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SPECIES AND ECOLOGICAL DIVERSITY OF BRYOPHYTES OCCURRING ON MIDFOREST ROADS IN SOME FOREST NATURE RESERVES IN CENTRAL POLAND

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ABSTRACT. The paper presents socio-ecological and ecological characterisation of 72 bryophyte species found in the years 2008-2012 on midforest roads passing through nine nature reserves situated in the Łódź region. Nine species occurred exclusively in this habitat. Most of the species noted (63%) were forest bryophytes occurring also inside the forest phytocoenoses studied, they constituted 95.5% of all the records. The non-forest species show different socio-ecological relations: some of them occur typically on meadows or in grassy forest ecotones, others – in fens or bogs but there are also some pioneer bryophytes colonizing initial sites, both of natural and anthropogenic character. They differ from the forest species occurring on midforest roads in their ecological demands regarding the habitat reaction (presence of subneutral species) and light (higher participation of heliophytes). Nine of them (13%) are considered to be synanthropic bryophytes. Details of the species occurrence are provided.

KEY WORDS: midforest roads, forest bryophytes, synanthropic bryophytes, nature reserves of Central Poland

INTRODUCTION

The role of midforest roads in development of forest vascular plants' diversity has been recognised quite well. By many authors they promote synanthropic plants spreading, including invasive kenophytes (e.g. Faliński 1961, Kujawa-Pawlaczyk 1991, Paszek and Załuski 2000, Tokarska-Guzik 2005). Others point their role as refuges for rare species retreating from inside forest, often low protected or threatened (e.g. Herbich and Herbichowa 1997, Ziarnek 2000). Data concerning bryophytes occurring on midforest roads, especially in lowland forests, are still scarce. That problem was usually omitted in regional research and studies. Instead bryofloristic relations of midforest paths in phytocoenoses of the Tatras' upper forest belt were studied and described in detail by Górski (2007, 2008, 2009).

During bryological studies in nine forest nature reserves situated in the Łódź region, carried out in 2008--2012 by the first author, the occurrence of 72 bryophyte species on midforest roads was stated (Wolski 2013). This is much more that it has been published so far from that habitat type both concerning the Łódź region in where 27 taxa were reported (Chmielewski and Urbanek 1960, Urbanek 1965, Rutowicz et al. 1981) as well as other parts of the country. Rusińska (1984) recorded 24 species on the area of Pojezierze Kartuskie while Fudali (1999) noted the six bryophytes occurring on roads passing through the five nature reserves in the Puszcza Bukowa forests near Szczecin. Data collected by Wolski (2013) would broaden the knowledge of the role of midforest roads in bryophyte diversity development in lowland forests.

In that article socio-ecological relations of the bryophyte species collected were analysed to find whether roads in the forests studied are colonized by non-forest species and what their origin is. Are there synanthropic species among them? In order to answer the question whether species occurring on midforest roads display ecological similarity, the species' general ecological demands in relation to light, moisture and site reaction were compared. Additionally it was also checked whether the law protected species occur on midforest roads in the reserves studied.

STUDY AREA

Research was carried out in nine forest nature reserves situated on the area of the Łódź region (Fig. 1), named in floristical and geobotanical works as Central Poland (Olaczek 1974, Mowszowicz 1978, Jakubowska-Gabara 2005, Kurowski 2009). According to current geomorphological approach the region spread from the valley of the middle Warta river on the West to the valley of the Pilica river and the Rawka river on the East (Turkowska 2006).

Fig. 1. Localization of the Łódź region on the map of Poland
Explanations: 1 – voivodeship border, 2 – Central Poland border.

The objects studied differ phytosociologically but all were set up in order to protect the stands of silver fir *Abies alba* Mill., which on the studied area reaches northern limit of its geographical range (Fig. 2). The species occur in there mainly as an addition in hornbeam--oak forests or mixed forests (Kurowski 2009).

