

Environmental changes of the Mazovian (Holsteinian /~MIS 11) palaeolake near Szymanowo (eastern Poland) in the light of malacological analysis

MARCIN SZYMANEK

*Faculty of Geology, University of Warsaw, Al. Żwirki i Wigury 93, PL-02-089 Warszawa, Poland.
E-mail: m.szzymanek@uw.edu.pl*

ABSTRACT

Szymanek, M. 2014. Environmental changes of the Mazovian (Holsteinian /~MIS 11) palaeolake near Szymanowo (eastern Poland) in the light of malacological analysis. *Acta Geologica Polonica*, **64** (2), 249–260. Warszawa.

The malacofauna of the palaeolake deposits at Szymanowo (eastern Poland) was investigated. It represents the younger part of the climatic optimum of the Mazovian (Holsteinian) Interglacial (~MIS 11) and possibly the post-optimal period. The mollusc assemblage is composed of both standing and running water species, mostly connected with temperate climate. The presence of biostratigraphical indicators of the Mazovian, *Viviparus diluvianus* (Kunth, 1865), *Lithoglyphus jahni* Urbański, 1975 and *Pisidium clessini* Neumayr, 1875, is noteworthy. Variability in the structure and composition of the assemblage enables palaeoecological reconstruction. Changes in the water-level, vegetation and energy conditions are inferred from the malacological succession. Three stages of the lake development were distinguished. The first one is connected with deeper conditions and predominance of *V. diluvianus* and *L. jahni*. The second one, dominated by *Bithynia tentaculata* (Linnaeus, 1758), records a fall of the water-level and the growth of aquatic plants, evidenced by high frequencies of *Valvata cristata* Müller, 1774 and *Acroloxus lacustris* (Linnaeus, 1758). The third stage corresponds to another rise of the water-level and an increase in *V. diluvianus*, *L. jahni*, *Valvata piscinalis* Müller, 1774 and *Pisidium henslowanum* (Sheppard, 1823), which evidence some higher energy conditions.

Key words: Molluscs; Palaeolakes; Mazovian (Holsteinian) Interglacial; Palaeoecology.

INTRODUCTION

Mollusc-bearing deposits were discovered in 1993 in the vicinity of the village of Szymanowo (eastern Poland) during fieldwork connected with the production of the Łomazy sheet of the 1:50 000 Geological Map of Poland (Albrycht 2002a). They are represented by sand, silt and mud, sometimes with organic and plant detritus (Albrycht 2002b). Mollusc shells are

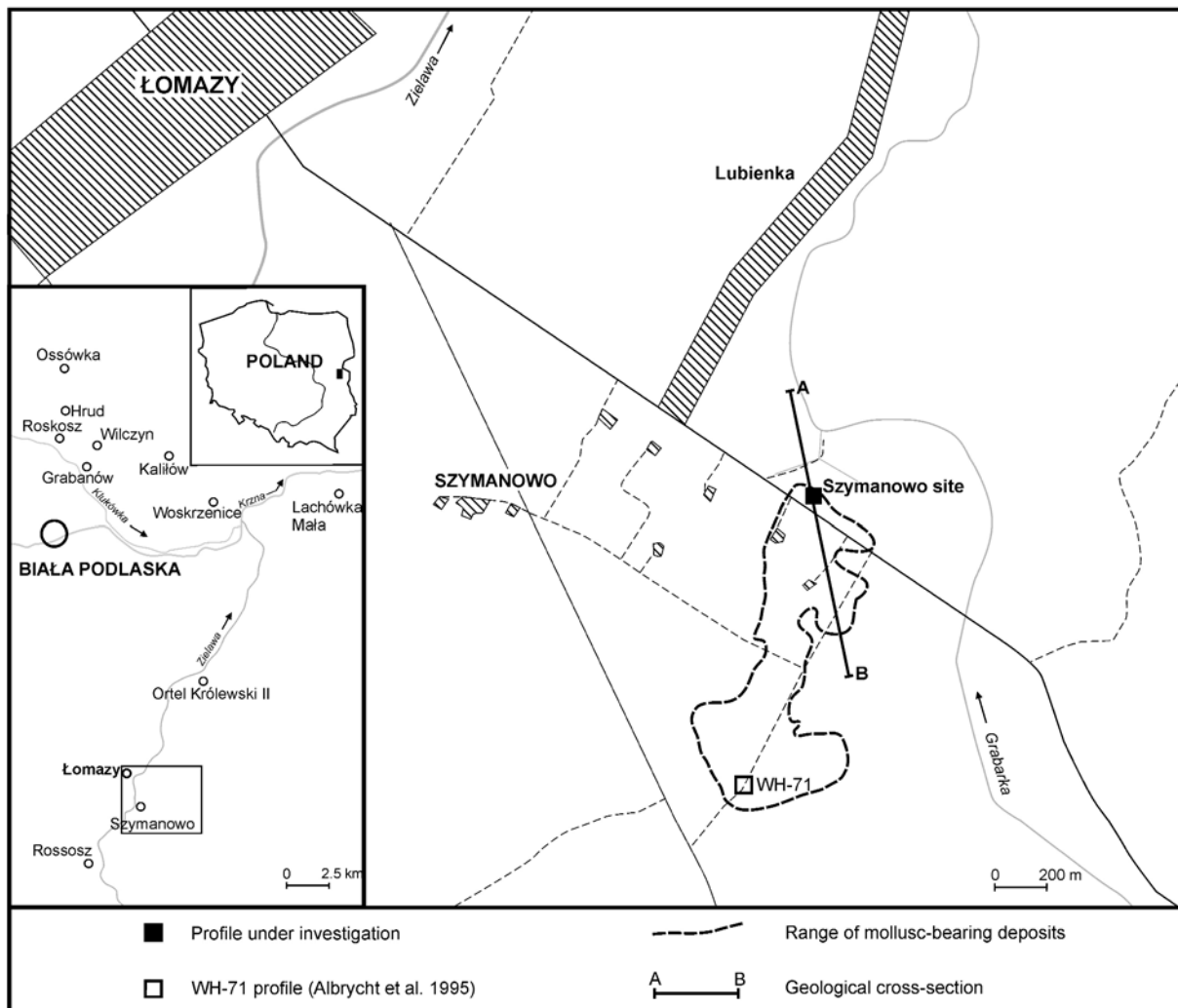
abundant and in good condition, but only a preliminary investigation has previously been undertaken, resulting in the analysis of barely one sample per 2.5 m interval (3.5–6 m depths) in the borehole WH-71 (Text-fig. 1). This enabled the general stratigraphy as well as the ecological and climatic conditions to be defined (Albrycht *et al.* 1995). According to the geological situation of the shell-bearing deposits and the composition of the malacocoenosis from Szymanowo Albrycht

et al. (1995) inferred a lake with possible overflow belonging to the Mazovian (Holsteinian) Interglacial which corresponds to Marine Isotope Stage 11 (MIS 11; Nitychoruk *et al.* 2005, 2006). A predominance of temperate climate with a slight cooling phase was concluded from the faunal record (Albrycht *et al.* 1995). The problem is that without any distinguishing beds or mollusc assemblages, virtually no changes in the succession could be inferred.

