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Distribution and spatial autocorrelation of carabid species in differently-treated post-agricultural areas

Axel Schwerk

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The distribution of carabid beetles in a landscape composed of forests and differently treated post-agricultural open fields was studied over the four years period from 2004 to 2007. The area was investigated using a net of pitfall traps with a distance of 100 m between the traps in east-west direction and about 50 m in north-south direction. Five species, which were collected with more than 1000 individuals (*Calathus erratus*, *Calathus fuscipes*, *Harpalus rubripes*, *Harpalus tardus*, *Poecilus versicolor*), were selected for further research. Preliminary analyses of the data have shown that the species react sensitively on the different treatments of the ground. However, data were pooled over the four years of study and the spatial pattern based on the single sampling plots has not been analysed yet.

In the present paper I analyse the spatial distribution patterns of the selected species for the single study years as well as for the pooled data collected over the four years. Geary's C index of spatial autocorrelation was used to assess the degree of aggregation of the species in defined parts of the study area.

As expected due to the preliminary studies, *Calathus erratus* and *Poecilus versicolor* showed generally strong spatial autocorrelations and *Harpalus tardus* showed weak spatial autocorrelations. *Calathus fuscipes* showed also strong spatial autocorrelations for the single years, but for the pooled data it was slightly below the expectations, suggesting variation in spatial aggregation between the years. An unexpected strong spatial autocorrelation was calculated for *Harpalus rubripes* when analysing the pooled data. However, this species showed high fluctuations in spatial autocorrelation between the sampling years, with a particular strong spatial autocorrelation calculated for 2006. Since the highest number of individuals of *Harpalus rubripes* was recorded in this year, this result may have influenced the calculated spatial autocorrelation for the pooled data. The results lead to the conclusion that the connection of individual species to specific habitat types may be differently pronounced between different years. This might be useful with respect to work out indicatory values of species for environmental monitoring.

Key words: Carabidae , bioindication, spatial autocorrelation, Geary's C index, management

Axel Schwerk. Laboratory of Evaluation and Assessment of Natural Resources, Warsaw University of Life Sciences – SGGW; e-mail: aschwerk@yahoo.de

INTRODUCTION

The ecological preferences of carabid beetles have been studied for decades (e.g. Lindroth 1945). Due to their preferences for specific habitat types most species show explicit distribution patterns in a wider space (landscape), but even on a small scale distinct patterns might occur, for example within agricultural fields (Holland et al. 2001, 2003). However, even in a comparatively homogeneous areas changes in these patterns can be observed. Long-term studies have proven that on fixed sampling plots massive fluctuations in numbers of given species are possible (e.g. den Boer 1981, 1990, Schwerk et al. 2006), which do not represent succession patterns but can be attributed to stochastic fluctuations (den Boer 1981, Gongalski & Cividanes 2008). However, such phenomena weaken the informative value of inventories on single species, because one might collect at the moment of a peak or minimum value and will be misdirected with respect to conclusions. The problem of species-specific temporal variation in the context of conservation planning has been already addressed by Koivula (2011).

The present paper is based on data which were elaborated over the period of four years (2004-2007) in a landscape composed of forests and differently treated post-agricultural open fields. Preliminary analyses of these data have been carried out on five species, which were collected with more than 1000 individuals (*Calathus erratus*, *Calathus fuscipes*, *Harpalus rubripes*, *Harpalus tardus*, *Poecilus versicolor*). These analyses have shown that the species react sensitive on the different treatments of the ground (Schwerk & Szyszko 2009). However, data were pooled over the four years of study and the spatial pattern based on the single sampling plots has not been analysed yet.

