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Mollusc faunas of lake deposits in Gorzów Wielkopolski (NW Poland) as an indicator of environmental changes during Eemian and Early Weichselian

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During the construction of the S-3 road near Gorzów Wielkopolski, a sedimentary succession of the Eemian Interglacial and the older part of the Weichselian Glaciation were exposed. The succession, ~22 m thick, consists of lacustrine and fluvioglacial deposits. Lake sediments, mainly calcareous gyttja with peat intercalations, represent the infills of two palaeolakes. The almost complete skeleton of a forest rhinoceros, *Stephanorhinus kirchbergensis*, and a bone of the fallow deer *Dama dama* were found in the older lake deposits. Mollusc shells were numerous in both lake sequences, analysis of which revealed two types of assemblage, representing the coastal, littoral zone of a shallow lake with a muddy bottom. The sequence of mollusc communities observed in vertical succession allowed reconstruction of environmental changes during deposition. Several hydrological changes have been recognized within the palaeolake, especially water level fluctuations probably due to climate change.

Key words: palaeolake, malacofauna, environmental changes, Eemian Interglacial, Early Weichselian, NW Poland.

INTRODUCTION

Eemian deposits are common in Europe, particularly in the belt stretching from northern France through the Benelux countries, northern Germany, Poland, to the Baltic countries (e.g., Turner, 2000; Caspers et al., 2002; Behre et al., 2005; Henriksen et al., 2008; Helmens, 2013). In this zone, they are usually overlain by younger deposits (Weichselian and/or Holocene) and are relatively rarely exposed to the surface. Most commonly the Eemian deposits are of lake or marsh facies, with peat as the dominant lithology, providing rich palynological material enabling reconstruction of climatic changes (e.g., Zagwijn, 1996; Cheddadi et al., 1998; Kukla et al., 2002; Klotz et al., 2004; Müller et al., 2005; Brewer et al., 2008). Carbonate deposits – lacustrine chalk and calcareous gyttja – are less common. Due to the presence of calcium carbonate, they create favourable conditions for the preservation of molluscs. Such successions have been described, e.g. in Germany (Meng et al., 2009a, b; Strahl et al., 2010; Menzel-Harloff and Meng, 2015; Milano et al., 2020), Poland (Alexandrowicz and Alexandrowicz, 2010; Hrynowiecka et al., 2018), Belarus (Sanko et al., 2011) and Baltic countries (Sanko and Gaigalas, 2007; Sanko et al., 2011).

In northern Poland, Eemian deposits are widespread. Among these, palaeolake infills are of great importance. Many such water bodies formed after the retreat of the Saalian ice sheet. Most of the localities recognized lie south of the maximum range of the Weichselian Glaciation (Bruj and Roman, 2007; Roman, 2016). North of this line the number of localities described is much smaller (Urbański and Winter, 2005; Brose et al., 2006; Winter et al., 2008; Niska and Mirosław-Grabowska, 2015).

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In the lower parts of the Warta and Odra basins, relatively few localities with Eemian deposits have been recognized and described so far. In addition to lithological descriptions, palynological, geochemical and malacological studies have been performed at several sites (e.g., Skompski, 1994; Urbański and Winter, 2005; Winter et al., 2008; Alexandrowicz and Alexandrowicz, 2010; Niska and Mirosław-Grabowska, 2015).

The composition and structure of mollusc communities closely reflect the environmental conditions prevailing at the time and place of sedimentation. This makes molluscs a well-suited group for the needs of palaeoenvironmental and palaeoclimatic reconstructions. Lacustrine molusc assemblages usually contain admixtures of terrestrial species. This creates a unique opportunity to recreate not only the conditions in the lake itself, but also on its banks.

Malacological analyses of Eemian lacustrine deposits in Poland have so far been restricted to a relatively small group of several dozen localities dispersed across the Polish Lowland (Skompski, 1996; Alexandrowicz and Alexandrowicz, 2010). From this perspective, Eeemian mollusc assemblages are poorly understood compared with those from Late Glacial and Holocene localities (Alexandrowicz, 1999a, 2013), or even to those of the Holsteinian Interglacial (Skompski, 1996; Szymanek, 2012, 2013, 2014). Similarly, relatively small numbers of Eemian sites containing freshwater mollusc communities have so far been described from other areas of the European Lowland (e.g., Sanko and Gaigalas, 2007; Meng et al., 2009a, b; Strahl et al., 2010; Sanko et al., 2011; Menzel-Harloff and Meng, 2015; Milano et al., 2020).

This study reconstructs the environmental conditions and features of an Eemian palaeolake near Gorzów Wielkopolski. From a regional point of view, the data collected will enrich knowledge of subfossil communities of molluscs in palaeolake deposits. And, the molluscan diversity enables palaeoenvironmental reconstructions, especially with regard to hydrological and climatic changes in central Europe during the Eemian and Early Weichselian. In its completeness, the sequence found here is unique and only sporadically appears in sites described in the literature from the entire area of the European Lowland.

SITE DESCRIPTION

The interglacial lake-marsh deposits were exposed (Badura et al., 2017; Sobczyk et al., 2020) 6 km WSW from the centre of Gorzów Wielkopolski in a cut along the S-3 highway (GPS 51°43'N, 15°10'E; Fig. 1). This artificial excavation cuts the morphological edge separating the moraine plateau of the Gorzów Plain (in the north) from the Toruń-Eberswalde ice-marginal valley (in the south) (Figs. 1 and 2). The relief of the area is characterized by heights in the range of 70–90 m a.s.l. for the moraine plateau, and ~18–20 m a.s.l. for the valley that is currently occupied by the Warta River. The southern slopes of the moraine plateau are in many places cut by small valleys developed after the retreat of the Weichselian ice sheet (Fig. 2).

The deposits exposed in the cut form a sequence with a total thickness of ~22 m and were described in detail by Badura et al. (2017) and Sobczyk et al. (2020). They comprise two lake successions underlain by sandy-gravel fluvioglacial deposits dated by OSL at 123.6 ±10.1 ka (Sobczyk et al., 2020). These represent the final phase of the Saalian Glaciation (MIS 6) (FG-1; Fig. 3). The lowest part of the lake deposits is of brown gyttja. Above, there is grey lacustrine chalk and gyttja with an admixture of sand, bones of *Stephanorhinus kirchbergensis* and numerous mollusc shells. The rhinoceros skeleton was characterized by exceptional completeness (>130 bones).

