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***Protura* of suboceanic and subcontinental (*Peucedano-Pinetum* and *Leucobryo-Pinetum*) pine forests in Poland**

Abstract. Species composition, community structure and microhabitat preferences have been studied in *Protura* of Polish pine forests. 6 *Protura* species have been identified, namely, *Eosentomon semiarmatum*, *E. vulgare*, *E. nariae*, *Berberentulus polonicus*, *E. pratense* and *E. pinetorum*. The abundance of the communities studied was low (14.2 - 17.9 ind./sq.m.). Imagines in the investigated material constitute 68.2%, maturi juniores - 23.2%, larvae II - 5.5%, larvae I - 3.1%.

INTRODUCTION

Protura is a group of small soil arthropods and are often included in the wingless insects. Their low abundance, (as compared to other soil arthropods) small body size and the covert mode of life were the reasons why this group had not been discovered before the turn of our century (SILVESTRI 1907, BERLESE 1909).

In Poland, the first representative of this group was recorded by STACH (1926). By the 1960's only three species had been identified in Poland (STACH 1964). This number has recently grown to 60 species (SZEPTYCKI, WEINER 1990, SZEPTYCKI 1991, 1993).

Relatively few ecological contributions concerned with soil zoology have mentioned *Protura*. Most of them just noted the occurrence of the group (ATHIAS 1976, DUNGER 1968, HÅGVAR 1984, HÅGVAR, ABRAHAMSEN 1980, HUHTA, KOSKENNIEMI 1975, PERSSONN et al. 1980, RAW 1956, SALT et al. 1948, TUXEN 1949). Newer papers sporadically provide a list of species (ALBERTI et al. 1989, GUNARSSON 1980, NOSEK 1967, RUSEK 1984, 1989, STUMPP 1990). However, owing to rapid advances in the taxonomy of the group (as many as 30 species new to knowledge have been described in Poland over the last 15 years), most of the older papers cannot provide a sufficient basis for comparative studies.

Protura of Polish pine forests have never been analysed in terms of ecology (community structure or microhabitat preferences). Scarce information, mostly

faunistical, can be found in papers by SZEPTYCKI (1969a, b, 1991, 1993) or in papers describing other regions of Europe (ALBERTI et al. 1989; GUNNARSON 1980; HÁGVAR 1984, STUMPP 1990), concerned particularly with the structure and size of *Protura* communities inhabiting forest associations, including coniferous forests.

AREAS OF STUDY

The study sites were located in a pine forest habitat in natural pine associations. The associations studied were mature (more than 100 years old) and belonged to the *Dicranio-Pinion* association (class *Vaccinio-Piceetea*). The research was carried out in three regions of Poland: Roztocze (Roztocze National Park), Puszcza Biała (Ostrów Mazowiecka forest district) and Puszcza Białowieska (Hajnówka forest district, Starzyna forest division). A detailed geobotanical and pedologic description of the study sites is contained in a paper by MATUSZKIEWICZ (1993).

In all the regions studied, samples were taken in three selected forest stands in the following microhabitats: patches of moss, blueberry, grass, heather, fern, coniferous litter and cow-wheat (*Melampyrum pratense*).

MATERIAL AND METHODS

The material was collected in the years 1986/1987/1988. Soil samples were taken at each stand in spring, summer and autumn. Five samples with an area of 20 sq. cm were taken of every patch. The samples were taken to a depth of 10 cm and extracted in Tullgren funnels.

Protura communities have been described according to the following biocological indices: an index of abundance (A) and an index of dominance (D).

The similarity of *Protura* communities or populations of individual species in forest microhabitat studied has been estimated according to the methods of numerical classification TYTAN'87 (BATKO, MORACZEWSKI 1980).

SPECIES COMPOSITION

Eosentomon semiarmatum Denis, 1927 - known from France and Poland (SZEPTYCKI 1986), often mistaken with *E. transitorium*. In Poland recorded at a few stands, found in *Tilio-Carpinetum* and pine forests.

Eosentomon mariae Szeptycki, 1968 - known so far from Poland and Germany only (SZEPTYCKI 1986), also found in Austria and Luxembourg (unpublished data). It appears to be quite common in the northern part of Poland. As yet, it has not been found in the Carpathians and the Kraków-Częstochowa Upland, despite a large number of materials from these areas (cf. SZEPTYCKI in print). It occurs in litter in various types of forests, but is more frequent in associations with an addition of pine.

Eosentomon pinetorum Szeptycki, 1984 common distributed in Poland (SZEPTYCKI 1986), recorded also from Germany (ALBERTI et al. 1979) and Czechia (RUSEK 1989). Found also in Austria (unpublished materials). It seems to be a xerophilous species commonly found in various types of warm and dry habitats such as pine forests, thermophilous brushwood, various types of xerothermic grasslands etc.