In the present paper I analyse the spatial distribution patterns of the selected species for the single study years as well as for the pooled data collected over the four years. Geary's C index of spatial autocorrelation was used to assess the degree of aggregation of the species in defined parts of the study area. Assuming that the spatial autocorrelation is exogenously induced (Kissling & Carl 2007), the aim of these analyses is to study if species with high preference for specific study sites according to Schwerk & Szyszko (2009) show high spatial autocorrelations. According to this hypothesis strong spatial autocorrelations are expected for *Calathus erratus* and *Calathus fuscipes*, which show a very strong preference to study site 18, as well as *Poecilus versicolor*, which shows a very strong preference for study sites 17 and 19. A medium spatial autocorrelation is expected for *Harpalus rubripes*, because the preference for study site 18 is less pronounced. A weak spatial autocorrelation is expected for *Harpalus tardus*.

METHODS

Study sites and field methods

Carabid beetles were studied at the research area "Krzywda" (west Poland, Wałecki district) from 2004-2007. The area serves with different forests and post-agricultural areas of different stages of succession as well as about 68 ha of swamps highly eutrophicated due to man's economic activity, supplied by three watercourses (Dymitryszyn et al. 2013).

53 pitfall traps were installed on former agricultural soils (Schwerk & Szyszko 2009). The traps were placed in a grid forming seven columns (A-G) and eight rows (1-8). The columns were about 100 m apart, while the rows were about 50 m apart, with the exception of the distance between row 2 and row 3 that was about 70 m. However, due to characteristics of the terrain, in some case the distances deviated a few meters from the values mentioned above (Fig. 1).

The traps were grouped to five different study sites (Fig. 1). Study site 16 constituted a pine forest of 26 years in 2004, study sites 17 and 19 were post-agricultural areas, which were irregularly mown without biomass removal, study site 18 was former agricultural land, which was regularly mown with biomass removal, and study site

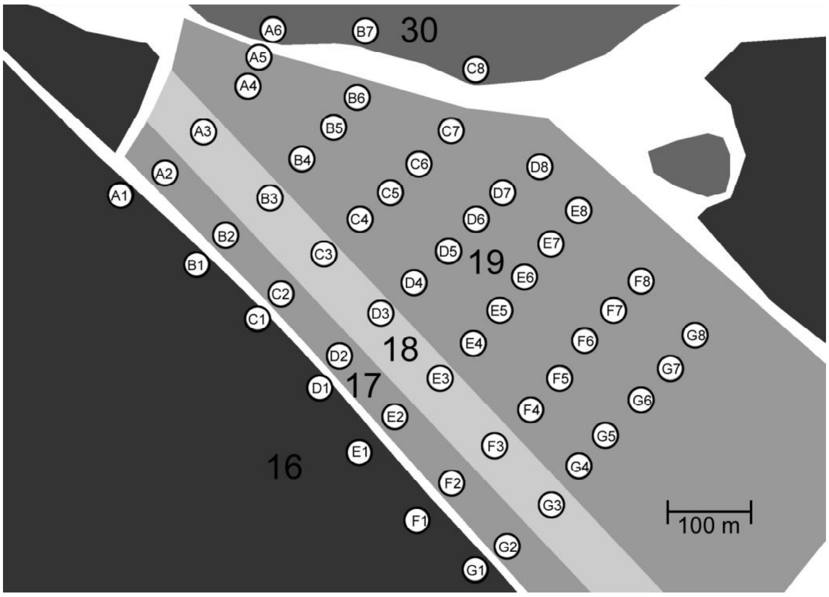

Fig. 1. Scheme of the spatial arrangement of the traps (A1-G8). Number 16, 17, 18, 19 and 30 indicate groups of traps regarded as study sites (after Schwerk & Szyszko 2009)

30 constituted a wet area with peat rich soil (Dymitryszyn et al. 2013). Carabids were collected using pitfall traps (Barber, 1931). Traps were glass jars topped with a funnel (upper diameter of about 10 cm) set flush with the soil surface. A roof was suspended a few cm above the funnel and ethylene glycol was used as a killing agent and preservative. Carabids were sampled in 2004 to 2007 from mid-May to mid-September.

Determination and nomenclature of the individuals collected was carried out according to Freude et al. (2004).