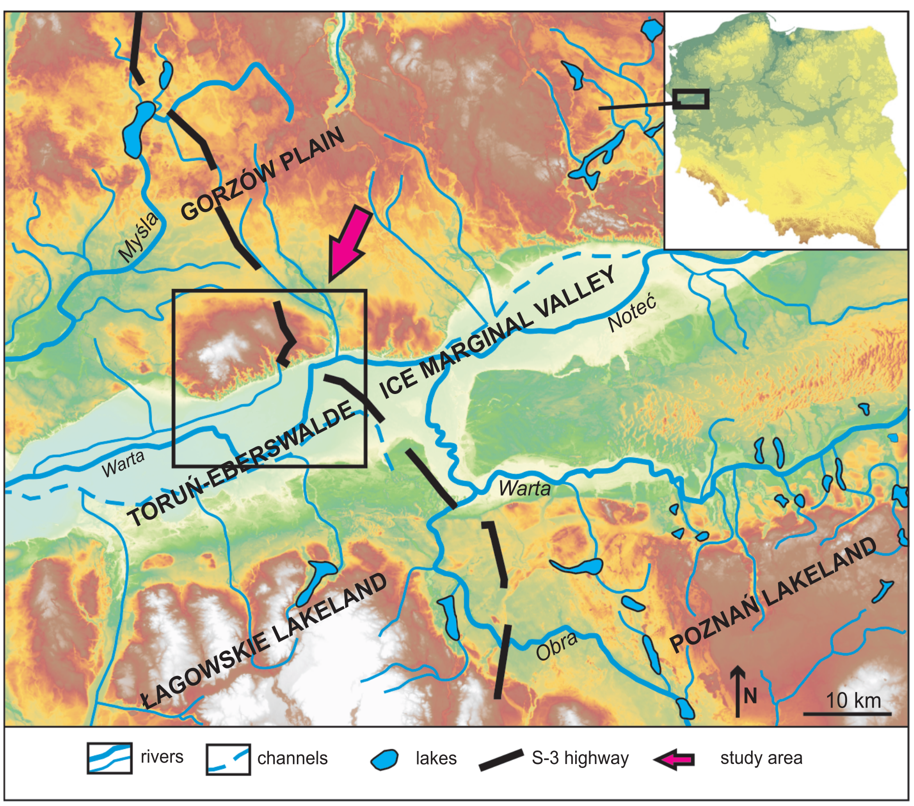

Fig. 1. Location of study area (map base: www.polska.e-mapa.net)

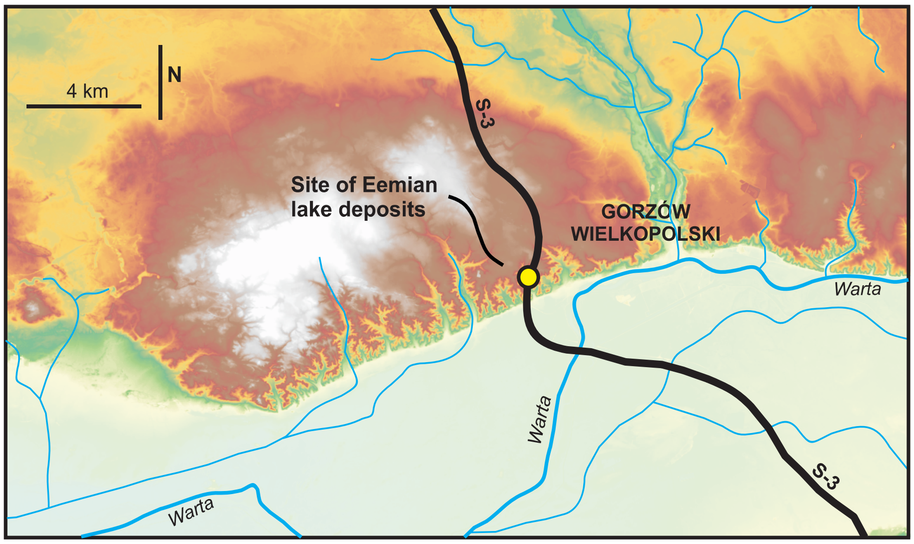

Fig. 2. Map of of localities with Eemian/Early Weichselian mollusc-bearing deposits (map base: www.polska.e-mapa.net)

Apart from individual elements, only the right hind limb was missing. The bones were probably quickly buried by sediment, as indicated by the remains of plant matter preserved in the tooth cavities (Sobczyk et al., 2020). The lower lake succession ends with a layer of peat mixed with sand, where the metatarsal bone of a fallow deer (*Dama dama*) was found. The total thickness of the older lacustrine sequence is ~4.5 m (L-1; Fig. 3). Palynological analyses of these deposits indicate that their deposition took place during the Eemian (MIS 5e) (detailed description: Sobczyk et al., 2020). The lower lake succession is overlain by light brown laminated sand and silty sand ~2 m thick (delta-type deposits), with an age estimated using the OSL method of 98.8 ±7.9 ka (MIS 5c; Sobczyk et al., 2020; FG-2; Fig. 3). Above, there are deposits belonging to the upper lake succession, including grey chalk and carbonate gyttja. This succession ends with peat overlain by a thin layer of gyttja and silty sand. This younger calcareous unit has a thickness of ~4.5 m (L-2; Fig. 3) and corresponds to the Early Weichselian (MIS 5a–d). Such a stratigraphic interpretation is supported by the results of palynological analyses of these deposits (see Sobczyk et al., 2020). Above the lake deposits, there is an 11 m thick fluvioglacial unit, its bottom part represented by 1.5 m of sands and gravels (OSL age 72.0 ±5.2 ka; Sobczyk et al., 2020) upwards giving way to gravel diamicton (FG-3; Fig. 3).

MATERIAL AND METHODS

Malacological analyses were performed on 62 samples representing the entire exposed sequence. Shells were found within the lacustrine sequences (L-1 and L-2), though they were absent from the fluvioglacial deposits (FG-1, FG-2 and FG-3; Fig. 3). The final analysis was based on 25 samples. Each of these represents an interval of 15 cm and had a mass of ~3 kg. The mollusc fauna in the upper part of the profile was relatively poor, making it necessary to combine adjacent samples. Each of the three samples representing this interval was made up by combining three samples taken directly from exposure. The samples were macerated on a 0.5 mm sieve, and after drying, all completely preserved mollusc shells (both adult and juvenile forms) and recognizable shell fragments were picked out. The shells are very well preserved. There are no signs of chemical dissolution, and the small amount of fragments indicated a minor role of mechanical comminution. Identification keys (Welter-Schultes, 2012; Piechocki and Wawrzyniak-Wydrowska, 2016) and reference collections were used. Malacological analysis was performed using standard methods after Alexandrowicz and Alexandrowicz (2011). Individual species were classified into ecological groups:

- M – mesophilous species,
- H – hygrophilous species,
- W_T – species of temporary water bodies,
- W_S – species of permanent water bodies,
- W_M – euryecological aquatic species.

