Studia Quaternaria, vol. 21: 109–115.

PALEOLIMNOLOGICAL STUDY BASED ON OSTRACODS (CRUSTACEA) IN LATE-GLACIAL AND HOLOCENE DEPOSITS OF LAKE KRAKOWER SEE (MECKLENBURG-VORPOMMERN, NE GERMANY)

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Abstract
Two cores were taken from the southern lake basin to record the lake development from the Allerød until today. The Late Glacial and Holocene deposits of Lake Krakower See (Mecklenburg-Vorpommern, NE Germany) revealed changing water levels of the lake. Subfossil freshwater ostracods were used to interpret signals in terms of hydrological changes, eutrophication and temperature. A diverse ostracod fauna of 24 species was found in the examined sediment samples. For the first time the development of Late-Glacial and Post-Glacial freshwater ostracod assemblage could be recorded in the study area.

Key words: freshwater-ostracoda, water level changes, *Cytherissa lacustris*, *Metacypris cordata*, paleolimnology, Mecklenburg West Pomerania

INTRODUCTION

The area around the Lake Krakower See was already geologically investigated in the 19th century by Geinitz (1886) and more recently by Schulz (1967, 1968). Moreover, a new study confirmed various water level variations during the Late-Glacial and Post-Glacial period (Lorenz 2002). His investigations are based on paleo-lake terraces, which are situated 1 m and 2 m above the present day water level (47.5 m a.s.l.).

For the presented study, ostracods were sampled from two cores, which were taken from the southern lake basin at different sites. The main objectives were to verify alterations of the lake level in an initially closed basin and to record the development of the lake. The results were finally discussed, whether the changes were a result of climate or geomorphologic changes.

Furthermore, the presented record on ostracods improves the knowledge on the distribution of this group in the studied area. As published data on Holocene freshwater ostracods in Mecklenburg-Vorpommern are rare (e.g. Diebel 1965, Krienke *et al.* 1999, Viehberg, Hoffmann 2003, Frenzel *et al.* 2004) and quantitative results are even missing. Although ostracods are valuable indicators of various ecological parameters, this group was rarely included in paleolimnological studies of this area. They are sensitive to various chemo-physical parameters (*e.g.* conductivity, pH, temperature) and even more complex environmental variables such as water depth, presence of macrophytes, and sediment types. The presence of specific species as well as changes in their assemblages can be used to reconstruct the paleo-environment.

STUDY AREA

The Lake Krakower See (16 km^2, ~28 m max. water depth) is located in central Mecklenburg, NE-Germany. Geologically it is situated between the Pomeranian terminal moraine lobe in the north and the Frankfurt end moraine in the south (Fig. 1). The lake is divided into two separate lake basins formed by glacial erosion. Its hydrological system is independent of the adjacent lake area "Obere Seen" (*i.e.* Lake Müritz, Lake Kölpinsee, Lake Plauer See). The catchment is maintained by groundwater inflow and the River Nebel, which originates in Lake Malkwitzer See (60.7 m a.s.l., 10 km SE) and passes other minor shallow lakes before entering Lake Krakower See in the south-east. Today, the river flows out of the basin (47.5 m asl.; mean water level) through a valley in the north, which was formed during the Allerřd (Mangerud *et al.* 1974), cutting the Pomeranian terminal moraine lobe and discharging into the River Warnow (Baltic Sea) (Rother 2002). Two different paleo-lake terraces surround the lake and imply higher water levels in the past. The upper terrace is situated at 51 m asl. and was formed in the Younger Dryas, whereas the lower terrace is situated at 49 m asl. and became visible as the outflow was artificially lowered by 1 m in the 19th century (Lorenz 2002). Two cores were taken in the southern trough-like basin, which has an orientation of NNE–SSW.