Eosentomon vulgare Szeptycki 1984 - species frequently noted in Poland (SZEPTYCKI 1986), recorded also from Germany (ALBERTI et al. 1989) and Czechia (RUSEK 1989). It has also been found in Austria and Luxembourg (unpublished data). It is common and widely distributed in Poland. It seems to prefer pine forests.

Eosentomon pratense Rusek, 1973 - known from Moravia, Poland and Yugoslavia (SZEPTYCKI 1985), probably eurytopic; recorded from both wet and over-dried habitats in forests and elsewhere.

Berberentulus polonicus Szeptycki, 1968 - registered at a few stands in Poland (SZEPTYCKI 1969a), but (in the light of unpublished materials) it appears to be widely distributed. In certain areas (e.g. the Kraków-Częstochowa Upland), it is one of the most common *Protura* species (SZEPTYCKI in print). It is found in various types of forest, but only in those with an addition of pine.

THE STRUCTURE AND SIZE OF PROTURA COMMUNITIES OF PINE FORESTS

ABUNDANCE. In the sampling season 1986-1988, the average abundance of *Protura* in suboceanic pine forests (*Peucedano-Pinetum*) ranged from 14.2 ind./sq.m (Puszcza Biała) through 40.5 ind./sq.m (Puszcza Białowieska) to 72.9 ind./sq.m in a *Leucobryo-Pinetum* association (Roztocze NP). The abundances of *Protura* in the microhabitats selected in pine forests are various and indicate a certain habitat selectivity (Tab. I).

Table I. Mean density N (ind./100 cm²) of *Protura* in different microhabitat of pine forests

Microhabitat	Roztocze	Puszcza Białowieska	Puszcza Biała
moss	1.50	0.10	0.35
bilberry	0.81	0.06	0.36
grass	0.29	0.08	0.64
heather	0.50	0.32	0.45
fern	0.74	0.03	0.29
<i>M. pratense</i>	0.13		
litter	1.13	0.26	0.34

The abundances of *Protura* recorded in Polish pine forests are relatively low as compared to abundances measured in forest associations with pine *Pinus silvestris* e.g. in Sweden, where the abundance amounted to 16,000 ind./sq.m (AXEL-

SEN et al. 1973, after STUMPP 1990). Higher abundances of *Protura* have also been recorded in other forest associations e.g. boreal spruce forests of Finland (HUHTA, KOSKENNIEMI 1975), spruce forests of Norway (PETERSEN, LUXTON 1982), spruce forests of Germany (STUMPP 1990), beech forests of Denmark and Germany (TUXEN 1949, PETERSEN, LUXTON 1982), oak forests of Sweden (GUNNARSSON 1980) or meadow associations (SALT et al. 1948, RAW 1956).

Number of species, dominance. 6 *Protura* species were found in the coniferous forest associations with pine. The highest number of species was noted in the pine forests of Roztocze (6 species), where *Berberentulus polonicus* was a dominant, and *Eosentomon semiarmatum* and *E. mariae* were co-dominants. In Puszcza Białowieska and Puszcza Biała, where *Eosentomon mariae* was the dominant species, number of species was lower (3 and 2 species respectively) (Tab. II).

Table II. Dominance structure of *Protura* in pine forests (N - ind./300 m²)

Species	Roztocze		Puszcza Białowieska		Puszcza Biała	
	N	%	N	%	N	%
<i>Eosentomon semiarmatum</i>	21	26.0				
<i>Eosentomon vulgare</i>	9	11.1	12	15.8		
<i>Eosentomon mariae</i>	13	16.0	62	81.6	12	75.0
<i>Eosentomon pinetorum</i>	9	11.1				
<i>Eosentomon pratense</i>			2	2.6		
Total	81	100	76	100	16	100

Most of the studies concerned with estimating the size *Protura* communities in certain well-defined plant associations leave out the species aspect, their scopes being limited to estimating community size on the basis of abundance indices or, sometimes, biomass (PETERSEN, LUXTON 1982). Estimates of the species composition and abundance of *Protura* communities are provided in few of them. For instance, 11 *Protura* species were registered during a study in spruce-beech forests near Heidelberg, with *Acerentomon gallicum* having the highest frequency. A study of spruce and oak forests of Sweden (GUNNARSON 1980) yielded 3 species, with *Eosentomon germanicum* functioning as the dominant. 11 species were found in spruce forests situated in southern Germany, where *Eosentomon transitorium* was the dominant in the majority of the stands studied (STUMPP 1990).

Age structure. In the *Protura* communities studied in pine forests, the share of younger stages is several times low than that of mature forms (Table III). The imagines constitute 68.3% of the communities, matus junior - 23.3%, larvae II - 5.5%, larvae I - 3.1%. Prelarval stages were not found in the study material. A similar development stage distribution of is given by STUMPP (1990).

