



Forest edge and carabid diversity in a Carpathian beech forest

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Abstract: Diversity relationships of carabids in forest edges and the neighbouring forest interior and the surrounding grassland were studied. Samples were taken along three replicated forest-grassland transects using pitfall traps in the Vârghiș-valley (Harghita County, Romania). The study revealed significant edge effect on the carabids. Both the number of species and the Shannon diversity of carabids were significantly higher in the forest edge than in the grassland and in the forest interior. The forest was also significantly more species rich and more diverse by Shannon diversity than the grassland. Carabids of the forest interior, forest edge and grassland can be separated from each other by ordination based on abundances, suggesting that all three habitats have a distinct species assemblage. Indicator species analysis detected significant edge associated species. Our results show that the high diversity of carabids in forest edges is due both to the edge-associated species and the presence of species characteristic of the adjacent habitats.

Abbreviation: NMDS - Non-metric multidimensional scaling.

Nomenclature follows: Hürka (1996) for carabids.

Introduction

Forest edges are transition zones between adjacent habitats and they are a type of ecotone, which is interpreted on the meso-spatial scale and on the community level (Holland et al. 1991). Forest edges are a focus of both ecological research and conservation (Samways 2005). Forest edges have distinctive microclimates, there are abrupt changes in light regimen, substrate, water conditions, and they are generally rich in microhabitats (Murcia 1995). These factors are highly significant for small animals such as insects, especially of ground-dwelling beetles (Lövei and Sunderland 1996). Therefore, recently the number of studies investigating edge effect on invertebrates is increasing (Horváth et al. 2000, 2002, Koivula et al. 2004, Lövei et al. 2006).

Because of the importance of the edge effect to the field of wildlife management and the increasing need and demand for the management of animal species, this study was initiated to evaluate carabid diversity in relation to forest edge between a forest and herbaceous grassland. Carabid beetles were selected as test organisms because they form a species-rich beetle family, they are widespread in many types of habitats and have a pronounced habitat preference (Thiele 1977, Lövei and Sunderland

1996, Tóthmérész and Magura 2005a). Our hypothesis was that according to the edge effect the diversity of carabids will be higher in the forest edge than in the forest interior. We have tested the edge effect for carabids along three repeated forest-grassland transects.

Materials and methods

Study area and sampling

Sampling area is located in the Carpathians in Transsylvania (Romania). The typical forest type is beech forest (*Fagetum sylvaticae*), with dense litter layer, moderate herbaceous and shrub layer. The neighbouring area is a moderately dry grassland with dense herbaceous vegetation. The forest edge is characterized by moderate litter layer and dense herbaceous vegetation. The shrub layer is also dense, consisting mainly of shrubs and saplings of the canopy trees.

The study was performed along three replicated transects running from the forest interior towards the grassland, perpendicularly to the forest edge. Distance between transects was 100 m to ensure independency (Digweed et al. 1995). Along each transect in the grassland, in the forest edge and in the forest interior a trapping station con-

taining 10 randomly placed pitfall traps was set. Trapping stations were at least 100 m from each other. In a trapping station distance between the traps was 10 m. Altogether there were $3 \times 3 \times 10 = 90$ traps. The pitfall traps were unbaited, consisting of plastic cups (diameter 100 mm, volume 500 ml) containing ethylene-glycol and water solution, and detergent (Spence and Niemelä 1994). Trapping period covered the snow-free season, and samples were collected monthly. For the numerical analysis, monthly samples were pooled. All carabid beetles taken in the pitfall traps were identified to species using standard keys (Freude et al. 1976, Hürka 1996).

