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FAUNISTIC ANALYSIS OF THE SECTION LEB 1 IN THE GARDNO-ŁEBA COASTAL PLAIN, NORTHERN POLAND

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Abstract:
The article presents results of the faunistic analysis of the Leb 1 sediment core collected from the marginal zone of the Lake Łebsko. The 5 m long core contained 10,603 specimens of freshwater and brackish-marine fauna, represented by 13 taxa of molluscs, 3 species of ostracods, 2 taxa of foraminifers and a species of the order Coleoptera, and genera *Balanus* and *Gammarus*. Lithology of the sediments and species composition of the fauna permitted distinguishing 3 development phases of the Lake Łebsko: brackish-marine phase (500–400 cm), limnic phase with varied salinity (400–100 cm) and swamp phase (100–0 cm), indicating progressive overgrowing of the marginal zone of the lake since the 13th century.

Key words: Holocene, faunistic analysis, Lake Łebsko, Gardno-Łeba Coastal Plain, northern Poland.

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INTRODUCTION

In research on history and evolution of a marine coastal zone, a special role is played by the organisms, which are important and indicative components of modern biocoenoses, and their subfossil remains are usually well preserved in the sediments. Among them there are primarily molluscs, ostracods and forams, but also many other animal groups characterised by widespread occurrence and low mobility. Individual species and their assemblages can serve as good indicators of environmental properties and their changes caused by natural factors (Alexandrowicz and Alexandrowicz, 2011).

The Gardno-Łeba Coastal Plain is exceptionally thoroughly investigated in terms of its fauna, both modern and the Holocene, due to the long-term research of this area. Most information on the geological history of the coastal plain was provided by analyses of Late Glacial and Holocene mollusc assemblages in numerous sediment sections and cores, among others provided by drillings done on the Łeba Barrier (Brodniewicz and Rosa, 1967; Rotnicki *et al.,* 2009) and in a coastal zone of the Baltic Sea (Alexandrowicz, 1998), as well as by numerous lake sediment sections, primarily from the Lake Łebsko and its shore zones (Brodniewicz, 1972; Wojciechowski, 1994, 1995, 1999, 2007, 2008, 2011). The analyses revealed high species and individual diversity of mollusc assemblages. This provided the basis for the assessment of the character of ecological environments and their transformations occurring at different stages of the evolution of the Gardno-Łeba Coastal Plain. It also allowed to construct malacostratigraphic subdivisions (Wojciechowski, 1996, 2008, 2011; Alexandrowicz, 1999). Next to molluscs, palaeoecological analyses in this region focused on ostracods (Ostracoda) and forams (Foraminifera) assemblages. However, they were only based on a single sediment core at Czołpino (Brodniewicz and Rosa, 1967).

The analysed section Leb 1 is a new site in the Gardno-Łeba Coastal Plain. It has been subjected to detailed palaeoecological analyses that covered many animal groups with indicator properties useful in a reconstruction of former sedimentation environments and improving their interpretation.

The primary objective of the presented study is a description of subfossil fauna assemblages occurring in the sediments of the already inactive shore zone of the Lake Łebsko. Results provide the basis for reconstruction of the environmental conditions at particular stages of the lake development. This type of research, considering characteristics of fauna assemblages, their species composition and additionally, textural and structures sediment properties, permit an assessment of environmental transformations in a longer time perspective.

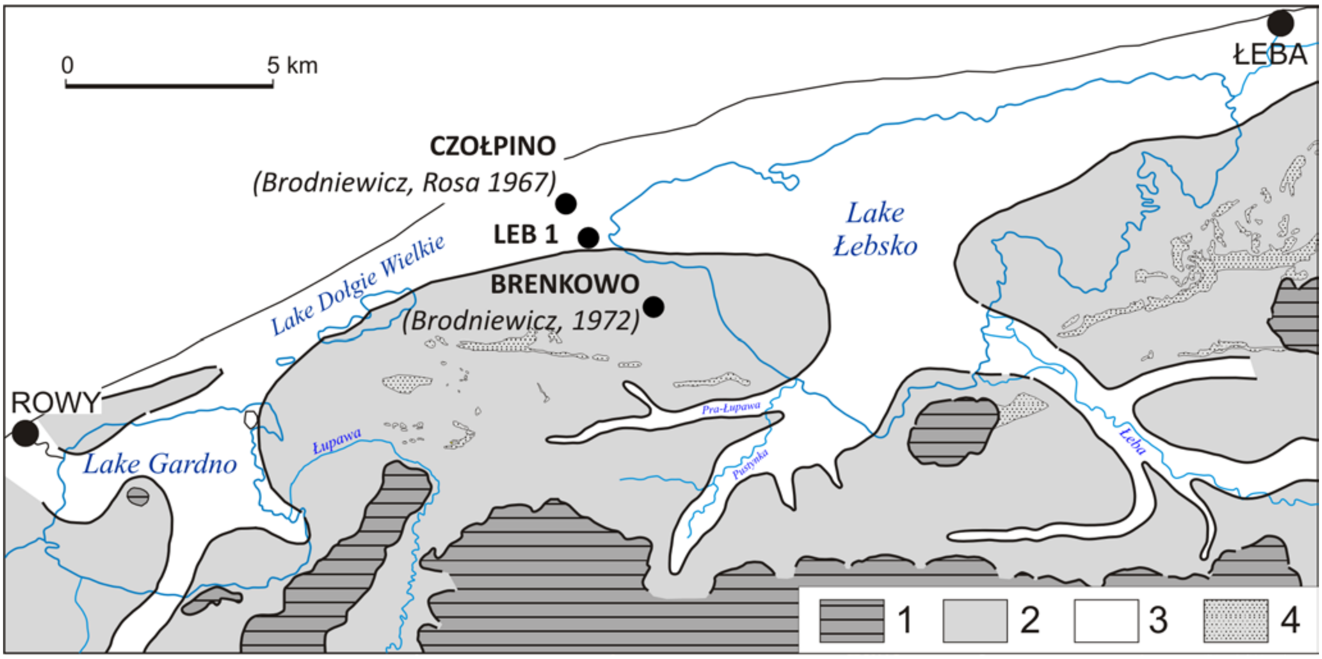

Fig. 1. Pre-Holocene substrate of the Gardno-Łeba Plain (based on Wojciechowski, 2008). The location of the sections discussed in the text is marked. 1 – morainic plateau, 2 – higher terrace of the proglacial stream valley outflow, 3 – lower terrace of the proglacial stream valley outflow, 4 – inland dunes.