Percentage shares of individual species and ecological groups were the basis for the construction of the malacological diagram showing how mollusc assemblages vary through the sequence. Within the fauna analysed, it was possible to distinguish two types of community, each of specific composition and with distinct ecological requirements. The data collected in this way were supported by the results of lithological, palynological and stratigraphical studies conducted at the site (Badura et al., 2017; Sobczyk et al., 2020), as well as malacological data from other Eemian localities in Poland (e.g., Skompski, 1994, 1996; Alexandrowicz and Alexandrowicz, 2010; Hrynowiecka et al., 2018) and in neighbouring countries (e.g., Sanko and Gaigalas, 2007; Meng et al., 2009a, b; Strahl et al., 2010; Sanko et al., 2011; Menzel-Harloff and Meng, 2015; Kenzler et al., 2018; Milano et al., 2020).

RESULTS

The material processed contains a relatively rich, though not very diverse malacofauna. The number of taxa in individual samples varied from 1 to 28, while the number of specimens ranged from 100 to 1672 (Fig. 3 and Table 1). In total, all material analysed included 8641 specimens belonging to 29 taxa (7 terrestrial taxa, 16 water snails and 6 bivalves). The plates of slugs were identified under the collective name Limacidae. There were also shell fragments in the material analysed (not taken into account in the calculations; Table 1).

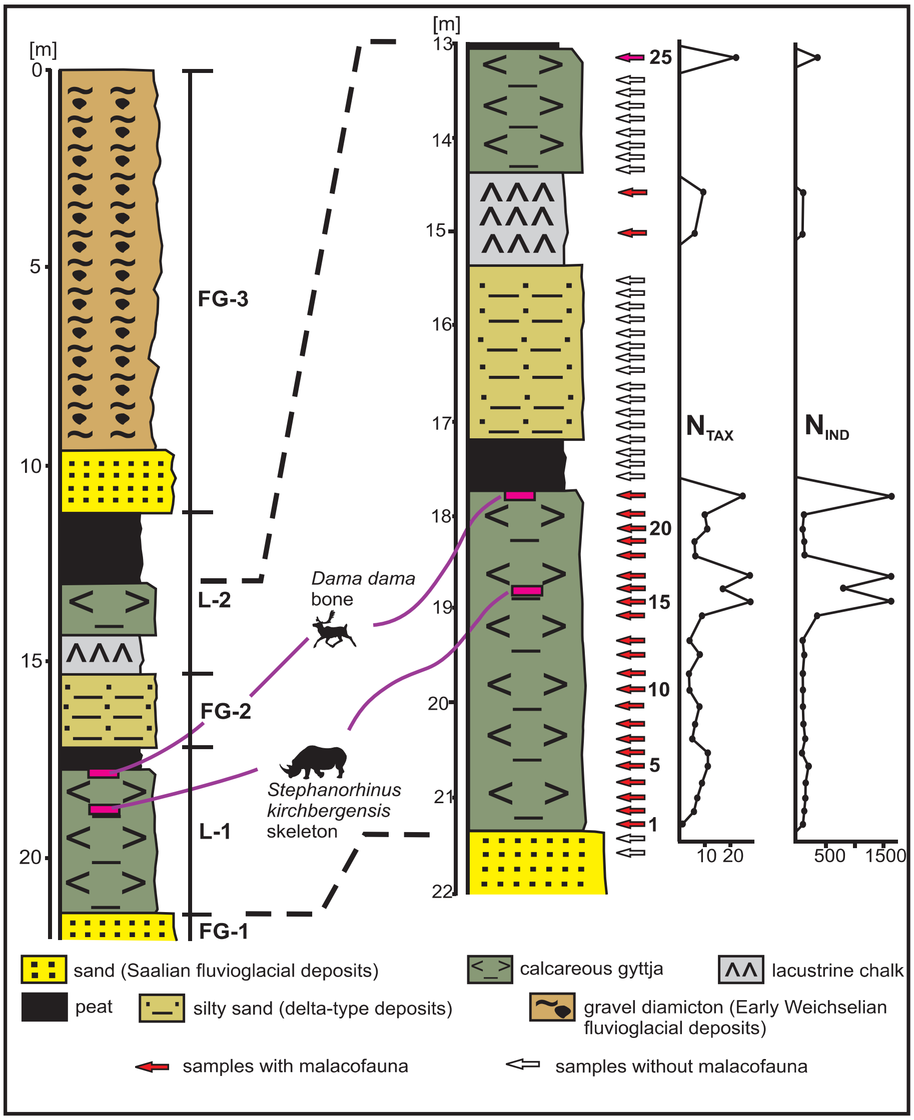

Fig. 3. Lithology and sampling of the Eemian/Early Weichselian mollusc-bearing deposits at Gorzów Wielkopolski

N_{TAX} number of molluscs species, N_{IND} – number of molluscs individuals, FG-1, FG-3 – fluvioglacial deposits (described in text), FG-2 – delta-type deposits (described in text), L-1, L-2 – lake deposits (described in text); lithology after Badura et al. (2017) and Sobczyk et al. (2020)

Terrestrial molluscs (ecological groups M and H) played a minor role. Only taxa of open or partially shaded, high humidity habitats were present. *Succinea putris* was the most numerous terrestrial snail. It is a hygrophilous taxon inhabiting open, periodically flooded biotopes, usually on the banks of water bodies. A similar type of habitat is preferred by other hygrophilous taxa identified in the fauna discussed, such as *Pseudotrichia rubiginosa* and *Vertigo antivertigo*. Terrestrial species were present only in 8 samples. Their share in the assemblages usually did not exceed 10%, though in some samples, they were more numerous, constituting up to 30% of the community (Fig. 4 and Table 1).

Species of temporary water bodies (ecological group W_T) were an important component of the fauna. They occur in almost all samples, comprising up to 30% of the assemblage (Fig. 4 and Table 1). The most numerous representatives of this group were *Valvata cristata* and *Valvata macrostoma*. Both forms prefer shallow water bodies with a muddy bottom, lush, especially submerged vegetation, and to a lesser extent reeds (Økland, 1990; Piechocki and Wawrzyniak-Wydrowska, 2016). They also tolerate periods of drying.

Species of permanent water bodies (ecological group W_S) formed the second group of aquatic species. This group was an important component in all samples (except for sample 1), and its percentage can reach 50% (Fig. 4 and Table 1). A characteristic representative is *Valvata piscinalis* – a taxon typical of permanent lakes (and not resistant to drying out), especially numerous in shallow, littoral zones (at a depth of 3 to 10 m). It has also been found at much greater depths (up to 80 m) (Welter-Schultes, 2012; Piechocki and Wawrzyniak-Wydrowska 2016). *Valvata piscinalis* is a benthic snail, living either directly on the bottom or within sediments. It prefers oxygen-rich waters, a muddy bottom, and moderate plant vegetation (Økland, 1990; Piechocki and Wawrzyniak-Wydrowska, 2016). The other taxa included in the W_S group played a smaller role (Fig. 4 and Table 1).

