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RECENT SEDIMENTATION AND EUTROPHICATION OF KRUKLIN LAKE AFTER ARTIFICIAL DROP IN WATER-LEVEL IN THE MIDDLE OF 19th CENTURY

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Abstract

Sediments of two short cores collected from two basins of Kruklin Lake were studied by means of ^{210}Pb and Cladocera analyses. The ^{210}Pb allowed to date sediments and was helpful to obtain changes of sedimentation rate during the last two centuries. The CRS model was applied to calculate sediments age. Sedimentation rate differed strongly (from 0.55 cm/yr to 6.25 cm/yr) not only in time, but also between each basin. An accurate chronology of sediments was the basis for tracking of palaeolimnological changes with Cladocera analysis. Cladoceran planktonic:littoral ratio reflects event of artificial drop of lake water-level in the middle of nineteenth century. However, this event was recorded only in sediments of the southern, shallower basin and we suggest, that cladoceran planktonic:littoral ratio is better representative in shallow lakes. Changes of Cladocera assemblage composition suggest also strong eutrophication of lake water during the last century.

Key words: ^{210}Pb dating, Cladocera, sedimentation rate, eutrophication, lake-level changes

INTRODUCTION

Kruklin Lake is one of the best-studied lakes of Masurian Lake District in Poland. The sediments deposited in the lake were studied since early 60's of the last century (Stasiak 1963, 1966, Czeczuga & Gołębiowski 1969, Gąsiorowski 2001). However, these studies consider mainly lacustrine chalk sedimentation and say almost nothing about recent sedimentation regime. Meanwhile, the last two centuries were period of very significant changes in lake and its surroundings. The lake water level was artificially lowered by over 6 m between 1841–1851, by connecting Kruklin Lake with Gołdapiwo Lake (Srokowski 1945). The lake area decreased then by *ca.* 5.5 km^2 and the emerged land was transformed into grassland and fields. Changes in land usage and lake's parameters (*i.e.* area, maximum and mean depth, water circulation *etc.*) could be expected to affect lake's condition (*e.g.* trophic state) and could be recorded in the uppermost part of sediments. For studying these processes, two sediment cores were collected from the lake. The results of preliminary investigation of subfossil zooplankton community shown gradual decline in diversity of Cladocera (Crustacea) (Gąsiorowski 2002). Unfortunately, the dating results were not attainable in the preview study. So, the observed changes in Cladocera frequency could not be correlated with specific natural or artificial factors. A complete and reliable reconstruction has to be supported by high-resolution dating.

^{210}Pb dating is one of the most powerful methods for the establishment of chronologies in the recent lake sediments (Goldberg 1963, Krishnaswami *et al.* 1971). It could be used for dating youngest sediments ($T_{1/2}$ = 22.26 yr), deposited during the last two centuries and for tracking processes of mixing, focusing and re-deposition (San Miguel *et al.* 2003, Sonke *et al.* 2003). So, applying this method allows for construction time scales for palaeobiological analyses, but also it is helpful to study of lake sedimentology.

SITE DESCRIPTION

Kruklin Lake is located in the Masurian Lake District in north eastern Poland, 12 km east of Giżycko (Fig. 1). It occupies widespread basin, which was formed during last glacial period. From the north and west it is surrounded by moraine hills, which are up to 170 m a.s.l.

Today the lake is 5000 m long, 1300 m wide with an area of about 320 ha. The lake is elongated in a northerly direction. It is composed of two basins. The northern basin is wider and deeper with a maximum depth of 25.1 m, while the average water depth is 4.9 m. The lake has a complex shoreline with a number of bays of different size. The surface of Kruklin Lake features numerous sand and gravel islets. The lake is surrounded by pine forest from the north and east, whereas farmer land and meadows exist to the south and west.

