Tree stumps from the bottom of the Vistula Lagoon as indicators of water level changes in the Southern Baltic during the Late Holocene*

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Abstract

The Vistula Lagoon is situated along the south-eastern shore of the Gulf of Gdańsk and is linked with the gulf through the Strait of Baltiysk. Separated from the open

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sea by the Vistula Spit, the Vistula Lagoon is a shallow body of water with a mean depth of 3 m; the bottom is covered with a layer of mud several metres thick.

This article presents a unique, newly discovered locality of tree stumps occurring in situ at the bottom of the Vistula Lagoon. The radiocarbon age of the alder stumps and the top of the peat in which they are rooted is Subboreal. The alder wood was dated to 4770 ± 35 and 3295 ± 35 years BP. The top layers of peat were dated to 4670 ± 40, 4410 ± 35 and 3690 ± 35 years BP. The considerable scatter of the dates indicates the significance of erosional processes during marine transgressions. Radiocarbon dates and pollen analyses indicate that in the late Atlantic – early Subboreal periods, the water level of the Vistula Lagoon was about 3 m lower than it is today. The -2 m level was passed no earlier than c. 3500 years ago; the -1 m level was reached around 2000 years ago.

1. Introduction

Sunken forests, the stumps of trees occurring in situ on the sea bed, are known from many places in the world. The first scientific reports of them appeared in 19th-century Great Britain, where many were discovered in coastal areas (e.g. James 1847, Fisher 1862). In the Baltic Sea region, tree stumps rooted in the sea bed were until not long ago known only from the coastal waters of Denmark and Germany (e.g. Christensen 1995, Lampe 2005, Lampe et al. 2005, Curry 2006). Quite recently, tree stumps have been identified some considerable distance offshore in Lithuanian waters (Damusyte et al. 2004, 2006).

Tree stumps occurring in situ underwater in the Polish coastal zone of the Baltic Sea have so far been reported only from a single locality in Puck Lagoon. The wood of a stump excavated from a depth of c. 3 m in the bottom of the Lagoon was dated to 9370 ± 90 BP (Gd-7938). The peat deposits at the bottom of Puck Lagoon are of a similar age, having been formed in the Preboreal and Boreal periods. Puck Lagoon itself is much younger and came into existence towards the end of the Atlantic (e.g. Kramarska et al. 1995, Uścinowicz & Miotk-Szpiganowicz 2003). Better known are the numerous localities of tree stumps on the beaches between Rowy and Łeba (e.g. Tobolski et al. 1981, Krąpiec & Florek 2005). The ages of the stumps examined there (oak, ash, alder and pine) ranged from 4610 to 210 years BP.

During field work carried out on behalf of the Polish Geological Institute in 2005 on coastal peatlands by the Vistula Lagoon (Zalew Wiślany), we were informed by the person in charge of the pumping station at a polder near the village of Różaniec (some 5 km NE of Frombork) that there were some tree stumps rooted in the peat at the bottom of the Lagoon. This article presents a unique, newly discovered locality of tree stumps occurring in situ at the bottom of the Vistula Lagoon. It will focus in particular on the age of the stumps and the nature of the plant communities in which those trees grew, and also on their position in relation to the then level of the sea. Tree stumps occurring in situ on the sea bed, along with peat deposits, are among the most reliable indicators of sea level changes.

The fieldwork was carried out by Leszek Łęczyński (the underwater explorations) and Szymon Uścinowicz. The palynological analyses were performed by Joanna Zachowicz and Grażyna Miotk-Szpiganowicz, and the dendrological analysis by Marek Krąpiec.

2. Area, range and methods of study

The Vistula Lagoon (838 km^2) is situated along the south-eastern shore of the Gulf of Gdańsk and is linked with the gulf through the Strait of Baltiysk. It is separated from the open sea by the Vistula Spit (Mierzeja Wiślana) (Fig. 1); this feature varies in width from c. 700 m to c. 1800 m, and the dunes on it can be as high as 30 m. The largest rivers at present flowing into the lagoon are the Pregoła and the Pasłęka. The total mean inflow of river waters is around 300 m^3 s^{-1}. Until 1914 some water from the River Vistula also entered the lagoon. The Vistula Lagoon is a shallow body of water with a mean depth of 3 m. As a result of the very considerable riverine inflow, the bottom is covered with a layer of mud several metres

