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SPECIES DIVERSITY OF PLANTS AND FUNGI ON LOGS OF FALLEN TREES OF DIFFERENT SPECIES IN OAK-HORNBEAM FORESTS

Renata Nowińska, Paweł Urbański, Wojciech Szewczyk

R. Nowińska, P. Urbański, Department of Botany, Poznań University of Life Sciences, Wojska Polskiego 71 C, 60-625 Poznań, Poland, e-mail: nowinska@up.poznan.pl, ptilium@up.poznan.pl
W. Szewczyk, Department of Forest Patology, Poznań University of Life Sciences, Wojska Polskiego 71 C, 60-625 Poznań, Poland, e-mail: wszew@up.poznan.pl

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ABSTRACT. The aim of the study was to assess the species composition of vascular plants, bryophytes and fungi on logs in terms of the location of these logs, the species of the fallen tree, types of substrates and the degree of log decomposition. Investigations were conducted in oak-hornbeam forest in the "Grabina" reserve and forest strip adjacent to its southern borders and in oak-hornbeam forest in the "Pod Dziadem" reserve. Collected results indicate that the richness of herbaceous plant species on observed logs is higher in the "Grabina" area, while the richness of bryophytes and fungi is identical in both objects. Fungi inhabit mainly deciduous wood, which for them is the primary substrate. Bryophytes grow on wood of different tree species at identical rate. The degree of bark overgrowing by bryophytes depends on the species of the host tree. On the analysed logs these bryophytes were found in biggest abundance which are capable of inhabiting different types of substrate (the so-called generalists). They overgrow logs of all decomposition classes (I-V) and their proportion in the coverage of logs from individual classes ranges from 53 to 78%. The first vascular plants appear on logs starting from the 2nd degree of wood decomposition. Logs are being inhabited simultaneously by herbaceous plants and seedlings of trees and shrubs. Vascular plants are found first of all on these logs, on which mats of mosses may act as substrates.

KEY WORDS: bryophytes, vascular plants, fungi, epixylic flora, Wielkopolska National Park, "Grabina", "Pod Dziadem"

INTRODUCTION

The presence of dead wood plays a considerable role in the functioning of forest ecosystems. Fallen logs modify the microrelief of the forest floor, participate in the circulation of nitrogen compounds and carbon, they are habitats for many organisms and are sites where their associations are formed. Despite the fact that in several Regional Directorates of State Forests decisions were passed concerning the establishment and protection of refuges of xylobionts, at present the only locations where dead fallen trees are found in certain bigger numbers are strictly protected forest areas in national parks and certain forest nature reserves.

The presented study constitutes an element of broader, more extensive studies on the occupancy of logs, hummocks and hollows, as well as canopy gaps formed as a result of tree deaths and treefalls (Nowińska 2008 c). Within this study the species composition of bryophytes and vascular plants as well as bracket fungi overgrowing logs of dead trees in the "Grabina" reserve and its edges, as well as the "Pod Dziadem" reserve in the Wielkopolski National Park. The species composition of plants and fungi, as well as density (only in case of bryophytes) were analysed depending on the location of logs, species of the fallen tree and the type of the substrate. Relationships were investigated between the degree of log decomposition and the occurrence of all vascular plants and bryophytes. Moreover, it was analysed whether there is a dependence between log decomposition and the proportions of individual ecological groups of bryophytes.

In the "Pod Dziadem" reserve the subject of earlier studies was connected with phytocenoses of bryophytes (Balcerkiewicz and Rzepka 1992, 1996). Moreover, preliminary mycological studies were also conducted (Bujakiewicz and Fiebich 1991 za Balcerkiewicz and Rzepka 1996, Bujakiewicz and Fiebich 1993).

In the years 2005-2007 in the Wielkopolski National Park studies were carried out on the diversification of the structure and composition of flora in the forest floor cover under the influence of tree falling (Nowińska 2008 a-d).

Study area

The "Grabina" reserve is an object of 8.49 ha in area, covered by oak-hornbeam forest (*Galio sylvatici-Carpinetum* R. Tx. 1937) and small fragments of elm-ash floodplain forest (*Fraxino-Ulmetum* R. Tx. 1952) and black alder bog forest (*Ribo nigri-Alnetum* Sol.-Górn 1975).

Forests of this reserve are characterised by the highest degree of natural character in comparison with the other forest areas in the Wielkopolski National Park. Analyses were conducted in the oak-hornbeam forests, in which stands were formed by oaks aged 150 years and hornbeams, with linden, birch, aspen and pine trees aged approx. 170 years found as admixtures. A total of 45% dead trees were uprooted trees (Nowińska 2008 b).

The "Pod Dziadem" reserve is an object of 13.7 ha in area, covered by oak-hornbeam forests, mostly degenerated as a result of the introduction of Scots pine to the community, diagnosed as the *Pinus-Quercus-Milium* community (Balcerkiewicz et al. 1996). This area could have been deforested for a certain period of time (Balcerkiewicz et al. 1992). After the nun moth outbreak in the years 1975-1982 a considerable number of pines died and is currently found as snag, broken or uprooted trees. At present the stand is composed jointly by sessile oak (approx. 170 and 90 years) and pine (170 years), while in the admixture we may find hornbeam, sycamore, beech, linden and elm. In the discussed phytocenoses uprooted trees account for 53% dead trees (Nowińska 2008 b).

A detailed characteristics of forest phytocenoses in both reserves may be found in studies by Balcerkiewicz, Brzeg and Kasprowicz (Balcerkiewicz et al. 1990, 1991, 1992, 1996).

Sampling

Field studies were conducted in the years 2006-2008. Data came from 86 logs, of which 40 are located in the "Grabina" reserve and in areas adjacent to the southern boundary of the reserve (further referred to as "Grabina" area), while 46 come from the "Pod Dziadem" reserve. The number and type of logs are presented by Table 1.

As it was previously mentioned, the study constitutes an element of broader, long-term observations of flora of logs, hummocks and herb layer under the canopy gaps made by fallen trees. For this reason this study includes only fallen trees in which the hummock is preserved. In the investigated phytocenoses the hummock made by the fallen tree is preserved in approx. 50% fallen trees (Nowińska 2008 c).

When characterising logs the following data were given: location (GPS), taxonomic affiliation of the tree in the rank of genus, log base diameter, log length, log

Table 1. Characteristics of examined logs in the "Grabina" reserve and its surroundings (GR) and in the "Pod Dziadem" reserve (PD)

	Total GR	Total PD	U-test/ K-S test	Forest area								
				GR					PD			
				tree species					tree species			
				B/P	C	P	Q	K-W test	P	Q	U	K-W test
No. of logs per 1 ha	96	196	–	–	–	–	–	–	–	–	–	–
No. of investigated logs	40	46	–	7	10	12	11	–	30	9	7	–
Area of investigated logs (m^2)	753.59 (18.84)	604.96 (13.44)	**	131.83 (21.97)	150.98 (13.73)	175.19 (15.93)	295.59 (24.63)	**	434.98 (15.53)	154.24 (15.42)	15.73 (2.25)	***
Mean degree of logs decomposition	(5.82)	(5.44)	NS	(7.13)	(5.88)	(4.53)	(6.36)	NS	(4.65)	(6.12)	(12.81)	*
Mean depth of metal bar penetrate (cm)	(5.82)	(5.44)	NS	(7.13)	(5.88)	(4.53)	(6.36)	NS	(4.65)	(6.12)	(12.81)	*
Mean bark cover	(2.60)	(1.67)	***	(2.33)	(2.55)	(2.09)	(3.25)	**	(1.57)	(2.40)	(1.00)	**
Mean log coverage by bryophytes (%)	(38.03)	(56.13)	**	(60.83)	(17.95)	(12.77)	(68.17)	***	(50.71)	(58.60)	(74.29)	NS
Log coverage by bryophytes (m^2)	317.73 (8.02)	303.31 (6.51)	NS	78.97 (13.16)	20.65 (1.89)	22.59 (2.05)	195.52 (16.54)	***	221.83 (7.80)	70.47 (6.82)	11.01 (1.57)	**
Coverage by bryophytes on wood (m^2)	59.24 (1.85)	237.94 (5.01)	*	17.22 (2.87)	4.36 (0.54)	14.30 (1.27)	23.36 (3.90)	NS	182.94 (5.85)	43.99 (4.89)	11.01 (1.57)	NS
Coverage by bryophytes on bark (m^2)	258.49 (6.71)	65.37 (2.97)	NS	61.75 (10.29)	16.29 (1.48)	8.29 (0.75)	172.16 (13.96)	**	38.89 (2.43)	26.48 (4.41)	0	NS

Type of logs: B/P – *Betula* sp./*Populus tremula*; C – *Carpinus betulus*; P – *Pinus sylvestris*; Q – *Quercus* sp.; U – undetermined taxonomic affiliation.
The method to calculate the area of logs in m^2 and bark cover of logs was described in the Methods chapter. Total values (without brackets) and arithmetic means (in brackets) are given.
No. of logs per 1 ha – source: R. Nowińska (2009 b).
*$p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; NS – no difference.

area, the degree of bark cover, as well as the degree of log decomposition.