GEOLOGICAL SETTING

According to the earlier research (Rotnicki, 2001; Wojciechowski, 2007, 2008), the northern and southern parts of the Gardno-Łeba Coastal Plain show evident differentiation of pre-Holocene land relief developed during an outflow of marginal waters during the ice sheet retreat after the Gardno Phase. Its primary morphological elements are two terraces of a proglacial stream valley outflow separated by evident edge, 5–8 m above the Lake Łebsko and 6–10 m in the area to the west of the Lake Łebsko (Fig. 1).

An older element of the relief of the pre-Holocene coastal plain is the upper horizon developed during ice sheet retreat after the Gardno Phase at 14,300–14,000 years ^{14}C BP (Rotnicki, 2001). It occurs in the southern part of the modern Gardno-Łeba Coastal Plain at 1–2 m b.s.l. and is composed of sand and gravel, locally silt and glacial loam. The lower sedimentary horizon, extending in the northern part of the lowland at 6–10 m b.s.l., is connected with the latitudinal proglacial stream valley system developed in the Late Glacial. It is composed of glaciofluvial sand and gravel, covered with a thin layer of fen, dated for the end of the Younger Dryas and beginning of the Holocene (Rotnicki, 2001; Wojciechowski, 2007, 2008).

This morphological diversity of the modern Gardno-Łeba Coastal Plain results in varied thickness of the Holocene sediments. It is the highest in the northern part of the plain, within the lower horizon (5–8 m). Within the range of the upper horizon, it does not exceed 2–3 m. A typical sequence of the Holocene deposits in the northern part of the lowland starts in the bottom with the Late Glacial and Preboreal peat, followed by the Boreal sand, silt and limnic gyttja, marine sand and brown-black lagoon silt of the Littorina transgression, limnic gyttja with interlayers of marine sand, and varied modern facies deposits (Rotnicki, 2001; Wojciechowski, 2008).

In geological terms, the coring Leb 1 was located north of the fault that separates two terraces of the proglacial stream valley outflow of the Gardno-Łeba Coastal Plain (Fig. 1). The study area is located within the lower terrace, then a sequence of the Holocene deposits with a complete record of the Littorina transgression could be expected in this core.

MATERIAL AND METHODS

The study material was collected in May 2016 during 2 expeditions. The preliminary geological investigation was performed in the Słowiński National Park between the lakes Dołgie Wielkie and Łebsko. Its objective was to locate a future coring in a place with the expected complete sequence of the Holocene swamp, limnic and marine deposits. The coring was performed 650 m west of the shore of the Lake Łebsko and 50 m north of the mouth of the Gardno-Łeba channel (Fig. 2). The detailed location of the coring is described by the geographic coordinates 54°42’55.6”N and 17°16’37.5”E, and altitude 0.5 m a.s.l.

Sediments for faunistic analyses were collected with a use of the Russian peat sampler, 7 cm in diameter and 82 cm long. A lithological description was done using the Troels-Smith (1955) classification modified by Aaby and Berglund (1986). It allowed to get characteristics of non-consolidated peat and limnic sediments, regardless of their origin (Aaby and Berglund, 1986).

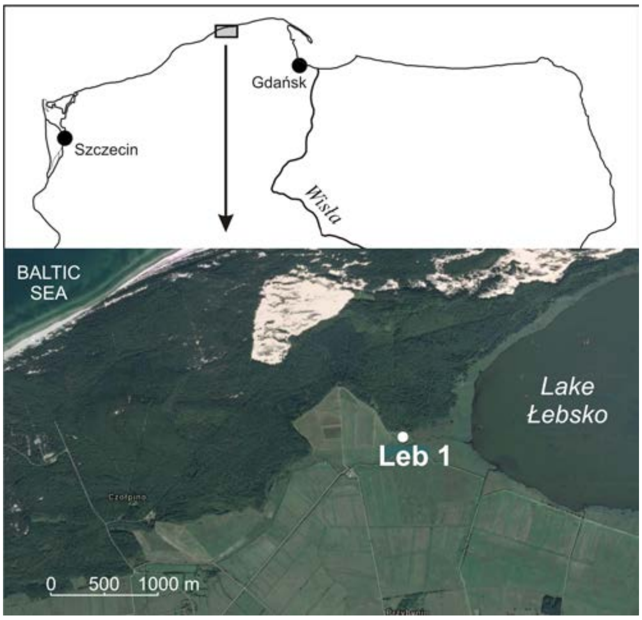

Fig. 2. Location of the study site and the location of section Leb 1

After a lithological description and photo documentation, 56 sediment samples were collected from the core, each 5–10 cm thick and 150–200 cm^3 in volume, depending on lithological boundaries. The samples were stored in a cold place.

A sample for radiocarbon dating was collected from the bottom peat layer, 76–82 cm depth. The dating was performed at the Laboratory of Absolute Datings at Cianowice. Calibration was performed with the software OxCal v. 4.4 (Bronk Ramsey, 2009).

At the laboratory, the samples were rinsed with warm water on a sieve 0.25 mm mesh, poured to steamers and placed in a dryer, where they were left to dry completely. This permitted later precise separation of shells and their fragments for species identification.

The malacological analysis was based on methods described by Alexandrowicz and Alexandrowicz (2011). Due to small environmental variability of malacofauna, identified mollusc species were classified in two ecological groups: freshwater species inhabiting permanent water bodies, and marine and brackish water species.

