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Occurrence of peat mosses in the Białowieża Forest (NE Poland) and their conservation status

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Abstract: Twenty-two *Sphagnum* species are reported from the Białowieża Forest in north-eastern Poland. Data on their distribution are based on 243 localities in 122 forest sections. The phytosociological preferences, conservation status, and short description of distribution in Poland of these species are described as well.

Key words: *Sphagnum*, distribution, Białowieża Forest, National Park, phytosociology, Poland

1. Introduction

The Białowieża Forest, located in north-eastern Poland, is the largest and most valuable primeval forest in the European lowlands. The best-preserved forest communities, which are the most precious, are protected as the Białowieża National Park. The Park covers 10 502 ha, which accounts for about 15% of the entire Białowieża Forest. In 1977 the Park was registered as a World Biosphere Reserve and in 1979 it was included in the UNESCO list of the World Natural Heritage (Denisiuk & Witkowski 1990; Okołów 1993). This ecosystem is extremely important for biodiversity conservation. Therefore, its area is particularly intensively investigated (Karpiński & Okołów 1969; Okołów 1976, 1983, 1991, 1997). The available literature, however, contains little information on bryophytes and particularly on *Sphagnum* mosses. General information on mosses in the Białowieża Forest was given by Gocławska (1968). Among other bryophytes, the distribution of 10 species of *Sphagnum* in the Białowieża National Park was presented by Żarnowiec (1997) within the framework of the 'CRYPTO' project (Faliński & Mułenko 1997). Besides, some information about *Sphagnum* species can be found in descriptions of forest communities in the Białowieża National Park (Sokołowski 1993) and of the bog Berezowe Lado (Magiera 1986).

This paper presents results of preliminary research on the distribution of mosses in the Białowieża Forest, including the Białowieża National Park. Information on occurrence of peat mosses in various plant communities is also included. Besides, on the basis of specimens from Polish herbaria, it was possible to compare the distribution of peat mosses in the Białowieża Forest with their distribution in Poland. A synthesis of previously recorded information and original results from field surveys was made to identify further research opportunities for effective, region-wide, plant conservation.

2. Material and methods

The study of peat mosses involved the Polish (western) part of the Białowieża Forest. Specimens collected during this study are deposited in the Department of Geobotany (presently part of Natural Collections, Adam Mickiewicz University (POZG). The herbarium materials of other researchers from the following institutions were verified: Department of Geobotany, Adam Mickiewicz University (POZG); Natural Forest Department, Forest Research Institute in Białowieża (BIL); Department of Systematic and Phytogeography, Maria Curie-Skłodowska University in Lublin (LBL) (abbreviations of herbaria are followed after Mirek *et al*. 1997). Besides my own collection, the following researchers kindly gave their gatherings for my studies: W. Adamski, A. Dembiński, D. Gocławska, K. Karczmarz, A. Kawecka, E. Krawczyk & E. Pszczółkowska, S. Lisowski, S. Nikitiuk, M. Petrowicz, A. Rusińska, P. Urbański, D. Sobotka, A. Sokołowski, G. Wojciuk and J. Żarnowiec.

The current status of explorations conducted in the Białowieża Forest on the basis of all the samples verified

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so far, is presented in Figure 1. Data coming from 243 sites are marked on a grid of 122 forest sections. The presence of *Sphagnum* species in a given section is marked by a circle, regardless of the number of its localities in the section (Fig. 1). Neither literature-derived data nor specimens from uncertain localities are included in the map.

