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Carabid assemblages in fragmented sandy grasslands

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Abstract

Effects of fragmentation on carabid assemblages were studied in sandy grassland patches in eastern Hungary. Relationship between the habitat characteristics (area, isolation and shape) and the species richness of carabid assemblages was examined by forward stepwise multiple linear regression analysis. The total number of the collected carabid species correlated negatively with grassland area. Overall carabid species richness increased as the isolation of patches increased. The importance of the habitat specific carabid species in the assemblages (expressed by the ratio of the number of open-habitat species associated with sandy soils to the total number of species) increased with patch size. These patterns could be explained by the influx of species entering from the surrounding matrix and edge habitats causing elevated overall species richness in habitat patches with limited size or higher degree of isolation.

Keywords: Area; Fragmentation; Habitat island; Isolation; Specialist species; Species richness

1. Introduction

In Hungary, grasslands covered almost 33% of the land surface in the 19th century, while their recent area has dropped to 11% (Anonymous, 2005). At many localities, this decline created a network of isolated and fragmented grassland habitats. In Hungary, this affected mostly the sandy grasslands. Such sandy grasslands, formerly used as pastures and/or meadows, were ploughed and used as cropland, afforested with non-native trees or built over.

Fragmentation of natural and semi-natural habitats has two components. First, the total area of the habitat sustaining populations decreases. Secondly, these habitats tend to be more isolated (Saunders et al., 1991). Less mobile arthropod species are especially sensitive to habitat loss and isolation (Mader, 1980; Samways, 2005). Ground-dwelling carabid beetles (Coleoptera: Carabidae) are exceptionally useful study organisms for examining the effects of landscape changes, such as fragmentation because they are diverse and abundant, their ecology and systematics are relatively well known (Lövei and Sunderland, 1996), and they seem to be highly sensitive to fragmentation (Magura et al., 2001; Niemelä, 2001; Koivula and Vermeulen, 2005; Lövei et al., 2006).

The classical theory of island biogeography (MacArthur and Wilson, 1967) predicts that the number of species supported by an island increases with the area of the island, and it decreases with the increasing degree of island isolation. Furthermore, it is emphasised that other factors, such as the shape of the habitat fragment could have an effect on the number of species (Laurence and Yensen, 1991). Recently, several papers refined the oversimplified original assumptions of the island biogeography theory emphasising the effects of surrounding habitats (edges and matrix) on the species richness (Kupfer et al., 2006; Lövei et al., 2006).

In the present study, carabid assemblages in fragmented sandy grasslands were evaluated in eastern Hungary to examine the relationships between the habitat characteristics and the species richness of carabid assemblages. We hypothesised that the relationship between species richness and area would be stronger if only the habitat specific species were considered. Moreover, we expected that the more isolated and elongated grassland patches would have

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elevated species richness because of species entering from the surrounding matrix and edge habitats.

2. Material and methods

Carabid assemblages of eight sandy grasslands (see Table 1) located in the Nyírség region, part of the Great Hungarian Plain (eastern Hungary) were studied. This region was covered by natural habitats (marshes, fen meadows, mires, sandy grasslands and sandy oak woods) in the 19th century. After the intensification of landscape management during the 20th century, these habitats were eliminated or became highly fragmented. Today, these fragmented sandy grasslands are surrounded by arable lands and non-native tree plantations. In the studied habitat islands, the prevalent vegetation association was *Potentillo arenariae–Festucetum pseudovinae*. The studied patches are remnants of formerly contagious grasslands, and recently they have been lightly grazed with cows and sheep (cattle density was <0.25 heads/ha). All of the investigated grasslands were surrounded both by non-native deciduous tree plantations (black locust and ennobled poplar species) and croplands (maize and corn). Therefore, the matrix habitats were similar for all the studied patches. The distance between the investigated grassland patches was at least 2 km.

During the 3-year trapping period (2001–2003) carabid beetles were collected using unbaited pitfall traps, consisting of plastic cups (diameter, 100 mm and volume, 500 ml) with 70% ethylene glycol as a killing and preserving solution. There were 10 traps, scattered randomly within the individual patches (at least 100 m from the grassland edges), and were checked fortnightly from the end of March to the end of October. Because of the difference in the size of the patches, it would be assumed that trapping effort was not the same for all the studied grassland patches, and therefore, larger patches could have been underestimated regarding species richness. However, using species richness estimating functions it is evident that in the larger patches the same proportion of the estimated species pool was sampled as in the smaller patches (results not shown). Carabid beetles were identified to species using the keys of Hůrka (1996).