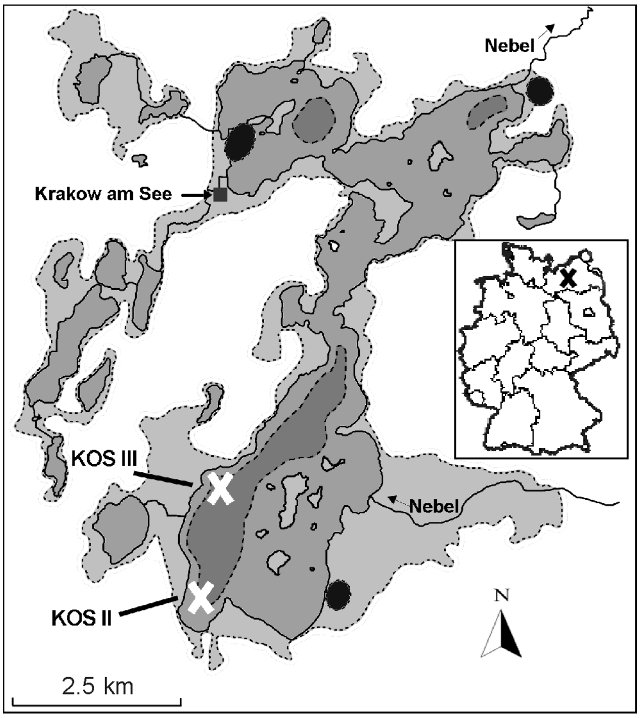

Fig. 1. Lake Krakower See, Locality KOS II & KOS III. Cross: coring site; light grey paleo-lake of the Younger Dryas; medium grey recent lake area; dark grey: paleo-lake of the (Pre-?) Boreal; black: island cores situated in the paleo-lake of the Younger Dryas.

METHODS

The cores were taken by a 60 mm modified Usinger-Livingstone-corer, cut in two halves and probed in the laboratory by 6 cm slices every 32 cm in core KOS II and 8 cm slices every 64 cm in KOS III. The 2 cm thick mid-segment was used for pollen, diatoms and sediment investigations (Hübener, Dörfler 2004, Lorenz *et al.* in prep.), while the ostracoda were examined from the remaining upper and lower horizontal slice. Each segment was digested in 3% H_2O_2 and sieved to 200 µm and 100 µm. The ostracod valves were picked and mounted on micropaleontological slides. The specific identifications followed Absolon (1978) and Meisch (2000) nomenclature. A minimum of 300 valves was examined from all samples, if the sample contained less, then all valves were picked. The ostracod diagrams were calculated on the basis of 25 ml sediment. The dating of the core horizons was done by pollen stratigraphy according to Firbas (1949) (Hübener, Dörfler 2004). The diagrams were plotted by "PanPlot"-software (Diepenbroek *et al.* 2001).

Core KOS II

The core KOS II was taken at a water depth of 4.35 m at E 12°15'53.9'', N 53°35'59.1''. The examined material was gained from a core depth of 1.65 to 7.15 m below sediment surface. The values of the $CaCO_3$-content in the deposits varied between (24–) 61–85%, while the organic compound values ranged from 2–8 %. (Hübener, Dörfler 2004, Lorenz *et al.* in prep.). Almost plain lake marl formed the lowest 33 cm (680–713) of the core, overlaid by 96 cm (584–680) calcareous siliceous silt with isolated laminated fine sand layers. In this section the lime values were also the lowest (23–36%). Above 569 cm up to the top the sediment was continuously formed by a homogeneous fine detritical calcareous gyttja (Lorenz *et al.* in prep.).

The pollen analysis signified a time span of the core from the late Allerød (pollen-zone II) to the Sub-Atlantic (pollen-zone IX) and also indicated a hiatus of almost 2000 years at 569 cm. The pollen zones IV and V were missing completely (Hübener, Dörfler 2004).

Core KOS III

The same coring device was used for core KOS III in a water depth of 24.5 m at E 12°16'21.7'', N 53°36'51.6''. The core ranges from 61 to 1940 cm below sediment surface. The sediment was very homogenous and formed by a calcareous gyttja. Its visible lamination structure fades towards the top. The $CaCO_3$-content varied between 30–77% and increased gradually to the bottom, while the organic compound values increased to the top of the core and ranged between 5–9% (Hübener, Dörfler 2004, Lorenz *et al.* in prep.). The time span estimated by pollen-analysis range from Late-Atlantic (pollen-zone VII) to 13th century (pollen-zone Xd) (Hübener, Dörfler 2004). Comparing the time-span to the length of the core, it becomes obvious that the sedimentation rate was unusually high.

