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Future Climate Impacts in Woodland and Forest Steppe Based on Holocene Paleoclimatic Trends, Paleobotanical Change in Central Part of the Carpathian Basin (Hungary)

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ABSTRACT

The Sirok Nyírjes-tó peat bog provides an almost full Holocene climatic record reconstructed by bog surface wetness investigations based on plant macrofossil analysis. We compared our macrofossil data to anthracological material derived from archaeological sites and to the newest bioclimatological models of the Carpathian basin. On the basis of environmental historical and climatic data we aimed to reconstruct the expected changes of forested areas in the Carpathian Basin. The results indicate that the surface wetness decreases in long term. Parallel to the *Sphagnum*-peat decline an open forest and forest steppe developed surrounding the bog. The complete disappearance of Sphagna from the area must be linked to a steady drop in rainfall, resulting in at least 50 mm deficit in the local water balance. This could have been achieved by an increased evapotranspiration as a result of elevated temperatures of the summer growth season. This deficit value must have exceeded even 100 mm during the Middle Holocene Transition.

Keywords: Carpathian Basin; Climatic Change; Forest Transformation; Paleoecological Data

1. Introduction

One of the most important features of the recent vegetation of the Carpathian Basin (**Figure 1**) is that both the upper (according to height) and the lower (according to drought) timber-line [1] as well as the transitional (ecoton) vegetation between the open and closed vegetation that developed behind the timber-line can be found in the area. Because of human impact [2] and environmental effects showing mosaic patterning [3] these boundaries and the ecoton zones indicate not a clear border rather a mosaic system in the basin and in the mountainous region surrounding the basin [3]. Thus the current and the prospective, modeled climatic changes [4] might have an important effect on the transitional zone of the open and closed vegetation, on the ecoton zone behind this boundary and on the forested areas in the mountainous region and the basin [5].

The ongoing climatic changes probably cause significant alterations in the forests of the Carpathian Basin [5]. It is hard to model these changes by recent climatic and vegetation data because there are data sets of only a few decades to model these alterations. Furthermore, on the basis of the palaeoecological and palaeoclimatological data until now the vegetation and climatic changes show a strong regional and local trend due to the mountainous zone in the Carpathian Basin. Consequently these changes differ from the global trends [3,6].

We aimed to reconstruct the Holocene climatic changes and vegetation cover, as well as to compare the obtained results to climatic models. Therefore we chose a small *Sphagnum* bog (Sirok, Nyírjes-láp) for study site [7-9] that is located at the lower timber-line, on the transitional zone of the Pannonian forest steppe and the forested areas of the Carpathians. This area is suitable for pollen and macrobotanical analysis so the local changes are provable. The palaeobotanical samples were derives from an undisturbed core with radiocarbon data. As a result of macrobotanical analysis of samples it was possible to create a model to detect climatic and vegetation changes for the prospective alterations, as well as the changes of forest ecosystems in the study area. We compared our data to anthracological material derived from archaeological sites [10] and to the newest bioclimatological models of the Carpathian Basin [11,12]. On the basis of environmental historical and climatic data we aimed to reconstruct the expected changes of forested areas in the Carpathian Basin.

The bog of Sirok is unique in Hungary. One of the most popular approaches is looking for proxies reflecting transformations in the biological and chemical composition of peat sequences as signals of past climatic fluctuations. A frequently used approach in chemical analysis is the investigation of humification [13,14]. This approach relies on the logic that surface humidity ultimately determines the rate of decay of plant matter. When peatlands are dried out, this is reflected in a sudden increase in humic acids within the deposits. These acids are extracted from the deposits using various alkalis and their concentration is determined in the solution by spectrophotometric approaches. The most widely adopted method in the analysis of biological components is the study of plant macrofossils, including mosses or testacea [15-19]. These studies enable us to identify various peatland types and past communities. However, there is a special feature of peatland plants that can aid the interpretation of earlier environmental conditions. Certain species are distributed along a gradient reflecting differing water depths. Bog surface wetness investigations using the QLCMA technique (semi-quantitative quadrat and leaf-count macrofossil analysis technique) of Barber *et al.* [20] permitted high-resolution reconstruction of past climatic changes. Former bog surface wetness studies aimed at deciphering past climatic conditions via detailed analysis of peatland deposits, primarily focusing on the investigation of *Sphagnum* peat from so-called ombrotrophic peatlands [16,17, 1-23].

Climatic conditions favoring the evolution of these type of peatlands are mainly restricted to the western parts of Europe under oceanic climatic influence [17,24] or in Fennoscandinavia [25], where the moisture gradient is unambiguously reflected in the distribution of certain Sphagnum taxa; no discussion, however, occurs on SE Europe, including Hungary. Barber and Charman [17] questioned the suitability of strongly continental peatlands for paleoclimatic reconstructions. This area appears blank on the data source maps, pointing to the paucity of available Holocene bog surface wetness records in this region [26].

The general climatic characteristics of Hungary are far from ideal for the emergence of *Sphagnum* peatlands. The majority of *Sphagnum* peatlands are restricted to the northern areas of the North Hungarian Range and the northern Great Hungarian Plain (GHP), as well as the eastern parts of the country enjoying more precipitation

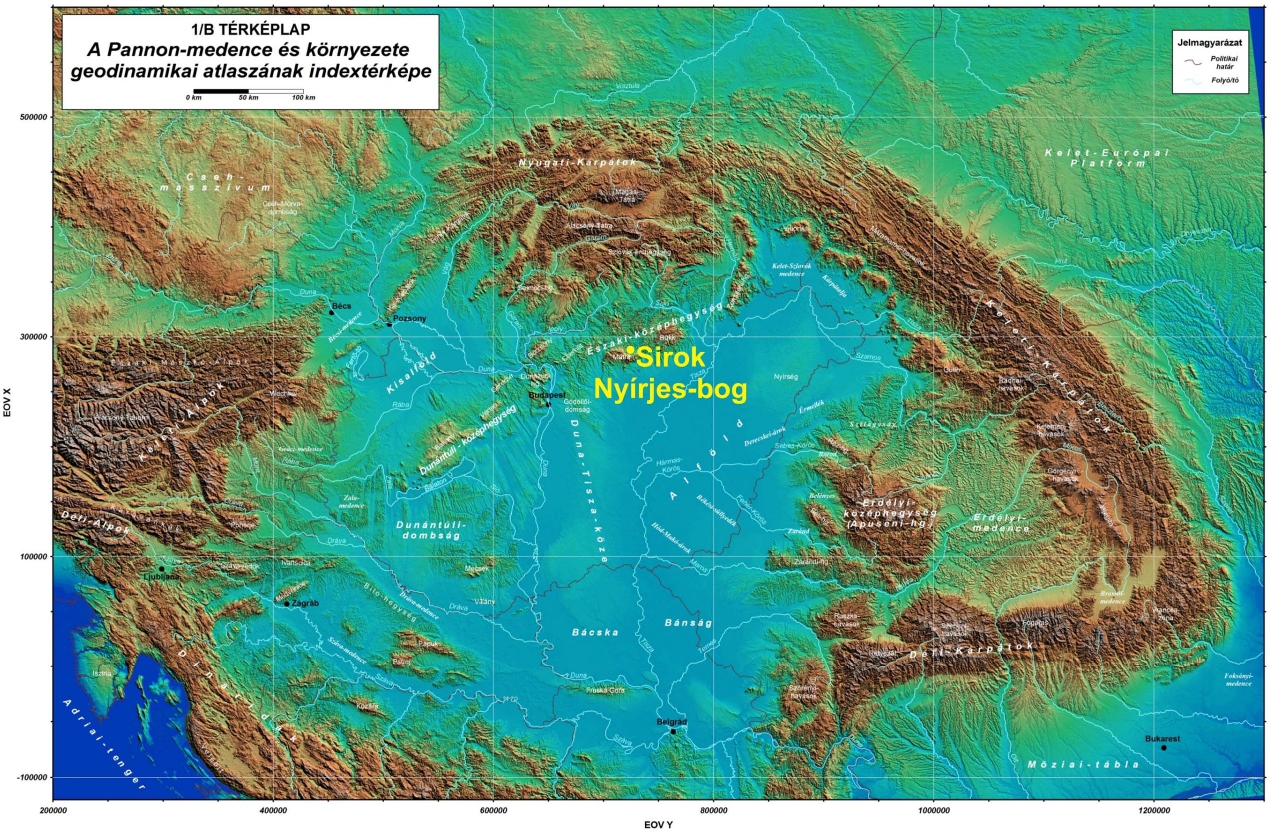

Figure 1. Location of Sirok Nyírjes-bog in the Carpathian basin (source: geophysics.elte.hu/atlas/geodin_atlas.htm).

