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PALAEOENVIRONMENTAL CHANGES IN THE HOLSTEINIAN (MIS 11C) PALAEOLAKE AT ORTEL KRÓLEWSKI II (EASTERN POLAND) IN THE LIGHT OF OSTRACOD ANALYSIS

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Abstract:
Lacustrine deposits from Ortel Królewski II (Eastern Poland) represent the Holsteinian Interglacial (MIS 11c). They are characterized by an extremely rich occurrence of ostracod and mollusc fauna. Collected samples represent pre-optimal part of the Holsteinian Interglacial corresponding to *Picea–Alnus*, *Taxus* and *Pinus–Larix* zones. Based on ostracod assemblage analysis a depth of the paleolake, the energy of the environment and the average January and July air temperature were reconstructed. Ostracods from Ortel Królewski II indicate a lake with possible periodic overflow surrounded by periodically flooded grasslands, which existed in the study area during the pre-optimal part of Holsteinian Interglacial.

Key words: ostracods, MIS 11, palaeolakes, climate change

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INTRODUCTION

Given the increasing attention paid to environmental and climatic change in the scientific literature, organisms that provide a proxy record of changes are particularly valuable. The group of tiny crustaceans–ostracods has an excellent fossil record and is among the few groups that can be equally palaeoenvironmentally informative in both the marine and non-marine environments.

The study of past interglacials can significantly contribute to improving our prediction of future climate change and its potential impact on the environment (Tzedakis *et al*., 2004, 2009; Jouzel *et al*., 2007). On the base of similarities of the Earth's orbital parameters Holsteinian Interglacial correlated with Marine Isotope Stage 11c (MIS 11c) (Tzedakis *et al*., 2001), appears to be one of the closest palaeoclimatic analogues for the present interglacial (Koutsodendris *et al*., 2013). Therefore, it is important to reconstruct these interglacial periods where the human impact was not so prominent as it is today.

The aim of the present study is to describe the ostracod assemblage in Ortel Królewski II and based on ostracod ecological preferences to reconstruct the evolution of the former lake. Despite interdisciplinary investigations which have produced faunal, pollen and petrographic analyses of the Ortel Królewski II site (Albrycht *et al*., 1995; Skompski, 1996; Szymanek, 2011, 2016, 2017a, b; Szymanek, *et al*., 2016) there is a lack of comprehensive analysis of the ostracod group. Variability in the structure and composition of the ostracod assemblage enabled palaeoecological reconstruction as their distribution in the profile document succeeding stages of lake development.

LOCATION AND GEOLOGICAL SETTING

The study area is located in eastern Poland, approximately 160 km east of Warsaw and 12 km south east of Biała Podlaska (Fig 1). The region is a sandy, swampy and peated plain, with relative hights reaching 11 metres. The whole area is dissected by the stream bed of the Zielawa River, running from the southwest to the northeast.

The site of lake deposits at Ortel Królewski II (51°57'11" N, 23°14'33" E) is located on the eastern slope of the Zielawa River valley. The exposed lake sediments are characterized by an extremely rich occurrence of molluscs and ostracods, reaching over 70% of the deposit volume (Albrycht *et al*., 1995). The deposits are exposed in a 50–100 m wide belt along the valley margin for a distance of approximately 500 m. Total thickness of the Holsteinian Interglacial deposits reaches here almost 7 m (Albrycht *et al*., 1995). The study site is located in the outcrop in NW-SE-oriented trough. The outcrop itself is approximately 3.5 m high and 5 m wide end expose 4 m of sediments. The interglacial

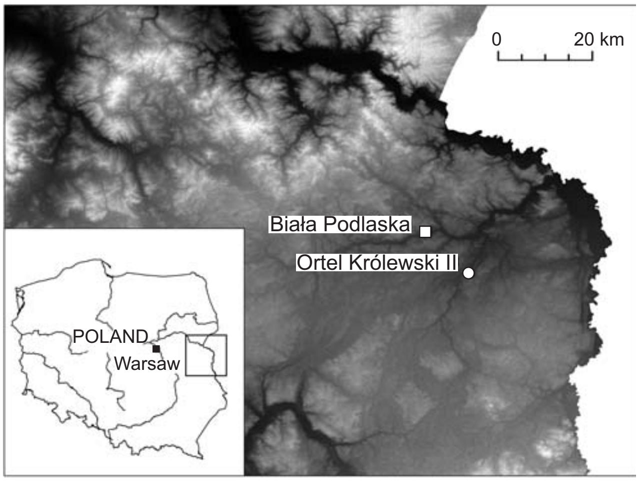

Fig. 1. Location of the study area.

sediments consist mainly of fine-grained silty sand, which in the bottom passes into grey-yellow and grey sandy and clayey silt. In the lowermost part they are developed as 40 cm of calcareous gyttja. Fig. 2 shows the exact study profile:

0–0.20 m – sandy soil
0.20–0.60 m – fine-grained sand, grey
0.60–1.40 m – fine-grained sand with abundant malacofauna, yellow-brown
1.40–1.90 m – fine-grained silty sand, yellow-brown
1.90–3.10 m – sandy silt, grey-brown
3.10–3.40 m – silt, grey-brown
3.40–3.60 m – silt, brown
3.60–4.50 m – fine-grained silty sand, green-yellow
4.50–4.80 m – silt, grey
4.80–6.80 m – fine- and medium-grained sand, brown-yellow

Mollusc and ostracod shells are generally well preserved, although shell detritus is also present. By the good state of shell preservation and the sediment features we can presume the lack or limited transport of material. The lake deposits lie on fluvio-periglacial sands of the Elsterian Glaciation and are covered by glaciofluvial deposits of the Saalian Glaciation, or by thin, about 1 m-thick colluvial sands. From the west the range of Holsteinian Interglacial deposits is marked by an erosional trough, which course corresponds to the present day Zielawa River valley and is filled with glaciofluvial deposits of the Saale Glaciation (Albrycht *el al.*, 1995).

According to Krupiński (1995) the development of palaeolakes around Biała Podlaska began in the late part of the Elsterian Glaciation. The cold, subarctic climate prevailing at that time led to tundra development (Krupiński, 1995, 2000; Nitychoruk, 2000; Szymanek *et al.*, 2016). The palinological record (see Albrycht *et al.*, 1995; Szymanek *et al.* 2005; Szymanek, 2011) starts with predominance of birch-pine forests (the *Betula–Pinus* zone). At the beginning of the Holsteinian Interglacial the average temperatures started to increase. Boreal climate resulted in average January temperature etimated at ~ -5°C and average July temperature of ca. 12–14°C (Krupiński, 1995, 2000). The gradual amelioration of the climate resulted in redevelopment of forest community, with rise of alder and spruce as well as appearance of oak and hazel. The average temperature in the following *Picea–Alnus* zone ranged from -5 to -3°C in January and from 16 to 19°C in July (Krupiński, 1995). The increase of humidity led to a rapid expansion of yew community. A warm and mild climate dominated during *Taxus* zone with average January temperature ca. -1°C and July temperature between 19 and 21°C (Krupiński, 1995). The palinological record ends with the so-called intra-interglacial cooling (the *Pinus–Larix* zone). Increase in continental influences and lower humidity led to a short regression in vegetation cover. Pine, birch and larch dominated the forest