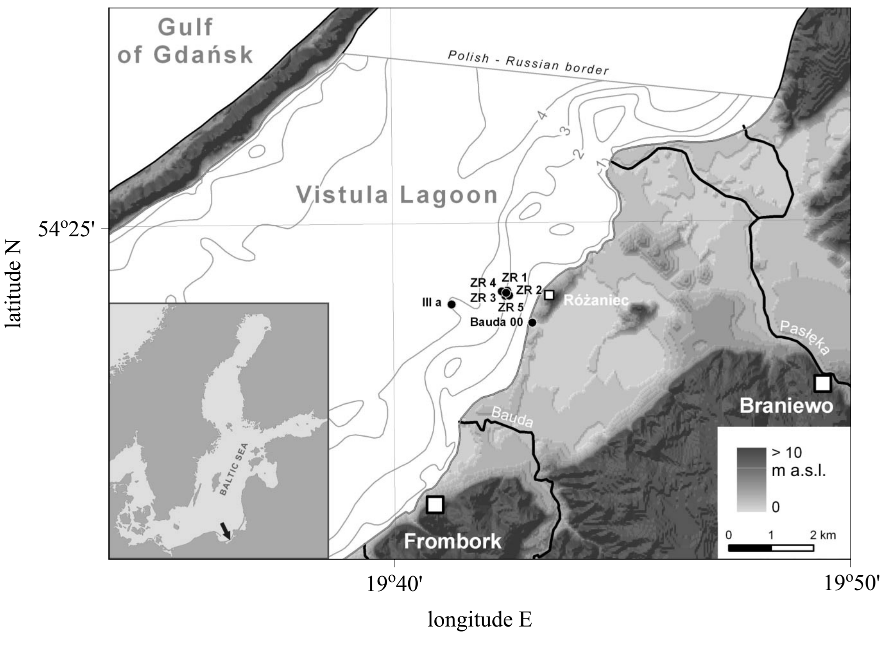

Fig. 1. Location of the study area

thick. The bottom is flat, with very few local changes in level. Sands occur only to a water depth of c. 1.5 m. Till and peat deposits outcrop here and there in the littoral zone.

The formation of the Vistula Lagoon and the Vistula Spit is associated with the Littorina Sea transgression during the Atlantic period. The beginnings of the development of both features in their present location date back to the early Atlantic (e.g. Janiszewska-Pactwa 1973, Przybyłowska-Lange 1974, Bogaczewicz-Adamczak & Miotk 1985, Zachowicz 1985, Uścinowicz 2003).

The peat outcrops with the rooted tree stumps are located some 500 m offshore, to the east of the village of Różaniec. The water in this area is 1.8–2.2 m deep (Fig. 1).

During the fieldwork in September 2005 the visibility under the water was less than 20 cm, which considerably hampered the diver-geologist's work, and made it impossible to compile a detailed description of the bottom or to produce a photographic (still and movie) record of the site. A dozen or so metres to the NW of the stumps, the diver found an area of hard bottom with cobbles lying on the surface. The water there was 1.8 m deep, that is, slightly shallower than at the site of the tree stumps and the peat outcrops. Fragments of two tree stumps, designated Zalew-Różaniec 1 and 2 (Z-R 1 and Z-R 2), were recovered from the bottom of the Lagoon, from depths of 2.15 m and 2.00 m respectively.

In the area of the excavated stumps, in water 1.8–2.1 m deep, three peat cores (designated Z-R 3, Z-R 4 and Z-R 5) from 0.63 m to 0.85 m in length were taken (Fig. 1) with an Eijkelkamp vacuum corer (length 2.0 m, int. diam. 0.04 m). Positions were defined by GPS accurate to ± 5 m, and water depths were measured with a lead-line accurate to ± 0.05 m. The distance between the excavation sites of stump fragments Z-R 1 and Z-R 2 was 37 m, and the maximum distance separating the peat core sampling sites was 80 m.

In addition, on the shore of the Vistula Lagoon, some 700 m from the site of the sunken stumps, a 3.5 m long core (Bauda 00) was taken with a peat sampler. At this locality, the topmost peat layer (1.26 m thick) lies 1.28 m below sea level. The peat deposits are underlain by fine-grained sands and overlain by silty sands, locally with large numbers of shells.