Apart from mollusc shells, all valves of ostracods (Ostracoda), shells of forams (Foraminifera), remains of beetles (Coleoptera), gammarus (*Gammarus* sp.) and barnacles (*Balanus* sp.) were counted. Selected plant remains were also collected, including oogonia of stoneworts from the genus *Chara* sp. In the analysed section, faunistic remains were usually preserved in a good state allowing a precise species identification, although many samples also contained a substantial number of crushed shells. Fractions of shells were counted in accordance with the pattern proposed by Alexandrowicz and Alexandrowicz (2011).

The identification of freshwater molluscs employed keys of Piechocki (1979) and Piechocki and Dyduch-Falniowska (1993). The key by Jagnow and Gosselck (1987) was applied to marine and brackish water molluscs. Molluscs from families Hydrobiidae and Rissoidae were identified based on the monograph by Falniowski (1987, 1989). Ostracod species were identified with a use of the key by Sywula (1974) and forams were based on the paper by Brodniewicz (1965).

Absolute faunistic diagrams presenting occurrence of species in the section were developed in Tilia and Tilia Graph software (Grimm, 1990).

RESULTS

Lithology of the section Leb 1

The section Leb 1 contains brackish-marine, limnic and swamp deposits, 501 cm thick (Table 1). The uppermost part (0–101 cm depth) is composed of interlayers of sedge-reed and sedge peat, dated at 740±35 years ^{14}C BP (72–77 cm depth) that is 1253–1288 calendar years at the adopted probability level of 68.2%, or 1219–1297 calendar years at the adopted probability level of 95.4% (Table 2). This age suggests that in this part of the Gardno-Łeba Coastal Plain the Lake Łebsko was at least 650 m more extensive in the 13th century than in the modern times.

The peat is underlain by detritus-calcareous gyttja and brown gyttja, passing in the lower part of the core into brown detritus gyttja, strongly sandy at the bottom, in total 356 cm thick. The lowest part of the core is composed of grey marine sand with rich mollusc fauna, interlayered with sandy gyttja (477–501 cm depth) (Table 1).

The drilling did not reach a bottom of the marine sand. It is also probable that it could be due to a hardly penetrable gravels and pebbles, as in the case of the drilling at Czołpino.

A sequence of deposits in the section Leb 1 corresponds with other sediment cores in the central part of the Gardno-Łeba Coastal Plain, particularly from Czołpino (Brodniewicz and Rosa, 1967) and Brenkowo (Brodniewicz, 1972).

The section Czołpino (Brodniewicz and Rosa, 1967), located at the lower terrace of a proglacial valley is composed of sediment series of various age, reflecting a typical geological structure of the southern shore of the Baltic Sea basin. The bottom series (40.0–6.7 m depth) is represented by the Pleistocene sand with abundant inserts of peat and organic matter, in its top covered with the Late Glacial sand and gravel of the marginal outflow horizon (Fig. 3). Marine deposits of the Littorina are composed of coarse sand, passing upwards into fine sand and brown-black silt with rich marine malacofauna. From 4.7 m depth (layers 1–6 in Fig. 3), a dune sand occurs, interbedded with fossil soils and peat, reflecting processes of the barrier development.

The section at Brenkowo (Brodniewicz, 1972) is located at the upper terrace of a proglacial valley (Fig. 3). It is composed of 3 m thick series of the Late Holocene marine sand with malacofauna (layer 3 in Fig. 3), sandy gyttja, (layer 2) and sandy peat in the uppermost part of the section (layer 1). According to Brodniewicz (1972), marine sand in the section was deposited during the late phase of

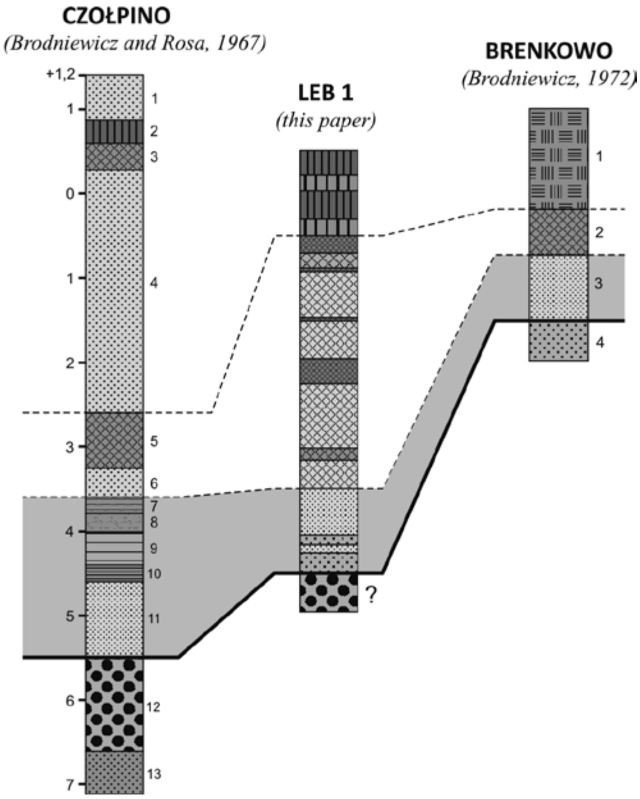

Fig. 3. Correlation of sediments from the section Leb 1 with the sections at Czołpino (Brodniewicz and Rosa, 1967) and Brenkowo (Brodniewicz, 1972). Extent of brackish-marine sediments are grey. Description of lithological signatures in Table 1.

Table 1. Lithology of the section Leb 1. Description of sediments after Troels-Smith (1955) classification modified by Aaby and Berglund (1986).