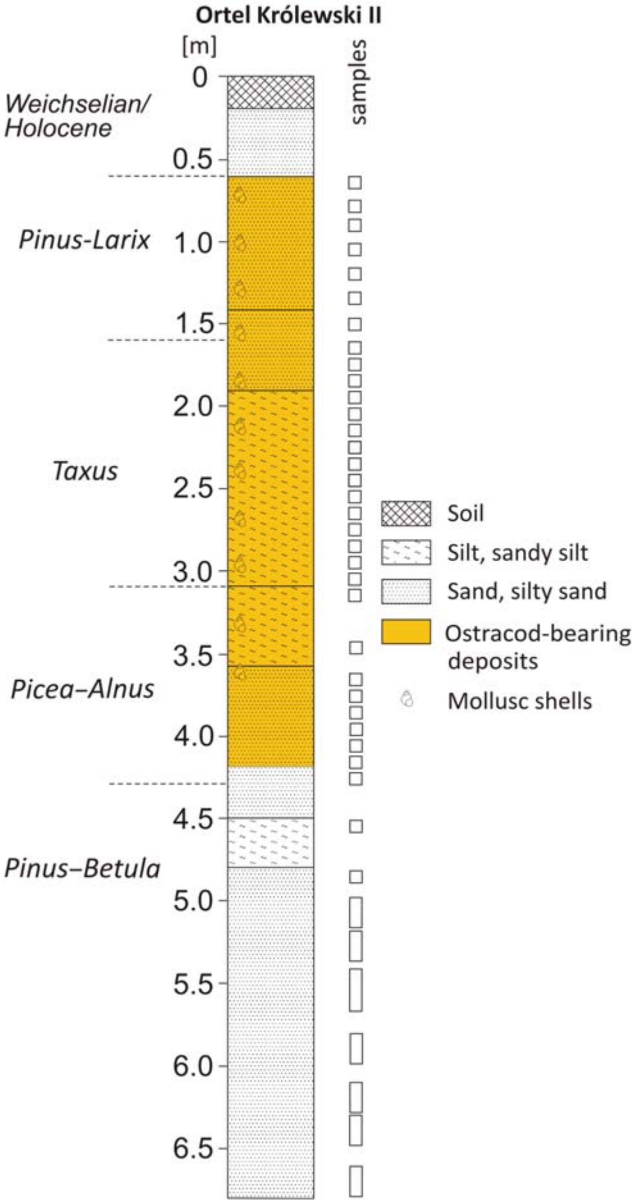

Fig. 2. Lithology and palynostratigraphy of the study profile. Pollen zones of the Holsteinian interglacial after Szymanek *et al.*, 2016.

community, whereas the yew population has been notably reduced. Estimated January temperatures dropped by a few Celsius degrees with no significant change in average July temperatures.

MATERIALS AND METHODS

In total 41 samples have been examined with an interval of 10 cm. Every sample had a volume of 5 cm^3. The material was gently washed through a 1.00, 0.50 and 0.25 mm mesh sieves. The aim of using such diameters was to separate adult ostracods from juvenile instars, which are often quite difficult to distinguish (Holmes, 2001).

At this point the dried samples were placed in individual glass vials pending analysis. Material was examined under a binocular microscope (with magnification up to ×50). Species identification was performed based on the shape, size and the sculpture features of valves and carapaces (see Skompski, 1991; Sywula, 1974; Meisch, 2000). To insure statistical validity of the results a minimum 300 individuals of ostracods were counted in each sample, if it was possible. The results of the ostracod analysis have been presented on diagram plotted using Pangea PanPlot (Fig. 3).

Environmental parameters

To represent the structure of ostracod assemblage ostracod spectra of species (OSS) and ostracod spectra of individuals (OSI) were used in the analysis. This method allows to clearly illustrate the ecological characteristic of the assemblage. Diagrams include percentage relations between groups of different ecological preferences. According to Alexandrowicz and Alexandrowicz (2011) spectra of species reflect properties and changes of environment in broad surrounding of the water body, whereas the spectra of specimens refers mainly to phenomena occurring in the closest vicinity of the thanatocoenosis accumulation place.

The two-component diagram method is another way for depicting climate or habitat traits. In subsequent samples ostracods of contrary environments are given by the formula $d_{AB} = A - B / A + B$, where A and B represents number of specimens representing each ostracod group. Results of the calculations in a form of graph correlated with the profile corresponds to changing lake conditions. The ratio ranges between -1 and 1, with extreme values indicating presences of only one of the components (Alexandrowicz and Alexandrowicz, 2011).

The subsequent part of the investigations was devoted to determine the air temperature fluctuations. To obtain January and July temperature ranges the MOTR (Mutual Ostracod Temperature Range) method was used. For the MOTR method to be applied it is necessary to know the temperature ranges of the species involved. The calculation was based on ostracod list given in Horne (2007) and Horne, Mezquita (2008). As a non-analogue method, the MOTR method makes use of the temperature range of individual ostracod species. Consequently, it allows all ostracod species in the assemblage (with the exception of extinct species) to be used, even if their modern day distributions do not overlap, contrary to methods which compare the fossil