The demographic structure of *Protura* communities observed in pine forests may be a result of inadequacy of the extraction techniques used (leading to greater losses in juvenile stages than in adults). It may, however, be attributable to shorter life-span of juvenile forms compared to a relatively longer life-span in adults.

Table III. Age structure of *Protura* in pine forests

Stages	ind	%
Praelarvae	-	-
Larvae I	7	3.1
Larvae II	12	5.5
Maturus junior	51	23.2
Imago female	95	43.2
Imago male	55	25.0
Imago female + male	150	68.2
Total	220	100

Protura communities as well as communities of other animals undergo seasonal changes in age structure (Fig. 1). In the populations of *E. semiarmatum* - in the autumn-spring period larval stages start to appear in communities of this species as well as males, females and matusus juniores; *Eosentomon mariae* - in spring and summer the proportion of the females decreases while the males and younger development stages become more frequent; *E. pinetorum* - the males are dominant from spring to summer, and females as well as preimaginal stages, in late autumn and early spring; *E. vulgare* - males are dominant in late spring, females, in early spring and summer; *Berbenterulus polonicus* - also shows temporary separation of the niches (males start to appear in late autumn and early spring).

This seasonal changes in age structure are probably related to differences in the ability to migrate and in habitat selectivity of each sex. It seems that after the breeding season the niches of the males and females are temporarily separated.

DISTRIBUTION OF PROTURA IN THE MICROHABITATS

Fairly is little known of the ecological distribution pattern of this group (IMMEDIATE 1973).

The pine forests types studied, situated in different, often remote, regions of Poland, are characterized by considerable diversification of their *Protura* communities both in terms of abundance and species composition. The diversification is seen in the microhabitats selected in the pine forests of Roztocze, Puszcza Biało-