The degree of log decomposition was considered equivalent to the degree of log softening. The depth to which a metal bar penetrated was measured in three locations on the log (basal, central and top). On the basis of the maximum recorded value the log was classified to one of the five classes: I – hard surface; the log is always supported by branches, II – a metal bar penetrates to a depth of up to 2 cm, III – a metal bar penetrates to a depth of up to 5 cm, IV – a metal bar penetrates to a depth of up to 10 cm, V – a metal bar penetrates through the log; the log is pressed against the ground over its entire length. Log area was calculated using a formula for the area of a cone, with the use of the diameter of the stem base and log length. Log cover with bryophytes was each time referred to the upper area and the lateral areas, both for lying and suspended logs. For this reason the obtained log area was multiplied by 0.75. Bark cover was assessed according to a 4-point scale: 0 – no bark; 1 – up to 50%; 2 – 60-90% and 3 – 100%, respectively.

Lists of species found on logs were prepared for bryophytes and vascular plants as well as bracket fungi. Lists of bryophytes and fungi were recorded once. Vascular plants were inventoried twice on each log in two successive vegetation seasons. For each bryophyte species the area of the log, bark and wood it covers was calculated. The occurrence of vascular plants and fungi was established based on the presence/absence of stems or sporocarps (Heilmann-Clausen 2001, Heilmann-Clausen et al. 2005).

The occurrence of vascular plants was recorded on the following types of substrates:

- bark (K) – when the specimen rooted at the location of the rhytidome, which was not covered by mineral soil transferred from outside the log. The information whether soil particles were found in cracks of the tissue covering the tree was not recorded. The primary source of biogens for these specimens was precipitation water retained in the cracks;
- wood (D) – when the specimen rooted in decaying, softened secondary xylem, which was not covered by mineral soil transferred from outside the log;
- moss layer (M) – the specimen grew of the mat of mosses, in which slight amounts of mineral soil could have accumulated;
- mineral soil accumulated in cracks of the stem (S);
- soil fallen from the hummock of the fallen tree in the basal part of the stem (O).

The occurrence and cover of bryophyte species were calculated separately for bark (K) and wood (D).

All bryophyte species were divided into four ecological groups (Andersson and Hytteborn 1991): epiphytes – growing mainly on the stems of living trees; epixylics – using dead wood as their main substrate; epigeics – strong competitors that normally cover the forest ground; and generalists – frequently occurring on a large number of different exposed substrates. The classification of species was based on a list presented in a study by Andersson and Hytteborn (1991), observations recorded within this study and results of investigations conducted by Żarnowiec (1997) and Klama (1997).

Macro- and microscopic characteristics of sporocarp structure were used in the identification of fungus species. The main characteristics which were considered when determining the species included the shape of the sporocarp, the colour, the surface of the sporocarp, coverage of the sporocarp with trichomes, scales or flakes, aroma, juice of the flesh, the type of plectenchyme, as well as hymenophor structure. When in doubt, the sporocarp was examined under a microscope in order to determine the structure of both the hymenum and the spores (Domański et al. 1967, Gumińska and Wojewoda 1985, Mańka 2005, Wojewoda 2003).

Nomenclature and taxonomy of fungi were adopted after Wojewoda (2003) and Kirk et al. (2001), those of liverworts were adopted after Szweykowski (2006), while those of mosses after Ochyra et al. (2003). Nomenclature of vascular plants was given after Mirek et al. (2002), while taxonomy after Rutkowski (2006).

Data analyses

Differences in the number of species occurrences between the reserves, types of logs and types of substrates were compared using the chi-square test. In tests with one degree of freedom the Yates' correction for continuity was introduced. Fisher's exact test was applied when one of the expected values was lower than five. Within the reserve the area of logs of a given type, as well as total coverage of logs, wood and bark of a given type by specific bryophyte species were calculated using the Kruskal-Wallis test (K-W test). The Mann-Whitney U test (U test) was used to compare the area of logs as well as coverage of logs and substrates by bryophytes between the "Grabina" and the "Pod Dziadem" areas. The significance of differences in the coverage of logs of a given type and substrates by specific bryophyte species was assessed using the Kolmogorov-Smirnov test (K-S test). In all statistical tests the minimum level of significance was assumed to be 0.05. When statistically significant differences were obtained in tests comparing more than two groups of variables, multiple comparisons were next conducted between each pair of variables using the Bonferroni correction for the level of significance of 0.05.

RESULTS

Characteristics of logs of dead trees

Information on the number of logs and their dimensions, together with data on the total coverage of log area with bryophytes depending on their type, are presented in Table 1.

In the "Grabina" area 30% examined logs were pine logs (*Pinus sylvestris*), 27.5% – oak logs (*Quercus* sp.), 25% – hornbeam logs (*Carpinus betulus*), while 17.5% analysed logs were birch logs (*Betula* sp.) and aspen logs (*Populus tremula*), included into one group. In the "Pod Dziadem" reserve pine logs (*Pinus sylvestris*) predominated, as they accounted for 65% examined logs, followed by oak logs (*Quercus* sp.) at 20% and strongly decomposed logs of unknown affiliation (15%).

The mean area of examined logs is considerably higher in the "Grabina" area (18.84 m²) in comparison to that in the "Pod Dziadem" reserve (13.44 m²). Individual types of logs differ in mean area. In the "Grabina" the biggest mean area was found for oak logs (24.63 m²) and birch/poplar logs (21.97 m²). In the "Pod Dziadem" reserve oak and pine logs were identical in mean mean area (approx. 15.50 m²), which considerably exceeds the mean area of logs with undetermined taxonomic affiliation (2.25 m²). The mean bark cover was higher in the "Grabina" area, mainly due to the presence of well-preserved oak logs found in that area and the fact that logs devoid of bark of undetermined affiliation from the "Pod Dziadem" reserve were included in this study. In the "Pod Dziadem" reserve the mean percentage of log coverage by bryophytes (56.13%) was considerably higher than in the "Grabina" (38.03%). Differences between both objects are manifested in the wood overgrowing by bryophytes (in the "Pod Dziadem" reserve the mean value was 5.01 m², while in "Grabina" it was 1.85 m²). Wood cover (m²) by bryophytes was independent of the species composition of dead trees. In turn, the tree species determines the bryophyte cover on bark, which is manifested in the "Grabina" area. Here the most strongly covered bark was observed for oak logs (13.96 m²) and birch/poplar logs (mean 10.29 m²) in comparison to hornbeam or pine logs (less than 1.5 m²).

Species occurrences

Synthetic information on the species composition and taxonomic affiliation, as well as the number of species occurrences in both areas on different types of logs and substrates is contained in Table 2.

