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Microhabitats and fragmentation effects on a ground beetle community (Coleoptera: Carabidae) in a mountainous beech forest landscape

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Abstract: The aim of this investigation was to analyze the effects of microhabitats and forest fragmentation on the composition and species abundance of a ground beetle community from three different beech forest patches on Mt. Osogovo (Macedonia), as well as to analyze the mobility (based on mark-recapture of individuals) and seasonal dynamics and sex ratio of the ground beetle community. The study site included three localities (A, B, C), one of them fragmented (A), with four microhabitats (open area, ecotone, forest stand, and forested corridor). Ground beetles were collected using pitfall traps during four sampling months (June–September 2009) that were operational for three continuous days per month. Species richness, abundance, diversity, homogeneity, and dominance were compared between the localities. Dissimilarities in carabid assemblages between localities and microhabitats were analyzed with Bray–Curtis UPGMA cluster analysis. In total 1320 carabid individuals belonging to 19 species were captured. The carabid assemblage structure of the continuous forest locality was substantially different from the other two smaller forest patches, indicating that microhabitat structure affects ground beetle communities through changes of species composition and richness.

Key words: Ground beetles, microhabitats, habitat fragmentation, beech forest, mountain landscape

1. Introduction

Habitat fragmentation is one of the most important causes of species decline and extinction throughout the world (Saunders et al., 1991; Haila et al., 1994; Didham et al., 1996; Didham, 1997; Davies et al., 2000). In the case of forests the fragmentation impacts the size of forest patches, increases edge and isolation effects, and contributes to overall habitat diversity in the place of a single continuous forest (Abildsnes and Tømmeros, 2000; Fahrig, 2003). Such habitat changes are suspected to impact biodiversity, but this impact varies greatly between taxonomic groups. Ground beetles are often used to assess the impact of habitat changes because of their sensitivity to environmental conditions (Thiele, 1977) and rapid responses to habitat changes (Niemelä et al., 1993a, 1993b).

Forestry practices, meaning clear-cutting of large forest areas and subsequent planting, have turned the forest of Mt. Osogovo (in the northwest of the Republic of Macedonia) into a fragmented area with many small isolated forest patches. The remaining young beech forest is mostly present as small, isolated fragments or as unproductive areas. So far, the diversity of the ground beetle fauna of Osogovo Mountain was only documented by Guéorguiev (1996, 1997, 1998).

This investigation aims at analyzing the composition and species abundance of a ground beetle community between different beech forest localities and microhabitats (forested part, ecotone, open space, and forested corridor), on Mt. Osogovo, as well as to analyze the effect of fragmentation on the ground beetle community, the seasonal dynamics, the sex ratio, and the mobility (based on mark-recapture of individuals). The collection of the material was done by pitfall trapping without use of a preservative during one season (June–September 2009). For appropriate evaluation of the effects of microhabitats, which undoubtedly lead to changes in the community structure of ground beetles, a complete qualitative-quantitative analysis of the carabidocoenosis from the forest interior, forested corridor, open space, and ecotone part was necessary. For this purpose analyses such as nonparametric Kruskal–Wallis tests followed by Mann–Whitney tests and Spearman rank correlation coefficient and Bray–Curtis (UPGMA) cluster analyses, as well as a rarefaction method, were used. We also used indices of richness – d, evenness – $J_{(e)}$, dominance – D, and Shannon–Wiener diversity – H' in order to supplement the evidence of the differences between microhabitats and localities.

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2. Materials and methods

2.1. Study area and sampling

The experiment was carried out in a beech forest of the Jamiško Osoe locality, at an altitude of about 1300 m. The forest association is *Calamintho grandiflorae-Fagetum* Em, 1948. The area falls within the mountain broadleaf forest landscape (Melovski, personal communication).

The study site was divided into three localities, A, B, and C: A contains a forested fragment, B is an unfragmented continuous forest, and C is a forested peninsula (Figure 1), with four microhabitats identified within them. A and B include three microhabitats (open space, ecotone, and forest), while C includes four microhabitats (open space, ecotone, forest, and corridor).

Beetles were collected using pitfall traps that consisted of plastic cups with volume of 500 mL, diameter of 8.5 cm, and height of 11.5 cm. In total, 150 traps were placed in all of the seven transects (Figure 1). The number of traps along transects was different and varied from 12 to 32.

