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ORIGINAL RESEARCH PAPER

Holocen history of vegetation at "Uroczysko Mokradła" (SW Poland) – paleobotanical research

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Abstract
Two peat bogs were studied in the Bory Dolnośląskie, the forest complex in Lower Silesia (Poland). An Instorf drill was used to collect two peat profiles from the deepest places. The macroremains analysis showed that after the initiation of peat-forming processes phytocoenoses responsible for the deposition of transition sphagnum peat were developed at both locations. Later on, the development of both peat bogs differed. The smaller peat bog continued to develop, whereas the big bog was shifted to ombrotrophic water regime. Therefore, phytocoenoses accumulated 1.3 m of *Sphagnum* peat. The peat-forming process was initiated at different times in both sites. For the smaller peat bog, it took place during the Atlantic period, while in the case of the larger peat bog – several thousand years later. The first identified forest phytocoenoses in the Atlantic period are mesophilic multi-species deciduous forests. Dry coniferous forests and mixed birch-pine forests grew in dry habitats. Riparian forests occupied lower grounds. In the Subboreal period, the oak–hazel communities initially developed and mixed coniferous forests were partially replaced by light oak forests. The encroachment of spruce, fir, hornbeam, and beech resulted in the development of dry ground forests, including beech–fir woods. The importance of riparian forests increased, whereas in dry grounds pine and mixed coniferous forests continued to occur. In the Subatlantic period, the transformations in forest communities were associated with the spread of hornbeam, beech, and fir and thereby vast fertile habitats were colonized by dry ground communities and beech woods. Pine and mixed forests as well as riparian forests were of lesser importance. Pollen records from the last 500 years showed the clear presence of humans. It was evident from the presence of cereal and weed pollen and from the disturbances in the pollen records caused by peat extraction in the Middle Ages.

Keywords
peat bogs; Uroczysko Mokradła; palynology; macroremains; anthropopression

Introduction

The Bory Dolnośląskie (Lower Silesia Forest) is one of the largest forest complexes in Poland – its area is more than 151 000 ha. From the geobotanical point of view, it belongs to the Silesian Basin (Kotlina Śląska) [1], whereas according to Kondracki's division [2] it is a part of the Silesian-Lusatian Lowland (Nizina Śląsko-Łużycka) macroregion. In the past, poor, infertile soils of the Bory Dolnośląskie forest did not encourage the development of settlement, which is the reason for the current high forest cover rate of this area. These forests were never parceled out. From the Middle Ages, the area belonged to two or three owners [3,4]. After World War II, the forest

authorities did not make intensive forest management practices due to the presence of a whole range of both Polish and Soviet military training grounds. *Pinus sylvestris*, the plant first introduced to the forest in the nineteenth century, is currently predominant in the Bory Dolnośląskie. The most common is *Leucobryo-Pinetum*, but *Molinio-Pinetum* and *Vaccinio uliginosi-Pinetum* are also encountered, while in the driest places – *Cladinio-Pinetum*. The lowland acid beech wood, *Luzulo pilosae-Fagetum*, is particularly interesting. The proportion of mixed coniferous forests (the association *Pino-Quercetum*) is relatively low, while riparian and alder forests are rare in the Bory Dolnośląskie [4].

In the literature, a lot of information can be found on the changes that have taken place in these forests since the Middle Ages. On the contrary, there is few information about the Holocene history of the Bory Dolnośląskie forest, because the paleobotanical data from this region are very poor [5,6].

The aim of this study was to present the changes in forest plant communities (within the area of the current Bory Dolnośląskie forest, Lower Silesia, Poland) that had taken place over the last several thousand years.

Material and methods

The "Uroczysko Mokradła" is located in the Bory Dolnośląskie forest, south of the A18 motorway connection, in the northern part of the Jeziory forest range [7]. It consists of two forest peat bogs separated by a dune which is at the same time a watershed. The larger one is located closer to the motorway, while the smaller one is more to the south. On a German map, Messtischblatt [8,9], the smaller peat bog, is marked as a body of water overgrown with vegetation and called "Lautrücken See", whereas the larger one as a lake called "Kranichsee". Modern topographic maps call the area in question "Mokradła", whereas in the written sources it is known under the name of "Uroczysko Mokradła".

In 2009, two peat profiles, with a thickness of 1.25 m (taken from the smaller peat bog) and 2.25 m (from the larger one), were sampled using an Instorf drill in either of the peat bogs from their deepest places. The presence of sand was found at the bottom of the profiles. The peat of profiles were used to make an analysis of plant macroremains and palynological analysis. For the analysis of macroremains, the profiles were divided into 5-cm-long sections. Material was taken from each section to determine the ash content (combustion in a muffle furnace at a temperature of 600°C) and to analyze plant remains. Based on identified plant species, peat species were determined following the classification developed by Tołpa et al. [10]. For the palynological analysis, peat samples were collected at a distance of every 2 cm. The samples were treated with a 30% aqueous hydrogen peroxide solution to remove undecomposed organic matter. Next, the material was macerated using Erdtman's acetolysis method [11]. Pollen analysis was performed for each sample. The pollen material was counted until a total of about 800–1000 grains was reached. The pollen analysis results are presented as a percentage pollen diagram plotted using POLPAL software [12,13]. Local pollen assemblage zones (LPAZs) were identified in the diagram and the reconstruction of local vegetation of the peat bogs and their adjacent area was based on these LPAZs.