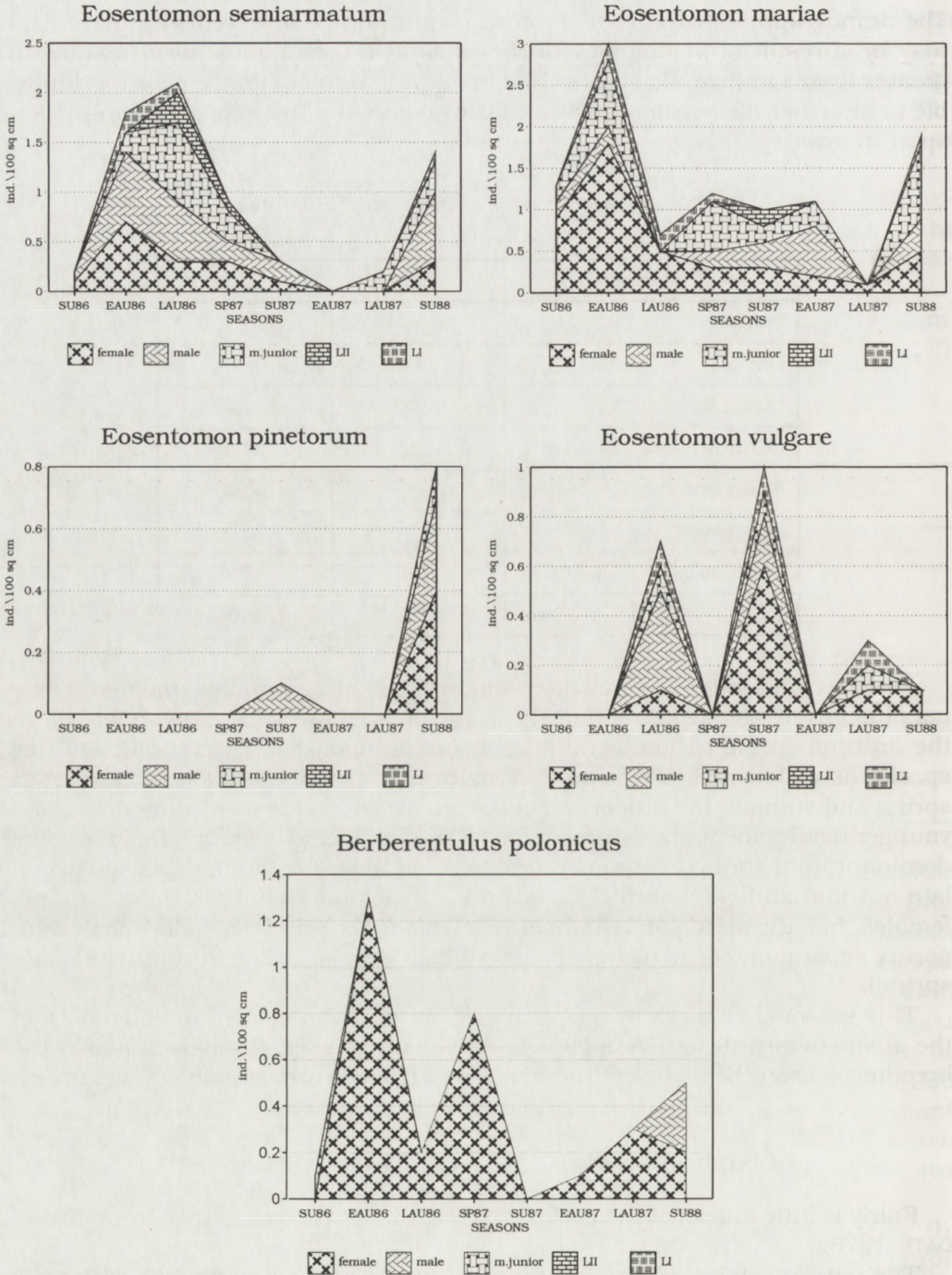


Fig. 1. Seasonal changes in population structure of *Protura*; SU86 – summer, EAU86 – early autumn, LAU86 – late autumn, SP87 – spring, SU87 – summer, EAU87 – early autumn, LAU87 – late autumn, SU88 – spring

wieska and Puszcza Biała (Fig. 2 a, b, c). Due to the considerable diversification, the observed regularities are by no means constant, differing in each of the pine forest type studied.

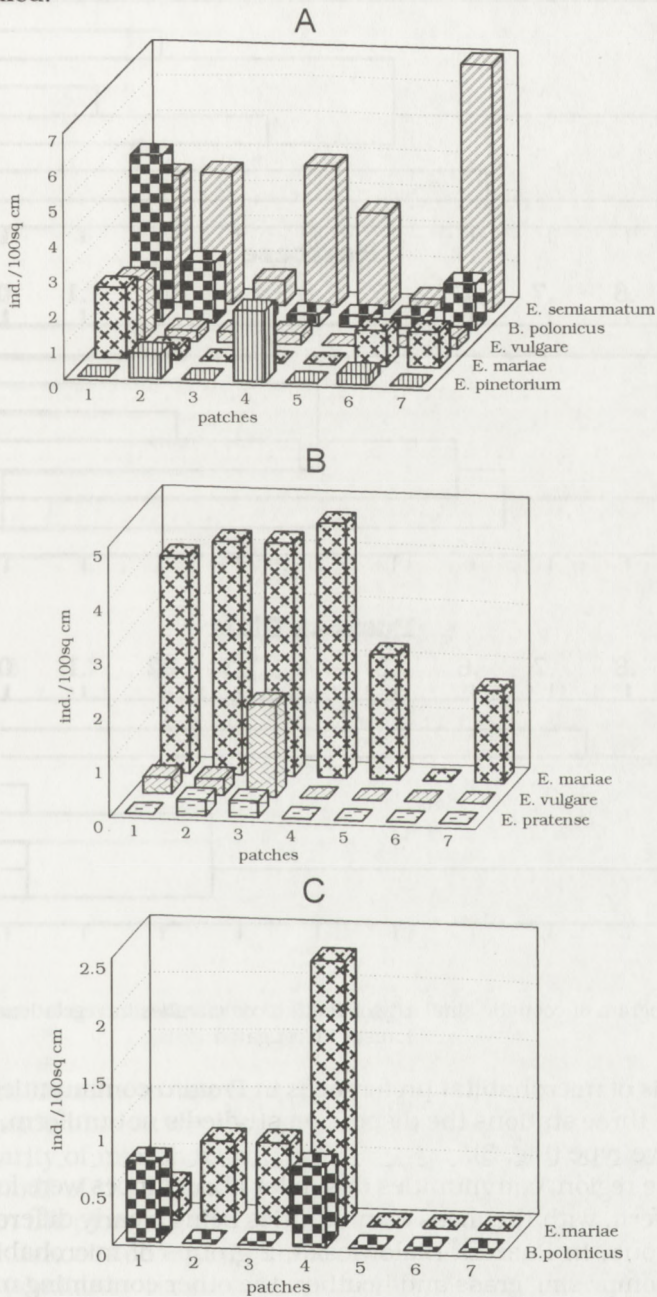


Fig. 2. Distribution pattern of *Protura* species in vegetation patches (microhabitats) in three stands of pine forest: A – Roztocze; B – Puszcza Białowieska; C – Puszcza Biała; 1 – moss, 2 – bilberry, 3 – grass, 4 – heather, 5 – fern, 6 – *M. pratense*, 7 – litter