Data analyses

Analysis of variance (ANOVA) and Tukey-type multiple comparisons were used to determine differences in the species richness and carabid diversity per trap between the three habitats of the transects. Tukey-type multiple comparisons were used to determine the significant differences (Zar 1984). Species richness was characterised by the number of species and Shannon diversity. Rényi diversity (a one-parametric diversity index family) was used for scale-dependent diversity characterization (Tóthmérész 2005, Tóthmérész and Magura 2005b). In the case of one-parametric diversity index families not just one numerical value is used to characterize the diversity of an assemblage, but a family of diversity values. These methods can be used in a graphical form to visualize the diversity relations of assemblages. The one-parametric diversity indices may be portrayed graphically by plotting diversities against a (scale) parameter. This curve frequently mentioned as the diversity profile of the assemblage. Members of a one-parametric diversity index family have varying sensitivities to the rare and abundant species as the scale parameter changes (Tóthmérész 1995, 1998). Recent papers (Bauer et al. 2004, Lövei 2005, Ricotta 2005) also emphasized the usefulness and importance of these scalable techniques in ecological studies.

Non-metric multidimensional scaling (NMDS) based on the Euclidean distance of the logarithmically transformed abundances of the species was used to assess similarities in composition of carabid assemblages of the studied habitat types (Digby and Kempton 1987). The characteristic species of the habitat types were explored by the IndVal (Indicator Value) procedure (Dufrene and Legendre 1997). IndVal is a quantitative characterisation of indicator species (accordingly to classical plant sociology), based on computerised randomisation procedure. The IndVal method proved to be a useful method to identify the characteristic carabid species in several habitats (Magura et al. 2000a, 2003, 2004, Elek et al. 2001).

Results

Edge effect on carabids

The ANOVA proved that there was significant difference in species richness and Shannon diversity among the habitats for the transects (Fig. 1, Table 1). The species richness and the Shannon diversity were significantly ($p < .05$) higher in the forest edge than in the forest and in the grassland (Fig. 1). Both the species richness and the Shannon diversity were significantly ($p < .05$) higher in the forest than in the grassland. The scale-dependent diversity characterization by the Rényi diversity demonstrated that the forest edge was the most diverse for the whole range of scale parameter (Fig. 2). Diversity profiles of the grassland and the forest crossed each other. The grassland was more species rich (scale parameter = 0), but the forest was more diverse in the frequent species (scale parameter larger than 2).

The results of the non-metric multidimensional scaling (NMDS) showed that the carabids of the forest interior, forest edge and grassland could be separated from each other by ordinations. The separation of the carabid assemblage of the forest was more pronounced from the edge than the separation of the grassland from the forest edge (Fig. 3). The traps were arranged along an arch in the scatter diagram of the NMDS, suggesting that the carabid assemblages change gradually from the forest interior towards the grassland along the transects.

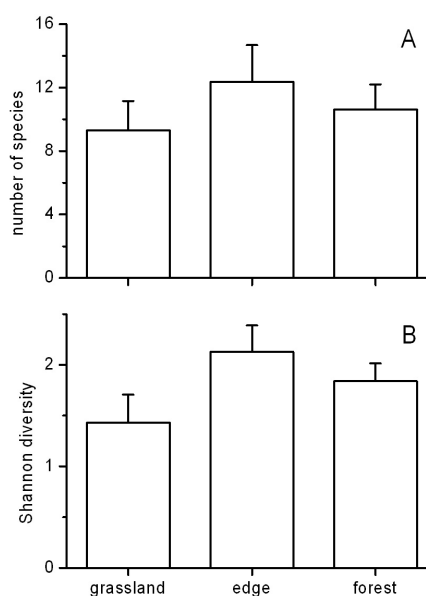


Figure 1. Number of species (A) and the Shannon diversity (B) of carabids per trap (with S.D.) in the studied habitats.

Table 1. ANOVA tables of the number of species and the Shannon diversity of the carabids in the studied habitats for the pooled samples.

