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Assemblage structure and altitudinal distribution of lady beetles (Coleoptera, Coccinellidae) in the mountain spruce forests of Poľana Mountains, the West Carpathians

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Abstract: In two successive years we recorded a total of 3,636 individuals and 17 species of adult lady beetles (Coleoptera, Coccinellidae) in the spruce forests of Poľana Mts (the West Carpathians) at altitudes ranging from 600 m to 1,300 m a.s.l. Four lady beetle species were documented as predominating (dominance of abundance > 5%) over the study period. They were the following: *Aphidecta obliterata* (1,828 individuals and 50.3%), *Coccinella septempunctata* (634 individuals and 17.4%), *Adalia conglomerata* (594 individuals and 16.3%) and *Anatis ocellata* (279 individuals and 7.7%). The assemblages of lady beetles differed among the areas and also between the years. The season revealed neglegible effect on distribution of lady beetles, whereas the effect of altitude was more pronounced. *A. conglomerata* preferred the areas at lower altitude (600–725 m) to those at middle (900–925 m) and/or upper altitude (1,250–1,300 m). In contrast, *A. obliterata* and *C. septempuctata* were most abundant in the area at middle altitude. The altitudinal location of area partly explained the variability in abundance of lady beetles. The first ordination axis constructed by means of correspondence analysis (CA) represented an altitudinal gradient and accounted for 19.4% of the total variance of the species data. The great proportion of lady beetle species not typically associated with spruce and/or other coniferous trees than spruce (70.6%, $n = 17$) may be explained by an ecotonal effect.

Key words: Coccinellidae; ladybirds; *Picea abies*; altitudinal gradient; assemblage structure; distribution pattern; Central Europe

Introduction

Lady beetles (Coleoptera, Coccinellidae) are frequently studied because of their attractiveness and ecological and/or economic significance. They are known as predators of scale insects, aphids and numerous other insects (Savoiskaya 1961; Hodek 1973; Bastian 1981; Koch 1989; Majerus 1994; Hodek & Honěk 1996), or herbivores feeding on weeds or crops (Sawada & Ohgushi 1994). Some lady beetle species are mycophagous (Koch 1989).

The lady beetle associates of Norway spruce [*Picea abies* (L.) Karst] in Europe were studied by Koehler (1961), Klausnitzer & Bellmann (1969), Bastian (1981), Nedvěd (1999), Klausnitzer (1999), Redderesen & Jensen (2002), Zelinková et al. (2002), Zelinková (2004), Zöbl et al. (2006). These works deal with numerous aspects of biology and ecology of coccinellids. Despite this, knowledge of occurrence, assemblage structure and altitudinal distribution of lady beetles in a mountain spruce forest is not adequate, even in common species. The effects of numerous factors on the occurrence and distribution of lady beetles in this habitat (e.g., climate – air temperature and moisture, forest structure, structure of adjacent habitats, presence of suitable food/prey, natural enemies etc.) are only poorly known (Zelinková et al. 2002; Zelinková 2004).

The present study was aimed to characterize the species assemblages and altitudinal distribution of lady beetles in the spruce forests of Poľana Mts and to clarify the effect of altitude on distribution of lady beetles.

Material and methods

Study area

Four areas (I–IV) were selected to study the occurrence and altitudinal distribution of lady beetles on the south-facing slopes of the volcanic Poľana Mts (the West Carpathians, Central Slovakia). Area I (600–625 m a.s.l.) is bottom of a valley, area II (700–725 m a.s.l.) represents its elevated part. In the further text both areas are referred to as lower altitude. Area III (900–925 m a.s.l.) lies between area II and area IV (middle altitude). Area IV (1,250–1,300 m a.s.l.) is a part of the main Poľana mountain ridge (upper altitude).

The beech forest in area I and II and beech-fir forest in area III were converted to monocultures of Norway spruce some 40–60 years ago. The climax acidophilous spruce forest (Kukla 1995; Kukla et al. 1995; Viceníková & Polák 2003) is typical of area IV. Tree species composition in particular areas is similar (spruce – 98%, beech, sycamore, goat willow and rowan – 2%). The age of spruce trees is varying, from 40 to 60 years. Small proportion of spruce trees over 200 years old are typical of area IV (mature spruce trees were not present in the forest margin where lady beetles were collected – see below). All the four areas border mountain meadows with diverse wildlife.