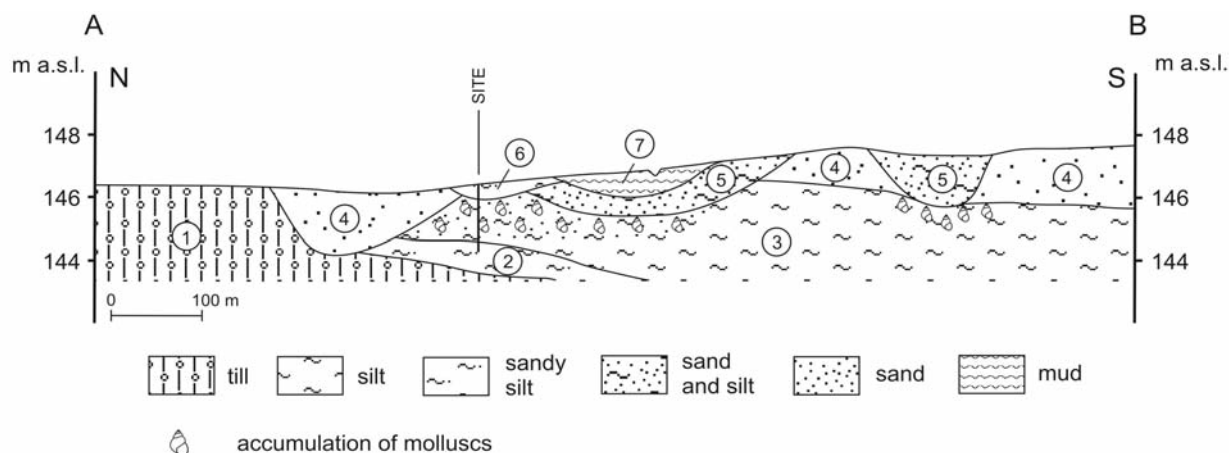
The next malacological studies at Szymanowo were connected with a biometrical investigation of *Viviparus diluvianus* shells (Szymanek 2007, 2008, 2011), when nine samples were collected from excavations located at the margin of the Holsteinian deposits, ca. 1.2 km north of the WH-71 profile (Text-fig. 1). A detailed analysis of the mollusc assemblage was therefore not the main focus of that study, which merely provided some environmental background for the morphometric changes shown by *V. dilu-*

vianus. Pollen analysis suggested that the deposits accumulated during the final part of the climatic optimum of the Mazovian Interglacial (Szymanek and Bińka 2006; Szymanek 2007, 2008, 2011). According to K. Bińka, the optimum itself was restricted to the *Carpinus-Abies* pollen Zone (Bińka 1994; Bińka and Nitychoruk 1995, 1996; Bińka *et al.* 1997). The end of the climatic optimum and its immediate aftermath witnessed an expansion of the thermophilous water-fern *Salvinia natans* (Linnaeus) and a contraction of forest communities, accompanied by a distinct increase in hazel (cf. Bińka and Nitychoruk 1996; Bińka *et al.* 1997).

The present paper provides a definitive study of the molluscan assemblages from Szymanowo. It presents quantitative analyses of the molluscan assemblages throughout the succession, which enable more detailed palaeoenvironmental reconstructions of the lake and its surroundings at Szymanowo.



Text-fig. 1. Location of the Szymanowo site



Text-fig. 2. Geological cross-section in the vicinity of Szymanowo. Sanian 2 (Elsterian) Glaciation: 1 – till; 2 – lacustrine sandy silt, Mazovian (Holsteinian) Inter-glacial; 3 – lacustrine sand and silt, Krznanian/Odranian? (Saalian) Glaciation; 4 – fluvioglacial sand, Vistulian Glaciation; 5 – lacustrine and riverine sand and silt; 6 – colluvial sandy silt, Holocene; 7 – mud

LOCATION AND GEOLOGICAL SETTING

The Szymanowo site is located in eastern Poland, about 18 km southeast of Biała Podlaska and 2 km east of the village of Łomazy (Text-fig. 1). It is in a marginal part of the Łomaska Depression. In the vicinity of the site there is a flat, mostly agricultural area underlain by Holocene fluvial deposits, Vistulian lacustrine sands and silts, fluvioglacial sands of the Krznanian/Odranian? (Saalian) Glacial Stage, and tills of Sanian 2 (Elsterian) age. Near the surface, Mazovian deposits with abundant mollusc shells occur (Text-fig. 2). Their age was established on the basis of the pollen analysis (Albrycht 2002b; Szymanek and Bińka 2006; Szymanek 2007, 2008, 2011), as well as the molluscan fauna, which included two species characteristic of the Mazovian, *Viviparus diluvianus* (Kunth, 1865) and *Lithoglyphus jahni* Urbański, 1975 (Albrycht *et al.* 1995; Szymanek 2011). In Britain *V. diluvianus* is also regarded as an indicator of the Hoxnian stage = early part of MIS 11 (Kerney 1971; Meijer and Preece 1995; Keen 2001; Roe 2001; White *et al.* 2013), whereas in the Netherlands it appears in both the Holsteinian and Tiglian (Meijer 1989; Gittenberger *et al.* 2004). *L. jahni* is unknown from the late Middle Pleistocene in NW Europe but is known from the Augustovian (Bavelian) of Poland (Skompski 2009) and the Netherlands, where it also occurs in the Tiglian (Meijer 1989; Gittenberger *et al.* 2004).

In the vicinity of the studied section the fossiliferous interglacial lake sediments are limited to a belt 1.3 km long and up to 600 m wide, extending from north to south (Text-fig. 1). They lie on sandy silts without mollusc remains, accumulated in the late phase of the Sanian 2 Glaciation (Szymanek and Bińka 2006; Szymanek 2011), or directly overlie the Sanian

2 till. They are covered by lacustrine sands and silts of the Vistulian Glaciation (Albrycht 2002a, b) (Text-fig. 2). In the northern part of their occurrence, at the excavated profile, they are covered only by topsoil and 0.2 m of colluvial silts. The mollusc-bearing deposits reach a thickness of 1.3 m and are represented by three layers: dark grey (N2 in the Munsell colour system) sandy silt (1.8–1.1 m), yellowish brown (5Y 4/6) fine-grained clayey sand (1.1–0.75 m) and light grey (N6) sandy silt (0.75–0.5 m). The mollusc accumulation is extremely rich, reaching about 90% of the deposit volume in the lower part of the profile and ca. 60% in the uppermost samples. These deposits, especially the dark grey silts, may correspond to the middle part of an interglacial series, which divides two complexes of organic lake and backwater sediments described in this area by Albrycht (2002b).

MATERIAL AND METHODS

At Szymanowo the same nine samples used in the biometric study of *V. diluvianus* were analysed for molluscs (Szymanek 2007, 2008, 2011). They were each 10 cm thick and were collected from an excavation ca. 0.9 m wide, 2.4 m long and 1.8 m deep, from depths of 1.6–0.55 m. About 3 litres of sediment per sample (weight 3–6 kg) were taken from the three mollusc-bearing horizons. Samples 9 to 6 (1.6–1.15 m) were taken from the lowest layer of sandy silt, samples 5 to 3 (1.1–0.8 m) and samples 2 to 1 (0.75–0.55 m) represented the sand and the uppermost sandy silt respectively.