For the needs of this paper, the results of the stratigraphic and palynological analysis are shown in a very simplified form (Fig. 1–Fig. 4).

Results

Macroremains provided information which phytocoenoses were responsible for the formation of a given peat bog, whereas palynological analysis indicated the moment of initiation of the peat-forming process, revealed the most important events in the transformation of plant cover, and illustrated any disturbances in their development.

Both investigated peat bogs developed in depressions between dunes, of which one is a watershed, and hence these bogs were fed with waters from two different catchments area. There are mineral-organic deposits in the bottom layers of the profiles from both peat bogs (Fig. 1, Fig. 2). The remains of *Carex*, *Sphagnum*, *Potamogeton*, *Nymphaea alba*, and *Cladium mariscus* indicated habitats with a varying water level, from only moist grounds to about 0.2 m thick layer of water on the surface. Under such conditions, the peat-forming process was initiated. After about 0.2-m-thick mineral-organic deposits had accumulated, the further development of the peat bogs was dependent on meso-oligotrophic waters which favored the development of phytocoenoses characteristic of transition bog. *Sphagno-Cariceti* peat (with *Carex*, *Scheuchzeria palustris* and a small amount of *Sphagnum* mosses) was initially deposited. Later on, *Scheuchzeria palustris* started to dominate and was responsible for the formation of a thin layer (0.05–0.1 m) of *Scheuchzerieti* peat. From then on, both peat bogs developed slightly differently. The larger peat bog shifted to ombrotrophic water regime, as a result of which a 0.8-m-thick layer of *Eusphagneti* peat formed from *Sphagnum magellanicum* as its main component. From a depth of 0.95 m, the