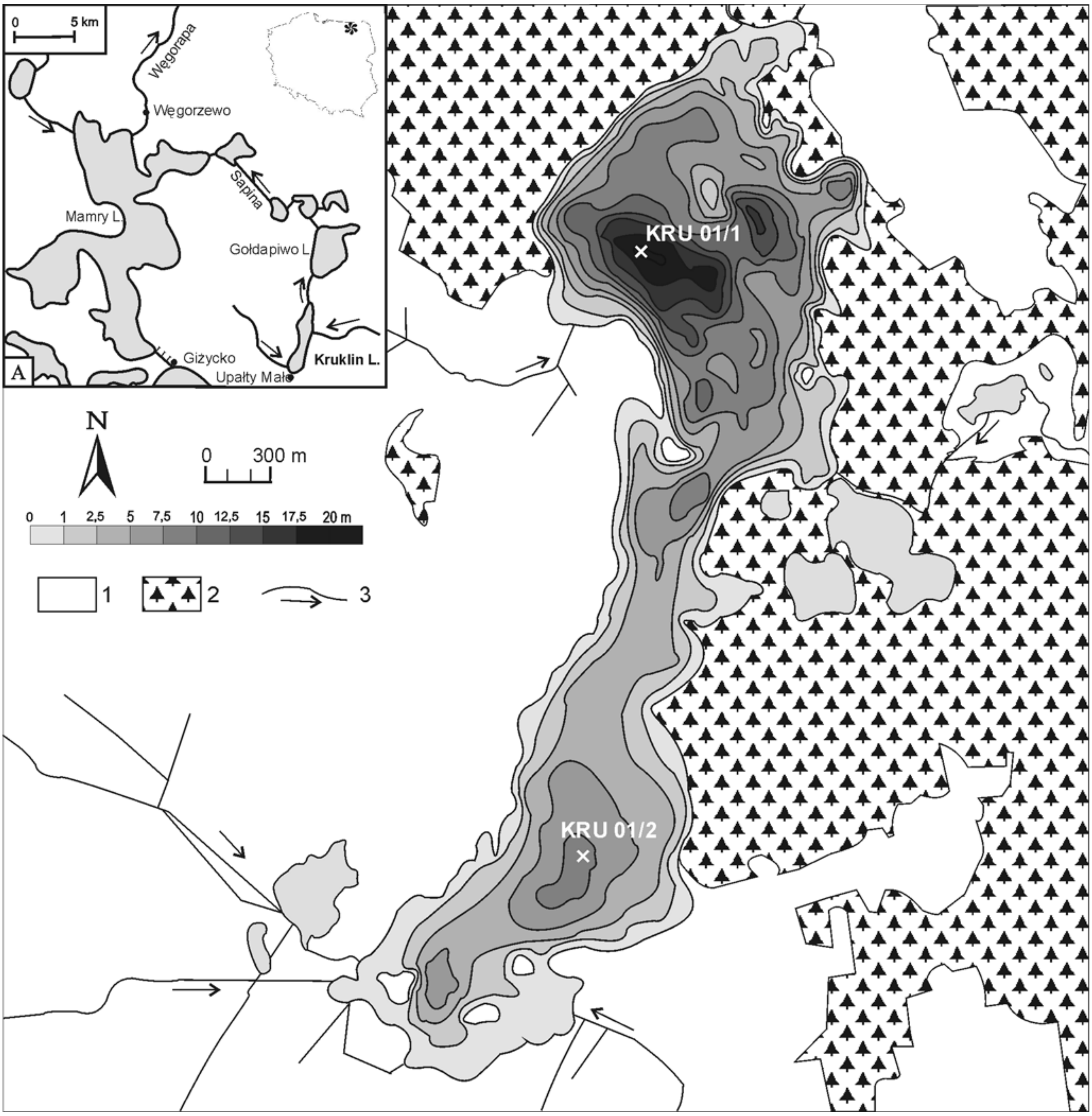

Fig. 1. Location of Kruklin Lake and coring sites: KRU 01/1 and KRU 01/2. *1* – cultivated land and meadow, *2* – forest, *3* – streams and rivers.

METHODS AND MATERIAL

The coring process is crucial for high-resolution studies of recent sediments. The uppermost part of sediments usually has semi-liquid or jelly-like consistence. Therefore, the sediment cores were collected with Kajak-type gravity corer. This corer gives opportunity to obtain almost undisturbed sediment cores. The cores of lake sediments were taken from the deepest sites of both basins: 8 m depth in the southern basin and 25 m depth in the northern basin (Fig. 1). The collected sediment is brownish-grey, calcareous, fine-detrital gyttja, which does not show any macroscopically distinguishable non-homogeneity along the profile. The core from the northern basin (KRU 01/1) was 54 cm long and that from the southern basin (KRU 01/2) was 41 cm long. The cores were divided into 1-centimeter thick slices in the field and stored in plastic bags. Then, the samples were selected for ^{210}Pb and Cladocera analyses, at every 1 cm from KRU 01/1 and every 3 cm from KRU 01/2.

For ^{210}Pb analysis, homogenised sample of 3 cm^3 was taken from each level. The fresh sediment samples were weighted, dried and weighted again to determine bulk density and water content. The dried sediment was heated for 1 hour at 550°C for partial decomposition of organic matter. ^{210}Pb activity of sediments was determined indirectly by alpha-spectrometry measurement of ^{210}Po (E_α = 5.31 MeV,