Mollusc analysis comprised quantitative methods. Samples were dried in the air and then wet-sieved using a 0.5 mm mesh, according to procedures described by Ložek (1964, 1986, 2000), Alexandrowicz (1987) and Alexandrowicz and Alexandrowicz (2011). All identi-

fiable shells and mollusc remains were collected from the dried residue. They were determined under a stereoscopic microscope at magnifications up to 64x and

counted following Ložek's (1964) method for broken individuals. The number of bivalves was halved in the calculation (1 individual = 2 valves). Some shell frag-

I	II	TAXA	SAMPLES								
			1 0.55-0.65 m	2 0.65-0.75 m	3 0.8-0.9 m	4 0.9-1.0 m	5 1.0-1.1 m	6 1.15-1.25 m	7 1.25-1.35 m	8 1.4-1.5 m	9 1.5-1.6 m
9	WD	<i>Succinea putris</i> (Linnaeus)			2		1				
10	Wp	<i>Valvata cristata</i> Müller		3	2	52	62	60	3	13	
10	Wd	<i>Galba truncatula</i> (Müller)	3	6	5	2	4	1			
10	WP	<i>Planorbis planorbis</i> (Linnaeus)		k	k						
10	Wp	<i>Anisus vorticulus</i> (Troschel)					3				
10	WP	<i>Segmentina nitida</i> (Müller)				3	18		1		
10	We	<i>Pisidium milium</i> Held						1			
11	We	<i>Viviparus diluvianus</i> (Kunth)	526	443	518	955	395	1550	1379	1190	
11	We	<i>Bithynia tentaculata</i> (Linnaeus) (+operculum)	37 6	103 120	89 51	606 775	1676 2145	543 556	95 110	182 227	
11	We	<i>Lithoglyphus jahni</i> Urbański	1076	1173	990	398	241	486	1723	3043	
11	We	<i>Valvata piscinalis</i> Müller	112	183	157	113	56	29	25	73	
11	WL	<i>Acroloxus lacustris</i> (Linnaeus)			1	29	94	237	77	99	
11	WL	<i>Lymnaea stagnalis</i> (Linnaeus)	2	3	1	2	1			2	
11	WL	<i>Planorbis carneus</i> (Linnaeus)					k	k			
11	WL	<i>Planorbis carinatus</i> Müller	5	4	2	2			1		
11	We	<i>Gyraulus albus</i> (Müller)	6	4	7	21	12	5	5	13	
11	WL	<i>Gyraulus crista</i> f. <i>cristatus</i> (Linnaeus)				2	2			1	
11	WL	<i>Gyraulus crista</i> f. <i>nautilus</i> (Linnaeus)				1			1		
11	We	<i>Sphaerium corneum</i> (Linnaeus)	25	24	12	70	172	17	8	3	
11	We	<i>Pisidium casertanum</i> (Poli)	1				1	1	7	4	
11	We	<i>Pisidium casertanum</i> f. <i>ponderosa</i> Stelfox							1	1	
11	We	<i>Pisidium henslowanum</i> (Sheppard)	144	135	203	118	39	2	5	5	
11	WL	<i>Pisidium lilljeborgii</i> Clessin	1			2			2	1	
11	WL	<i>Pisidium hibernicum</i> Westerlund							1		
11	We	<i>Pisidium moitessierianum</i> Paladilhe	7	3	7	9	3	1	2	14	
12	We	<i>Borysthenia naticina</i> (Menke)		2	8						
12	We	<i>Unio pictorum</i> (Linnaeus)		1		1					
12	We	<i>Unio tumidus</i> Philipsson		5	5	7	9			2	
12		<i>Unio</i> sp.	d	d	d	d	d	d	d	d	
12	We	<i>Sphaerium rivicola</i> (Lamarck)	3	3	3	6	6	4	5	4	
12	We	<i>Sphaerium solidum</i> (Normand)	7	7	8	6	6				
12	We	<i>Pisidium amnicum</i> (Müller)	2	17	3	1	2		2	1	
12		<i>Pisidium clessini</i> Neumayr	9	2	13	5	1		3	3	
12	We	<i>Pisidium supinum</i> Schmidt	7	24	6	4	2	1	2		
12	We	<i>Pisidium nitidum</i> Jenyns	4	2	8	35	71	40	5	3	
12	We	<i>Pisidium subtruncatum</i> Malm	2			2	1		7	3	
		<i>Lymnaea</i> sp.	9	3	4	4				1	
		<i>Anisus</i> sp.	1			2					
		<i>Gyraulus</i> sp.	6	9	8	11	4		3		
		<i>Sphaerium</i> sp.	1	1	k		d	d	d	d	
		<i>Pisidium</i> sp.	5	2	3	3	2	4	8	5	
TOTAL OF TAXA			26	27	28	32	30	19	27	22	
TOTAL OF SPECIMENS			2007	2282	2116	3247	5029	3537	3481	4879	

Text-fig. 3. Molluscs from the Szymanowo site. I – ecological groups (after Ložek 1964; Alexandrowicz 1987): 9 – species of damp and swampy habitat, 10 – species of temporary water bodies, 11 – species of permanent water bodies of stagnant waters, 12 – species of flowing waters; II – supplementary ecological symbols (after Ložek 1964, 1976, 1982; Körnig 1966; Piechocki 1979; Skompski and Makowska 1989): WD – snails of swamps, flooded meadows and shores of water bodies, Wd – amphibious species of marshy and water environs, WP – molluscs of episodic, periodically drying out water bodies, Wp – molluscs of shallow, intensively overgrown water bodies, WL – species of permanent water bodies of various size, We – species present both in rivers and lakes, in stagnant and flowing waters, Wc – species preferring flowing waters with weak current; 13 – number of specimens, d – shell detritus, k – few fragments of shell

ments were classified only to the rank of genus. The molluscs were then grouped in accordance with their ecological preferences (Text-fig. 3). The latter attributions were based on Ložek (1964), Alexandrowicz (1987), Alexandrowicz and Alexandrowicz (2011) and supplemented after Ložek (1976, 1982), Körnig (1966), Piechocki (1979), Skompski and Makowska (1989), Piechocki and Dyduch-Falniowska (1993), Glöer (2002) and Welter-Schultes (2012). The structure of mollusc assemblages was shown by spectra of species and specimens (Text-fig. 4). Changes in the associations in the vertical succession were illustrated on the percentage malacological diagram (Text-fig. 5). The Bithynia-index (BIN), representing the proportion of opercula and shells of *Bithynia tentaculata* according to the formula $BIN = (\text{opercula} - \text{shells}) / (\text{opercula} + \text{shells})$ (Steenberg 1917; Alexandrowicz 1999), was calculated in order to characterise the sedimentary environment.