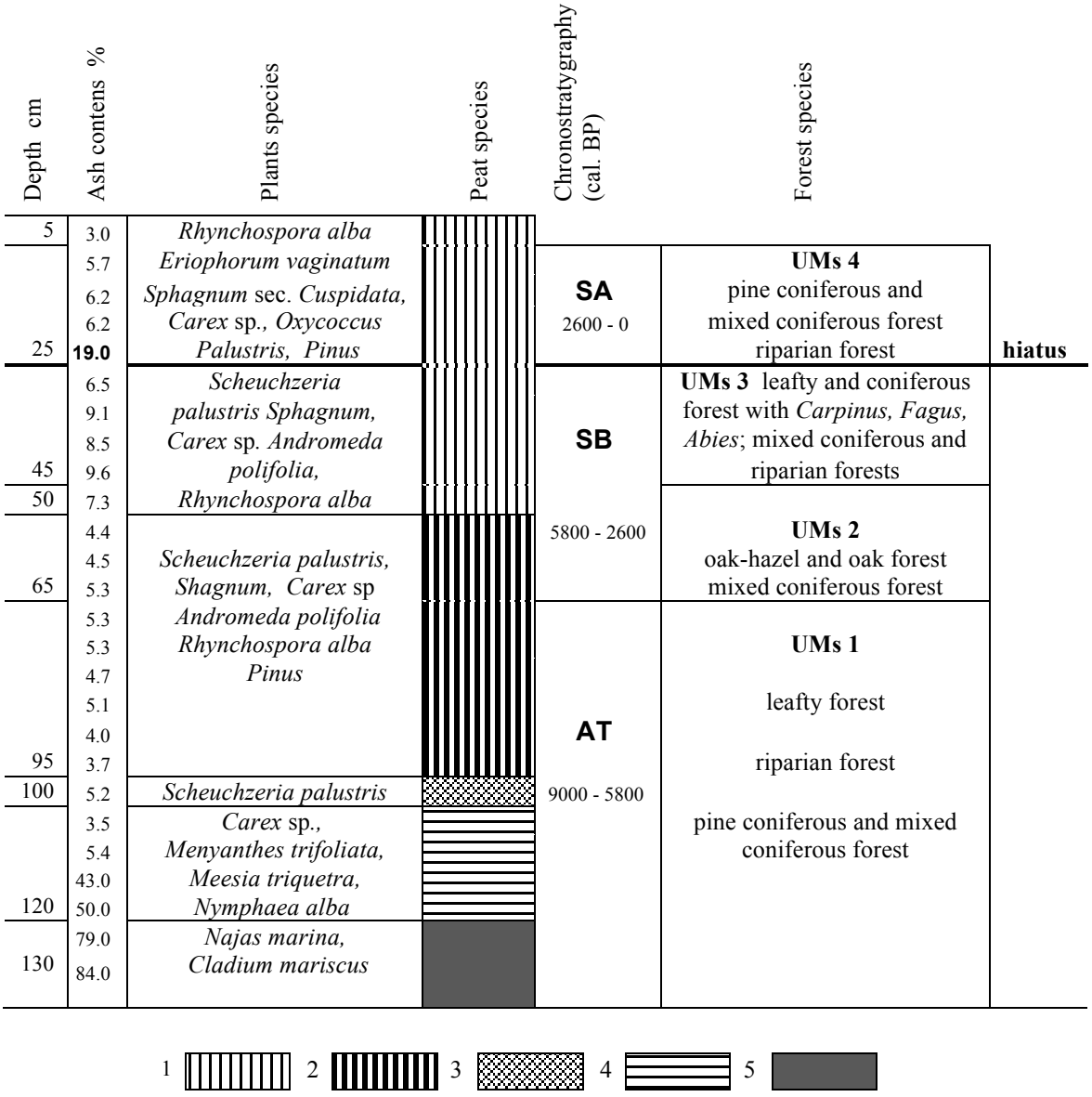

Fig. 1 Plant species, peat species, forest types, and age recorded in the smaller peat bog "Uroczyska Mokradła", Bory Dolnośląskie (Lower Silesia, Poland). 1 – *Sphagno-Scheuchzerieti* peat; 2 – *Sphagno-scheuchzerieti* peat with *Pinus*; 3 – *Scheuchzerieti* peat; 4 – *Sphagno-Cariceti* peat; 5 – mineral-organic deposit; AT – Atlantic period; SB – Subboreal period; SA – Subatlantic period.

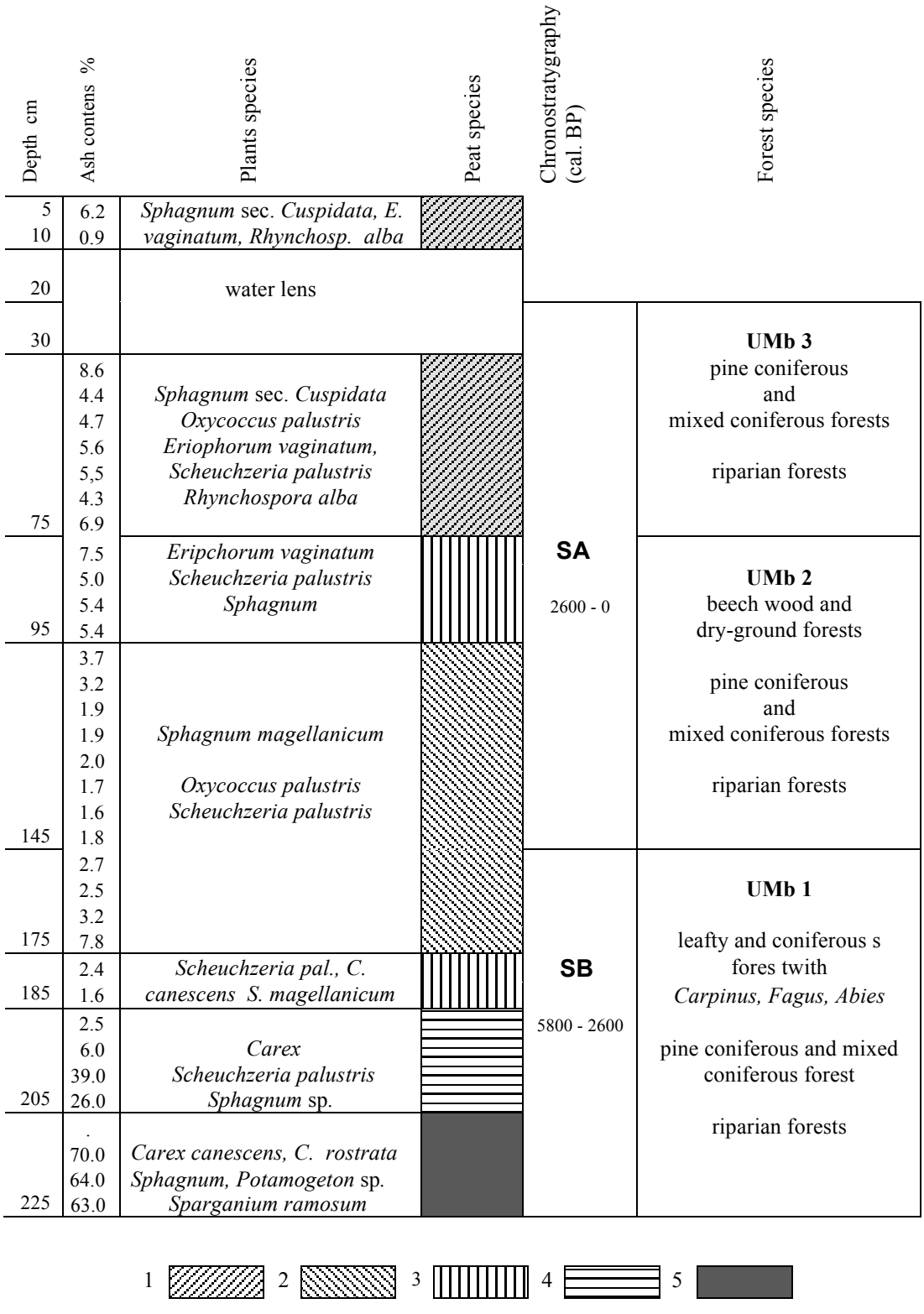

Fig. 2 Plant species, peat species, forest types, and age recorded in the bigger peat bog "Uroczyska Mokradła", Bory Dolnośląskie (Lower Silesia, Poland). 1 – *Cuspidato-Sphagneti* peat; 2 – *Eusphagneti* peat; 3 – *Sphagno-Scheuchzerieti* peat; 4 – *Sphagno-Caticeti* peat; 5 – mineral-organic deposit; SB – Subboreal period; SA –Subatlantic period.

