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Regional diversity of temporary wetland carabid beetle communities: a matter of landscape features or cultivation intensity?

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Abstract

The challenge of finding applicable indicators for sustainable agriculture requires evaluations at regional scales to lead to policy-relevant results. In this study, the regional diversity of temporary wetland carabid beetles was analysed for six landscapes of $10\,\mathrm{km}^2$ each. The relative importance of landscape features and cultivation intensity for the regional diversity was compared. Total species richness was correlated with the mean soil-indices that were used as indicators of cultivation intensity. This is consistent with studies on local scales, which emphasise the importance of cultivation intensity for arthropod communities. The diversity of wetland and habitat-specific species correlated with the temporary wetlands mean duration of flooding and the density of temporary wetlands, but apart from this, there was no impact of landscape features on diversity. These results do not corroborate concepts of using indices of landscape structure as biodiversity indicators, but the importance of cultivation intensity cannot be too strongly emphasised.

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1. Introduction

As a consequence of the Rio convention, biodiversity has been used as a means to assess landscape sustainability (Paoletti, 1999). On regional scales, interest was directed towards the mosaic structure of landscapes and its influence on biodiversity (Hansson et al., 1995). This has led to the mosaic concept, which predicts that species richness increases with habitat variability, i.e. the number of habitat types,

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and habitat heterogeneity, i.e. the number and proportional distribution of habitat patches with constant habitat variability (Duelli, 1997).

On local scales, the importance of cultivation intensity for arable land communities has been emphasised (review in Kromp, 1999). While our knowledge of animal and plant communities of arable fields has been continuously growing, we know little about the communities of the accompanying small within-field habitats, such as temporary wetlands. However, they contribute a substantial proportion to the biodiversity in agricultural landscapes. Hence, in this study the combined effects of landscape features and cultivation intensity on the regional diversity of temporary wetland carabid beetles are analysed. Due to the fact that total diversity is sometimes dubious in evaluating

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land-use, the diversity of obligate wetland species and habitat-specific species is also taken into account.

2. Materials and methods

The study was carried out in the agricultural landscape of north-eastern Germany (between 53°22′N, 13°34′E and 52°22′N, 14°15′E; Fig. 1). This younger pleistocene landscape is characterised by numerous types of potholes and temporary wetlands. Temporary wetlands are cultivated and typically produce crops in the driest years. During years of average or above-average precipitation, temporary wetlands retain water until spring or summer. In 1998, six landscapes of 10 km² each were chosen, and the fieldwork was carried out until 2000.

2.1. Landscape mosaic structure

The habitat types of the landscapes were classified into seven groups: small habitats (temporary wetlands, potholes) were recorded by their numbers and the main land-use types (meadows, arable land, forests, fallow land and marshland) by their surface area. All entities refer to the landscape area of $10 \, \mathrm{km}^2$. Landscape

diversity was calculated as the Shannon-Wiener diversity of the main land-use types:

$$H_S = -\sum_{j=1}^S p_j \log p_j,$$

where S represents the number of habitat types and p_j the proportion of habitat type j (Magurran, 1988). Landscape diversity and the densities of potholes and temporary wetlands represent habitat heterogeneity. Habitat variability (number of habitat types) was equal in all landscapes.

2.2. Cultivation intensity and mean duration of flooding

The cultivation intensity of the arable fields was indicated by the soil-indices (German: mittlere Bodenzahlen), which provide information about the productivity of the soils and indicate the potential yield. Furthermore, the soil productivity determines which crops can be grown on the fields. As the application of fertilisers and pesticides depend on crop type and potential yield, both applications correlate with the soil index. The soil-indices were determined for each arable field in the study areas and, subsequently, the

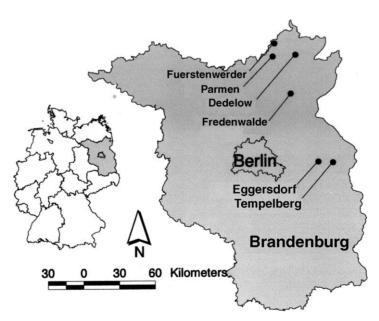


Fig. 1. Location of the landscapes studied in Brandenburg, Germany.

mean of the soil-indices was recorded for each of the landscapes studied.