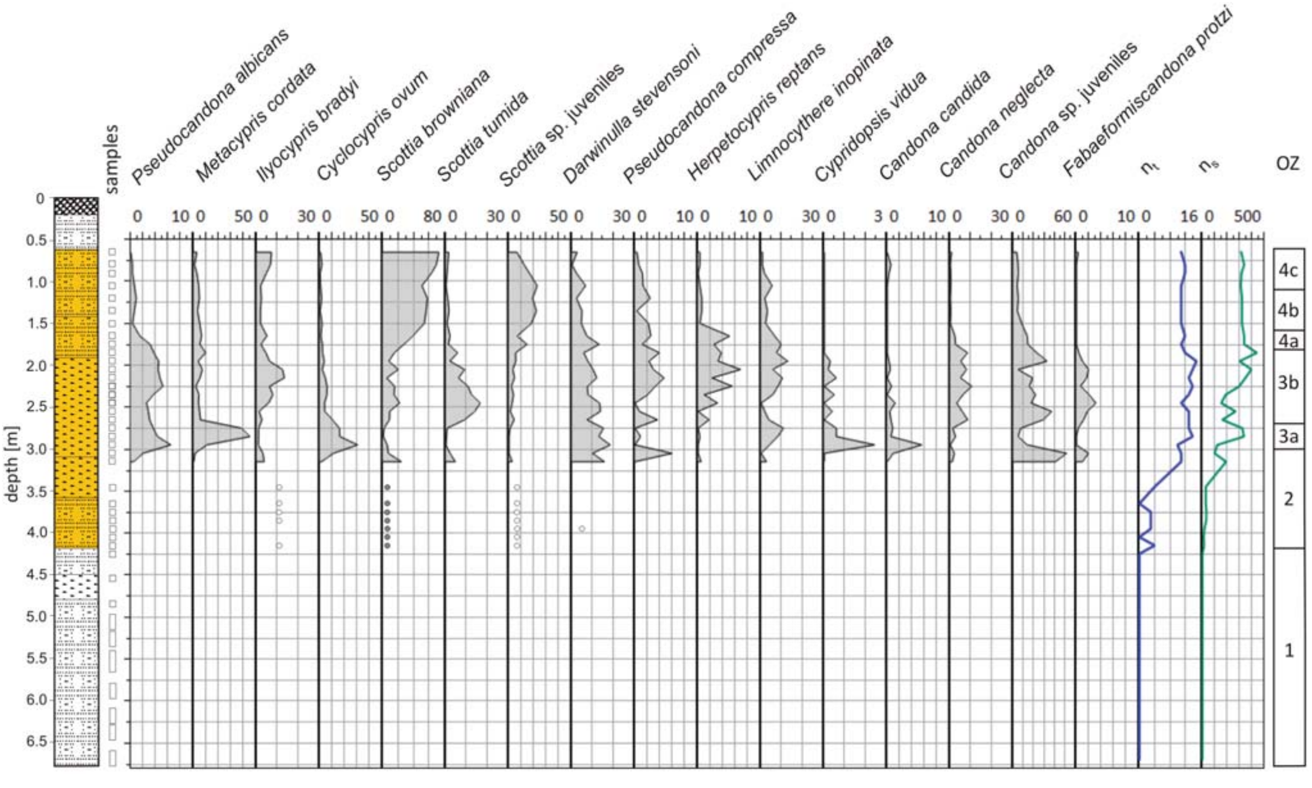

Fig. 3. Ostracod diagram of the Ortel Królewski II site. OZ – Ostracod zonation. Ostracods from samples with low valve abundance are indicated by white (less than 50% of the sample) and grey (more than 50% of the sample) circles. n_t – total sum of taxa, n_s – total sum of specimens

assemblages to recent ostracod communities. Comparison of the calibrated ranges of species in an assemblage allows the overlapping mutual ranges within which they could have lived to be determined and used as palaeotemperature estimates (Horne *et al.*, 2012). The results were compared with air and water temperature reconstructios based on the pollen (Krupiński, 1995) and isotope record of mollusc shells (Szymanek, 2017b).

RESULTS

The counting resulted in an amount of 17 ostracod species and 2 taxa recognized with a total of 6634 specimens (Table 1). The number of both taxa and specimens varies from 10 to 15 and from 99 to 447 per sample, respectively. Taking into the consideration number of specimens, the most abundant species were: *Scottia browniana* – 2596, *Candona neglecta* – 1178, *Metacypris cordata* – 554 and *Darwinula stevensoni* – 594 specimens. Additionally most abundant in species was sample from the depth 2.00–1.90 m, with 15 species counted, least abundant was sample from depth 3.00–2.90 m with only 10 species. The number of specimens can somehow be correlated with this data, with the highest amount of specimens in a sample from depth 1.90–1.80 m – 447 specimens, likewise the least abundant in specimens was sample from dept 4.20–4.10 with only 13 specimens. Although, it is worth noting that from the bottom of the profile up to 4.20 m depth (samples 31–41) no ostracods were found in this interval (Fig. 3). Therefore, only the upper interval of the profile will be analyzed (4.20–0.60 m).

Ecology of species

Fourteen species were chosen to represent the ostracoda assemblage in the profile, on the basis of their high abundance – over 2.5% in any sample. Following a brief description of their ecological preferences.

Candona candida – Eurytopic species living in various types of water bodies: lakes, permanent and temporary smaller water bodies, water-covered areas related to springs, running and underground water, in water increased salinity (Krzymińska and Namiotko, 2013). It often occurs in profundal part of lakes (Namiotko *et al.*, 2004). Oligothermophilic species, living in a temperature range of 0.1–27°C (Frenzel *et al.*, 2010). It has been suggested that bottom type is one of the most important factors for the occurrence of *C. candida*, which tends to prefer muddy bottoms (Külköyluoglu and Vinyard, 2000).

Candona neglecta – The species tends to live in lakes and various small water bodies, both permanent and temporary (Krzymińska and Namiotko, 2013). Tends to have higher occurrence in profundal zone (Namiotko *et al.*, 2004). Oligothermophilic species, 1.2–24°C (Frenzel *et al.*, 2010). *C. neglecta* prefers sediment with no vegetation (Kiss, 2007). Generally lives in colder waters, though it is tolerant of temperatures higher than 20°C. It appears to be quite tolerant to low oxygen levels, tolerating eutrophic and hypoxic conditions of as low as 0.3 mg/L O_2 in the summer (Danielopol *et al.*, 1993).

Cyclocypris ovum – Eurybiontic species living in inland water bodies varying in type and size (Krzymińska and Namiotko, 2013). Lives mainly in very shallow and rheoeuryplastic water. It is a thermoeuryplastic species, mainly found in water temperatures from 0.1°C to 24°C (Frenzel *et al.*, 2010).

Darwinula stevensoni – The species lives in lakes, rivers, small permanent water bodies and wet habitat of moss of forest swamps, tolerating only minor increases in water salinity (Krzymińska, Namiotko, 2013). It lives in shallow waters, mainly only to 10m depth. Oligorheophilic, thermoeuryplastic, from 0.1°C to 27°C (Frenzel *et al.*, 2010).

Fabaeformiscandona protzi – Considered as an important indicator of cold water (e.g. Sohar and Kalm, 2008). The species appears to have only a limited tolerance for eutrophication (Danielopol *et al.*, 1993).

Herpetocypris reptans – The species lives in small permanent basins with abundant vegetation and littoral of lakes. It tolerates slightly increased salinity of water (Krzymińska and Namiotko, 2013). Lives in shallow water, mesorheophilic species. Thermoeuryplastic, temperatures from 0.2°C to 106°C (Frenzel *et al.*, 2010).

Ilyocypris bradyi – Lives in freshwater water bodies of various types, especially associated with springs, mesorheophilic (Krzymińska and Namiotko, 2013). Polythermophilic, temperatures from 0.1°C to 25°C (Frenzel *et al.*, 2010).

Limnocythere inopinata – The species lives in lakes and small, permanent water bodies of stagnant and slowly flowing water, being also found on inland salines and in underground water (Krzymińska and Namiotko, 2013). It is found on muddy as well as sandy substrates. In lakes, it is primarily a species of the shallow littoral zone, though it does occur at greater depths (Meisch, 2000). Polythermophilic, water temperature from 0.5°C to 24°C (Frenzel *et al.*, 2010).

Metacypris cordata – The species lives in shallows of lakes and sometimes rivers and small permanent water bodies (Krzymińska and Namiotko, 2013). It lives in very shallow and oligorheophilic water. Thermoeuryplastic species, temperatures from 3°C to 23°C. (Frenzel *et al.*, 2010) characteristic species of eutrophic lakes (Sohar, 2010) is a warm stenothermal summer form, known from shallow, macrophyte-rich freshwater environs, which is considered an indicator of lake ageing (Griffiths and Holmes, 2000; Danielopol *et al.*, 1996; Meisch, 2000; Viehberg, 2004). It populates mainly littoral vegetation in eutrophic lake margins or floating vegetation masses, avoiding groundwater outflows (Danielopol *et al.*, 1996; Meisch, 2000).

