Internat. Rev. Hydrobiol.	**91**	2006	4	326–340

DOI: 10.1002/iroh.200610888

Michael Gerisch*, [1], Arno Schanowski[2], Wolfgang Figura[3], Bernd Gerken[4], Frank Dziock[5] and Klaus Henle[1]

[1]Department of Conservation Biology, Centre for Environmental Research UFZ-Leipzig-Halle, Permoser Str. 15, D-04318 Leipzig, Germany; e-mail: Michael.Gerisch@ufz.de, Klaus.Henle@ufz.de
[2]Institut für Landschaftsökologie und Naturschutz (ILN) Bühl, Sandbachstraße 2, D-77815 Bühl; e-mail: Arno.Schanowski@ilnbuehl.de
[3]Ingenieurbüro Umwelt Institut Höxter, Gruppe Ökologie und Planung, Schlesische Straße 76, D-37671 Höxter; e-mail: Figura@uih.de
[4]University of Applied Sciences of Lippe und Höxter, Department of Environmental Planning and Management, Liebigstr. 87, D-32657 Lemgo; e-mail: Bernd.Gerken@fh-luh.de
[5]Technische Universität Berlin, Biodiversity Dynamics of Terrestrial Ecosystems, Rothenburgstr. 12, D-12165 Berlin, Germany; e-mail: Frank.Dziock@tu-berlin.de

Carabid Beetles (Coleoptera, Carabidae) as Indicators of Hydrological Site Conditions in Floodplain Grasslands

key words: bioindication, River Elbe

Abstract

The relationship of carabid beetle species occurrence patterns and environmental variables characterising the hydrological regime has been studied at the River Elbe in Central Germany. Both flood duration and groundwater depth had major influence on species assemblages as the ordination of study plots mainly followed a gradient along these two variables. The simultaneous ordination of the plots according to species occurrence and environmental parameters showed a highly significant joint structure with the first two axes of a co-inertia analysis, explaining >98% of the variance. A total of 27 species out of 129 caught fulfilled criteria of fidelity and specificity to the plots of the five clusters revealed by their abiotic conditions and were sufficiently abundant to be suitable indicators for one or a combination of clusters of plots.

1. Introduction

Natural features of European floodplains are the result of dynamic geomorphological processes that lead to a high habitat diversity of these ecosystems (Gerken, 1981; Gerken, 1992a; Ward, 1998; Wolfert *et al.*, 2001). Due to their heterogeneity in space (habitat mosaics) and time (habitat change), natural riverine landscapes are characterised by a highly adapted and diverse flora and fauna (Robinson *et al.*, 2002). However, in recent decades Central European floodplains were affected by a severe decline in biodiversity (Godreau *et al.*, 1999), due to loss of habitats (and thus species) mainly caused by changed water regimes and increased land use pressure on these ecosystems. Hence, floodplains are considered as landscapes with high conservation value and protection needs and have become a focus of conservation research (Foeckler and Bohle 1991; Gerken, 1992b; Amoros and Petts, 1993; Young, 2001; Jessel, 2005; Scholz *et al.*, 2005).

Floodplain management and conservation requires a sound understanding of species-environment relationships and suitable bioindicators to assess and monitor ecological conditions, since parameters characterising the hydrological regime are time consuming to measure and

* Corresponding author

 1434-2944/06/408-326

costly in terms of resources required (McGeoch, 1998; Dziock *et al.*, 2006). In floodplains, the hydrological regime is the key process determining patterns of occurrence in many taxonomic groups (e.g. Dziock, 2006; Foeckler *et al.*, 2006) including carabid beetles (Siepe, 1989; Bonn *et al.*, 2002); however, there can be other factors playing a major role (e.g. Hildebrandt *et al.*, 2005).