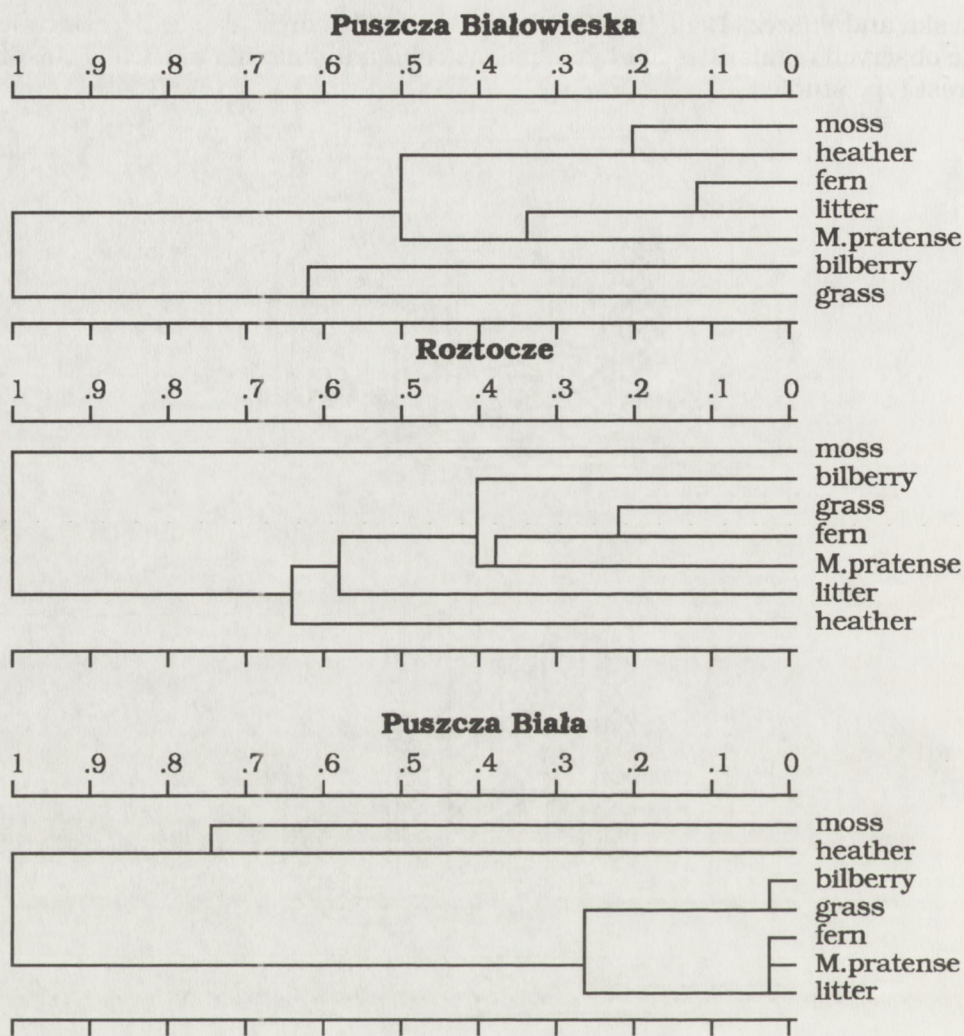


Fig. 3. Dendrogram of coenotic similarity of *Protura* communities in vegetational paths in pine forests investigated

An analysis of microhabitat preferences in *Protura* communities indicates that in each of the three stations the dispersion studied is not uniform, but is rather of the aggregative type (Fig. 3).

In Roztocze region, communities of similar abundances were found in patches of grass and fern, with the moss communities being clearly different and forming a separate group. In Puszcz Białowieska, 2 groups of microhabitats can be recorded: one comprising grass and heather, the other containing moss, blueberry, fern, litter and *M. pratense*. A characteristic of the patches studied in Puszcz Biała is the presence of major differences in abundance, with the heather, moss and grass *Protura* communities still forming a separate group.