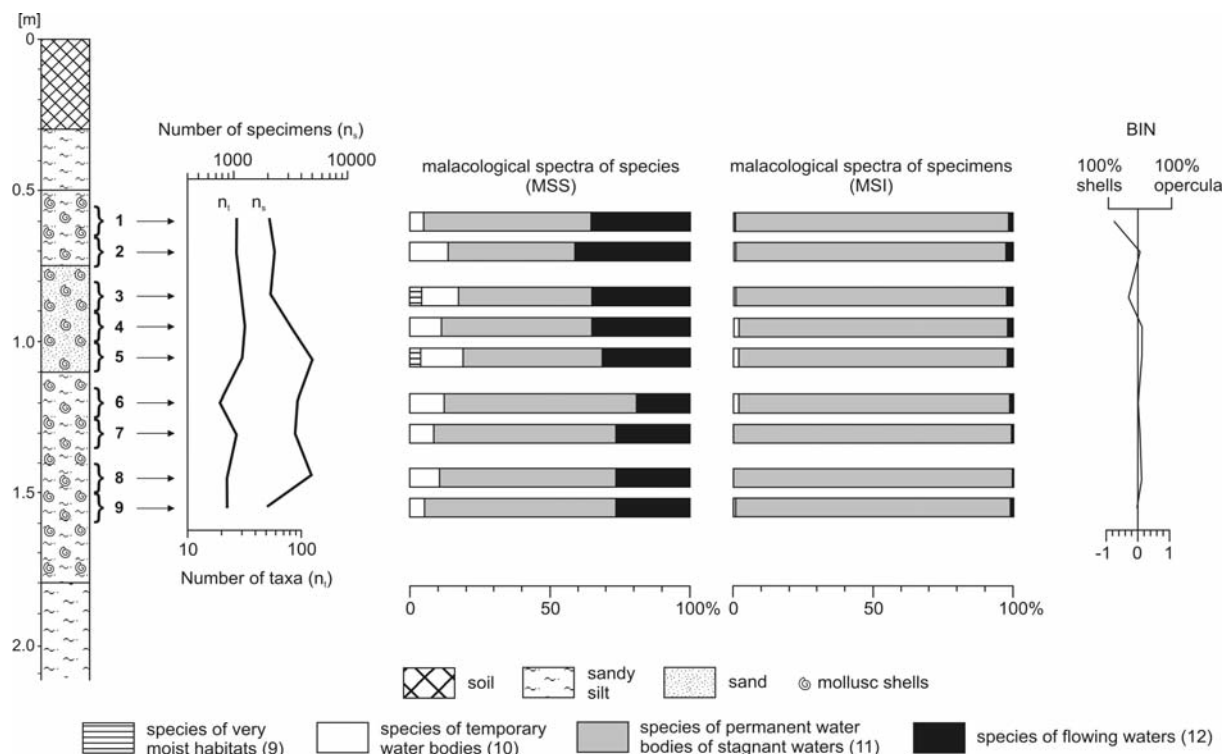
RESULTS

The mollusc assemblage from Szymanowo comprises 21 snail taxa and 20 bivalve taxa, represented altogether by 28,548 individuals (Text-fig. 3). The numbers of both taxa and specimens fluctuate in the profile, ranging from 19 to 32 and from 1970 to 5029 respectively (Text-figs 3, 4).

In the lower part of the section (samples 9 to 5; 1.6–1.0 m), single valves of ostracods assigned to four taxa were also found: *Scottia browniana* (Jones, 1850), *Scottia tumida* (Jones, 1850), *Darwinula stevensoni* (Brady and Robertson, 1870) and *Candona* sp. In most samples occasional remains of fishes, rodents, and amphibia also occurred, including Pike, *Esox lucius* Linnaeus, 1758 (sample 9), and Water vole *Arvicola terrestris* (Linnaeus, 1758) (sample 1).

Palaeoecology

Except for one land snail *Succinea putris* (Linnaeus, 1758), usually connected with moist habitats and shores of water bodies (Kerney *et al.* 1983; Wiktor 2004; Welter-Schultes 2012), all the species represent freshwater conditions. They were classified as species of temporary water bodies (ecological group 10), species of permanent water bodies of stagnant waters (group 11) and species of flowing waters (group 12) (Text-fig. 3). The samples are dominated by group 11, which represents between 45 and 69% of all species and between 96 and 100% of all specimens (Text-fig. 4). Most species in this group, including the most frequent *Bithynia tentaculata*, *Lithoglyphus jahni* and *Viviparus diluvianus*, are common in both standing and running waters. However, amongst molluscs typical of lakes *Pisidium lilljeborgii* Clessin, 1886 and



Text-fig. 4. Malacological composition and the Bithynia-index (BIN) of the Szymanowo site

Acroloxus lacustris (Linnaeus, 1758) should be mentioned. The latter inhabits zones of rich immersed vegetation, often accompanied by *Gyraulus albus* (Müller, 1774). The euryoecious *Pisidium henslowanum* (Shepard, 1823) is also common in lakes (Alexandrowicz 1987; Alexandrowicz and Alexandrowicz 2011), but it almost never inhabits closed water bodies, indicating overflow through the lake (Piechocki and Dyduch-Falniowska 1993; Welter-Schultes 2012).

Rheophile species (group 12) are also numerous with a frequency of 19 to 41%, but the number of individuals in this group is distinctly lower and does not exceed 3% (Text-fig. 4). Fluvial conditions are preferred by *Borysthenia naticina* (Menke, 1845), *Unio pictorum* (Linnaeus, 1758), *Sphaerium solidum* (Normand, 1844), *Pisidium supinum* Schmidt, 1851 and the euryoecious *P. nitidum* Jenyns, 1832 (Piechocki 1979; Piechocki and Dyduch-Falniowska 1993; Welter-Schultes 2012). They are rather an accessory element of the fauna, which become slightly more common in the upper part of the section (samples 1 to 5; Text-figs 3, 5). The mollusc assemblage also contains a few taxa of temporary water bodies, but these are usually represented by single specimens. Only *Valvata cristata* Müller, 1774 and *Segmentina nitida* (Müller, 1774), regarded as plant-associated taxa (Piechocki 1979; Glöer 2002; Welter-Schultes 2012), reach somewhat greater abundances. The amphibious form *Galba truncatula* (Müller, 1774) is also a noteworthy element of this group.

Many species from Szymanowo prefer well-oxygenated waters, for example *Valvata cristata*, *Bithynia tentaculata*, *V. piscinalis*, *Acroloxus lacustris*, *Sphaerium rivicola* (Lamarck, 1818), *Pisidium nitidum* and *P. supinum*. In addition *V. cristata*, *V. piscinalis* and *Pisidium henslowanum* favour eutrophic conditions (Welter-Schultes 2012).

Also worth noting is the presence of the plant-associated ostracod *Scottia browniana* (Roe 2001) and the ostracod *Darwinula stevensoni* (Sywula 1974; Skompski 1991), indicative of rather shallow zones of water-bodies.

Stratigraphy

Three mollusc species from Szymanowo have stratigraphical significance. Apart from *Viviparus diluvianus* and *Lithoglyphus jahni*, *Pisidium clessini* (described by Albrycht *et al.* (1995) as *Pisidium sulcatum* (S.V. Wood, 1851)) is also quite abundant. In western Europe Meijer (1989), Keen (2001), and Gittenberger *et al.* (2004) link the last appearance of this species with the Holsteinian Interglacial, but in Britain it also occurred in sequences assigned to both MIS 9 and

MIS 7 (Roe *et al.* 2009). It was also common in the Early Pleistocene, but in Poland it has only been found in the Mazovian. However, Skompski (1996) mentioned its occurrence in the Eemian Interglacial of Ukraine and Belarus.

The ostracods *Scottia browniana* and *S. tumida* used to be considered typical of the Holsteinian Interglacial (Kempf 1971; Robinson 1979; Skompski 1991) until both were found in younger deposits in Germany (Pietrzyński 1987). In addition, *S. tumida* occurs in the Eemian Interglacial at Ruszkówek in central Poland (Kozdra and Skompski 1995).