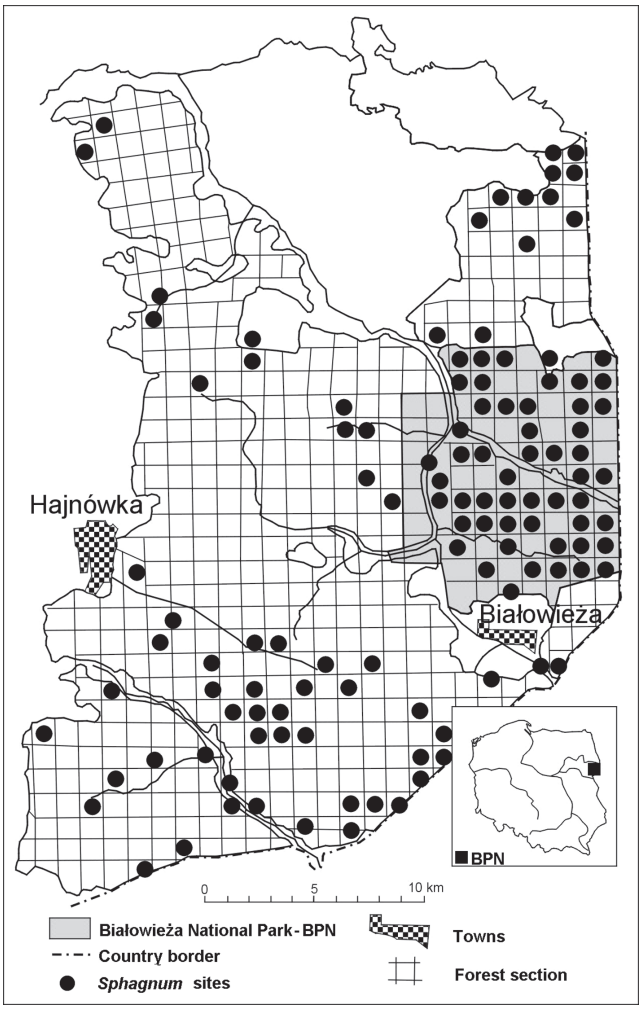

Fig. 1. The status of bryological explorations of the Białowieża Forest, based on distribution of *Sphagnum* species

The criteria shown in Table 1 were used for the determination of frequency. Occurrence of *Sphagnum* species in main forest associations in the Białowieża Forest, and their ecological characteristics is presented in Table 2.

The conservation status of peat mosses (Table 3) was based on an assessment of the following factors: (*i*) estimated number of sites of the given species in the study area, (*ii*) abundance of the species on those sites on the basis of published phytosociological releves and my own observations, (*iii*) geographic distribution (range) of the species, and (*iv*) actual or potential threats to the species or its habitats (see also: Hallingbäck *et al*. 1995). The conservation status is only preliminary because no detailed information is available on population size and its changes during the past years. Also, no quantitative analysis of extinction probability is at hand.

All information on the occurrence of *Sphagnum* species in Poland is based on verified herbarium materials, which are available in Polish herbaria (Melosik 1993, 1996, 2000, 2006; Melosik & Urbański 1997) and original, unpublished results. Materials from the following herbaria were taken into account: BIL, KTU, KRAM, LBL, LOD, OLS-M, POZG, POZM, POZNB, SOSN, SZCZ, SZUB, TRN, UGDA-B, WA, WRAB, WRSL, WSRP (Mirek *et al*. 1997).

The nomenclature and systematics of *Sphagnum* followed Corley *et al*. (1981), except for the names of species of the section *Subsecunda* which were accepted after Isoviita (1966).

Full scientific names of all plant communities mentioned in this article are in accordance with the Code of Phytosociological Nomenclature (Barkman *et al*. 1986; Brzeg & Wojterska 1996; Brzeg *et al*. 2000). The information about plant communities derives from labels of herbarium samples and the literature where those specimens were mentioned. Besides, original field observations were made.

3. Results

Field research and herbarium material indicate that 22 *Sphagnum* species occur in the Białowieża Forest. *S. capillifolium**, *S. palustre*, *S. girgensohnii*, *S. squarrosum*, *S. fallax* , and *S. magellanicum* are the most frequent in the study area (Table 2). Three of them (*S. capillifolium*, *S. palustre*, *S. girgensohnii*) grow in plant communities from three phytosociological classes: mesotrophic habitats of boreal coniferous forests

* Author's names see Table 3

Table 1. Criteria defining the assigning of species to the frequency classes

Frequency class (K)	Definition of frequency	Number of localities
I	rare	1-3
II	rather rare	4-11
III	infrequent	12-18
IV	rather frequent	19-44
V	frequent	45-68
VI	common	69-113

(*Vaccinio-Piceetea*), willow thickets and alder swamp forests (*Alnetea glutionosae*) and bog communities (*Oxycocco-Sphagnetea* The peat mosses can be found in all or almost all specified plant communities where they form mats in relatively dry, partly shaded or shaded sites (Table 2). In the habitats examined, *S. fallax* is a component of plant communities belonging to two classes (*Oxycocco-Sphagnetea* and *Vaccinio-Piceetea*) where it accommodates to different conditions of light and water supply.

patches of sub-continental bog pine forest and sub-boreal spruce forest, but it is also often present in more distinctly minerotrophic sites: in birch swamp forest (ass. *Dryopterido thelypteris-Betuletum pubescentis*). Rarely, it is found in woodless bogs, where it is scattered among *S. magellanicum* and *S. russowii*. In wooded areas (coniferous forests) it co-dominates with *S. magellanicum*.