RESULTS

Overall there were a total of 24 identified species recorded in the deposits of Lake Krakower See (Tab. 1, Fig. 2). All species, except *Potamocypris villosa*, are known from the local fauna (Frenzel, Viehberg 2004).

The amount of instars dominated the adult valves indicating that the examined material had an autochthonous origin in the lake (Fig. 3, 4). Almost every sample contained ostracod valves, except the sample at 617 cm in KOS II, where only few broken valves were found.

KOS II

The mean total number of ostracod valves was 2255 (adult 665) valves x 25 ml^{-1}, while the maximum abundance of ostracods was 7353 (adult 1935) valves x 25 ml^{-1} in the upper core. Samples with less than 300 valves were found at a depth of 485–551 cm (21–24) and 585–651 cm (28–32) (Fig. 3). In the same depth a higher proportion of thinner and broken valves was found, which could possibly be attributed to calcareous leaching processes in the sediment (high HCO_3^--content).

The ostracod fauna found in this core separates into two clearly different assemblages over the time. At the bottom (613–713 cm), in the Allerød/ Younger Dryas period, the ostracod community is characterised by a low diversity, dominated by four species: *Cyclocypris ovum*, *Candona neglecta*, *Candona candida*, and *Cyclocypris serena*. They were accompanied by a high amount of stoneworts residue (oogonium, organs), indicating a dense stand of charophyta.