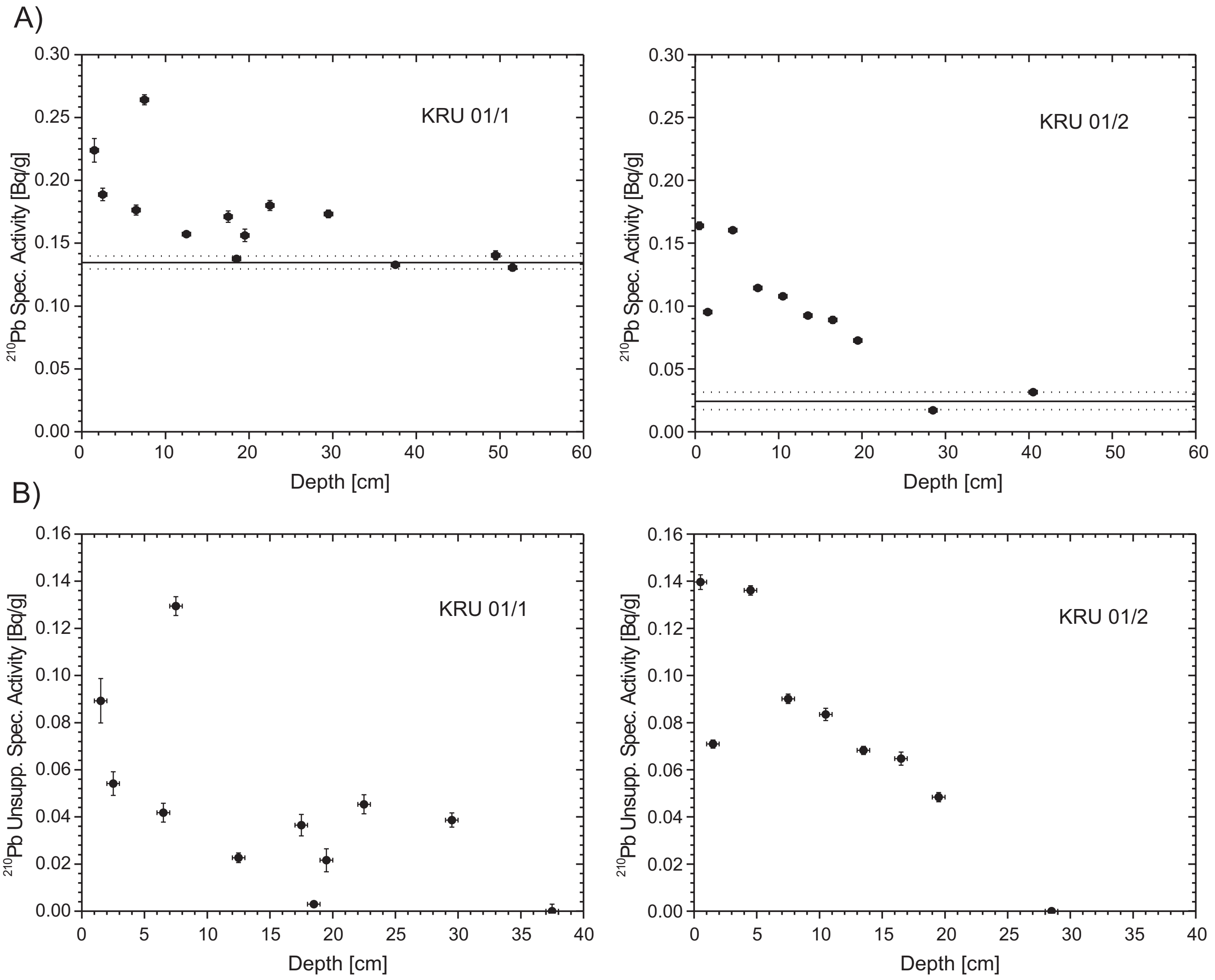

Fig. 2. Total (**A**) and unsupported (**B**) activity of ^{210}Pb versus depth from KRU 01/1 and KRU 01/2 sediments. Horizontal solid lines in Fig. 2A indicate activity of supported ^{210}Pb.

$T_{1/2}$ = 138 days) radioactivity (Flynn 1968). ^{210}Po is generated by decay of ^{210}Pb and then ^{210}Bi and it is assumed to be in equilibrium with the parent isotopes. As an internal yield tracer, the known amount of ^{208}Po was added to the weighted sample. Polonium was extracted from the sample using strong hydrochloric and nitric acids and was deposited on silver disks (Flynn 1968). Activity of ^{210}Po and ^{208}Po was measured using OCTETE PC alpha spectrometer produced by EG&G ORTEC. Constant rate of unsupported ^{210}Pb supply model (CRS) was used to calculate sediment age (Appleby 2001). This model assumes a variable sedimentation rate, sediment compaction and mixing. Activity of unsupported (allochthonous) ^{210}Pb was calculated from the total activity of ^{210}Pb by subtraction of supported (authigenic) ^{210}Pb activity. Supported ^{210}Pb was determined by ^{210}Pb measurements in sediments older than 200 years (which do not contain allochthonous ^{210}Pb) with assumption of constant activity of authigenic ^{210}Pb along the sediment column. The sedimentation rate was calculated basing on age of sediment layer at uncompacted depth and assuming constant deposition rate between dated points. The dated points correspond to centres of sediments slices. The sediment was considered uncompacted on the basis of changes of its porosity, determined previously by measured the water content (loss of sample mass after drying at 105°C for 24 hours).

Samples for Cladocera analysis were prepared according to standard procedure (Frey 1986). A sample (2 cm^3 of fresh sediment) was treated with 10% HCl (hydrochloric acid) in order to remove calcium carbonate. Then the sample was boiled for 20 minutes in 10% KOH (potassium hydroxide) with magnetic stirrer in order to deflocculate the material. Afterwards the sample was sieved through 33 μm mesh and dissolved in 10 cm^3 of distilled water and coloured with safranine dye. A slide was prepared from 0.1 ml of each sample and inspected with biological microscope (magnification 100 and 200). 2 to 5 slides were scanned from each sample. The basic sum for counting in most samples was 350-400 cladoceran remains (headshields, shells, ephippia, postabdomens). The most abundant body part was chosen for each species to represent the number of individuals and the percentages were calculated from the sum of individuals.