Other species were forms of high ecological tolerance that live in different types of permanent water body (ecological group W_M). The most important is *Bithynia tentaculata*. It is a euryecological, widely-spread, palaearctic taxon living in various types of water body. In lakes, it prefers the shallow, oxygen-rich part of the littoral zone (to a depth of 5 m, usually 0.5 to 2 m), and also survives short periods of drying (Økland, 1990; Welter-Schultes, 2012; Piechocki and Wawrzyniak-Wydrowska, 2016). It is rarer in deeper zones (up to 20 m), and usually lives in zones rich in macrophytes, with a muddy bottom. It is the most common snail species in the entire material (~35% of all individuals identified). *Bithynia tentaculata* produces two hard skeletal elements that preserve well in sediments: the shell and the lid (*operculum*). Morphologically these two elements differ significantly from each other and react differently to sedimentation processes. The shells have good buoyancy and are easily displaced by currents and/or waves, while the heavy lids quickly fall to the bottom. In the material analysed, lids are always more numerous than shells (Fig. 4 and Table 1). The lack of chemical dissolution of the shells and the relatively small number of broken shell fragments indicate that the differences in the relative frequency of shells and lids are the result of sedimentation sorting by currents or waves, rather than of selective destruction of skeletal elements (chemical and/or mechanical). *Bithynia tentaculata* is a frequent component of subfossil communities, particularly those associated with warmer climatic phases (e.g., Alexandrowicz, 1999a, b, 2013; Meng et al., 2009a, b; Menzel-Harloff and Meng, 2015; Milano et al., 2020). Other species belonging to the W_M ecological group are of lesser importance (Fig. 4 and Table 1).

The mollusc fauna identified in the palaeolake deposits of Gorzów Wielkopolski shows vertical variation and it is possible to distinguish two types of assemblage representing different types of habitat.

Assemblage A occurred only in 4 samples (Fig. 4). It was characterized by the presence of terrestrial species (reaching up to 30% of the assemblage): mesophilous, and especially hygrophilous (ecological groups M and H). Characteristic components of this community were *Succinea putris*, *Pseudotrichia rubiginosa* and *Vertigo antivertigo*. The other important group comprised species typical of temporary water bodies (ecological group W_T), especially *Valvata macrostoma*. Taxa of permanent water bodies were less numerous. Assemblage A represents the lake bank environment. Species composition indicates the presence of wet, open habitats. Water level fluctuations led to periodic flooding or drying of the coastal zone. Hence, both hygrophilous terrestrial taxa and aquatic species typical of temporary water bodies are present, while the share of lake taxa is relatively low. Faunas with similar characteristics have been described from many lacustrine localities representing both the Eemian (e.g., Meng, 2009a, b; Alexandrowicz and Alexandrowicz, 2010; Sanko et al., 2011; Menzel-Harloff and Meng, 2015) and the Holocene (e.g., Alexandrowicz, 1999a, 2013).

Assemblage B was identified in 21 samples (Fig. 4). It is characterized by the dominance of aquatic taxa, especially forms living in permanent water bodies. The share of species of temporary water bodies is relatively low and does not exceed 30%. Land snails are not present or, at most, are an accessory component of the community, and their share does not exceed 5%. Two species, *Valvata piscinalis* and *Bithynia tentaculata*, play the most important role in community B. Both these forms are characterized by significant ecological tolerance. The larger share of *Valvata piscinalis* may (though does not have to) imply a slightly greater depth of the lakes, as well as a more limited spread of aquatic plants. That relationship is implied by results of analyses of molluscs found in interglacial deposits (e.g., Alexandrowicz, 1999a, 2013; Alexandrowicz and Alexandrowicz, 2011; Szymanek, 2012, 2013, 2014; Hrynowiecka et al., 2018) and of the recent fauna (Welter-Schultes, 2012; Piechocki and Wawrzyniak-Wydrowska, 2016).

DISCUSSION

LAKE EVOLUTION

The variation in species composition and ecological structure of mollusc assemblages observed in vertical profile indicates environmental changes occurring during lacustrine deposition. The base of the succession is formed of fluvioglacial deposits representing the final phase of the Saalian Glaciation (MIS 6) and dated by OSL at 123.6 ±10.1 ka (Sobczyk et al., 2020). Within the older lake deposits, the malacological sequence is complete and continuous. Molluscs occurring in the deposits forming the younger lake succession were much poorer. The Gorzów Wielkopolski deposits accumulated in a shallow, nearshore part of the littoral zone, of a depth possibly not exceeding several metres. The lake was characterized by a muddy bottom covered by macrophytes, numerous remains of Characeae, *Najas marina* and *Najas flexilis* being found in the deposits (Sobczyk et al., 2020). There was no reed belt at the lake shore, as indicated by the scarce presence of their remains in the deposits (Sobczyk et al., 2020) and by a lack of mollusc species characteristic of this type of habitat. *Bithynia tentaculata* opercula are more common the respective shell reflecting current sorting given the lack of traces of chemical dissolution. According to palynological data (Sobczyk et al., 2020), the area surrounding the lake was forest-covered. However, the mollusc assemblages not include any forest, or even shade-loving species, indicating a predomination of wet, or even periodically flooded open habitats. Therefore, the lake shore was probably flat and covered by low, hygrophytic vegetation. In these morphological situations, the scale of shell material transport is very limited. This phenomenon has been described for the present alluvial plains of river valleys and flat lake shores (Ilg et al., 2012; Čiliak et al., 2015). This limitation does not concern pollen, which can be easily transported over larger distances. Thus, it is most probable that forest communities reconstructed on a basis of palynological analyses grew at a certain distance (maybe metres or tens of metres) from the lake shore.

The sequence of assemblages observed indicates significant variations in deposition conditions, enables the distinction of several phases (Fig. 5).

Phase I (M-1, samples 1–4) represents the floor deposits of the older palaeolake. The type B assemblage was identified here. Molluscs are relatively scarce, with *Bithynia tentaculata* playing the most important role. In the floor sample (sample 1), *Bithynia tentaculata* is the only species identified. Upwards, its share gradually decreases. In the entire interval discussed, opercula predominate over shells. The mollusc fauna indicates the shallow, nearshore part of the littoral zone, with relatively abundant vegetation and a muddy bottom. The observed increase in the share of *Valvata piscinalis* upwards may indicate a slight deepening of the lake (Fig. 5).