In the examined logs in both sample plots a total of 38 taxa of bryophytes were recorded (including one determined to the rank of a genus), belonging to 18 families, of which 34 taxa were mosses (Bryophyta) belonging to 14 families, while four species were liverworts (Marchantiophyta) belonging to four families. In the "Grabina" area a total of 22 species of mosses belonging to 13 families and two liverwort species were recorded. In the "Pod Dziadem" reserve 27 species of mosses belonging to 11 families and four liverwort species belonging to four families were found. A total of 20 bryophyte species were recorded in both areas. Six species were found only in the "Grabina" area, while 11 species – only in the "Pod Dziadem" reserve. In both objects most exclusive species were generalists and epigeic species. In the "Grabina" area in the group of exclusive species there was also one epiphyte (*Isothecium alopecuroides*), while in the "Pod Dziadem" reserve there were two epixylic species (*Callicladium haldanianum* and *Orthodicranum flagellare*).

Overall as many as 27 species were recorded on fewer than 10 logs. Only seven species were recorded on more than 20 logs. In the "Grabina" area oak logs (16 species) and birch/poplar logs (15 species) were richest in species. The lowest number of bryophyte species was found on hornbeam logs (nine species). In turn, in the "Pod Dziadem" reserve the biggest number, i.e. 25 species, was recorded on pine logs, while the lowest number, i.e. 10 species, was observed on old logs of an unknown taxonomic affiliation. The richness of bryophyte species overgrowing bark and wood of fallen logs did not differ in the "Grabina" (18 and 16 species, respectively). In the "Pod Dziadem" reserve differences were more marked, as on bark 19 bryophyte species were found, while on wood there were 29 species.

Differences in the number of liverworts occurrences in both reserves turned out to be insignificant at $\alpha = 0.05$. Among the recorded moss species *Brachythecium salebrosum* and *Platygyrium repens* were observed significantly more frequently in the "Grabina" area, while *Aulacomium androgynum*, *Pohlia nutans*, *Dicranum scoparium*, *Herzogiella seligeri, Orthodicranum tauricum*, *Sciuro-hypnum oedipodium* and *Callicladium haldanianum* were found significantly more frequently in the "Pod Dziadem" reserve. The number of occurrences of *Lophocolea heterophylla*, *Brachythecium rutabulum*, *Orthodicranum montanum* and *Orthodicranum tauricum* is different on different tree species. In the "Pod Dziadem" reserve *Orthodicranum montanum* occupied most frequently pine logs. It was found on 83% pine logs. In that reserve similar trends were found for *Orthodicranum tauricum* occupying 40% pine logs. For *Lophocolea heterophylla* a considerable number of observations was recorded for oak and pine logs (56% and 40%, respectively; differences statistically non-significant according to the Yates χ^2 test with a correction) in comparison to the strongly decomposed logs of undetermined taxonomic affiliation (for the P-U pair in the Fisher test with a correction $p = 0.0001$).

In contrast, in the "Grabina" *Lophocolea heterophylla* occupied more frequently pine logs rather than hornbeam logs (where no samples were found; Yates χ^2 with a correction $p = 0.0001$). Here *Brachythecium rutabulum* was observed less often on pine logs in comparison to oak logs (Yates χ^2 with a correction $p = 0.0017$). This difference in the occupancy of oak and pine logs was not confirmed by data from the "Pod Dziadem" reserve. The analysis of the number of bryophytes occurrences on bark and wood showed that a species commonly found throughout the entire area of analysis, i.e. *Hypnum cupressiforme*, occupies significantly more often the substrate, which in a given location is found in greatest abundance. For this reason in the "Grabina" it was reported more often on bark, while in the "Pod Dziadem" reserve it was on decomposing wood. A similar trend was observed for other moss species common in that area, such as *Brachythecium rutabulum* and *Orthodicranum montanum*. In both areas *Lophocolea heterophylla* in bigger numbers occupied wood in comparison to bark.

On the examined logs three fern species were recorded, as well as 33 taxa of seed plants (in the rank of species and genus). Ferns represent the family Aspidiaceae. Seed plants are grouped in 24 families. Fourteen families were found only in the "Grabina", representatives of three families were found only in the "Pod Dziadem" reserve, while eight families were observed in both investigated areas. Examined logs in the "Grabina" were characterised by a bigger richness of vascular plant species. They comprised 28 species, of which 21 were recorded solely in this area. Analogously, in the "Pod Dziadem" reserve the occurrence of 15 plant species was recorded, with nine taxa being found only at that

TABLE 2. A list of species of plants and fungi in the taxonomic system and the number of their occurrences in relation to types of logs (tree species) and substrate in the "Grabina" reserve and its surroundings (GR) and in the "Pod Dziadem" reserve (PD)

Family	Species	The tree species												The types of substrate											
					GR					PD				GR						PD					
		total GR	total PD	χ^2 test	B/P 7	C 10	P 12	Q 11	χ^2 test	P 30	Q 9	U 7	χ^2 test	D 32	K 39	M 40	O 7	S 3	χ^2 test	D 42	K 22	M 46	O 6	S 14	χ^2 test
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
	Bryophyta[1]																								
Amblystegiaceae	*Orthotheciella varia*	1	0	NS		1			NS				–		1				NS						–
Aulacomniaceae	*Aulacomnium androgynum*	5	28	***	1		4		NS	22	4	2	NS	3	2				NS	20	8				NS
Brachytheciaceae	*Brachytheciastrum velutinum*	2	1	NS	1			1	NS			1	NS		2				NS	1					NS
	Brachythecium rutabulum	25	21	NS	5	8	2	10	*	11	6	4	NS	5	20				**	15	6				NS
	Brachythecium salebrosum	7	0	**	2	3		2	NS				–	1	6				NS						–
	Sciuro-hypnum oedipodium	0	8	**					–	6	2		NS						–	5	3				NS
Bryaceae	*Pohlia nutans*	1	8	*			1		NS	7	1		NS	1					NS	5	3				NS
Dicranaceae	*Dicranella heteromalla*	0	4	NS					–	4			NS						–	2	2				NS
	Dicranum polysetum	0	1	NS					–	1			NS						–	1					NS
	Dicranum scoparium	6	21	**	1		2	3	NS	16	4	1	NS	3	3				NS	15	6				NS
	Orthodicranum flagellare	0	1	NS					–	1			NS						–	1					NS
	Orthodicranum montanum	16	29	NS	4	2	8	2	NS	25	4		**	6	10				NS	24	5				*
	Orthodicranum tauricum	3	13	**	1		1	1	NS	12	1		*		3				NS	10	3				NS
Ditrichaceae	*Ceratodon purpureus*	1	0	NS		1			NS				–	1					NS						–
Echinodiaceae	*Isothecium alopecuroides*	1	0	NS				1	NS				–		1				NS						–
Hylocomiaceae	*Hylocomium splendens*	1	3	NS				1	NS	2	1		NS	1					NS	2	1				NS
	Pleurozium schreberi	1	4	NS	1				NS	3	1		NS		1				NS	2	2				NS
Hypnaceae	*Callicladium haldanianum*	0	9	**					–	6	3		NS						–	5	4				NS
	Herzogiella seligeri	11	25	*	2		7	2	NS	21	2	2	NS	7	4				NS	19	6				NS
	Hypnum cupressiforme	36	45	NS	6	10	11	9	NS	30	9	6	NS	10	26				**	34	11				*
	Platygyrium repens	11	4	*	2	6	2	1	NS	4			NS	3	9				NS	3	1				NS
Mniaceae	*Mnium hornum*	1	2	NS		1			NS	1	1		NS	1					NS	2					NS