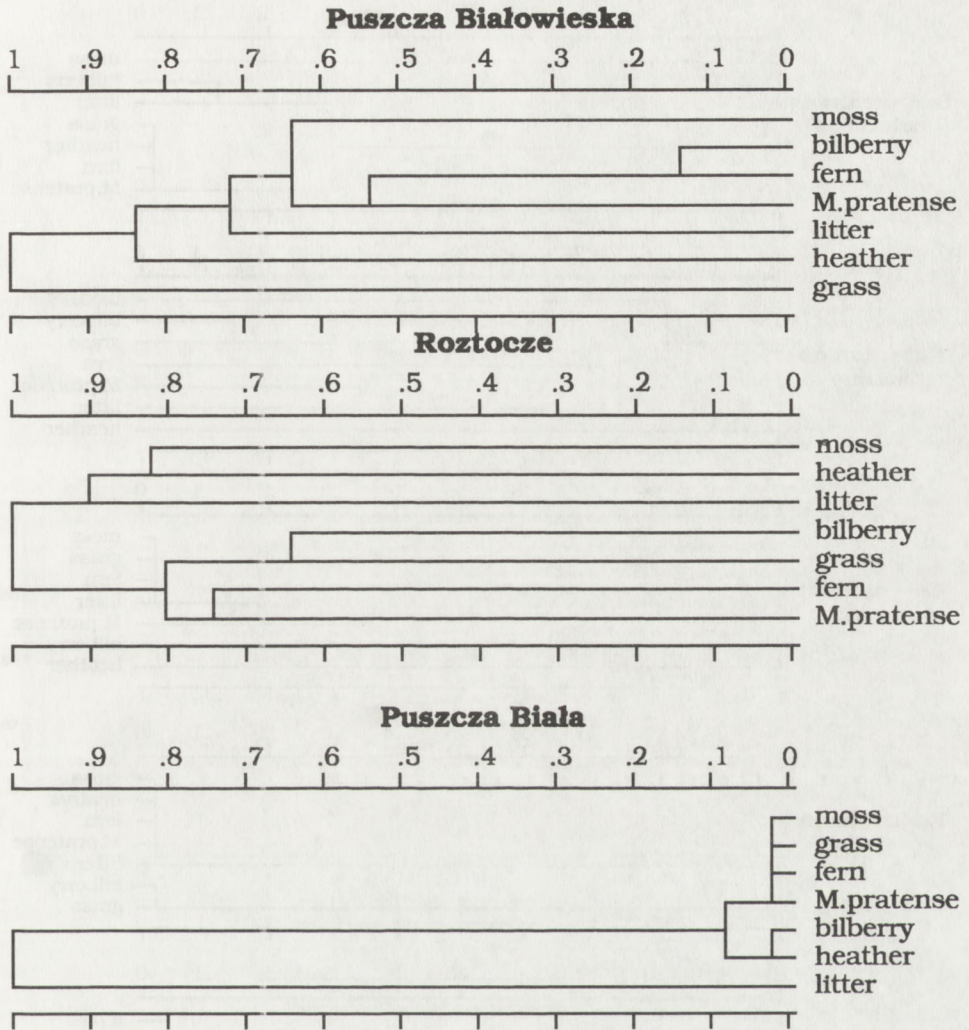


Fig. 4. Dendrogram of coenotic similarity during seasons of *Protura* communities in vegetational patches in pine forests investigated

Seasonal fluctuations in the abundance of *Protura* may provide an explanation for the considerable differences in microhabitat occupation. Estimates of the degree of similarity of microhabitat occupation in *Protura* communities recorded in different periods of the sampling season reveal a relatively low degree of similarity (Fig. 4). In the plots studied in Roztocze, the greatest seasonal fluctuations in *Protura* abundance is observed in patches of litter, but it remains high in other microhabitats (similarity index does not exceed 35%). In Puszczka Białowieska the greatest abundance fluctuations are noted for patches of grass. It is also high in patches of heather, litter and moss, due to which *Protura* communities in these plots do not resemble one other. The relatively high similarity of different