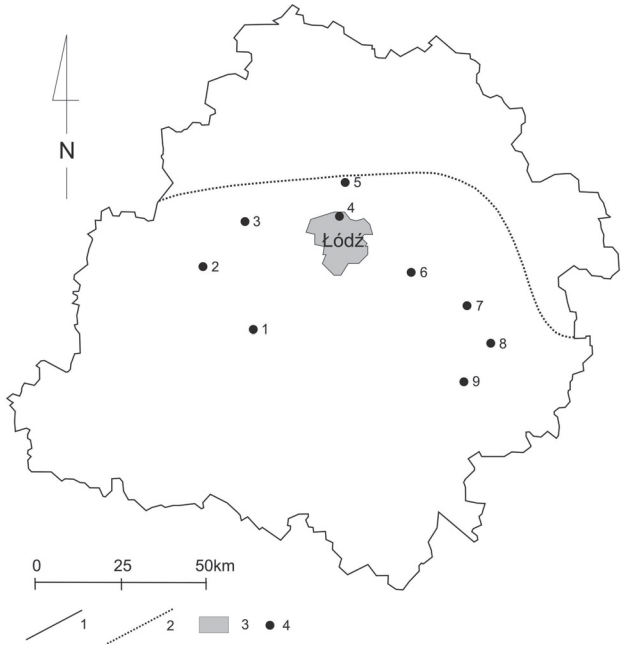

Fig. 2. Localization of the nature reserves studied on the area of the Łódź region
Explanations: 1 – voivodeship borders, 2 – northern limit of the *Abies alba* Mill. geographical range, 3 – the Łódź town, 4 – nature reserves studied: 1 – Jodły Łaskie, 2 – Jamno, 3 – Jodły Oleśnickie, 4 – Las Łagiewnicki, 5 – Grądy nad Moszczenicą, 6 – Łaznów, 7 – Kruszewiec, 8 – Jeleń, 9 – Błogie (Kurowski et al. 2009 – modified).

Brief characterisation of the nature reserves studied was presented in the Table 1. Up to now the bryophytes have not been studied in details in these reserves. The total length of midforest roads passing through the objects studied amounts to 10 830.5 m. They were covered with four various types of material: gravel, slag, asphalt or toughened ground but the latter dominate (80%).

MATERIALS AND METHODS

Field studies were conducted systematically in the years 2008-2012 in a grid system of squares (250 × 250 m) based on the ATPOL-squares grid system which cover the area of the reserves selected. Together 143 research squares were investigated. Diagram of squares' grid system was put on maps of the natural vegetation of the reserves studied. Midforest roads were thought to be a special habitat type in which bryophytes occur on five substratum types: mineral soil, humus and three types of litter: of needles, broad leaves or mixed. Within each of the square every species of liverworts and mosses was recorded from every substratum type. Every species' occurrence on every substratum type was given as a record (note). Patches (turfs) of the same species were recorded separately only when they were detached from one another and more than 1 m apart. If not they were regarded as one note. In total 10 784 records were collected.

Nomenclature of mosses follows Ochyra et al. (2003) and liverworts Szweykowski (2006). General ecological requirements of species and their socio-ecological assignment were accepted by Dierssen (2001).

RESULTS

Socio-ecological characterization of the species recorded

In total 72 bryophytes species were noted on midforest roads passing through the nature reserves studied, including 14 liverworts and 58 mosses. There are both forest and non-forest species (Table 2). Majority (45-63%) are forest bryophytes and their records make 95.5%. The prevailing number of these forest species (21-78%) were recorded no more than 100 times and 10 of them – no more than 10 times but only six of them were limited in occurrence to one or two objects. 26 species occurred in all nine nature reserves studied or in almost all of them (8-7) and seven of them were noted very often: *Plagiomnium affine* (2044), *Polytrichastrum formosum* (1059), *Kindbergia praelonga* (722), *Oxyrrhynchium hians* (705), *Pleurozium schreberi* (584), *Atrichum undulatum* (570) and *Dicranella heteromalla* (501).

The non-forest species recorded are related to the various vegetation formations: meadows or grassy forest ecotones (5 taxa), fens or wetlands (7) or they colonize initial habitats (15) both of natural and anthropogenic character. To the latter belong: *Barbula convoluta*, *B. unguiculata*, *Bryum argeneteum*, *B. cespiticium*, *B. rubens*, *Ceratodon purpureus*, *Funaria hygrometrica* and *Marchantia polymorpha*. 21 (78%) of these non-forest species were noted no more than 100 times and 10 of them only in one or two nature reserves studied.