Since the ecology and taxonomy of many carabid beetle species is well-known, and as they can be surveyed easily and cost-efficiently, carabid beetles are potentially suitable bioindicators (Rainio and Niemelä, 2003). For these reasons they are frequently used for bioindication (in floodplains e.g. Gerken, 1981; Gerken *et al.*, 1991; Siepe, 1989; Nelles and Gerken, 1990; Greenwood *et al.*, 1991, 1995; Obrdlik and Schneider, 1994; Zulka, 1994; Dörfer *et al.*, 1995; Spang, 1996; Hugenschütt, 1997; Wohlgemuth-von Reiche *et al.,* 1997; Bonn *et al.*, 2002; Hanning and Drewenskus, 2005).

However, present investigations on the relationships between carabid species occurrence and environmental variables are mainly based on empirical and qualitative data and thus limited in power of expression. Several studies focused on the effect of the habitat type and the habitat structure on carabid beetles assemblages, but without using quantified environmental variables (e.g. Ings and Hartley, 1999; Weller and Ganzhorn, 2004; Aviron *et al.*, 2005).

This is especially true for floodplains, as several studies showed that the hydrological regime in floodplains is a main driver for species occurrence (e.g. Dörfer *et al.*, 1995; Bonn *et al.*, 2002; Guenther and Assmann, 2005), but scarcely validated with quantified environmental data. Metzner (2004) analysed the impact of flood dynamics on carabid species assemblages along 62 kilometres of the River Main in Germany, but could only use data from three gauges to explain these relationships. Wohlgemuth-von Reiche *et al.* (1997) divided their sampling plots into sub-plots as determined by the different hydrological conditions, based on a qualitative classification (non-flooded, seasonal flooded, uncontrolled flooding) in order to analyse the reaction of different arthropod groups to a flood event.

In consequence, there are a lot of open questions concerning occurrence patterns of species in floodplains and environmental variables, as it is uncertain which environmental parameters are most responsible for species. It is likely the case that several environmental variables responsible for species occurrence may be overseen in present bioindication analyses, because they were simply not recorded or used as qualitative data with high generalisation.

The purpose of this study is to match quantified hydrological parameters with carabid species occurrence and to define carabid indicator species for groups of plots with defined quantified hydrological conditions.

This study assesses whether carabid beetles can be used to group plots of similar hydrological conditions and tests whether the ‘environment-plot’ dataset and ‘species-plot’ dataset show a significant joint structure. As an innovative step, quantified environmental variables were used to match species occurrence with the hydrological conditions of the plots.

2. Methods

2.1. Field Data

The study was integrated in the project RIVA – “Development and Testing of a Robust Indicator System for Ecological Changes in Floodplain Systems” – carried out in floodplains of the Middle Elbe (Henle *et al.*, 2006; Foeckler *et al.*, 2006). In this contribution results from the study area “Schöneberger Wiesen” near the village Steckby (25 km West of Dessau), Saxony-Anhalt, Central Germany, are presented. The study area is part of the Elbe River Landscape Biosphere Reserve and can be characterised as seasonally flooded grassland with an intermediate intensity of use. For a detailed description of the study area and the characteristics of the Middle Elbe and its floodplains see Henle *et al.* (2006) and Scholz *et al.* (in press).

Within the study area 36 sampling plots have been established using a stratified randomized design. Site morphology and obvious vegetation types were used to delineate four strata: flood-channels, depressions and ditches, wet grassland, dry grassland close to the river, and dry grassland distant from the river. HENLE *et al*. (2006) give extensive details of the study design.

On each plot carabid beetles and environmental variables were sampled. Carabid beetles were caught using five pitfall traps per plot. The traps were filled with a 7% solution of acetic acid and a detergent to reduce surface tension. They were serviced fortnightly in the spring of the years 1998 and 1999 (end of April – end of June). This sampling period was chosen in order to reduce sampling effort but to maximise the number of species recorded (DUELLI *et al.*, 1999). However, we sampled carabid beetles during a whole vegetation period (end of April – end of October) but since analyses showed no significant seasonal differences in the correlation of species occurrence and environmental variables we present here only the results for the spring season.

Samples were sorted out and stored in an alloy of one third acetic acid and two thirds ethyl alcohol. All adult carabids were determined to species-level using the following references: FOLWACZNY (1959), FREUDE (1976), HIEKE (1970), LINDROTH (1985, 1986), SCHMIDT (1994), and TRAUTNER and GEIGENMÜLLER (1987).