Number of species	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p</i>	<i>F critical</i>
Between groups	141.9	2	70.93	18.92	<0.001	3.10
Within group	326.3	87	3.75			
Total	468.1	89				

Shannon diversity	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p</i>	<i>F critical</i>
Between groups	7.39	2	3.70	63.36	<0.001	3.10
Within group	5.08	87	0.06			
Total	12.47	89				

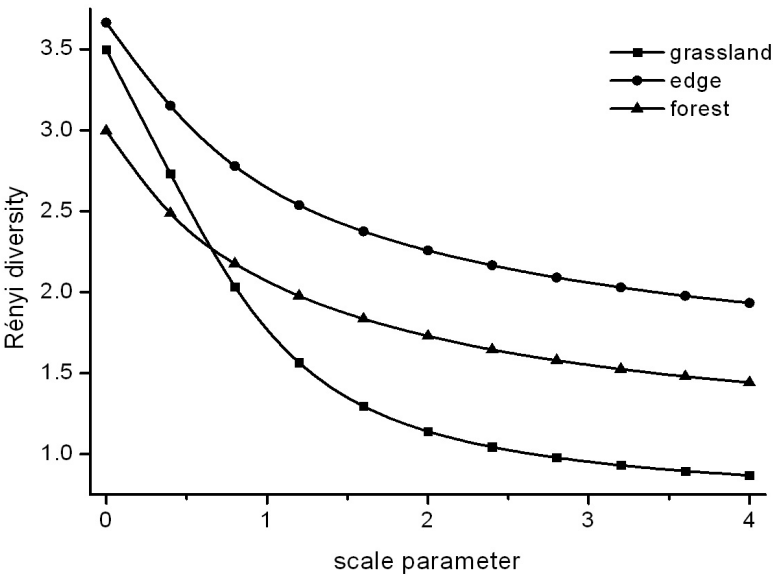


Figure 2. Diversity profiles of the carabid assemblages of the studied habitats.

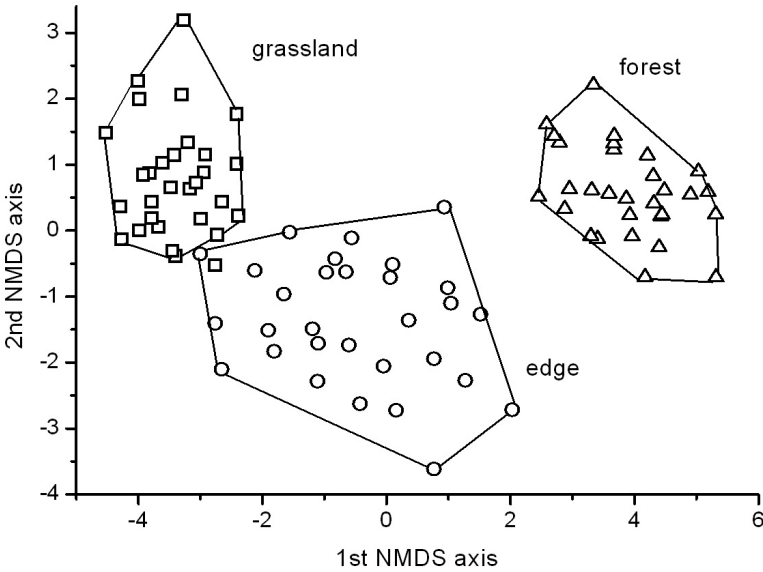


Figure 3. Ordination (NMDS) of the pitfall catches based on the abundance of the species after a logarithmic transformation using the Euclidean distance of the logarithmically transformed counts.

Table 2. Species indicator power for the habitats. Only the significant indicator species are included ($p < .05$). The IndVal column shows the species indicator value for the corresponding clustering level. In the cells of the table, the first number indicates the number of specimens present and the second one corresponds to the number of traps where the species is present, in this sample group.