thanks to the positive effect of the oceanic and montane climatic influences [27,28]. Climatic influences characteristics of the Köppen type steppe zone (BS) [29] are traceable in the heart of the Carpathian Basin alone and appear with a frequency of 2 - 3 times during a decade. Furthermore, their development is by no means regular and cyclical but rather sporadic [30]. So by using the Köppen type climate classification system, the area of the Carpathian Basin falls mainly into the category Cfb (warm temperate fully humid with warm summer) and subordinately into Cfa (warm temperate fully humid with hot summer). The marginal hilly and montane areas within analysed Nyírjes bog at Sirok belong to the category D (snow zone) according to this system [12]. Conversely, in order to better highlight the climatic background of the forest-grassland ecotone system, which is present in the heart of the Carpathian Basin, the vegetation classification system of Holdridge [31,32] is better suited than the climate classification system of Köppen [12,33]. According to the modified Holdridge classification (**Figure 2**), the major part of the basin is put to the transitional category found between those of cool temperate steppe, cool temperate moist forest and warm temperate dry forest, where the first (steppe) and the last categories (dry forest) also turn up climatically in the form of scattered patches. This grassy area forming an ecotone between the actual grasslands and dry and humid woodlands corresponds to the Pannonian forest-steppe vegetation of the Great Hungarian Plains while the on the foothill, hilly and mountainous region covered by woodland (**Figure 1**). The ratio of the evapotranspiration and precipitation (**Figure 3**) is essential in separating forested and ecoton areas so primarily we aimed to model the alterations of these factors.

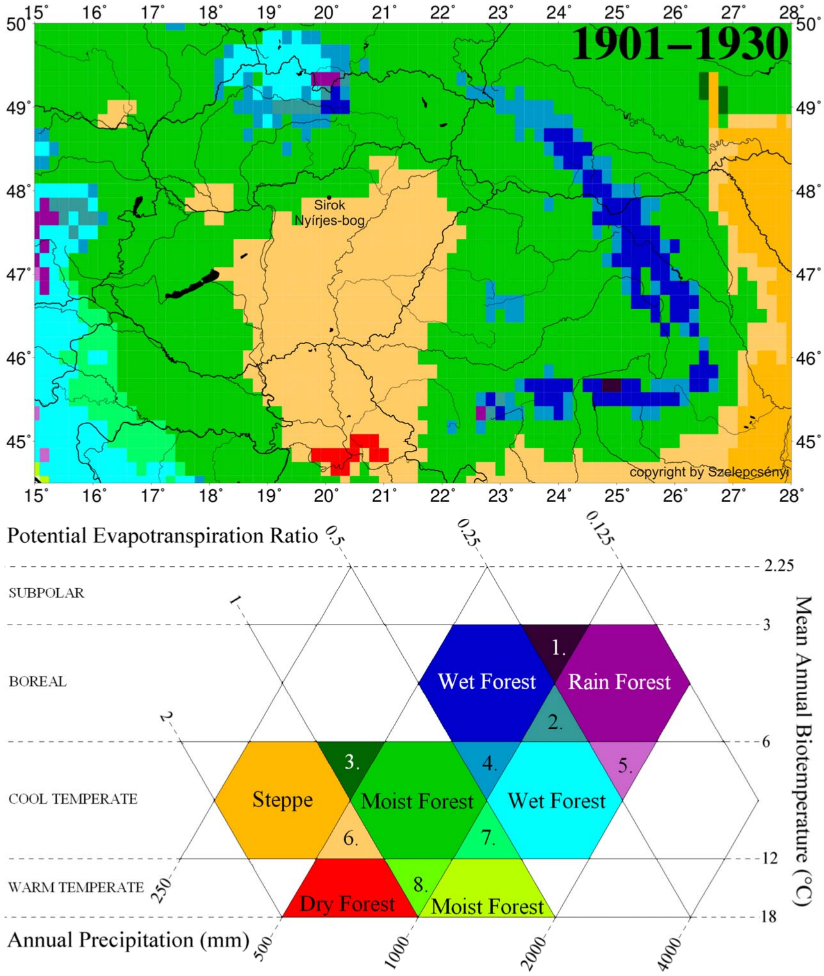

Figure 2. The spatial pattern of life zones at the beginning of 20th century (1901-1930) in Carpathian Basin for the modified Holdridge life zone classification [33] for the database CRU TS 1.2 [34]: 1) Boreal superhumid wet-rain forest; 2) Boreal perhumid wet-rain forest; 3) Cool temperate humid forest-steppe; 4) Cool temperate perhumid moist-wet forest; 5) Cool temperate superhumid wet-rain forest; 6) Cool temperate subhumid forest-steppe; 7) Cool temperate humid moist-wet forest; 8) Warm temperate humid dry-moist forest.

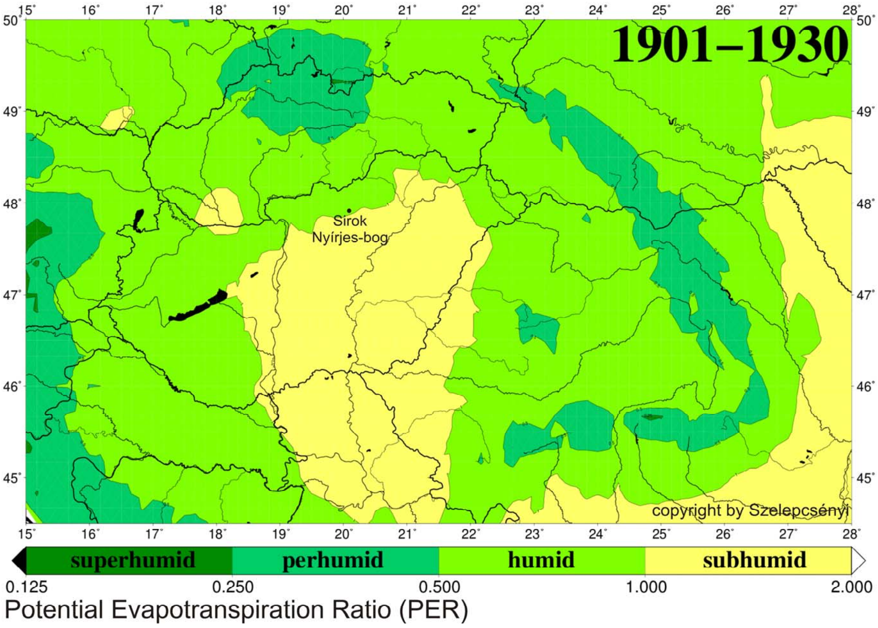

Figure 3. The humidity provinces at the beginning of 20th century (1901-1930) in Carpathian basin for the potential evapotranspiration ratio (PER) for the database CRU TS 1.2 [34].

2. Study Area

The location of the Nyírjes-tó peat bog of Sirok is situated in the northern part of the country, in the eastern foothills of the Mátra Mts, at an elevation of 250 m (**Figure 4**). It covers a small area, of about 9,000 m2. No surficial watercourses feeding or draining the peatland are known. The basin is fringed by a woodland of hornbeam (*Carpinus betulus*) and oak (*Quercus petraea*). The following plant communities are present, moving from the margins towards the center: *Salicetum cinereae*, *Salicetum cinereae-Sphagnetum*, *Carici lasiocarpae-Sphagnetum*. There is a small stand of reedbed on the eastern side of the peat bog. This peatland harbors the following peat moss taxa: *Sphagnum palustre*, *S. subsecundum*, *S. magellanicum*, *S. recurvum s. l.*, *S. fimbriatum*, *S. squarrosum*, *S. obtusum* and *S. angustifolium*. The most common are those of *Sphagnum recurvum s. l.* and *S. palustre* [35,36].