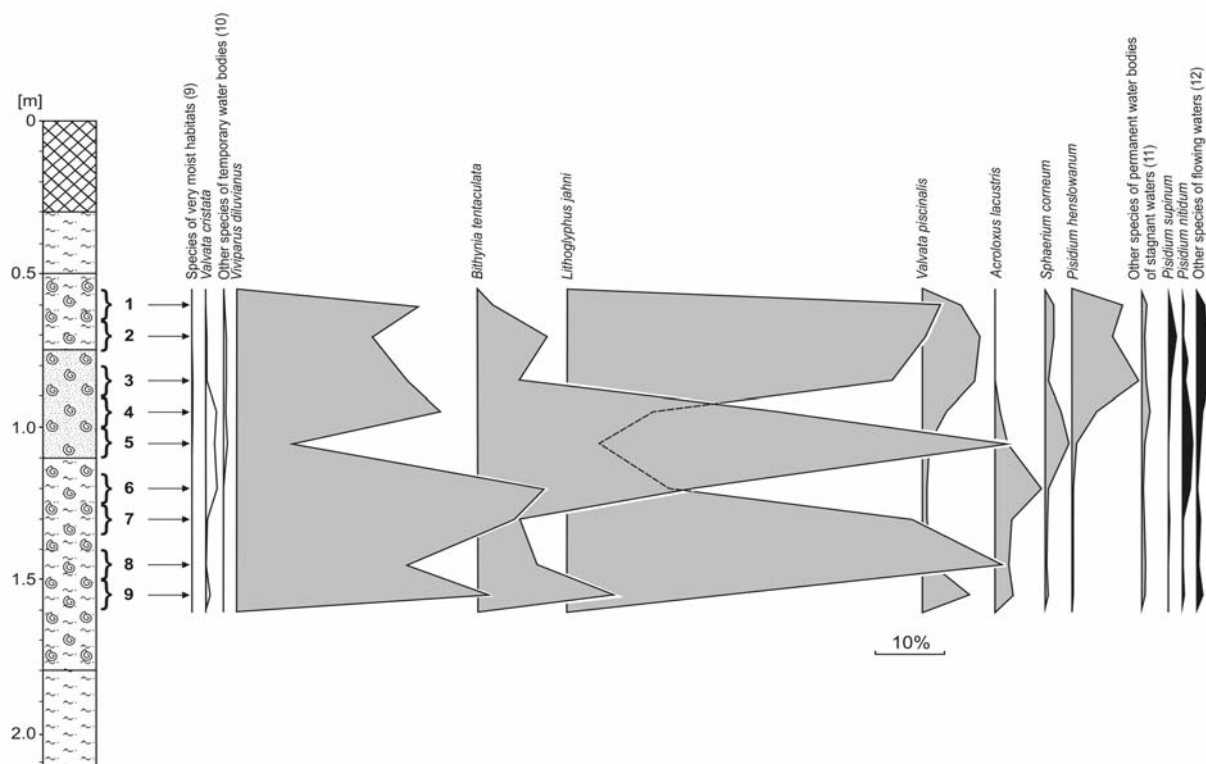
Palaeoclimate

Most of the identified species have wide climatic amplitude. Interglacial conditions are indicated by warm-demanding species e.g. *Viviparus diluvianus*, *Borysthenia naticina*, *Sphaerium rivicola* and *Pisidium moitessierianum* Paladilhe, 1866. The thermophilous *Bithynia tentaculata* indicates a somewhat warmer phase of lake development. Some species reach the Arctic Circle, but they are also frequent in temperate climates e.g. *Valvata piscinalis*, *Pisidium henslowanum* or even the cold-tolerant *P. lilljeborgii*.

DISCUSSION

The molluscan assemblages from Szymanowo represent the Mazovian (Holsteinian) Interglacial (~MIS 11). The correlation with MIS 11 in the study area is certain, based on detailed isotopic and palynological investigations of a 55 m thick core of lake deposits of the nearby Ossówka site, and has already been widely discussed (Nitychoruk *et al.* 2005, 2006). An assignment to the Mazovian is also documented in the stratigraphic papers of Gozhik *et al.* (2012) and Lindner *et al.* (2013) and is obligatory for eastern Poland at the moment.

The pollen analysis of the deposits from Szymanowo suggests that they represent the final part of the climatic optimum and its transition to the post-optimal period (Szymanek 2011). The composition of the mollusc assemblage, with the dominant species and great abundance of specimens reflecting stagnant water, points to a lacustrine environment. The considerable amount of river species, despite the low number of individuals, suggests some higher energy conditions. Periods of possible water movements as well as ecological changes in the water body can be derived from the variability of the malacological succession.



Text-fig. 5. Malacological diagram of the Szymanowo site

The mollusc assemblage at Szymanowo is dominated by *Lithoglyphus jahni*, *Bithynia tentaculata* and *Viviparus diluvianus*, which constitute ca. 5–62%, 2–76% and 8–46% of the community respectively (Text-fig. 5). The frequency of the dominant species is very unstable and the associated species such as *Valvata piscinalis*, *Pisidium henslowanum*, and *Acroloxus lacustris* do not exceed 10%. The lowermost part of the succession (samples 9 to 6) is dominated by *L. jahni* and *V. diluvianus*. *B. tentaculata*, which prefers well-oxygenated waters with rich vegetation, expands distinctly between samples 7 and 5, accounting for over 70% of the assemblage (Text-fig. 5). This is a warm-loving species and it occurs only occasionally during cooler periods (cf. Alexandrowicz 1999; Jaekel 1960; Dzierżek and Szymanek 2013). Such conditions are also supported by the expansion of *V. cristata* and *A. lacustris*, which attain the highest abundance in samples 6 to 4 and 6 respectively (Text-fig. 5). At this time, the water body was densely overgrown by the water fern *Salvinia natans* (Szymanek 2008, 2011). It is reasonable to assume that the water level in the lake was low, as *S. natans*, *V. cristata* and *B. tentaculata* prefer relatively shallow water, typically 0.7–1.8 m (Piechocki 1979; Alexandrowicz 1987, 1999; Alexandrowicz 2008). Also noteworthy are the almost

equal numbers of shells and opercula of *B. tentaculata* indicated by Bithynia-index (BIN) values close to 0 (Text-fig. 4). It suggests that the lake, despite supporting a rich vegetation, was generally devoid of rush and reed beds which often favour the separation of shells and opercula. Such separation may be also influenced by currents (e.g. Sanko *et al.* 2011), which were clearly minimal. Also noteworthy is the fact that the maximum of *B. tentaculata* corresponds to the lowest values of *V. diluvianus* and *L. jahni*. Usually such disproportion is explained by changes in water chemistry (Skompski 1980, 1989, 1996; Lindner *et al.* 1991). Increase in acidification connected with an increase in humidity and supply of humic acids affects the disappearance of *B. tentaculata*, as noted at Boczów in Western Poland (Skompski 1980, 1989), while its decrease may cause a rise in populations of *B. tentaculata*. The latter was observed in the neighbouring Hrud I site (Lindner *et al.* 1991; Skompski 1996; Szymanek 2012). According to Piechocki (1979) *B. tentaculata* finds optimal conditions in a pH range of 6.4 to 8.55.

The mollusc assemblage from the upper part of the profile (samples 3 to 1, 0.9–0.55 m) is dominated by *L. jahni* and *V. diluvianus* but again depleted in *B. tentaculata*. This time they are associated with *Valvata pisci-*

nalis and *Pisidium henslowanum* (Text-fig. 5). The former may point to deeper conditions since it prefers a water depth of 3–10 m (Welter-Schultes 2012) or even of 8–10 m (Alexandrowicz 1987). The decline of *V. cristata* and *A. lacustris* is probably connected with a rise of the water level and limited growth of aquatic plants. Significant representation of *P. henslowanum* suggests overflow through the lake. The general rise in rheophile species is gradual, but segregation of *Bithynia* opercula and shells in sample 1, with predominance of the latter, may also imply increasing water energy (cf. Sanko *et al.* 2011). The occurrence of *P. supinum*, which is usually restricted to rivers, seems to support this interpretation. However, sometimes this species can also be found in lake margins, where water movements are caused by wave action (Piechocki and Dyduch-Falniowska 1993). The oxygen content in the lake water was probably still high. Considerable frequencies of *V. piscinalis* and *P. henslowanum* may indicate amelioration of trophic conditions but could be inconsistent with good oxygenation. A notable decrease in number of specimens may be indicative of some deterioration of climatic conditions (Text-fig. 4).