The wood from the recovered stump fragments and the peat samples were radiocarbon-dated by AMS at the Poznań Radiocarbon Laboratory. Two wood samples, five peat samples and one sample of *Dreissena polymorpha* shell were dated.

Dendrological analysis of the wood samples from the stumps showed them both to be from alder trees.

18 peat samples from the 0.00–0.85 m section of core Z-R 3 and 37 samples of sandy sediments and peat from the 0.35–3.15 m section of the Bauda 00 core were analysed for their pollen composition. Prior to pollen analysis, extraneous material was removed from the samples by the following processes: treatment with HF for 48 h to digest silicates; boiling in 10% KOH; acetolysis (Faegri & Iversen 1975, Berglund 1985). Counting showed each sample to contain at least 500 arboretous pollen grains and other sporomorphs. Percentage contents were calculated on the basis of the total number of pollen grains from trees and shrubs (arboretous pollen – AP) and from terrestrial herbaceous plants (non-arboretous pollen – NAP). The proportions of pollen grains from aquatic plants, telmatic plants, spores and *Pediastrum* coenobia were calculated as ratios to the sum AP + NAP. The results of the pollen analysis are presented in the form of a simplified percentage diagram drawn in the POLPAL program. Data from core IIIa taken nearby (Bogaczewicz-Adamczak & Miotk 1985) (Fig. 2) were used for comparative purposes.

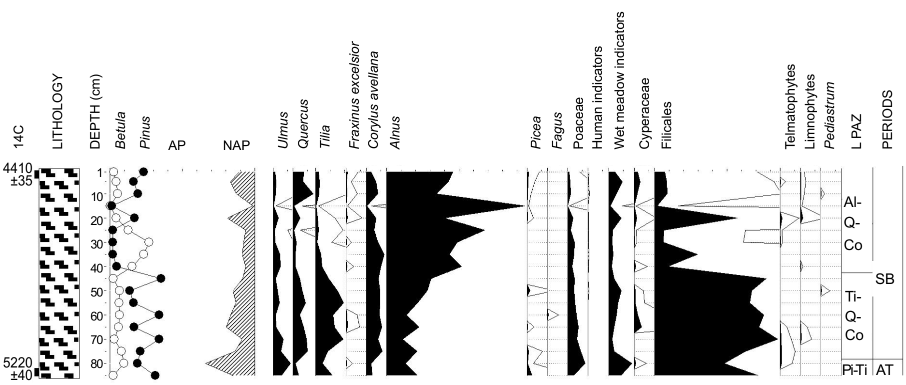

Fig. 2. Simplified pollen diagram of the Zalew-Różaniec 3 core (Z-R 3). The depth of the core is 200 cm below the water level

3. Results

The fragments of alder stumps recovered from the Vistula Lagoon were similar in cross-section: 0.1×0.07 m. The wood fragment from locality Z-R 1 was c. 0.4 m long, soft and somewhat decayed, whereas that from locality Z-R 2 was c. 0.3 m long, hard and in a good state of preservation, including the bark layer. Each of the samples exhibited a dozen or so annual growth rings, so the trees would have been young ones. However, there were too few rings to allow dating by wiggle-matching, which combines dendrochronological analysis with the radiocarbon technique, so the wood samples were dated using the latter method only: sample Z-R 1 to 4770 ± 35 BP(Poz-15115) and sample Z-R 2 to 3295 ± 35 (Poz-1516) BP (Table 1).