Table 1. Characters of the nature reserves studied

Name of the nature reserve (geographic coordinates)	Year of the reserve establishment	Area (ha)	Incidence of the phytocoenoses regarded on the level of the vegetation alliances	Length of the midforest roads (m)
Jodły Łaskie (19°06′E 59°32′N)	1991	59.19	DP: 40%; Cb: 40%; AU: < 5%; Alg: < 5%; Pa: 15%	2 112.5
Jamno (18°53′E 51°42′N)	1959	22.35	Cb: 95% DP: 5%	223
Jodły Oleśnickie (19°04′E 51°49′N)	1962	9.88	Cb: 100%	173
Las Łagiewnicki (19°28′E 51°49′N)	1996	69.85	Cb: 80%; Qrp: 15%; PaQ: 5%	1 683
Grądy nad Moszczenicą (19°30′E 51°55′N)	1994	42.14	Cb: 80%; DP: 15%; AU: 5%	127
Łaznów (19°46′E 51°41′N)	1979	60.84	Cb: 20%; Pa: 50%; DP: 30%	2 057
Kruszewiec (19°59′E 51°35′N)	1979	81.54	Cb: 100%	1 880
Jeleń (20°06′E 51°29′N)	1976	47.19	Alg: 40%; Cb: 30%; DP: 20%; non-forest vegetation: 10%	1 112.5
Błogie (19°59′E 51°23′N)	1976	69.48	Alg: < 5%; AU: < 5%; DP: 15%; Cb: 80%	1 462.5
∑				10 830.5

Explanations: Alg – *Alnion glutinosae* (Malc. 1929) Meijer Drees 1936, AU – *Alno-Ulmion* Br.-Bl. et R. Tx. 1943, Cb – *Carpinion betuli* Issl. 1931 em. Oberd. 1953, DP – *Dicrano-Pinion* Libb. 1933, Pa – *Piceion abietis* Pawł. et all. 1939, Qrp – *Querceion robori-petraeae* Br.-Bl. 1932, PaQ – *Potentillo albae-Quercion petraeae* Zól et Jakucs n. nov. Jakucs 1967

Table 2. Socio-ecological characteristics of the species reported and details of their occurrence

Status of law protection	Name of species	Number of reserves in which species occurred	Number of squares in which species occurred	Number of notes			Type of the phytocoenose (on a level of the vegetation alliance
				mineral soil	humus	litter	
1	2	3	4	5	6	7	8
Non-forest species – medows and grassy forest ecotones							
	Brachythecium albicans	6	**12**	41	3	2m	Cb, DP
	Cirriphyllum piliferum	6	**14**	37	0	0	Alg, A-U, Cb, DP
	Lophocolea bidentata	8	**28**	119	34	2L, 5m	Alg, Cb, DP, Qrp
PP	*Pseudoscleropodium purum*	9	**27**	88	98	14L, 8m	Alg, A-U, Cb, DP
PP	*Rhytidiadelphus squarrosus*	7	**33**	574	327	0	Alg, A-U, Cb, DP
Non-forest species – initial habitats							
	Atrichum tenellum	4	**7**	7	0	0	Cb, DP, Pa
	Barbula convoluta	1	**1**	6	0	0	Cb
	Barbula unguiculata	6	**8**	76	0	0	Cb, DP
	Bryum argenteum	6	**11**	91	0	0	Cb, DP, Pa
	Bryum ceaspiticium	1	**1**	0	10	0	DP

Table 2 – cont.