2.2. Environmental Data

On each study plot hydrological variables, soil variables, chemical variables, and leaf litter variables were measured. These variables were augmented by landscape variables (distances to and area of habitats) and variables characterising the management of the area. In total, more than 300 environmental variables have been measured or derived from the data (RINK *et al.*, 2000; HENLE *et al.*, 2006). In order to reveal the variables with the highest biological importance for the presence/absence of species, the number of environmental variables had to be reduced carefully (VAUGHAN and ORMEROD, 2005). Within the RIVA project, this was achieved by pair-wise correlation analyses, principal component analysis, removal of invariant parameters, and by forward selection in a canonical correspondence analysis (RINK, 2003; HETTRICH and RINK, in press). Using this approach RINK (2003) identified those abiotic parameters that significantly explained the assemblages of carabid species. Since here we are interested in parameters that quantify characteristics of the hydrological regime, those five hydrological parameters that contributed most to the explanation of carabid species assemblages for further analyses, were selected (Table 1).

Table 1. Environmental variables used in this study.

Code	**Brief description**
DurIn	duration of inundation within the hydrological year (in days)
DistTemp	distance to closest temporary pool (in m)
DistPerm	distance to closest permanent pool (in m)
MnGW	mean groundwater depth during the vegetation period (from 01.04. to 30.09.) of a year (in cm), groundwater depth was measured fortnightly and during flood events daily or weekly with a water level contact meter from spring 1998 to spring 2000
SDWatLev	standard deviation of the water level of a year, i.e. difference between maximal groundwater depth and maximal flood height

2.3. Statistical Analyses

A three step analysis explores the relationships between species and their environment:

i. The ‘species-plot’ dataset was analysed with a between-plot correspondence analysis (CA) to ordinate the plots based on the occurrence of carabid beetles. In order to find groups of plots with similar environmental conditions, plots were clustered (Ward’s method, distance type: Euclidian) based on the results of the CA. The cluster analysis was verified by a discriminance analysis followed by a Monte-Carlo-permutation test to validate the identified cluster groups. CA was used in favour of the detrended version (DCA), because DCA lacks a convincing theoretical basis and does not perform desirably well in some situations (critique summarized in PALMER, 1993).

ii. The 'environment-plot' dataset was analysed with a principal component analysis (PCA) to ordinate the plots based on their environmental characteristics. PCA was used, because this method is much better suited for environmental data on a metric scale than CA.

iii. For revealing relationships between the occurrence of species and environmental parameters a co-inertia-analysis was conducted which allowed the detection and evaluation of a joint structure between these two matrices. The use of co-inertia analysis was proposed by DOLÉDEC and CHESSEL (1994) for the simultaneous detection of faunistic and environmental relationships when many species and several environmental variables are sampled in a number of plots. The results have been validated by permutation tests.

All multivariate calculations were carried out with the ADE-4 software package (THIOULOUSE *et al.*, 1997).

The spring-data of both sampling years were pooled, as a preliminary discriminance analysis based on a CA showed no significant differences between years but between plots (SCHANOWSKI *et al.*, in press).

2.4. Identification of Indicator Species

The suitability of carabid species as indicators for hydrological site conditions was assessed according to their fidelity and specificity to the clusters identified in the PCA as well as to their relative abundance. The method used in this study is therefore very similar to that proposed by DUFRÊNE and LEGENDRE (1997). We measured fidelity as the frequency of presence of a species within the plots allocated to a cluster. We measured specificity as the percentage occurrence within a cluster relative to total occurrence. As a measure of abundance, the percentage of individuals of a sample that belonged to a particular species was calculated. Relative abundances were grouped in six classes of "dominance activity" following the suggestion of ENGELMANN (1978).

Thresholds of >40% for specificity and >80% for fidelity were set to accept a species as a suitable indicator for a cluster of plots with similar hydrological conditions. In addition, only sufficiently common species, i.e. comprising at least 1% of the sample of the plots within a cluster, were considered.