Ecological preferences of cladoceran taxa have been determined on the basis of Müller (1964), Whiteside (1970) and Szeroczyńska (1998a). The results were plotted as percent-

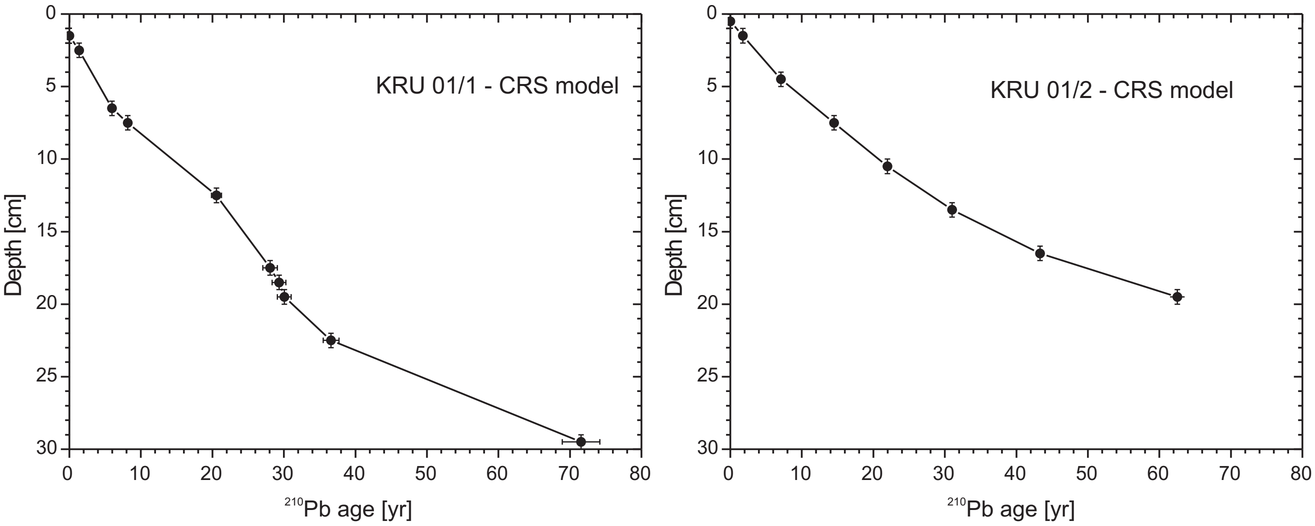

Fig. 3. ^{210}Pb age versus depth. Ages calculated using Constant Rate of ^{210}Pb Supply model.

age diagrams in ^{210}Pb-time scale. Such presentation of changes into cladoceran community allowed relating they to specific time periods.

RESULTS

Plots of total specific activity of ^{210}Pb (Fig. 2A) show significant differences between cores KRU 01/1 and KRU 01/2. The samples from core KRU 01/1 have *ca.* twice higher ^{210}Pb activities than those from KRU 01/2. The higher total activity is caused by higher level of supported ^{210}Pb (0.135 Bq/g in core KRU 01/1 and 0.024 Bq/g in core KRU 01/2) that derives from *in situ* decay of the parent radionuclide ^{226}Ra. The plots of unsupported ^{210}Pb activity versus sediment depth (Fig. 2B) also differ distinctly. The unsupported ^{210}Pb activity in core KRU 01/1 varies and does not decrease according to theoretical logarithmic function. The 'disturbed' graph of activity could suggest processes of physical, biological or chemical mixing. Unsupported ^{210}Pb activity in core KRU 01/2 declines with depth and is more concordant with theoretical decrease of activity. However, also in this plot some disturbances could be observed. The measured ^{210}Pb activity was the basis for age calculation. The choice of the ^{210}Pb dating model was conditioned by the pattern of activity changes. We apply the constant rate of ^{210}Pb supply dating model, which is adequate for cores with detected mixing or focusing processes. Fig. 3 shows plots of depth-age relation in KRU 01/1 and KRU 01/2 sediments. The depth-age line for KRU 01/1 is irregular and its slope varies, whereas for KRU 01/2 it is more regular. It indicates changes in sedimentation regime between coring sites. Sedimentation rate was very different in both sites (Fig. 4). The mean sedimentation rate was higher in KRU 01/1, however, it varied strongly from 0.55 cm/yr to 6.25 cm/yr. This parameter was much less variable in KRU 01/2 (from 0.67 to 1.02 cm/yr). The time scale for sediments older than 70 years was constructed basing on assumption of constant sedimentation rate in the lower part of cores.

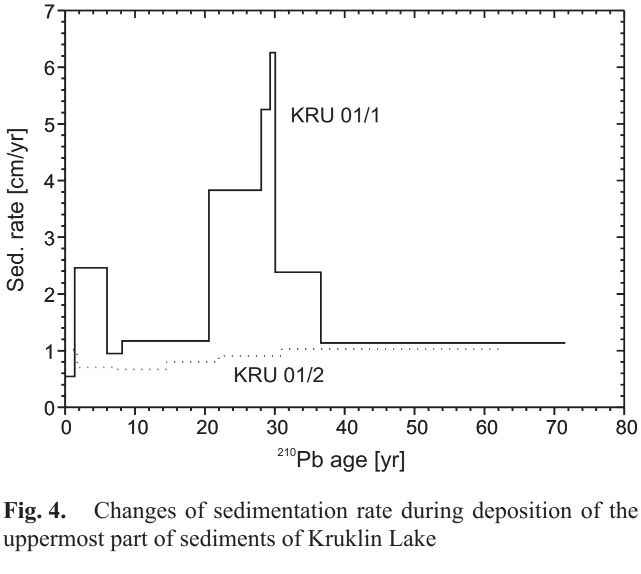

Fig. 4. Changes of sedimentation rate during deposition of the uppermost part of sediments of Kruklin Lake