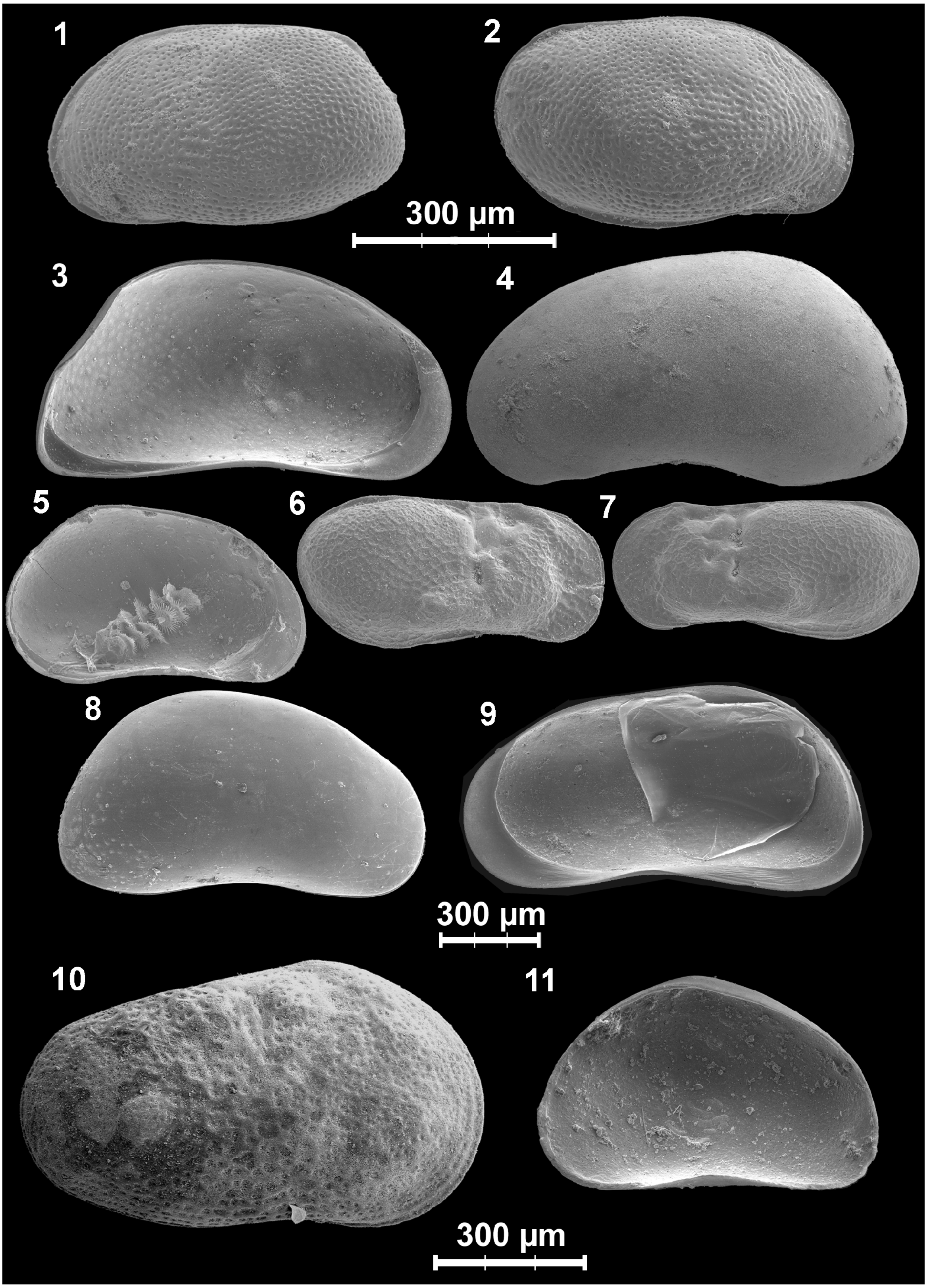

Fig. 2. 1–7: "cordata"-fauna (Post-Glacial), 8–11: "candida"-fauna (Late-Glacial) sensu Absolon (1973). 1: *Metacypris cordata* Brady & Robertson, 1870, female, left valve, external, length: 525 µm. 2: *M. cordata* Brady & Robertson, 1870, male, right valve, external, length: 520 µm. 3: *Fabaeformiscandona levanderi* (Hirschmann, 1912), female, left valve, internal, length: 1215 µm. 4: *F. levanderi* (Hirschmann, 1912), male, left valve, external, length: 1290 µm. 5: *Pseudocandona hartwigi* (G.W. Müller, 1900), male, left valve, internal, Zenker organ, length: 885 µm. 6: *Limnocytherina sanctipatricii* Brady & Robertson, 1869, female, right valve, external, length: 908 µm. 7: *L. sanctipatricii* Brady & Robertson, 1869, male, left valve, external, length: 893 µm. 8: *Candona candida* (O.F. Müller, 1776), female, right valve, external, length: 1080 µm. 9: *Candona neglecta* Sars, 1887, female, right valve, internal, length: 1178 µm. 10: *Cytherissa lacustris* (Sars, 1863), female, right valve, external, length: 905 µm. 11: *Potamocypris villosa* (Jurine, 1820), female, right valve, internal, length: 670 µm.

Table1
Species recorded in the Late- and Post-Glacial sediments of Lake Krakower

Species	Late-Glacial[1]	Post-Glacial
Candona candida (O.F. Müller, 1776)	+	+
Candona neglecta Sars, 1887	+	+
Cyclocypris laevis (Jurine, 1820)		+[1]
Cyclocypris ovum (O.F. Müller, 1776)	+	+
Cyclocypris serena (Koch, 1838)	+	+
Cypria ophtalmica (Jurine, 1820)	+	+
Cypridopsis vidua (O.F. Müller, 1776)	+	+
Cytherissa lacustris (Sars, 1863)		+
Darwinula stevensoni (Brady & Robertson, 1870)	+	+
Fabaeformiscandona fabaeformis (Fischer, 1851)		+
Fabaeformiscandona hyalina (Brady & Robertson, 1870)		+[1]
Fabaeformiscandona levanderi (Hirschmann, 1912)		+
Fabaeformiscandona protzi (Hartwig, 1898)	+	+
Herpetocypris reptans (Baird, 1835)	+	+
Ilyocypris decipiens Masi,1905		+[2]
Limnocythere inopinata Baird, 1843		+
Limnocytherina sanctipatricii Brady & Robertson, 1869		+
Metacypris cordata Brady & Robertson, 1870		+
Physocypria kraepelini G.W. Müller, 1903		+
Potamocypris villosa (Jurine, 1820)	+	
Pseudocandona compressa (Koch, 1838)	+	+
Pseudocandona hartwigii (G.W. Müller, 1900)		+[1]
Pseudocandona insculpta (G.W. Müller, 1900)		+
Pseudocandona marchica (Hartwig, 1899)		+[2]

[1] found in KOS II only; [2] found in KOS III only

A more diverse assemblage was found at the top 165–587 cm, where *Limnocytherina sanctipatricii*, *Fabaeformiscandona levanderi, Metacypris cordata*, and *Cytherissa lacustris* were abundant.