trophic and aquatic conditions changed slightly. *Sphagnum magellanicum* retreated and *Scheuchzeria palustris* began to dominate, forming 0.2 m of transitional *Sphagno-Scheuchzerieti* peat. After this short period, the proportion of *Sphagnum* mosses, but of those from the *Cuspidata* section, increased again with a simultaneous decrease in the proportion of *Scheuchzeria palustris*. The formed plant communities deposited 0.45 m of *Cuspidato-Sphagneti* peat. There was no raised-bog stage in the development of the smaller peat bog. From a depth of 1.00 m, there were phytocoenoses with a large proportion of *Scheuchzeria palustris*, while in the upper 0.2-m layer with a contribution of *Rhynchospora alba* and a larger proportion of *Sphagnum*. A 0.65-m-thick layer of *Sphagno-Scheuchzerieti* peat was deposited.

The pollen analysis showed that the peat bogs were formed at different times. The smaller bog, in which the peat-forming process began during the climatic optimum period of the Holocene, proved to be older (Fig. 1–Fig. 4). The larger bog, on the other hand, started to function several thousand years later, as late as the Subboreal period. Therefore, the history of the forests within the area of the current "Uroczysko Mokradła" can be traced from the Atlantic period. During this time (UMs1 L PAZ), mesophilic multi-species deciduous forests developed in the immediate surroundings of the peat bogs. Dry dune habitats, with a low groundwater level, were overgrown with pine forests with an admixture of *Betula* and *Quercus* as well as with mixed