Pseudocandona albicans – Very shallow, mesorheophilic species. Lives in water of intermediate temperature, from 2°C to 24°C (Frenzel *et al.*, 2010).

Pseudocandona compressa – Lives in lake littoral and small permanent and temporary waters, halophilic species (Krzymińska and Namiotko, 2013). Oligorheophilic, mesothermophilic species, temperature from 1.5°C to 27°C (Frenzel *et al.*, 2010). In lakes it shows a clear preference

Table 1. Ostracods from the Ortel Królewski II site.

Depth [m]	Samples	*Pseudocandona albicans* (Brady, 1864)	*Metacypris cordata* (Brady and Robertson 1870)	*Ilyocypris bradyi* (Sars, 1890)	*Cyclocypris ovum* (Jurine, 1820)	*Scottia browniana* (Jones, 1850)	*Scottia tumida* (Jones, 1850)	*Scottia sp. juveniles*	*Darwinula stevensoni* (Brady and Robertson, 1870)	*Pseudocandona compressa* (Koch, 1838)	*Herpetocypris reptans (Baird, 1835)*	*Limnocythere inopinata* (Baird, 1843)	*Cypridopsis vidua* (O.F. Müller, 1776)	*Potamocypris fulva* (Brady, 1868)	*Cyprideis torosa* (Jones, 1850)	*Candona candida* (O.F. Müller, 1776)	*Candona neglecta* (Sars, 1887)	*Candona* sp. *juveniles*	*Fabaeformiscandona protzi* (Hartwig, 1898)	*Cytherissa lacustris* (Sars, 1863)	Total sum of taxa	Total sum of specimens
0.60–0.70	1		8	23	2	235	4	21	8	1	1	2					2	11	1		11	319
0.75–0.85	2	1	2	23	6	241	3	43		2	1	2			1	2		16			12	343
0.85–0.95	3	1	8	15	1	205	2	54	7	4		5		1		1	1	16			12	321
1.00–1.10	4	2	13	6	2	162		73	21	4	1	17		1			1	12			11	315
1.15–1.25	5	3	15	7	5	190	3	63	7	8	2	6						16			11	325
1.30–1.40	6	2	10	6	1	185	5	73	16	1	2	10					1	13			11	325
1.45–1.55	7	1	16	6	6	177	2	60	15	7	1	7						27			11	325
1.60–1.70	8	5	22	17	3	135	7	23	25	9	18	23		1			8	47			12	343
1.70–1.80	9	11	17	7	7	95	4	51	46	4	9	34					9	49			11	343
1.80–1.90	10	17	44	20	10	67	26	24	26	18	17	34					38	104	2		12	447
1.90–2.00	11	14	11	19	11	24	6	17	24	7	10	40	1			1	16	102	3	1	15	306
2.00–2.10	12	18	28	51	8	81	37	13	42	12	28	23	1			2	32	18	8		14	402
2.10–2.20	13	17	18	48	16	18	22	16	43	17	8	37	2				18	67	6		13	353
2.20–2.30	14	16	5	19	18	47	33	6	23	10	17	25				2	32	48	2	1	14	303
2.30–2.40	15	7	8	15	11	28	24	7	15	4	2	11	1				12	42	4		13	191
2.40–2.50	16	4	6	9	6	34	26	4	21		5					2	5	27	5		11	154
2.50–2.60	17	8	13	3	11	24	39	3	38	2		5	1			1	16	103	5		13	272
2.60–2.70	18	5	9	4	17	14	15	7	12	6	3	6				1	14	48	2		13	163
2.70–2.80	19	12	129	3	53	5	2	3	51			36	2			3	4	24	1	1	13	328
2.80–2.90	20	15	158	3	56	2	1		45	3	1	28	2			2	9	16		1	14	341
2.90–3.00	21	8	13	1	38	7			23			5	3			7		17			10	122
3.00–3.10	22	2	1	3	11	7	2		10	6						1	2	52	2		11	99
3.10–3.20	23	1		7	3	47	9	5	31		1	5					2	81	2	1	11	194
3.40–3.50	24			1		23		1										2			4	27
3.60–3.70	25			1		25		1													3	27
3.70–3.80	26			2		29		1													3	32
3.80–3.90	27			1		17		13													3	31
3.90–4.00	28					14		1	1												3	16
4.00–4.10	29					9		1													2	10
4.10–4.20	30			1		8		3										1			4	13
4.20–4.30	31																					
4.50–4.60	32																					
4.65–4.75	33																					
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6.30–6.50	40																					
6.60–6.80	41																					

