

Affinity indices for environmental assessment using carabids

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Abstract

Three new habitat-affinity indices were developed, based on the concepts of habitat specificity and fidelity. The usefulness of these indices was assessed using data on ground beetles (Carabidae) from the Hungarian GlobeNet site, in the city of Debrecen (Eastern Hungary), studying a rural-urban gradient. We demonstrated that the carabid assemblage of the rural end of the gradient is characterized by a high forest affinity value that decreased across the gradient towards the urban area. Forest affinity values were attributed to the species based on our earlier research, and literature data. The affinity indices based on fidelity or specificity of the species proved to be useful in comparing different habitat patches. The index based on a combination of specificity and fidelity characteristics produced a good alternative to the otherwise hazy "ecological character" of the studied carabid assemblages.

Key words: Environmental monitoring, ecological indices, forest species, GlobeNet, urban-rural gradient

Introduction

Environmental monitoring to follow and assess the human impact on the environment is of central importance (Loreau *et al.*, 2002). Plants and animals are good indicators of the quality of the environment, so their habitat-affinity and other ecological indices are generally used to assess the natural or "protection" value of an assemblage in a given patch of habitat

(Spellerberg, 1991). Indicator and/or affinity indices are useful tools to characterize carabid assemblages (Pizzolotto 1994); they are also widely used in botany (Ellenberg, 1973), and in water qualification (Ruoppola *et al.*, 2003).

Ground-dwelling carabids are especially useful to study environmental impacts, because they are sensitive to environmental changes, abundant and sufficiently variable both taxonomically and ecologically (Lövei & Sunderland, 1996). Carabid beetles are among the most reliable taxa for applied research in environmental evaluation, as they are sensitive to soil disturbance and to other changes in environmental conditions in their habitats (Elek *et al.*, 2001; Niemelä, 1999; Desender *et al.*, 1999; Magura *et al.*, 2000, 2001, 2002, 2003).

This paper deals with some problems related to the use of habitat affinity indices. We evaluated the performance of different indices to assess the natural value of the habitat patches based on the forest-affinity values of the carabid species in habitats across an urbanization gradient. Our hypothesis was that the rural end of the gradient is characterized by an assemblage with a high forest affinity value, and was expected to decrease along the gradient towards the urban area.

Material and methods

Study area and sampling

The study areas were the Hungarian GlobeNet site, in the city of Debrecen (Eastern Hungary) (Magura *et al.*, 2004). Three forested sampling areas were selected along an urbanisation gradient; these represented urban, suburban and rural areas, following the GlobeNet protocol (Niemelä *et al.*, 2000, 2002). All sampling sites were in continuous patches of forest dominated by English oak (*Quercus robur*), each covering at least 6 ha. Distance between the studied areas was at least 1 km. In the urban park area, there were several asphalt-covered paths and the shrub layer was strongly thinned, while in the suburban area the fallen trees were removed. The urban-rural gradient extended over a distance of approximately 6 km from the city centre through the suburbs to the neighbouring Nagyerdő Forest Reserve. Details of the sampling is discussed in Magura *et al.* (2004).

Data analysis

To test for differences in habitat affinities, nested analysis of variance (ANOVA) were performed on the different habitat affinity index values among the three sampling areas (urban, suburban and rural) and among the 12 sites. The distribution of data used in the ANOVA model was normal (Kolmogorov-Smirnov test, Sokal and Rohlf 1995). When ANOVA revealed a significant difference between the means, an LSD (least significant difference) test was performed for multiple comparisons among means.

Affinity Indices

Although the habitat affinity indices are simple and straightforward from an ecological point of view, the mathematical formulas are technically sophisticated. The base dataset is organized into a table; the entries of the table are x_{ir} , where the species are indexed by i and the traps by r :

$$\begin{pmatrix} x_{11} & \dots & x_{1r} & \dots & x_{1P} \\ \vdots & & \vdots & & \vdots \\ x_{i1} & \dots & x_{ir} & \dots & x_{iP} \\ \vdots & & \vdots & & \vdots \\ x_{S1} & \dots & x_{Sr} & \dots & x_{SP} \end{pmatrix}, \quad (1)$$

where x_{ir} is the number of individuals of species i captured in the trap r . The value of i runs from 1 to the total number of species, S ; likewise, that of the number of traps, r runs from 1 to P .

The crucial step of the habitat qualification procedure is how to define the A_i affinity values. We have used the five levels of affinity values, ranging from +1 to -1, suggested by Allegro & Sciaky (2002):

- +1: obligate forest species (forest specialist),
- +0.5: partial forest species (forest generalist),
- 0: species indifferent to forest coverage (habitat generalist),
- 0.5: partial open-habitat species (open habitat generalist),
- 1: obligate open-habitat species (open habitat specialist).