Table 1. Radiocarbon dating of the samples

Core	Coordinates		Core altitude	Sample altitude	^{14}C age BP	Lab. code	Material dated
	ϑ	λ	[m b.s.l.]				
Z-R 1	54°24.0284′	19°42.6056′		2.15	4770±35	Poz-15115	alder wood
Z-R 2	54°24.0349′	19°42.6326′		2.00	3295±35	Poz-15116	alder wood
Z-R 3	54°24.0268′	19°42.6216′	2.00	2.00–2.02	4110±35	Poz-15192	peat
Z-R 3	54°24.0268′	19°42.6216′	2.00	2.83–2.85	5220±40	Poz-15193	peat
Z-R 4	54°24.0259′	19°42.6026′	2.10	2.10–2.13	4670±40	Poz-15244	peat
Z-R 5	54°24.0409′	19°42.6655′	1.80	1.81–1.83	3690±35	Poz-15195	peat
Bauda 00	54°23.7206′	19°43.0226′	−0.26	1.19–1.24	1655±30	Poz-15128	*Dreissena* shells
Bauda 00	54°23.7206′	19°43.0226′	−0.26	1.28–1.30	3820±35	Poz-15153	peat
IIIa	54°23.40′	19°41.70′	3.00	5.50–5.75	6735±65	Gd-1238	peat
IIIa	54°23.40′	19°41.70′	3.00	6.00–6.27	7120±100	Gd-1237	peat
IIIa	54°23.40′	19°41.70′	3.00	6.90–7.15	7600±90	Gd-1239	peat

Three samples from the topmost layer of the peat deposits where the alder stumps were found were radiocarbon-dated to 4670 ± 40 (Poz-15244), 4410 ± 35 (Poz-15192) and 3690 ± 35 BP (Poz-15195) (Table 1, Fig. 2). All these dates lie within the first half of the Subboreal. The topmost layer of peat from core Z-R 4, taken close to the site of stump Z-R 1, is only 100 years younger than the stump itself. On the other hand, the topmost peat layer in core Z-R 5, taken 80 m away from Z-R 4, is almost 1000 years younger. This suggests that the surface areas affected by erosional processes must have varied greatly over very short distances.

Pollen analysis of the peat deposits making up the bottom of the Vistula Lagoon where the alder stumps were found endorsed the radiocarbon dates. The peat deposits from core Z-R 3 came into existence during a time extending from the late Atlantic to the middle Subboreal – see Figs. 2, 4 (see p. 253).

The pollen diagram (Fig. 2) shows three local pollen assemblage zones (LPAZ) in the peat layers of core Z-R 3: *Pinus–Tilia, Tilia-Quercus-Corylus, Alnus-Quercus-Corylus.*

The *Pinus-Tilia* LPAZ was distinguished on the basis of the pollen spectra of just two samples from the 85–75 cm level, the lower boundary of this level having been radiocarbon dated to 5220 ± 40 BP. A feature of the pollen data here is the high proportion of pollen grains from lime (*Tilia* 4.7 –1–1.6%)), elm (*Ulmus* 5.8–11.9%), oak (*Quercus* 1.7–4.1%) and pine (*Pinus* 19.1–31.4%). There are also considerable quantities of NAP (up to 34%). The *Tilia-Quercus-Corylus* LPAZ exhibits high values of lime (*Tilia* 8.4 –19.3%), oak (*Quercus* 4.5–10%) and hazel (*Corylus* 7.9–11.1%); at the same time, there is an abrupt drop in the amount of elm (*Ulmus* 5.3–1.5%) pollen compared to the previous level. There is a very high proportion (up to 76.2%) of fern spores (Filicales) in this pollen zone. In the *Alnus-Quercus-Corylus* LPAZ alder pollen (*Alnus* 34.2–95.3%) is absolutely dominant.

These results correlate well with the age of the peat deposits in the Bauda 00 core. The topmost layer of peat in this core at 1.28 m below sea level was radiocarbon-dated to 3820 ± 35 BP (Poz-15153). The pollen spectra of the peat layers from this core indicate that these deposits were formed during the early Subboreal (Fig. 3). The most compelling evidence