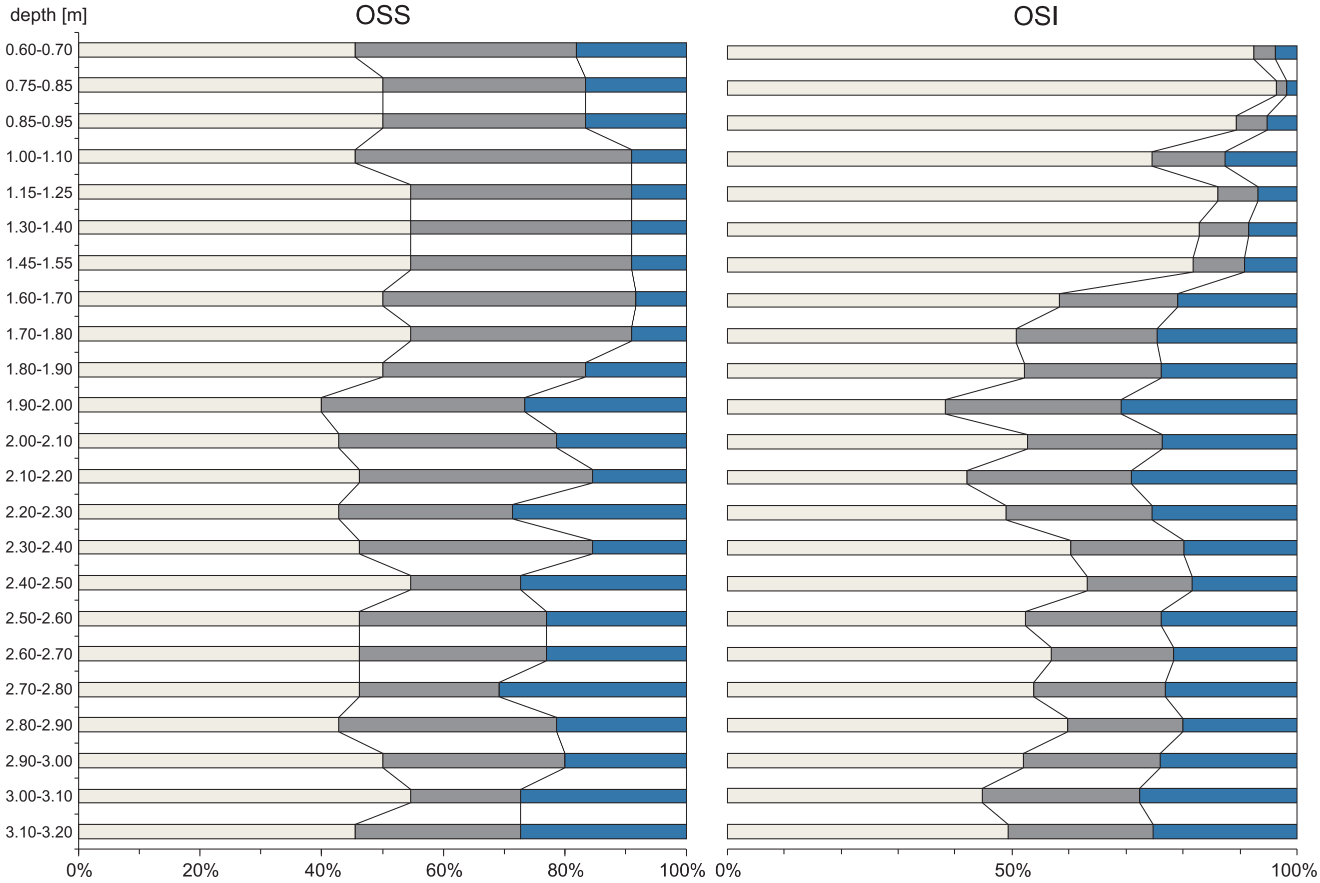

Fig. 4. Composition of the ostracod assemblage at Ortel Królewski II. OSS – ostracod spectra of species, OSI – ostracod spectra of individuals. Colors indicate ecological groups: white – ostracods of temporary water bodies, grey – species widely occurring in litoral zone, dark blue – ostracods preferring deeper parts of water bodies.

for the shallow littoral zone. It has been reported from a maximum depth of 8 m. *Pseudocandona compressa* is quite tolerant of low oxygen conditions, and has even been shown to tolerate near-zero oxygen levels for short periods of time (Delrome, 1991; Kiss, 2007).

Scottia browniana – Extinct species. It seems that it mainly lived in shrinking parts of large water bodies (lakes and oxbows) (Krzymińska and Namiotko, 2013) .

Scottia tumida – Extinct species. The species lives in habitats including shrinking parts of lakes and major oxbows, similar to that of *S. browniana* (Krzymińska and Namiotko, 2013) .

Ostracod diversity

Three ecological groups were distinguished on the basis of their water depth/lake zones preferences: I group – ostracods of temporary water bodies (6 species), II group – ostracods widely occurring in litoral zone (7 species) and III group – those preferring deeper parts of water bodies (4 species). In addition, for all samples spectra of species (OSS) and specimens (OSI) (Fig. 4) as well as an ostracod diagram showing changes in the assemblage were constructed.

In the ostracod spectra we can observe rather constant species composition with slightly decreasing number of species preferring deeper parts of water bodies towards upper part of the profile. This disparity is even more noticeable in specimens spectra (OSS). Additionally presence of litoral zone species is decreasing in favor of species preferring especially temporary water bodies.

Going from the bottom of the profile, where both number of taxa and specimens is low, on the depth 3.00–2.90 m both parameters increase rapidly. Then they are fluctuating, with one episode of distinct decrease at a depth of 2.50–2.40 m, but overall we can observe an increasing tendency in number of both taxa and specimens. At a depth of 1.90–1.80 m the number of specimens and taxa drops and fluctuations towards the top of profile are less distinctive.

Depth conditions

Fluctuations in the water depth were analyzed using two-component diagram (Fig. 5) based on the main characteristic species from I and III group. *Pseudocandona albicans*, *Metacypris cordata*, *Ilyocypris bradyi* and *Candona candida*, *Candona neglecta*, *Fabaeformiscandona protzi*, *Cytherissa lacustris*, respectively. An overall trend in in-

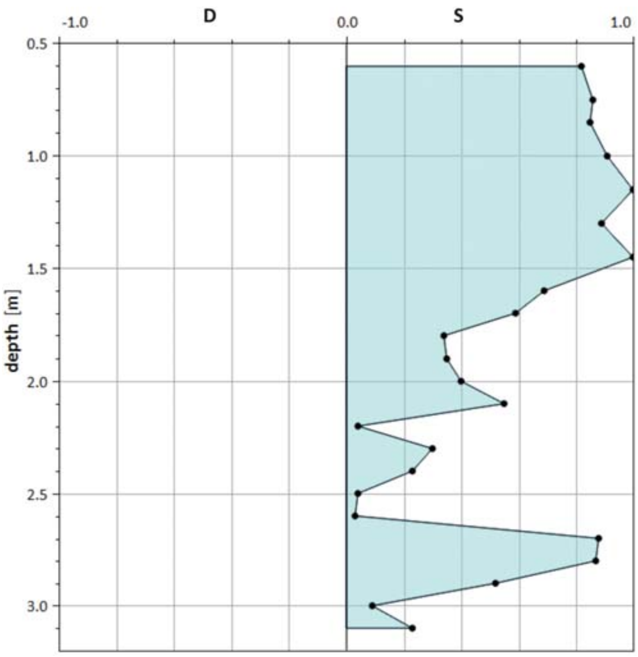

Fig. 5. Changes in the water depth based on two-component diagram. S – shallow water taxa, D – deep water taxa.

creasing number of shallow water taxa towards the top of the profile, with some fluctuations in the lower part is noted in the diagram. Two samples from depth 2.90–2.70 m differ from the overall trend, however it is caused by extremely high abundance of *Metacypris cordata*. This species is characteristic for shallow water, but it also prefers macrophyte-rich warm water and is very characteristic species of eutrophic lakes. Thus this part of diagram may not be a direct indication of changes in the water depth.

To better understand changes in the water body and possible lake shallowing important to look of the percentage composition of *Scottia browniana* and *Scottia tumida* (Fig. 6). They are extinct species but it seems that they mainly lived in shrinking parts of large water bodies (lakes and oxbows). The increased ratio of this two species would indicate lake shallowing. This value is fluctuating through the whole profile, but we can see some significant changes. From the bottom of the profile till roughly 1.85–1.75 m the percentage composition is fluctuating slightly, but from this depth we can see a big rise in the number of this two species (about 70–80%) which stays stable towards the top of the profile. This can indicate a significant lake shallowing, which started at that time.