In localities A and B, traps were placed along two transect lines placed on the same isohypse. In locality A, transect line T1 contained 28 pitfall traps (traps 1–8 in the forest fragment, trap 9 in the ecotone, 10–18 in the open space, 19 and 20 in the next ecotone, 21 and 22 in the open space (grassland), 23 in the ecotone, and 24–29 in the forest of the same fragment). Transect T2 contained 32 pitfall traps (traps 1–9 placed in the forest fragment, 10 in the ecotone, 11–18 in the open space, 19–21 in the ecotone, 22 and 23 in the forest, 24–26 in the ecotone, and 27–32 in the forested part of the same locality).

In locality B there were also two transect lines. Transect T3 contained 21 pitfall traps and T4 contained 23 pitfall traps. All of the traps in T3 and T4 were placed in a forested part.

Locality C consisted of three transect lines (T5 with 12, T6 with 14, and T7 with 16 pitfall traps). Transect T5 contained 12 traps (traps 1–6 in the forested part, 7 in the ecotone, and 8–12 in the open space (grassland)). Transect T6 contained 14 traps (traps 1–12 in the forested part, 13 and 14 in the forested peninsula). Transect T7 contained 16 traps (traps 1–5 in the forested part, 6–9 in the ecotone, and 10–15 in the open space).

The traps and the transect lines were placed at 5 m and at least 10 m apart, respectively. Traps were without preservatives and placed flush with the soil surface. To prevent flooding from the rain during the noninvestigated period, plastic roofs were mounted above each trap. Ground beetles were collected, captured, registered, and immediately released. The traps were operational for three continuous days in four sampling months from June until September 2009.

2.2. Data analyses

The distribution of the specimens was analyzed using two approaches: 1) comparison of the carabid distribution between four microhabitats and 2) comparison of their distribution between three localities, A, B, and C.

Species abundance data were tested for normality of distributions and variance of homogeneity by using Shapiro–Wilks and Levene tests, respectively. To obtain normal distributions, data were log(x + 1) transformed.

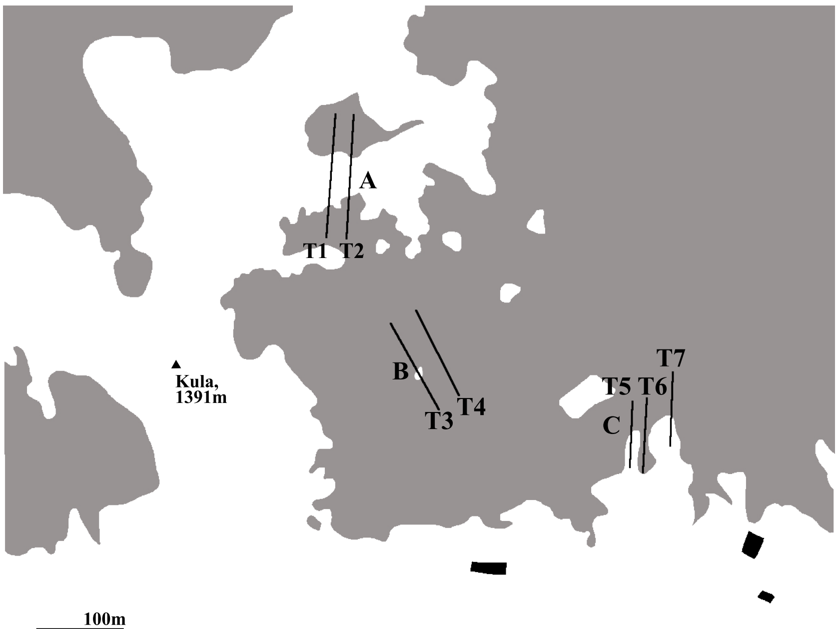

Figure 1. Jamiško Osoe study area with 3 localities (A, B, and C) and transects T1–T7 (gray color represents beech forests, black – potato fields, and white – mountain pastures and forest clearings).

During the analyses normal distribution and homogeneity of variance were not obtained, so nonparametric tests, such as the Kruskal–Wallis test followed by the Mann–Whitney U test, were applied to examine the differences of average beetle abundance between microhabitats and localities, and the results were presented as box plots. Spearman rank correlation was used to analyze the relationship between the average number of captured specimens and the type of locality, microhabitat, or month.

In order to analyze structural characteristics of carabid communities, indices of richness – d (Margalef, 1958), evenness – $J_{(e)}$ (Pielou, 1966), dominance – D (Balogh, 1958), and Shannon–Wiener diversity – H' (Glowacinsky, 1975) were used. These indices were used in order to compare the microhabitats and localities although the pitfall-trapping method may be biased toward actively moving, large-sized species and does not always represent the true composition and structure of carabidocoenosis (Koivula, 2011).