	IndVal	Grassland	Edge	Forest
Grassland				
<i>Poecilus versicolor</i>	80.00	52/ 24	0/ 0	0/ 0
<i>Calathus fuscipes</i>	60.92	101/ 19	4/ 2	0/ 0
<i>Anisodactylus binotatus</i>	53.33	45/ 16	0/ 0	0/ 0
<i>Pseudoophonus rufipes</i>	37.92	28/ 13	3/ 2	1/ 1
<i>Cymindis humeralis</i>	36.67	28/ 11	0/ 0	0/ 0
<i>Amara equestris</i>	32.83	25/ 13	8/ 3	0/ 0
<i>Pterostichus vernalis</i>	26.67	20/ 8	0/ 0	0/ 0
<i>Amara montivaga</i>	25.33	19/ 8	1/ 1	0/ 0
<i>Calathus melanocephalus</i>	21.39	11/ 7	1/ 1	0/ 0
<i>Bembidion lampros</i>	18.96	13/ 7	0/ 0	3/ 2
<i>Amara aenea</i>	13.33	4/ 4	0/ 0	0/ 0
Grassland and Edge				
<i>Carabus cancellatus</i>	98.33	941/ 30	320/ 29	0/ 0
<i>Poecilus lepidus</i>	81.67	385/ 29	83/ 20	0/ 0
<i>Harpalus latus</i>	20.00	8/ 7	5/ 5	0/ 0
<i>Leistus piceus</i>	16.67	7/ 5	6/ 5	0/ 0
<i>Pterostichus ovoideus</i>	13.33	3/ 3	5/ 5	0/ 0
Edge				
<i>Pterostichus niger</i>	60.35	4/ 3	81/ 19	0/ 0
<i>Abax carinatus</i>	57.7	12/ 8	48/ 22	1/ 1
<i>Carabus glabratus</i>	54.44	0/ 0	77/ 21	22/ 12
<i>Carabus marginalis</i>	50.00	0/ 0	29/ 15	0/ 0
<i>Carabus convexus</i>	21.33	0/ 0	8/ 8	2/ 2
<i>Carabus ullrichi</i>	17.5	1/ 1	7/ 6	0/ 0
<i>Carabus hampei</i>	15.56	0/ 0	10/ 7	5/ 4
<i>Carabus arvensis</i>	13.33	0/ 0	4/ 4	0/ 0
Forest				
<i>Abax parallelepipedus</i>	98.02	0/ 0	32/ 17	794/ 30
<i>Carabus obsoletus</i>	97.8	0/ 0	16/ 10	355/ 30
<i>Carabus coriaceus</i>	90.58	3/ 3	13/ 11	119/ 29
<i>Abax schueppeli</i>	90.38	0/ 0	86/ 24	404/ 30
<i>Cychrus caraboides</i>	85.5	0/ 0	14/ 10	133/ 27
<i>Molops piceus</i>	73.88	0/ 0	11/ 6	43/ 25
<i>Carabus linnei</i>	67.91	0/ 0	158/ 21	211/ 28
<i>Carabus auronitens</i>	43.33	0/ 0	0/ 0	22/ 13
<i>Carabus intricatus</i>	29.33	0/ 0	3/ 3	11/ 10
<i>Licinus depressus</i>	14.58	2/ 2	0/ 0	7/ 5

The collected carabid species can be divided into four groups by characterization of habitats by indicator species (Table 2): (1) grassland-associated species that were recorded exclusively in the grassland or were the most abundant in the grassland; (2) grassland and edge associated species that were recorded both in the grassland and edge; (3) edge associated species that were recorded exclusively in the edge or were the most abundant in the forest edge; (4) forest species, that occurred exclusively in the forested habitats or were the most abundant in the forest habitats.

Discussion

Edge effect is the result of an interaction between two adjacent habitats. There are two kinds of edge effects: (1) abiotic effects, involving changes in the environmental conditions which result from proximity to a structurally dissimilar matrix; (2) biological effects, which involve both changes in the abundance and distribution of species caused directly by the physical conditions in the edge and are determined by the physiological tolerances of species, and changes in species interactions. All these factors have

influence on the species richness of the assemblages of the forest edges (Murcia 1995). There are abiotic and biotic components of edge effect. The first is when different species prefer different habitats (e.g., grassland or forest interior). The second is when the individuals of the same population behave differently in different locations (e.g., because predation is higher in the edge; Batáry and Báldi 2004). This paper is about the first case.