Field sampling
We sampled lady beetles in the adult stage in the areas I–IV from May to September 1999 and 2000. Sampling was performed by beating branches of spruce trees growing in the forest margin and, consequently, by collecting the lady beetles that dropped into a circular beating sheet (diameter 1.0 m) when disturbed. The sheet was modified to avoid escapes of highly mobile insects like lady beetles. The sampling heights in trees varied from 1.0 m up to 3.0 m (measured from the ground). Lady beetles obtained from 20 branches (1.0 m long each) of different trees constituted one sample. In each area they were sampled in 10 scattered and originally randomly selected, and then stable, plots every month (in the middle of May, June, until September). Thus, every year, lady beetles were obtained from the branches, the total length of which was 4,000 m (4 x 1,000 m). They were sampled only if weather conditions were favourable. That is, the sampling was not made on rainy days or shortly after rain, or on windy days. The beetles were preserved in 70% ethanol and identified in the laboratory. The voucher specimens of all lady beetle species detected in the study are maintained in the collections of the authors.

Data analysis
Assemblages of lady beetles were characterized by abundance and relative abundance of the species recorded (Table 1). We used the Simpson's index of dominance (c) to characterize concentration of dominance of abundance in lady beetle assemblages. Then, diversity indices were counted according to the formula $d = 1 - c$ (Odum 1971).

Lady beetle assemblages were compared among the four areas and between two years using Wishart's index (Wishart 1969) and complete linkage method in hierarchical clustering. Logarithmically transformed abundances of individual taxa were used for computations in the Syntax 5.0 program (Podani 1993).

Correspondence analysis (CA) was performed to assess the distribution of lady beetles in time and space using the Canoco program (Ter Braak & Šmilauer 1998). The taxa by sites matrix included 17 species and 40 samples (four areas monitored in two years in five months). Two samples (area I and area II monitored in June 1999) were excluded from the analysis because of small number of individuals (less than 3 individuals). The analysis was based on the logarithmicaly transformed abundances [$y = \log(x+1)$] of individual taxa.

As the data did not meet the assumptions of analysis of variance even after transformation, we resorted to

Table 1. Distribution pattern of lady beetles and characteristics of lady beetle assemblages in altitudinal areas I–IV. Data are numbers of lady beetles obtained from 1,000 branches of Norway spruce in 1999 and 2000, or from 2,000 branches (1.0 m long each) in 1999–2000. Predominating species (dominance of abundance over 5%) are given in bold letters. Area I (600–625 m), area II (700–725 m), area III (900–925 m), area IV (1,250–1,300 m a.s.l.).

Year	Code	1999				2000				1999–2000	
Species / area		I	II	III	IV	I	II	III	IV	$\sum n$	$\sum n$ (%)
Scymnus abietis Paykull, 1798	Scy abi	10	6	18	3	6		8	7	58	1.6
Exochomus quadripustulatus (L., 1758)	Exo qua							1		1	0.0
Tytthaspis sedecimpunctata (L., 1758)	Tyt sed		1							1	0.0
***Aphidecta obliterata* (L., 1758)**	Aph obl	**16**	**43**	**55**	**30**	**345**	**275**	**810**	**254**	**1828**	**50.3**
***Adalia conglomerata* (L., 1758)**	Ada con	**46**	**29**	**5**		**261**	**231**	**14**	**8**	**594**	**16.3**
Adalia bipunctata (L., 1758)	Ada bip			2		1	3	7	2	15	0.4
Adalia decempunctata (L., 1758)	Ada dec					2		10	2	14	0.4
Adonia variegata (Goeze, 1777)	Ado var								3	3	0.1
Ceratomegilla notata (Laicharting, 1781)	Cer not	6	9	5		1	49	31		101	2.8
Coccinella quinquepunctata L., 1758	Coc qui			1						1	0.0
***Coccinella septempunctata* L., 1758**	Coc sep	**1**	**7**	**98**	**84**	**12**	**58**	**278**	**96**	**634**	**17.4**
Propylea quatuordecimpunctata (L., 1758)	Pro qua		2	4	5		5	19	1	36	1.0
Anisocalvia quatuordecimguttata (L., 1758)	Ani qua		1			9	2	3	6	21	0.6
Myzia oblongoguttata (L., 1758)	Myz obl	4	5			4	8	1		22	0.6
***Anatis ocellata* (L., 1758)**	Ana oce	**5**	**6**	**3**	**1**	**36**	**57**	**146**	**25**	**279**	**7.7**
Psyllobora vigintiduopunctata (L., 1758)	Psy vig	1		1			1	3		6	0.2
Halyzia sedecimguttata (L., 1758)	Hal sed		3		3	1	3	1	11	22	0.6
Number of species (S)		8	11	10	6	11	11	14	11		
Number of individuals (n)		89	112	192	126	678	692	1332	415	3636	100
Simpson's index of dominance (c)		0.31	0.24	0.36	0.51	0.41	0.29	0.42	0.43		
Diversity ($1 - c$)		0.69	0.76	0.64	0.49	0.59	0.71	0.58	0.57		