Phase II (M-2; samples 5 and 6) is characterized by the presence of a different community. Terrestrial species, and those of temporary water bodies (assemblage type A), play the most important role. This fauna in question is typical of flat lake

Composition of the mollusc fauna from the Eemian/Early Weichselian

E	Taxon	Samples 1	2	3	4	5	6	7	8	9	10	11
M	Limacidae											
	Vertigo substriata (Jeffr.)											
	Vertigo angustior Jeffr.											
H	*Succinea putris* (L.)					21	18					
	Vertigo antivertigo (Drap.)											
	Zonitoides nitidus (Müll.)											
	Pseudotrichia rubiginosa (Rossm.)					17	15					
W_T	*Valvata cristata* (Müll.)		8	14	21	19	12	1	5	6	7	3
	Valvata macrostoma Mörch		17	18	22	26	6	3	13	9	12	6
	Galba truncatula (Müll.)				5		1			1		
	Aplexa hypnorum (L.)											
	Planorbis planorbis (L.)		3	9	1	5	1		4			
	Segmentina nitida Müll.											
	Pisidium obtusale (Lam.)		1	7		8	5			1		
W_S	*Valvata piscinalis* (Müll.)		43	69	73	54	21	32	18	18	16	14
	Acroloxus lacustris (L.)											
	Stagnicola palustris (Müll.)				2		2					
	Lymnaea stagnalis (L.)											
	Physa fontinalis (L.)											
	Anisus contortus (L.)				9	3	1			1		
	Gyraulus albus (Müll.)											
	Pisidium nitidum Jen.											
	Pisidium milium Held											
W_M	*Bithynia tentaculata* (L.) (including *operculum*)	112 *84*	37 *22*	26 *22*	27 *17*	44 *29*	18 *10*	121 *76*	74 *55*	64 *40*	71 *54*	85 *60*
	Radix peregra (Müll.)											
	Gyraulus crista (L.)			4	8	1				3		
	Pisidium casertanum Poli											
	Pisidium henslowanum (Shep.)											
	Pisidium subtruncatum Malm											
Total species		1	6	7	9	11	11	5	6	8	4	4
Total individuals		112	109	157	168	198	100	157	114	103	106	108
Indeterminate shell fragments		68	47	31	56	54	18	21	33	23	20	15
Terrestrial snails						6	2					
Bithynia cf. *tentaculata*		34	6	4	9	8	1	5	8	6	5	4
Valvata cf. *piscinalis*		9	12	5	15	10	2	3	6	4	2	2
Valvata sp.		9	7	7	13	11	3	4	6	5	4	3
Other snails fragments		14	19	12	18	16	10	8	10	7	7	5
Pisidium sp.		2	3	3	1	3	1	1	3	1	2	1

Ecological group of molluscs (after: Alexandrowicz and Alexandrowicz, 2011): M – mesophilous species, H – of permanent water bodies, W_M – euryecological aquatic species

shores and is characterized by wet, swampy, periodically flooded terrestrial biotopes. The periodic appearance of intercalations with terrestrial fauna within successions containing lake mollusc assemblages has been widely described throughout the European Lowland (e.g., Alexandrowicz, 1999a, 2013; Meng et al., 2009a, b; Fig. 5).

Phase III (M-3, samples 7–21) encompasses most of the older palaeolake succession. Species typical of a permanent water body (type B assemblage) predominate. The taxa represented are more diverse than those representing Phase I. *Bithynia tentaculata* and *Valvata piscinalis* are the most common species. *Bithynia tentaculata* is particularly common at the base (samples 7–13) and top (samples 18–21) of this interval. In the middle part (samples 14–17) the share of *Valvata piscinalis* increases noticeably. In this part of the profile, the molluscs are most numerous and diverse. Furthermore, a nearly complete skeleton of a rhinoceros *Stephanorhinus kirchbergensis* was found here (Badura et al., 2017; Sobczyk et al., 2020). The increase in the share of *Valvata piscinalis* in this part of this interval may indicate a slight deepening of the lake. At the same time, the maintained predominance of opercula over shells of *Bithynia tentaculata* suggests the presence of currents or the proximity of the wave zone (Fig. 5).

Table 1

deposits of Gorzów Wielkopolski

12	13	14	15	16	17	18	19	20	21	22	23	24	25
					7					8			5
			21	2	10					45			15
			17		3					38			19
		1	29	12	47					89			34
			28	11	12					49			15
			18	1	15					38			10
			19	5	12					68			4
9	1	29	122	76	87	1	3	4	8	112	10	8	31
7	2	45	158	59	98	7	6	8	14	147	8	14	44
1			39	19	36			1		19			3
			8		8					14			
			36						1	21		1	1
			2		6					17			2
4		4	29	28	17			5	1	39	7	5	4
19	14	144	509	269	444	19	9	19	21	487	19	23	24
			7		3								
			10		21					2			
			9		1								2
			3		6					19			1
2			29	10	39	1		7	3	32		9	1
			5		19	1		2	2	17			2
			29	44	24				4	55		7	
			33	31	28			5					
72 *44*	86 *57*	66 *41*	348 *279*	190 *121*	535 *421*	87 *63*	79 *56*	40 *28*	45 *38*	285 *221*	59 *47*	41 *31*	93 *69*
			3		2					3			12
8		17	19	22	35		3	4	9	58	8	4	12
		8	47	15	39		4	7		10	1	1	2
		12	12	17	10								
			18		21								
8	4	9	28	17	28	6	6	11	10	25	7	10	22
122	103	326	1607	811	1585	119	104	102	108	1672	112	113	325
32	16	57	159	120	232	18	18	13	21	168	14	23	59
		1	24	16	21					19			7
8	5	8	17	12	17	6	5	2	5	22	3	5	10
6	2	12	19	8	31	3	2	1	3	17	1	3	8
6	2	11	39	27	44	1	1	1	4	34	2	3	12
10	6	18	49	38	86	6	4	7	6	62	5	8	16
2	1	7	11	19	33	2	3	2	3	14	3	4	6

higrophilous species, W_T – aquatic species of temporary water bodies, W_S – aquatic species

Phase IV (M-4; sample 22) represents the top of the older lake succession. The molluscs here include relatively numerous terrestrial species (assemblage type A), while the taxa of periodic water bodies also play a greater role. The observed change in the species composition and ecological structure of the fauna indicates a coastal, periodically flooded part of the lake and wetland. At the same time, there is a change in the nature of the sediments: gyttja is replaced by peat (Fig. 5).

Phases I–IV, representing the infill of the younger palaeolake, possibly correspond to the warm period of the Eemian Interglacial. This interpretation is supported by the results of lithological and palynological analyses performed on that interval (Sobczyk et al., 2020). The composition and structure of the molluscan communities, with the predominance of euryecological aquatic taxa (*Valvata piscinalis* and *Bithynia tentaculata*), do not provide firm evidence for stratigraphical conclusions, only allowing characterization of changes in ecological conditions in the lake and on its shores.

The absence of mollusc shells in the sands (delta-type deposits) separating the lake successions is associated with the very low content of carbonates in these deposits (Sobczyk et al., 2020). OSL data (98.8 ±7.9 ka) indicates that these deposits accumulated in the initial stage of the last glaciation, probably during stage MIS5c (Sobczyk et al., 2020).