Both assemblages are divided by a hiatus (613–619 cm) where no adult valves were found. The adjacent samples are characterized by a high amount of fine-sand deposit, few ostracod-valves, and poor preservation of valves. According to these samples the analysis of pollen also showed a hiatus in the sediment history (Hübener, Dörfler 2004).

It is of further interest, that *M. cordata* is almost constantly accompanied with *L. sanctipatricii*, *F. levanderi*, and *C. lacustris*. The latter species are affiliated to coldstenothermal habitats, on the opposite *M. cordata* is a warmstenothermal summer form with a temperature optimum range from roughly 14°C to more than 20°C (Hiller 1972). Additionally, this species is well-known from shallow, macrophyte-rich freshwater habitats (Danielopol *et al.* 1996).

KOS III

The mean abundance of ostracods was remarkably low (151 valves x 25 ml^{-1}) and so was the maximum abundance of adult ostracods respectively (165 valves x 25 ml^{-1}). The low abundance of ostracods might be explained by the high sedimentation rate at the locality, although a total of 21 species were collected and a diversity of 12 different species in one sample was recorded. A general increase of ostracods can be noticed in the uppermost part of the core (Fig. 4). This coincides the postulated eutrophication of the lake (Hübener, Dörfler 2004) and results in a slight increase of species number.

Some species such as *Ilyocypris decipiens* and *Pseudocandona marchica* were exclusive collected in the KOS III core, the most frequent species were *Fabaeformiscandona protzi* and *Candona neglecta*.

DISCUSSION

The interpretation of ostracod-analysis is still more descriptive than precise. Significant ecological training-sets of ostracods are still missing, therefore straightforward prediction of various factors as known from *e.g.* diatoms (Schönfelder *et al.* 2002) are rarely possible. Nevertheless, interesting conclusion for the water regime of Lake Krakower See could be drawn from the results of the ostracod records in the presented Holocene deposits.

Reconstructing the hydrological system of Lake Krakower See from the beginning of the record, analysis of ostracod assemblages revealed that the catchment was maintained by running waters (River Nebel) and springs. This is indicated by the occurrence of species such as *P. kraepelini*, *C. serena*, and *P. villosa*, which were collected frequently from recent lothic environments (Meisch 2000).

The assemblage found in the Allerød deposits indicate a macrophyte-rich habitat in a shallow water realm. Over time the basin must have been filled continuously, to form the paleo-lake terraces of Lake Krakower See, which were dated back to the Younger Dryas (Lorenz 2002). They reflect a high stand of the lake level (approx. 53 m a.s.l.). While this high stand, the River Nebel broke somehow through the end moraine in the north, forming paleo-deltas in lower adjacent basins and drained Lake Krakower See (Rother 2002). However, this does not explain the necessary water level drop of at least 15 m to stop the sedimentation process at the site of KOS II (37 m a.s.l.). A deeper drainage system must have existed, such as a postulated subterranean outflow through the still 'young' end moraine, which was eventually blocked permanently in the Late Boreal (pollen zone VI). It seems to be unlikely, that climate changed to a very dry and warm period and increased evaporation in such a quantity. Still it remains unclear whether there was low water event or even a terrestrial condition, which interrupted the sedimentation process. Undoubtedly, the bad preservation of the valves in the sample below the hiatus can be explained by reworked sediment as the lake level rose again. The time-following samples sup-

