* were abundant. Most recently *Chydorus sphaericus* was a very important component of Chydoridae (to 50%) (Fig. 8.30, Fig. 9.19 in Chapter 9.1.4) . It may represent a pelagic zone of the lake. A similar abundance of *Chydorus sphaericus* was noted by Hofmann (1986) in Großer Plöner See (Germany). According to the concentration diagram (Fig. 8.29), *Chydorus sphaericus* reached its maximum abundance during the period of domination of *Leptodora kindti* and all planktonic species of Bosminidae and Daphnidae. A simultaneous decrease of *Alona rectangula*, which dominated till then, may confirm the planktonic character of *Chydorus sphaericus*.

A small number of littoral remains, especially a low abundance of *Alona guttata*, *A. costata*, *Alonella exigua*, and *A. excisa* (Flössner 1990), show that the littoral zone of Lake Gościąż was poorly developed.

Profile characterization

On the basis of the absolute frequency diagram and percentage curves and on the knowledge about the climatic and ecologic preferences of Cladocera, 7 phases of Cladocera development in Lake Gościąż were distinguished. Phases I-II correspond to the Late-Glacial, the phases III-VII – to the Holocene (the phases I-II are presented in the Chapter 7.5.2).

Phase III (samples 84–104, 11,508–10,508 cal BP). The specimens of *Daphnia longispina*-group disappeared, and *D. pulex*-group developed in its place. The planktonic species *Bosmina longispina* (Patalas 1954) expanded. Chydorid species such as *Pleuroxus uncinatus* and *Chydorus gibbus* occurred in greater numbers. The development of clear-water temperate species *Camptocercus rectirostris* (Duigan 1992, Poulsen 1944) indicates that suitable climatic conditions existed during this phase. In the latter part of phase III a temporary setback of Cladocera development was recorded.

Phase IV (samples 105–147, 10,459–8246 cal BP). This phase shows a renewed expansion of Cladocera. The pelagic species Bosminidae dominated during this period, especially *Bosmina longispina* suggesting an oligotrophic character of the lake (Hofmann 1986). *Daphnia pulex*-group was also abundant. Littoral species especially of *Alona* were common.

Table 8.5. Species of Cladocera from the Lake Gościąż Holocene sediments and from water samples (Błędzki 1993).

Taxon	Sediment	Surface sediment only	Water
Acroperus harpae	+	–	+
Alona affinis	+	+	–
Alona quadrangularis	+	+	–
Alona guttata	+	–	–
Alona costata	+*	–	–
Alona rustica	+*	–	–
Alona intermedia	+*	–	–
Alonella excisa	+	–	–
Alonella exigua	+	–	–
Alonella nana	+	+	–
Alonella (Disparalona) rostrata	+	–	+
Bosmina coregoni	+	–	+
Bosmina longirostris	+	–	+
Bosmina longispina	+	–	+
Camptocercus sp.		+	–
Camptocercus rectirostris	+		–
Camptocercus lilljeborgi	+*		–
Ceriodaphnia sp.	+*		–
Ceriodaphnia pulchella		–	+
Ceriodaphnia quadrangula		–	+
Chydorus gibbus	+	–	–
Chydorus globosus	+	–	–
Chydorus piger	+	–	–
Chydorus sphaericus	+	–	–
Diaphanosoma brachyurum	?	–	+
Daphnia cucullata	–	–	+
Daphnia longispina-group	+	–	+
Daphnia pulex-group	+	–	–
Eurycercus lamellatus	+	+	–
Graptoleberis testudinaria	+	+	–
Iliocryptus sp.	+*	–	–
Leptodora kindtii	+	–	+
Leydigia leydigi	+	–	–
Leydigia acanthocercoides	+	–	–
Monospilus dispar	+	–	–
Oxyurella tenuicaudis	+*	–	–
Pleuroxus aduncus	–	+	–
Pleuroxus trigonellus	+	–	–
Pleuroxus uncinatus	+	+	–
Peracantha truncata	+*	+	–
Sida crystallina	+	–	–

* – noted only occasionally

The phase IV was divided into subphases a and b. In the second part of this phase an increase of *Bosmina longirostris* and a fall in the abundance of *Bosmina coregoni* was followed by the development of the ß-mesotrophic species *Alonella exigua*, and the species *Camptocercus rectirostris*, indicating a milder climate with an intense