S. fimbriatum has a broad phytosociological amplitude but predominantly it can be found in shaded situa-

Table 2. Occurrence and of *Sphagnum* species in main forest associations in the Białowieża Forest, and their ecological characteristics

Sphagnum species	Frequency class	No of localities	Plant communities										Ecological characteristics		
			1	2	3	4	5	6	7	8	9	10	11	12	13
palustre	VI	99	•		•	•	•	•	•	•	•	•	S/P/O	MT	P
centrale	III	17			•	•				•		•	S/P	MT	P
magellanicum	V	53	•		•	•		•		•	•	•	O/P	O	P
capillifolium	VI	113	•	•	•	•	•	•	•	•	•	•	P/S	O/MT	MS/P
warnstorfii	II	8	•							•		•	O/P	E/MT	P
russowii	III	18				•	•	•		•	•	•	P/O	M	P
girgensohnii	V	62	•	•	•	•	•	•		•	•		S	MT	P
fimbriatum	IV	37			•	•	•	•	•	•		•	P/S	MT	P
subnitens	II	7			•	•		•				•	S	MT	P
teres	I	3										•	O/P	E	P
squarrosum	V	68			•	•		•	•	•	•	•	P/S	M/E	P/MS/W/L
wulfianum	III	12		•	•	•						•	S/P	MT	MS/P/W/L
subsecundum	I	2				•							O/P	M/E	P
contortum	I	1										•	O/P	M/E	P
inundatum	I	1	undefined community										O	M	P
angustifolium	IV	44	•		•	•						•	O/P/S	M	P
fallax	VI	81	•		•			•					O/P/S	*	*
flexuosum	III	13	•					•		•		•	*	*	*
obtusum	I	3				•				•			*	*	*
cuspidatum	II	11	•	•				•			•	•	P	O/M	P
riparium	II	10				•							P	M	P
compactum	I	3				•		•					O	O	P

Explanations: 1-10 plant communities: 1 – continental bog *Ledo-Sphagnetum magellanici* Sukopp 59 em. Neuhsl. 69; 2 – moist pine forest *Vaccinio myrtilli-Pinetum* Juraszek 28 nom invers.; 3 – sub-continental bog pine forest *Vaccinio uliginosi-Pinetum* Kleist 294; 4 – sub-boreal spruce forest *Sphagno girgensohnii-Piceetum* Polakowski 62; 5 – swamp birch-spruce forest *Betulo pubescenti-Piceetum* Sokoł. 80; 6 – oak-spruce forest *Querco-Piceetum* (Mat. 52) Mat. et Pol. 55; 7 – willow thicket *Salicetum cinereae* Kobendza 30; 8 – alder swamp forest *Sphagno-Alnetum* Lemée 37; 9 – acidophilous oak-dominated forest *Carici elongatae-Quercetum* Sokoł. 72; 10 – birch swamp forest *Dryopterido thelypteris-Betuletum pubescentis* Czerwiński 72; 11-13 ecological characteristics: 11 – light conditions: P – partly shaded; S – shaded; O – open; 12 – trophic conditions: O – oligotrophic; MT – mesotrophic; E – eutrophic; 13 – substrate: MS – damp mineral soil; P – peat; W – rotten wood; L – slightly decomposed litter; understrike – optimal conditions; * lack of the data

In turn, *S. squarrosum* is found in patches of *Vaccinio-Piceetea* and *Alnetea glutinosae*, with an optimum of its occurrence in the latter.

S. magellanicum forms deep peat in acidophilus communities from the class *Vaccinio-Piceetea*. Rarely, it can be found in mesotrophic birch or alder swamp forests. Besides, it grows in *Ledo-Sphagnetum magellanici*, an association typical for continental bogs. The species is associated with numerous taxa, most commonly with *S. angustifolium, Polytrichum strictum* and *Aulacomnium palustre*.

S. angustifolium, and *S. fimbriatum* are rather frequent (frequency class IV, Tables 1 and 2) in the Białowieża Forest. *S. angustifolium* is found predominantly in partly shaded or shaded habitats in acidophilous

tions in associations from classes *Vaccinio-Piceetea* and *Alnetea glutinosae* (Table 2, ass. 3-8, and 10), where it forms extensive loose hummocks or cone-shaped mounds. It is usually found with sporophytes. *S. angustifolium* and *S. fimbriatum* are not threatened with extinction under present conditions (Table 3).