Based on the malacological succession, three phases of lake development can be distinguished at Szymanowo. Two periods of somewhat deeper conditions are separated by a phase of shallowing accompanied by the development of aquatic plants. The pollen record (Szymanek 2008, 2011) is rather poor but the higher representation of the water fern *Salvinia natans* in the nearby Wilczyn and Kalitów profiles coincides with lower precipitation and a fall of the water level at the end of the climatic optimum of the Holsteinian Interglacial and in the post-optimal period (Bińska and Nitychoruk 1996; Bińska *et al.* 1997). Distinct continental influences at this time are also documented by the pollen and isotopic record of the Ossówka profile (Krupiński 1995, 2000; Nitychoruk 2000; Nitychoruk *et al.* 2005). The following deepening of the lake could be linked with the post-optimum, but there is no clear evidence for such an interpretation.

The fluctuating frequencies of *Viviparus diluvianus* and *Lithoglyphus jahni* might be also linked to taphonomic differences relating to variable hydrological conditions, without any direct climatic cause. In Britain *V. diluvianus* is a key element of the fluvial ‘Rhenish’ fauna (e.g. Roe 2001; White *et al.* 2013) while in Germany both Schmierer (1923) and Heck (1930) also regard this as a fluvial species, albeit Hannemann (1964) postulated a lacustrine origin for deposits containing *V. diluvianus*. At many sites in Poland, especially at Ossówka, shells of this species occur in calcareous gyttja, which undoubtedly accumulated in lakes (Nity-

choruk 2000). *Lithoglyphus jahni* is likewise also known from both lakes and rivers (Urbański 1975; Gittenberger *et al.* 2004; Kondrashov 2007). It is possible that their occurrence was connected with depth (cf. Szymanek 2012, 2013) and the water chemistry. The results from Szymanowo imply somewhat deeper zones of lakes occupied by *V. diluvianus* and *L. jahni*.

The palaeolake in the vicinity of Szymanowo contributes to the list of Holsteinian water bodies documented malacologically in the region of Biała Podlaska (cf. Lindner *et al.* 1991; Nitychoruk 1994; Albrycht *et al.* 1995; Krupiński and Skompski 1995; Szymanek *et al.* 2005; Szymanek 2011, 2012, 2013). Out of the few sites in the area, only the profiles from Hrud, Roskosz and Wilczyn yielded fully comparable material (cf. Szymanek 2012, 2013). The malacological records from the well known sites at Ortel Królewski and Ossówka (e.g. Nitychoruk 1994, 2000; Albrycht *et al.* 1995; Szymanek *et al.* 2005; Szymanek 2011) lack good quantitative data, precluding detailed comparison with the succession of Szymanowo. The composition of the mollusc assemblages from Hrud, Roskosz, Wilczyn and Szymanowo is similar and is characterised by the same group of taxa but some substantial differences exist. Usually three or four taxa predominate, *Lithoglyphus jahni*, *Bithynia tentaculata*, *Valvata piscinalis* and *Viviparus diluvianus*, but the dominant species varies, as do the occurrences of associated species. The most notable features at Szymanowo are the absence of *Valvata piscinalis* f. *antiqua* and the occurrence of *Sphaerium rivicola*, *S. solidum* and *Pisidium clessini*. The representation of species of running waters is highest in this region, but this group is still just an accessory element of the fauna, suggesting rather restricted water movements. Nevertheless, some overflow and higher energy conditions cannot be excluded. Such situations are typical of all of the water-bodies under investigation, but at Szymanowo the situation seems to be a little bit clearer. Another significant difference is the scarcity of rich bulrush zones shown by low values of the Bithynia-index. At Hrud, Roskosz and Wilczyn, expansion of reeds and bulrush is well documented by the changes of the Bithynia-index throughout the sections (Szymanek 2012, 2013).

The exact age of the mollusc associations from the palaeolakes of Biała Podlaska region is still disputed. It is certain that they represent the Mazovian Interglacial but they may not be synchronous. It is difficult to draw a picture of the mollusc assemblages typical of the different periods of the Holsteinian because they could have been strongly influenced by local conditions. The oldest, pre-optimum fauna was described from the Hrud I site. The molluscan assemblages from

Hrud II, Roskosz and Szymanowo seem to have accumulated during the climatic optimum but at Szymanowo they seem to date from the final part of the optimum and possibly the period immediately following. The molluscs from Wilczyn, with the restricted occurrence of *Viviparus diluvianus* and *Lithoglyphus jahni* and some cold-loving taxa, suggest cooler conditions of the final part of the Mazovian, supported by the occurrence of *Pisidium obtusale lapponicum* (Clessin) Favre and Jayet, 1938 (Szymanek 2013). In all periods changes of the water level and aquatic vegetation were noted. The palaeolake from Szymanowo appears to have been the shallowest because of the highest contribution of species of permanent water bodies. A shallow bay can also be inferred here.

CONCLUSIONS

The malacological changes through the Holsteinian palaeolake sequence in the vicinity of Szymanowo indicate a quite shallow, well-vegetated and well-oxygenated flow-through water body. Three phases in lake evolution were distinguished from initial deeper conditions, followed by a fall of the water level and an expansion of aquatic plants, to a late phase of deepening, with little water movement and a marked reduction in aquatic vegetation. The first stage of lake existence is characterised by high content of *Viviparus diluvianus* and *Lithoglyphus jahni*. The shallowing of the lake is probably connected with the development of a more continental climate in the final stage of the interglacial climatic optimum, which is evidenced by many pollen successions in the surrounding area (e.g. Bińka and Nitychoruk 1996; Krupiński 2000; Nitychoruk 2000). A fall of the water level and growth of aquatic plants are evidenced by considerable amounts of *Valvata cristata* and *Acroloxus lacustris*, with *Bithynia tentaculata* being dominant in the assemblage. Another rise of the water-level and some movement of the water in the third stage of lake development is recorded by an increase in *Viviparus diluvianus*, *Lithoglyphus jahni*, *Valvata piscinalis* and *Pisidium henslowanum*. The palaeoecological changes derived from the malacological succession enrich knowledge of this water body, especially in relation to the preliminary investigations previously conducted in the area (cf. Albrycht *et al.* 1995; Szymanek 2011).

Acknowledgements

I am extremely grateful to K. Binka and M. Krajcarz for palynological and vertebrate expertises respectively. The

valuable comments by the journal referees, Tivadar Gaudenyi, Richard Preece and Aleksander Sanko, are highly appreciated, as well as final linguistic correction by Christopher J. Wood. Project has been financed by National Science Centre, Poland, decision no. DEC2011/03/B/ST10/06329.