Szurdoki [36] investigated the abiotic conditions of some of the most frequent Sphagnum, in five Hungarian mires, among others the Nyírjes-tó peat bog. Conductivity, pH, height above water table, Na, K, Ca and Mg concentrations were detected. The investigated peat bogs were similar, but there were many significant differences between them in terms of analytical variables, and only weak differences within mires. On the basis of water table, pH, and conductivity the investigated species can be separated. *S. fallax* and *S. angustifolium* do not differ from each other, which is not a surprise since they live together in mixed carpets in most investigated mires.

They mainly occur in wet and acidic locations with poor mineral content. S. palustre lives in the driest places and *S. fimbriatum* in wet and less acidic ones, which are characterized by the highest mineral content. According to Szurdoki [36] the most characteristic features of the Hungarian peat bogs are low pH (c. pH 4) and conductivity of 40 - 80 μS/cm; however, the concetration of calcium proved to be relatively high (10 mg/dm^3) within aEuropean context. The pH of the Nyírjes-tó surface peat layer fluctuated between 3.5 and 4.5 [35,36]. The concentration of nutrients and the water level of Nyírjes-tó is the lowest among the Hungarian peat bogs. The main water level is 17 cm from the peat surface, but in late summer it can be as low as 30 cm [36]. Penksza *et al*. [37] investigated the heavy metal accumulation in peat and in peat-forming mosses and vascular plants from the Nyírjes-tó. Unfortunately the stratigraphic resolution was insufficient and radiocarbon dating was lacking. Therefore the comparison with our paleoecological results is problematic. A detailed palynological work on the peatland was published by Gardner [17,18]. The comparison of terrestrial and wetland vegetation development is based on the results of Gardner [17,18].

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3. Methods

The sampling of the 401 cm deep, undisturbed sedimentary sequences of the Nyírjes-tó Basin was carried out using a 5 cm-diameter Russian-type corer [38]. Overlapping cores were extracted conforming to the general practice in Quaternary paleoenvironmental studies [39]. Coring was carried out in the central part of the bog, now occupied by the Carici lasiocarpaea-Sphagnetum community. Samples taken between the depths of 401 and 4 cm were subjected to plant macrofossil analyses. The Psimpoll program [40] was used for plotting the analytical results. The main lithostratigraphic features of the sedimentary sequence were determined and analyzed. For the description of the cores, the internationally accepted system and symbols of Troels-Smith, developed for unconsolidated sediments, was adopted [41]. Dating of the sequence was carried out by conventional radiocarbon dating at the radiocarbon dating facility in Gliwicze, Poland. Four bulk samples (6 - 10 g peat) of sediment were analyzed for radiocarbon ages. In order to allow comparison with other archeological data, the dates were calibrated using the CalPal-2007 online calibration programme, using the most up-to-date CalPal-2007 Hulu calibration data set [42]. The original dates (^{14}C) are indicated as BP, while the calibrated dates are indicated as cal BC/AD or cal BP. For a more accurate dating of the lower part of the core, additional radiocarbon measurements are under way. For the description of macrofossils a modified version of the QLCMA technique (semi-quantitative quadrat and leaf-count macrofossil analysis technique) of Barber *et al*. [22] and [43] was used. To obtain concentrations for the macrofossil components, a known amount of marker grains (0.5 g poppy seeds, ca. 960 pieces) were added to the samples. In the diagrams the total number of seeds relates to 20 cm^3 sediment, while other macrofossil components are expressed as concentrations (piece·cm^{-3}). Organic remains from peat and lacustrine sediments rich in organic matter can be divided into two major groups. Some remains can be identified with lower ranking taxa (specific peat components), while others cannot be identified using this approach (non-specific peat components).

The archaeobotanical material for anthracological analysis was obtained from samples of archaeological profiles and the deposits of the archaeological features [10]. The sampled objects were both short (e.g. hearth) and long-term deposits (e.g. midden, refuse pit, fills, well fills, ceramic filling). In obtaining and processing the samples we followed the guidelines of the German standards [44, 45] regarding sampling and flotation process. The samples were wet floated; afterwards charcoal fragments were selected and counted. The number of charcoal fragments varied according to the archaeological objects excavated from the level of a certain archaeological culture. During charcoal analysis pieces larger than 4 mm were the most useful, as smaller fragments are in most cases unidentifiable [46-48]. The microscopic identification of wood is possible by knowing the unique tissue map of the given genera or species. Cross-sectional, radial and tangential sections were prepared when analysing charcoals [49], created by breaking new surfaces by hand or with a scalpel. The charcoal pieces were placed in fine sand for ease of manipulation. The three directional sections were analysed using a petrographic microscope, at 50× and 100× objectives. The identification was carried out by reference to published specimens [50-52].

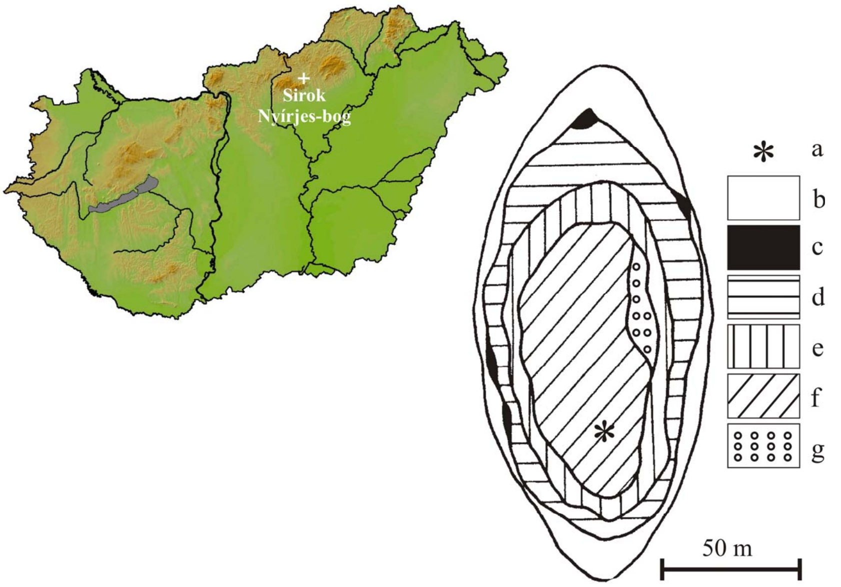


Figure 4. Location of the study site in Hungary and the coring point in the peat bog (a: coring point, b: marginal marsh, c: *Lemno-Utricularietum*, d: *Salicetum cinereae*, e: *Salicetum cinereae* with *Sphagnum*, f: *Carici lasiocarpae-Sphagnetum*, g: *Saliceto-Sphagnetum*, original map: [35].

4. Results and Discussion

4.1. Chronology and Sediment Stratigraphy

On the basis of the sedimentological features the core was divided into 12 units. In general mixed Sphagnum, reed and sedge peat was found down to a depth of 210 cm. Between 210 - 300 cm mixed reed and sedge peat was encountered; between 300 - 340 cm occurred a brown moss peat with high wood content. Between 340 - 410 cm dark gray, silty lacustrine sediments were found with wood and moss fragments. The detailed sediment description is presented in **Table 1**.

The results of the radiocarbon measurements of the sequence described in this udy are shown in **Table 2**. The age-depth model was established by linear terpolation between the calibrated radiocarbon dates (**Figure 5**). Sedimentation rates are shown in **Table 3**. The bottom part of the investigated part of the core, between 195 - 315 cm, is characterized by very low values (0.25 mm·yr^{-1}); the dimentation rate increases gradually between 38 - 195 cm from 0.25 to 1.16 mm^{-1}, and attains the highest values in the top 38 cm of the core (3.39 mm·yr^{-1}).