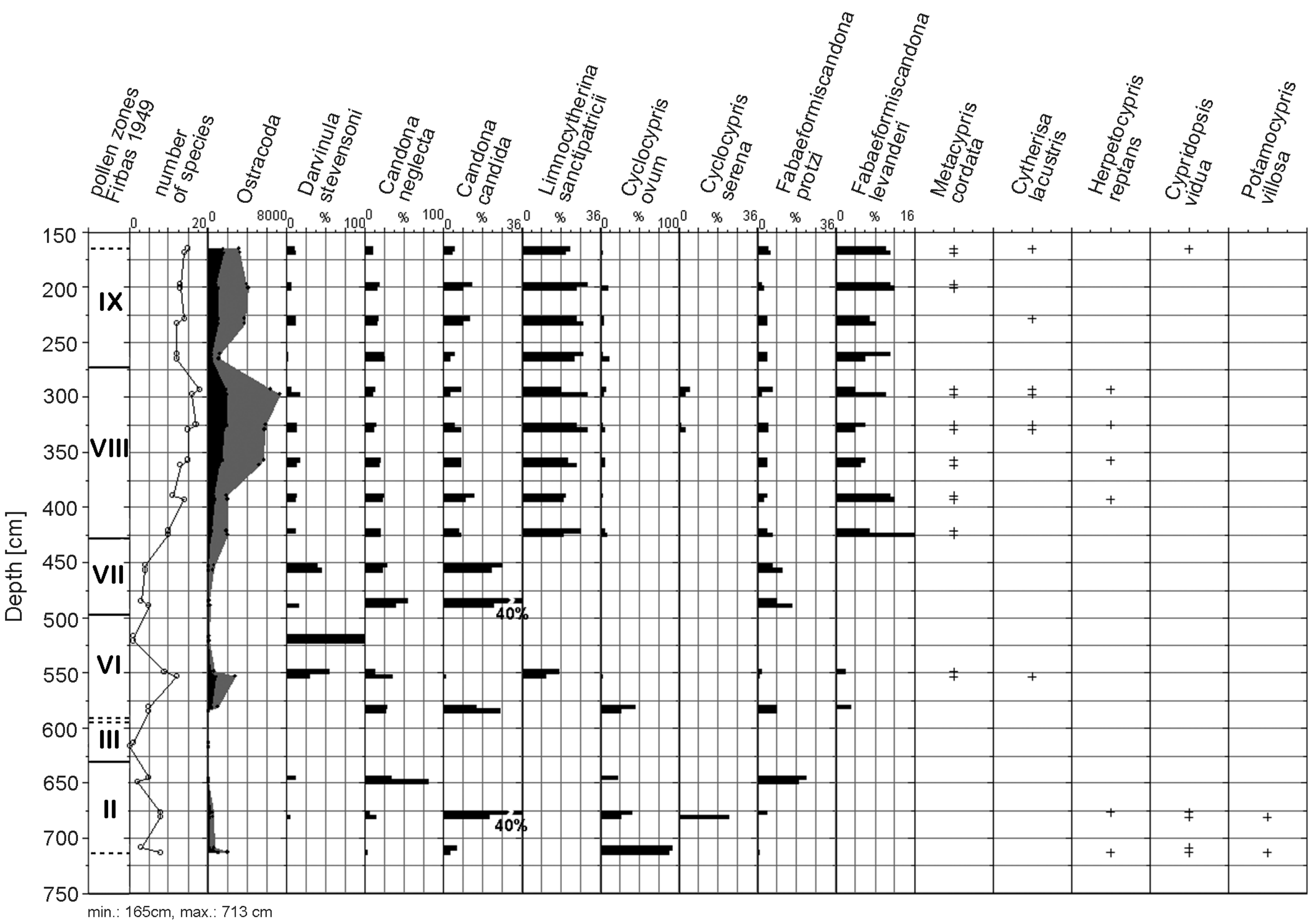

Fig. 3. KOS II, Selected ostracod species. Total ostracod valves * 25 ml^{-1}, black: adult, grey: juvenile; dominant species shown in percentage columns, (sub-) recendent species occurrence indicated by +.

ported this hypothesis, as *Limnocytherina sanctipatricii* was continously found from a sediment depth of 427 cm (pollen zone VI). It indicated a stable population in a deeper, oligothermal habitat (Meisch 2000).