Statistical methods

Species, which were collected with more than 1000 individuals, were chosen for further statistical analysis.

Each pitfall trap was considered as a sampling plot. Spatial autocorrelation was calculated for the sampling plots on the study sites 17, 18, and 19 (in all 43 sampling plots). Study sites 16 and 30 were omitted from these analyses, because they constitute non-typical habitats for the selected species, which were collected on these sites only accidently. Spatial autocorrelations were calculated for each of the species using the trapping results obtained at the sampling plots in the single years of study as well as the four years of study pooled together by calculating Geary's C index (Geary 1954, in Universität Wien 2014):

$$C = \frac{n-1}{2 * (\sum_i \sum_j w_{ij})} * \frac{\sum_i \sum_j w_{ij}(x_i - x_j)^2}{\sum_i (x_i - \bar{x}) \sum_i (x_i - \bar{x})^2}$$

with:
n: Number of samples
x_i: Value for sample *i*
x_j: Value for sample *j*
w_{ij}: Weighting factor; $w_{ij} = 1$ if *i* and *j* directly neighbouring (4-adjacent), otherwise $w_{ij} = 0$
$\bar{x}$: Mean value of *x*

If C = 1 no spatial autocorrelation exists, if C < 1 a positive spatial autocorrelation exists, and if C > 1 a negative spatial autocorrelation exists.

RESULTS

Distribution patterns

Five species were collected with more than 1000 individuals, which are *Calathus erratus* (1078 individuals), *Calathus fuscipes* (1230 individuals), *Harpalus rubripes* (2038 individuals), *Harpalus tardus* (1067 individuals) and *Poecilus versicolor* (1428 individuals). The distributions of these species in the single years of study as well as the pooled data (Figs. 2-6) show that all species are only sporadically present in the pine forest and the wet habitat.

Calathus erratus (Fig. 2) shows clear preference for the regularly mown study site with biomass removal, even if there are strong fluctuations in total catches with very low results in 2007. However, there are some individual sampling plots on other study sites, which show in some years elevated numbers of collected individuals (C5, F4). *Calathus fuscipes* (Fig. 3) also prefers the regularly mown study site with biomass removal, but visible are somewhat higher values outside this area. Sampling plot C5 again shows elevated values. As with *Calathus erratus*, generally low numbers were collected in 2007. A much less pronounced preference for the regularly mown study site with biomass removal shows *Harpalus rubripes* (Fig. 4). This preference is even not visible in 2004 and 2005. The species was collected in low numbers in 2004 and 2007 and in particularly high numbers in 2006. *Harpalus tardus* (Fig. 5) does not show a very clear preference, but the values are somewhat higher on study sites 18 and 19. Sampling plots with higher catching results are B4, D7 and F4. Generally high numbers were recorded in 2005. *Poecilus versicolor* (Fig. 6) shows a preference for the irregularly mown