1	2	3	4	5	6	7	8
	Bryum rubens	3	**4**	10	0	0	Cb, DP
	h*Cephaloziella divaricata*	3	**3**	4	0	0	Cb, DP, Pa
	Ceratodon purpureus	5	**10**	40	0	0	Cb, DP
	h*Conocephalum conicum*	4	**8**	10	2	0	Alg, A-U, Cb, DP
	h*Conocephalum salebrosum*	2	**2**	1	1	0	Alg, A-U, Cb, DP
	Didymodon fallax	1	**1**	7	0	0	Cb
	Funaria hygrometrica	1	**2**	25	0	0	DP
	h*Marchantia polymorpha*	4	**10**	87	58	0	Cb
	Pohlia wahlenbergii	6	**12**	177	0	0	Cb, DP, Pa
	h*Scapania curta*	1	**1**	2	0	0	DP
Non-forest species – fens or wetlands							
PP	*Aulacomnium palustre*	1	**1**	0	1	0	DP
	Bryum pseudotriqetrus	1	**3**	2	36	0	DP
	Calliergon cordifolium	2	**2**	14	0	0	Cb, DP
PP	*Calliergonella cuspidata*	6	**16**	86	206	0	Alg, A-U, Cb, DP
	Campylium stellatum	1	**3**	0	18	0	Cb, DP
	h*Chiloscyphus polyanthos*	3	**5**	0	9	0	Alg, Cb, DP
PP	*Climacium dendroides*	3	**5**	0	63	0	Alg, Cb, DP
Forest species							
	Atrichum undulatum	9	**46**	554	16	0	Alg, Cb, DP, Pa
	Aulacomnium androgynum	9	**45**	9	1	0	Alg, Cb, DP, Pa, Qrp
	Brachythecium rutabulum	9	**49**	104	58	3n, 1m	Alg, Cb, DP, Qrp
	Buxbaumia aphylla	4	**4**	4	0	0	Cb, DP
	h*Calypogeia mülleriana*	1	**5**	0	5	0	Alg, Cb, DP
	h*Cephalozia bicuspidata*	5	**9**	22	10	0	Alg, Cb, DP, Pa, Qrp, AU
	Dicranella heteromalla	9	**46**	426	74	1m	Alg, Cb, DP, Pa, Qrp, AU
PP	*Dicranum polysetum*	6	**10**	0	12	0	Alg, Cb, DP, Pa
PP	*Dicranum scoparium*	9	**25**	1	33	1n	Alg, Cb, DP, Pa, Qrp
PP	*Eurhynchium angustirete*	9	**20**	31	4	1m	Cb, DP, Qrp
PS	*Fissidens adianthoides*	1	**2**	0	36	0	Alg, Cb
	Herzogiella seligeri	9	**9**	0	9	0	Alg, Cb, DP, Qrp, AU
PP	*Hylocomium splendens*	7	**24**	35	31	0	Cb, DP
	Hypnum cupressiforme	9	**45**	12	75	1m	Alg, Cb, DP, Qrp
	Hypnum jutlandicum	4	**10**	0	117	6m	DP, Pa
	h*Jungermania gracillima*	1	**1**	2	0	0	DP
	Kindbergia praelonga	9	**36**	666	54	2L	Alg, Cb, DP, Pa, Qrp, AU
	h*Lepidozia reptans*	9	**38**	9	51	0	Alg, Cb, DP, Pa

Table 2 – cont.

1	2	3	4	5	6	7	8
PP	*Leucobryum glaucum*	5	**11**	0	280	0	Cb, DP, Pa
	h*Lophocolea heterophylla*	9	**51**	73	7	0	Alg, Cb, DP, Pa, Qrp
	Orthodicranum montanum	5	**5**	5	0	0	Cb, DP, Pa, Qrp
	Oxyrrhynchium hians	9	**42**	679	25	1n	Cb, DP, Qrp
	h*Pellia epiphylla*	7	**15**	76	43	1L	Alg, Cb, DP
	h*Pellia endiviifolia*	1	**1**	0	1	0	Alg
	Plagiomnium affine	9	**49**	1 457	556	18L, 13m	Alg, Cb, DP, Pa, Qrp, AU
	Plagiomnium undulatum	7	**19**	7	28s	0	Alg, AU, Cb
	Plagiothecium curvifolium	9	**51**	130	30	3n, 13m	Alg, Cb, DP, Pa, Qrp, AU
	Plagiothecium denticulatum	9	**9**	2	12	0	Alg, Cb, DP, Pa, Qrp
	Plagiothecium laetum	3	**3**	3	0	0	Cb, DP, Pa
	Plagiothecium ruthei	4	**6**	0	9	0	Alg, Cb
PP	*Pleurozium schreberi*	9	**52**	88	492	3n, 1m	Alg, Cb, DP, Pa, Qrp
	Pohlia nutans	9	**52**	240	75	0	Alg, Cb, DP, Pa, Qrp
	Polytrichastrum formosum	9	**52**	815	236	8m	Alg, Cb, DP, Pa, Qrp
	Polytrichastrum longisetum	5	**5**	5	0	0	Alg, Cb, DP, Pa
PP	*Polytrichum commune*	7	**10**	43	7	0	Cb, Pa, AU
PP	*Ptilium crista-castrensis*	3	**3**	3	0	0	Cb
	Rhizomnium punctatum	7	**10**	2	8	0	Alg, Cb, DP, AU
	Sciuro-hypnum oedipodium	8	**33**	84	35	8n, 4L, 18m	Alg, Cb, DP
	Sciuro-hypnum starkei	1	**2**	2	0	0	Cb
PS	*Sphagnum capillifolium*	3	**3**	0	17	0	Alg, Cb, DP
PS	*Sphagnum girgensohni*	3	**6**	0	6	0	Cb, DP, Pa
PS	*Sphagnum palustre*	6	**11**	6	7	5m	Alg, Cb, DP, AU
PP	*Sphagnum squarrosum*	1	**1**	0	1	0	Alg, Cb, DP
	Tetraphis pellucida	9	**41**	44	3	0	Alg, Cb, DP, Pa, Qrp
PP	*Thuidium tamariscinum*	9	**42**	43	133	4L, 6m	Alg, Cb, DP, Pa, Qrp
∑ of species		x	**x**	57	54	6n, 7L, 15m	x