Table 1. Lithological description of the Nyírjes-tó sequence.

Depth (cm)	Troel-Smith system (1959)	Zone description
0 - 20	Tb(Sphag.)4Th+As+Gs+	Light brown recent *Sphagnum*-peat with silt.
20 - 60	Tb(Sphag.)2Th2	Light brown mixed *Sphagnum*-, reed and sedge peat
60 - 80	Tb(Sphag.)4Dl+	Dark brown *Sphagnum* peat.
80 - 120	Th2Tb2Dl+	Dark brown *Sphagnum*, reed, sedge peat with wood fragments.
120 - 160	Tb(Sphag.)3Th1Dl+	Dark brown *Sphagnum*, reed, sedge peat with wood fragments.
160 - 185	Th3As1Tb(Sphag.)+Dl+	Dark brown reed, sedge peat with wood and *Sphagnum* moss fragments.
185 - 210	Tb(Sphag.)4Th+Tl+	Dark brown *Sphagnum*-peat, with reed, sedge and wood fragments.
210 - 285	Th2As1Dl1Tb(Sphag.)+	Dark brown reed, sedge, peat with wood and *Sphagnum* moss fragments.
285 - 300	Th3As1Dl+Tb+	Dark brown sedge (*Carex elata*) peat with some wood and *Sphagnum* moss fragments.
300 - 340	Tb2As1Tl1Th+	Dark brown brownmoss peat with many wood fragments.
340 - 360	As2Ag2Gs+	Dark grey clayey silt (lake) sediment layer.
360 - 410	As3Sh1Gs+Tb+Dg+	Dark grey clayey silt (lake) sediment layer with moss and wood fragments.

Table 2. Radioocarbon data from the Nyírjes-lake.

Sample No.	Depth (cm)	Sample type	^{14}C age (uncal BP)	cal AD/AD (2σ)
GdA-565	37 - 38	peat	55 ± 30	1889 ± 83
GdA-566	99 - 100	peat	560 ± 30	1364 ± 41
GdA-567	195 - 196	peat	1680 ± 30	353 ± 41
GdA-568	315 - 316	peat	5640 ± 40	4465 ± 52

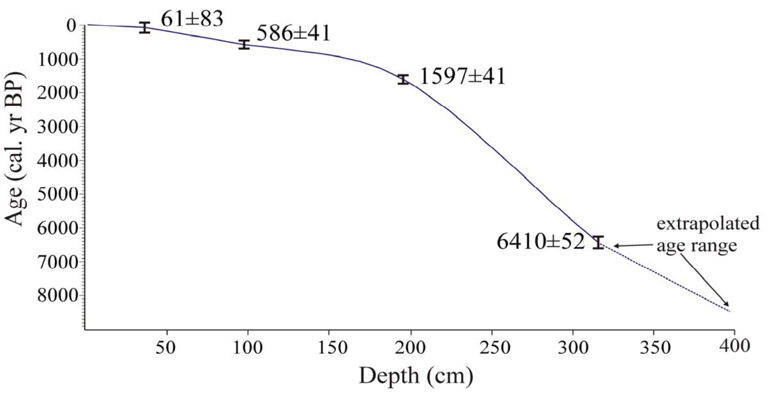


Figure 5. Calibrated radiocarbon age ranges (1) and suggested age-depth curve for core SI (Sirok Nyírjes-tó). All dates were converted into calendar years BP using the CalPal-2007 online calibration program [42].

Table 3. Sediment accumulation rates from the Nyírjes-tó sequence. The age of the upper point concerned AD 2007.

Depth ranges	Sediment accumulation rates (mm/year)
0 - 38	3.39
38 - 99	1.16
99 - 195	0.95
195 - 315	0.25

These sedimentation rates are related to the sediment types accumulated in the basin. Above 210 cm Sphagnum and reed peat can be found with high organic content. Subsamples for macrofossil analysis were taken at 4 cm intervals, which correspond to 40 - 50 yr resolution in the last 2000 years and 130 - 150 yr resolution before 2000 yrs BP. Nevertheless the resolution of radiocarbon dating in the lower 2 meters is unsatisfactory, so a more accurate stratigraphic resolution requires further radiocarbon measurements. Terrestrial and wetland vegetation development **Figure 3** displays the tissue, moss, animal and seed remains extracted from the investigated sequence. **Table 4** presents the most important characteristics of the local macrofossil zones. On the basis of the results the following evolutionary history of the peatland and the sorrounding watershed can be drawn.

4.2. Terrestrial and Wetland Vegetation Development

The first emergence of aquatic conditions in the depression can be dated to 9500 cal. yr BP, resulting in the emergence of a relatively deep, oligotrophic lake with scant aquatic vegetation. As shown by the palynological

Table 4. Discussion of the macrofossil assemblages of the Nyírjes-lake sequence.

Depth (cm)	Age (cal BP years)	Local zones	Zone description
6 - 32	61-	SIM-9	Degrading oligotrophic peat bog conditions. Beside the high amount of *Sphagnum recurvum*, the leaves of *S. squarrosum* and *palustre* indicate gradual eutrofication. Clay particles and mollusc shells indicate soil erosion in the catchment. *Carex lasiocarpa*, *Calamagrostis canescents* were the most common vascular plants.
32 - 71	380 - 61	SIM-8	Dry oligotrophic peat bog conditions, *Sphagnum* concentrations decrease, *Carex elata* and *Phragmites* concentrations rise. *Juncus* indicates degradation.
71 - 88	500 - 380	SIM-7	Wet oligotrophic peat bog conditions. Beside the dominant *S. recurvum*, *S. cuspidatum* show a remarkable peak. Peat bog vegetation dominated by *Calamagrostis canescens*, *Carex lasiocarpa*, *C. canescens*, *C. limosa* and *Eriophorum vaginatum*. Occurrence of *Sphagnum cuspidatum* and *Carex limosa* indicates conditions wetter than now.
88 - 188	1500 - 500	SIM-6	Macrofossil concentrations show remarkable fluctuations in this zone. High concentrations of reed and peat moss remains alternate from time to time. The first *Sphagnum* peaks dominated by *S. obtusum*, *S. subsecundum*, *S. magellanicum*.
188 - 213	2300 - 1500	SIM-5	Oligotrophic peat bog conditions with high concentrations of *Sphagnum* leaves, *Carex lasiocarpa* and *C. rostrata* rhizomes and *Betula* remains.
213 - 284	5200 - 2300	SIM-4	Amount of *Quercus* remains decreased caused by rising water level. Pond weeds, weeds living on wet mud and planctonic invertebrates were characteristic of this zone. Lakeshore vegetation dominated by *Carex elata*, *C. paniculata*, and *Glyceria maxima.* Later *Phragmites*, *Carex rostrata* and *Typha angustifolia* become dominant. A short peat bog expansion was detected at 3900 yr BP, with *Sphagnum* and *Eriophorum.*
284 - 299	5800 - 5200	SIM-3	High macrofossil concentrations. Shallow mesotrophic mire conditions with higher water levels. Hummock-holow structure with *Carex elata* and *Menyanthes trifoliata.*
299 - 343	7500 - 5800	SIM-2	High macrofossil concentrations. Shallow mesotrophic mire conditions, with fluctuating water level and abundant brown moss carpet. Remains of *Quercus* were quite frequent in this zone. The rhizomes of *Phragmites*, *Carex elata*, *C. paniculata*, *Glyceria maxima* and the moss *Drepanocladus aduncus* dominated the macrofossil record. A short peat bog expansion was detected at ca. 6800 cal. yr. BP, when *Sphagna*, *Carex rostrata*, *C. pseudocyperus*, *C. lasiocarpa*, *Thelypteris palustris* and *Meesia longiseta* spread in the basin.
343 - 401	9500 - 7500	SIM-1	Low macrosossil concentrations. Deep oligotrophic lake conditions, with a short peatland expansion at ca. 8200 cal. yr BP. Lakeshore vegetation was dominated by *Carex elata*, *Phragmites*, *Sphagnum magellanicum* and *S. recurvum* s.l.