S. russowii is an infrequent species, but it is apparently not threatened in the study area (Tables 1-3). It occurs in wet coniferous woods, wet birch forests, and other habitats (e.g. on sides of drainage ditches). The optimum of its occurrence is in communities of the class *Vaccinio-Piceetea*, although it can also be found in plant communities of the class *Alnetea glutinosae*.

In the Białowieża Forest, *S. centrale* is an infrequent species, which prefers mineral-rich, shaded swampy

habitats. It occurs mainly in alder swamp forest but it is also reported from boreal spruce forest and bog forest. This moss can be classified as vulnerable in the study area (Tables 2 and 3).

S. wulfianum is also infrequent in the Białowieża Forest (frequency class III, Tables 1 and 2). It has been collected in plant communities of the classes *Vaccinio-Piceetea* and *Alnetea glutinosae*. It can be classified as critically endangered in the study area because it occurs in only a few localities, with fewer than 250 individuals each.

S. flexuosum is an infrequent species. Lake *S. fallax* it exhibits a similar, relatively broad, phytosociological pattern of its occurrence (Tables 1 and 2). However, it is not so widely distributed in the studied complex probably due to lack of suitable wet or inundated, acid habitats.

Like the previous species, *S. cuspidatum* is also rather rare and vulnerable in the Białowieża Forest (Tables 1 and 3). It can be rarely found in oligotrophic or oligo-mesotrophic acidic communities, in local depressions with the water table above the ground level. Additionally, several rare species have been found in the Białowieża Forest (Table 1). The lowest frequency classes (I and II) contain the following species: *S. subsecundum, S. contortum*, *S. teres*, *S. warnstorfii*, *S. obtusum*, *S. riparium*, *S. inundatum*, *S. compactum* and *S. subnitens*.

S. riparium (Tables 1 and 2) is found in mesotrophic bog spruce forest in hollows filled with stagnant water. Besides, several other herbarium specimens of this species originate from pine-birch forest and alder forest, but the plant communities have not been defined precisely.

The basophilic species, like *S. warnstorfii* (Tables 1 and 2), *S. teres*, *S. obtusum*, *S. contortum* and *S. subsecundum* are found in wet, shaded mesotrophic habitats. *S. obtusum* and *S. warnstorfii* has been recorded in *Sphagno-Alnetum, S. contortum* and *S. warnstorfii* are present in *Dryopterido thelypteris-Betuletum pubescentis,* while *S. obtusum* and *S. subsecundum* in *Sphagno girgensohnii-Piceetum*. *Sphagnum inundatum* was found in an undefined forest community and, in turn, *S. subnitens* in bog pine and spruce forests. *S. compactum* was also found in wet forests but there it tends to occur on sunny, disturbed sites where the associated vegetation is low. All these peat mosses are endangered (Table 3) in the study area.

Sphagnum species in the Białowieża Forest are very common and important constituents of the moss flora of the following plant communities: *Betulo pubescenti-Piceetum, Sphagno girgensohnii-Piceetum, Vaccinio uliginosi-Pinetum*, *Sphagno-Alnetum* and *Ledo-Sphagnetum magellanici* (Table 2).

4. Discussion

According to a recent regional division of Europe (Kondracki 1988), Poland is generally viewed as a physiographic section of Western Europe. Only some units in the east and north-east of Poland are regarded

Table 3. Suggested conservation status of *Sphagnum* species in the Białowieża Forest

Sphagnum species	Suggested local conservation status in Białowieża Forest	Definition of local conservation status
capillifolium (Ehrh.) Hedw.	secure	common to very common, not threatened with extinction under present conditions
girgensohnii Russ.	secure	
palustre L.	secure	
magellanicum Brid.	secure	
squarrosum Crome.	secure	
angustifolium (Russ.) C. Jens.	secure	
fallax (Klinggr.) Klinggr.	secure	
fimbriatum Wils.	secure	
russowii Warnst.	apparently secure	uncommon but widespread in Poland and in study area
centrale C. Jens.	vulnerable	rare and local, found only in a restricted range
cuspidatum Erhr. *ex* Hoffm.	vulnerable	
flexuosum Dozy & Molk	vulnerable	
subsecundum Nees	endangered	rarity or some factor(s) threaten it with extinction in the study area
inundatum Russ.	endangered	
contortum Schultz	endangered	
teres (Schimp.) Ångstr.	endangered	
warnstorfii Russ.	endangered	
riparium Ångstr.	endangered	
compactum DC	endangered	
subnitens Russ.	endangered	
obtusum Warnst.	endangered	
wulfianum Girg.	critically endangered	extreme rarity

as belonging to Eastern Europe. This subdivision is related to the extent of Atlantic and continental climatic influences, the diversification of geological substrate, and, as a consequence, the presence of specific vegetation zones.