Explanations: h – liverwort; PP – species party protected, PS – species strictly protected; grey label – species which occurred in the reserves studied exclusively on midforest roads; L – leaves of deciduous trees; n – needles of the coniferous trees; m – mixed liter; others as in Table 1.

Six non-forest species: *Calliergonella cuspidata*, *Lophocolea bidentata*, *Pseudoscleropodium purum* and *Rhytidiadelphus squarrosus* were often component of the roads's bryophyte layer as they were reported from the majority of the reserves studied and noted quite frequently.

Nine taxa (12%) were reported exclusively from the midforest roads (Wolski 2013) and seven of them are non-forest species but only *Pohlia wahlenbergii* was noted more than 20 times (Table 2).

Most of the non-forest species were noted on roads passing through phytocoenoses of the *Dicrano-Pinion* Libb. 1933 alliance (24 species with 5 which occurred exclusively within this forests' type) and the *Carpinion betuli* Issl. 1931 em. Oberd. alliance (22; 3).

Law protected species

Among the species recorded there are 20 species protected by law; five strictly protected and 15

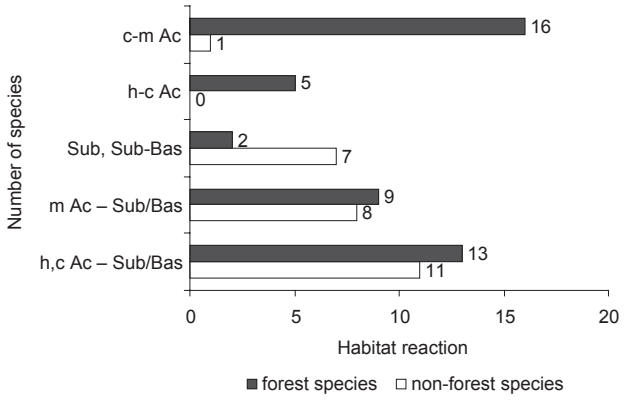

Fig. 3. Comparison of the habitat reaction's demands between non-forest and forest species recorded on the midforest roads in the studied nature reserves
Explanations: Ac – acid, Bas – Basic, Sub – subneutral; c – considerably, h – highly, m – moderately.

partly protected (Dz.U. z 2012 r. nr 0, poz. 81). They occurred with various frequency: eight (including four strictly protected) were noted no more than 20 times, six (1 strictly protected) – no more than 100 times (Table 2). Most of them (15) are forest species of various phytosociological assignation. Three species occurred only in one of the nature reserves studied while five – in all.

Ecological demands of the species in relation to the light, moisture and habitat reaction

The species recorded are not ecologically the same. Clear differentiation appears in relation to habitat reaction (Fig. 3) and light requirements (Fig. 4) as well as to the moisture conditions (Fig. 5). Regarding the habitats' reaction demands they represent three main groups of species: acidophilic (22), subneutral (including subneutral to basophilic) (9) and eurytopic which are able to