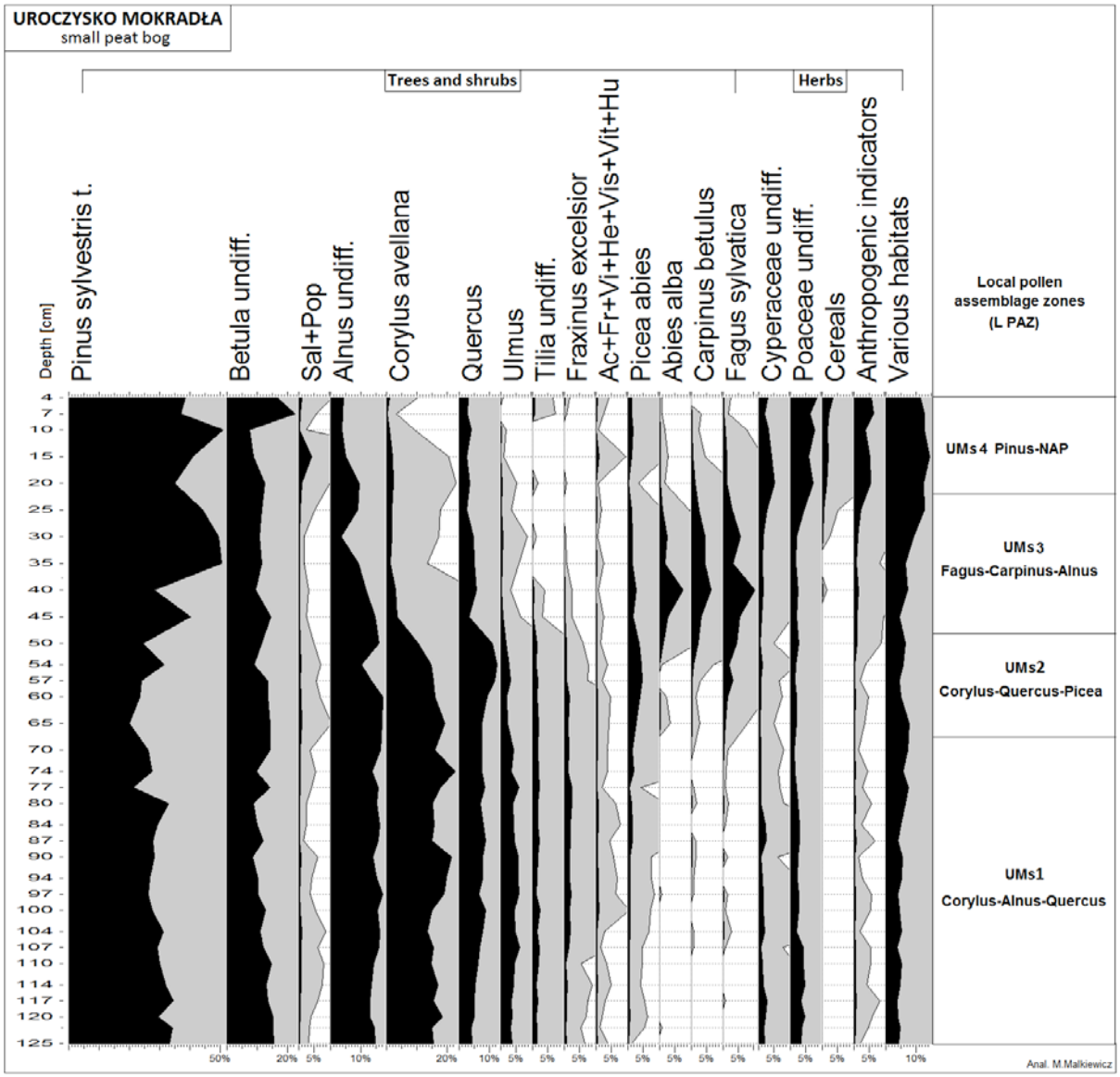

Fig. 3 Pollen diagram from the smaller peat bog "Uroczysko Mokradła", Bory Dolnośląskie (Lower Silesia, Poland).

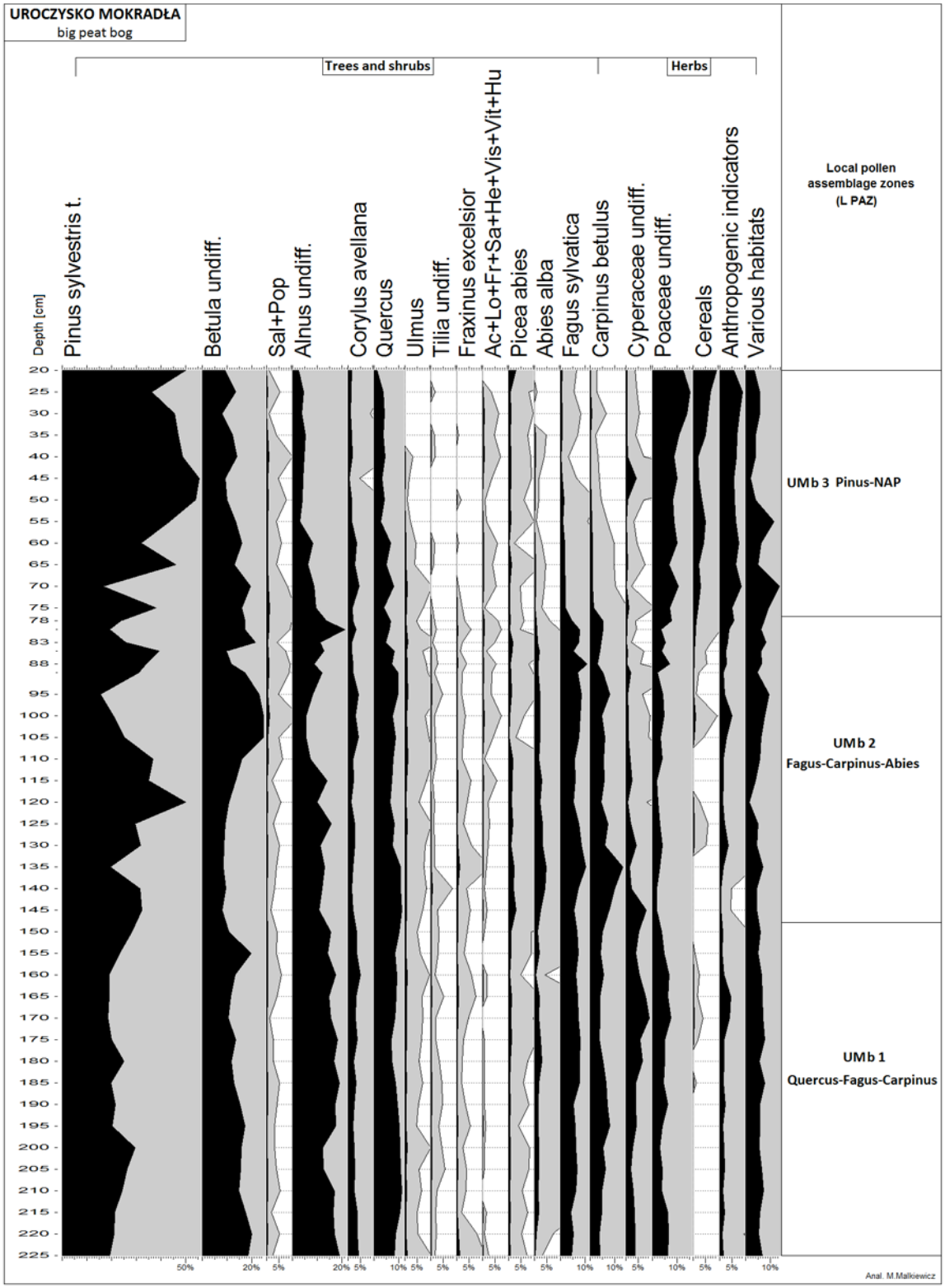

Fig. 4 Pollen diagram from the bigger peat bog "Uroczysko Mokradła", Bory Dolnośląskie (Lower Silesia, Poland).