Depth [cm b.g.l.]	Description	Sample no
0–28	Brown-black *Carex* peat **Th4, Sh+**	1–3
28–43	Brown *Carex–Phragmites* peat **Th4, Dg+**	4–5
43–82	Brown-black *Carex* peat **Th4, Sh+**	6–8
82–101	Brown *Carex–Phragmites* peat with admixture of silt and sand **Th4, Dg+, As+, Ag+**	9–10
101–119	Brown sandy detritus gyttja **Ld3, Gmin1, Ag+, Sh+**	11–12
119–138	Grey fine detritus gyttja **Ld4, As+**	13–14
138–143	Brown-black detritus gyttja **Ld4, Sh+**	15
143–190	Brown detritus-calcareous gyttja **Lc2, Ld2, As+**	16–20
190–202	Brown detritus gyttja with mollusc shells **Ld4, test. moll.+**	21–22
202–244	Brown fine detritus-calcareous gyttja **Ld2, Lc2, As+, Ag+**	23–26
244–275	Brown fine detritus gyttja **Ld4, Sh+**	27–30
275–356	Beige detritus-calcareous gyttja with mollusc shells **Ld2, Lc2, As+, test. moll.+**	31–38
356–367	Brown detritus-calcareous gyttja with admixture of fine sand **Lc2, Ld2, Ag+**	39
367–404	Beige fine detritus gyttja **Ld4, Sh+, As+**	40–43
404–458	Light brown sandy detritus gyttja with admixture of mollusc shells **Ld2, Ga2, test. moll.+**	44–50
458–467	Light grey medium sand with large admixture of mollusc shells **Ga4, test. moll.+**	51
467–477	Light brown sandy detritus gyttja with admixture of mollusc shells **Ld2, Ga2, test. moll.+**	52–53
477–501	Light grey medium sand with large admixture of mollusc shells **Ga4, test. moll.+**	54–56

the Littorina transgression, as evidenced by a composition of the mollusc assemblage and particularly lack of species dominant in the early phase of the Littorina transgression in the sediments, namely *Littorina littorea* and *Scrobicularia plana*. A similar interpretation of the age of the sediments is presented by Tobolski (1972), based on pollen analysis. The analysis points out that the accumulation of marine sands started in the Late Atlantic Period.

The section Leb 1 contains all sediments observed in the sections Czołpino and Brenkowo. The bottom marine sand with interlayers of sandy detritus gyttja is equivalent to marine sediments (layers 7–10 and uppermost part of layer 11) at Czołpino whereas sand (layer 3) – to Brenkowo (Fig. 3). These sediments contain a rich marine fauna, with similar species composition in all sections. Detritus gyttja in the section Leb 1 has its equivalents in the sections at Czołpino (layer 5) and Brenkowo (layer 2) (Fig. 3). A varied thickness of limnic sediments in these sections results from different development of a water body at all these sites. Ceasing of the lake in the barrier zone (Czołpino) was caused by development of the Łeba barrier and its migration southwards, as well as accumulation of aeolian sand. In the vicinity of Brenkowo, it resulted from overgrowing of the shore zone of the contemporary Lake Łebsko.

The uppermost sediment series in all analysed sections is represented by terrestrial facies: a barrier at Czołpino and a swamp at Brenkowo and in section Leb 1.

Table 2. Results of calibration of conventional radiocarbon date of peat sample in the section Leb 1.

Depth [cm b.g.l.]	Laboratory number	Sample description	Conventional radiocarbon date [BP]	Calendar year [AD]	
				68.2%	95.4%
76–82	MKL-2866	Leb 1/1 *Carex* peat, brown	740±35	1253–1288	1219–1297

Faunistic analysis of sediments in the section Leb 1

The analysed sediment section contained abundant aquatic fauna. A total of 56 samples contained 10,603 individuals of freshwater and brackish-marine fauna represented by 13 mollusc taxa, 3 ostracod species, 2 foram taxa and single species of the order Coleoptera and genera *Balanus* and *Gammarus* (Table 3).

Molluscs

A total of 1,661 specimens belonging to 13 mollusc taxa were identified in the section. Brackish-marine fauna covers 7 taxa, represented by 1,595 specimens (96% of malacofauna), and freshwater fauna is represented by 6 taxa, including only 66 specimens (4%) (Table 3).

In terms of species and specimens, the section Leb 1 is strongly variable. The richest malacofauna assemblages occur at the bottom of sandy gyttja and its sandy interlayers. In particular samples, they cover from 59 to 205 specimens belonging to 10 taxa (Fig. 4). A thicker series of detritus-calcareous gyttja is considerably poorer in fossils. Within this series, there are 1–20 specimens, whereas the highest number of specimens was recorded at 183–193 cm and 199–205 cm depth (Fig. 4).

The highest contribution among the identified brackish-marine taxa is recorded for *Cerastoderma glaucum* (27.5% of all malacofauna), followed by *Ecrobia ventrosa* (24.0%), *Peringia ulvae* (20.1%), *Mytilus edulis* (12.1%) and *Macoma balthica* (7.6%). The highest contribution among freshwater taxa is determined for *Bithynia tentaculata* (1.4%), most abundant at 188–202 cm depth. The remaining aquatic molluscs (*Valvata piscinalis*, *Radix labiata*, *Theodoxus fluviatilis*, *Pisidium* sp.) account for a small admixture of all specimens (Table 3, Fig. 4).

The stratigraphic structure of malacofauna in the analysed section shows that molluscs primarily occur in its bottom part at 405–501 cm depth, within detritus gyttja interlayered with sandy gyttja and grey sand (Fig. 4). In this part of the section, the most abundant are *C. glaucum* (456 specimens in all samples), *E. ventrosa* (398), *P. ulvae* (334), *M. balthica* (127) and *M. edulis* (201), with accessory occurrence of *B. tentaculata*, *T. fluviatilis*, *R. labiata* and unidentified shells of bivalves of the genus *Pisidium*.