Table 2 – cont.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Plagiomniaceae	*Plagiomnium affine*	0	2	NS					–		2		NS						–		2				NS
	Plagiomnium cuspidatum	1	0	NS				1	NS				–		1				NS						–
	Plagiomnium undulatum	3	0	NS	1			2	NS				–	1	2				NS						–
	Plagiothecium cavifolium	0	1	NS					–			1	NS						–	1					NS
	Plagiothecium curvifolium	2	1	NS	1		1		NS	1			NS	2					NS	1					NS
	Plagiothecium laetum	0	1	NS					–			1	NS						–	1					NS
	Plagiothecium sp.	0	9	**					–	7	2		NS						–	5	4				NS
Polytrichaceae	*Atrichum undulatum*	4	1	NS		1		3	NS			1	NS		4				NS	1					NS
	Polytrichastrum formosum	0	4	NS					–	3	1		NS						–	2	2				NS
	Polytrichum juniperinum	0	1	NS					–		1		NS						–		1				NS
Seligeriaceae	*Dicranoweisia cirrata*	2	3	NS	1			1	NS	2	1		NS		2				NS	2	1				NS
Tetraphidaceae	*Tetraphis pellucida*	0	5	NS					–	5			NS						–	5					NS
The total number of the occurrences		141	255	396	29	33	39	40	141	190	46	19	255	45	97	0	0	0	142	184	71	0	0	0	255
The percentage of occurrences		36	64	**100**	21	23	28	28	**100**	75	18	7	**100**	32	68	0	0	0	**100**	72	28	0	0	0	**100**
	Marchantiophyta[2]																								
Cephaloziaceae	*Nowellia curvifolia*	1	14	NS			1		NS	14			NS	1					NS	14					**
Geocalycaceae	*Lophocolea heterophylla*	17	35	NS	2		11	4	**	28	5	2	**	12	5				*	33	2				***
Lepidoziaceae	*Lepidozia reptans*	0	2	NS					–	2			NS						–	2					NS
Ptilidiaceae	*Ptilidium pulcherrimum*	0	4	NS					–	4			NS						–	4					NS
The total number of the occurrences		18	55	73	2	0	12	4	18	48	5	2	55	13	5	0	0	0	18	53	2	0	0	0	55
The percentage of occurrences		25	75	**100**	11	0	67	22	**100**	87	9	4	**100**	72	28	0	0	0	**100**	96	4	0	0	0	**100**
	Pteridophyta[3]																								
Aspidiaceae	*Dryopteris carthusiana*	7	25	***	2	2		3	NS	15	3	7	NS		1	4	2		*	4	5	18	1	4	NS
	Dryopteris dilatata	0	2	NS					–	1		1	NS						–	1	1			1	NS
	Dryopteris filix-mas	0	1	NS					–	1			NS						–		1				NS
The total number of the occurrences		7	28	35	2	2	0	3	7	17	3	8	28	0	1	4	2	0	7	5	7	18	1	5	36
The percentage of occurrences		20	80	**100**	29	29	0	42	**100**	60	11	29	**100**	0	14	57	29	0	**100**	14	19	50	3	14	**100**
	Spermatophyta[4]																								
Aceraceae	*Acer pseudoplatanus*	0	4	NS					–	2	1	1	NS						–		2	2		1	NS

Table 2 – cont.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Asteraceae	*Mycelis muralis*	0	1	NS					–		1		NS						–			1			NS
Balsaminaceae	*Impatiens parviflora*	17	16	NS	2	6	1	8	NS	10	3	3	NS	2		13	3	1	***	1	4	8	1	4	NS
Betualceae	*Betula pendula*	1	0	NS	1				NS				–			1			NS						–
	Betula pubescens	1	0	NS	1				NS				–			1			NS						–
Brassicaceae	*Alliaria petiolata*	1	0	NS				1	NS				–			1			NS						–
Caryophyllaceae	*Moehringia trinervia*	4	3	NS	2			2	NS	1	2		NS			4			NS			3			NS
Corylaceae	*Carpinus betulus*	5	0	*	1	3		1	NS				–	1		4			NS						–
Cyperaceae	*Carex digitata*	3	0	NS		1		2	NS				–		1		1	1	NS						–
Ericaceae	*Vaccinum myrtillus*	1	0	NS		1			NS				–			1			NS						–
Fagaceae	*Fagus sylvatica*	1	0	NS				1	NS				–			1			NS						–
	Quercus petraea	0	1	NS					–	1			NS						–			1			NS
Geraniaceae	*Geranium robertianum*	4	0	*	3			1	NS				–			2	1	1	NS						–
Juncaceae	*Luzula pilosa*	3	0	NS	1			2	NS				–			2	1		NS						–
Lamiaceae	*Ajuga reptans*	2	0	NS				2	NS				–				2		**						–
	Galeobdolon luteum	16	0	***	3	3	1	9	NS				–		2	10	6		***						–
	Lycopus europaeus	1	0	NS	1				NS				–			1			NS						–
	Scutellaria galericulata	1	0	NS	1				NS				–			1			NS						–
	Stachys sylvatica	0	1	NS					–		1		NS						–			1			NS
Oxalidaceae	*Oxalis acetosella*	6	23	**	1	3		2	NS	12	5	6	NS	1		3	1	1	NS	3	6	16	1	4	NS
Pinaceae	*Pinus sylvestris*	3	0	NS	1	1		1	NS				–	1	1	1			NS						–
Poaceae	*Milium effusum*	3	2	NS	1			2	NS	1	1		NS			3			NS			2			NS
Polygonaceae	*Fallopia dumetorum*	1	0	NS	1				NS				–			1			NS						–
Rosaceae	*Geum urbanum*	0	1	NS					–	1			NS						–			1			NS
	Rubus sp.	0	9	**					–	7		2	NS						–		1	7		1	NS
	Sorbus aucuparia	0	1	NS					–	1			NS						–		1			1	NS
Saxifragaceae	*Ribes uva-crispa*	1	0	NS				1	NS				–			1			NS						–
Scrophulariaceae	*Scrophularia nodosa*	1	0	NS				1	NS				–		1				NS						–
	Veronica officinalis	1	0	NS		1			NS				–				1		NS						–
Tiliaceae	*Tilia cordata*	3	0	NS		1		2	NS				–			3			NS						–

Table 2 – cont.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Ulmaceae	*Ulmus* sp.	2	0	NS		2			NS				–	1		1			NS						–
Urticaceae	*Urtica dioica*	6	5	NS	1			5	NS	1	1	3	NS			6			NS	1		3		1	NS
Violaceae	*Viola reichenbachiana/ V. riviniana*	6	0	**		1		5	NS				–	1		4	3		**						–
The total number of the occurrences		101	95	196	23	25	2	51	101	54	18	23	95	7	6	69	21	4	107	10	21	63	3	17	114
The percentage of occurrences		52	48	**100**	23	25	2	50	**100**	57	19	24	**100**	7	6	63	20	4	**100**	9	18	55	3	15	**100**
	Basidiomycota[5]																								
Bondarzewiaceae	*Heterobasidion annosum*	2	0	NS			2		NS				–	2					–	0					–
Coniophoraceae	*Coniophora puteana*	2	0	NS			2		NS				–	2					–	0					–
	Serpula himantioides	0	7	*					–	7			NS	0					–	7					–
Fomitopsidaceae	*Fomitopsis pinicola*	1	2	NS	1				NS	2			NS	1					–	2					–
	Postia ptychogaster	1	0	NS			1		NS				–	1					–	0					–
Ganodermataceae	*Ganoderma applanatum*	12	0	***	2	2		8	*				–	12					–	0					–
Hymenochaetaceae	*Phellinus pini*	0	2	NS					–	2			NS	0					–	2					–
Polyporaceae	*Fomes fomentarius*	4	2	NS	3	1			NS	2			NS	4					–	2					–
	Trametes ochracea	2	2	NS				2	NS		2		NS	2					–	2					–
	Trametes versicolor	0	1	NS					–		1		NS	0					–	1					–
	Trichaptum biforme	0	1	NS					–			1	NS	0					–	1					–
	Trichaptum fuscoviolaceum	0	2	NS					–	2			NS	0					–	2					–
Tricholomataceae	*Armillaria (ryzomorfy)*	9	4	NS	1	4		4	NS		4		*	9					–	4					–
	Panellus serotinus	0	2	NS					–		2		NS	0					–	2					–
The total number of the occurrences		33	25	58	7	7	5	14	33	16	9	0	25	33	0	0	0	0	33	25	0	0	0	0	25
The percentage of occurrences		57	43	**100**	21	21	15	43	**100**	64	36	0	**100**	100	0	0	0	0	**100**	100	0	0	0	0	**100**