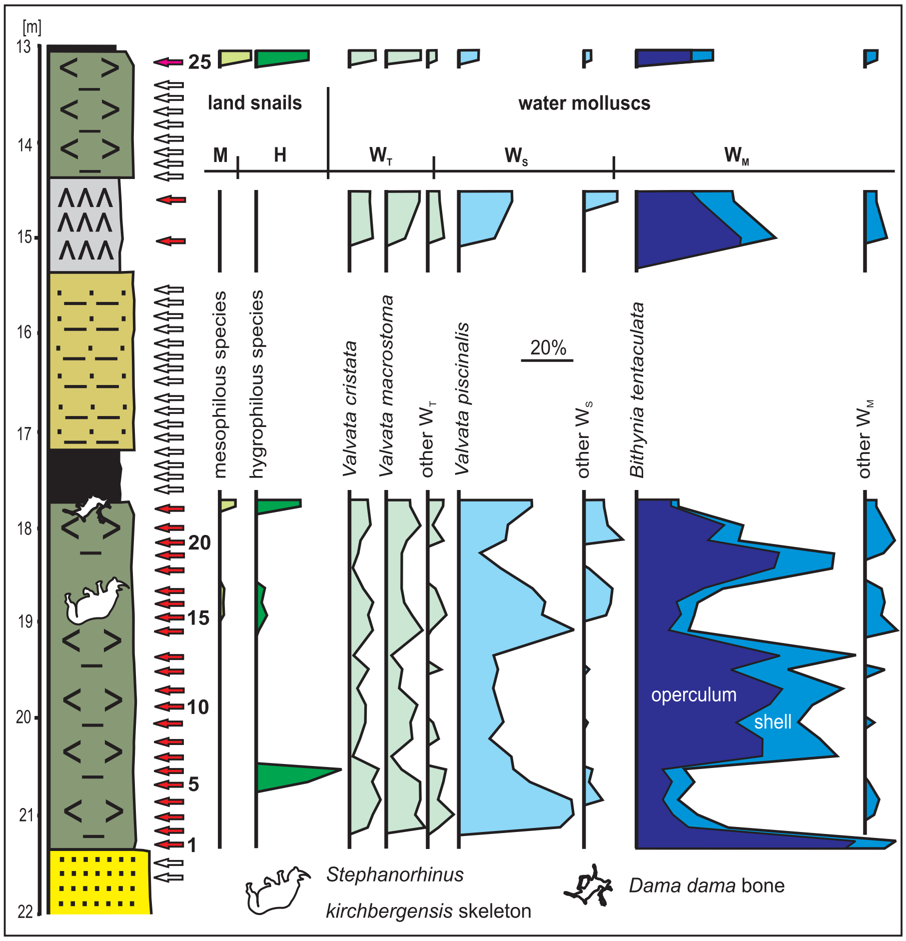

Fig. 4. Ecological composition of molluscs from the Eemian and Early Weichselian lake deposits of Gorzów Wielkopolski

For explanations see Table 1

The mollusc assemblages present in the younger lake succession is poorer and allows less interpretation. Samples 23 and 24 (Phase V, M-5; Fig. 5) are dominated by taxa of permanent water bodies, indicating a relatively shallow, littoral zone of the lake. The top of the malacological sequence (Phase VI, M-6, sample 25; Fig. 5) represents significant environmental change. The share of terrestrial species increases significantly, reaching 25% of the community. Molluscs of periodic water bodies also play a greater role. The M-6 phase, therefore, represents the lake shore. The younger lake succession may well be associated with the early stage of the last glacial (probably MIS5b and/or MIS5a; Sobczyk et al., 2020). The results of palaeobotanical analyses indicate a cooling of the climate during the deposition of these sediments (Klotz et al., 2004; Behre et al., 2006; Helmens, 2013), though the molluscs do not show this trend, with a lack of cold-loving species. Early Weichselian localities in the European Lowland are relatively few, and only exceptional ones contain a malacological record (Sanko and Gaigalas, 2007; Strahl et al., 2010; Kenzler et al., 2018; Hrynowiecka et al., 2018). From this perspective, the Gorzów Wielkopolski profile should be considered unique in Europe.

REGIONAL IMPORTANCE OF THE MALACOFAUNA

The profile of lake deposits revealed at Gorzów Wielkopolski is an exceptionally complete malacological sequence corresponding to two climatic stages:

– warmer (Eemian – MIS 5e);
– cooler (Early Weichselian – MIS 5b or MIS 5a).

The malacofauna is characterized by the dominance of aquatic species, while increases in the share of terrestrial forms is visible only in short sections of the sequence. The mollusc community found in the older part of the lake sequence does not contain cold-loving species and undoubtedly indicates the interglacial age of the sediments. On the other hand, no *Belgrandia marginata* was found here. This thermophilic species is indicative of Eemian river and lake deposits that accumulated in the warmest (optimal) stage of the interglacial. It has been recorded at this stratigraphical position at many sites throughout Europe (Sanko and Gaigalas, 2007; Alexandrowicz and Alexandrowicz, 2010; Sanko et al., 2011; Menzel-Harloff and Meng, 2015; Kenzler et al., 2018). The results of geochemi-