Within detritus and detritus-calcareous gyttja in the upper part of the section, malacofauna is scarce and it is

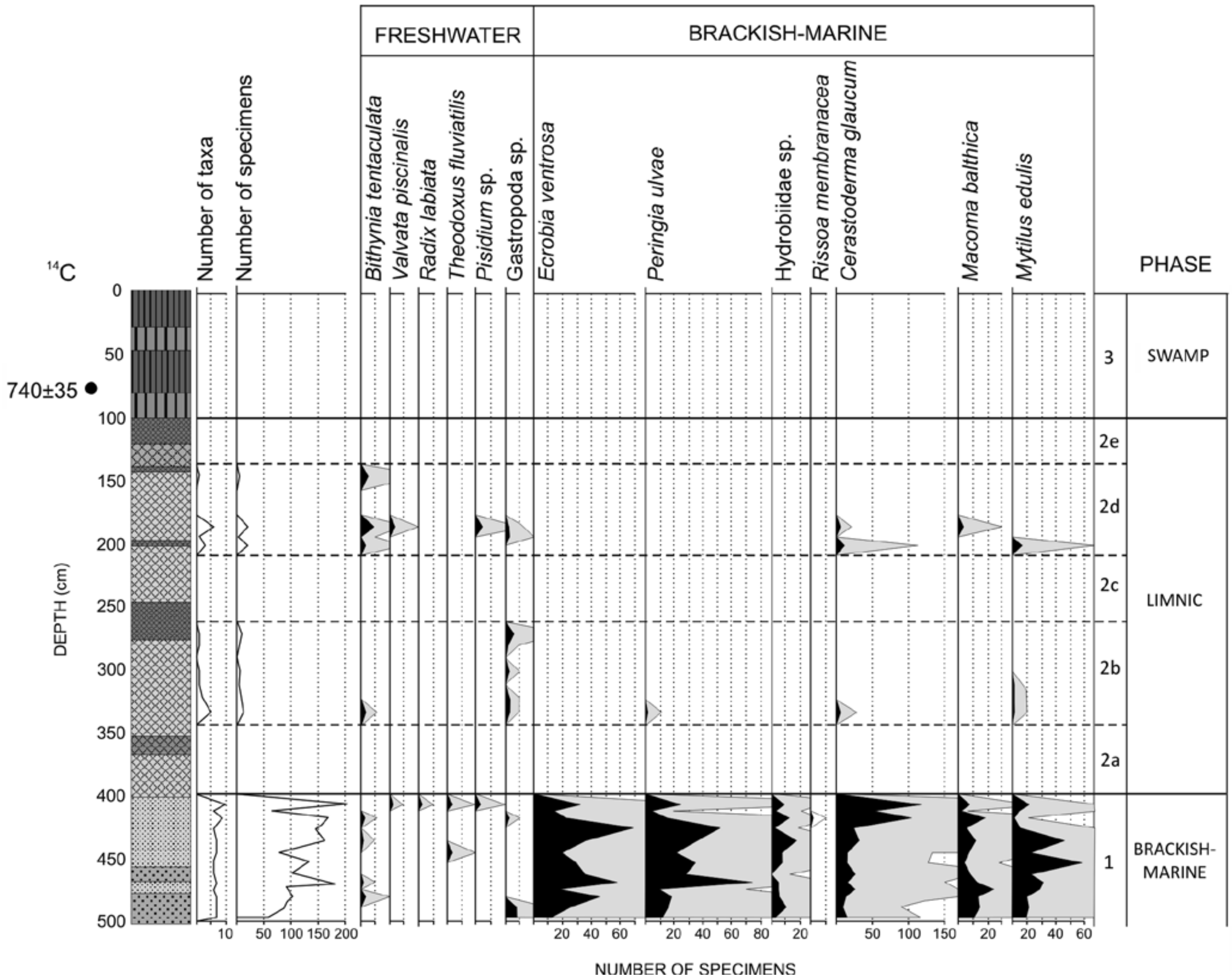

Fig. 4. Absolute frequency diagram of mollusc assemblages (number of specimens) in the section Leb 1. Lithological signatures as in Table 1.

present exclusively at 268–358 cm and 142–199 cm depth (Fig. 4). The bottom horizon (2b) is represented by a mixed assemblage of single individuals of freshwater malacofauna (*B. tentaculata* and unidentified fragments of Gastropoda sp.) and marine malacofauna (*P. ulvae*, *C. glaucum*, and *M. edulis*). The uppermost horizon (2d) is represented by several to a dozen individuals of freshwater fauna: *B. tentaculata*, *V. piscinalis*, *Pisidium* sp, Gastropoda sp., and marine bivalves: *C. glaucum*, *M. balthica* and *M. edulis* (Fig. 4).

Ostracods

In section Leb 1 a 8,409 specimens were identified, represented by 3 species: *Candona neglecta*, *Limnocythere inopinata* and *Cyprideis torosa* (Table 3). Two of them (*C. neglecta* and *L. inopinata*) are freshwater species, although they can also occur in water with low salinity (Sywula, 1974). *C. torosa* is a typical species of European brackish waters of oligo- and mesohaline type. It can also exceptionally occur in freshwater (0–0.5‰) and marine water with salinity exceeding 30‰ (Brodniewicz and Rosa, 1967; Sywula, 1974).

The most abundant ostracod is *C. torosa*, reaching 8,375 specimens throughout the section. Particular samples contain 200–300 specimens, with a maximum of 2,002 specimens at 199–205 cm depth (Fig. 5). They cover all development stages, from juvenile to mature specimens. *C. torosa* is represented both by smooth valves and valves with nodes (Fig. 6). According to van Harten (2000) and Keyser and Aladin (2013) a morphological variability of valves of *C. torosa* may reflect salinity changes in the lake. *C. torosa* with smooth valves occurs in water with higher salinity, usually exceeding 5–6‰, and *C. torosa* with valves with nodes develops in water bodies with salinity of up to 5–6‰ (Keyser and Aladin, 2013).

The section Leb 1 shows an evident correlation between a contribution of morphologically variable forms of *C. torosa* and a sedimentary environment. In the uppermost part of the section to 405 cm depth, covering detritus and detritus-calcareous gyttja, a contribution of valves with nodes is equal 26–28% of all specimens. In the bottom part of the section, at 405–501 cm depth, covering sandy detritus gyttja and marine sand, their contribution is considerably lower, equal 0.5–2.6% (Fig. 5).