The area of logs in m² refers to the upper and lateral surfaces of logs and it was calculated according to the formula $P = 3.14 \cdot r \cdot l \cdot 0.75$ (explanation in the Methods chapter).
Tree species: B/P – *Betula* sp./*Populus tremula*; C – *Carpinus betulus*; P – *Pinus sylvestris*; Q – *Quercus* sp.; U – undetermined taxonomic affiliation. Type of substrate: bark (K), wood (D), moss layer (M), mineral soil accumulated in cracks of trunk (S) and soil which had slid from hummock to the basal section of the trunk (O). Numbers given below denotations of the type of log and substrate refer to the number of logs and substrates of a given type.
K-S test – the Kolmogorov-Smirnov test; K-W test – the Kruskal-Wallis test.
*$p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; NS – no difference.
[1]leg. et det. P. Urbański, [2]leg. P. Urbański, det. P. Górski, [3]leg. et det. R. Nowińska, [4]leg. et det. R. Nowińska, [5]leg. et det. W. Szewczyk.

location. In the "Grabina" area logs of broad-leaved trees were rich in species of vascular plants (21 species grew on oak logs; 16 – on birches and poplars, and 12 – on hornbeams). On pine logs only two species of vascular plants were observed. In turn, in the "Pod Dziadem" reserve pine logs were overgrown by 13 species of vascular plants, while for oak logs and logs with undetermined affiliation there were nine and seven species of vascular plants. In both analysed areas logs covered by moss mats were markedly richer in species. In the "Grabina" on the moss mat a total of 23 vascular plant species was recorded. In the "Pod Dziadem" reserve 12 species were listed.

The species of vascular plants found most frequently on logs in the "Grabina" area included *Impatiens parviflora* (occupying 42.5% examined logs) and *Galeobdolon luteum* (40%), while in the "Pod Dziadem" reserve the most frequently recorded species were *Dryopteris carthusiana* (54% logs), *Oxalis acetosella* (50%) and *Impatiens parviflora* (35%). On logs in the "Grabina" area *Galeobdolon luteum*, *Viola reichenbachiana/V. riviniana* as well as *Geranium robertianum* and *Carpinus betulus* were recorded significantly more often, whereas in the "Pod Dziadem" reserve *Oxalis acetosella* and *Rubus* sp. were listed more frequently. Statistical testing indicates that all species are found with an identical number of occurrences on logs of different tree species. Moreover, the number of occurrences of all species in the "Pod Dziadem" reserve, as well as most in the "Grabina" area (including sporadic species) on tested types of substrates is identical. Exceptions in this respect were *Dryopteris carthusiana*, *Impatiens parviflora*, *Ajuga reptans*, *Galeobdolon luteum* and *Viola reichenbachiana/V. riviniana*. Analyses based on multiple comparisons indicate that the number of occurrences of all the above mentioned species on bark and wood is low and identical. In contrast, landslides and fragments of logs covered by moss mats displayed an identical, high number of occurrences, which was specifically manifested in case of *Impatiens parviflora* and *Galeobdolon luteum* (χ^2 test, $P > 0.0051$). Moreover, *Galeobdolon luteum* equally often occupied bark cracks with accumulated soil (χ^2 test, $P > 0.0051$).

On the examined logs 14 fungal species were listed, belonging to seven families. The most numerous family in terms of the number of species was the family Polyporaceae, with five species. On logs in the "Grabina" sporocarps of seven species of bracket fungi were observed as well as one species of a soil fungus (*Armillaria* sp., which also develops in wood). Fungal formations were detected on 23 logs. Sporocarps of nine species of bracket fungi, as well as one species of a soil fungus were recorded on dead wood in the "Pod Dziadem" reserve. These species grew on 19 logs. Statistical analysis showed that two species differed in their number of occurrences in both reserves: *Ganoderma applanatum* (found only in the "Grabina") and *Serpula himantioides* (found solely in the "Pod Dziadem"). Sporocarps of *Ganoderma applanatum* were listed with an identical number of occurrences (the Fisher test with a correction $P > 0.0085$) on oak, hornbeam and birch/poplar logs. *Serpula himantioides* was reported only on pine wood.

Cover of logs and substrates by bryophyte species

Total and mean cover of different log types by bryophyte species in both objects are presented in Table 3.

Five species of bryophytes differ in the mean cover depending on the area of analysis. A higher cover in the "Pod Dziadem" reserve in comparison to the "Grabina" area was reported for *Lophocolea heterophylla*, *Dicranum scoparium*, *Aulacomnium androgynum* and *Orthodicranum montanum*. In contrast, a higher cover in the "Grabina" area was found for *Brachythecium rutabulum*.

In terms of the total cover of all types of logs in the "Grabina" area the dominant species included *Brachythecium rutabulum* (171.16 m^2) and *Hypnum cupressiforme* (70.81 m^2), while in the "Pod Dziadem" reserve the dominant species were *Hypnum cupressiforme* (87.74 m^2), *Lophocolea heterophylla* (74.83 m^2) and *Brachythecium rutabulum* (27.78 m^2).

In the "Grabina" *Brachythecium rutabulum* grew in biggest abundance on oak logs (arithmetic mean 13.44 m^2), while a considerably lower cover was observed on the other types of logs (the K-S test with a correction $P < 0.0085$). The situation was similar in the "Pod Dziadem" reserve, although mean cover of oak logs was in this case only 2 m^2. *Hypnum cupressiforme* in the "Grabina" area did not exhibit significant differences in the coverage of different types of logs. In the "Pod Dziadem" reserve differences were slight and they were not confirmed in multiple tests. In turn, *Lophocolea heterophylla* in both analysed objects occupied in bigger numbers pine logs rather than all the other log types (the K-S test with a correction $P < 0.085$ and $P < 0.017$).

Total and mean cover of bryophyte species on bark and wood are presented in Table 4.

In the "Grabina" area *Brachythecium rutabulum* and *Hypnum cupressiforme* with a bigger cover were observed on bark. In the "Pod Dziadem" reserve *Hypnum cupressiforme*, *Lophocolea heterophylla* and *Orthodicranum montanum* dominated in wood, while the other species did not exhibit significant differences between their cover rates of bark and wood.

As it was already mentioned, logs in both areas differed significantly in terms of bark cover. It was also shown that despite these differences, overall overgrowing of bark by bryophytes on logs lying in both experimental areas was comparable. Calculations of mean cover on bark of most species also indicate a lack of differences between the two areas. *Brachythecium rutabulum*, *Hypnum cupressiforme* and *Orthodicranum montanum*, which grew more abundantly on bark in the "Grabina" area rather than in the "Pod Dziadem" reserve, is an exception in this respect. Growth of four species (*Hypnum cupressiforme*, *Lophocolea heterophylla*, *Aulacomnium androgynum*, *Dicranum scoparium*) was stronger on wood of logs lying in the "Pod Dziadem" reserve than in the "Grabina" area.

Decomposition of dead logs and differentiation of flora

Differentiation of log overgrowing by vascular plants and bryophytes was analysed jointly for both investigated areas. The number of logs in individual classes of decomposition is as follows: class I – 3 logs, II – 21, III – 32, IV – 25 and V – 5.