In order to estimate the number of taxa that were expected to be found in a sample with the smallest total number of individuals, an individual rarefaction test was used.

The similarity of the carabid abundance between microhabitats and three different localities was compared with cluster analysis. When studying clustering of carabid assemblages among localities, Bray–Curtis paired grouping (clusters were joined based on the average distance between all members in the two groups) was used.

Seasonal dynamics and sex structure were examined, as well. The collection of specimens was performed in June (12–14), July (3–5), August (17–19), and September (4–6) 2009.

The sex of the collected specimens was determined in the field by checking the sexual differences, mainly the protarsal segments (normal in females, widened in males).

All statistical data analyses were done with statistical programs PAST and STATISTICA 6. Significant values were those with $P < 0.05$.

Assessment of the mobility of ground beetles in the investigated area was done on the basis of recaptured specimens of the larger species that were marked with unique numbers and colors.

3. Results

The total dataset consisted of 1320 individuals representing 19 species. The number of carabid individuals in site A was 655 (15 species), 338 individuals (9 species) in B, and 327 individuals (13 species) in C (Table 1).

Table 1. The total carabid sample in 3 different localities on Mt. Osogovo (A – small forest fragment; B – continuous forest; C – large forest fragment; Ind. – number of captured individuals; D (%) – Dominance, dc – category of dominance, *D* = dominant, *SD* – subdominant, *R* – recedent, *SR* – subrecedent).

No.	Species	A			B			C		
		Ind.	D (%)	dc	Ind.	D (%)	dc	Ind.	D (%)	dc
1	*Myas chalybaeus* (Palliardi, 1825)	430	65.65	*D*	119	35.21	*D*	239	73.09	*D*
2	*Tapinopterus balcanicus* Ganglbauer, 1891	74	11.30	*D*	130	38.46	*D*	37	11.31	*D*
3	*Xenion ignitum* (Kraatz, 1875)	51	7.79	*SD*	67	19.82	*D*	19	5.81	*SD*
4	*Carabus convexus dilatatus* Dejean, 1826	54	8.24	*SD*				5	1.53	*R*
5	*Molops rufipes denteletus* B.V. Guéorguiev, 1997	5	0.76	*SR*	5	1.48	*R*	11	3.36	*R*
6	*Cychrus semigranosus balcanicus* Hopffgarten, 1881	10	1.53	*R*	7	2.07	*R*			
7	*Carabus intricatus intricatus* Linnaeus, 1761	1	0.15	*SR*	6	1.78	*R*			
8	*Carabus hortensis* Linnaeus, 1758	13	1.98	*R*				3	0.92	*SR*
9	*Carabus violaceus azurescens* Dejean, 1826	4	0.61	*SR*	2	0.59	*SR*	6	1.83	*R*
10	*Carabus montivagus montivagus* Palliardi, 1825	9	1.37	*R*						
11	*Pterostichus bruckii* Schaum, 1859				2	0.59	*SR*	1	0.31	*SR*
12	*Calathus distinguendus* Chaudoir, 1846	1	0.15	*SR*						
13	*Harpalus honestus honestus* (Duftschmid, 1812)	1	0.15	*SR*						
14	*Laemostenus terricola punctatus* (Dejean, 1828)	1	0.15	*SR*						
15	*Leistus spinibarbis rufipes* Chaudoir, 1843	1	0.15	*SR*						
16	*Abax carinatus carinatus* (Duftschmid, 1812)							3	0.92	*SR*
17	*Poecilus lepidus lepidus* (Leske, 1785)							1	0.31	*SR*
18	*Poecilus versicolor* (Sturm, 1824)							1	0.31	*SR*
19	*Zabrus balcanicus rhodopensis* Apfelbeck, 1904							1	0.31	*SR*

3.1. Structure of carabid community and occurrence of dominant species

Carabid species and abundance were higher in locality A compared to B and C, although these changes were not statistically significant.

The Kruskal–Wallis test followed by the Mann–Whitney test showed significant differences ($P < 0.05$) of the average abundance of ground beetles between open area and forest, as well as between ecotone and forest (Figure 2a). The average abundance of beetles did not change significantly during the sampling period June–September (Figure 2b). The average abundance of beetles showed the highest values in the forested microhabitats (Spearman rank correlation coefficient $R = 0.556$; $P < 0.05$) (Figure 2c).

Myas chalybaeus was by far the most abundant and dominant species (in total 788 specimens, 59.74%), followed by *Tapinopterus balcanicus* (in total 241 specimens, 18.27%) and *Xenion ignitum* (137 specimens, 10.39%). All other species had an occurrence of less than 10% of total catch. *Myas chalybaeus* and *Tapinopterus balcanicus* were dominant in all three localities, while *Xenion ignitum* had an occurrence of more than 10% only in locality B (19.88%) (Table 1).