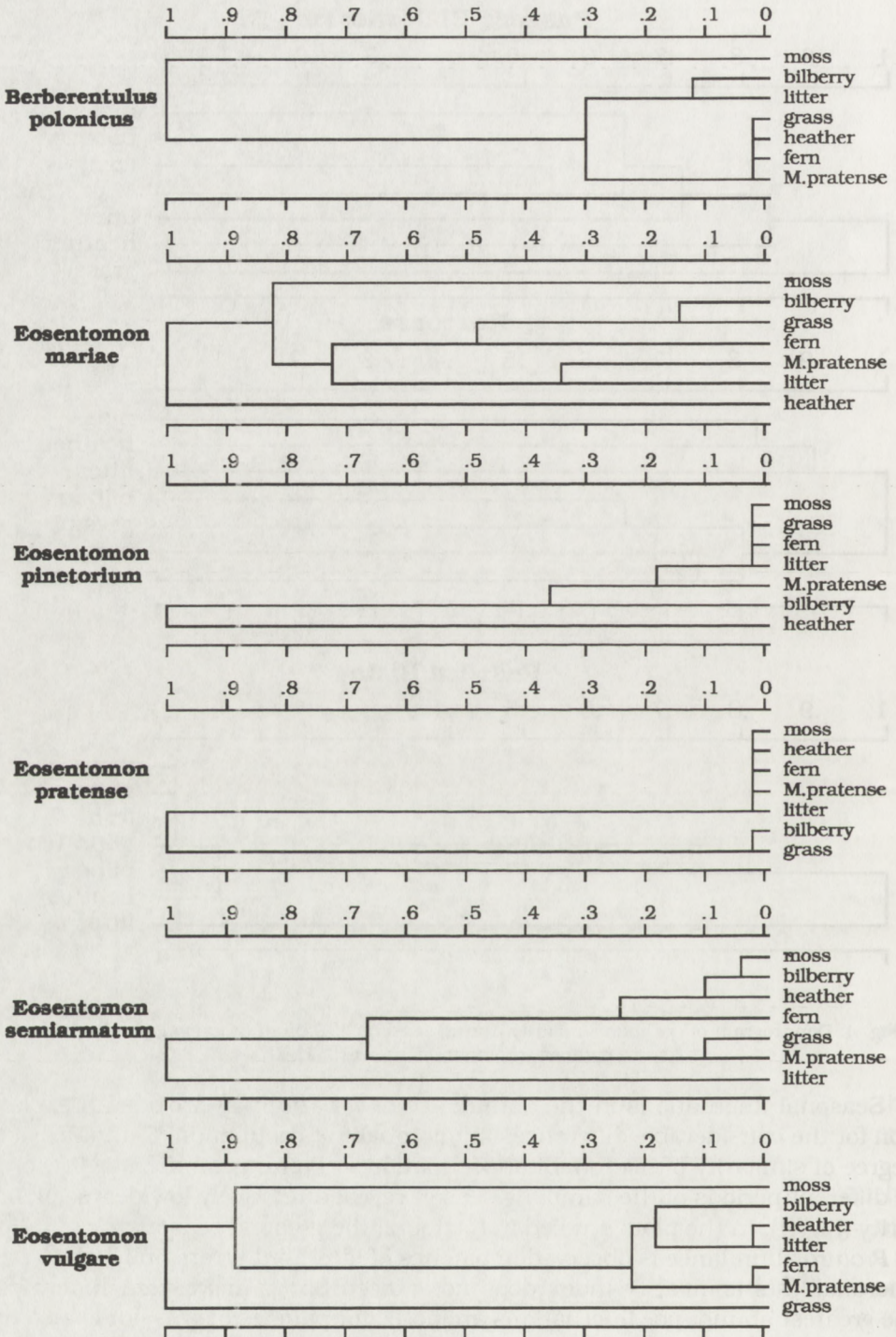


Fig. 5. Dendrogram of fidelity of *Protura* species to vegetational patches in pine forests investigated