the non-parametric Kruskal-Wallis ANOVA test (Sokal & Rohlf 1995) to test for differences in variance location (abundance – primary data) among different areas or different altitudes, respectively. In case significant difference was detected among the areas compared, the Kruskal-Wallis test by ranks was followed by multiple comparison to locate pairs of areas with different numbers of lady beetles. A total of 200 samples (four areas × five months × 10 replicates in each area and month) were analysed separately for 1999 and 2000. Statistical analyses were performed for lady beetles together (all species considered) and the three predominating species, *A. obliterata, A. conglomerata* and *C. septempunctata*, using Statistica 7 software (StatSoft, Inc. 2005).

Results

Over a period of two years (1999–2000) we recorded a total of 3,636 individuals and 17 species of lady beetles from spruce trees at altitudes between 600 and 1,300 m. Four species were predominating on spruce (dominance of abundance > 5%) in the study area. They were the following: *Aphidecta obliterata* (1,828 individuals, 50.3%), *Coccinella septempunctata* (634 individuals, 17.4%), *Adalia conglomerata* (594 individuals, 16.3%) and *Anatis ocellata* (279 individuals, 7.7%). Lady beetles were more abundant in 2000 (3,117 individuals) than in 1999 (519 individuals) (Table 1).

The assemblages of lady beetles differed among the areas and also between the years (Fig. 1). They were subject to change throughout the season but seasonal changes in their composition showed no clear trend in general. The samples in the ordination diagram (CA) showed greater dispersal in time but were nicely packed together in space (area I + II, area III + IV) (Fig. 2). Taken in aggregate, the season revealed neglegible effect on the distribution of lady beetles.

The ordination diagram of CA (Fig. 3) confirmed the affinity of lady beetle species to particular areas or altitudes, respectively. The species on the left side of the ordination diagram were more frequent and abundant at lower altitude (area I and II), whereas the species on the right side of the diagram were more frequent and abundant at middle (area III) and upper altitude (area IV). The predominating species confound strictly on conifers (*A. obliterata, A. conglomerata* and *Anatis ocellata*) were located on the X axis, while the rest of species, most of them living on deciduous trees or herbaceous plants, were more scattered through space (Fig. 3). The first ordination axis ($\lambda_1 = 0.234$) was strongly associated with the altitudinal gradient and accounted for 19.4% of the total variance of the species data. The second ordination axis ($\lambda_2 = 0.161$) was likely to be associated with the host tree, Norway spruce in this case. The two axes together explained 32.8% of the total variance of the species data (Fig. 3).

The abundance of lady beetles (all species considered) significantly differed among the areas compared (1999: $Q = 22.732$, $n = 200$, $P < 0.001$; 2000: $Q = 37.868$, $n = 200$; $P < 0.001$, Kruskal-Wallis ANOVA). In both 1999 and 2000, lady beetles were most abundant in area III at middle altitude. High numbers of