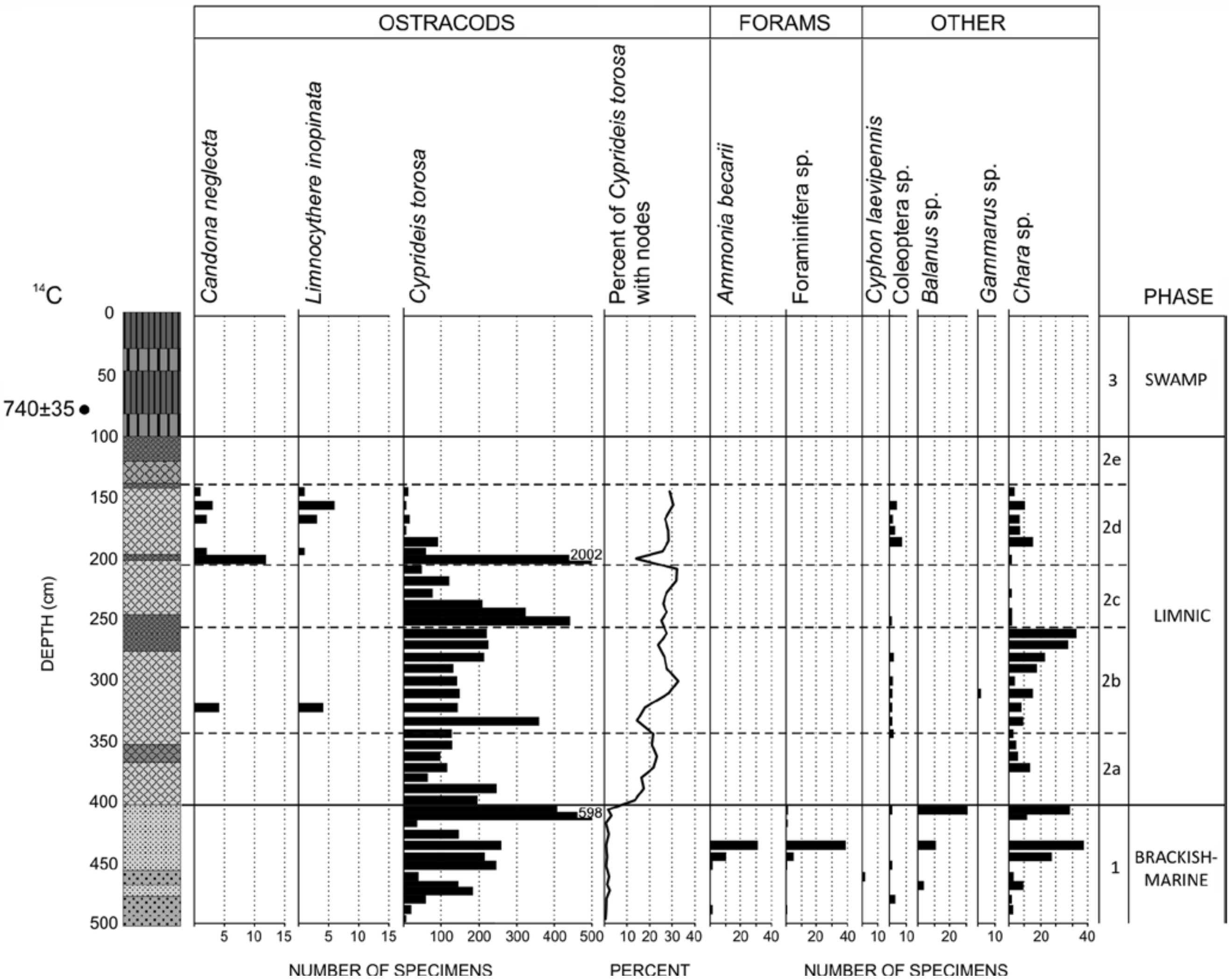

Fig. 5. Absolute frequency diagram of other micro- and macrofossils (absolute number of specimens) in the section Leb 1. Lithological signatures as in Table 1.

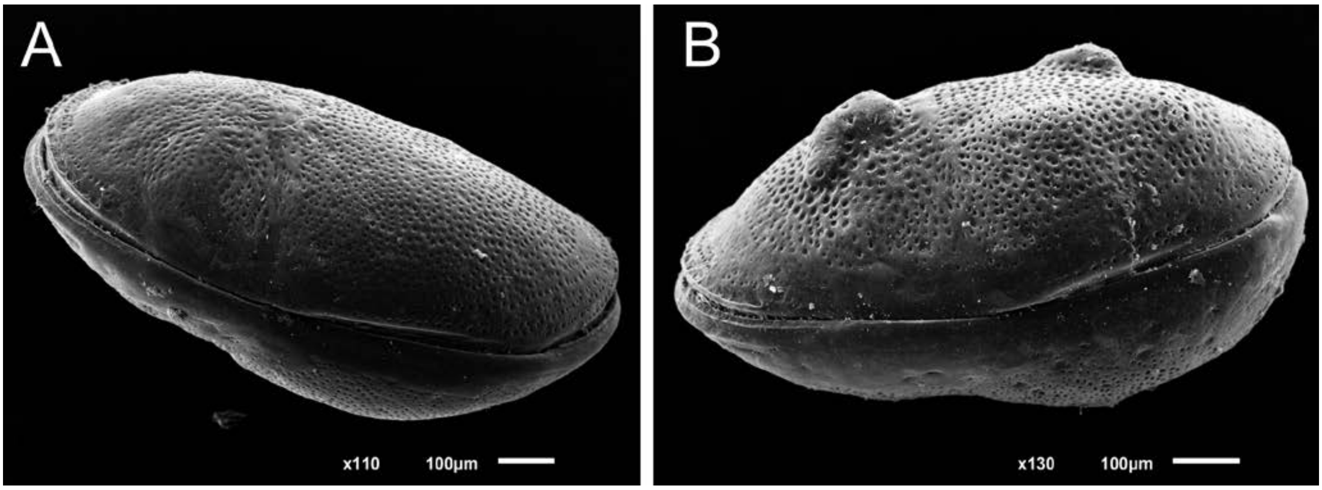

Fig. 6. Morphological diversity of *Cyprideis torosa* valves in the SEM image. A – smooth valve, B – valve with nodes.

Table 3. List of subfossil taxa occuring in the section Leb 1.