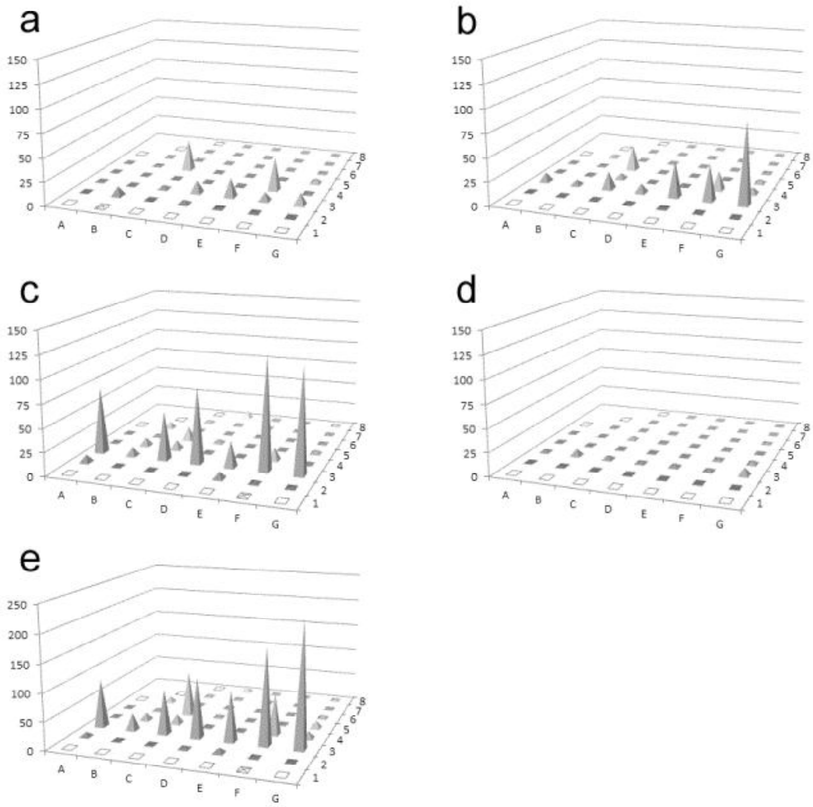

Fig. 2. Numbers of individuals of *Calathus erratus* collected at the sampling plots in (a) 2004, (b) 2005, (c) 2006, (d) 2007, and (e) the sum of the individuals collected in 2004-2007

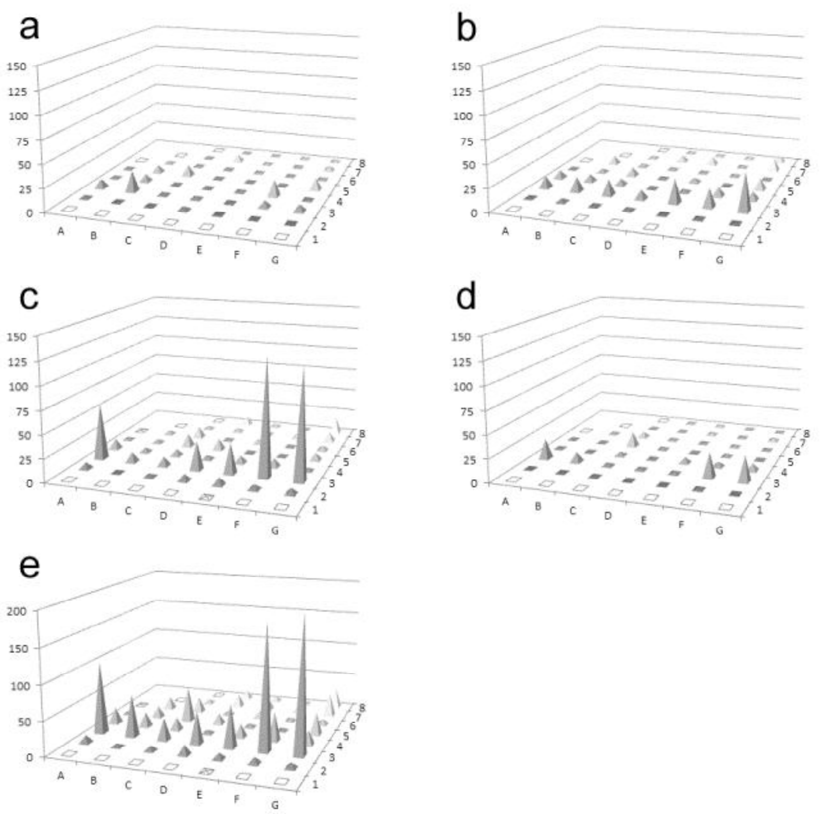

Fig. 3. Numbers of individuals of *Calathus fuscipes* collected at the sampling plots in (a) 2004, (b) 2005, (c) 2006, (d) 2007, and (e) the sum of the individuals collected in 2004-2007.

study sites – especially study site 19, but less pronounced also for study site 17. This species was collected in low numbers in 2004 and especially in 2007.