33 cladoceran taxa belonging to 5 families (4 belong to family Bosminidae, 2 to Daphnidae, 1 to Leptodoridae, 1 to Sididae and 25 to Chydoridae) have been identified from chitinous remains. The number of identified taxa is comparable to other subfossil cladocera assemblages of eutrophicated lakes in Polish lowland (Szeroczyńska 1998b). In the core KRU 01/1 the number of taxa ranges from 26 at 52 cm (187 yr) to 6 in the surface sediment. The variety of taxa number in the core KRU 01/2 is smaller and the minimal number of taxa, 17, occurs in the surface sediment.

The age scales in the two cores coincide well with the changes in the clacoceran record (Fig. 5 and 6) and the same zones could be distinguished in both cores.

Zone I contains sediments deposited during 19th century (*ca.* 195-100 years ago). Its most characteristic attribute is domination of *Bosmina coregoni* and relatively low proportion of *Bosmina longirostris*. The zone was divided into two subzones, Ia and Ib. The basis of this separation is decrease of *Bosmina coregoni* and increase of *Chydorus sphaericus* seen clearly in sediments of KRU 01/1. According to ^{210}Pb dating, the end of subzone Ia (*ca.* 150 years ago) is correlated with the artificial drop of water-level (1841-51).

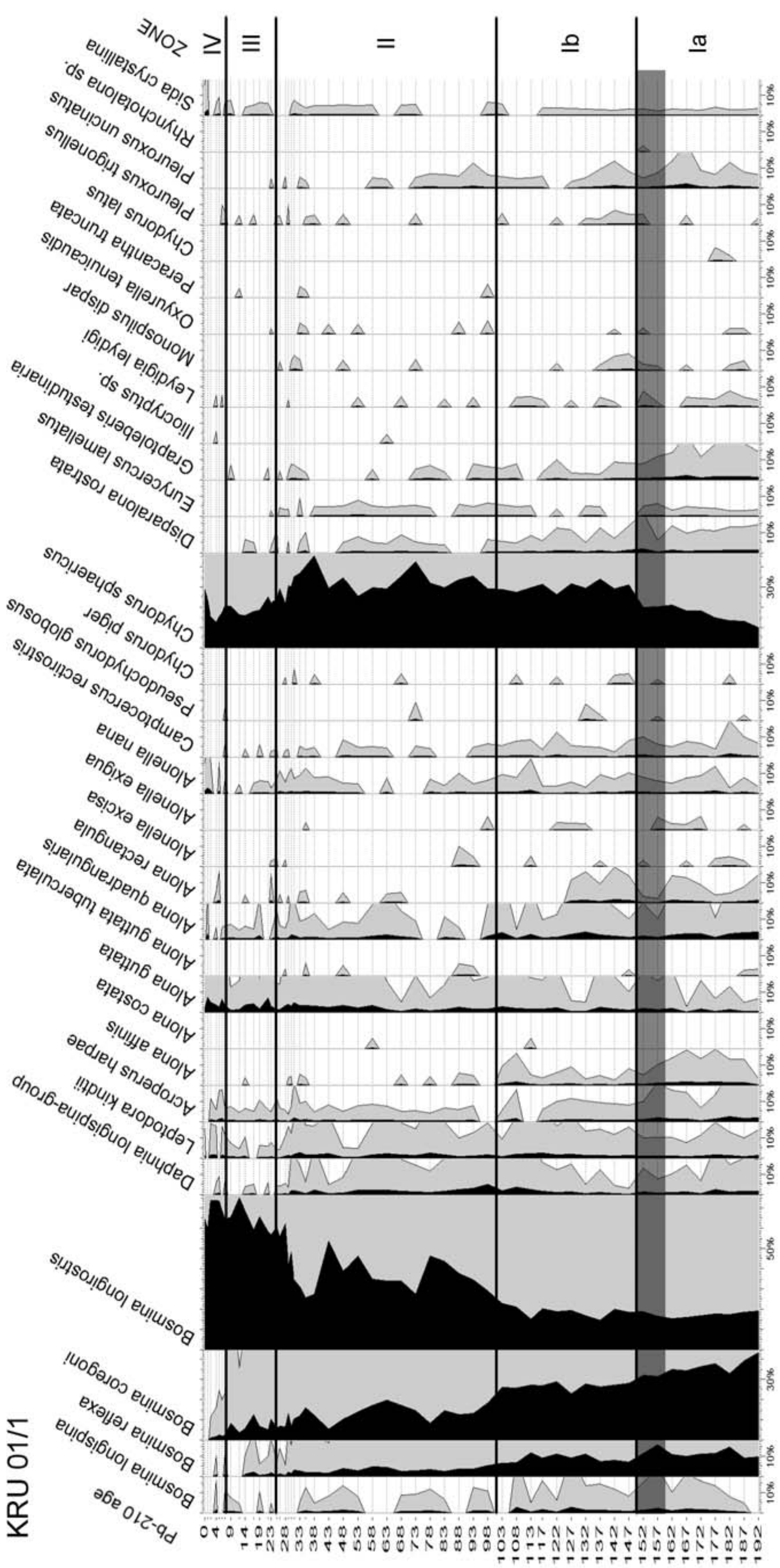

Fig. 5. Cladocera percentage diagram from core KRU 01/1. Shadowed belt indicates period of artificial drop of water-level.