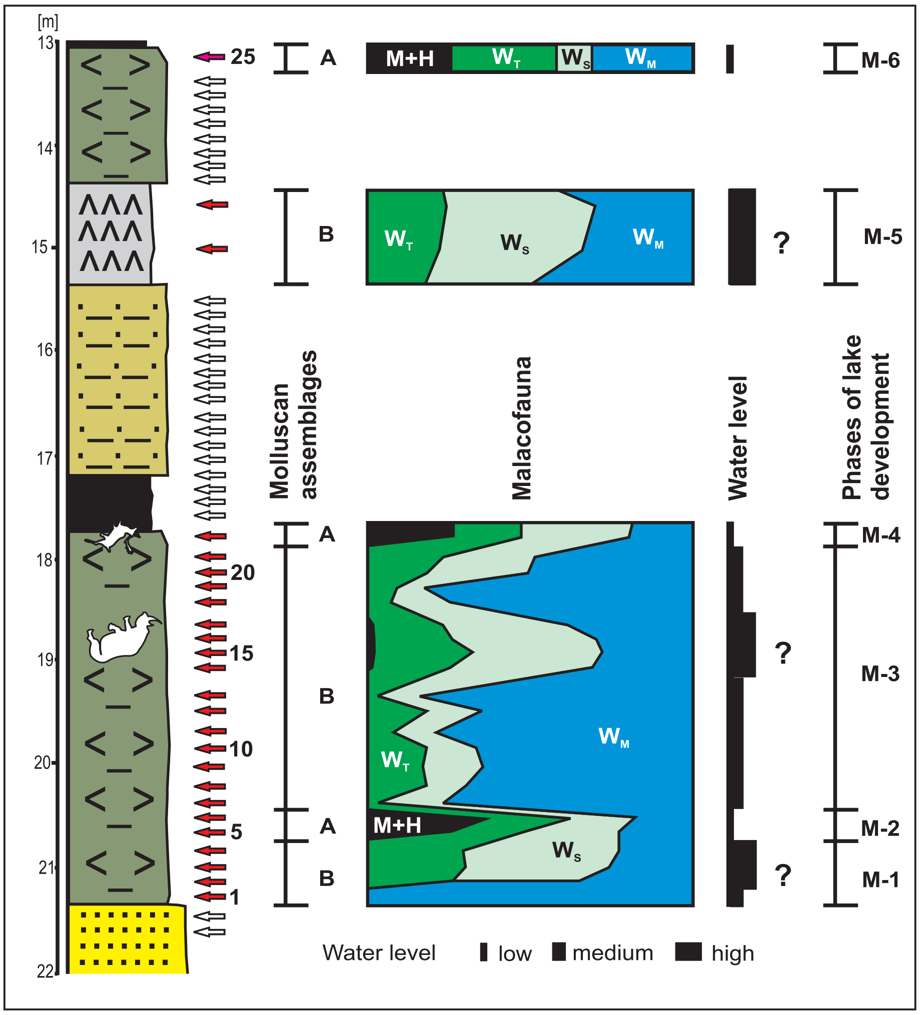

Fig. 5. Evolution and environmental changes of Eemian/Early Weichselian lakes near Gorzów Wielkopolski

A, B – molluscan assemblages (described in text), M-1–M-6 – phases of lake development (described in text), ? – possible higher water level in the lake – increased share of *Valvata piscinalis*

cal and palynological analyses carried out within the older lake sequence indicate that it represents a complete profile (Badura et al., 2017; Sobczyk et al., 2020). The absence of *Belgrandia marginata* may result from the existence of a stratigraphical gap covering the interglacial optimum (which is not supported by the results of other studies, especially palynological ones; Sobczyk et al., 2020). It seems more likely that this species did not inhabit the lake and, consequently, its shells did not appear here.

The changes in faunal communities observed in vertical profile indicate fluctuations in the water level in the lake, probably related to climate changes, especially with the appearance of colder and warmer phases, as well as drier and wetter ones (e.g., Cheddadi et al., 1998; Kukla et al., 2002; Koltz et al., 2004; Müller et al., 2005; Brewer et al., 2008). The presence of alternating stages of high and low water levels in lakes has been thoroughly studied for the period of the Late Glacial and the Holocene (e.g., Goslar et al., 1993; Punning et al., 2005; Gałka et al., 2015). Similar analyses with regard to the Eemian Interglacial are much less advanced.

In the sequence discussed, it is possible to distinguish two periods of low water level in the lake. The older one occurs at the bottom of the sequence (phase M-2) and may be associated with the end of the Early Eemian. It corresponds to the phase distinguished in this profile that is characterized by a significant share of *Corylus* pollen (Co-Qe-Al phase; Sobczyk et al., 2020). A decrease in the water level in lakes at that time is recorded at several sites across the European Lowland (Kupryjanowicz, 2008; Helmens, 2013), which indicates the regional nature of this phenomenon. The later period represents the disappearance of the lake in the declining stage of the interglacial (phase M-4) and is recorded in many other lake profiles of the Eemian Interglacial (e.g., Kupryjanowicz, 2008; Mirosław-Grabowska and Gąsiorowski, 2010; Pawłowski, 2011; Helmens, 2013; Niska, 2015; Hrynowiecka et al., 2018; Salonen et al., 2018). In both phases, there is a mollusc assemblage with a significant share of terrestrial species (assemblage type A) indicating a lake shore (Fig. 5). A fauna with aquatic species (assemblage type B) indicates the littoral zone, with a muddy bottom and more or less rich plant vegetation. This indicates the relatively shallow depth of the lake, though also its stability (phases: M-1 and M-3; Fig. 5). A temporary increase in the *Valvata piscinalis* share observed in phases M-1 and M-3 may indicate a slight deepening of the lake. The water level fluctuations in the Gorzów Wielkopolski palaeolakes, reconstructed based on changes in mollusc assemblages, show significant convergence with the reconstruction of hydrological conditions carried out by means of palynological analysis and Cladocera studies (e.g., Kupryjanowicz, 2008; Mirosław-Grabowska and Gąsiorowski, 2010; Pawłowski, 2011; Helmens, 2013; Niska, 2015; Salonen et al., 2018; Sinopoli et al., 2019), as well as with the conclusions of palaeoclimatic and isotope studies (Mirosław-Grabowska and Gąsiorowski, 2010; Milano et al., 2020). This site is the first Eemian sedimentary profile in Europe where an attempt has been made to reconstruct water level fluctuations using mollusc communities. The phases of high water level reconstructed in the Gorzów Wielkopolski palaeolake correlate with the marine transgressions described from the Lower Vistula Basin (Makowska, 1986).

Similarly, complete sequences of lake deposits with freshwater molluscs representing an Eemian Interglacial are known only from a few sites across the European Lowland (Sanko and Gaigalas, 2007; Meng et al., 2009a, b; Alexandrowicz and Alexandrowicz, 2010; Strahl et al., 2010; Sanko et al., 2011; Menzel-Harloff and Meng, 2015; Kenzler et al., 2018; Milano et al., 2020; Fig. 6 and Table 2). These malacological sequences show many similarities, with similar species compositions (usually ~20–30 species of aquatic molluscs, and several terrestrial taxa). As at Gorzów Wielkopolski, the predominant species are most often *Bithynia tentaculata* and *Valvata piscinalis*. The increased share of terrestrial fauna in some profiles is due to the presence of cold-loving taxa within the glacial deposits that underlie or overlie the Eemian strata. No such assemblages were found at Gorzów Wielkopolski. There are also no cryophilic species here, which are present at most other sites. There are gaps within the malacological sequences in all profiles, but typically they cover short segments, especially in the intervals corresponding to MIS 5e. Deposits representing the end of the Saalian Glaciation (MIS 6) are present in only one site, while the succession corresponding to the Early Weichselian (MIS 5a-d) is usually incomplete (Table 2). A comparison of selected malacological sites from across the European Lowland (Table 2) shows that the Gorzów Wielkopolski profile may be included among the key malacological profiles of the Eemian Interglacial in this part of Europe. At these sites, molluscs of similar species composition and ecological structure have been identified, the dominant species usually being *Bithynia tentaculata* and *Valvata piscinalis*. These observations may suggest considerable stability of environmental conditions (climatic, hydrological) in this region. Similar conclusions are prompted by regional palynological (e.g., Cheddadi et al., 1998; Behre et al., 2005; Sinopoli et al., 2019) and climatic (e.g., Kukla et al., 2002; Brewer et al., 2008; Salonen et al., 2018) reconstructions. On the other hand, each of these studies shows the influence of local factors modifying regional trends to a greater or lesser extent. The water level fluctuations observed at Gorzów Wielkopolski correlate with climatic phases reconstructed on the basis of palaeobotanical studies (e.g., Zagwin, 1996; Kupryjanowicz, 2008; Helmens, 2013). Therefore, it may be inferred that they are a record of regional climate trends.