The Kruskal–Wallis test followed by the Mann–Whitney test showed significant differences ($P < 0.05$) in the abundances of *Myas chalybaeus* and *Xenion ignitum* between open area and forest, as well as between ecotone and forest, respectively, and for *Tapinopterus balcanicus* between open area and corridor, open area and forest, and ecotone and forest, as presented in box plots (Figure 3).

3.1.1. Diversity indices

The index of dominance was higher in locality C, where the value of the Shannon index of diversity was lowest. The index of richness was lowest in locality B, where the lowest number of carabid species was registered. Ground-beetles

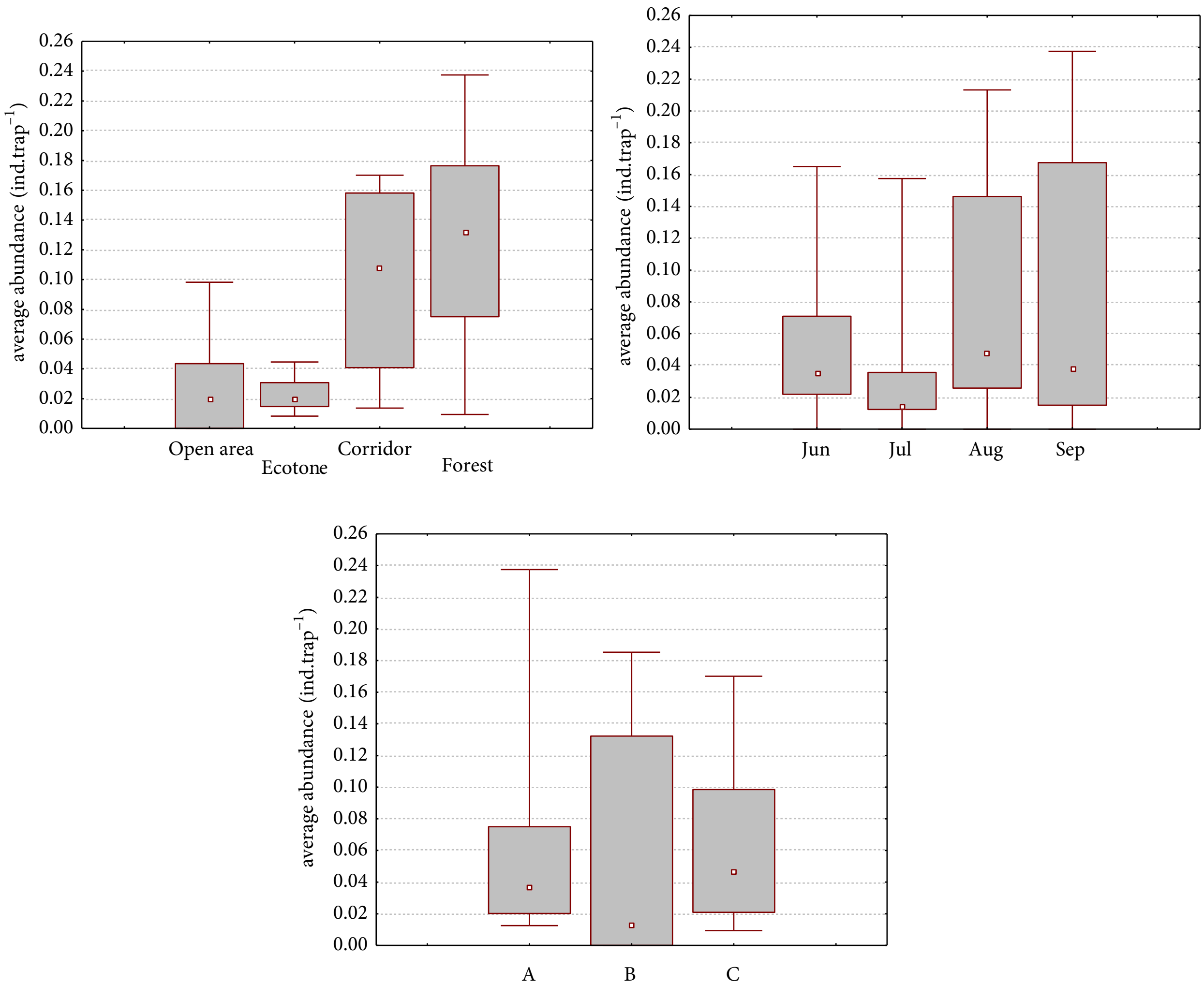

Figure 2. Variation of the average beetle abundance (ind. trap^{-1}) between a) microhabitats, b) months, and c) fragments.