The affinity values of the species in our samples were determined from our earlier research in the same area (Magura et al. 2004), and on relevant literature (Hůrka 1996, Thiele 1977). When used the term ‘forest affinity’ rather than the general term of ‘habitat affinity’.

The simplest way to characterize a habitat is to sum up the affinity values of the species (A_i) in the traps; a habitat affinity value, HA_r , can be defined as:

$$HA_r = \sum_{i=1}^S I_{ir} \cdot A_i, \quad (2)$$

where I_{ir} is the so-called indicator function:

$$I_{ir} = \begin{cases} 1, & \text{when the species } i \text{ is present in the trap } r, \\ 0, & \text{when the species } i \text{ is missing in the trap } r. \end{cases}$$

It is easy to see that the role of I_{ir} is to ensure that species that are not present in a trap do not contribute to the affinity value of the habitat. If species i is absent from trap r , it will contribute 0 to the sum and not increase the value of HA .

HA_r is the simplest way to characterize habitat affinity. A high HA_r value indicates a high number of forest species in the trap, whereas a low value indicates the opposite.

Notice that only presence-absence influences the value of HA . The value of the following habitat affinity index, HAR , defined by the equation (3), gets the higher values the more forest species are present in the habitat patch. The index is calculated as the weighted average of the affinity values; thus, the affinity values are weighted by the relative frequency of the species:

$$HAR_r = \sum_{i=1}^S p_{ir} \cdot A_i, \quad (3)$$

where p_{ir} is the relative frequency of the species i in the trap r . $p_{ir} = 0$, if the species i is missing from the trap r . Therefore, the I_{ir} indicator function is not necessary in the formula (3). Notice that this is the same as Allegro & Sciaky's (2002) forest affinity index (FAI) but calculated individually for every trap.

The abundances of the species may fluctuate considerably. For this reason, weight other than p_{ir} , based on the consistency of the occurrence of a species in a habitat may be useful (see Dufrene and Legendre 1997). This kind of weight is defined by the number of traps a given species is present within a habitat patch (fidelity). An alternative approach is when the differences in abundance among habitat patches are used for weighting the affinity of the species (specificity). For these purposes we propose three new habitat-affinity indices (4-6) that include the components of fidelity and specificity.

Habitat-affinity-fidelity index (HAF) is defined as:

$$HAF_r = \sum_{i=1}^S I_{ir} \cdot \pi_i \cdot A_i, \quad (4)$$

where π_i is the relative frequency of traps with species i present. A species i is present 7 out of 10 traps, then $\pi_i = 7/10 = 0.7$.

Habitat-affinity-specificity index (HAS) is defined as:

$$HAS_r = \sum_{i=1}^S I_{ir} \cdot e_i \cdot A_i, \quad (5)$$

where e_i is the specificity of the species i . The specificity is defined as the ratio of the average number of individuals of the species in the habitat patch (\bar{x}_{ir}) compared to the average of the individuals across all the studied habitats (\bar{x}_i); thus,

$$e_i = \bar{x}_{ir} / \bar{x}_i.$$

The combined habitat-affinity index, based on both specificity *and* fidelity (*HAFS*) is defined as:

$$HAFS_r = \sum_{i=1}^S I_{ir} \cdot \sqrt{\pi_i \cdot e_i} \cdot A_i. \quad (6)$$

The geometric average of the fidelity and affinity weights, $\sqrt{\pi_i \cdot e_i}$, is used to guarantee a constant unit sum of the weights for all the species.

Results and discussion

The performance of the indices

The ANOVA indicated significant differences in the averages of the habitat affinity values of the compared carabid assemblages (Table 1). All the indices gave similar results regarding the compared habitat patches (Fig. 1).

Table 1. Nested ANOVA for four habitat affinity-index values (*HAR*, *HAF*, *HAS*, *HAFS*). Gradient: urban, suburban, and rural sampling area. There were four sites within each sampling area.

	Source of variation	df	MS	F	p
<i>HAR</i>	Gradient	2	6.8347	44.0097	<0.001
	Sites	9	0.1553	1.4563	0.1736
	Error	108	0.1067		
<i>HAF</i> (fidelity)	Gradient	2	4.6290	56.1772	<0.001
	Sites	9	0.0824	2.0135	<0.05
	Error	108	0.0409		
<i>HAS</i> (specificity)	Gradient	2	28.9290	95.9184	<0.001
	Sites	9	0.3016	0.8501	0.5720
	Error	108	0.3548		
<i>HAFS</i> (fidelity and specificity)	Gradient	2	9.9943	87.9006	<0.001
	Sites	9	0.1137	1.3061	0.2421
	Error	108	0.0870		

The average of the forest affinity values of the carabids was lowest in the urban area with each affinity index, indicating that the number of obligate forest carabids was low (Fig. 1). Moreover, in the urban park there were more open-habitat than forest carabids. In this area, there were several asphalt-covered paths and the shrub layer was strongly thinned, which resulted in higher openness in that area. As soon as the forest affinity is low or negative, the

assemblage is characterized by generalist and/or open habitat species.