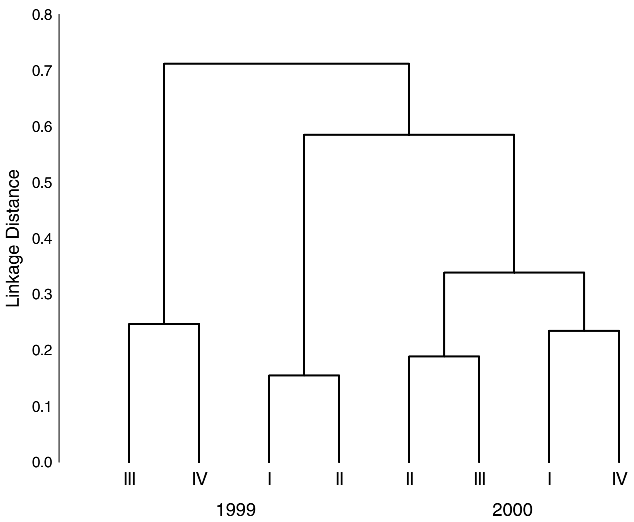

Fig. 1. Dendrogram of four areas in two years based on logarithmically transformed abundances of 17 lady beetles species (hierarchical clustering, complete linkage, Wishart's index). Area I (600–625.), area II (700–725 m), area III (900–925 m), area IV (1,250–1,300 m a.s.l.).

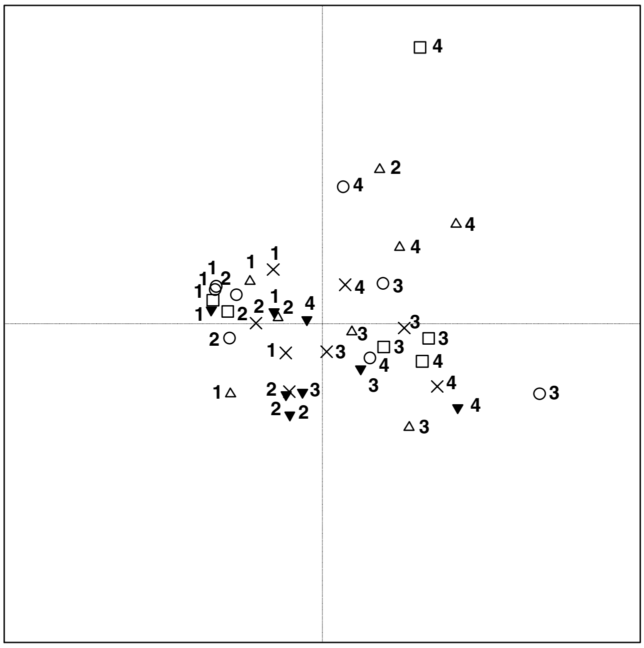

Fig. 2. First two axes of CA as a scatter plot of samples (up triangle – May, circle – June, square – July, X-mark – August; down triangle – September; 1–4 – altitudinal areas I–IV). Area I (600–625 m), area II (700–725 m), area III (900–925 m), area IV (1,250–1,300 m a.s.l.).

A. obliterata and *C. septempunctata* in this area contributed much to the overall distribution pattern of lady beetles (Fig. 4).

The abundance of *Aphidecta obliterata* significantly differed among the areas compared (1999: $Q = 10.482$, $n = 200$, $P = 0.015$; 2000: $Q = 34.349$, $n = 200$, $P < 0.001$, Kruskal-Wallis ANOVA). In 2000, *A. obliterata* was shown to be significantly more at middle altitude (area III) than at lower (area I, II) and up-

Fig. 3. First two axes of CA as a scatter plot of species. The first two ordination axes ($\lambda_1 = 0.234$ and $\lambda_2 = 0.161$) accounted for 32.8% of the total variance of the species data (see Table 1 for codes of species). The first axis corresponds to the increase in altitude, the second axis is likely to be associated with the tree species (host).

per altitudes (area IV) ($P < 0.05$) (Fig. 5). It tended to aggregate on spruce branches (e.g., as many as 51 individuals in a sample from area III and July 2000).

The abundance of *Adalia conglomerata* was significantly different among the areas compared (1999: $Q = 23.017$, $n = 200$, $P < 0.001$; 2000: $Q = 90.833$, $n = 200$, $P < 0.001$, Kruskal-Wallis ANOVA). The distribution pattern of *A. conglomerata* was different from that of *A. obliterata*. In 2000, *A. conglomerata* was significantly less at middle (area III) and upper altitude (area IV) than at lower altitude (area I, II) ($P < 0.05$) (Fig. 6).

Also, the abundance of *C. septempunctata* significantly differed among the areas (1999: $Q = 76.587$, $n = 200$, $P < 0.001$; 2000: $Q = 44.841$, $n = 200$, $P < 0.001$, Kruskal-Wallis ANOVA). Its distribution pattern was different from that of *A. conglomerata* and resembled that of *A. obliterata*. *C. septempunctata* preferred the area at middle altitude to the other areas and/or altitudes, respectively. For more information see Fig. 7.