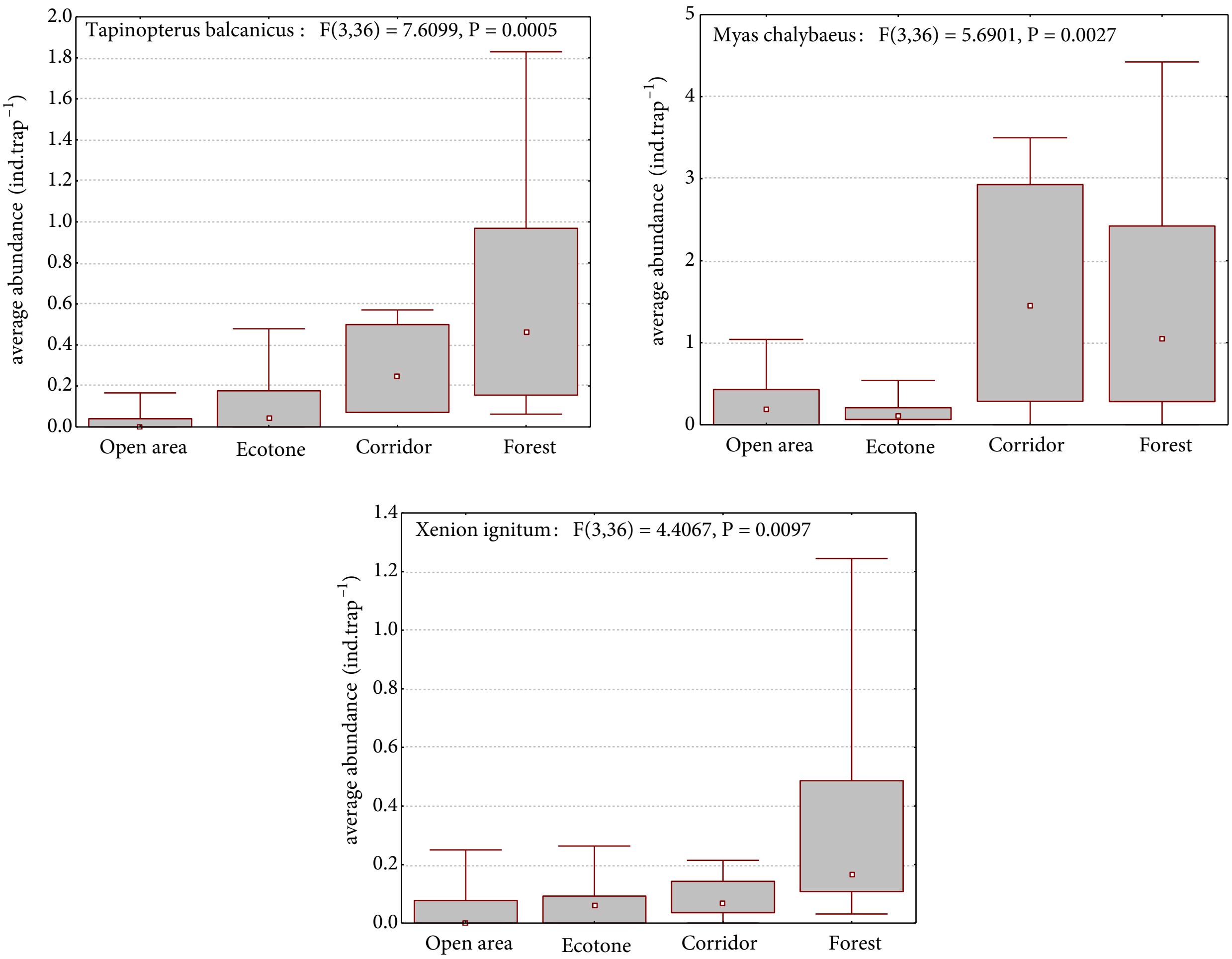

Figure 3. Variation of the abundances (ind. trap^{-1}) of the three dominant species between microhabitats.

in locality B had the most homogeneous distribution, which corresponds to the lowest values of dominance and highest values of diversity indices in the same locality (Table 2).

Table 2. Diversity indices in 3 different localities (A – small forest fragment; B – continuous forest; C – large forest fragment).