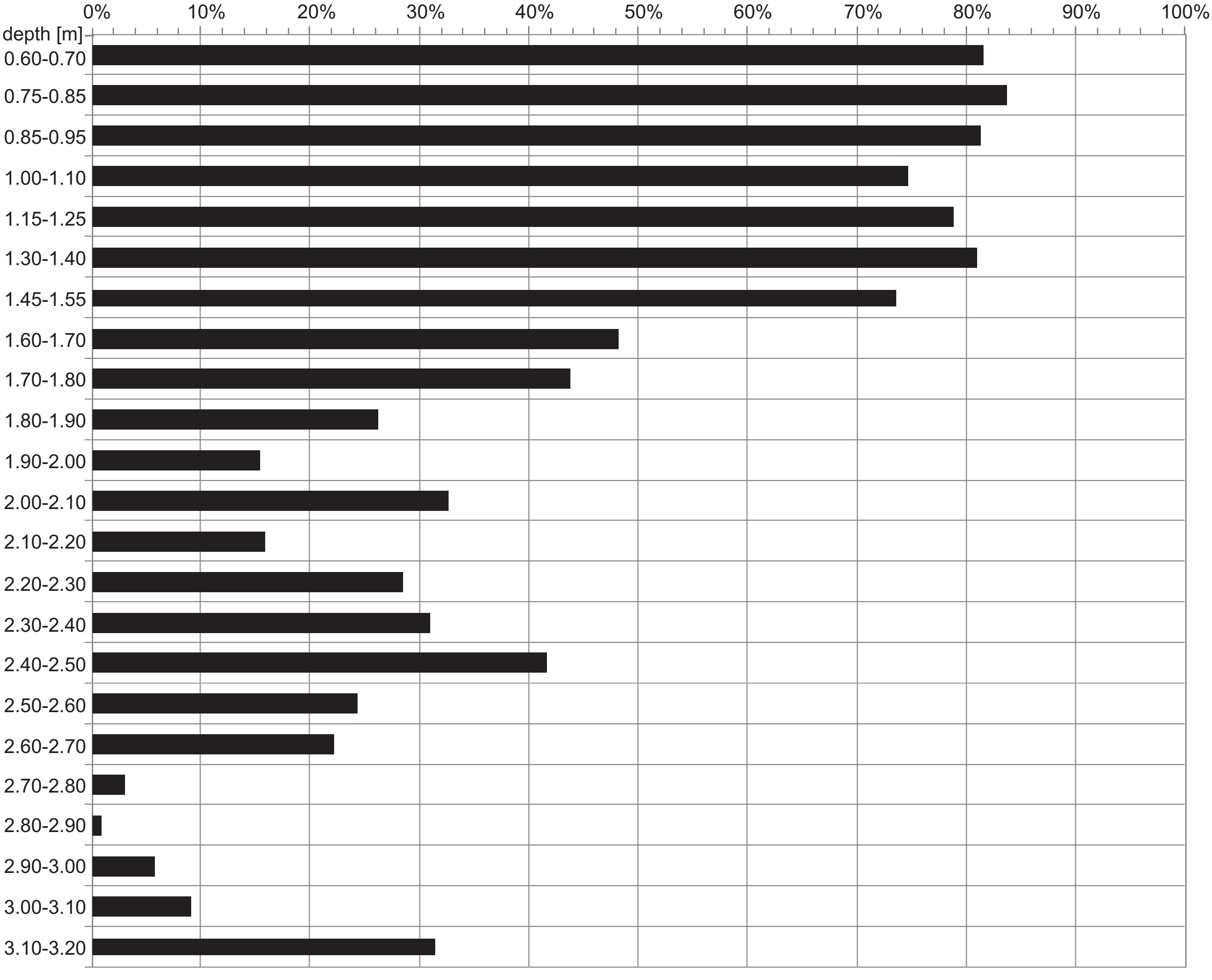

Fig. 6. Percentage composition of *Scottia browniana* and *Scottia tumida*.

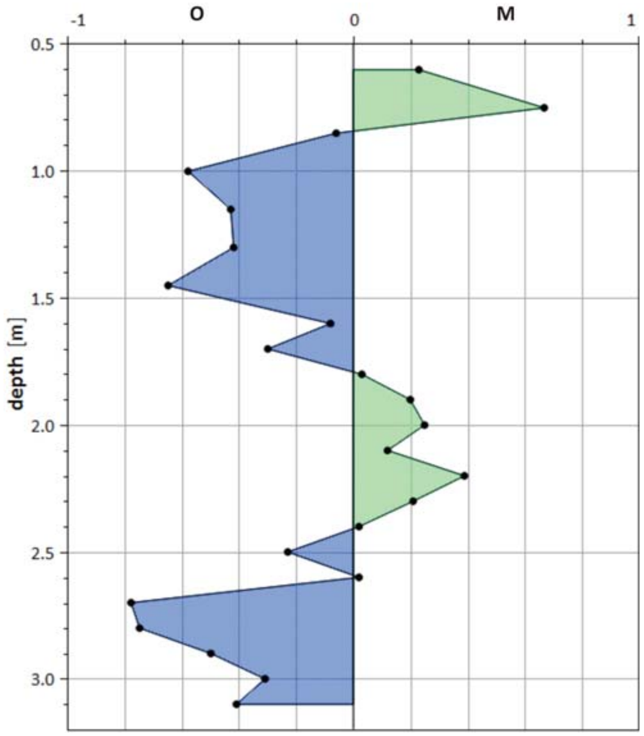

Fig. 7. Water energy based on two-component diagram. O – oligorheophilic species, M – mesorheophilic species.

Energy of the environment

To study the variability of the water energy or the possible flow of the water oligorheophilic (occurring in turbulent littoral waters of lakes and/or sometimes in flowing water) and mesorheophilic (frequently occurring in flowing waters with various velocities) species have been taken into the consideration (Fig. 7). In most of the samples the oligorheophilic species prevailed, but two episodes with a dominance of mesorheophilic species may be distinguished (samples 1–2 and 10–15). It is mainly caused by high abundance of *Ilyocypris bradyi* living in freshwater bodies of various type, but especially associated with springs and rivers.

Average air temperature

To estimate the mean January and July air temperatures based on ostracod assemblages the Mutual Ostracod Temperature Range (MOTR) method was used. This method compares ostracod species distributions to January and July maximum and minimum temperatures.

This was performed for all 23 samples. The number of specimens was left out of the analysis. Constructed mutual temperature range is showed in Fig. 8. At the bottom of the profile we can observe a minor deflection toward lower temperatures, both winter (-8–3°C) and summer (12–21°C). Then through many samples (3.10–1.80 m) temperature ranges are higher by 1–2°C, with only one peak at the depth 3.00–2.90 m, when the temperature range is even wider with winter and summer temperatures -7–7°C and 14–24°C, respectively. In the top part of the profile (1.80–0.75 m) temperature fluctuations become stronger. This is even more visible in winter temperature ranges, but in overall they are higher by 1–3°C (Fig. 8).

Ostracod zonation

By excluding all ostracods with maximum abundance less than 2.5% in any given sample, 17 species were left for analysis (Fig. 3). Species were plotted vs. depth. *Scottia browniana*, *Candona neglecta*, *Darwinula stevensoni* dominated the ostracod assemblage. *Herpetocypris reptans*, *Metacypris cordata*, *Limnocythere inopinata* and *Pseudocandona albicans* were the main accessory ones. As indicated above, ostracods are particularly sensitive indicators of climate change. Based on their ecological preferences, the profile has been divided into 4 main zones. Therefore, each of them was subdivided.

Zone 1 extends from the bottom of the profile up to 4.20 m depth (samples 31–41). No ostracods were found in this interval. Additionally, samples were characterized by a high amount of fine sand deposit.

Zone 2 (4.20–3.00 m; samples 22–30). The mean abundance of ostracods was remarkably low and so was the species diversity. The low abundance of ostracods might be explained by the high sedimentation rate at the locality, or by an unfavorable conditions in the water body. A general increase of ostracods can be noticed in the uppermost part of the zone (samples 22–23). This interval is dominated by juveniles of *Candona* sp., *Scottia browniana* and *Darwinula stevensoni*. Juveniles of *Candona* sp. dominate the whole assemblage with their percentage abundance reaching almost 60% of the sample. *Cyclocypris ovum* and *Pseudocandona compressa* are the main accessory species.