Spatial autocorrelations

All calculated values of Geary's C index are below 1 (Tab. 1), showing that all species have a regular tendency to positive spatial autocorrelations. For almost all species the weakest spatial autocorrelation was recorded in 2004. The only exception is *Harpalus rubripes* with the weakest spatial autocorrelation in 2007. The strongest spatial autocorrelations were recorded for *Calathus erratus* and *Calathus fuscipes* in 2005 and *Harpalus rubripes*, *Harpalus tardus* and *Poecilus versicolor* in 2006. Generally strong spatial autocorrelation in the single years were recorded for *Calathus erratus*, *Calathus fuscipes* and *Poecilus versicolor*. *Harpalus tardus* shows comparatively weak spatial autocorrelations, whereas the values for *Harpalus rubripes* show high fluctuations.

When considering the pooled data *Calathus erratus* shows the strongest and *Harpalus tardus* the weakest spatial autocorrelation. Quite strong spatial autocorrelations were also recorded for *Harpalus rubripes* and *Poecilus versicolor* and a weaker spatial autocorrelation for *Calathus fuscipes*.

DISCUSSION AND CONCLUSIONS

All five species are characteristic for rather young stages of succession, with particularly *Calathus*

Tab 1. Geary's C indices of spatial autocorrelation on study sites 17, 18 and 19 for the five species in the single years of study and for the pooled data

Species	Sampling period				
	2004	2005	2006	2007	2004-07
Calathus erratus	0.4731	0.3379	0.3692	0.3472	0.3202
Calathus fuscipes	0.5094	0.3637	0.3656	0.3739	0.3466
Harpalus rubripes	0.4571	0.4294	0.2958	0.5481	0.3249
Harpalus tardus	0.5358	0.4870	0.3830	0.4516	0.4639
Poecilus versicolor	0.5185	0.3841	0.3623	0.3946	0.3277

erratus often mentioned as a pioneer species of disturbed open areas of young stage of succession (e.g. Neumann 1971, Skłodowski & Sławski 2003, Güth et al. 2006, Schwerk 2014). However, the species prefer different parts of the studied area, what is in accordance with the statement by Rainio & Niemelä (2003) that carabid beetles are affected by grassland management practices as cutting. The particular preferences of the species for the different study sites are in detail discussed by Schwerk & Szyszko (2009). The present paper shows additionally that also on single study sites some preferred plots could be identified. Quite similar types of patterns were obtained by