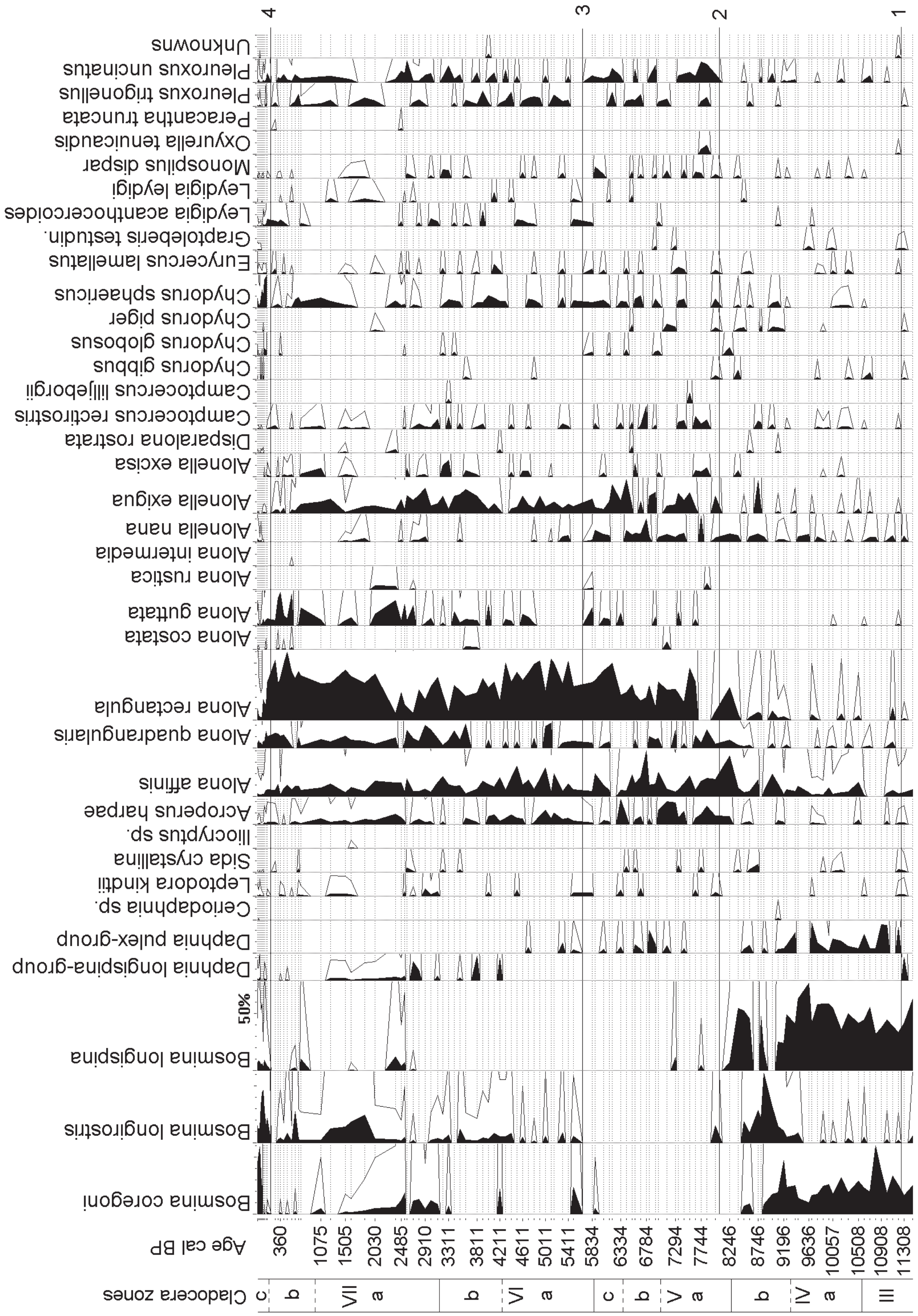


Fig. 8.30. Percentage diagram of Cladocera species in the Holocene part of profile G1/87. Numbers on the right side of the diagram (1–4) indicate the boundaries between the stages of lake development.

development of littoral forms and thus rising trophy (Goulden 1964, Hofmann 1986, Mikulski 1977, Whiteside 1970).

Phase V (samples 148–190, 8196–5934 cal BP). This phase is characterized by an almost complete disappearance of *Bosmina*, which dominated the Cladocera composition previously. It is mainly distinguished by species of the Chydorids, in particular *Alona* and *Alonella* species. Phase V was divided into subphases a, b and c. In each of three subphases an expansion and then a fall in the abundance of the ß-mesotrophic *Alonella exigua* occurred, accompanied by the appearance of acidophilous species *Alonella excisa*. According to the results of palynological analysis, during this phase the first traces of human activity appeared, probably of the Mesolithic cultures. Development of *Camptocercus rectirostris* and *Pleuroxus* indicates a milder climate in phase V than in earlier one.