Discussion

The species assemblages in this study are difficult to compare with those mentioned in the literature (Koehler 1961; Bielawski 1961; Klausnitzer & Bellmann 1969; Nedvěd 1999; Redderesen & Jensen 2002; Zöbl et al. 2006). This is because lady beetles were sampled by different techniques (e.g., beating or sweeping vegetation, collecting in different traps, hand picking, etc.); or sample items were different (larvae or adults); or sampling was performed in habitats with different structure (e.g., closed- and open-canopy forests, forest edges, coniferous and mixed forests, etc.); or lady beetles were sampled from different tree strata or from populations which differed in abundance (low or mass occurrence); or they were collected (observed) at different altitudes.

According to Klausnitzer & Bellmann (1969) *A. conglomerata* is the most typical inhabitant of a spruce forest (stenotopic species), together with *A. obliterata.* They both were predominanting on spruce in the study area as well, followed by the further typical associate of spruce or other conifers, *Anatis ocellata* (Table 1). Not surprisingly, the proportion of *A. obliterata* over

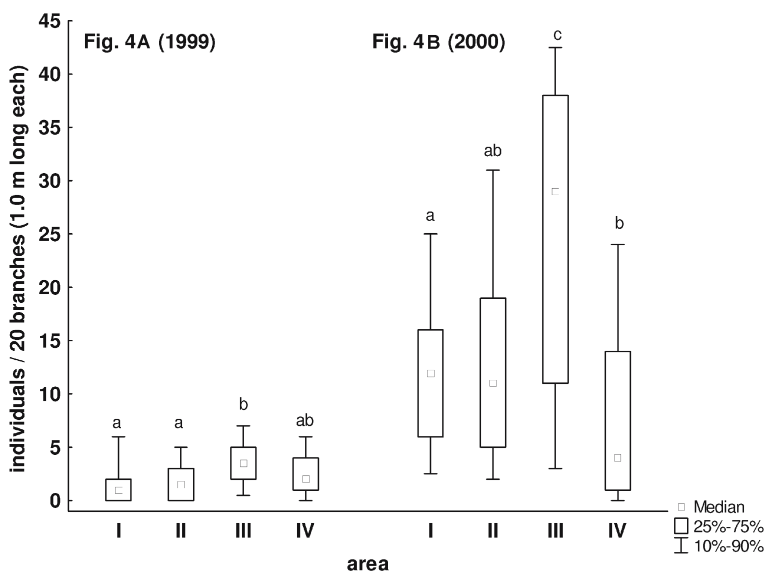

Fig. 4. Distribution pattern of all lady beetles species: abundance per 20 spruce branches (1.0 m long each): A – situation in 1999; B – situation in 2000. Area I (600–625 m), area II (700–725 m), area III (900–925 m), area IV (1,250–1,300 m a.s.l.). Different letters indicate significant differences at $P = 0.05$ (multiple comparison).

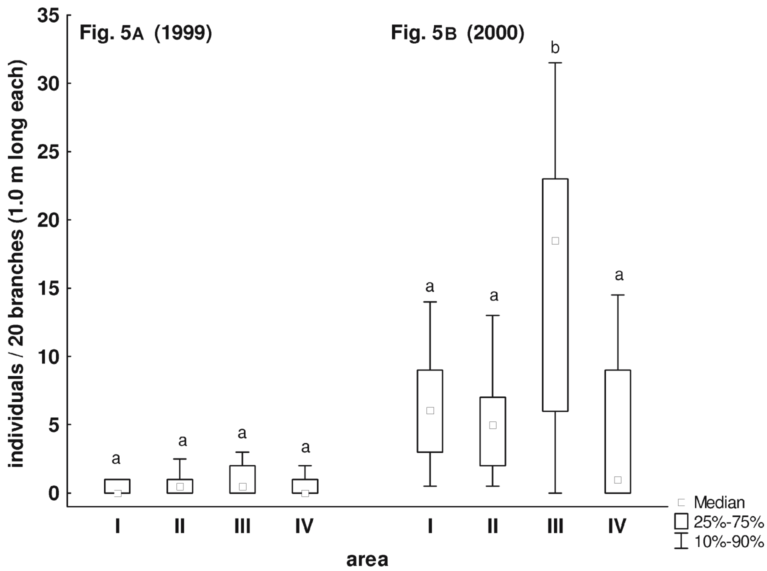

Fig. 5. Distribution pattern of *A. obliterata*: abundance per 20 spruce branches (1.0 m long each): A – situation in 1999; B – situation in 2000. Area I (600–625 m), area II (700–725 m), area III (900–925 m), area IV (1,250–1,300 m). Different letters indicate significant differences at $P = 0.05$ (multiple comparison).