Table 2

Comparison of selected Eemian malacological profiles from the European Lowland

Location	Gorzów Wielkopolski (this article) (GW)	Piła Alexandrowicz and Alexandrowicz (2010) (PI)	Peene Valley Meng et al., (2009a) (PV)	Klein Klütz Höved Menzel-Harloff and Meng (2015) (KH)	Neumark Nord Strahl et al. (2010) (NN)	Petrovshchina Sanko et al. (2011) (PE)	Rumlovka Sanko et al. (2011) (RU)	Netiesos Sanko and Gaigalas (2007) (NE)
	NW Poland	NW Poland	NE Germany	NW Germany	Middle Germany	Belarus	Belarus	Lithuania
Type of sediments	lacustrine littoral zone	lacustrine littoral zone	fluvial/lacustrine lowland river/ littoral zone	lacustrine littoral zone	lacustrine littoral zone	lacustrine littoral zone	lacustrine littoral zone	lacustrine littoral zone
Malacofauna								
Number of species W – water, L – land	29 22(W), 7(L)	21 17(W), 4(L)	29 29(W), 0(L)	43 30(W), 13(L)	25 14(W), 11(T)	24 22(W), 2(L)	39 28(W), 11(L)	33 25(W), 8(L)
Most common species	*Bithynia tentaculata; Valvata piscinalis*	*Bithynia tentaculata; Valvata piscinalis*	*Bithynia tentaculata; Valvata piscinalis*	*Bithynia tentaculata*	*Bithynia tentaculata, Gyraulus laevis*	*Valvata piscinalis*	*Pisidium moitessieria-num, Valvata piscinalis*	*Bithynia tentaculata, Valvata piscinalis*
Occurrence of *Belgrandia marginata*	lack	present	lack	present	lack	present	present	present
Comments to malacofauna				cold-loving, land snails in MIS 6	cold-loving, land snails in MIS 5d		cold-loving, land snails in MIS 4	cold-loving, land snails in MIS 5d
Stratigraphy								
Stratigraphy range	MIS 5e; MIS 5b or/and MIS5a	MIS 5e	MIS 5e	MIS 6 (upper part); MIS 5e	MIS 5e, d	MIS 5e	MIS 5e; MIS 4	MIS 5e, d
Stratigraphical gaps	lack: MIS 5d, c	some small gaps during MIS 5e	some gaps during MIS 5e	some small gaps during MIS 5e	some small gaps during MIS 5e	probably lack of the lowermost part of MIS 5e	lack: MIS 5d-a	probably lack of the lowermost part of MIS 5e

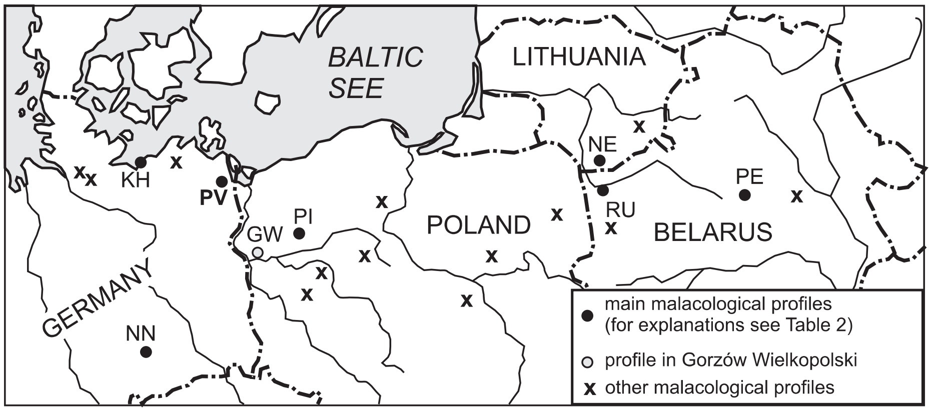

Fig. 6. Distribution of the most important malacological profiles of Eemian deposits in European Lowland

For symbol explanations see Table 2

CONCLUSIONS

The malacological sequence described from Gorzów Wielkopolski is discontinuous. It covers the Eemian Interglacial and the older part of the Weichselian Glaciation and can be correlated with the isotope stages MIS 5e (older lake), MIS 5b and/or MIS 5a (younger lake) (Sobczyk et al., 2020). While mollusc communities have been reported from Eemian palaeolakes at many sites throughout Europe (Sanko and Gaigalas, 2007; Meng et al., 2009a, b; Alexandrowicz and Alexandrowicz, 2010; Sanko et al., 2011; Menzel-Harloff and Meng, 2015; Kenzler et al., 2018; Milano et al., 2020), Weichselian early phase molluscs are known from only a few sites, mainly within loess (Moine et al., 2005; Alexandrowicz and Dmytruk, 2007; Sümegi et al., 2016). The molluscan assemblages recognized have enabled the reconstruction of the features of a lake and its banks. The mollusc communities indicate the shallow littoral zone of the lake with a muddy bottom covered by less or more abundant submerged vegetation, though lacked a reed belt along the shore. The lake was located in a forest area, while the lake shore was flat, wet and covered by low, hygrophytic vegetation. This kind of shore zone made possible periodic flooding or drying, as a consequence of relatively minor changes in lake level, and these episodes were reflected in the changes in molluscan community composition and structure.

Vertical variation in the faunal assemblages indicates environmental changes in the sedimentation zone. Several fluctuations in water level likely reflect climate fluctuations. A clear relationship between climate change and fluctuations in lake level has been recognized for the Late Glacial and the Holocene (e.g., Goslar et al., 1993; Punning et al., 2005; Gałka et al., 2015). For the Eemian, such studies are fewer. The profile described is so far the only one in Central Europe where such fluctuations have been identified and defined based on mollusc assemblages. Malacological analysis has here allowed the recognition of two periods of low water in the lake: the older one at the end of the early interglacial stage and the younger one corresponding to the period of the lake's disappearance at the end of the interglacial.

The conclusions drawn in this study very closely match the results obtained using other methods (Badura et al., 2017; Sobczyk et al., 2020). The results as a whole, revealed during excavation of the S-3 motorway near Gorzów Wielkopolski, indicate that this site is one of the most valuable exposures of Eemian Interglacial deposits on the European Lowland.

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