Species/taxon	Number of specimens in the section	
	No	%
MOLLUSCS (MOLLUSCA)	**1,661**	**100.0**
Freshwater	**66**	**4.0**
Bithynia tentaculata (Linnaeus, 1758)	22	1.3
Valvata piscinalis (O.F. Müller, 1774)	3	0.2
Radix labiata (Rossmässler, 1835)	2	0.1
Theodoxus fluviatilis (Linnaeus, 1758)	4	0.2
Pisidium sp.	5	0.3
Gastropoda sp.	30	1.8
Brackish-marine	**1,595**	**96.0**
Ecrobia ventrosa (Montagu, 1803)	398	24.0
Peringia ulvae (Pennant, 1777)	334	20.1
Rissoa membranacea (Adams, 1800)	1	0.1
Cerastoderma glaucum (Bruguière, 1789)	456	27.5
Macoma balthica (Linnaeus, 1758)	127	7.6
Mytilus edulis (Linnaeus, 1758)	201	12.1
Hydrobiidae sp.	78	4.7
OSTRACODS (OSTRACODA)	**8,409**	**100.0**
Candona neglecta Sars, 1887	23	0.3
Limnocythere inopinata (Baird, 1843)	11	0.1
Cyprideis torosa (Jones, 1850)	8,375	99.6
FORAMS (FORAMINIFERA)	**90**	**100.0**
Ammonia becarii (Linnaeus, 1758)	46	51.1
Foraminifera sp.	44	48.9
OTHER MACROFOSSILS	**443**	**100.0**
Cyphon laevipennis Tournier, 1868	1	0.2
Coleoptera sp.	31	7.0
Balanus sp.	42	9.5
Gammarus sp.	1	0.2
Oogonia *Chara* sp.	368	83.1
TOTAL	**10,603**	**100.0**

The differentiated contribution of *C. torosa* valves with nodes confirms varied salinity in the lake. A bottom part of the section, characterised by a small share of *C. torosa* valves with nodes, may point out to a marine basin with salinity considerably exceeding 5–6‰, whereas the uppermost part of the section, composed of detritus and detritus-calcareous gyttja dominated by *C. torosa* valves with nodes, represents a brackish lake with salinity less than 5–6‰. A decrease in the contribution of *C. torosa* with nodes at 199–205 cm and 330–340 cm depth overlaps with horizons with brackish-marine malacofauna, evidently indicating the transgression phases (Fig. 5).

The freshwater ostracod species *C. neglecta* and *L. inopinata* constitute a small admixture to the assemblage (0.4% of all ostracods) and their occurrence was recorded exclusively within detritus-calcareous gyttja at 143–174, 190–202 and 330–340 cm depth (Fig. 5). This suggests a decreased salinity of the Lake Łebsko towards the top of the section.

Forams

Forams were not a subject to detailed analysis due to research methodology covering only the malacofauna rinsed on sieves with 0.25 mm mesh. Nonetheless, occurrence of all specimens collected after rinsing and identified was recorded.

Forams occur exclusively in the bottom part of the section, within grey marine sand and sandy gyttja interlayers, at 405 to 501 cm depth (Fig. 5), i.e. in the part of the section dominated by marine malacofauna. A total of 90 specimens was identified in the section, dominated by *Ammonia beccarii*, the most characteristic and common species of shallow water brackish-marine fauna. Forams were most abundant at 432–442 cm depth (70 specimens, including 31 of *A. beccarii*) and at 442–450 cm depth (15 specimens). In the remaining samples, the share of forams was small, 1 to 3 specimens (Fig. 5).

Other macrofossils

Apart from the primary groups of animal subfossils, numerous carapaces and body parts of beetles (Coleoptera sp.) were identified. A single well preserved specimen of a beetle from the family Scirtidae (*Cyphon laevipennis*), single individuals of barnacles (*Balanus* sp.), gammarus (*Gammarus* sp.) and plant fragments, including oogonia of *Chara* sp. were found (Fig. 5).

In the whole section shows there are oogonia of *Chara* sp. and remains of beetles (Coleoptera sp.), suggesting a well-developed shore of the lake with abundant underwater *Chara* meadows and macrophyte vegetation favouring development of entomofauna. Specimens of *Balanus* sp. occur only in the bottom part of the section, at 404–501 cm depth, covering marine sand and sandy detritus gyttja, corresponding well with their environmental characteristics. A single specimen of *Gammarus* sp. was identified in the transgressive layer, at 307–318 cm depth.

DISCUSSION

A development of the shore zone of the Lake Łebsko is closely correlated with development of the entire Gardno-Łeba Coastal Plain and particularly, of the coastal zone of the Southern Baltic. It was most dependent on sea level fluctuations during subsequent transgression and regression phases, accumulation of terrigenic material resulting in shallowing of the water body and overgrowing. These processes changed bathymetry and shifted a shoreline of the lake and also its deposition zones, among others reflected in structure of water fauna assemblages (Wojciechowski, 2008).

The faunistic sequence in the section Leb 1 points to several development phases of the Lake Łebsko, caused by water level fluctuations in the Baltic Sea and paludification in a shore zones of the lake. This provides the basis for a designation of three primary development phases: brackish-marine, freshwater with variable salinity and swamp ones.

Brackish-marine phase (phase 1). The commencement of the Lake Łebsko in its westernmost part is determined by marine sand interlayered with sandy gyttja, deposited at a 405–501 cm depth. It contains a rich brackish-marine malacofauna represented by 7 taxa: *H. ulvae*, *H. ventrosa*, *R. inconspicua*, *C. glaucum*, *M. balthica*, and *M. edulis*, and unidentified fragments of shells of the family Hydrobiidae. Mollusc assemblages are accompanied by abundant *C. torosa* with smooth valves, as well as forams with a dominant share of *A. becarii* and remains of barnacles (*Balanus* sp.).