	A	B	C
Taxa S	14	8	12
Individuals	655	338	327
Dominance D	0.46	0.31	0.55
Shannon H'	1.25	1.32	1.05
Margalef d	2.01	1.20	1.90
Evenness $J_{(e)}$	0.25	0.47	0.24

3.1.2. Rarefaction species richness

Individual-based rarefaction curves were obtained to compare species richness between three different localities (A, B, and C). The obtained curves, which represent the number of species (represented with discontinuous lines, while standard deviation is presented with continuous lines in Figure 4), approached asymptotes of 10–12 species in A and C and 8 species in B (after 320 individuals had been collected), thus indicating significant differences in species richness between locality B on one side and localities A and C on the other (Figure 4).

3.1.3. Cluster analysis

Similarity of the ground beetle abundances between localities was analyzed by Bray–Curtis UPGMA dendrogram, which reflected marked separation between localities A and C and the continuous forest (B). A and C formed a distinct cluster showing 64% similarity, while B was separated (Figure 5a), thus indicating two types of carabid assemblages: assemblages of the fragmented

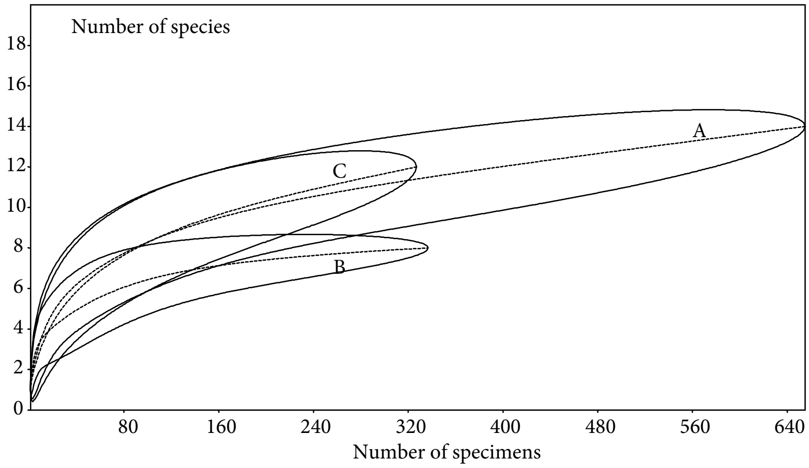

Figure 4. Individual-based rarefaction curves of the carabid assemblages in three studied localities (A, B, C).

localities with 3–4 microhabitat types and assemblages of the continuous forest. This was further supported by the separation of the forest microhabitat from the other habitats (60%) (Figure 5b).

3.2. Seasonal dynamics and sex ratio

Ground beetle species showed similar seasonal dynamics in all localities (Figure 6). There was a tendency of increasing abundance during August and September, when summer peaks were reached. The sex ratio shifted in favor of males (66.87% on average) in all three localities.

3.3. Mobility

The sample size of recaptured specimens was very small (in total 54 specimens), thus disabling appropriate statistical analysis. Nevertheless, the obtained data were