Although any species, whether abundant or scarce, will contribute to ordination results, abundant species are usually mostly responsible for clustering plots with similar conditions. However, they can play an important role in more than one cluster, due to their wide ecological valence. While they are less relevant for a particular cluster they may still be suitable to indicate the hydrological conditions of a group of clusters. Thresholds of >60% for both specificity and fidelity were defined to declare a species as a suitable indicator for a group of clusters. Again, the species must comprise >1% of the individuals sampled in the group of clusters.

3. Results

3.1. Ordination of Sampling Plots Based on Carabid Beetle Occurrences

During the surveys in the sampling area "Schöneberger Wiesen" in spring of 1998 and 1999 altogether 44,986 individuals representing 129 species were caught and identified to species level.

The correspondence analysis (CA) of the 'species-plot' dataset revealed a strong gradient along the first two axes with an explained variability of 26.4% (F1: 19.1%, F2: 7.3%) (Fig. 1). The first axis represents moisture, as the plots located in flood channels or depressions can be found on the right side of the ordination plot (cluster 1 and 2) and are clearly separated from the more elevated and dry plots (cluster 3 and 4) on the left side of the figure. The corresponding ordination of the species responsible for clustering the plots is shown in Figure 2.

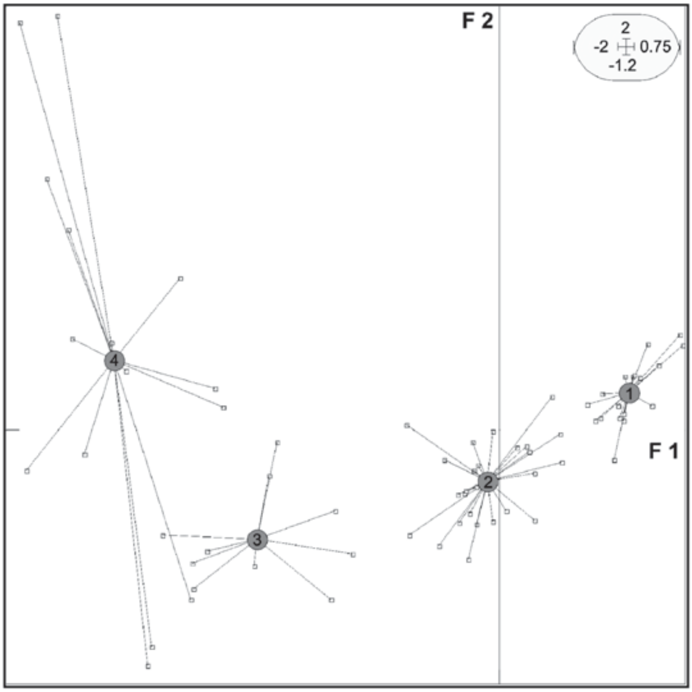

Figure 1. Ordination of sampling plots based on occurrence of carabid species using a correspondence analysis. The numbers correspond to the groups resulting from a cluster analysis.

Cluster 1 almost exclusively contains plots of deep flood channels (plots 1–7). Exceptions are plots 8 and 9 in 1999, which are located at a shallow edge of a temporary depression and plot 12, which is a flood channel as well but small and isolated. Additionally, this cluster contains two *Phalaris*-reed plots (30, 34). Plots within this cluster are characterised mainly by the carabid species *Agonum afrum*, *A. versutum*, *A. duftschmidi*, *Anthracus consputus*, *Bembidion biguttatum*, *Pterostichus gracilis,* and *Stenolophus mixtus* (Fig. 2).

Cluster 2 mainly consists of plots located in *Phalaris*-reed (plots 29–36) and at banks of shallow, isolated temporary flood channels. Furthermore, several plots are situated in a transition zone to meadows (13, 14, 16). Basically, five species are mainly responsible for this plot grouping: *Amara communis*, *Bembidion guttula*, *Clivina fossor*, *Epaphius secalis,* and *Pterostichus strenuus*.