This development phase of the shore zone of the Lake Łebsko can be correlated with the late phase of the Littorina transgression. Such age is suggested by similarity of the faunistic record to other sediment cores in the Gardno-Łeba Coastal Plain (Wojciechowski, 2007, 2008, 2011), as well as absence of species indicative of the optimum of the Littorina transgression, such as *S. plana* and *L. littorea* (Brodniewicz and Rosa, 1967; Wojciechowski, 2008, 2011). They usually occur in sediments at the beginning of a marine transgression and at lower ordinates, for example in the section at Czołpino at 5–6 m depth (Brodniewicz and Rosa, 1967), in the northern part of the Lake Łebsko at 6–8 m depth (Wojciechowski, 2008, 2011), and under the Łeba Barrier at 6–8.5 m depth (Rotnicki *et al.*, 2009).

Limnic phase with varied salinity (phase 2). A regressive drop of the water level of the Baltic Sea in the Subboreal Period and particularly, development and stabilisation of the Łeba Spit separating the Lake Łebsko from a sea, caused a gradual decrease in salinity of the lake, reflected in lithology of sediments and species structure of fauna assemblages. Marine sand is overlain by detritus gyttja, passing into detritus-calcareous gyttja towards the top of the section. In the malacological diagram, this phase is represented by freshwater malacofauna assemblages with *T. fluviatilis, V. piscinalis*, *L. peregra*, and *B. tentaculata*.

Lower water salinity in the Lake Łebsko (<5–6‰) is also manifested in a higher than average share of *C. torosa* valves with nodes, as well as complete disappearance of typical marine species: forams and barnacles (*Balanus* sp.). Abundant remains of beetles (Coleoptera sp.) appear throughout the section Leb 1, suggesting development of macrophyte vegetation in the shore zone.

Two transgressive horizons with marine fauna are distinguished within this phase. The older one, at 318–340 cm depth, contains shells of *P. ulvae*, *C. glaucum*, and *M. edulis*, as well as *C. torosa* with dominance of smooth valves The younger horizon (183–205 cm depth) is predominated by the assemblage with *C. glaucum, M. balthica* and *M. edulis*, with admixture of freshwater molluscs.

Similar transgressive horizons with identical malacofauna assemblages were also recorded in other sections from the area of the Lake Łebsko, among others in the sections C1a, C2, B7, and B10 (Wojciechowski 1995, 2007, 2008). In the core B10 at the northern part of the lake, transgressive horizons with marine fauna are accompanied by increased contribution of terrigenic silica and higher Mg/Ca ratio. It records a transgressive character of the sediment series with marine malacofauna assemblages. Based on the species structure of malacofauna, the older and younger transgressive horizons in the Leb 1 can be therefore correlated with LMAZ Leb 4 and LMAZ Leb 5 from the section B10 (Wojciechowski, 1995).

The end of the limnic phase is recorded at 143–177 cm depth, with freshwater ostracod species: *C. neglecta* and *L. inopinata*, a lower content of *C. torosa* and increased share of Coleoptera sp. remains and *Chara* sp. oogonia in the sediment.

Swamp phase (phase 3). The uppermost part of the section Leb 1 from 143 cm depth, is represented by a brown detritus gyttja with high content of organic matter and contains no fauna. This suggests a lower pH of lake waters, caused by shallowing of the lake that prevented its inhabiting by organisms with calcareous shells. The commencement of overgrowing processes is evident from 101 cm depth. At this depth, a layer of sedge-reed peat appears, passing into brown sedge peat towards the top of the section. According to radiocarbon dating, the commencement of overgrowing of the shore zone of the Lake Łebsko occurred before the 13th century (radiocarbon date 740±35 years ^{14}C BP) and since then, the lake has become gradually shallower, with its shoreline moving towards the lake.

SUMMARY AND CONCLUSIONS

The analysis of the mollusc assemblage and other faunistic groups from the section Leb 1 provided valuable information regarding the Late Holocene development of the Lake Łebsko. In this time, the lake was inhabited by species characteristic of both lagoonal and marine coastal zones, as well as freshwater bodies.

In the western part of the Łebsko Lake 6 taxa of freshwater molluscs and 7 taxa of marine molluscs occurred, represented by 1,661 specimens. Malacofauna was accompanied by a rich representation of ostracods (more than 8,000 specimens) and other macrofossils: Foraminifera sp., *Chara* sp., *Balanus* sp. and *Gammarus* sp., and beetles (Coleoptera sp.). The species and specimens of the western part of the Lake Łebsko were highly varied. Among molluscs, species with the greatest dominance and permanence included: *C. glaucum*, *E. ventrosa*, and *P. ulvae*, among ostracods – *C. torosa* and among forams – *A. beccarii*, i.e. species typical of littoral zones of seas or lagoons.

A variability of fauna assemblages designed three development phases of the lake. The phase 1 was brackish-marine, with largely favourable habitat conditions, high species and individual diversity of assemblages, and uniform ecological structure of the malacocoenosis. The phase 2 was freshwater with varied salinity, primarily represented by freshwater mollusc species and periodical contribution of brackish-marine species (*P. ulvae*, *C. glaucum*, *M. balthica*, *M. edulis,* and *C. torosa* with a higher share of smooth valves), related to two transgressive phases of the Southern Baltic. The phase 3 was represented by a swamp, related to the shallowing and consequently complete overgrowing of the shore zone of the Lake Łebsko, resulting in complete disappearance of molluscs and other groups of fauna.

The study results point out to remarkably high accordance of the faunistic record in the section Leb 1 with other analyses of fauna assemblages performed by Brodniewicz and Rosa (1967) for the section at Czołpino, and Brodniewicz (1972) for the section at Brenkowo, as well as Wojciechowski (1995, 1999, 2007, 2008) for numerous sediment sections in the Lake Łebsko area. Mollusc assemblages as well as ostracods and forams occur within the same lithostratigraphic horizons and at approximate ordinates, and show occurrence of species with approximate habitat preferences.

Development phases of the western part of the Lake Łebsko designated in this paper can be correlated with the Holocene transformations of the coastal zone of the Southern Baltic resulting from sea level fluctuations and barrier shoreline migrations towards land, limnic accumulation processes in the water body, as well as the progressive overgrowing of the near-shore parts of the lake.

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