Our results show that there is a significant edge effect on carabids. The results revealed that the Shannon diversity of the carabids was significantly higher in the forest edge and the forest interior than in the grassland. Studying carabids of farmland-forest transects Bedford and Usher (1994) also reported that forest edge has higher species richness than the forest interior. Butovsky (1994), Asteraki et al. (1995), Magura and Tóthmérész (1997, 1998), and Magura et al. (2001a) also showed that diversity is higher in the forest edge than in the forest interior. On the other hand, Taboada et al. (2004) found significant edge effect for carabids neither in oak forests nor in beech forests in NW Spain.

Scale-dependent diversity characterization based on the Rényi diversity index family also demonstrated that the forest edge was the most diverse. This is an important finding: frequently the edges are just more diverse for the rare species than the surrounding forest and/or grassland, because of the immigration of the species of the surrounding habitats. Magura and Tóthmérész (1998) also reported a similar situation for the edge of an oak-hornbeam forest, where the carabid assemblage of the edge was more diverse for the whole range of the scale parameter than the surrounding habitats.

Ordination of carabid assemblages and analysis of indicator species show that all studied habitat types have a characteristic assemblage of carabid species associated with them (Fig. 3 and Table 2). Using the quantitative indicator species analysis (IndVal method) we identified eight edge-associated species (*Pterostichus niger*, *Abax carinatus*, *Carabus glabratus*, *Carabus marginalis*, *Carabus convexus*, *Carabus ullrichi*, *Carabus hampei*, and *Carabus arvensis*). Magura et al. (2000b, 2001b) and Molnár et al. (2001), studying spatial distribution of carabids along grassland-forest transects, also showed that *Pterostichus niger* prefers forest edges, as they captured this species exclusively in the forest edges. However, in Hungary *Abax carinatus* proved to be a forest interior species (Magura et al. 2000b, Molnár et al. 2001), *Carabus convexus* a habitat generalist species (Magura et al. 2000b, 2001b, Molnár et al. 2001), while *Carabus arvensis* to be a habitat generalist species (Magura et al. 2001b, Molnár et al. 2001) or a grassland specialist spe-

cies (Magura et al. 2000b). These differences in the spatial pattern of a species suggest that habitat preference may be changed depending on the geographical localities and/or the studied forest and grassland types.

In the present situation the studied habitats (forest interior, forest edge and grassland) are not isolated from one another. Therefore, small scale dispersal between habitat patches considerably influences species composition and structure of carabid assemblages (Niemelä 1988). The high diversity of the forest edge may be caused by dispersal processes, as carabid beetles are able to cover large distances while looking for food (Baars 1979, Magura 1995) and exhibit density-dependent migration (Grüm 1971), aggregation in habitats with high amount of prey available (Bryan and Wratten 1984) and movement between reproduction habitat and hibernation habitat (Wallin 1986, Andersen 1997). This is also consistent with previous observations (Spence et al. 1996), which demonstrated that forest specialists also maintain populations in the forest edge. The discussed dispersal processes and the edge associated species (Table 2) contribute to the increased diversity of carabids in the forest edge. Overall, edge effect on carabids is due in part to the presence of species characteristic of each of the adjacent habitats (forest interior and grassland) plus species inhabiting the edge. These edge species may find habitats at the edge which are not present in either habitat alone, or they may require two structurally different habitats in close proximity to one another.

Our research pointed out that forest edges may have a crucial role in the maintenance and preservation of the diversity of carabids. Many carabid species characteristic of grassland and forest interior can disperse into the forest edge. Thus, forest edges have viable populations of carabids of the adjacent habitats. Therefore, they may contribute to the recolonization of carabid species in the adjacent habitats after local extinction or destruction of suitable habitats (e.g., burning, ploughing, grazing, timbering etc.). These data indicate a considerable potential of the forest edges for succession and regeneration of adjacent disturbed sites. This feature of the forest edge may also be applied for conservation purposes.

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