Cluster 3 contains only a few plots in fresh and moist meadows, mainly characterised by *Amara lunicollis* and *Syntomus truncatellus*. These plots show intermediate moisture conditions and lead to the more elevated and dry plots of cluster 4, which are basically characterised by *Carabus auratus* as well as *Amara lunicollis* and *Syntomus truncatellus*.

3.2. Ordination of Plots Based on Environmental Variables

The sampling plots were classified using a PCA and a cluster analysis based on the five environmental variables given in Table 1 (Fig. 3). The first two axes of the PCA explained 67.5% of the total variance in the 'environment-plot' dataset (F1: 44.1%, F2: 23.4%). The

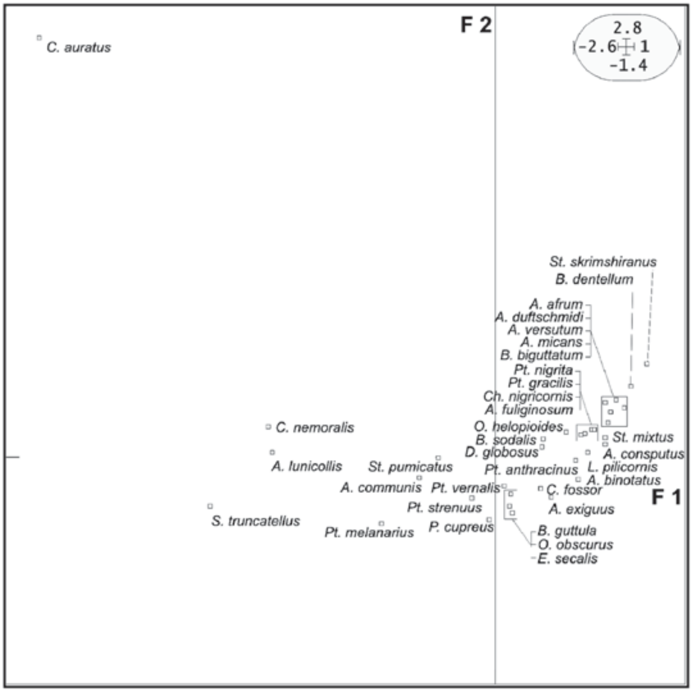

Figure 2. Ordination of the species responsible for clustering the plots using correspondence analysis.

first axis mainly represents the influence of flood duration and the distance to the closest temporary pool, whereas the second axis mainly reflects the distance to the closest permanent water body (Fig. 4).

Five clearly separated clusters of plots can be distinguished ($\alpha < 0{,}001$) that are aligned along two gradients: the flood duration decreases among the clusters, whereas the mean groundwater depth increases (Table 2).

3.3. Relationship between Carabid-Occurrence and Environmental Variables

In spite of the different numbers of clusters resulting from ordering the plots by species (see 3.1) or by environmental parameters (see 3.2), a joint structure between the two datasets is evident in a direct ordination of the plots simultaneously using occurrence of species and environmental parameters in a co-inertia analysis. The joint structure is highly significant (permutation tests: fixed D, fixed Table 1, fixed Table 2; $\alpha < 0.001$) visualised by the rather short distances between dots and arrowheads in Figure 5, in which the first two axes of the co-inertia explain 98.3% of the total variance.

3.4. Indicator Species

Indicator species for clusters of plots with similar abiotic conditions had to fulfil the criteria of specificity and fidelity to the clusters defined in the methods section and in addition had to reach a dominance of at least 1%. Table 3 lists all species that fulfilled these condi-