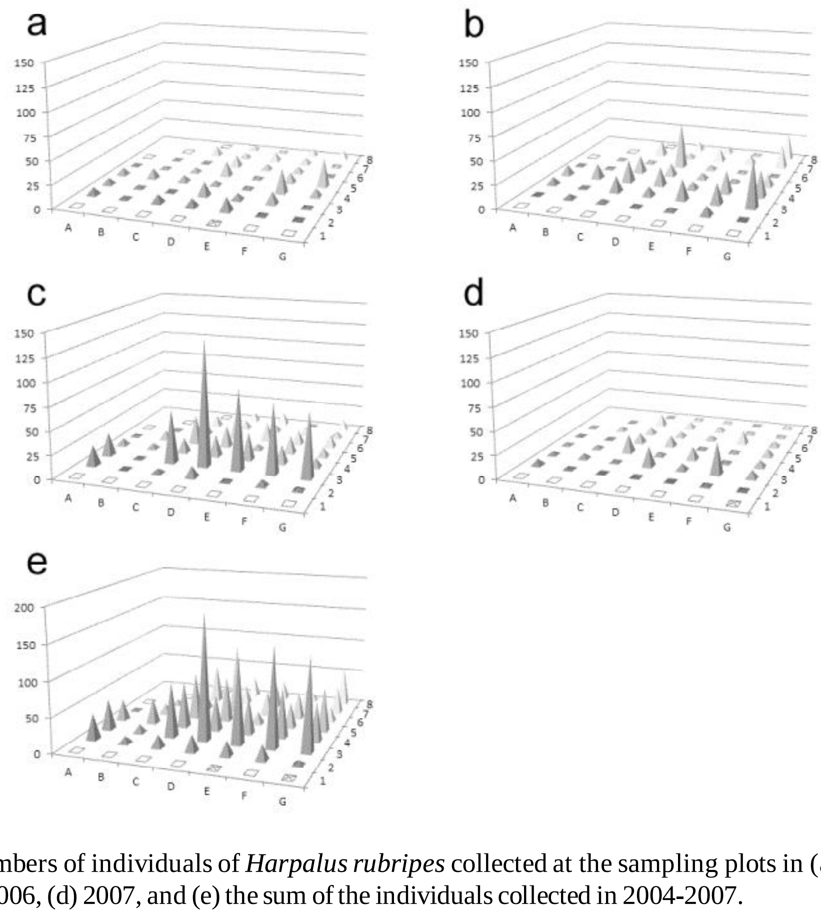

Fig. 4. Numbers of individuals of *Harpalus rubripes* collected at the sampling plots in (a) 2004, (b) 2005, (c) 2006, (d) 2007, and (e) the sum of the individuals collected in 2004-2007.

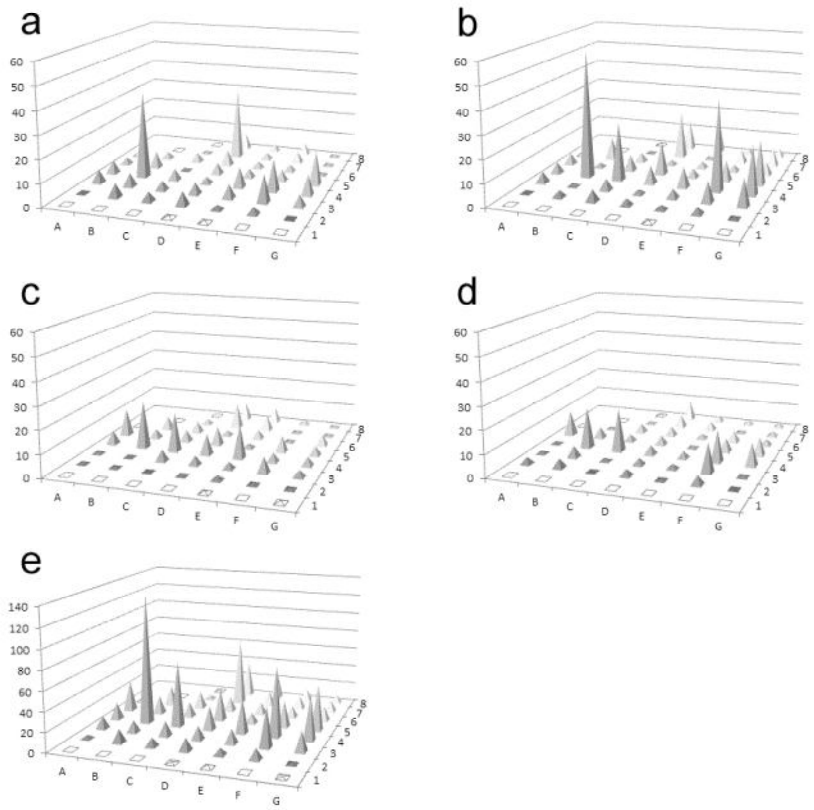

Fig. 5. Numbers of individuals of *Harpalus tardus* collected at the sampling plots in (a) 2004, (b) 2005, (c) 2006, (d) 2007, and (e) the sum of the individuals collected in 2004-2007

Holland et al. (2001) for the carabid species *Bembidion lampros* and *Pterostichus madidus* in different agricultural fields. All species show also fluctuations in catch numbers both in total numbers as well as on the single sampling plots. Such fluctuation in catching results on fixed sampling plots between years have been demonstrated for *Poecilus versicolor* by den Boer (1990) and Schwerk et al. (2006). Kabacik (1962) reported different high numbers of *Calathus erratus* at study plots located in agricultural fields between different years.