study of Gardner [7,8] the lake basin was fringed by an open parkland-type woodland with predominance of *Picea*, *Quercus* and *Corylus* untill about 8950 cal. yr BP. This was transformed into a woodland dominated by *Tilia* until 8300 cal. yr BP, which was then finally transformed into a deciduous woodland dominated by *Quercus*, *Tilia* and *Ulmus* until 6900 cal. yr BP, with substantial stands of *Corylus*. Despite the clearly observable transformation of the surrounding vegetation, water levels remained relatively stable in the basin, apart from minor fluctuations, until 7500 cal. yr BP. A drop in water level (increasing concentrations of UOM, UBF and wood) and peat initiation took place almost 1000 years after the development of a closed, deciduous woodland. Therefore there is no direct link between the transformation of the vegetation of the peatland itself and the surrounding terrestrial areas. There is a gradual decrease in water levels from 7500 cal. yr BP, reaching an all time minimum at 6400 cal. yr BP. Open water areas almost completely disappeared, giving way to the expansion of oak shoots in the major part of the basin. The deepest areas turned into an eutrophic marshland and as such we must assume a gradual decrease in the water level from 5800 cal. yr BP, yielding a tussock vegetation. During this period the peatland was fringed by a woodland of *Corylus*, *Quercus* and *Carpinus betulus* [7,8].

There is another rise in the water level from 5200 cal. yr BP , resulting in the expansion of the peatland. This was accompanied by the appearance of floating mats in the expanding shallow eutrophic pond harboring peat mosses in larger amounts. There is a rapid spread of *Carpinus betulus* in the adjacent closed oak woodlands at that time [7,8]. Peak distribution of *Fagus sylvatica* and *Carpinus betulus* was found between 3700 and 1750 cal. yr BP [7]. A similar expansion of Sphagna is indicated by the macrofossil diagram after 3900 cal. yr BP in the basin, with the first appearance of real acidophyllic Sphagnum peatlands dated between 2300 and 1500 cal. yr BP. From 1500 cal. yr BP there is an alternating succession of *Sphagnum* peatlands with reed and sedge peatland horizons, reflecting the alternations of cooler (*Sphagnum* peaks) and warmer (*Phragmites* peaks) periods up to the present day. Optimal *Sphagnum* peatland conditions were inferred at 500 cal. yr BP (AD 1550), with such taxa as *Sphagnum cuspidatum*. As shown by the results of Gardner [7] there is an increase in human influence in the area from 1750 cal. yr BP as seen in the drop in the amount of *Fagus* and *Carpinus*, accompanied by an advent of *Quercus*.

The past century was also a period of *Sphagnum* peatland expansion. The presence of clayey horizons embedding mollusc shells and carbonate concretions intercalating the peat horizons are clear signs of soil erosion in the adjacent areas, triggered by deforestation of the nearby slopes. As an outcome of these activities the amount of rainfall reaching the surface substantially increased, resulting in an increase of the water level in the bed of the peatland and triggering the expansion of Sphagna. A similar phenomenon was described from several other European sites [53-55].

4.3. Changes in Bog Surface Wetness

The climate reconstrucion is based on the plant macrofossil investigations of the peat sequence. **Figure 6** presents the changes of the main macrofossil groups on the cal. BP timescale. The spread of shrubs, trees and sedges at the expense of Sphagna due to the drainage or the present-day climate change is a well-known phenomenon of the Hungarian peat bogs, which are under strong continental climatic effects [56,57]. It is an obvious assumption that the detected shifts in Sphagna percentages were triggered by climatic deteriorations (colder or more humid climate). Such climate deteriorations can be noticed at 8200, 6800, 3800, 2150, 1750, 1300, 1000, 850, 500 and 200 cal. yr BP.

During these wet shifts different *Sphagnum* taxa become dominant in the basin, producing an unusual assemblage. According to the ecological investigations of Szurdoki [36] the niche breadth of the different Sphagnum species in the Hungarian peat bogs was wide, with high overlap. Szurdoki [36] argues that certain Sphagnum species utilize the different ecological resources similarly; therefore the competition between the different *Sphagnum* species is minimal. It is concluded that the strongly fluctuating environment caused the vanishing and re-establishment of Sphagna in the Hungarian peat bogs; therefore competition shortly after appearance determines the abundances. These frequently changing habitats produce strange species compositions.

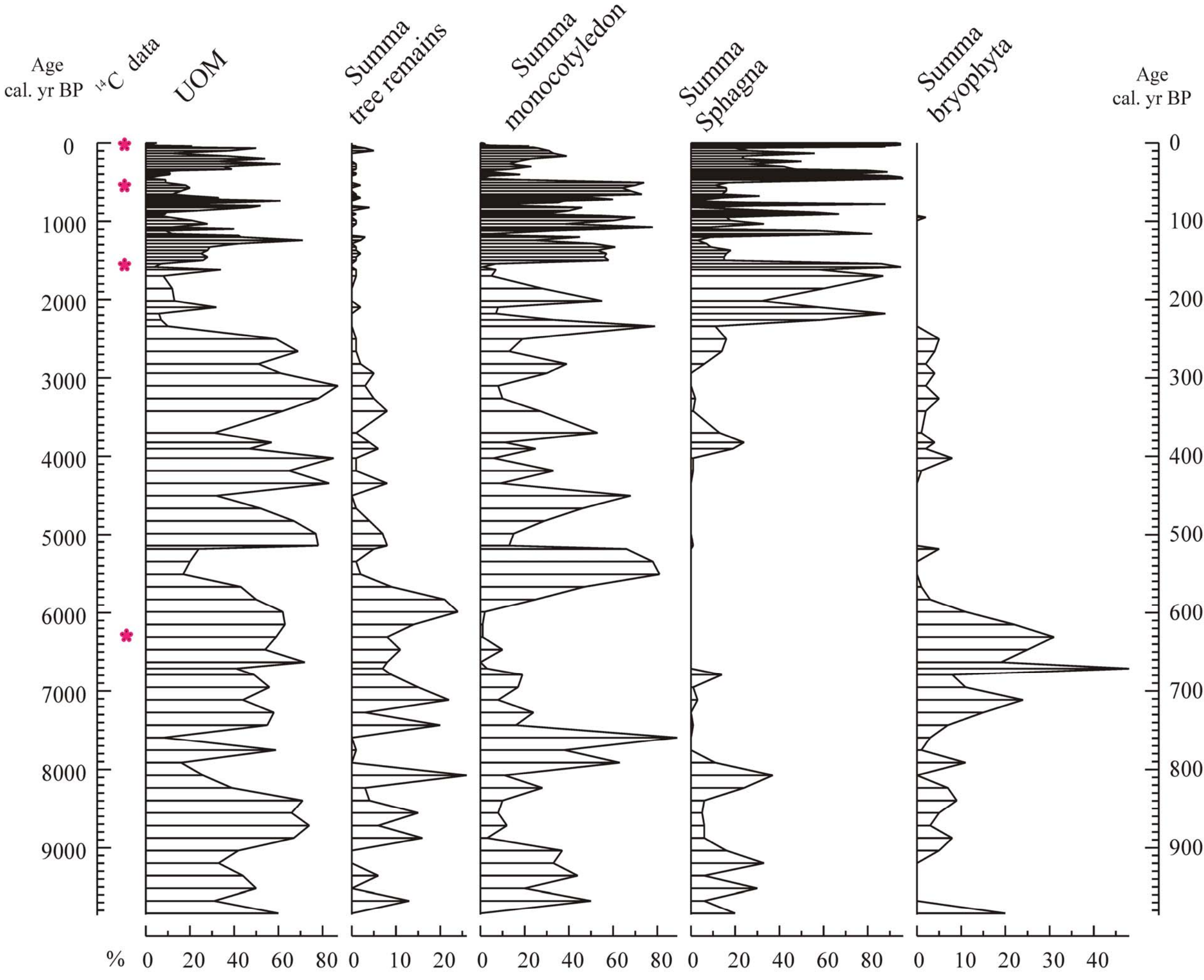
The period between 7500 and 5200 cal. yr BP can be labeled as the driest part of the bog surface wetness history. The concentration of monocot remains is very low (<5%); Sphagna remains are completely absent. In contrast UOM and tree remains (wood, ULF and budscales) show high peaks (>60 % and >20%). Open water almost completely disappeared from the basin, and an oak forest occupied most of it.