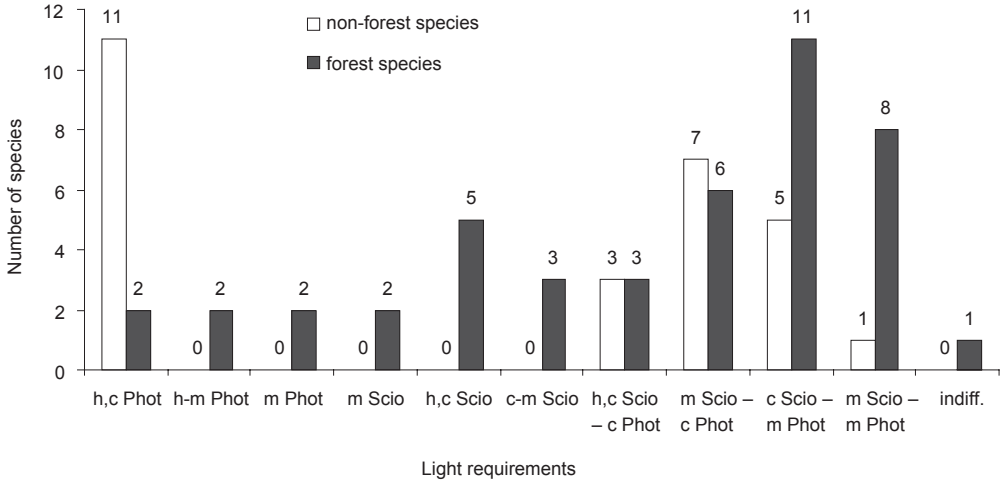

Fig. 4. Comparison of the light requirements between non-forest and forest species recorded on the midforest roads in the studied nature reserves
Explanations: Phot – full light, Scio – shadow, indiff. – lack of reaction to light intensity; others as on Figure 3.

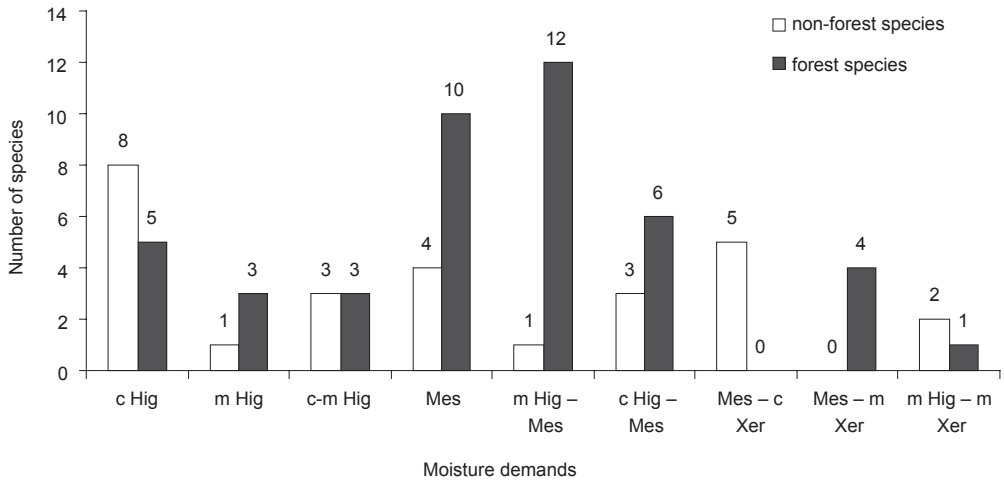

Fig. 5. Comparison of the moisture requirements between non-forest and forest species recorded on the midforest roads in the studied nature reserves
Explanations: Hig – humid, Mes – fresh, Xer – dry; others as on Figure 3.

occur in a wide range of habitat reaction from acid to neutral and basic (41). Comparison of the sites reaction requirements between forest and non-forest species shows some differences concerning share of stenotopic species (Fig. 3). Acidophytes are mainly forest species while group of subneutral taxa is built in 78% of non-forest bryophytes. Considering the species demands in relation to the light a share of eurytopic species is well pronounced – 45 species (63%) tolerate a wide range of light intensity in the habitat from highly shaded to quite open. 16 species are heliophytes and 11 of them are non-forest bryophytes. All the sciophytes are forest species.

The analysis of moisture habitat requirements show the species differentiation in that aspect but a dominance of species preferring rather humid and/or fresh habitats is visible (Fig. 5). There are no xerophytes able to survive in dry sites. Most of the forest species (18-40%) occur in habitats of changeable moisture conditions from humid to fresh while 13 non-forest species (48%) were higrophilic.