pine–birch forests with *Quercus* and *Picea*. *Corylus* occurred in the undergrowth of these forests, while *Calluna vulgaris* and other species of Ericaceae in the forest undergrowth. At nutrient-richer and moister sites, mixed deciduous forests developed with *Quercus*, *Tilia* as well as *Acer*, *Picea*, and *Populus*. *Corylus*, *Viburnum*, and *Frangula* occurred in the undergrowth layer. Moist, periodically inundated habitats were dominated by riparian forests with *Alnus*, *Ulmus*, *Fraxinus*, *Salix*, and *Populus*, with *Humulus lupulus* and *Viburnum*, *Viscum*, and *Hedera helix* in the undergrowth. Changes in tree composition of the Bory Dolnośląskie forest began in the Subboreal period (UMs2, UMs3 and UMb1 L PAZ). In the surroundings of the "Uroczysko Mokradła", both mesophilic mixed forests and coniferous communities underwent changes. During the first stage, the proportion of *Ulmus* distinctly decreased. The occurrence of *Tilia* and *Fraxinus* also decreased, while *Quercus* began to displace *Pinus*. In effect, in the older part of the Subboreal period oak–hazel communities developed, whereas mixed coniferous forests were partially replaced by light oak forests. In turn, climate moistening, coupled with climate cooling, resulted in increased importance of riparian forests in which *Alnus* was the main component, accompanied by *Populus*, *Fraxinus*, *Ulmus*, *Tilia*, and *Picea*. *Acer* and *Humulus lupulus* also appeared.

Major changes in the forest communities of "Uroczysko Mokradła" took place in the younger part of the Subboreal period (UMs2 L PAZ). *Corylus avellana* and *Quercus* lost their importance and *Pinus* began to occupy their former habitats. In sandy and dry grounds, mixed forests still occurred, but with a smaller proportion of *Quercus*. Likewise, the amount of hazel in the undergrowth of these forests decreased. Riparian forests persisted in fertile sites with high habitat humidity, but *Ulmus* and *Fraxinus* were of lesser importance. The above-mentioned transformations in the forest communities favored the colonization of this area by *Picea*, *Abies*, *Carpinus*, and *Fagus*.

During the older part of the Subatlantic period (UMb2 L PAZ), the transformations of forest communities within the study area were associated with the spread of hornbeam, beech, and fir. At that time, these species played an important forest-forming role. *Carpinus* with *Quercus* as well as *Fagus* with *Abies* became significant components of the forests probably until the Middle Ages, since during this time the proportion of hornbeam, beech, fir, and spruce in tree stands in the surroundings of the "Uroczysko Mokradła" was the highest. Pine and mixed coniferous forests were definitely of lesser importance.

During the younger part of the Subatlantic period (UMs4 and UMb3 L PAZ), a distinct and quite drastic change in the forest communities took place which was a result of increasing anthropopressure. Except for pine, practically all the other tree and shrub species lost their importance. Pine and mixed coniferous forests with an admixture of birch, oak, poplar, and hazel as well as *Calluna vulgaris* and *Vaccinium* in the undergrowth became the only important forest communities. Alders and willows grew only in the immediate vicinity of the peat bogs and nearby watercourses. At the same time, the importance of herbaceous vegetation increased, which may indicate that large areas became deforested and were occupied by open communities.

The pollen analysis of the sediments from both peat bogs of "Uroczysko Mokradła" showed the human impact both on the development of the investigated bogs and on their surroundings, but only during the younger section of the Subatlantic period. In the studied sediments, there is no record of human impact, which is probably due to low economic activity of humans in that time. The main anthropogenic indicators (ruderal, pasture, and cultivated plants as well as weeds) did not occur in large numbers in the vicinity of both peat bogs, therefore, forests remained unchangeably prevailing plant communities. It was only in the younger part of the Subatlantic period (probably during the mediaeval period) that anthropopressure became stronger, which resulted in an increase in the anthropogenic indicator, a change in the species composition of the forests, and a change in the proportions between forest communities and herbaceous vegetation communities. The pollen analysis revealed that humans did not settle in the immediate vicinity of the studied peat bogs, but close to them there could have been cultivated fields and meadows. The low pollen percentage of ruderal vegetation (*Artemisia*, Chenopodiaceae, *Urtica*, *Plantago media/major*, and *Rumex acetosella*) indicates the distant location of human settlements. On the other hand, the continuous curves of *Cerealia*, *Secale cereale*, and *Fagopyrum* in the upper

sections of the peat profiles confirm that farming was carried out. Evidence of the occurrence of cultivated fields in close vicinity to the "Uroczysko Mokradła" is the co-occurrence of the pollen of cereals and *Centaurea cyanus* – a weed of cereal crops, while an increased amount of pollen of *Plantago lanceolate*, *Rumex acetosa*/*acetosella* and other meadow plants indicates the greater role of meadows.