Climatically, the Eastern European subdivision (i.e. north-eastern part of the country, where the Białowieża Forest is located), is characterized by an eastward gradient of increasing continentality. In Poland the range of annual mean temperatures is from 6°C in the north-east to 8°C in the southwest (Woś 1999; Krawczyk & Błażejczyk 1999).

A biogeographical analysis of vegetation indicates a transitional location of the Białowieża Forest in Europe. In comparison with the western and southern regions, boreal-(sub-)continental and boreal-mountain elements are much more numerous there. This is most evident in the continental-type forest habitats (e.g. spruce forest communities). On the other hand, one can still find there affinities with the flora of the Baltic Subdivision, e.g. species with a suboceanic distribution (Faliński 1977, 1986; Sokołowski 1966a, 1966b, 1968, 1972, 1979, 1980, 1993), which dominate in deciduous woodlands.

The following species found in the Białowieża Forest are assigned to the north-eastern group of species (Daniels & Eddy 1985): *S. angustifolium, S. centrale, S. warnstorfii, S. contortum, S. obtusum, S. riparium* and *S. wulfianum*. Among them, only *S. angustifolium* and *S. centrale* are not rare in the study area, although the latter is rare and scattered in Poland (Melosik 2006). The distribution of *S. angustifolium* in Poland has not yet been investigated fully but it can be found certainly more often in the study area than in north-western Poland (Melosik & Urbański 1997; Brzeg *et al*. 1995, 1996; Lisowski *et al*. 2000 and my original results of verification of herbarium specimens). In the study area it colonizes rather shaded sites, but in other areas of the country it is found predominantly in open, wet, mesotrophic mires and oligotrophic peat bogs, where it grows as an intermediate between hollow species and hummock-builders.

The remaining north-eastern species – *S. obtusum, S. warnstorfii* and *S. contortum* – are rare and scattered in the study area. Similarly, *S. subsecundum*, considered as a circumpolar boreal-montane taxon (Hill & Preston 1998), is frequently encountered in north-eastern Poland, which is more strongly affected by the continental climate (Melosik 2000). Therefore, the climate is not a limiting factor of their restricted occurrence in the studied complex. Their rarity can be explained by the absence of suitable habitats: open or only partly shaded small-sedge communities and related communities of fens, transitional mires and quaking bogs with high cationic contents of water.

Also, the scarcity of bog meadows (from the order *Molinietalia*) and minerotrophic fens (from the class *Scheuchzerio-Caricetea fuscae*, mainly from the alliance *Caricion lasiocarpae*) is probably the cause of rarity of *S. teres* in the study area. Like the above-mentioned species, it is an indicator of more base-rich areas.

The lack of sites subject to mineral groundwater flow, or lakes and ponds where the contact with water movement is present, can explain the limited occurrence of *S. obtusum* in the study area.

Also *S. riparium* has its optimum in wet, minerotrophic fens and open swamps, which are extremely rare in the study complex. According to Daniels & Eddy (1985), *S. riparium* is restricted in Poland to only the northern part of the country. However, on the basis of verified Polish herbarium collections (Melosik, unpublished), this information cannot be fully confirmed. The majority of its sites are indeed concentrated in the northern part of the country (mainly the Pomeranian Lakeland) where it can be found in minerotrophic fens, open swamps and small fens in the transition zone between water (lakes, ponds) and mineral soil. Besides, it occurs also in central and southern regions but in scattered locations. In the Western Carpathians it is rare and reaches a maximum altitude of 1230 m a. s. l. in the Pyszniańska Valley in the Tatra Mts. Outside the Carpathians it is rare, reported from only single localities in the Sudety Mts. (but see: Wojtuń 2006).