TABLE 3. Total and mean (in brackets) cover rates (m^2) of individual types of logs by bryophyte species in the "Grabina" reserve and its surroundings (GR) and in the "Pod Dziadem" reserve (PD)

Species	Total GR	Total PD	U-test	Forest area GR					Forest area PD			
				B/P	C	P	Q	K-W test	P	Q	U	K-W test
1	2	3	4	5	6	7	8	9	10	11	12	13
Atrichum undulatum	r	r	NS		r		r	NS			r	NS
Aulacomnium androgynum	0.55 (0.01)	9.89 (0.21)	**	0.31 (0.04)		0.24 (0.02)		NS	5.73 (0.19)	3.5 (0.39)	0.66 (0.09)	NS
Brachytheciastrum velutinum	r	0.11 (0.00)	NS	r			r	NS			0.11 (0.02)	NS
Brachythecium rutabulum	171.16 (4.28)	27.78 (0.60)	*	16.95 (2.42)	5.95 (0.60)	0.41 (0.03)	147.85 (13.44)	***	7.64 (0.25)	18.02 (2.00)	2.12 (0.30)	**
Brachythecium salebrosum	5.63 (0.14)		NS	5.63 (0.80)	r		r	*				–
Callicladium haldanianum		1.87 (0.04)	NS					–	0.65 (0.02)	1.21 (0.13)		NS
Ceratodon purpureus	r		NS		r			NS				–
Dicranella heteromalla		0.1 (0.00)	NS					–	0.10 (0.00)			NS
Dicranoweisia cirrata	0.60 (0.01)	r	NS	0.30 (0.04)			0.29 (0.03)	NS	r			NS
Dicranum polysetum		r	NS					–	r			NS
Dicranum scoparium	r	4.08 (0.09)	**	r		r	r	NS	1.05 (0.03)	2.52 (0.28)	0.51 (0.07)	NS
Herzogiella seligeri	8.13 (0.20)	12.63 (0.27)	NS	0.24 (0.03)		1.16 (0.10)	6.73 (0.61)	NS	10.62 (0.35)	0.98 (0.11)	1.03 (0.15)	NS
Hylocomium splendens	r	0.24 (0.01)	NS				r	NS	r	0.24 (0.03)		NS
Hypnum cupressiforme	70.81 (1.82)	87.74 (1.91)	NS	33.83 (4.83)	9.64 (0.96)	8.18 (0.68)	19.15 (3.48)	NS	55.32 (1.84)	27.39 (3.04)	5.03 (0.72)	*
Isothecium alopecuroides	r		NS				r	NS				–
Lepidozia reptans		r	NS					–	r			NS
Lophocolea heterophylla	5.87 (0.15)	74.83 (1.63)	***	r		3.98 (0.33)	1.88 (0.17)	***	72.15 (2.40)	2.57 (0.29)	0.37 (0.05)	***
Mnium hornum	r	0.14 (0.00)	NS		r			NS	0.14 (0.00)	r		NS

Table 3 – cont.

1	2	3	4	5	6	7	8	9	10	11	12	13
Nowellia curvifolia	r	7.85 (0.17)	NS			r		NS	7.85 (0.26)			NS
Orthodicranum flagellare		r	NS					–	r			NS
Orthodicranum montanum	0.59 (0.01)	19.69 (0.43)	**	0.31 (0.04)	0.26 (0.03)	r	0.02 (0.00)	NS	17.57 (0.59)	2.12 (0.24)		NS
Orthodicranum tauricum	3.65 (0.09)	1.95 (0.05)	NS	3.63 (0.52)		r	0.02 (0.00)	NS	1.90 (0.06)	0.05 (0.01)		NS
Orthotheciella varia	r		NS		r			NS				–
Plagiomnium affine		0.29 (0.01)	NS					–		0.29 (0.03)		NS
Plagiomnium cuspidatum	r		NS					NS				–
Plagiomnium undulatum	r		NS	r			r	NS				–
Plagiothecium cavifolium		0.26 (0.01)	NS					–			0.26 (0.04)	NS
Plagiothecium curvifolium	2.46 (0.06)	0.14 (0.00)	NS	2.46 (035)		r		NS	0.14 (0.00)	r		NS
Plagiothecium laetum		0.9 (0.02)	NS					–			0.90 (0.13)	NS
Plagiothecium sp.		1.41 (0.03)	NS					–	0.25 (0.01)	1.17 (0.13)		NS
Platygyrium repens	3.97 (0.10)	r	NS	0.54 (0.08)	3.12 (0.31)	0.31 (0.03)	r	NS	r			NS
Pleurozium schreberi	r	1.21 (0.03)	NS	r				NS	0.97 (0.03)	0.24 (0.03)		NS
Pohlia nutans	0.07 (0.00)	0.75 (0.02)	NS			0.07 (0.01)		NS	0.71 (0.02)	0.05 (0.01)		NS
Polytrichastrum formosum		0.02 (0.00)	NS					–	0.02 (0.00)	r		NS
Polytrichum juniperinum		0.24 (0.01)	NS					–		0.24 (0.03)		NS
Ptilidium pulcherrimum		1.42 (0.03)	NS					–	1.42 (0.05)			NS
Sciuro-hypnum oedipodium		16.51 (0.36)	NS					–	16.51 (0.55)	r		NS
Tetraphis pellucida		0.31 (0.01)	NS					–	0.31 (0.01)			NS

Legend to abbreviations: B/P – *Betula* sp./*Populus tremula*; C – *Carpinus betulus*; P – *Pinus sylvestris*; Q – *Quercus* sp.; U – undetermined; r – minimal cover; K-W test – the Kruskal-Wallis test. *p < 0.05; ** p < 0.01; *** p < 0.001; NS – no difference.

TABLE 4. Total and mean (in brackets) cover rate (m^2) of bark and wood by more abundantly occurring bryophyte species in the "Grabina" reserve and its surroundings (GR) and the "Pod Dziadem" reserve

Species	Forest area GR		K-S test	Forest area PD		K-S test	K-S test for GR-PD data	
	bark	wood		bark	wood		bark	wood
Aulacomnium androgynum	0.27 (0.01)	0.27 (0.01)	NS	3.34 (0.07)	6.55 (0.14)	NS	NS	**
Brachythecium rutabulum	157.82 (3.95)	13.34 (0.33)	*	11.76 (0.26)	16.02 (0.35)	NS	**	NS
Brachythecium salebrosum	5.14 (0.13)	0.49 (0.01)	NS			–	NS	NS
Callicladium haldanianum			–	0.41 (0.01)	1.46 (0.03)	NS	NS	NS
Dicranum scoparium	r	r	NS	0.40 (0.01)	3.68 (0.08)	NS	NS	*
Herzogiella seligeri	3.84 (0.10)	4.29 (0.11)	NS	1.43 (0.03)	11.20 (0.24)	NS	NS	NS
Hypnum cupressiforme	58.87 (1.51)	11.94 (0.30)	*	18.20 (0.40)	69.54 (1.47)	***	**	***
Lophocolea heterophylla	2.03 (0.05)	3.84 (0.12)	NS	12.59 (0.28)	62.25 (1.35)	***	NS	***
Orthodicranum montanum	0.44 (0.01)	0.16 (0.00)	NS	0.18 (0.00)	19.51 (0.42)	*	**	NS
Orthodicranum tauricum	3.65 (0.09)		NS	0.10 (0.00)	1.85 (0.04)	NS	NS	NS
Plagiothecium curvifolium	r	2.46 (0.06)	NS		0.14 (0.00)	NS	NS	NS
Platygyrium repens	3.71 (0.09)	0.26 (0.01)	NS	r	r	NS	NS	NS
Sciuro-hypnum oedipodium			–	0.09 (0.00)	16.42 (0.36)	NS	NS	NS

Legend to abbreviations: see Table 3.
K-S test – Kolmogorov-Smirnov test.

Colonization of logs by vascular plants starts from the 2nd class of log decomposition, while the mean number of species exhibits an upward trend with the progress in log decomposition (Fig. 1). Seedlings of trees and shrubs appeared simultaneously with herbaceous plants already on logs in the 2nd degree of decomposition. The mean number of species belonging to both groups increased systematically with the progressing log decomposition, while no abrupt increase was observed (Fig. 2).