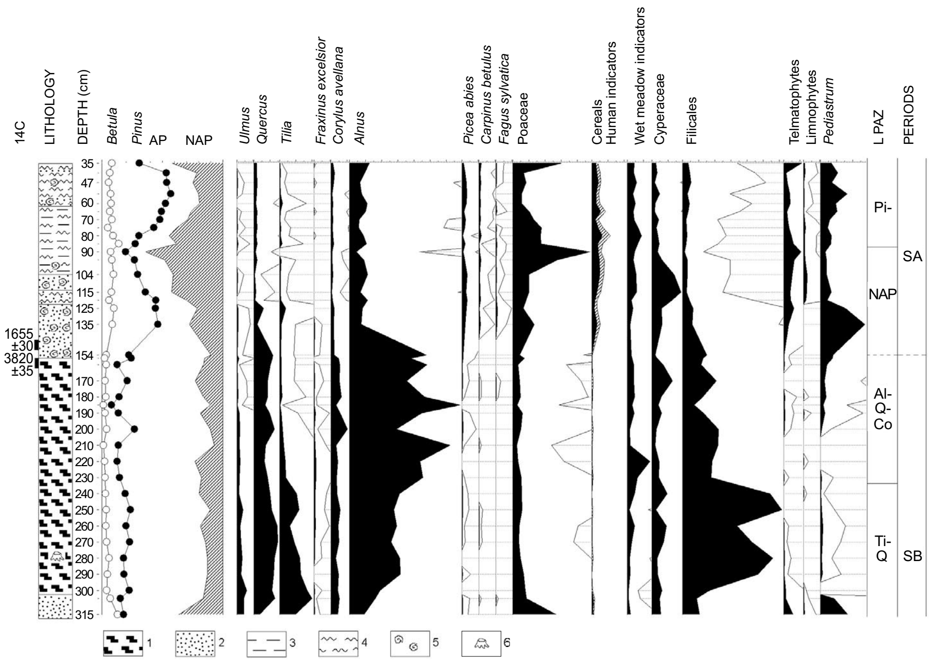

Fig. 3. Simplified pollen diagram of the Bauda 00 core. The depth of the core is 26 cm below the water level. 1 – peat, 2 – sand, 3 – silt, 4 – mud, 5 – shells, 6 – wood

for this is the diminishing proportion of elm (*Ulmus*) pollen and the rising quantities of oak (*Quercus*) pollen.

Palynological analysis of the peat deposits in the Bauda 00 core differentiated a number of LPAZs on the pollen diagram (Fig. 3). While generally resembling the zones distinguished on the diagram of core Z–R 3, they do display some local peculiarities and, above all, cover a much longer period of time.

Reflecting the first half of the Subboreal, *Tilia-Quercus* is the oldest LPAZ; characteristic of this zone are the large quantities of lime (*Tilia* 6.3 –20.0%) and oak (*Quercus* 3.5–14.7%) pollen, and of fern spores (Filicales 8.3–61.4%). The next LPAZ in these peat deposits is *Alnus-Quercus-Corylus*, the distinguishing feature of which is the predominance of alder pollen (*Alnus* 29.0–68.5%). The boundary with the adjacent sandy layer is sharply demarcated by a distinct change in the pollen composition. Such an abrupt change is conclusive evidence for a sedimentation gap. In the sandy sediments overlying the peat deposits there are two distinct LPAZs: *NAP* and *Pinus*. The *NAP* zone contains a good proportion of pollen from herbaceous plants (up to 64.0%), in particular grasses (Poaceae 4.4–48.1%), sedges (Cyperaceae 2.1–18.0%), and plants cultivated by man. The *Pinus* zone is dominated by pine (*Pinus* 27.5–57.0%) pollen. The composition of the pollen spectra of these two zones indicates unequivocally that these deposits accumulated during the second half of the Subatlantic.

4. Discussion

The radiocarbon dates of the topmost peat layers differ by as much as 980 years; the scatter of the alder wood dates is greater still – 1475 years (Table 1, Fig. 4). But in spite of these considerable differences, both topmost peat layers and alder wood originated in the first half of the Subboreal. The differences in the dates of the topmost peat layers are probably due to the erosion caused by the transgression of the lagoon's waters on to the coastal peatlands. The hiatus in the Bauda 00 core, covering a period of some 2000 years (Fig. 3), is a further indication of the erosion of the peatland surface. Now, the oldest wood date is 100 years older than the oldest peat date, and the youngest wood date is some 400 years younger than the youngest peat date: these facts can also be explained by the erosion of the peat by the floodwaters of the Vistula Lagoon. The tree stumps were and are rooted in the peat deposits, but the surface layer of the peat was without doubt eroded. The difference between the age of the top of the peat and the age of *Dreissena polymorpha* shells in the Bauda 00 core is 2165 years (Table 1); this provides concrete evidence of erosional processes. The *D. polymorpha* shells were dated to 1655 ± 30 years BP. If the reservoir effect is taken into