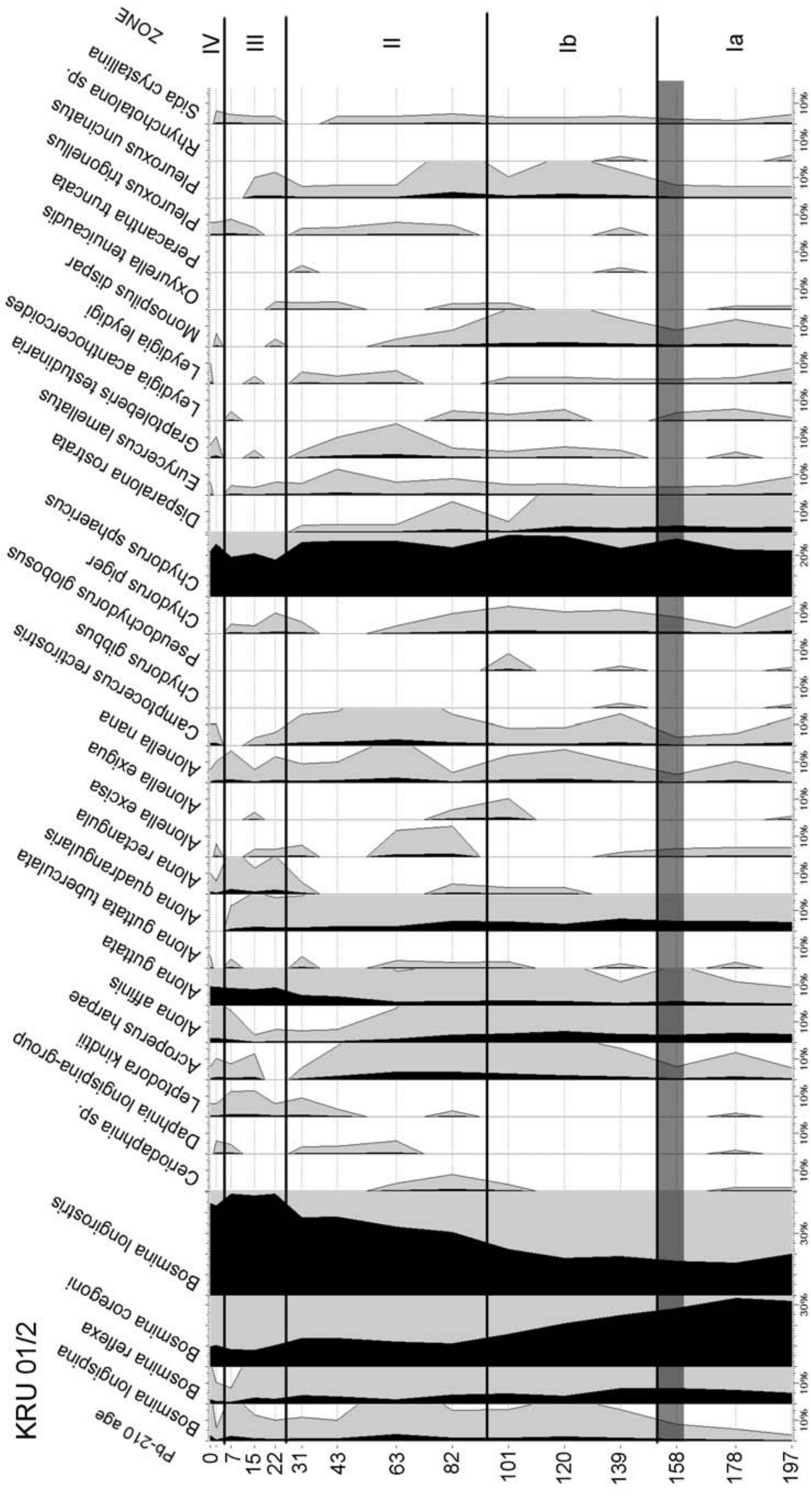

Fig. 6. Cladocera percentage diagram from core KRU 01/2. Shadowed belt indicates period of artificial drop of water-level.

Zone II (*ca*. 100-25 years ago) starts with rapid and significant decline of *Bosmina coregoni*. This species and other Eubosmina spp. (*e.g*. *Bosmina reflexa*) are linked with lower state of trophy (Szeroczyńska 1998a). Increasing of *Bosmina longirostris* and *Chydorus sphaericus* also indicates eutrophication of the lake.

Zone III (*ca*. 25-5 years ago) is a period of maximum development of *Bosmina longirostris* and could be related to the highest eutrophication. However, *Chydorus sphaericus* declines at the same time. Among other chydorids, *Alona guttata* increased significantly and *Disparalona rostrata* almost disappeared.