4.4. Paleoclimatic Reconstruction Based on Macrobotanical Remains

Investigations of the Sirok Nyírjes-lake peat bog provide an almost full Holocene record of vegetation development affected by climatic changes. The emergence of an oligotrophic lake in the area was dated to 9500 cal. yr BP, with deeper lake water conditions. Changes in the surficial moisture gradient of peatlands in the Carpathian Basin and those of lake level fluctuations are rather contradictory for this period.

High lake-level phases are known at 8500 cal. yr BP for different lakes and bog sin Hungary [58,59]. The inferred water levels of Lake Sf Ana in Romania show a highstand at 9500 cal. yr BP, with the emergence of a lowstand at 9000 cal. yr BP [60,61]. Conversely, studies implemented at various sites of the Great Hungarian Plain reconstructed a long-lasting dry and warm period till about 4400 cal. yr BP [43,59,62]. There seem to be substantial regional differences in the Early and Middle Holocene climate of the Carpathian Basin. Decreasing water levels inferred at 7500 cal. yr BP culminated in the driest phase of the peatland, recorded at 6400 cal. yr BP. This period is the time of Holocene climatic optimum, when there is a substantial retreat of the Swiss Alp glaciers between 7450 and 6650 cal. yr BP and between 6200 and 5650 cal. yr BP [63]. Conversely, there is an inferred increase in the water level of Lake Szent Anna in Romania from 7500 cal. yr BP onward, interrupted by a short decrease between 5500 and 5300 cal. yr BP [60, 61]. According to Cheddadi *et al*. [64] and Davis *et al*. [65] the traditionally postulated Holocene climatic optimum is identifiable only in Northern Europe. At this time southern Europe was characterized by colder conditions, with Central Europe occupying a transitionary phase. This assumption is refuted by the findings of paleoecological studies made on lake and marshland basins in the Carpathian Basin.

Nevertheless the definition and limitation of the Holocene climatic optimum is ambiguous and depends on the geographic position and the type of applied methodology. Paleoclimatological reconstructions based on pollen analytical results from Hungary argue that the Holocene climatic optimum can be detected between 7000 and 8000 cal. yr BP [66], or somewhat earlier between 7000 an 8100 cal. yr BP [67].



Figrue 6. Selected macrofossil diagram of the Sirok Nyírjes-lake peat bog. UOM = Unidentified organic material.

Following the climatic optimum there are two periods when a substantial increase in the surface moisture gradient was observable in the referred study site: at 5800 and 5400 cal yr BP. This change is congruent with the pattern observable in other lacustrine and marshland basins of the Carpathian Basin, also displaying an increase in the water level. There is a sudden increase in the water level of the Lake Szent Anna from 5500 cal. yr BP [60, 61] and Lake Balaton from 5200 cal. yr BP [58]. A somewhat delayed, similar pattern is observable in the peatlands of the GHP starting at 4400 cal. yr BP [43]. This period between 5600 and 5300 cal. BP is referred to as the Middle Holocene Climatic Transition, characterized by a sudden deterioration of the previously warm conditions as a result of the collective transformation of orbital forces, solar activity and ocean currents [68,69].

Three short-lived peat formation events were identified at 8200, 6800 and 3800 cal. yr BP, reflecting cooler conditions. Paleoecological records available from the Carpathian Basin have yielded no information of climate change for this period so far. There is a marked cooling related to a global cooling event lasting for merely 200 years, known as the “8.2 ky event” [70-73]. At 6000 cal. BP a high lake-level phase of Swiss lakes [74,75] and changes in the moisture gradient of some British peatlands [15] point to the emergence of cooler conditions. Similarly at 3500 cal. yr BP, the higher lake phase of Swiss lakes [74,76], the expansion of Alpine glaciers [77], and an increase in the moisture gradient of numerous Western European peatlands marks a cooling of the climate [15,17]. These Sphagnum shifts around 8200, 6800 and 3800 cal. yr BP at Nyírjes-lake coincide with the short-term climatic oscillations presented by Feurdean *et al*. [78] using pollen-based climate reconstruction methods.

An increase in the amount of Sphagna from 2800 cal. yr BP in the Nyírjes-lake peat bog also marks a cooling of the climate and the accompanying rise in rainfall. This deterioration of the climate, starting at 3500 cal yr BP, culminates here in the Carpathian Basin, as was shown by numerous records. Water levels were the highest in the Lake Szent Anna in Romania at this time, and there is information concerning the development of layering in the water body for this period [60,61]. Along with this data, information from studies of testacea and humic content of peatlands in the Eastern Carpathians show an increase in the moisture gradient [79]. The resuming peat formation in certain Hungarian peatlands marks the cooling of the climate here [80]. On the whole these data suggest increasing moisture availability in the Carpathians and the adjoining Carpathian Basin from ca. 3400 yr BP, with maximum moisture availability around 2700 - 2800 years BP.

The first real acidophyllic Sphagnum peatland developed at Sirok between 2300 and 1500 cal. yr BP. From here on we have a record of alternating phases of Sphagnum peatlands and sedge/reed peatlands. As displayed by the record of vegetation changes, the catchment of the referred peatland was highly prone to climatic fluctuations. Certain periods are characterized by a rapid expansion of Sphagna, and others by the expansion of sedge and reed. A sudden expansion of Sphagna was recorded at least 10 times. **Figure 6** displays a comparison of changes inferred from the Nyírjes-lake peat bog with cooler periods determined by Barber *et al*. [20] and Mauquoy and Barber [21], emphasizing changes for the last 3000 years. The Sphagnum peaks perfectly match the more humid periods identified in the British Isles at 2150, 1750, 1300, 1000, 850, 500 and 200 cal. yr BP [17,20, 21], indicating some collective global force as the cause for these changes. Barber and Charman [17] identified centennial-scale climatic fluctuations in different parts of Western Europe. The length of these cycles was variable, spanning 210, 600, 800 or 1100 years in different peatlands. No such cycles have been identified in Central Europe so far.

The bog-surface wetness investigations with testate amoebae of Schnitchen *et al*. [81] from the eastern Carpathians presented a period of greater variability in hydrological conditions after 3000 cal. yr BP. Significant shifts to wet conditions occurred, peaking at 2725, 2240, 1665, 1170, 590 and 385 cal. yr BP. These wet shifts more or less coincide with the wet periods of the Nyírjes-lake (**Figure 7**). It is worth comparing paleoecological data of the site of the present study over the last 3000 years with those of written historical records. One major climatic crisis in the Carpathian Basin is connected to the Migration Age. Written records blame famines and wars triggered by the extreme droughts during this period [82, 83]. Little environmental historical data for this time has been available so far. As shown by the *Sphagnum* curve of our referred study site, this period was indeed characterized by dry conditions (**Figure 7**) troughts during this period [82,83]. Little environmental historical data for this time has been available so far. As shown by the *Sphagnum* curve of our referred study site, this period was indeed characterized by dry conditions (**Figure 7**).