REFERENCES

- Albrycht, A. 2002a. Szczegółowa mapa geologiczna Polski 1:50 000, arkusz Łomazy (605). Centralne Archiwum Geologiczne Państwowego Instytutu Geologicznego; Warszawa.
- Albrycht, A. 2002b. Objąsnienia do Szczegółowej mapy geologicznej Polski 1:50 000, arkusz Łomazy (605). Centralne Archiwum Geologiczne Państwowego Instytutu Geologicznego; Warszawa.
- Albrycht, A., Skompski, S. and Pidek, I.A. 1995. Significance of mollusk fauna from Ortel Królewski and Rossosz sites for the Quaternary stratigraphy of Podlasie (East Poland). *Przegląd Geologiczny*, **43**, 321–330. [In Polish with English abstract]
- Alexandrowicz, S.W. 1987. Malacological analysis in Quaternary research. *Kwartalnik AGH, Geologia*, **12**, 1–240. [In Polish with English summary]
- Alexandrowicz, S.W. 1999. *Bithynia tentaculata* (Linnaeus, 1758) as an indicator of age and deposition environment of Quaternary sediments. *Folia Malacologica*, **7**, 79–88.
- Alexandrowicz, S.W. and Alexandrowicz, W.P. 2011. Analiza malakologiczna. Metody badań i interpretacji. Rozprawy Wydziału IV Przyrodniczego PAU, T. 3, pp. 1–302. Wydawnictwa PAU; Kraków.
- Alexandrowicz, W.P. 2008. Mollusc fauna from deposits of the Eemian interglacial in Piła. *Prace Komisji Paleogeografii Czwartorzędu PAU*, **6**, 49–57. [In Polish with English abstract]
- Bińka, K. 1994. Ewolucja interglacialnych zbiorników w Wilczynie i Woskrzenicach na Podlasiu w świetle analizy paleobotanicznej. PhD Thesis. Faculty of Geology, University of Warsaw; Warsaw, Poland.
- Bińka, K. and Nitychoruk, J. 1995. Mazovian (Holsteinian) lake sediments at Woskrzenice near Biała Podlaska. *Geological Quarterly*, **39**, 109–120.
- Bińka, K. and Nitychoruk, J. 1996. Geological and palaeobotanical setting of interglacial sediments at the Kaliów site in southern Podlasie. *Geological Quarterly*, **40**, 269–282.
- Bińka, K., Lindner, L. and Nitychoruk, J. 1997. Geologic-floristic setting of the Mazovian Interglacial sites in Wilczyn and Lipnica in southern Podlasie (eastern Poland) and their palaeogeographic connections. *Geological Quarterly*, **41**, 381–394.
- Dzierżek, J. and Szymanek, M. 2013. Interplenivistulian (MIS

- 3) environmental changes recorded in sub-till lake deposits at Wildno, Dobrzyń Lakeland (Polish Lowland). *Quaternary International*, **294**, 99–107.
- Glöer, P. 2002. Die Süßwassergastropoden Nord- und Mitteleuropas. Bestimmungsschlüssel, ebensweise, Verbreitung. Die Tierwelt Deutschlands 73, pp. 1–327. ConchBooks; Hackenheim.
- Gittenberger, E., Janssen, A.W., Kuijper, W.J., Kuiper, J.G.J., Meijer, T., Van Der Velde, G. and De Vries, J.N. 2004. De Nederlandse Zoetwatermollusken: Recente en fossiele weekdieren uit zoet en brak water. Nederlandse Fauna 2, pp. 1–292. Nationaal Natuurhistorisch Museum Naturalis. KNNV Uitgeverij and EIS-Nederland; Leiden.
- Gozhik, P., Lindner, L. and Marks, L. 2012. Late Early and early Middle Pleistocene limits of Scandinavian glaciations in Poland and Ukraine. *Quaternary International*, **271**, 31–37.
- Hannemann, M. 1964. Quartärbasis und älteres Quartär in Ostbranderburg. *Zeitschrift für Angewandte Geologie*, **10**, 370–376.
- Heck, H.L. 1930. Zur Fossilführung der Berliner Paludinschichten, ihrer Beschaffenheit und Verbreitung. *Zeitschrift der Deutschen Gesellschaft für Geowissenschaften*, **82**, 385–404.
- Jaecckel, S.G. 1960. Ergänzungen und Berichtigungen zum rezenten und quartären Vorkommen der mitteleuropäischen Mollusken. In: P. Brohmer (Ed.), Die Tierwelt Mitteleuropas Ergänzung, **1**, 27–293.
- Keen, D.H. 2001. Towards a late Middle Pleistocene non-marine molluscan biostratigraphy for the British Isles. *Quaternary Science Reviews*, **20**, 1657–1665.
- Kempf, E. 1971. Ökologie, Taxonomie und Verbreitung der nichtmarinen Ostrakoden- Gattung *Scottia* im Quartär von Europa. *Eiszeitalter Gegenwart*, **22**, 43–63.
- Kerney, M.P. 1971. Interglacial deposits in Barnfield pit, Swanscomb, and their molluscan fauna. *Journal of the Geological Society of London*, **127**, 69–93.
- Kerney, M.P., Cameron, R.A.D. and Jungbluth, J.H. 1983. Die Landschnecken Nord- und Mitteleuropas, pp. 1–384. Verlag Paul Parey; Hamburg und Berlin.
- Kondrashov, P.E. 2007. New gastropod species from the Pleistocene of the upper Don basin. *Paleontological Journal*, **41**, 513–519.
- Kozydra, Z. and Skompski, S. 1995. Unique character of the Eemian Interglacial site in Ruszkówek (Pojezierze Kujawskie, central Poland). *Przegląd Geologiczny*, **43**, 572–575.
- Körnig, G. 1966. Die Molluskengesellschaften des mitteleuropäischen Hügellandes. *Malakologische Abhandlungen*, **11**, 57–85.
- Krupiński, K.M. 1995. Pollen stratigraphy and successions of vegetation during the Mazovian Interglacial. *Acta Geographica Lodziensia*, **70**, 1–200.
- Krupiński, K.M. 2000. Palynostratigraphic correlation of deposits of the Mazovian Interglacial of Poland. *Prace Państwowego Instytutu Geologicznego*, **169**, 1–61. [In Polish with English summary]
- Krupiński, K.M. and Skompski, S. 1995. *Viviparus diluvianus* (Kunth) in the sediments of Mazovian Interglacial from Grabanów In Podlasie (E Poland). *Przegląd Geologiczny*, **43**, 1045–1048. [In Polish with English abstract]
- Lindner, L., Krupiński, K.M., Marciniak, B., Nitychoruk, J. and Skompski, S. 1991. Pleistocene lake sediments of the site Hrud I near Biała Podlaska. *Geological Quarterly*, **35**, 337–362. [In Polish with English summary]
- Lindner, L., Marks, L. and Nita, M. 2013. Climatostratigraphy of interglacials in Poland: Middle and Upper Pleistocene lower boundaries from a Polish perspective. *Quaternary International*, **292**, 113–123.
- Ložek, V. 1964. Quartärmollusken der Tschechoslowakei. *Rozprawy Ústředního Ústavu Geologického*, **31**, 1–374.
- Ložek, V. 1976. Klimaabhängige Zyklen der Sedimentation und Bodenbildung während Quartärs im Lichte malakozoologischer Untersuchungen. *Rozprawy Československé Akademie Věd*, **86**, 1–97.
- Ložek, V. 1982. Faunengeschichtliche Grundlinien zur spät- und nacheiszeitlichen Entwicklung der Molluskenbestände in Mitteleuropa. *Rozprawy Československé Akademie Věd*, **92**, 1–106.
- Ložek, V. 1986. Mollusca Analysis. In: Berglund, B.E. (Ed.), Handbook of Holocene Palaeoecology and Palaeohydrology, pp. 729–740.
- Ložek, V. 2000. Palaeoecology of Quaternary Mollusca. Sborník geologických ved, Rada A – Anthropozoikum, **24**, 35–59.
- Meijer, T. 1989. Notes on Quaternary freshwater mollusca of the Netherlands, with descriptions of some new species. *Mededelingen Werkgroep voor Tertiaire en Kwartaire Geologie*, **26**, 145–181.
- Meijer, T. and Preece R.C. 1995. Malacological evidence relating to the insularity of the British Isles during the Quaternary. In: Preece, R.C. (Ed.), Island Britain: A Quaternary perspective. *Geological Society of London, Special Publication*, **96**, 89–110.
- Nitychoruk, J. 1994. Stratigraphy of the Pleistocene and palaeogeomorphology of Southern Podlasie. *Rocznik Międzyrzecki*, **26**, 23–107. [In Polish with English abstract]
- Nitychoruk, J. 2000. Climate reconstruction from stable-isotope composition of the Mazovian Interglacial (Holsteinian) lake sediments in eastern Poland. *Acta Geologica Polonica*, **50**, 247–294.
- Nitychoruk, J., Bińka, J., Hoefs, J., Ruppert, H. and Schneider, J. 2005. Climate reconstruction for the Holsteinian Interglacial in eastern Poland and its comparison with isotopic data from Marine Isotope Stage 11. *Quaternary Science Reviews*, **24**, 631–644.