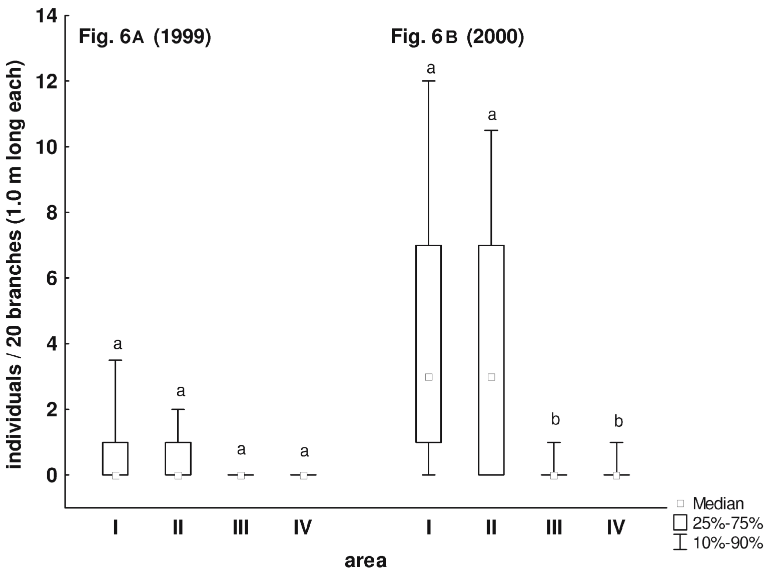

Fig. 6. Distribution pattern of *A. conglomerata*: abundance per 20 spruce branches (1.0 m long each): A – situation in 1999; B – situation in 2000. Area I (600–625 m), area II (700–725 m), area III (900–925 m), area IV (1,250–1,300 m a.s.l.). Different letters indicate significant differences at $P = 0.05$ (multiple comparison).

a two-year period was as high as 50.3% ($n = 3{,}636$). The spruce forest was also inhabited by *Scymnus abietis* Paykull, 1798. It is known to prefer the crown area of spruce trees (Koch 1989; Starý et al. 1987). This might explain its low abundance in samples obtained from the lower branches of spruce trees (Table 1). *Exochomus quadripustulatus* (L., 1758), a commom species in coniferous forests (Bielawski 1961), was reported to be the most abundant coccinellid on spruce in central Bohemia (part of the Czech Republic) (Nedvěd 1999). Although it was not scarce in the Poľana area at some 400 m a.s.l., we sampled only a sole specimen at middle altitude (Table 1). It may be concluded that only five (29.4%) of the seventeen lady beetle species recorded were the associates of spruce. They live on coniferous trees (e.g., spruce, pine, etc.) and feed on aphids (Hodek 1973; Koch 1989) and, possibly, other insects as well. For example, we observed *A. obliterata* adults feeding on the representatives of Psocoptera which were frequent on spruce in the study area.

Population densities of lady beetles in a Norway spruce forest are low but diversity of their assemblages is high (Nedvěd 1999). We have also shown that spruce forests bordering mountain meadows are characterized by species-rich assemblages of lady beetles. Greater proportion of lady beetle species not typically associated with spruce and/or other coniferous trees than spruce (70.6%, $n = 17$) may be explained by an eco-