Another major historical crisis was the appearance of Mongol tribes in the area n 1241 - 1242. Certain sources blame this on severely cold weather, while others lk about the extreme droughts [84,85]. As shown by our paleoecological data for the Nyíres-lake peat bog, Hungary was characterized by extremely warm conditions during this period, resulting in an almost complete dessication of the *Sphagnum* peatland. The *Sphagnum* curve of the Nyíres-lake enables us to identify the period of the

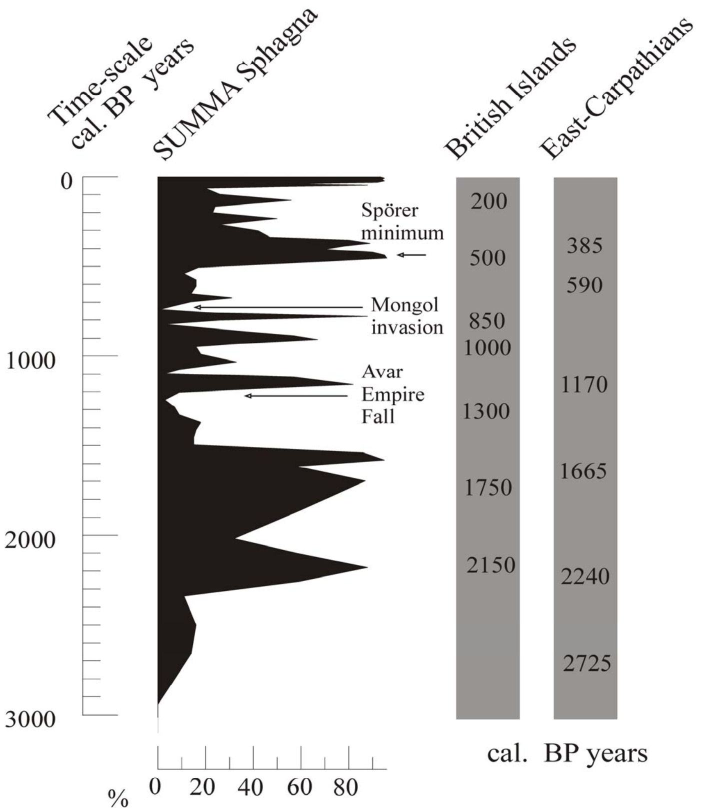


Figure 7. Comparison of bog surface wetness changes of the Sirok Nyírjes-lake and some British [20,21] and Romanian [79] peat bogs in the last 3000 years. The arrows show some historical events.

Little Ice Age (LIA), dated between the middle part of the 16th century till the middle part of the 19th century [86-88]. The environmental record for the Nyírjes-lake peat bog fits with these events as well. The most diverse Sphagnum taxa, including the hygrophilous *Sphagnum* cuspidatum, was present here at the end of the 16th century. *Sphagnum cuspidatum* does not currently occur in the Nyírjes-lake. Western European peatlands were similarly prone to the fluctuating climate of the LIA [89]. Wetter conditions were identified from the beginning of the 16th and middle part of the 17th centuries. LIA climate deterioration can be detected in several proxy-climate records in the Carpathian Basin as well. Based on the Eastern Carpathian tree-ring width chronology of Popa and Kern [90] the fingerprint of the LIA is visible between AD 1370 and 1630, followed by lagged cold decades in AD 1820 and 1840. Tree-ring data between AD 1460 and 1510 strongly correlated with Alpine reconstructions. This suggests strong regional forcing predominant over the eastern Carpathians and the Alps, producing a uniquely European signal. The high-resolution stable isotope and trace element records from a stalagmite from Hungary showed that during the LIA, the coldest years (longer or colder winters) occurred from around AD 1550 to ca. 1700 [59].

4.5. Anthracological Analysis

A total of 138 samples, containing 6062 identified pieces of charcoal derive from the rescue excavations of the MO motorway [10]. The age of the samples was obtained according to the archaeological findings. **Figure 8** represents the relative frequencies of the identified taxa obtained from the charcoal fragment counts of the most frequent taxa and the sum of *Spagnum* chronologically.

During the Late Iron Age only two genera occurred, 87.3% of the charred wood material is *Quercus*, while the remaining 12.7% is *Fraxinus* (**Figure 8**). During the Sarmatian period the anthracological material is more diverse, unlike in the previous period. 85.4% of the charred wood remains is *Quercus*, 12.2% is *Ulmus*, 1.4% is *Fraxinus*, 0.8% is *Fagus* and 0.2% is *Carpinus*. The diversity of the anthracological material may indicate that because of the decrease in the number of the main forest taxon (e.g. *Quercus)* other species have also been used for firewood as well as *Quercus*, although the number of *Quercus* fragments in the charred wood assemblage is still the highest. For the enlargement of ploughed land areas the felled trees may have been used for cooking, fires and making tools.

During the Migration period only a few pieces of

Quercus and *Ulmus* charcoals were found. The anthracological material of the Middle ages indicate *Quercus* and *Carpinus* presence with values of 74% and 26%.

5. Conclusions

If we would like to understand the background of the natural variability of the prospective climatic change, it is important to study the climate of the past. For this reason and the understand the changeability of the Holocene climate, it is significantly important to study and analyze peatbogs. As a matter of fact, by the analysis of plant macrofossils it is possible to detect the change of the surface wetness of bogs. In this way, the proxy data give information about the temperature of the different vegetation periods of different periods of time.

According to Blaauw *et al*. [91] there is a strong relationship between the moisture gradient of peatlands and solar activity reflected in the correlation of the former parameter with a proxy for δ^{14}C. One may properly ask what component of the climate controls the moisture gradient of peatlands via fluctuating solar activities? Surficial wetness is controlled by a complex interplay of precipitation and evapotranspiration of the plants, seen in such parameters as annual average rainfall and evaporation and influenced by the temperatures of the growth season. There are no surficial water courses feeding the Nyírjes-lake peat bog, so runoff must have been influential only during the past 100 years based on the hydrology of the peatland.

As was shown in Western Europe the moisture gradient of peatlands for the past 3000 years was primarily determined by fluctuations in the temperature of the vegetation season, rather than the amount of rainfall [16, 17,22,92-94]. According to Charman [95], in the Atlantic part of Europe summer precipitation and summer temperatures control the moisture gradient of peatlands. The pollen-based climate reconstructions from the eastern Carpathians [78] suggest that summer temperatures between 11200 and 8300 cal. yr BP were similar to those of the present. Between 8000 and 2400 cal. yr BP summer temperatures were higher than now. Pollen-based climate reconstructions indicated that summer temperatures became cooler in the last 2400 years. It seems that these general trends of summer temperatures determined the surface wetness history of the Nyírjes-lake peat bog. The relationships to other climatic parameters (e.g. annual precipitation, annual and winter temperature) investigated by Feurdean *et al*. [78] are conflicting. Unfortunately, macrofossil studies are not capable to accurately predict former temperatures or precipitation rates. Only the major trajectories of climate changes can be identified.