Table 1
The habitat characteristics of the eight studied sandy grasslands

Site	Area (ha)	Isolation-index (ha)	Shape-index
1	99.0	121.5	1.4
2	249.7	122.1	1.3
3	250.6	58.3	1.4
4	353.5	137.6	2.3
5	188.7	130.5	1.2
6	29.1	1.6	1.5
7	51.8	7.3	1.3
8	2.3	137.3	1.2

The area of the sandy grassland patches was measured using the ArcView GIS program package on a digitized 1:25,000 map. Isolation of a habitat island is most often measured as the distance to the nearest patch. However, isolation of a habitat patch depends not only on the distance to the nearest patch, but also on the area of the nearest patch. A large habitat patch is more likely to have a greater number of species that can colonise the neighbouring patches. Isolation was measured by the inverse isolation measure (Vos and Stumpel, 1995), defined as the total sandy grassland area within a radius of 1000 m around the studied grassland patch. This measure was used as an inverse of the isolation, because its value decreased as the isolation of the grassland increased. The radius was chosen 1000 m, because even flightless carabids can cover this distance (Thiele, 1977). Laurence and Yensen (1991) stressed that shape could also influence the number of species inhabiting habitat island. The shape of grasslands was characterized by the shape index (Patton, 1975) defined as $P/200\sqrt{\pi A}$, where P was the perimeter of the sandy grassland patch (m), and A was patch area (ha). Its value was 1 for a round-shaped grassland fragment, while values greater than 1 represented deviation from circularity (Laurence and Yensen, 1991).

The relationships between the studied habitat characteristics and the species richness of carabid assemblages were examined by forward and backwards stepwise multiple linear regression analyses. Forward stepwise multiple linear regression analysis provided a better fit, thus this method was used as suggested by Kutner et al. (1996). We analysed both the total number of carabid species collected in the fragment, as well as the habitat specialists. To ensure a more complete species inventory in the studied grasslands, carabid catches from the three trapping years were pooled. The distribution of data used in the multiple linear regression analyses was normal (tested by the Kolmogorov–Smirnov test, Sokal and Rohlf, 1995).

3. Results

During the 3-year trapping period, 8620 carabids belonging to 67 species were collected from the eight sandy grasslands. Thirty-one species (7469 individuals) were identified as open-habitat species associated with sandy soils.

The result of the forward stepwise multiple linear regression analysis showed that out of the studied habitat characteristics, only the area and the isolation of the grasslands had an influence on the total number of species. There was a significant negative relationship between the total number of species and the area of the sandy grassland ($R = -0.6983$, $p = 0.0052$, Fig. 1A). The inverse isolation index and the number of all captured carabid species showed a significant negative relationship ($R = -0.4211$, $p = 0.0475$): an increasing isolation resulted in elevated species numbers.

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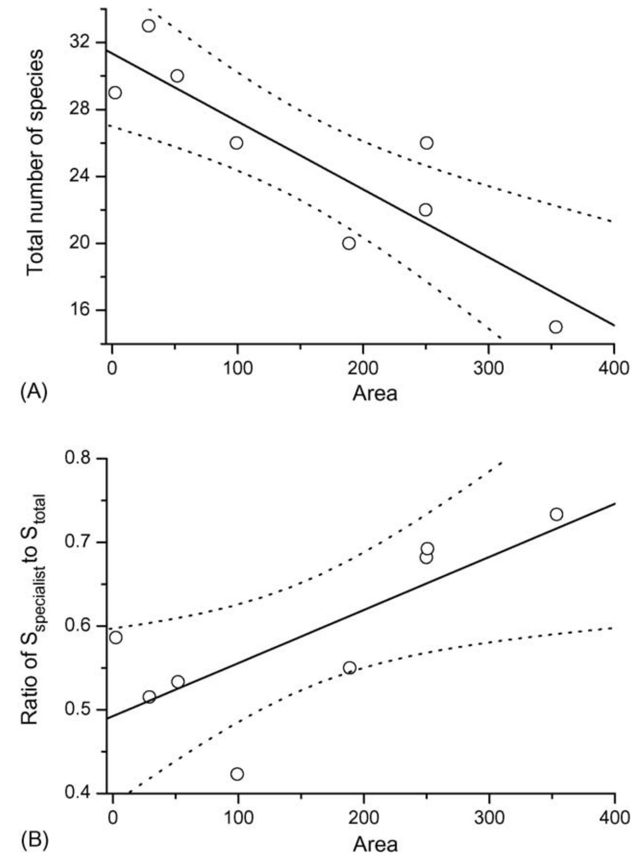

Fig. 1. Relationship between the sandy grassland patch area and the total number of carabid species collected (A) and the ratio of open-habitat carabid species associated with sandy soils to the total number of carabid species (B). Both regressions are significant ($p < 0.05$). Dotted lines represent the confidence bands (95%).

A significant positive relationship was found between the ratio of open-habitat species associated with sandy soils to the total number of species and the grassland area ($R = -0.7599$, $p = 0.0287$, Fig. 1B; equation: ratio = 0.4923 + 0.0006 area), indicating the importance of habitat specific species with increasing patch size.

Both the overall species richness and the ratio of habitat specific species were unrelated to the shape index.