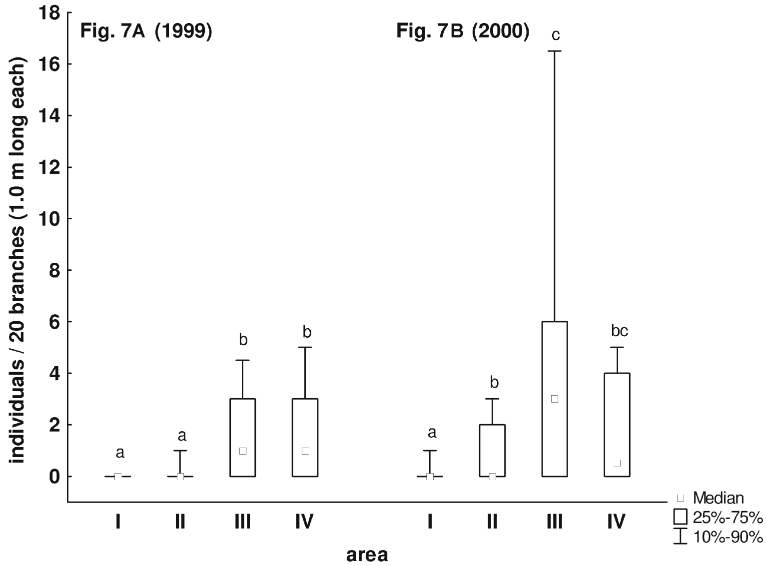

Fig. 7. Distribution pattern of *C. septempunctata*: abundance per 20 spruce branches (1.0 m long each): A – situation in 1999; B – situation in 2000. Area I (600–625 m), area II (700–725 m), area III (900–925 m), area IV (1,250–1,300 m). Different letters indicate significant differences at $P = 0.05$ (multiple comparison).

tonal effect. The spruce trees in the forest margin were highly efficient at intercepting lady beetles and/or other insects flying near or through them ("brush effect"). Some eurytopic ladybirds were frequent and abundant on spruce. *C. septempunctata*, living on both herbaceus and woody plants and feeding on aphids (Koch 1989) or other insects, was a good example of this. Nevertheless, there were many other species which were much scarcer (Table 1).

Populations of lady beetles were shown to fluctuate over time. We revealed high response rates (see Berryman 1986) to changing environmental conditions in the four predominating species, namely: *A. obliterata, A. conglomerata, C. septempunctata* and *A. ocellata* (see also Hodek & Hoňek 1996; Nedvěd 2006). In the study area, rainy weather was typical for 1999, when precipitation over April – September was some 730 mm, but not for 2000, when precipitation over the identical time period was some 330 mm only. Frequent rain and low air temperature were most likely responsible for low abundance of lady beetles in areas I–IV in 1999 (Table 1, Figs 4–7).

Although the effect of the season on lady beetle assemblages has been considered neglegible (Fig. 2), the assemblages were not stabile and changed over time. Seasonal changes in the species composition are typical for lady beetles and may be observed in various habitats (Kalushkov & Nedvěd 2005). In the study, we did not confirm the increase in abundance of lady beetles in the forest margin during autumn migration (September), although this was expected, at least in the case of *C. septempunctata* (see Nedvěd 2006).

The species optima at altitudes between 600 and 1,300 m a.s.l. were recognized in the predominating associates of spruce with ease. *A. conglomerata* was shown to prefer the areas at lower altitude. The optimum of *A. ocellata* and that of *A. obliterata* was located above that of *A. conglomerata*, at middle altitude (Fig. 3). Nevertheless, there is much uncertainly about the optimum of *C. septempunctata*, the abundant eurytopic species in the study area. Also, a few individuals of *S. abietis* and *E. quadripustulatus* (both associates of spruce) cannot provide sound estimates of their optima, and the same is true for the rest species living on deciduous trees or herbaceous plants (Table 1, Fig. 3).

In general, there is a drop of 1°C for every 100 m increase in altitude in dry air. One should also consider the sinking of cold air into the bottom of valley which can make it much colder (Begon et al. 1996). Also, the effect of wind currents should be considered in exposed mountain areas. The areas I, II and III were sheltered, and thus much better protected against wind compared to area IV which was much cooler and more windy (M. Uradnik, unpublished results). There was found no preference for area IV in the predominating lady beetle species recorded (Table 1, Figs 5–7).

The first and second ordination axis explained 32.8% of the total variance of the species data (CA, Fig. 3). Undoubtedly, there must have been other sources of the remaining variability. Numerous other factors (e.g., slope steepness, parameters of neighbouring meadows, forest structure, presence of prey, etc.) may have a substantial influence on both occurrence and abundance of lady beetles. Further research is required to clarify the effect of these factors on distribution of lady beetles in mountain spruce forests and to generalize the known results.

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