Phase VI (samples 191–240, 5884–3120 cal BP). Bosminidae species reappeared in small abundances, especially *Bosmina longirostris* and *B. coregoni*. *Bosmina longispina*, a typically oligotrophic plankton species (Hofmann 1986), was absent. *Bosmina longirostris* was present with varying intensity; chiefly in the second part of the phase, this species expanded along with a remarkable increase of the ß-mesotrophic species *Alonella exigua*, marking a change towards mesotrophy in the lake. The number of littoral specimens, especially of *Alona*, also rose considerably. In the percentage diagram (Fig. 8.30) *Alona rectangula* became gradually dominant (to 50%).

Phase VII (samples 241–287, 3060 – -35 cal BP). It is characterized mainly by the development of *Bosmina longirostris* and *B. coregoni*. The drastic increase and then decrease of plankton species suggest external causes, probably connected with human activity. Deforestation and human settlements caused an increased inflow of mineral and organic compounds, producing the increase of trophy in the lake. Fluctuations in abundance of species and specimens were the basis for subdivision of this phase into subphases a, b and c.

Subphase VIIa is characterized by an intense development of *Bosmina longirostris* and of *Alona* and *Leydigia*, which are indicators of eutrophy (Frey 1986a, Hofmann 1986, Whiteside 1970). Towards the end of this subphase a decrease in their abundance was noted. It might have been caused by a setback in the inflow of the nutrients into the lake, resulting in a deterioration of living conditions of Cladocera.

Subphase VIIb is characterized by a renewed expansion of some Chydoridae species. *Chydorus sphaericus*, which had occurred so far in very small numbers, attained its maximum abundance, as did the acidophilous *Alona guttata*. This species was accompanied by an increase of acidobiontic *Alonella excisa* (Krause-Dellin & Steinberg 1986). A sudden fall in species abundance, especially of littoral species and the eutrophy indicator species, took place again towards the end of this subphase. The abundance of *Alona*, which earlier dominated for a long time, diminished (Figs 8.29, 8.30).

Subphase VIIc is characterized by an increase of pelagic species, mainly *Bosmina longispina* and *B. coregoni*. Intensively increasing trophy was restricted in the lake, as confirmed by a decrease in the mesotrophic species *Alonella exigua*. Also the eutrophic species *Bosmina longirostris* decreased a little. The pelagic species *Bosmina coregoni* and *B. longispina* occurred abundantly again, after a long period of absence. *Chydorus sphaericus*, which is often planktonic in character, dominated among Chydoridae.

Conclusions

The species composition of Cladocera in the Holocene sediments of Lake Gościąż generally shows a rather oligo- or mesotrophic character of the lake. Change towards eutrophy was observed during periods of the supposed influence of human activity (except Cladocera zones IVb and first part of Va). Planktonic species of Bosminidae and Daphnidae dominated only during the Preboreal, Boreal, and early Atlantic periods (Fig. 8.29). It should be assumed that the lake was nearly always as deep, as today, but the quantity of Cladocera species of both, littoral and pelagic zones was minimal. In its deepest part the sediments were not mixed, so annually laminated sediments could accumulate. Nowadays it is considered to be an eutrophic lake (Błędzki 1993), though human pressure has no major influence over it. As a result changes today are taking place in a natural way (Kentzer & Żytkowicz 1993, and Chapter 3.5).

Cladoceran zone V is of special interest. Species of Bosminidae suddenly disappeared for a rather long time. The palynological data suggest (Ralska-Jasiewiczowa & van Geel 1993 and Chapter 9.1.3) and archaeologic finds confirm (Pelisiak & Rybicka 1993 and Chapter 9.1.1) the presence of Mesolithic camping-sites in the area around the lake. The $\delta^{18}O$ curve (Kuc et al. 1993 and Chapter 8.6) would suggest a cooling of climate during this phase, although not indicated by the species composition of Cladocera. *Camptocercus rectirostris*, *Monospilus dispar*, and *Pleuroxus* prefer warmer water.

The phases of Cladocera development correlate with the pollen-assemblage zones differentiated by Ralska-Jasiewiczowa et al. (Chapter 8.3). Their species composition indicates a rather mild climate. Four distinct boundaries dividing the diagrams into parts may be observed (Figs 8.29, 8.30):

1 – the boundary corresponding with the stratigraphic transition between the Late-Glacial and the Holocene. It is sharply marked by the abundance of species of Da-

phnidae. At that time a drastic fall in the abundance of *Daphnia longispina*-group was followed by a development of *Daphnia pulex*-group. It was also the beginning of the domination of the planktonic species *Bosmina longispina*.

2 – the boundary shows an almost complete decline in the abundance of all species of Bosminidae and the beginning of dominance of littoral species, especially of *Alona*. *A. rectangula*, which often accompanies a process of changing trophy, became dominant and persisted almost until the present day.