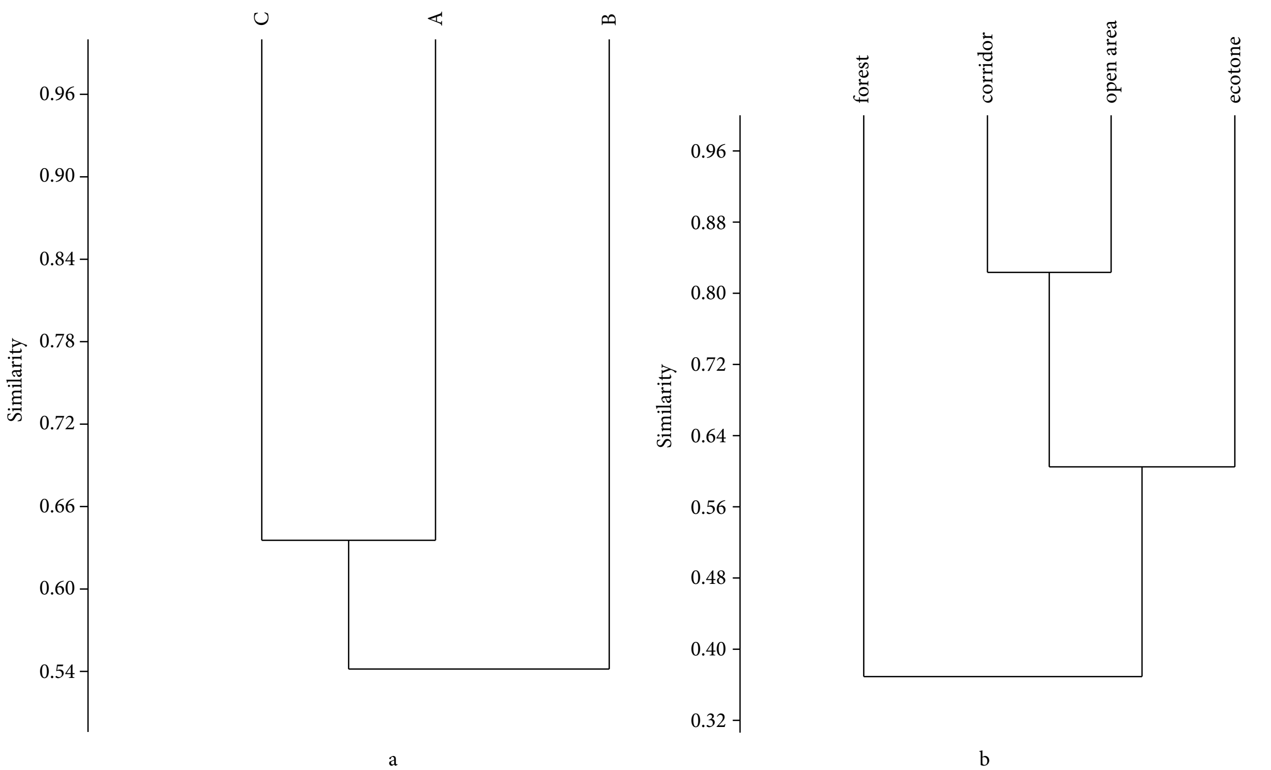

Figure 5. Bray–Curtis cluster dendrograms showing differences in carabid composition between a) three different localities (small forest fragment – A, continuous forest (control area) – B, large forest fragment – C) and b) four different microhabitats (ecotone, corridor, open area, and forest).

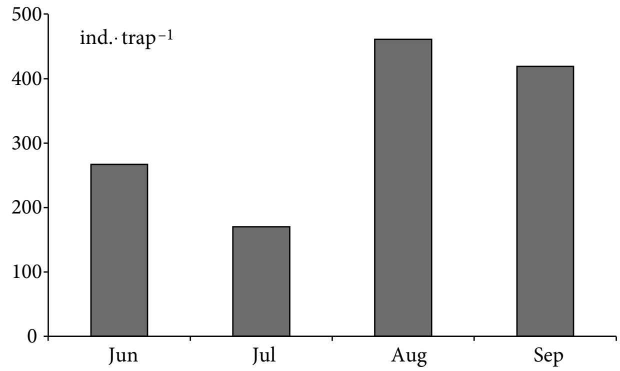

Figure 6. Seasonal dynamics (ind. trap^{-1}) of the ground beetle community.

used to show some preliminary results (Table 3). In total, 28 specimens were recaptured in locality A (11 in the ecotone, 2 specimens in the open space, and 15 in the forested part), while in locality B there were 9 specimens recaptured (1 specimen in the ecotone and 8 in the forest) and in locality C 17 specimens (6 specimens in the ecotone, 7 in the corridor, and 4 specimens in the forested part). Followed by seasons, there was only one specimen recaptured during June, 8 in July, 16 in August, and 29 in September.

Specimens of only three species with individual markings were recaptured: *Myas chalybaeus*, *Xenion ignitum*, and *Carabus convexus*. Most of the recaptured specimens belonged to *Myas chalybaeus*. It is interesting to note that 26 of the recaptured specimens of *Myas chalybaeus* were males and only 10 were females, implying the higher mobility of males.

4. Discussion

Forests on Mt. Osogovo are fragmented in comparison to the extensive continuous forest landscape that existed before the fragmentation (clear-cutting processes) and urban expansion started. The impact of habitat connectivity on beetle assemblages depends on species dispersal power and flight ability, which vary between ground beetle species (den Boer, 1990), and landscape structure (Dunning et al., 1992), species interaction (Niemelä et al., 1988), and degree of habitat preference.

Spatial behavior of ground beetles is prone to vary between species, between habitats, and between seasons. In general, during the investigation period, which coincided with the warm summer season, the smallest number of individuals was recorded during July, while the maximum was reached in August. High values were recorded in September also, probably as a result of the high abundance of *Myas chalybaeus* and its life cycle.

The analysis of the sex structure showed that males dominated over females in all three localities and in general. This is a result of the higher number of males mainly of *Myas chalybaeus*. The preliminary results for mobility also suggest that the males are more mobile than females and may contribute to the obtained results. Hristovski et al.