As a consequence of the rising water level, nutrients might have been remobilised from the flooded area. In fact, oligotrophic species *e.g. L. sanctipatricii* (Löffler 1975, Scharf 1980) and *C. lacustris* (Danielopol *et al.* 1988, Scharf 1993) were not present at 453 – 523 cm in core KOS II, which could indirectly indicate a higher trophic status of Lake Krakower See in late Atlantic (pollen zone VI/VII). Eventually the basin of Lake Krakower See reached (continuously?) a water level comparable to today's (with minor fluctuations?) and the water quality returned back to a oligotrophic status.

Further investigation is needed to resolve the hydrological processes, therefore geochemical analysis on ostracod valves would give distinct signals in isotope and trace element proxies (Griffiths, Holmes 2000, Schwalb 2003). In general, sudden water level changes are also described in recent ecosystems by Gotsmann (1955) and Thienemann (1933) and have to be taken into consideration.

Cytherissa lacustris was expected to be found in higher abundances than it was actually recorded. It was collected only in low numbers in Post-Glacial sediments of both cores. *C. lacustris* are often found in very high population densities in Late Glacial freshwater deposits and in environments with high oxygen-saturation, oligothermal condition, and oligotrophic waters. A reason for the unexpected result gained from KOS II could be, that the host water had an annual temperature above its optimum. As already mentioned, *C. lacustris* coexists with shallow littoral species such as *M. cordata* and *H. reptans*, but they prefer water temperature of at least 14°C (Meisch 2000).

While on the other side the reason for the surprising low abundance in the deep water core KOS III could be unfavourable environmental conditions for benthic organisms in general, due to the high sedimentation rate and its consequences.

From the faunistical point of view, the analysis of core KOS II documented a freshwater-ostracod fauna of the Allerød and its development until the Sub-Boreal, it is observed for the first time in the study area. Griffiths & Evans (1995) discussed the (re-)colonisation of freshwater habitats by ostracods after the Last Glacial Maximum and proclaim an increasing diversity of species over time. Furthermore Absolon (1973) documented a characteristic species assemblage for the Late-Glacial in central European lacustrine sediments, known as the "candida"-fauna. Similar results were reported by Günther (1986) from Lake Duvensee in north-west Germany and she referred to it as a "neglecta"-fauna. The early ostracod assemblage of Lake Krakower See in core KOS II matches these data very well. Beside the already mentioned dominating species, the following are also represented in the