The mean number of bryophyte species was lowest in the 1st and 5th classes of log degradation (fewer than four species), while the highest in class II – with over six species per log (Fig. 1). The cover rate of logs by bryophytes increased with progressing substrate softening (Fig. 3). Logs from group I were overgrown on average in approx. 6%, while the most decomposed logs were covered on average in over 50%. In terms of the intensity of log overgrowing generalists dominated over the other ecological groups of bryophytes (Fig. 3), as they occupied at least 50% overgrown log surface, irrespective of the degree of decomposition of these logs. On logs from classes IV and V the proportion of this group of bryophytes increased to 75-78%. Among generalists *Hypnum cupressiforme* was most abundant on logs (Fig. 4). This species, as well as *Brachythecium rutabulum* were found on logs belonging to all the distinguished classes. In terms of proportions the second ranking ecological group of mosses comprises epixylics. They appeared on logs starting from the 2nd degree of decomposition and remained there until stage V. In this group the widest spectrum of occurrence in relation to the degree of log decomposition was found for *Lophocolea heterophylla*, as well as *Herzogiella seligeri* and *Aulacomnium androgynum*. Epiphytes and epigeic species exhibited similar, low cover rate values on examined logs. In most cases they constituted an admixture in mats of generalists and epixylics. Epiphytes covered logs from classes I to IV. The biggest spectrum of occurrence

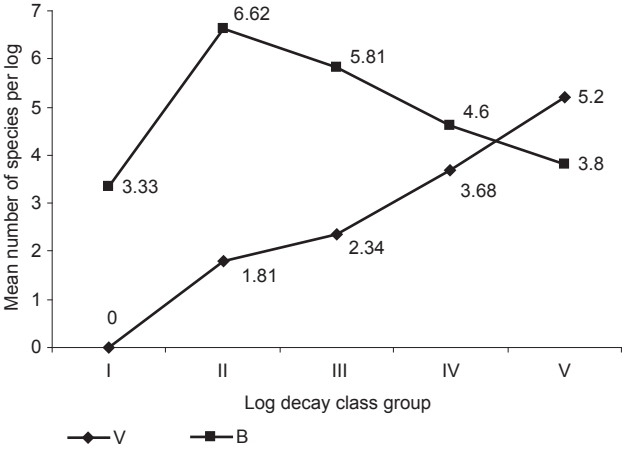

FIG. 1. Mean number of species of bryophytes (B) and vascular plants (V) depending on the log decomposition rate (I-V)

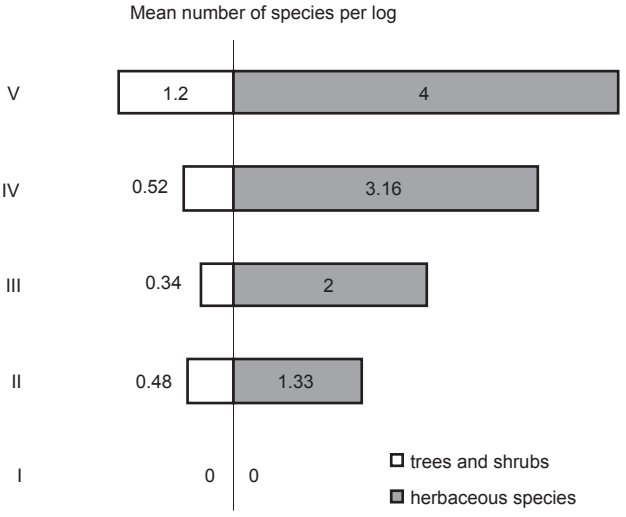

FIG. 2. Mean number of species of herbaceous plants and seedlings of trees and shrubs depending on the log decomposition rate (I-V)

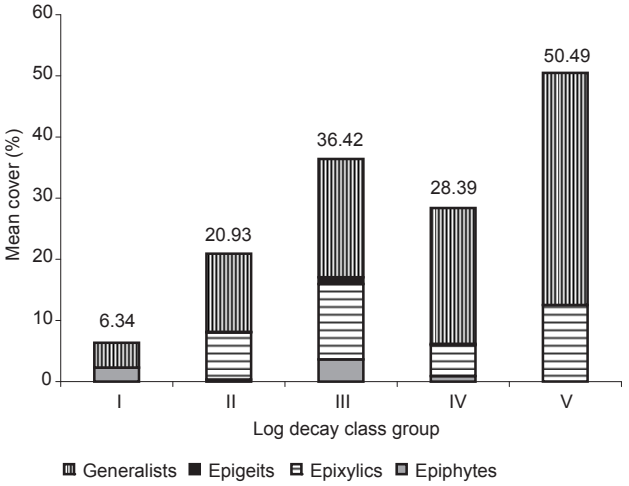

FIG. 3. Mean cover (%) of ecological groups of bryophytes on logs of different decomposition degrees (I-V)

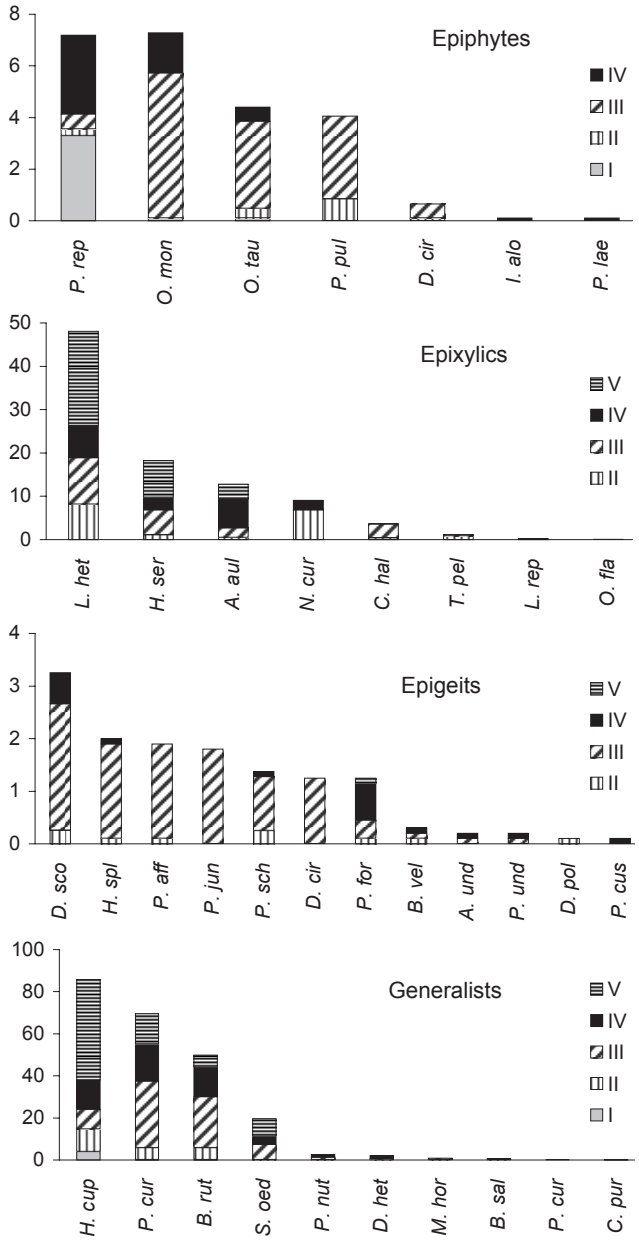

FIG. 4. Mean cover (%) by bryophyte species on logs of different decomposition degrees (I-V)

was found for *Platygyrium repens* and *Orthodicranum montanum*. Among epigeic species only *Polytrichastrum formosum* was observed on four types of logs (II-V), although it was always at a low cover rate. The most common epigean species, with the highest cover rate was *Dicranum scoparium*.

DISCUSSION

On the examined logs a total of 71 plant species and four genus of plants unidentified to the rank of species were listed, together with 14 species of fungi. In the total flora vascular plants account for 50%, mosses – 45%, while liverworts – only 5%.

Four types of logs substratum (bark, wood, mosses and cracks) in the "Grabina" area were inhabited by a total of 26 vascular plants species. Earlier, unpublished study conducted on 238 logs located in "Grabina" reserve (PISKORZ 2004), mentioned the number of 25 species. Despite more extensive observations the number of species of vascular plants overgrowing decomposing logs still remains relatively low. A similar abundance of species was recorded on logs in beech forests of the "Bukowica" reserve, where a total of 12 species were found (CHMURA 2008), and in subalpine forest, where 20 species were listed (ZIELONKA and PIĄTEK 2004). An exception in this respect may be found for old-growth forests of the Białowieża Primeval Forest, where among 303 species of vascular plants growing on different substrates in six types of forest communities, 108 were found on wood of lying trees, while 139 – on bark of lying trees (GŁOWACKI and ZAŁUSKI 1995). This study confirmed the results of earlier observations that all species of vascular plant recorded on logs are frequent components of the herb layer (GŁOWACKI and ZAŁUSKI 1995, PISKORZ and KLIMKO 2001, ZIELONKA and PIĄTEK 2004, CHMURA 2008), the herb layer under canopy gaps (NOWIŃSKA 2008 c) as well as hummocks formed by fallen trees (NOWIŃSKA 2008 d). A small number of species on logs in phytocenoses of the Wielkopolski National Park, as well as beech forests and upper subalpine spruce forests to a considerable degree results from the fact that the ground flora of these phytocenoses is moderately abundant in vascular plant species.