Table 3. Mobility of *Myas chalybaeus*, *Xenion ignitum*, and *Carabus convexus* in the 3 studies localities (A, B, C) and estimated one-day movement.

Species	One-day movement	Number of recaptured specimens		
		A	B	C
Myas chalybaeus	Recaptured in the same trap	7	1	4
	Recaptured in a neighboring trap	3	2	0
	Recaptured in traps 10 m or more apart	1	1	5
	n/a	1		
	Longest recorded distance per day (m)	10	20	30
Xenion ignitum	Recaptured in the same trap	2	0	0
	Recaptured in a neighboring trap	2	0	0
	Longest recorded distance per day (m)	5	/	/
Carabus convexus	Recaptured in the same trap	1	0	0
	Recaptured in a neighboring trap	2	0	0
	Recaptured in traps 10 m or more apart	1	0	0
	Longest recorded distance per day (m)	30	/	/

(2004) hypothesized that during summer months, after the breeding period, females enter deeper into the soil to lay eggs, avoiding severe climatic conditions. The increased proportion of females over males with soil depth is a well-known phenomenon for some species in other beech forests (Loreau, 1987).

Most of the 19 studied ground beetles on Mt. Osogovo were forest species. They are the first ones to suffer from forest fragmentation impact and habitat modifications (Oates et al., 2005). The results of this study show that ground beetles, mainly brachypterous (with low dispersal abilities), are vulnerable to fragmentation and microhabitat changes. However, those changes did not influence dominant species such as *Myas chalybaeus* and *Tapinopterus balcanicus*. These species were captured in high numbers in well-forested microhabitats of all three localities. Furthermore, species richness in the studied area on Osogovo was smaller in the continuous forest (B), but similar between localities A and C. Grez et al. (2004) suggested that smaller and more isolated forested patches may support more species of insects than larger patches, and that more fragmented landscapes may harbor an enriched fauna of insects compared to an equivalent continuous area. It seems more likely that distant forest patches would have more independent colonization events by different species than a group of fragments that are close together. According to Gilbert et al. (1998), isolation of patches may make the redistribution of these species across the landscape more difficult. Undoubtedly, the degree to which forests are isolated and their sizes are critical factors for the survival of carabid beetles that require forest habitats (Fournier and Loreau, 2001; Koivula et al., 2002). Furthermore, the shape of the patch affects species richness so that forested parts with high edge-to-area ratios contain more species because of a high invasion rate from the surroundings (Usher et al., 1993).

Although species richness may remain the same in differently sized patches, species abundance may change (Niemelä et al., 1988; Davies and Margules, 1998). During the study on Mt. Osogovo the total abundance was highest in small locality A, compared to locality C and the continuous forest B, where similar ground beetle abundance was registered.

According to Halme and Niemelä (1993) and Niemelä (2001), species that occur in the smaller forest patches are probably invaders from the surrounding areas. Such species in our study were *Calathus distinguendus*, *Poecilus versicolor*, *Poecilus lepidus*, *Zabrus rhodopensis*, and probably *Laemostenus terricola*. Cluster analysis showed higher similarity between A and C and thus supported this hypothesis. Although forest generalists occur even in the small fragment A, possible long-term effects of such a fragmented habitat influence their survival. Such species often have limited dispersal ability, and fragmentation and isolation make it increasingly difficult for them to find a suitable habitat (e.g., the Balkan endemic species *Xenion ignitum* and *Tapinopterus balcanicus* or the near-threatened IUCN species *Carabus intricatus*).

Shade- and moisture-preferring species can be expected to suffer more from the edge effects. On Osogovo, it is quite certain that the impact of edge effects was strongest in the ecotone of fragmented locality A and forested peninsula C, which was demonstrated with Bray–Curtis dendrogram analysis of the ground beetle abundances between microhabitats. This analysis showed marked separation of the ecotone from the corridor and the open space. The forest interior showed the highest dissimilarity compared with other microhabitats.

Similar results were obtained from other investigations (Burke and Goulet, 1998; Tscharntke et al., 2002; Grez et al., 2004; Yaacobi et al., 2007): total carabid abundance was lowest in the continuous forest and beetle catches increased as the size of the fragment decreased. However, opposite results can be found in the literature, as well (Oates et al., 2005; Halme and Niemelä, 1993).

The results of this investigation indicate that forest size area and habitat changes affect ground beetle community structure through changes of the species richness, composition, and abundance. Namely, although with low abundance, the presence of the carabid species from the surrounding area caused considerable similarity between the two smaller forest localities, A and C, in comparison with continuous forest B.

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