Zone IV is related to the last 5-6 years. In sediments from core KRU 01/1 *Eubosmina spp*. disappeared, as well as many other species and only 6 species remain in surface sediment. In southern basin (KRU 01/2) cladoceran assemblage is richer and much more diverse.

Remains of open-water taxa (mainly *Bosmina* spp.) are mostly dominant in both cores. Only in the middle parts of both cores (subzone Ib and zone II), where *Chydorus sphaericus* was dominant, littoral taxa prevail. The changes of proportion open-water to littoral taxa were the basis for calculation of cladoceran planktonic:littoral (P/L) ratio. This ratio may be used to indicate changes of lakes' water-level (Alhonen 1970, Sarmaja-Korjonen 2001). Figure 7 presents changes of P/L ratio for both cores and the comparison of its value calculated for entire cladoceran assemblage and with excluded *Bosmina longirostris* and *Chydorus sphaericus*. These species have very wide ecological tolerances. They could dwell in littoral and open-water zone and their behaviour is controlled rather by changes of trophy than water depth changes (Hoffman 1996). P/L ratio calculated for core KRU 01/2 shows good correlation with artificial drop of water-level. In KRU 01/1 site, which is significantly deeper than KRU 01/2, the P/L ratio is almost constant. The very low P/L ratio in the youngest sediment is caused by total absence *Eubosmina* spp. and *Daphnia* spp.

DISCUSSION

The differences in activity of supported ^{210}Pb might be caused by dissimilar sources of material transported into lake's basins. In core KRU 01/2 the level of supported ^{210}Pb is similar to other sites from lowland part of Poland (Gąsiorowski, Hercman in press). Supported ^{210}Pb specific activity for KRU 01/1 is much higher and similar to the values known from sites located close to outcrops of rocks with high U-series isotopes content, *e.g.* mountain area (Appleby 2000, Kotarba *et al.* 2002). Therefore, sediments deposited in northern basin (KRU 01/1) have probably higher content of the U-series isotopes, however, this supposition is not confirmed. The reason of such high content of the U-series isotopes in sediments is also unclear. The different levels of supported ^{210}Pb proves not only different source of material but also high isolation of both basins. Brenner *et al.* (2004) suggested, that ^{226}Ra-rich groundwater pumped to water bodies for irrigation, residential use, industrial applications and mining, could disturb equilibrium between ^{226}Ra and ^{210}Pb. The Kruklin Lake receives groundwater pumped from cultivated land and lacustrine chalk mine, which can be sources of ^{226}Ra. However, cultivated land and open mine exist around shores of the southern basin, where we found sediments with lower supported ^{210}Pb activity. This hypothesis also does not explain significant differences of supported ^{210}Pb between two sites (basins) in the same lake. In spite of that, the maximum unsupported ('atmospheric') ^{210}Pb activity is similar (0.13-0.14 Bq/g) in both cores. So, we could suppose, that atmospheric flux of ^{210}Pb, or rather transfer of ^{210}Pb from lake waters to the sediments, is similar in the entire lake-area.

One can easily explain different sedimentation rates in both basins. Higher values of this rate in the northern basin during almost whole studied period could be related to higher inclination of the lake floor and higher dynamics of sediment slip processes. However, in the northern basin sedimentation rate was very variable and in recent time it was even lower than in the southern basin. A reason for such differences in sedimentation rate occurring in the same site is not obvious, since an intensification of slip processes on lake's floor might be caused by many factors.

An increase of cladoceran indicators of high-trophy is observed towards the top of the cores. Especially, a sharp change is observed within open-water taxa group - a clear and relatively fast decline in *Bosmina coregoni* with a simultaneous increase of *Bosmina longirostris*. The sediments of the first cladoceran zone were deposited during nineteenth century. The Cladocera remains indicate almost stable conditions prevailed during entire this period. However, the first symptoms of increasing eutrophication, namely rising *Chydorus sphaericus* percentage and decreasing *Bosmina coregoni* and *Bosmina reflexa*, are recorded in this zone. These trends are visible after the artificial drop of the water-level (the end of Cladocera subzone Ia). However, the range of changes is relatively small comparing extent of the water-level drop (6 m).

Better correlation with the artificial lake-level drop is shown by the ratio of planktonic:littoral (P/L) cladocera (Fig 7). Cladoceran P/L ratio might be applied to reconstruct changes of extent of open-water and shallow-water zones. The usefulness of this ratio was widely discussed in many papers (*e.g.* Alhonen 1970, Korhola & Rautio 2001, Sarmaja-Korjonen 2001) and many arguments for and against applicability of that ratio were presented. However, this method gives better results when *Bosmina longirostris* and *Chydorus sphaericus* are excluded from the data set, because these particular species show much stronger relation to changes of trophy, than to water-level fluctuations. In this study we found very clear decrease of cladoceran P/L ratio in sediments of the southern basin (KRU 01/2) after artificial lake-level drop. Similar decrease is not recorded in sediments of the northern basin, what could be explained by significantly higher maximum and mean depths of this part of the lake. Therefore, even 6-meters drop of water-level was not reflected by Cladocera assemblages. *Bosmina longirostris* has strongly dominated planktonic Cladocera since the beginning of twentieth century. Usually, a transition from *Eubosmina* species to *B. longirostris* is connected with increase of eutrophication and often is followed by increase of *Chydorus sphaericus*. We observe such pattern also in Kruklin Lake sediments. The process of eutrophication, derived from cladoceran record, reached its maximum intensity during Cladocera zone III