The pollen analysis of the upper samples of the core from the small peat bog showed that at a depth of 0.20–0.25 m there was a sedimentation gap associated with the absence of a part of the sediment. An unexpected increase in the ash content of the peat, up to as much as 19%, was a confirmation of disturbances in the development of the peat bog. The shape of the tree and shrub curves indicated that the loss in peat volume related to the youngest part of the Subboreal period and a substantial part of the Subatlantic period. The pollen spectra of the upper level of the core should therefore be correlated with the youngest section of the Subatlantic period and they probably represent a picture of vegetation of the last ca. 500 years. It is difficult to determine unambiguously the reason for the absence of a part of peat sediments. No fire indicators (charcoal) were found in the peat, which excludes a fire in the peat bog and its immediate vicinity. It seems more probable that the loss in peat volume occurred due to the activities of humans in that time.

Discussion

The area of the Bory Dolnośląskie has not been of particular interest to palynologists [5,6]. The study provided new information on plant history of this area and supplemented by data on Holocene migration trees and shrubs in Poland [14].

The obtained pollen spectra made it possible to follow the progress in plant communities changes starting from the Atlantic period to the Subatlantic period. In general, the obtained pollen spectra do not differ too much from the pollen spectra situated in other sites in the Lubuskie region [15–18].

Studied peat bogs are situated close to one another, each one of them started its development in different time: smaller in Atlantic period, bigger in Subboreal period. Such age diversity may be characteristic for the Bory Dolnośląskie forest. However, at localized nearby peat bog, the peat-forming process was initiated there in the Boreal period [5].

Literature indicates the presence of *Viscum* and *Hedera helix* in multi-species deciduous forests of the climatic optimum (Atlantic period). Studied profiles confirm the occurrence of these species in the Bory Dolnośląskie forests in Atlantic period. They indicate certain climate conditions. *Viscum*, an important climate indicator [19,20] indicates that the mean temperatures of the warmest month were above 15°C, summers were very warm, and the mean temperatures of the coldest month were higher than −7°C, whereas the common occurrence of *Hedera helix* confirms that winters were mild [19]. A similar vegetation was found nearby, in Tomisław [5].

The obtained pollen spectra also show quite early appearance of spruce in plant communities of the "Uroczysko Mokradła" environs. In that part of the Bory Dolnośląskie, spruce was present in forest communities starting from the beginning of the Boreal period and it comes into prominence in the time of climate optimum [5,6]. The similar forests' composition was recorded in the Holocene sites from the territory of the Polish foreland [21] and mountain areas [22–24]. In the sites located more to the north, from the Lubuskie region [15,18,25] and the Prosna Valley [26], spruce does not appear before the Atlantic period and it is decidedly of less importance in forest communities.

In Subboreal period, a clear change in tree composition is visible in the development of the forest surrounding the "Uroczysko Mokradła". During the first stage, the proportion of *Ulmus* distinctly decreased. This phenomenon took place in the period 5300–5000 BP and is described both in Poland and in other parts of Europe [27–30]. The significant reduction in forest communities with oak and hazel as well as the expansion of hornbeam was marked towards the end of Subboreal period. [14].

Particularly interesting is the absence of a part of the sediment at a depth of 0.20–0.25 m in the small peat bog. Paleobotanical analyses were not able to determine

which type of human activity caused a disturbance in the development of peat bogs. Historical data was helpful. It is known that from the fifteenth century Ławszowa (the village situated near the "Uroczysko Mokradła") was a center of pottery, iron smelting, and spinning, whereas after World War II there was also an ironworks there. In turn, a settlement located right by the smaller peat bog, which existed there at that time, was called "Nieder Pechofen" and its name is associated with tar-making which also developed in this area [4]. Boryna [31] reminds that forests of the Bory Dolnośląskie have always provided to local residents, among others, fuel and construction timber, charcoal, wood tar, peat, and bog ore. Peat was commonly extracted and after the World War I it was even transported beyond the Bory Dolnośląskie. It seems that the disturbances in the development of the peat bog, that is, the above-mentioned sedimentation gap, could be explained by peat extraction. Unfortunately, it cannot be determined precisely how thick a layer was extracted. A comparison with the pollen diagram from the other peat bog would suggest that this could have been at least 0.8 m (assuming that the increase in peat volume in both peat bogs proceeded more or less at the same pace). If we assume that peat extraction was abandoned when a layer of water formed on the surface of the small bog, in such case conditions allowing the initiation of the peat-forming process reappeared. The habitat conditions favored the development of phytocoenoses characteristic of transition mires. Assuming after Żurek [32] that the average increase in peat volume in Polish peatlands is 0.56 mm/year, it would indicate that the time when the disturbances in the peat profile in question occurred was most probably in the Middle Ages, i.e., during the period of manufacturing boom in the area of Ławszowa. Such record of human activity is reported for the first time. Previous paleobothanic studies identified several other directions of peatland development disorders caused by the human activity. The most common phenomenon was the mineralization of peat as the effect of lowering the level of water in the bed of peat. Such process was already documented, e.g., in the Bory Dolnośląskie forest [5] as well as in the Lower Silesia and Pomerania [4,33–37]. As a result of the mineralization process, the peat layer developed during subatlantic of Subboreal and Subatlantic or even Atlantic Subboreal and Subatlantic periods could "disappear".