From March to July 1998, the water-levels of the temporary wetlands were recorded. In the middle of each month, it was recorded for each temporary wetland in the landscapes studied whether it still contained flooded parts (Brose, 2001). The hydroperiods of the temporary wetlands ranged between 1 (drying up until mid-April) and 4 (drying up until mid-July). The mean of these hydroperiods was recorded as the mean duration of flooding in the landscapes.

2.3. Sampling design for carabid beetle diversity

In each landscape, six temporary wetlands were sampled with five pitfall traps on each site. The surface area of the temporary wetlands studied ranged between 50 and 2400 m² (mean = 926 + 568). Pitfall traps with a minimum separation distance of 4 m were installed from mid-April until mid-July, when harvesting and soil tillage began. To assess regional diversity, the catches were totalled within each landscape. Three variables of diversity were recorded: total species richness (all species), number of wetland species (Scheffler et al., 1999) and number of habitat-specific species (own classification based on comparisons with other agricultural habitats).

2.4. Data analysis

The data set met the assumptions of normality and linearity, and the independent variables were not correlated (Pearson's product moment correlation). Stepwise multiple regression analyses were performed with a significance level P of 0.05 for entering a variable into the model and a significance P of 0.1 to retain the variable.

3. Results

Total species richness of the landscapes studied ranged between 74 and 94 (see Table 1 for an overview of the results). There was a strong negative correlation between the mean soil-indices and total species richness (Fig. 2). However, there was no correlation between the mean soil-indices and the number of wetland and habitat-specific species, which were both positively correlated with the mean duration of flooding (Fig. 3). The results of the stepwise regression analyses are summarised in Table 2. The number of habitat-specific species also depended on the density of temporary wetlands. Apart from the density of temporary wetlands, no other landscape feature was correlated with the dependent variables.

Table 1
The study landscapes: mean soil-indices, mean duration of flooding (number of month after mid-March), landscape features and carabid beetle diversity^a

	Egg	Temp	Dedel	Parm	Fuerst	Fred
Mean soil-indices	32.33	39.29	52.65	45.99	46.90	45.02
Mean duration of flooding	2.64	2.15	3.11	2.71	2.30	3.00
Landscape diversity	0.16	0.14	0.24	0.22	0.55	0.44
Landscape features						
Density of potholes	45	42	23	17	61	27
Density of temporary wetlands	13	17	8	19	27	15
Marshland (ha)	3.44	4.56	64.04	12.35	51.98	80.67
Meadowland (ha)	19.87	11.39	33.58	110.38	133.11	49.07
Forest (ha)	54.77	28.58	38.63	14.76	160.46	112.76
Arable land (ha)	865.35	883.06	833.47	803.48	449.80	652.66
Fallow land (ha)	3.66	20.03	0.00	0.00	41.60	38.71
Regional diversity						
Total species richness	94	89	74	78	75	84
Wetland species	42	38	43	38	38	43
Habitat-specific species	11	9	12	11	10	12

^a The small habitat types were recorded by their numbers, the main land-use types by their surface area. Landscape diversity = Shannon-Wiener H_S of main land-use types. Study landscapes: Egg: Eggersdorf, Temp: Tempelberg, Dedel: Dedelow, Parm: Parmen, Fuerst: Fuerstenwerder, Fred: Fredenwalde.

Table 2 Results of the stepwise regression analyses

Dependent	Independent	r^2	Coefficient + S.E.	P	n
All species	Mean soil index	0.90	-1.10 + 0.19	**	6
Wetland species	Mean duration of flooding	0.681	5.82 + 2.0	*	6
Habitat-specific species	Mean duration of flooding	0.958	3.75 + 0.14	***	6
- •	Density of temporary wetlands	0.997	0.05 + 0.008		

^{*} P < 0.05.