4. Discussion

Several papers investigating the relationship between the area of habitat island and the number of all sampled animal species reported significant positive correlation (Mader, 1980; Peintinger et al., 2003; Watson et al., 2005). Some studies found that overall animal species richness was unrelated to the habitat area (Hopkins and Webb, 1984; Juliao et al., 2004). Moreover, several other papers, similarly to our results, and contrary to the prediction of the classical theory of island biogeography, described a significant negative relationship between the area of habitat island and the total number of animal species (Bauer, 1989; Magura et al., 2001; Lövei et al., 2006). The above contradiction could arise from the fact that the original theory considered real islands. However, there is a major difference between real and habitat islands. In real islands, the surrounding habitat is usually inhospitable to organisms occurring on islands, while in the case of habitat islands, the bordering habitat (the matrix) is usually less hostile. Due to the above difference, habitat islands could be inhabited by colonists from the matrix: ‘‘species can colonize the islands from the sea’’ (Cook et al., 2002). Consequently, the species–area relationship observed may be positive, negative or neither, depending on the balance of contribution by habitat specific and non-habitat specific species. Such results lead to call for further refinements of the paradigm (Cook et al., 2002). Therefore, when studying predictions of island biogeography theory on habitat islands, a distinction must be drawn between specialist species that truly perceive the habitat patches as islands and are unable to survive in the surrounding matrix and those species that occur in both the habitat patch and the matrix (Bauer, 1989; Magura et al., 2001; Cook et al., 2002; Lövei et al., 2006).

In the present study, the open-habitat carabid species associated with sandy soils could survive and reproduce in large numbers only in the sandy grassland patches and were unable to survive in the adjacent non-native deciduous plantations. However, the other carabid species could survive in the surrounding matrix as well. Accordingly, removing the non-habitat specific species and analysing the importance of only habitat specific open-habitat carabid species associated with sandy soils, the significant negative relationship became significant positive as predicted by the theory of island biogeography. This duality in the species–area relationship concerning carabid beetles is not a special case, as several studies reported similar results in different habitats (Bauer, 1989; Usher et al., 1993; Halme and Niemelä, 1993; De Vries, 1994; Magura et al., 2001; Lövei et al., 2006).

Our findings that overall species richness increased as grassland area decreased and grassland isolation increased, as well as that the importance of habitat specialist species in the assemblage increased with increasing grassland area could be explained by the influence of species entering from the surrounding matrix and by the need of habitat specific species for a minimum area of their habitat. Several previous studies on carabids showed that species richness patterns in habitat patches with limited size and/or high degree of isolation could be influenced by species from the neighbouring matrix and from the edge, causing increased overall species richness (Bauer, 1989; Halme and Niemelä, 1993; Desender et al., 1999; Magura et al., 2001; Lövei et al., 2006). Furthermore, highly isolated patches may ‘‘sample’’ more generalist species with good dispersal ability than less isolated ones. Other investigations focusing on carabids in grasslands also emphasised that landscape features (proximity of other habitats,

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proportion of natural, semi-natural habitats, etc.) were especially important, as species incoming from the adjacent habitats may considerably alter the local species composition and diversity (Jeanneret et al., 2003; Purtauf et al., 2005). Furthermore, a habitat patch needs to be of a minimum size to ensure habitat heterogeneity and special environmental conditions required by specialist species (Niemelä et al., 1987; De Vries and Den Boer, 1990). Moreover, according to Den Boer (1985) the survival time and the extinction rate of a carabid population are greatly influenced by the area of the habitat. In a suitably large habitat patch a population could consist of several, asynchronously fluctuating subpopulations contributing to the enhancement of survival and the reduction of extinction. The above discussed minimum required area for carabids can vary, depending on geographic location, habitat structure or the age of the fragment but it is estimated to be tens of hectares (Niemelä, 2001).

Factors like land use or management intensity (Dauber et al., 2005), mowing regime (Haysom et al., 2004; Grandchamp et al., 2005), grazing pressure (Grandchamp et al., 2005) and fertilization (Kromp, 1999) could also have significant impacts on both overall species richness and diversity of habitat specific carabids. However, in our situation the studied grasslands were managed (grazed) in a similar way.

Because of the adhesion to the common European agricultural policy the study area is bound to be subject to even further landscape scale modification in the future. Therefore, for the conservation of the habitat specific open-habitat species associated with sandy soils in the studied region the following measures are recommended during the sandy grassland management. All of the grassland patches should be preserved because habitat specific species are important even in the assemblages of the smallest patches. Moreover, to enlarge small patches, converting adjacent arable lands to grasslands is recommended. Recent papers (Niemelä et al., 2002; Magura et al., 2004) emphasised that in habitat patches invaded by generalist species from the surrounding habitats the number of habitat specific species may decrease indicating interspecific competitive interactions. In our study, however, it was not the case, because overall carabid species richness and the number of habitat specific open-habitat species associated with sandy soils showed a significant positive correlation.

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