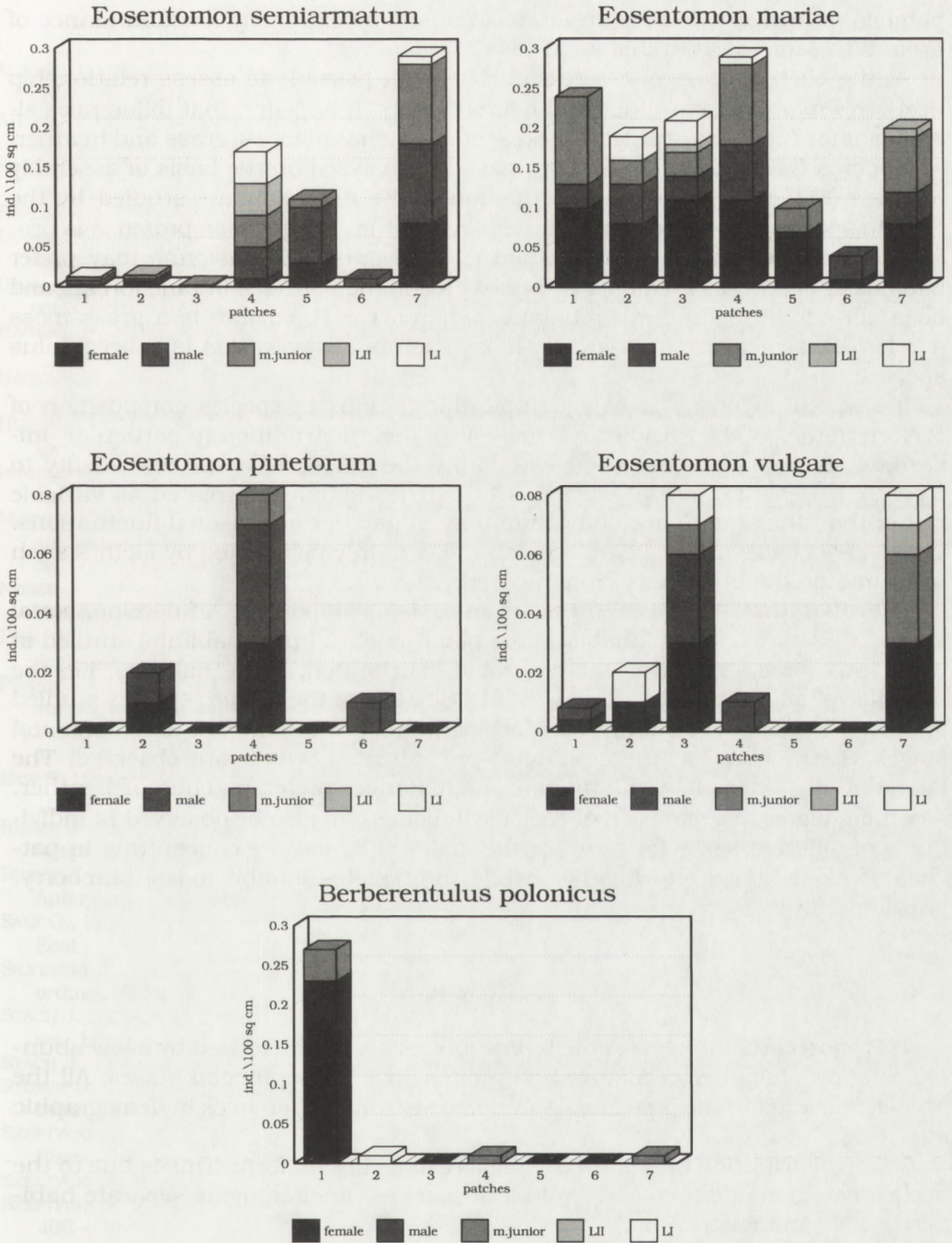


Fig. 6. Population structure of *Protura* species in vegetational patches in pine forests investigated: 1 - moss, 2 - bilberry, 3 - grass, 4 - heather, 5 - fern, 6 - *M. pratense*, 7 - litter; *E. pinetorum*, *B. polonicus*, *E. mariae*, *E. vulgare*, a) - *E. semiarmatum*

patches in Puszcza Biała is an artefact caused by extremely low abundance of *Protura* in samples from this area.

At the current stage of the research it is not possible to assess relationship between *Protura* communities and microhabitats. It appears, that differences significant for the taxon studied are present in patches of moss, grass and heather.

Species fidelity. Species fidelity was also analysed on the basis of assembly analysis (Fig. 5). Estimates of occupation of the microhabitats studied by the *Protura* species registered in pine forests reveal that *Eosentomon pratense* is probably a species associated with blueberry and grass; *E. pinetorum* may prefer patches of heather; *Eosentomon mariae* is a common species in pine forests and does not exhibit definite microhabitat preferences; *E. vulgare* is a grass-moss species; *E. semiarmatum* is a litter-moss species; *B. polonicus* is a bryophilus species.

It seems that owing to considerable fluctuations in species composition of *Protura* in the patches studied an analysis of their distribution in particular microhabitats should be aimed at estimating the degree of a species' fidelity to a patch. The abundance of a species in patches should be treated as variable rather than the abundance of a community in patches or seasonal fluctuations. The degree of species fidelity to a patch will certainly be affected by factors such as humidity, the presence of root mycorrhiza, etc.

Microhabitats, age structure. An analysis of proportions of developmental stages of *Protura* species inhabiting the plant patches (microhabitats) studied in coniferous forests confirms their variable distribution in the habitats, i.e. the presence of microhabitat preferences (Fig. 6). Most of the *Protura* species studied show no tendencies to change their ecological niches at different developmental stages. Such changes in microhabitat preferences however are observed. The larvae of *Eosentomon semiarmatum*, for instance, prefer patches of heather. A certain degree of separation of ecological niches can also be observed in individuals of different sexes for example the males of *E. vulgare* concentrate in patches of moss, grass and heather, while the females inhabit moss, blueberry, grass and litter.

SUMMARY

1. *Protura* communities of Polish pine forests are characterized by a low abundance and dominance of mature and preimaginal developmental stages. All the species recorded in the pine forests undergo seasonal differences in demographic structure

2. The distribution of *Protura* in pine forests is not uniform. This is due to the occurrence in coniferous forests of plant patches functioning as separate habitats for the animals.

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STRESZCZENIE

[Tytuł: *Protura* subkontynentalnych i suboceanicznych borów sosnowych Polski]

W badanych borach sosnowych stwierdzono 6 gatunków *Protura*. Liczebność zgrupowań *Protura* w borach sosnowych Polski jest niska i waha się w granicach od 14.2 – 72.3 os./m². Największym bogactwem gatunkowym charakteryzują się bory sosnowe typu *Leucobryo-Pinetum* na Roztoczu (5 gatunków). Zdecydowanie uboższe gatunkowo są zbiorowiska borowe (*Peucedano-Pinetum*) w Puszczy Białowieskiej i Puszczy Białej. W zgrupowaniach *Protura* w borach sosnowych Roztocza dominuje – *Berberentulus polonicus*, w Puszczy Białowieskiej i Białej – *Eosentomon mariae*. Populacje *Protura* w badanych borach cechują się znacznym udziałem stadiów dojrzałych i preimaginalnych. U wszystkich stwierdzonych w borach sosnowych gatunków *Protura* występują sezonowe zmiany w strukturze demograficznej i proporcji płci.

Rozprzestrzenienie *Protura* w borach sosnowych jest nierównomierne. Nierównomierność rozprzestrzenienia *Protura* warunkuje występowanie w borach sosnowych facji roślinnych stanowiących jednocześnie dla nich odrębne mikrosiedliska.