The mesotrophic and shade-tolerant species *S. wulfianum* is one of the rarest peat mosses in Poland. It is located in several isolated stands across the north-eastern province of Poland (Gocławska 1966; Sokołowski 1969; Sobotka 1975; Karczmarz & Kornijów 1981; Karczmarz & Sokołowski 1981, 1987, 1992, 1995). The sites in Poland form the western limit of this species. This confirms that *S. wulfianum* is clearly dependent on the sub-continental climate (Daniels & Eddy 1985). However, the known Polish north-eastern stands of this species together with its single locality in the north-western part of country (Herbichowa 2001) indicated that the map of distribution presented by Daniels & Eddy (1985) is not complete. In Poland, most frequently it can be found in the lowland wet spruce forest *Sphagno girgensohnii-Piceetum*.

The abundance of sites of boreal-mountain elements, like *S. girgensohnii* and to a lesser extent *S. russowii* (Düll & Meinunger 1989) in the Białowieża Forest, probably results from the abundance of suitable microhabitats (shaded, rather mesotrophic, and relatively dry) and the influence of sub-continental climate. However, the most favourable habitats for *S. girgensohnii* are found in mountains in the southern part of Poland, where it predominantly occurs in planted spruce forests (Melosik, unpublished).

Sphagnum russowii, like *S. girgensohnii,* occurs abundantly in the mountains, predominantly in the Carpathian spruce forest and dwarf mountain pine thickets. The upper altitudinal limit (1800 m a. s. l) in Poland is in the Tatra Mts., in the association *Trifido-Distichetum*. In Poland, this peat moss is scattered but it occurs throughout most of the country. It can be found in habitats similar to *S. girgensohnii*, which often accompanies it. However, it tends to favour more exposed sites than the latter species. Unlike *S. girgensohnii, S. russowii* does not appear to form a dominant part of the vegetation and usually grows in smaller tufts.

Also, the majority of verified Polish collections of *S. compactum* are from uplands and mountains, whereas 37% come from lowlands. It is widely distributed in mountainous regions (particularly in the Tatra and Beskid Mts.) of southern Poland, reaching the altitude of 1890 m on Kołowa Czuba (Tatra Mts.) (Melosik unpublished).

The lack of open oligotrophic habitats and of habitats that are subject to human disturbance (where the associated plants are low and sites are well illuminated) can be a reason of its rarity in the study area. Also the amount of precipitation can limit its growth (Daniels & Eddy 1990; Zechmeister 1995). Annual precipitation in Poland ranges from 1200 to 1500 mm in the highest parts of mountains, from 700 to 1000 mm in the uplands (where the majority of its stands are located), and from 400 to 600 mm in the lowlands (in the Białowieża Forest – 670 mm).

On the other hand, as was mentioned above, it is still possible to find suboceanic species in the study area. *S. cuspidatum,* a hygrophilous species restricted to more oligotrophic, wet conditions (Daniels & Eddy 1985), is infrequent in the study area. However, in Poland it demonstrates the greatest growth dynamics in communities of the order *Littorelletalia uniflorae* Koch 1926, particularly in the association *Sphagneto cuspidato-obesi*, restricted in its occurrence to the western part of the country. Two other suboceanic species – *S. subnitens* and *S. flexuosum* (Daniels & Eddy 1985; Hill & Preston 1998) – are rather rare in the Białowieża Forest. According to the Polish herbarium material verified by me to date and original observations, *S. subnitens* is scattered mainly in the western parts of the country, gradually becoming rare towards the east and south. In Poland it has its optimum in acidophilous mires with low sedges (order *Caricion fuscae*), which are rare in the Białowieża Forest. The detailed distribution of *S. flexuosum* in Poland is unknown although it probably occurs throughout the country.

The part of the peat moss flora of the Białowieża Forest is made up of widespread, common or frequent circumboreal or Europeo-boreo-temperate species (Hill & Preston 1998). A high proportion of these species are found in all or almost all provinces of Poland. The following species can be assigned to this group: *S. capillifolium S. palustre, S. magellanicum, S. squarrosum, S. fallax* and *S. fimbriatum*.

The lack of appropriate habitats – open sites, oligotrophic conditions – also accounts for the absence of *S. rubellum* and *S. fuscum*. The latter species, although restricted in its occurrence in hyperoceanic and oceanic areas, becomes a dominant hummock species under subcontinental and continental conditions.

According to general information of Gocławska (1968), 21 *Sphagnum* species had been reported from the area. Some of them were very rare in Poland, e.g. *S. tenellum* (Brid.) Brid. and *S. jensenii* Lindb. However, these records lack proper documentation, which would provide a basis for either accepting or rejecting the report.

In conclusion, climatic conditions, local water chemistry and predominance of forested areas are the most important factors limiting the occurrence of peat mosses in the study area.

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