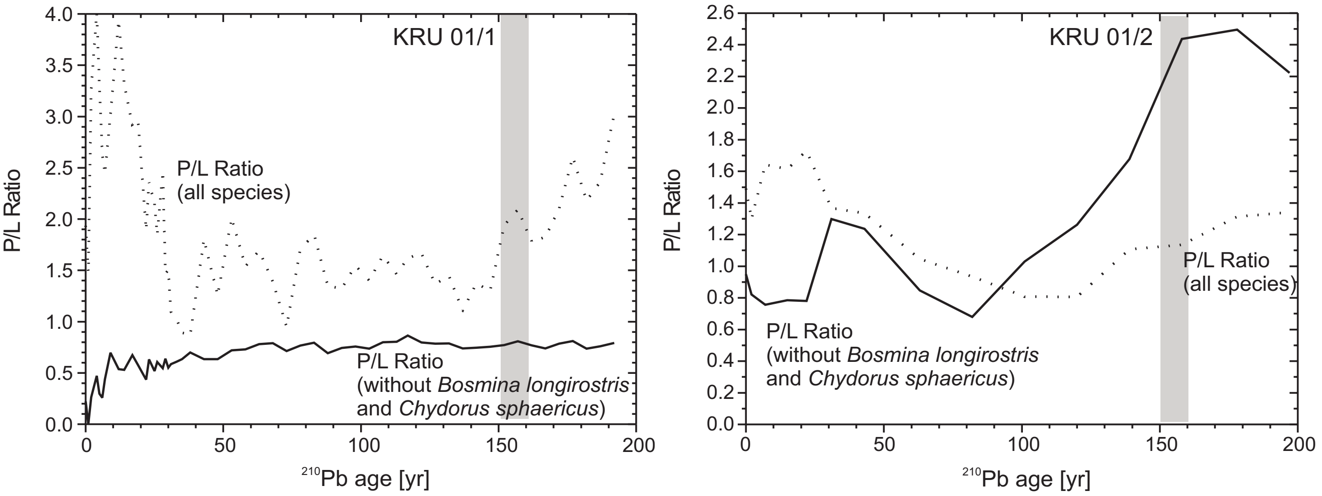

Fig. 7. Changes of cladoceran planktonic:littoral ratio. Shadowed belt indicates period of artificial drop of water-level.

(from 25 to 6 years ago). However, process of trophy increase was initialised long ago (Ralska-Jasiewiczowa 1966). Its peak in recent 20 years is probably related to the intensification of agriculture and fertilization of soils around the lake.

The uppermost part of sediments (zone IV) is characterized by the lowest diversity of Cladocera remains. In surface sediments of northern basin (core KRU 01/1) only 6 species were identified. It suggests further habitat's reduction, which probably was caused by increase of trophy. The eutrophication processes can eliminate some macrophytes and Cladocera species, *e.g. Graptoleberis testudinaria*, *Oxyurella tenuicaudis*, which are largely restricted to vegetation (Stansfield *et al*. 1989, Duigan 1992). Lower depth of the southern basin caused better preservation of more diverse habitat (*e.g.* with many submerged water plants) and allowed for dwelling of higher number of Cladocera species.

CONCLUSIONS

^{210}Pb and Cladocera analyses showed very strong hydrological and ecological separation of both basins of Kruklin Lake. The differences concern not only activity of supported (authigenic) ^{210}Pb and sedimentation rate dynamics and changes, but also composition of Cladocera community. The differences in sedimentation rate could be explained by different depth and topography of each basin. Changes of sedimentation rate in time are not easy to interpret. Especially in the northern basin changes of sedimentation rate are very strong and dynamic. The periods of increase of deposition rate are probably related to frequent events of sediment slip. However, at the present state of knowledge, it is difficult to point to mechanism and reason for that changes. Differences in morphology and bathymetry might be also the reason of differences in Cladocera species composition between both basins. It stresses problem of site selection during collecting of lake sediment cores for palaeoecological reconstructions. The widely accepted rule of collecting only one core from the deepest part of the lake could lead to incorrect conclusions concerning entire lake. It seems to be justified to collect two or three cores, especially if lake of complicated bathymetry is studied.

The Kruklin Lake is very special, since the lake was the object of hydrotechnical intervention and consequently its water-level was lowered by over 6 meters. This decline was reflected by changes of cladoceran planktonic:littoral ratio in sediments of the shallower, southern basin. In the deeper northern basin, Cladocera community did not reflect that event. Cladoceran P/L ratio shows good correlation with lake water-level changes if it is calculated excluding *Bosmina longirostris* and *Chydorus sphaericus*, the species which strongly reflect changes of lake's trophy. Such modified calculation of planktonic:littoral ratio should be applied if eutrophic lake is studied.

Changes of Cladocera assemblage composition reflect also intensification of eutrophication processes in Kruklin Lake. Increase of trophy was especially strong during twentieth century and peaked *ca.* 20 years ago. Eutrophication could be related to agricultural activity around the lake and in its catchment.

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