- Nitychoruk, J., Bińka, J., Ruppert, H. and Schneider, J. 2006. Holsteinian Interglacial = Marine Isotope Stage 11? *Quaternary Science Reviews*, **25**, 2678–2681.
- Piechocki, A. 1979. Mięczaki (Mollusca). Ślimaki (Gastropoda). Fauna słodkowodna Polski z. 7, pp. 1–173. Państwowe Wydawnictwo Naukowe; Poznań.
- Piechocki, A. and Dyduch-Falniowska, A. 1993. Mięczaki (Mollusca). Małże (Bivalvia). Fauna słodkowodna Polski z. 7A, pp. 7–185. Wydawnictwo Naukowe PWN; Warszawa.
- Pietrzeniuk, E. 1987. Süßwasser-Ostracoden aus pleistozänen Ablagerungen von Röpersdorf bei Prenzlau. *Zeitschrift für Geologische Wissenschaften*, **15**, 315–325.
- Robinson, J.E. 1979. The ostracod fauna of the interglacial deposits of Sugworth, Oxfordshire. *Philosophical Transactions of the Royal Society of London B*, **289**, 99–106.
- Roe, H.M. 2001. The Late Middle Pleistocene biostratigraphy of the Thames Valley, England: new data from eastern Essex. *Quaternary Science Reviews*, **20**, 1603–1619.
- Roe, H.M., Coope, G.R., Devoy, R.J.N., Harrison, C.J.O., Penkman, K.E.H., Preece, R.C. and Schreve, D.C. 2009. Differentiation of MIS 9 and MIS 11 in the continental record: vegetational, faunal, aminostratigraphic and sea-level evidence from coastal sites in Essex, UK. *Quaternary Science Reviews*, **28**, 2342–2373.
- Sanko, A.F., Gaigalas, A. and Yelovicheva, Y.M. 2011. Paleoclimatic and stratigraphic significance of *Belgrandia marginata* (Michaud) in Late Quaternary malacofauna of Belarus and Lithuania. *Quaternary International*, **241**, 68–78.
- Schmierer, T. 1923. Beitrag zur Kenntnis des faunistischen und floristischen Inhalts der Berliner Paludinenbank. *Zeitschrift der Deutschen Geologischen Gesellschaft*, **74**, 207–236.
- Skompski, S. 1980. New localities of molluscs in interglacial deposits of western Poland. *Biuletyn Instytutu Geologicznego*, **322**, 5–31.
- Skompski, S. 1989. Molluscs and ostracod fauna of selected sites of the Mazovian Interglacial in Poland. *Geological Quarterly*, **33**, 495–524.
- Skompski, S. 1991. Fauna czwartorzędowa Polski. Bezkręgowce, pp. 1–239. Wydawnictwa Uniwersytetu Warszawskiego; Warszawa.
- Skompski, S. 1996. Standard assemblages of malacofauna in different Quaternary stratigraphic units. *Prace Państwowego Instytutu Geologicznego*, **151**, 1–47. [In Polish with English abstract]
- Skompski, S. 2009. Pleistocene fauna in the Sucha Wieś (Elk Lakeland) and Czarnucha (Augustów Plain) sections, Northeastern Poland. *Biuletyn Państwowego Instytutu Geologicznego*, **435**, 85–96. [In Polish with English abstract]
- Skompski S. and Makowska A. 1989. Mięczaki. In: Rühle, W. and Rühle, E. (Eds), Atlas skamieniałości przewodnich i charakterystycznych cz. 3b. Kenozoik, Czwartorzęd. Budowa geologiczna Polski, **3**, 40–95.
- Steenberg, C.M. 1917. Furesoens molluskenfauna. *Köngelige Danske Videnskabs Selskab Skrifter*, **8** (III-1), 78–200.
- Sywula, T. 1974. Małżoraczki (Ostracoda). Fauna słodkowodna Polski z. 24, pp. 1–315. Państwowe Wydawnictwo Naukowe; Poznań.
- Szymanek, M. 2007. Rekonstrukcja warunków klimatyczno-środowiskowych w interglacjale mazowieckim na podstawie zmienności muszli ślimaka *Viviparus diluvianus* (Kunth) w stanowiskach okolic Białej Podlaskiej. Ph.D. Thesis. Faculty of Geology, University of Warsaw; Warsaw, Poland.
- Szymanek, M. 2008. *Viviparus diluvianus* (Kunth) in the vicinity of Biała Podlaska as an indicator of climatic-environmental changes in the Mazovian (Holsteinian) Interglacial. *Prace Komisji Paleogeografii Czwartorzędu PAU*, **6**, 19–27. [In Polish with English abstract]
- Szymanek, M. 2011. Climate oscillations of the Holsteinian (Mazovian) Interglacial recorded in shell morphometry of *Viviparus diluvianus* (Kunth, 1865) from eastern Poland. *Quaternary International*, **241**, 143–159.
- Szymanek, M. 2012. Malacofauna of the Holsteinian lake deposits at Hrud II (eastern Poland) and its ecological significance. *Geological Quarterly*, **56**, 117–126.
- Szymanek, M. 2013. Palaeoecology of the Holsteinian lake in vicinity of Wilczyn (Eastern Poland) based on molluscan studies. *Geological Quarterly*, **57**, 637–648.
- Szymanek, M. and Bińka K. 2006. *Viviparus diluvianus* (Kunth) from the Mazovian (Holsteinian) Interglacial deposits at Szymanowo (eastern Poland). In: Ekologofunkcjonalni ta faunistichni aspekti doslidzhennia moluskiv, ih rol u bioindikacii stanu navkolishnogo sere-dovishcha. Zbirnik naukovykh prac 2, pp. 277–279. Zhytomyr University Press; Zhytomyr, Ukraine.
- Szymanek, M., Nitychoruk, J., Trammer, J. and Bińka, K. 2005. Influence of climate on the variability of snails of the genus *Viviparus* in deposits of the Holsteinian (Mazovian) Interglacial from Ortel Królewski, eastern Poland. *Boreas*, **34**, 335–344.
- Urbański, J. 1975. *Lithoglyphus jahni* n. sp. aus den Mitteleuropäischen Ablagerungen des Mindel/Riss Interglazials, nebst Bemerkungen über den nordbalkanischen *Lithoglyphus fuscus* (C. Pfeiffer, 1828) (= *L. pyramidatus* Moellendorff, 1873) (Gastropoda, Prosobranchia, Hydrobiidae). *Bulletin de la Société des Amis des Sciences et des Lettres de Poznań*, **15**, 107–111.
- Welter-Schultes, F. 2012. European non-marine molluscs, a guide for species identification, pp. 1–679. Planet Poster Editions; Goettingen.
- Wiktor, A. 2004. Ślimaki lądowe Polski, pp. 1–302. Wydawnictwo Mantis; Olsztyn.

White, T.S., Preece, R.C. and Whittaker, J.E. 2013. Molluscan and ostracod successions from Dierden's Pit, Swanscombe: insights into the fluvial history, sea-level

record and human occupation of the Hoxnian Thames. *Quaternary Science Reviews*, **70**, 73–90.

Manuscript submitted: 18th February 2014

Revised version accepted: 15th May 2014