^{***} P < 0.001.

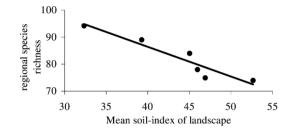


Fig. 2. The relationship between the mean soil-indices of the landscapes (indicators of land-use intensity) and the regional species richness of temporary wetlands' carabid beetle communities ($r^2 = 0.9$; P < 0.01, n = 6).

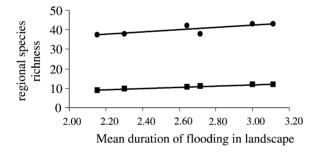


Fig. 3. The relationship between the mean duration of flooding (number of months after mid-March) in the landscapes and the regional species richness of temporary wetlands' wetland species (circles, $r^2 = 0.681$, P < 0.05, n = 6) or habitat-specific species (squares, $r^2 = 0.958$, P < 0.001, n = 6).

4. Discussion

The relationship between landscape features and regional diversity of carabid beetles was analysed. It has been hypothesised that heterogeneous landscapes have a higher regional diversity, because meta-community-dynamics lead to a faster recolonisation of vacant

niches (Duelli, 1997). Apart from the density of temporary wetlands, the studied landscape features did not have an impact on regional diversity, which contradicts the mosaic concept. However, communities of arable land are distinct from those of other habitats, primarily because the sites are ploughed. Therefore, recolonisation of vacant niches is unlikely for species that belong to more natural and unploughed habitats. Empirical studies on the consequences of different landscape structures have been largely restricted to the community responses at the spatial levels of habitats or plots of few square meters (Kareiva, 1987; Wiens et al., 1993; Hansson et al., 1995; Collinge and Forman, 1998; Thies and Tscharntke, 1999). In these studies, correspondence to landscape features has mainly been reported for flying arthropods. In a study that included flying as well as ground-inhabiting arthropods, Jeanneret et al. (2000) have documented varying effects of landscape features; while butterflies were affected, spider communities were not. As in the present study the regional diversity of carabid beetles did not respond to landscape heterogeneity, this pattern might be supported at a regional level. In conclusion, there are two explanations for this lack of relationship: (i) vacant niches at temporary wetlands are not recolonised by species of more natural habitats; (ii) landscape features are generally less important for ground-inhabiting organisms.

There was a strong impact of cultivation intensity—indicated by the mean soil-indices—on total species richness. This is in accordance with studies on local scales, where similar effects have been explained by application of pesticides and differences in the land-use systems (Büchs et al., 1997; Kromp, 1999). Surprisingly, cultivation intensity has not yet been included in studies on the landscape scale, a fact that might be due to problems of finding indicators on this

^{**} P < 0.01.

topic scale. The mean soil index provided a relative indicator, which is due to changes in production systems limited to concurrent comparisons of landscapes in the same region. Future research should lead to absolute indicators, which are transferable in space and time. However, the present study emphasises the importance of cultivation intensity as a key factor for regional diversity.

The diversity of wetland and habitat-specific species was strongly dependent on the mean duration of flooding. There might be two reasons: (i) a high attractiveness of landscapes with a high mean duration of flooding for potential immigrants (Duelli, 1997) and (ii) a generally high number of available niches for hygrophilous species in these landscapes.

5. Conclusion

The present study could not confirm the universal importance of landscape heterogeneity for species diversity, as predicted by the mosaic concept. Accordingly, the application of landscape heterogeneity as an indicator for sustainable land-use might be restricted to specific habitats or certain taxa. The regional diversity of carabid beetles was dependent on the mean soil-indices. However, future research is needed to create absolute parameters of cultivation intensity on the landscape scale, which may result in potential indicators for sustainable land-use. For the diversity of wetland and habitat-specific species, the mean duration of flooding was a strong predictor. This variable, which is easily accessible by aerial pictures, might be an indicator for sustainable land-use with respect to the carabid beetle communities of temporary wetlands.

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