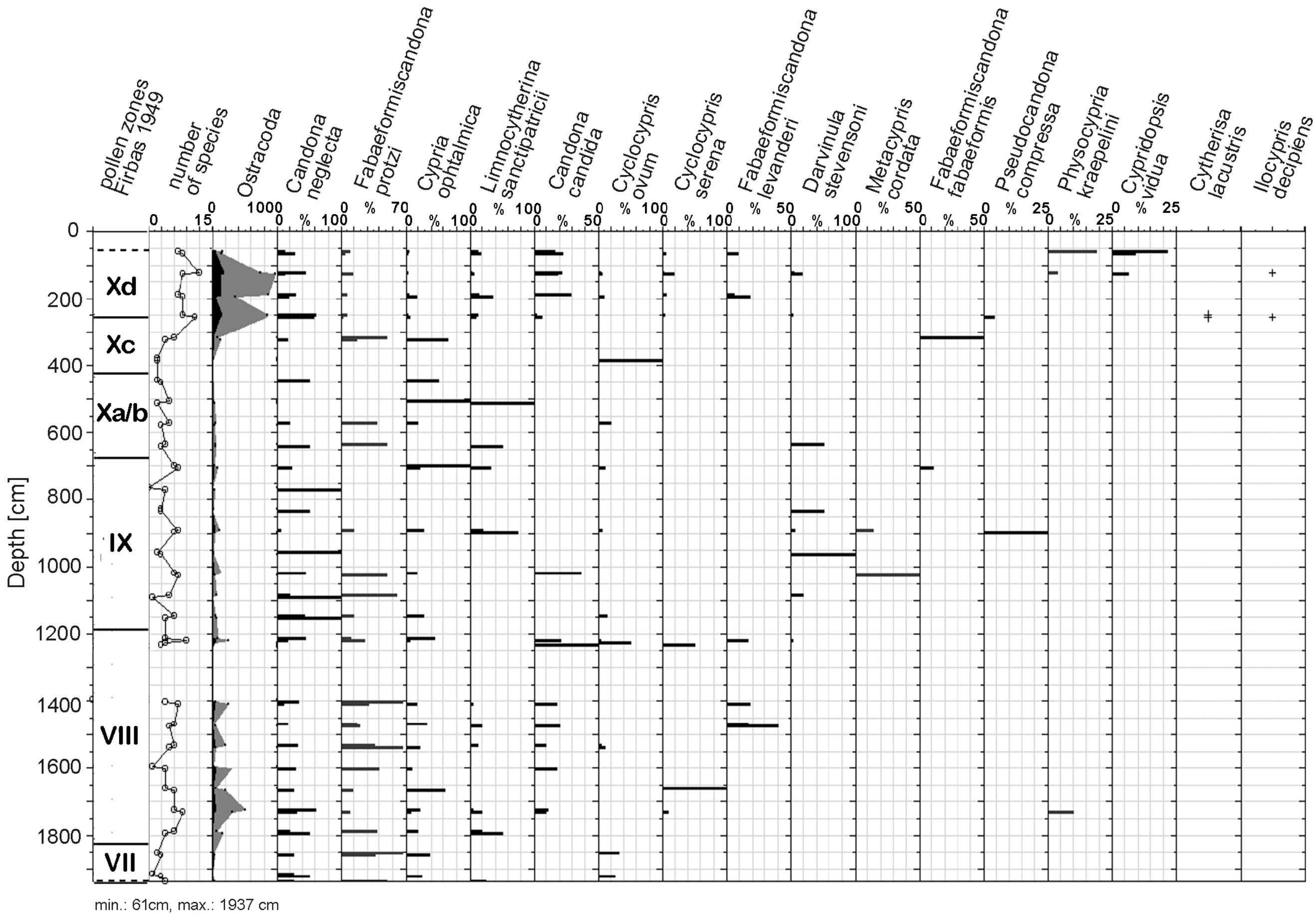

Fig. 4. KOS III; Selected ostracod species. Total ostracod valves * 25 ml^{-1}, black: adult, grey: juvenile; dominant species shown in percentage columns, (sub-) recendent species occurrence indicated by +.

local Late-Glacial fauna: *Fabaeformiscandona protzi*, *Cyclocypris serena*, *Herpetocypris reptans*, *Pseudocandona compressa*, and *Potamocypris villosa*. Additionally, *Cypridopsis vidua* and *Darwinula stevensoni* occured as well, although both species are so far only reported for the transition fauna or the Post-Glacial fauna respectively.

The Post-Glacial "cordata"-fauna described by Absolon (1973) is characterized by an increased faunal diversity. *Fabaeformiscandona levanderi* seems to initiate the local "cordata"-fauna after the mentioned hiatus. The diverse assemblage developed to a community of up to 18 species at a given time point. *Metacypris cordata* itself is recorded for the first time later in the Boreal (pollen zone VI) together with *Limnocytherina sanctipatricii*, *Limnocythere inopinata*, and *Cytherissa lacustris*.

CONCLUSION

Changes in ostracod fauna were analysed in two sediment cores from the littoral of Lake Krakower See (Mecklenburg-Vorpommern, Germany). The ostracod fauna reflected changes in water level over time as already known from geomorphical studies. The closed basin of Lake Krakower See was filled until the late Allerød/Younger Dryas to a high stand of at least 3 m above today's water level (51 m a.s.l.). Soon after, a major event must have happened, as the water level dropped dramatically in a short period of time and sedimentation process was interrupted. The changes of Lake Krakower See were probably driven by threshold dynamics rather than climatic changes, although cooler and drier climates might have supported the decreasing water level. It rose again in the early Atlantic, which meant that the former outflow must have been blocked again. Eventually, during the rising water level eutrophication processes were postulated (pollen zone VI/VII).

Acknowledgements

I like to thank S. Lorenz for providing the samples and geochemical analyses of the sediment and Marc Cartellieri and Gösta Hoffmann for the critical review of the final manuscript.

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