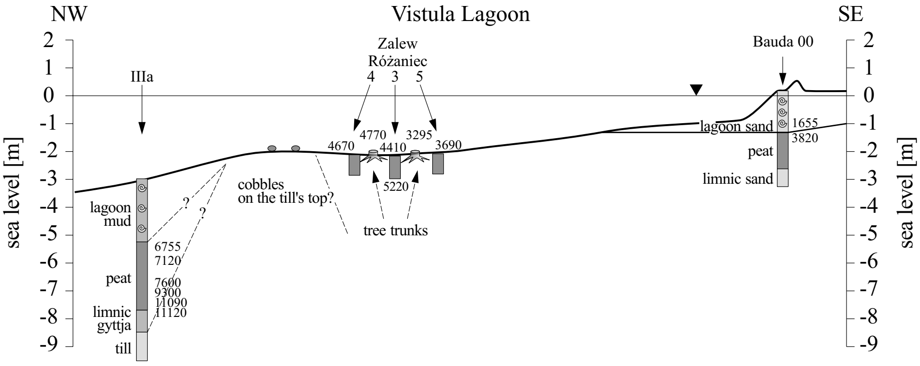

Fig. 4. Geological cross-section of the Vistula Lagoon in the vicinity of the village of Różaniec

account, the hiatus could have been somewhat longer, but the range of this effect is not known for mollusc shells from the Vistula Lagoon. The age of *D. polymorpha* shells also indicates that this species invaded the southern Baltic earlier than in the 19th century, as it is generally believed.

Evidence for the erosional processes is also the poor state of preservation (decay) of the older stump dated to 4770 ± 35 BP (Poz-15115), which indicates that after the tree finally died, the stump remained in the peat and was periodically exposed to the action of the atmosphere. The age and good state of preservation of the younger stump indicate that the tree died just before or during the flooding of the coastal peatland by the lagoon's waters in the second half of the Subboreal.

All the evidence set out above (radiocarbon dates, results of pollen analysis) indicates that in the Late-Atlantic – Early-Subboreal, the water level of the Vistula Lagoon lay some 3 metres below the present-day level. From the date of the younger alder stump we may infer that the lagoon's waters passed the -2 m level no earlier than some 3500 years ago. Analysis of the Bauda 00 core indicates that the lagoon reached the -1 m level some 2000 years ago (Fig. 5).

During the Atlantic and the first half of the Subboreal coastal peatlands developed in the study area. The pollen spectra of the peat layer (the Z–R 3 and Bauda 00 cores – Figs. 2, 3) indicate that woodlands containing alder (*Alnus*), much resembling present-day alder swamps, played a big part in the structure of the local forest communities. They may well have supported fern communities (Filicales) as well. But they may also have occupied other, discrete habitats, particularly in the period preceding the development of alder swamps, when deciduous mixed forests with lime (*Tilia*), oak (*Quercus*) and hazel (*Corylus*) were still playing an important role.

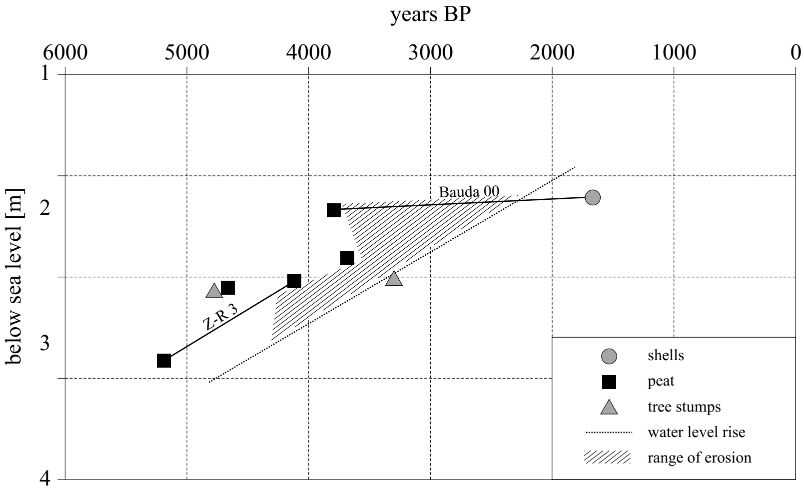

Fig. 5. Water level rise in the Vistula Lagoon

The development of plant communities in the region of the present-day Vistula Lagoon and on its margins was dependent to a large degree on changes in the water level in the Baltic Sea. The peat deposits were formed following the overgrowth of a local water body in the immediate vicinity of the Vistula Lagoon. This is testified by the drop in values of the Telmatophyte, Limnophyte and *Pediastrum* (alga) curves. Concomitantly, there was a rise in the level of the waters in the Baltic, and thus in the lagoon. Further peat growth appears to have been linked to a large extent with the rise in the lagoon's water level. Sedentation of the peat deposits came to an end when they were flooded by the lagoon's waters: the transgressing waters eroded the topmost layer of peat (Figs. 3, 4 and 5).