Substrata preferences of the species recorded

56 species occurred on a mineral soil and 20 of them colonized only that substratum. 13 of the latter (65%) are non-forest species. On humus 52 species were noted including the 15 exclusive. Most of the latter, 10 (67%), are forest species. 19 bryophyte taxa were collected from litter and they are mainly forest species (Table 2).

DISCUSSION

In the nature reserves studied midforest roads were colonized by many bryophyte species, both forest and non-forest appearing different socio-ecological relations: some of them occur typically on meadows or in grassy forest ecotones, others – in fens or bogs but there are also some pioneer bryophytes colonizing initial sites, both of natural and anthropogenic character. However, most of them (45-63%) are forest taxa occurring also inside forest phytocoenoses studied. Among them there are species common in the Łódź region (e.g. *Pleurozium schreberi*, *Polytrichastrum formosum*, *Plagiomnium affine*, *Atrichum undulatum*) and very rare as *Ptilium crista-castrensis* and *Buxbaumia aphylla* (Staniaszek-Kik and Wolski 2008).

The species recorded differ ecologically but eurytopic species outnumber in every aspect, the analysed ones. Some differences between forest and non-forest species were revealed: almost all acidophytes are the forest species while subneutral species are mainly non-forest, the majority of heliophytes are non-forest bryophytes but all the sciophytes – only forest species. The presence of non-forest species of various socio-ecological assignation and ecological demands which make 37% of bryoflora studied and the occurrence of nine species recorded only on midforest roads in the nature reserves studied show they are important environmental factor forming bryophyte biodiversity in the forests studied. However, in total estimation the records' number of non-forest species was not significant and their percentage incidence was 4.5%.

The investigations carried out on the area of the Kartuskie Lakeland (Rusińska 1984) and Kraków-Częstochowa Upland (Fojcik 2011) also showed ecological differentiation of species occurring on midforest roads and participation both of non-forest heliophytes (as: *Bryum argenteum*, *B. caespiticium*, *Barbula convoluta*, *B. unguiculata*, *Ceratodon purpureus*) and forest sciophytes or euryphotophilic species (*Dicranella heteromala*, *Hylocomium splendens*, *Pohlia nutans*). Data reported by other authors concern mainly non-forest species, such as: *Ceratodon purpureus*, *Bryum argenteum*, *Barbula convoluta*, *B. unguiculata*, *Funaria hygrometrica*, *Polytrichum piliferum* (Fudali and Friedrich 1993, Fudali 1999, Szczepański et al. 2008). All species listed above were recorded also in a course of the research presented.

According to Fojcik (2011) species composition of bryophytes occurring on midforest roads depends on the material which covers their surface and intensity of use. These factors were not studied in the research presented but ecological differentiation of the species may be an indicator of the road microhabitats' variety. Gravel or slag, used in some reserves to coat the road, may promote a presence of some subneutral species.

European mosses are hardly affected by the process of alien species inflow what differentiates them from vascular plants (Söderström 1992, Fudali et al. 2009). There were no aliens in the bryoflora of midforest roads investigated. But nine species: *Barbula unguiculata*, *Bryum caespiticium*, *B. rubens*, *Ceratodon purpureus*, *Didymodon fallax*, *Funaria hygrometrica*, *Marchantia polymorpha*, *Bryum argenteum* and *Barbula convoluta* frequently colonize anthropogenic sites and are thought to be synanthropic mosses (Ochyra 1983). The two latter are regarded by Balcerkiewicz and Rusińska (1989) as indicators of the processes of the natural biocoenoses ruderalization as they occur commonly in cities. The number of records of the synanthropic mosses was in every case not significant. Similarly as the number of the nature reserves they were noted – in five or six objects occurred only three species: *Barbula unguiculata*, *Bryum argenteum* and *Ceratodon purpureus*, others were more limited in their distribution.

20 of the species reported, including five non-forest species, are low protected but all these species were also recorded inside the forests studied (Wolski 2013). So a presence or absence of midforest roads does not affect directly the occurrence of protected species in the objects studied.

CONCLUSION

Midforest roads create a special kind of habitat influencing the bryophyte species and ecological diversity in forest ecosystems of the reserves studied as they are colonized by the group of non-forest species, which differ in ecological demands from the forest species. They constitute 37% of the bryoflora reported.

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