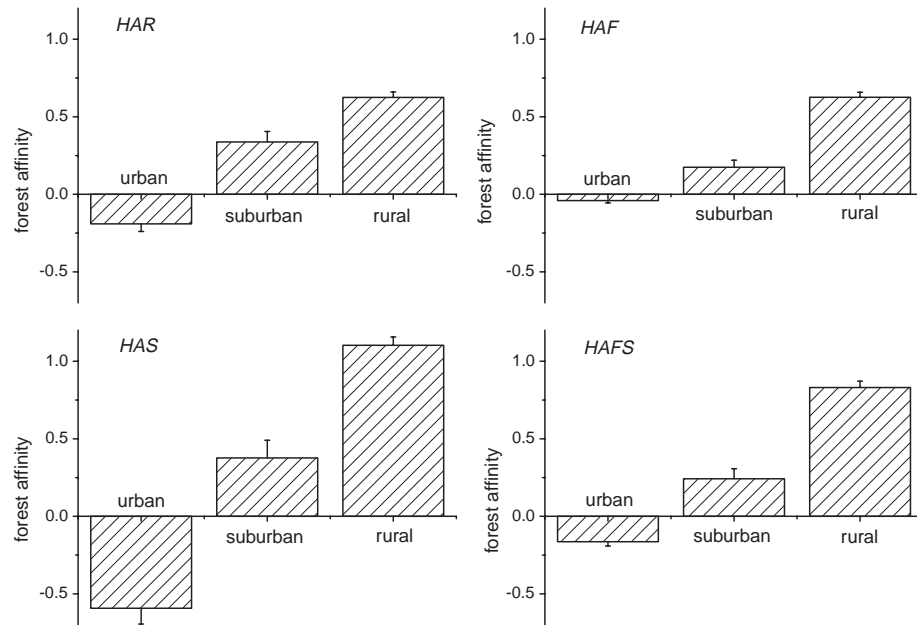


Figure 1. The mean habitat affinity values ($\pm SE$) for the forest species, weighted by the relative frequency of the species (*HAR*), by fidelity (*HAF*), by specificity (*HAS*), and by the geometric average of fidelity and specificity (*HASF*).

The average forest affinity was positive for the suburban area with each affinity measure, but significantly lower than in the rural area. This is explained by the fact that the species richness of forest carabids increased significantly across the urban-rural gradient (Magura *et al.*, 2004).

Every affinity index indicated that the average forest-affinity value was significantly higher in the rural area (Fig. 1, Table 1). The number of individuals belonging to forest-associated species, the number of such species, and the average carabid catch all peaked in the rural area (Magura *et al.*, 2004).

The difference between the rural and the suburban areas was pronounced using the fidelity (*HAF*) and the combined habitat affinity (*HASF*) indices (Fig. 1). The difference was lowest between the suburban and rural areas using the usual habitat affinity index that is based on the relative frequencies of the species (Fig. 1, *HAR*).

The habitat affinity-specificity index produced a relatively large negative forest affinity value for the urban area (Figure 1, *HAS*), while the habitat affinity-fidelity index stressed the high forest affinity value of the rural area (Fig. 1, *HAF*). The combination of these two aspects of the weighting of the carabids affinity values produced a balance between these two aspects (Fig. 1, *HASF*).

There were no remarkable differences between the results provided by the different affinity indices. This is a result of sampling within similar types of habitat. There were no extreme

values in our test dataset. The differences and the usefulness of the different indices may be better understood in more extreme comparisons, with more variation among catches.

It is important to stress that fidelity and specificity emphasize two independent aspects of commonness and rarity. For example, a species has high fidelity in a habitat if it is represented by the following catches in five traps: 2, 3, 1, 5, 1. Another species with catches 0, 0, 0, 427, 0 individuals in the same traps may be more abundant overall, but not as "true" to the habitat as the former one: its occurrence is more sporadic. Thus, its fidelity is low. However, its specificity may be high, if the number of captured individuals in other habitats is low.

The "standard" version of the habitat affinity index, based on the relative frequency of the species in the trap (*HAR*), is sensitive to extreme values of captures. Fidelity quantifies the spatial uniformity of the species, while specificity is based on the variation of the average abundance of the species in the habitats studied. In comparison to indices using the mere occurrence or the relative frequency of species, they capture more aspects influencing their distribution. Therefore this is a fascinating tool for comparisons of carabid communities in ecological and environmental studies. The behaviour of these indices should be studied with more data sets to explore their features and realise their potential.

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