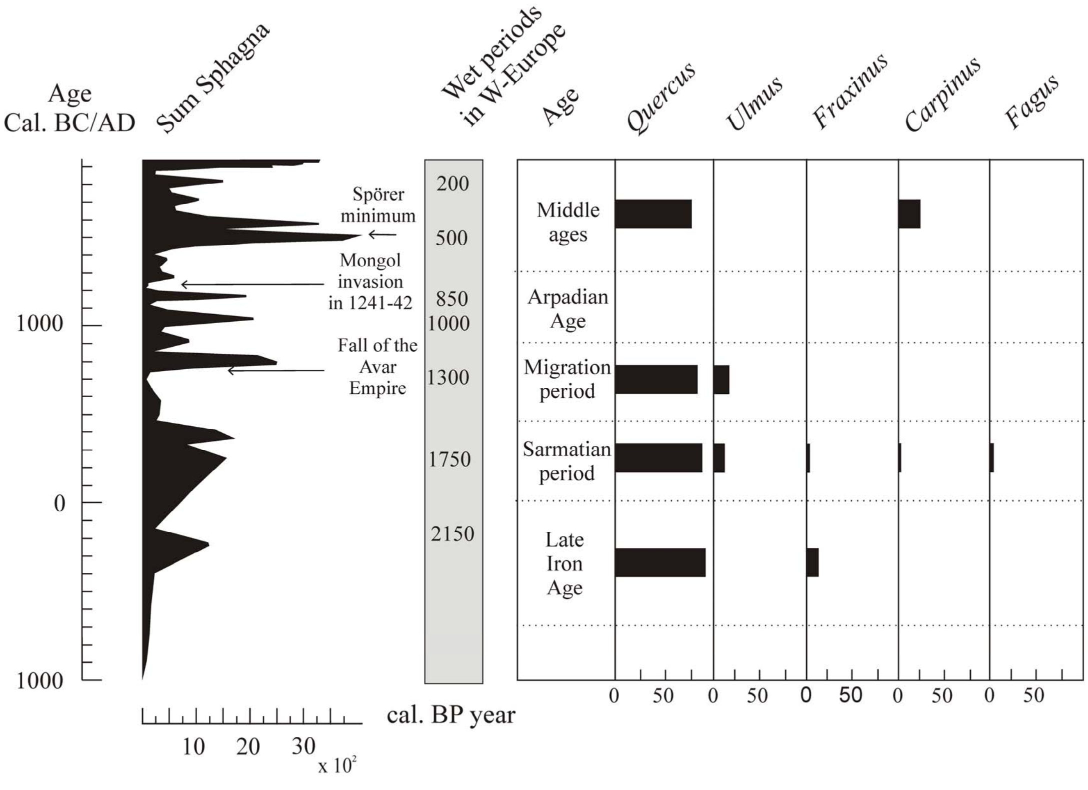


Figure 8. Bog surface wetness changes and relative frequencies of the most frequent taxa obtained from charcoal fragment counts.

The modern distribution of *Sphagnum* peatlands in Hungary enables us to provide a rough estimate. *Sphagnum* peatlands appear in areas characterized by a precipitation of 600 mm per annum. Below this threshold one comes across only sporadic occurrences, while there are no Sphagna known below the lower limit of 550 mm. Based on the results for the Nyírjes-lake peat bog conditions in the lower hilly areas during the drier periods of the past 3000 years may be inferred to have been similar to those of the central parts of the GHP. The complete disappearance of Sphagna from the area must be linked to a steady drop in rainfall, resulting in at least 50 mm deficit in the local water balance. This could have been achieved by an increased evapotranspiration as a result of elevated temperatures of the summer growth season. This deficit value must have exceeded even 100 mm during the Middle Holocene Transition.

These changes are supported by the studies of Zoltán Szelepcsényi [11,12]. In as much as the increase of the "cool temperate subhumid forest-steppe", life zone's area was successful in visualizing in the centre of Carpathian Basin applying the modified Holdridge life zone system during the last century. Thus we can observe the regional effect of the global warming (**Figure 9**). This progression's influence was detected in the change of the surface wetness of the Nyírjes bog. The surface wetness decrease

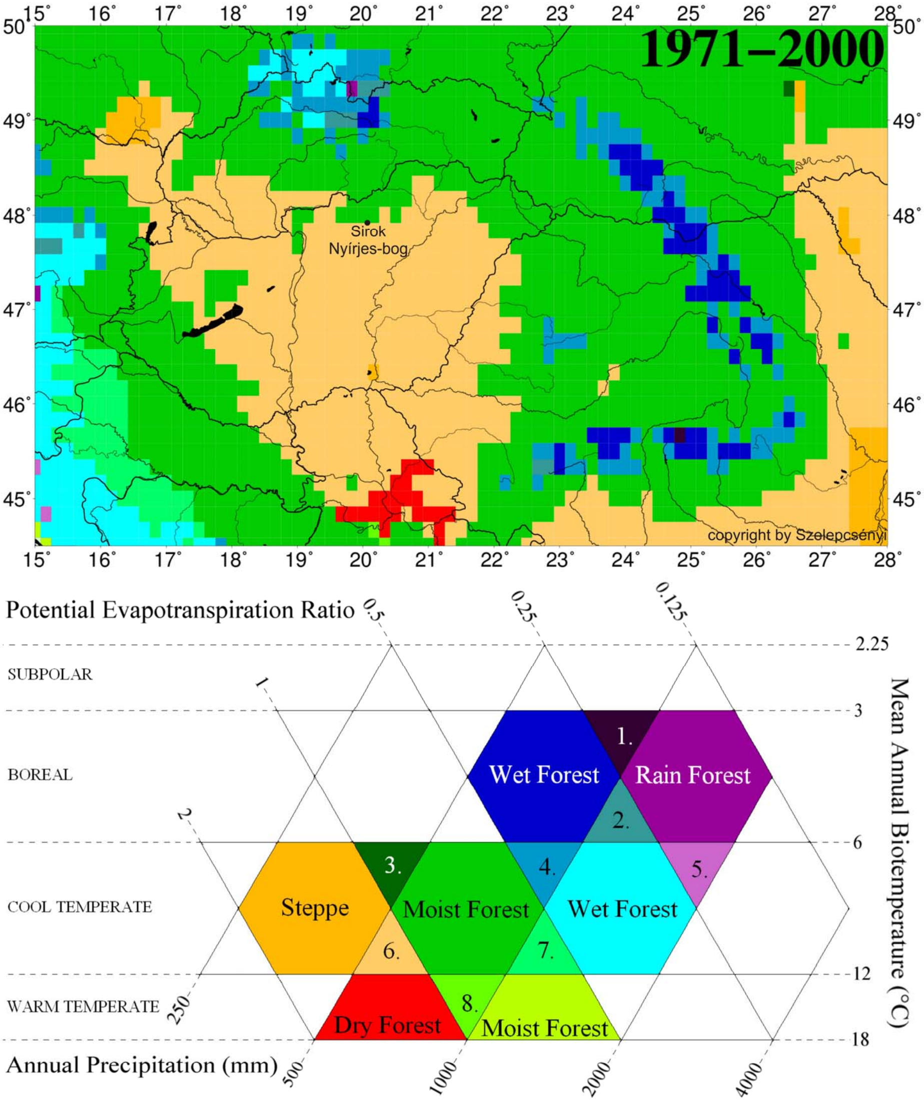


Figure 9. The spatial pattern of life zones at the end of 20th century (1971-2000) in Carpathian Basin for the modified Holdridge life zone classification [33] for the database CRU TS 1.2 [34]: 1) Boreal superhumid wet-rain forest; 2) Boreal perhumid wet-rain forest; 3) Cool temperate humid forest-steppe; 4) Cool temperate perhumid moist-wet forest; 5) Cool temperate superhumid wet-rain forest; 6) Cool temperate subhumid forest-steppe; 7) Cool temperate humid moist-wet forest; 8) Warm temperate humid dry-moist forest.

in long term and in 30 - 50 years the amount of *Sphagnum* species decline. The development of Sphagna peat decline, the amount of reed and sedge decrease and reed-sedge peat formed in Nyírjes-bog at Sirok. Parallel to this an open forest and forest steppe developed surrounding the bog.

These changes had a major effect on the human populations living in the basin during the last 3000 years. Almost in every warmer and drier climatic phase the forest steppe vegetation expanded and stock-breading populations (Scythian, Sarmatian, Avarian, Pecseng, Kun) became significant in the study area. The use of different types of wood was very low and homogenous, only a few species were used on the basis of the anthracological analysis of samples derive from archaeological sites [10].

On the basis of palaeoecological and environment historical research until now, the recent climatic change and warming up [4] would cause similar changes in the ecosystem of the Carpathian Basin as the previous warming up phases. The forest steppe vegetation would expand from the recent 100,000 km^2 to 130,000 - 150,000 km^2 parallel to this the ratio of the forested areas decrease on the foot of Carpathians the forests will open up and forest steppe vegetation will develop. The drought and temperature sensitive species such as Fagus could survive these conditions on the north slopes of hills and in deep valleys, populations living on plains or lowlands will dry out [5]. Drought resistive wood species, such as oaks will come into prominence but their stands will be loose structured. Parallel to these changes the agriculture and forestry of these areas will transform. The importance of forestry might decrease while animal husbandry increases —populations and agricultural communities living in the Carpathian Basin responded very similar to climatic changes during the last 3000 years.

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