Zone 3 a (3.00–2.70 m; samples 19–21). Although *Metacypris cordata* is most of the time accessory species, it has its highest percentages here (up to 50%). This marks the only time in this study that this species is present in dominating numbers. Main accessory species are *Darwinula stevensoni*, *Limnocythere inopinata*, *C. ovum*, *C. candida* and *P. albicans*. We can observe a rapid increase both in number of taxa (n_t) and number of specimens (n_s) during this zone.

Zone 3 b (2.70–1.80 m; samples 10–18). The zone is dominated by *S. tumida*, juveniles of *Candona* sp. with *I. bradyi*, *H. reptans* and *F. protzi*. as primary accessory ones. This zone is especially characteristic by the highest abundance of *I. bradyi* (15%). The number of taxa (n_t) and number of specimens (n_s) fluctuate with the highest peak in the end of this zone.

Zone 4 a (1.80–1.60 m; samples 8–9) is characterized by decreased ostracod diversity. This may point to unfavourable, less stable conditions during this stage of lake development. This zone is mainly dominated by *S.*

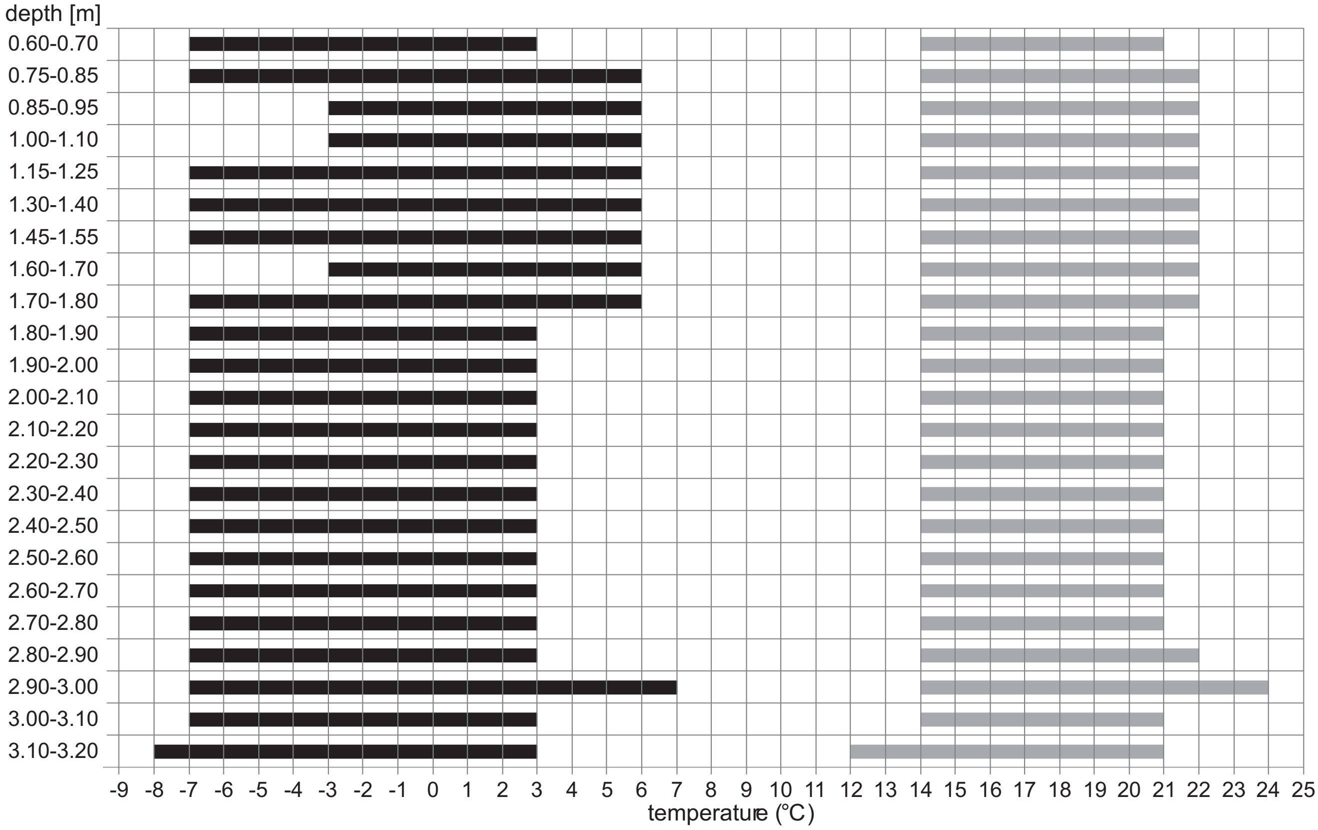

Fig. 8. Estimated January and July air temperature ranges; January – black, July – grey.

browniana, *L. inopinata* and juveniles of *Scottia* sp. and *Candona* sp.. *D. stevensoni*, *H. reptans* and *P. albicans* are the main accessory species in this zone. The deepwater species such as *F. protzi* and *C. candida* are absent in this zone, on the contrary, ostracods typical for shrinking parts of lakes like genus *Scottia* are present in this zone in increased numbers. Generally, this part of the profile with increasing dominance of temporary water bodies may be interpreted as a transition to a next stage of the lake development, which is characterized by an ongoing lake-level decline.

Zone 4 b (1.60–1.10 m; samples 4–7). *S. browniana* and juveniles of *Scottia* sp. clearly dominate the ostracod assemblage. *D. stevensoni* and *P. compressa* are the main accessory species in this zone. The ostracod abundance and diversity are distinctly decreasing during this zone.

Zone 4 c (1.10–0.60 m; samples 1–3) represents the uppermost part of the profile, extending from 1.10 m up to 0.60 m depth (samples 1–3). This zone, as a previous one is dominated by *S. browniana* and juveniles of *Scottia* sp. Main accessory species are *D. stevensoni* and *I. bradyi*. It is worth noting that the abundance of *S. browniana* is the highest within the whole profile (up to about 80 %). The diversity is relatively moderate. In addition in the upper part of this zone at about 0.80 m depth an increased abundance of *I. bradyi* can be observed. It is the second time when this species has that high concentration in the ostracod assemblage.

DISCUSSION

The ostracod zonation reflects partly the palinological record, but in some periods it is much more detailed. The distribution and abundance of ostracods depends on habitat type, water characteristic and composition. Information about the water temperature, salinity, solute composition and dissolved oxygen content can be inferred from ostracod assemblages.

The whole Zone 1 is characterized by absence of ostracods. According to palynological analysis it can be correlated with the initial phase of the Holsteinian Interglacial – *Pinus–Betula* pollen zone (Szymanek *et al*., 2016). Unfortunately, the lack of fauna in this interval preclude any palaeoenvironmental conclusion.