The results of the study are basically in agreement with the hypotheses, but there are two exceptions. Firstly, the spatial autocorrelation for the pooled data of *Harpalus rubripes* is above the expectations. However, a very low Geary's C value (i.e. strong spatial autocorrelation) was calculated for 2006. Since also the highest number of individuals of *Harpalus rubripes* was recorded in 2006, the results of this year have the biggest influence on the calculated spatial autocorrelation for the pooled data. Secondly, despite generally strong spatial autocorrelations in the single years the calculated spatial autocorrelation for the pooled data for *Calathus fuscipes* is below the expectations. This result suggests variation in spatial aggregation between the years.

A basic result of the present study is that the connection of individual species to specific habitat types may be differently pronounced between different years. This might be interesting with respect to assess indicatory values of species in

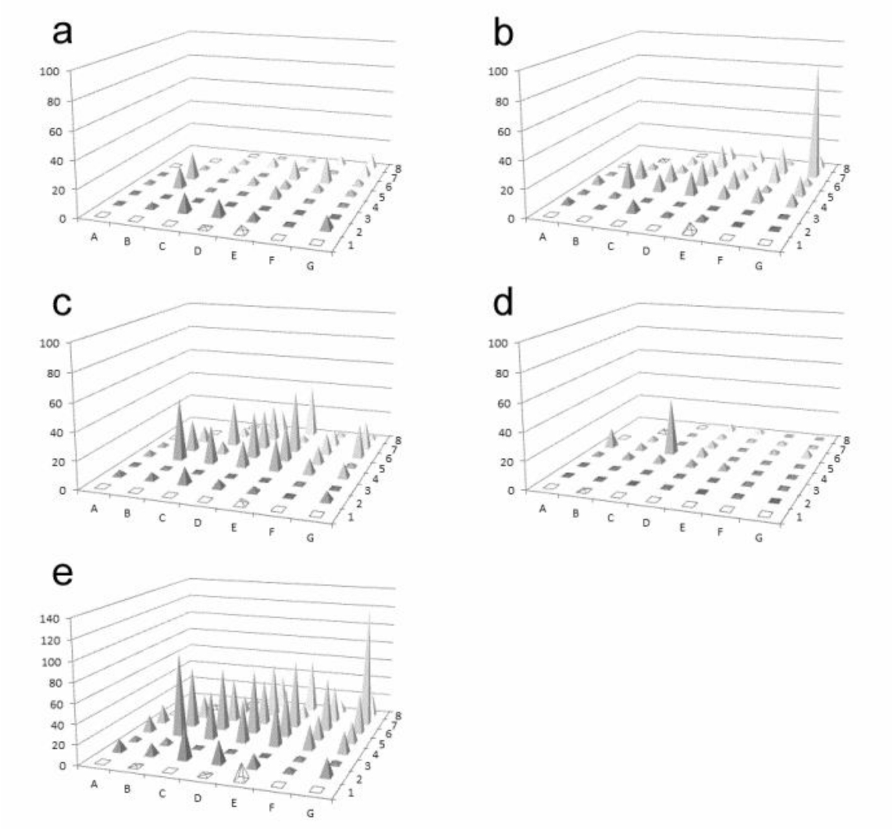

Fig. 6. Numbers of individuals of *Peocilus versicolor* collected at the sampling plots in (a) 2004, (b) 2005, (c) 2006, (d) 2007, and (e) the sum of the individuals collected in 2004-2007.

the context of environmental monitoring. Already Koivula (2011) mentioned that in varying conditions long-term sampling is required in order to define suitability of carabid species as indicators. The results of my study support this statement. Calculation of spatial autocorrelation can serve as an instrument in order to quantify and analyse appropriate datasets. Thus, despite posing a serious shortcoming for hypothesis testing and prediction in many kinds ecological studies (Dormann et al. 2007), spatial autocorrelation may be helpful in defining the indicatory value of a given species.

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