Conclusions

- The peat bogs of the "Uroczysko Mokradła" (Bory Dolnośląskie, Poland) were formed as a result of paludification of mineral soils. The initial stages of development the process was the same for small and big peat bogs. Differences appeared later on: the small bog maintained its nature of transition bog throughout the entire time, whereas the big bog was supplied for a long time with oligotrophic water which enabled the development of raised-bog communities. Layers of *Eusphagneti* peat went down first, followed by *Cuspidato-Sphagneti* layer.
- The peat-forming process in both peat bogs was initiated at a different time. In the case of the smaller bog, it was during the Atlantic period, while the larger one began its development several thousand years later. Therefore, we can trace the history of the Bory Dolnośląskie from the climate optimum of the Holocene (9000–5800 calendar years).
- The first identified forest communities in the Atlantic period are mesophilic multispecies deciduous forests with oak, linden, maple, and poplar as well as with hazel, *Viburnum*, and *Frangula* in the undergrowth. Dry coniferous forests and mixed birch–pine forests with oak and spruce grew in dry habitats. Riparian forests occupied lower grounds.
- In the Subboreal period, some tree species (elm, linden, ash, and pine) started to slowly recede; therefore, oak–hazel communities initially developed and mixed coniferous forests were partially replaced by light oak forests. The encroachment of spruce, fir, hornbeam, and beech resulted in the development of hornbeam–lime and oak–hornbeam forests, including beech–fir woods. The importance of riparian forests increased, whereas in dry grounds pine and mixed coniferous forests continued to occur.

- In the Subatlantic period, the transformations in forest communities were associated with the spread of hornbeam, beech, and fir and thereby vast fertile habitats were colonized by hornbeam–lime and oak–hornbeam communities and beech woods. Pine and mixed forests, as well as riparian forests, were definitely of lesser importance.
- The presence of humans can be clearly seen over the last ca. 500 years: there were probably cultivated fields and meadows in the vicinity of the peat bogs, while slightly further on – human settlements.
- In the case of the small peat bog, the pollen records revealed disturbances in the peat deposition process, which most probably occurred in the younger part of the Subatlantic period. The historical data showed that this could have been caused by peat extraction during the Middle Ages.
- The current structure of the Bory Dolnośląskie, with a small representation of mesophilic forest tree species, differs from forests in the Atlantic and Subboreal periods.

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Holoceńska historia roślinności „Uroczyska Mokradła" (południowo-zachodnia Polska) – badania paleobotaniczne

Streszczenie

Badano dwa torfowiska, wchodzące w skład „Uroczyska Mokradła" znajdującego się w Polsce, w Borach Dolnośląskich. Z najgłębszych miejsc obu obiektów pobrano świdrem Instorfu po dwa profile. W ich spągu był piasek. Pobrany torf poddano badaniom makroszczątków oraz badaniom palinologicznym. Analizy makroszczątków wykazały, że po zainicjowaniu procesu torfotwórczego w obu obiektach rozwijały się fitocenozy odpowiedzialne za odłożenie torfu przejściowego. Później drogi rozwoju w każdym obiekcie przebiegały inaczej. W przypadku torfowiska mniejszego utrzymany został ten sam kierunek rozwoju (torfowisko przejściowe), natomiast torfowisko większe przeszło na ombrotorficzną gospodarkę i fitocenozy odłożyły 1.3 m torfu wysokiego. Proces torfotwórczy obu obiektów został zainicjowany w różnym czasie. W przypadku torfowiska mniejszego – w okresie atlantyckim (9000–5800 lat kalendarzowych), natomiast większe rozpoczęło rozwój kilka tysięcy lat później. Pierwsze rozpoznane fitocenozy leśne w okresie atlantyckim to mezofilne wielogtunkowe lasy liściaste z udziałem dębu, lipy, klonu i topoli oraz z leszczyną, kaliną i kruszyną w warstwie podszytu. Na siedliskach suchych występowały bory suche i mieszane sosnowo-brzozowe z dębem i świerkiem. W obniżeniach terenu rosły lasy łęgowe. W okresie subborealnym zaznaczyło się powolne ustępowanie wiązu, lipy, jesionu i sosny, w związku z czym rozwinęły się zbiorowiska dębowo-leszczynowe, a bory mieszane częściowo zastąpione zostały przez widne lasy dębowe. Dodatkowo wkraczanie świerku, jodły, grabu i buka spowodowało rozwój lasów w typie grądów, m.in. bukowo-jodłowych. Wzrosło znaczenia lasów łęgowych, ale na terenach suchych wciąż występowały bory sosnowe i mieszane. W okresie subatlantyckim odnotowano rozprzestrzenienie się graba, buka i jodły, w związku z czym rozległe, żyzne siedliska opanowane zostały przez zbiorowiska grądowe i buczyny. Zdecydowanie mniejsze znaczenie miały bory sosnowe i mieszane oraz lasy łęgowe. W zapisie pyłkowym ostatnich 500 lat zaznaczyła się wyraźnie obecność człowieka. Świadczy o tym obecność pyłku zbóż, chwastów pól i łąk oraz zaburzenia w zapisie pyłkowym spowodowane wydobyciem torfu w okresie średniowiecza.