3 – the boundary presents a renewed expansion of species from the family Bosminidae. After this time the eutrophic species *Bosmina longirostris* dominated among the Bosminidae, replacing *Bosmina longispina,* which had been dominant until then. The abundance of this species in Lake Gościąż during the periods of human activity was much lower than in other lakes studied in Poland. However, considering the particular character of this lake, the fluctuations in the development of this genus (even very small) should be regarded as connected with the settlement fluctuations. A strict analysis of the concentration curve of *Bosmina longirostris* and other indicator species of eutrophy (Figs 8.29, 8.30) shows a great coincidence of their development phases with the phases of supposed settlement, recorded in a pollen diagram and confirmed by archaeological data (Pelisiak & Rybicka 1993, Ralska-Jasiewiczowa & van Geel, Chapter 9.1.3).

4 – the boundary separates the sediments accumulated during the last two centuries. In these sediments a special cladoceran succession was observed. This short-lasting period (Cladocera zone VIIc) was characterized not only by the domination of planktonic forms but also by the coexistence of all species of Bosminidae and Daphnidae. Also among Chydoridae was a high abundance of *Alonella nana* and *Chydorus sphaericus*, which are often planktonic in character in deep lakes and invade the pelagic zone (Frey 1986b).

Fluctuations of the water level may be studied by the analysis of the relations between planktonic and littoral Cladocera (Barry et al. 1984, Korhola 1990, Tikkanen & Korhola 1993). Two species were excluded from the comparative analysis, *Bosmina longirostris* from planktonic taxa and *Chydorus sphaericus* from littoral taxa. In unsuitable conditions, *Bosmina longirostris* often moves to the littoral zone (Goulden 1964), and in conditions of high trophy it may become the only representative of Bosminidae. Thus, it indicates then an increasing eutrophy, not a higher water-level (Goulden 1964, Hofmann 1986, Matveev 1986, Szeroczyńska 1991). The littoral species *Chydorus sphaericus* is often found in the planktonic zone (Alhonen 1970, Frey 1988, Goulden 1964, Hofmann 1978), often connected with existence of Cyanobacteria, or with a cold climate. In the cold climate it may be the only representative of Chydoridae (Szeroczyńska 1984). Thereby, it is an indicator of cool conditions not of a developed littoral zone.

Two diagrams of planktonic/littoral species ratio (traditional one and with *Bosmina longirostris* and *Chydorus sphaericus* excluded) were made for comparison (Fig. 9.18, Chapter 9.1.4). According to the curves of dominating planktonic species in profile G1/87 a higher water-level in Lake Gościąż occurred in the Late-Glacial time (Fig. 7.36, Chapter 7.5.2), in the Preboreal, Boreal, and early Atlantic, and partly in Subboreal and Subatlantic periods (Fig. 9.18, Chapter 9.1.4).

Because of an absence of species of Bosminidae during the Atlantic period (Cladocera zone V) and their poor representation during the next two periods, fluctuations of water-level during these periods cannot be accurately defined. A strong predominance of Chydoridae may indicate a very low water level with “an absence” of the planktonic zone, a situation impossible in such a deep lake. A possible explanation may be that during these periods, the pelagic zone of Lake Gościąż was poorly oxygenized, thereby making the existence of planktonic species impossible. Thus an analysis of Cladocera index P/L for these periods is useless, because it gives a false suggestion of the water-level changes in the Lake Gościąż.

8.5. LAKE-LEVEL CHANGES AND PALAEOHYDROLOGICAL RECONSTRUCTIONS DURING THE HOLOCENE

Leszek Starkel, Anna Pazdur, Mieczysław F. Pazdur†, Bogumił Wicik & Kazimierz Więckowski

Reconstruction based on sediments and landforms

The record of lake-level changes and groundwater fluctuations during the Holocene is not well marked because of the dominance of steep shores and small water-level variations, which are connected with the sandy substratum and the continuous supply of groundwater from the south. The detailed examination of deposits in the lake bottom and shore zone (see Chapter 5) made it possible to distinquish several oscillations up to +1 m above and to –3 m below the present lake level (Figs 8.31, 8.32). At the same time the reconstruction of ^{14}C content variations in the lake water was made as it is related to the water volume (Fig. 8.33).

The information concerning the Preboreal period is scarce, but we may infer a lowering of the water level from the change of lacustrine to bog sedimentation in shallow depressions, as well as from the rise of Fe_2O_3 content in sediments (see Chapter 5.2, Fig. 5.12). Probably by the end of this phase the segments of Ruda stream connecting the deeper water bodies were joined (Fig. 8.34), starting the drainage of the lakes by the Ruda to the Vistula River.