Numerous localities with Early Subboreal peat deposits have also been found around the edges of Puck Lagoon, some 80 km NW of the Vistula Lagoon. Their palynological investigation points to the occurrence of very similar plant habitats. In the first half of the Subboreal there were coastal peatlands on the low shores of Puck Lagoon and very probably on the area of its present-day bottom, and the local forest communities were dominated by alder (*Alnus*) woodland (e.g. Miotk-Szpiganowicz 1997).

At the bottom of the present-day Puck Lagoon, Subboreal peat deposits have been reported from only a few localities no deeper than 1.1 m below sea level (Uścinowicz et al. 2007), whereas in the Vistula Lagoon peat deposits of a similar age lie at depths of up to 2.1 m below the present-day sea level. In view of the above, we can assume that erosional processes during the transgression were more destructive and more extensive in Puck Lagoon than in the Vistula Lagoon, and that Subboreal peat deposits originally lying deeper than 1.1 m below sea level were destroyed during or after the transgression. It was Jelgersma (1961) and van de Plassche (1980) who drew attention to the fact that, when dating transgressional contacts between peat deposits and overlying marine sediments, erosion of the topmost layer of peat during the transgression was the factor that had to be taken into consideration when constructing and analysing curves of relative sea level change. The date of the actual transgression on to a given area may be younger than the date of the transgression calculated on the basis of the age of topmost peat layers (see Fig. 5).

An alternative explanation for the differences in the levels of the peat deposits in Puck Lagoon and the Vistula Lagoon is that they are the effect of neotectonic movements of different strengths during the last 3000 years.

Pine stumps in the Lithuanian part of the Baltic occur at depths of 27.0 and 14.5 m below sea level and have been radiocarbon dated to 9160 ± 60 (Vs-1372) and 6930 ± 130 (Vs-1388) BP (Damusyte et al. 2004, Damusyte 2006). Therefore, they cannot be correlated with the data from the Vistula Lagoon. Rooted tree stumps from the Early Subboreal reported from localities in the SW Baltic (Lampe 2005) lie no deeper than 1 m below the present-day level of the sea. The numerous deeper localities (from 2 to 14 m below sea level) at the bottom of the German part of the Baltic date from the Atlantic (Lampe et al. 2005). We can therefore infer from these comparisons that the Vistula Lagoon locality furnishes significant information about water levels in this part of the Baltic during the Subboreal.

5. Summary and conclusions

- At the bottom of the Vistula Lagoon there occur alder stumps rooted in peat deposits. The alder wood was dated to 4770 ± 35 (Poz-15115) and 3295 ± 35 (Poz-1516) BP.
- The topmost layers of peat were dated to 4670 ± 40 (Poz-15244), 4410 ± 35 (Poz-15192) and 3690 ± 35 BP (Poz-15195). The considerable scatter of the dates indicates the significance of erosional processes during marine transgressions.
- The formation of peat deposits in the Vistula Lagoon area was due initially to the overgrowing of the shores of an earlier-existing local body of water, and later to the rise in the level of the Baltic Sea and hence of the lagoon itself.
- Peat sedentation came to an end when the waters of the lagoon flooded the peat bog, and eroded away the topmost layer of peat.
- The erosional processes and the associated sedimentation gaps (hiatuses) were also identified by palynological methods.

- Radiocarbon dates and pollen analyses indicate that in the Late Atlantic – Early Subboreal, the water level of the Vistula Lagoon was about 3 m lower than it is today. The -2 m level was passed no earlier than c. 3500 years ago; the -1 m level was reached around 2000 years ago.
- The differences in the levels of occurrence of the topmost layer of the Subboreal peat deposits in the Vistula Lagoon and Puck Lagoon may be due to the different intensity of erosion or to neotectonic influences. The problem requires further research.

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