Observations conducted within this study indicate that the presence of bryophytes on logs enhances the richness of vascular plant species on logs. Among 36 species of vascular plants a total of 16 were found on bark and/or wood, while 26 species were observed in the moss layer. Statistical tests also showed that some common species grow on the moss layer more frequently than they do on bark or wood. CHLEBICKI et AL. (1996), based on analyses conduced in the Białowieża National Park, also showed that logs dominated by bryophytes offer a bigger chance for occupancy to vascular plants. It is our suggestion that this situation may be explained by the fact that mosses retain a bigger number of seeds on logs and they create better conditions for seed germination (e.g. by increasing substrate moisture content and enhancing soil accumulation, supplying humus originating from the decomposition of moss residue). We are

of the opinion that it is the presence of mosses which at present determines the number of vascular plants occurrences on logs in the investigated area. It seems that with the progressing log disintegration, substrate softening, growing N concentration (Hendrixon 1991) and increasing water holding capacity of logs (Sollins et al. 1987) the presence of vascular plants will become largely independent of the occurrence of bryophytes. However, further coexistence of both groups of plants may not be excluded.

It was shown in the study that landslides and log cracks increase the number of occurrences of certain vascular plants on logs, thus they may facilitate colonization of such substrates as bark or wood. However, due to their relatively limited presence they serve in the examined area a minor role in the occupation of logs by vascular plants.

Our studies indicate that in a case when fallen trees are not removed, stands with different degrees of natural character may exhibit an identical richness of bryophyte species occupying logs of trees. Richness of bryophytes on logs examined in our study is comparable or even higher in comparison to that, which was observed in many protected broad-leaved and mixed forests in Poland and Europe (Heilmann-Clausen et al. 2005, Andersson and Hytteborn 1991, Paltto et al. 2008, Fudali 1999, Sobotka 1969). However, it is lower than the richness of bryophyte species colonizing dead logs in semi-primeval forests of the Białowieża Forest (Żarnowiec 1997, Klama 1997).

The moss layer develops well on the strongly cracked bark of oaks, and poplars and birches (comprising one group). These logs are also richest in terms of the number of moss species. Low values of mean bryophyte cover on bark of hornbeam logs are probably caused by their slight cracking and lower accumulation of water and organic soil particles. Low mean bryophyte cover rates on bark of pine logs result from the fact that most of these logs are almost completely devoid of bark. Usually only in the basal part of pine logs slight patches of bark were retained. However, their surface is easily flaked off. In the examined area the bark flaking process is accelerated by animals, mainly boars and foxes, which use hollows and hummocks formed by fallen trees as locations for their lairs and dens. A study by Heilmann-Clausen et al. (2005) on bryophytes on logs in mixed nemoral deciduous forest confirmed that the species of trees have an effect on richness of bryophyte species. A high richness of bryophyte species was found for linden and birch logs, slightly lower – for poplar, oak, beech, alder, while the lowest for ash logs. Andersson and Hytteborn (1991) showed that aspen logs are overgrown by a bigger number of species in comparison to birch, fir and pine logs. Distinct preferences in relation to species of host trees were also observed for epiphytic mosses. In forests of the Białowieża National Park the richest epiphytic bryoflora was recorded for oaks and hornbeams, an average level for birches and aspens, while a low level for pines (Żarnowiec 1995).

A decomposed trunk is a substrate changing in terms of its properties throughout its entire existence. These changes are accompanied by the replacement of species and communities in the course of time (Fudali 1999). Initially epiphytes are found on logs in large numbers, while in the final stage epigeic species predominate (Rajandu et al. 2009, Lisowski and Kornaś 1966, Andersson and Hytteborn 1991); however, in different types of phytocenoses individual stages of microsuccession may vary (Kushnevskaya et al. 2007). Since the primary objective of our investigations was a simultaneous, long-term observation of changes in the flora of dead wood and fallen trees, we did not investigate dead trees which had not formed hummocks. These trees most frequently represent the last stages of log disintegration. It is probably for this reason that a lower cover rate was found for epigeic species on logs examined in our study than the other ecological groups of bryophytes. In turn, epixylytic species, considered to be a group with poor competitive potential (Södertröm 1988), were recorded here at a relatively high cover rate. This most probably results from a lack of competition by epigean species. It was shown in our study that epiphytes are retained up to the 4th stage of decomposition. They did not dominate over the other ecological groups at any stage. Generalists were found in biggest abundance on logs in both analysed reserves. They overgrow logs of all classes of log decomposition (I-V) and their proportion in log cover in individual classes ranged from 53 to 78%.

Most listed species of plants and fungi are common in Poland. The most frequently found fungus in the "Grabina" area, *Ganoderma applanatum*, is a common species causing white rot, first in the heartwood, followed by sapwood. It is mainly a saprotroph, also acting as a parasite of weakened trees and a species parasitizing on wounds. We also need to stress here the frequent occurrence of *Serpula himantioides* in the "Pod Dziadem" reserve. It is a saprotrophic fungus causing brown rot of wood. This species is included in the Red Book and until recently it was considered extinct in Poland (Lisiewska 2006); however, in the last years it has been recorded throughout the country (Wojewoda 2003). The occurrence of this species in the "Pod Dziadem" reserve was already reported earlier (Bujakiewicz and Fiebich 1993) and it was confirmed in the course of studies coducted for the purpose of this publication. *Panellus serotinus* is rarely found in Poland. Moreover, in the "Pod Dziadem" reserve on a log neighbouring with the examined logs we observed *Orthodontium lineare* – a moss species originating from the southern hemisphere, which has been spreading in Europe since the first half of the 20th century and which has been given the status of an invasive species (Fudali et al. 2009).

CONCLUSIONS

1. The richness of vascular plant species was bigger on logs in the "Grabina" area, while the richness of species of bryophytes and fungi was identical in both reserves.

2. In the "Grabina" area a bigger richness of plant species was found for logs of broad-leaved trees (mainly oak and birch/poplar logs). In the "Pod Dziadem" reserve more species grew on pine logs. Fungi occupied mainly deciduous wood, which is a primary substrate for

these species. This principle applies to both investigated reserves.

3. Logs of individual tree species differed in terms of the overall cover rates by bryophytes, but only in case when a considerable proportion of logs is covered with bark. Coverage by bryophytes on wood was identical for different tree species.

4. Only individual species of fungi and bryophytes exhibited significant differentiation in the number of log occupancy occurrences for different tree species. No such variation in the occupancy was found for vascular plants. There were an identical number of occurrences of most observed bryophyte species on bark and wood. *Hypnum cupressiforme*, *Brachythecium rutabulum* and *Orthodicranum montanum*, commonly found on logs, markedly more frequently grew on this substrate which was found in bigger abundance.

5. Vascular plants were observed first of all on these logs, on which mats of mosses could serve as a substrate. Also site microforms indirectly connected with the presence of logs, such as landslides on root collars or cracks in logs with accumulated soil, were frequently occupied by vascular plants. However, these microforms, due to their relatively scarce presence, did not play a significant role in the enhancement of richness of vascular plants on logs in the analysed area.

6. Generalists predominated in the moss layer of logs: they covered logs of all decomposition classes (I-V), and their proportion in the coverage of logs from individual classes ranged from 53 to 78%. The first species of vascular plants grew on logs of the 2nd degree of decomposition, which refers to both herbaceous plants and seedlings of trees and shrubs. Mean cover rate by vascular plants increased with progressing substrate decomposition.

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