The structure of the ostracod assemblage in zone 2 is very puzzling. Low abundance and diversity of ostracods during most of this interval make the analysis difficult. The uppermost part of the zone shows increasing number of specimens. We can observe the dominance of the *Candona* sp. juveniles whereas abundance of adults is relatively small. This may reflect some unfavourable conditions, which prevailed at that time in the lake and caused extinction of juveniles from this genus. An explanation for this pattern could be also the valves segregation associated with wave action (Holmes, 2001; Keatings *et al*., 2010). The small abundance and diversity of ostracods during the Zone 2 seems to support the first interpretation.

Alternating Zone 3 a (2.90–2.70 m) is correlated with Holsteinian *Taxus* zone (Fig.2). In the ostracod diagram is represented by the dominant position of *Metacypris cordata*. According to Sohar (2010) it is characteristic species of eutrophic lakes. Enhanced productivity at that time is also reflected in decreased abundance of *F. protzi*. This particular species appears to have only a limited tolerance for eutrophication (Danielopol *et al*., 1993). During this time interval the percentage abundance of *F. protzi* rapidly decreases, which is demonstrated in Fig. 3. The ostracod data slightly correlate with geochemical studies of freshwater snail shells carried out in Ortel Królewski II (see Szymanek, 2017a). The Fe/Mn ratio used there to as a redox indicator does not indicate that strong reducing conditions, which might be correlated with enhanced productivity.

At the same time the percentage abundance of species present in zone 2, typical for profundal zone gradually decrease. Additionally both number of species and specimens significantly rise. It is the first time in the profile that we can note such a great diversity. A higher ostracod diversity and abundance suggest more stable conditions for ostracods development. It is reflected in the relative temperature changes presented in the MOTR analysis, where a significant rise both in the winter and summer temperature was noted (Fig.8) This period is also characterized by a slightly increasing δ^{18}O values. It may indicate an increased evaporation and/or increased temperature (Szymanek *et al*., 2016). The data from ostracods and isotope analysis is consistent with the temperature ranges derived from pollen (Krupiński, 1995). A warm and humid climate dominated at that time, which is evidenced by increased abundance of yew and spruce. Average July and January temperatures increased by c. 3° C and ranged between 19 and 21° C and -1° C, respectively.

Zone 3 b also correlated with *Taxus* zone is the stage of full lake development. Both number of species and specimens display a significant increase throughout this zone. At this profile section the water depth might increased slightly. This can be inferred by increased percentage abundance of deep water species: *Fabaeformiscandona protzi, Candona neglecta, Candona candida*. The isotopic studies of gastropod shells carried out at Ortel Królewski II seem to support this interpretation (Szymanek *et al*., 2016; Szymanek, 2016). The δ^{13}C values decrease slightly by the end of this zone indicating increased water level and/or decreased productivity (Szymanek *et al*., 2016). Another worth noting aspect in this zone is a higher percentage abundance of reophile species: *Ilyocypris bradyi* and *Herpetocypris reptans*. It is especially noticeable at the depth of around 2,00 m. This two species are rather an accessory element, though in this section its percentage abundance is about four times greater than in other zones. The appearance of these species suggest that the lake could have experienced temporary overflow or a wave action in the littoral zone.

Favourable conditions are confirmed in malacological analysis (see Szymanek *et al.,* 2005). During this part of the profile significant rise in number of specimens can be observed. According to the research full lake development can be noted at the depth around 1,50 m, where highest percentages of *Viviparus diluvianus* were noted. Larger frequencies are observed for yew, elm, ash and oak, which suggest improvement of climatic conditions and influence of oceanic climate (Szymanek *et al*., 2005).

The deterioration of the environmental conditions is noted relatively soon. Climate became drier and less favourable for the lake development. Ostracod assemblage record from the Zone 4 might be correlated with the *Pinus–Larix* zone, which is regarded as an intra-interglacial cooling and drying of the climate (Bińka and Nitrychoruk, 1995). Increased percentage abundance of *Scottia* sp. points to shallow water conditions (Fig. 6). In the Zone 4a we can observe increasing percentages of *Scottia browniana*. From about 20% at the beginning of Zone 4a to almost 80 % by the end of Zone 4b.

The general gradual deterioration at the start of *Pinus–Larix* zone is also reported in the isotopic data, both in δ^{13}C and δ^{18}O values (Szymanek *et al*., 2016; Szymanek, 2016). Depletion of δ^{18}O corresponds with the deterioration of the environmental conditions, recorded by the rise in abundance of pine in the pollen spectrum. This is a quite notable period of climate deterioration and lake level was declining. This is consistent with increasing δ^{13}C values indicating an increase in lake productivity (Szymanek, 2016).

However the MOTR analysis shows an opposite trend, with rising both winter and summer temperatures. This is caused by the changes in the ostracod assemblage. Firstly the species abundance has decreased and population has been dominated by species preferring shallow water bodies, especially by the one species *Scottia browniana* (Figs. 4, 6). Deepwater ostracods and other litoral forms almost disappear in Zone 4c. At the same time the abundance of temporary water bodies ostracods is increasing.

This changes are also reflected in mollusc studies. The fauna assemblage from Ortel Królewski II was developing in the overgrowing, shallow lake as evidenced by plant-associated gastropods *Segmentina nitida*, *A. lacustris*, *Gyraulus crista* and *Valvata cristata* (Szymanek *et al*., 2005).

CONCLUSIONS

In total 41 samples have been examined, mainly with an interval of 10 cm. They represent pre-optimal part of the Holsteinian Interglacial corresponding to *Pinus–Betula*, *Picea–Alnus*, *Taxus* and *Pinus–Larix* zones. Some environmental parameters were reconstructed using ostracod assemblage analysis, including changes in the water level, vegetation and energy conditions. Variability within the structure and composition of the ostracod assemblage enabled palaeoecological reconstruction as their distribution in the profile document succeeding stages of lake development.

Based on their ecological preferences, the profile has been divided into three main zones. From initial deeper conditions during the *Picea–Alnus* zone, followed by an expansion of aquatic plants and a second phase of deepening signalized during *Taxus* zone, and finally the phase of further water level drop (*Pinus–Larix* zone). The record of specific ostracods (e.g. *Scottia browniana*, *Metacypris cordata*) reflects ongoing eutrophication and progressive shallowing of the lake. Ostracod assemblages can also point out the most likely sections for periodic flow or wave action (e.g. during *Taxus* and *Pinus–Larix* zones).

The data from the ostracod analysis largely corresponds with already published studies from this area (Szymanek *et al.*, 2005, 2016; Szymanek, 2016). However, in several places it points changes not captured in other studies. Ostracod assemblages indicate periods of increased water depth during *Taxus* zone and time of water level drop in the *Pinus–Larix* zone. They show changes in the trophy level of the lake through the increased number of species *Metacypris cordata*. Finally, with some reservations estimate temperature ranges for July and January for the duration of the lake sediment sequence. Unfortunately the outcome from the MOTR is not that reliable as we could expect. These ranges were rather wide as a result of the poor species diversity in most samples and the fact that most of the recovered species have wide ecological tolerances (e.g. *Candona candida, Cypridopsis vidua*), with very few species being stenothermic. Nevertheless, the MOTR method is a useful tool in palaeoecology as it provides a set of limits within which temperature changes occurred. The results of this study provide very good information on changes of the lake depth and energy of the environment during the pre-optimal part of Holsteinian Interglacial.

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