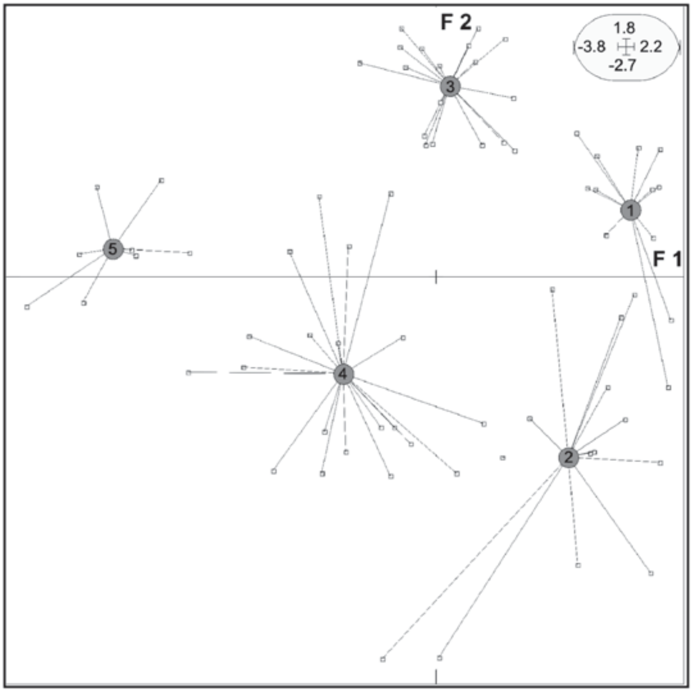

Figure 3. Ordination of the plots based on abiotic parameters using principle component analysis. The numbers correspond to the groups resulting from a cluster analysis.

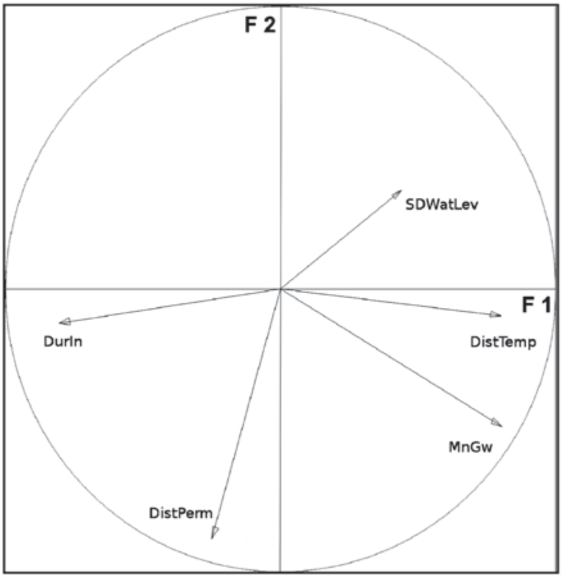

Figure 4. Correlation circle of the abiotic parameters for the first two axes (F1, F2) of the principle component analyses of the 'environment-plot' dataset (spring 1998).

Table 2. Mean values of the parameters "flood duration" and "mean groundwater depth" for the clusters of plots.

Description of clusters	Flood duration [months]	Mean groundwater depth [cm]
Cluster 1 – deep, coherent flood channels with long inundation	6	156
Cluster 2 – shallow, temporary pools with relative short inundation	5	200
Cluster 3 – *Phalaris* reeds with short and episodic inundation	1	170
Cluster 4 – plots in transition zone (moist and fresh meadows)	0.4	296
Cluster 5 – typical meadows (elevated, dryer meadows)	0.2	358

tions. The abiotic conditions in cluster 1, representing deep flood channels with a long inundation period, are best indicated by *Agonum duftschmidi*, *A. versutum*, *Bembidion dentellum,* and *Stenolophus skrimshiranus*. The species *Chlaenius nigricornis* and *Pterostichus nigrita* also mainly occurred in plots of cluster 1.

There is no clear evidence of a suitable indicator species for cluster 2 (shallow temporary flood channels). Only *Anisodactylus binotatus* is associated with these habitats, but without fulfilling the defined criteria for indicator species.

The species *Agonum afrum*, *A. fuliginosum*, *Pterostichus gracilis,* and *Oodes helopioides* appeared with a fidelity >60% in deep, coherent flood channels (cluster 1) as well as in *Phalaris* reeds (cluster 3), and thus can be considered as indicator species for both habitat types. Additionally, *Epaphius secalis* occurred only in these plots with a high dominance activity and showed fairly high fidelity and specificity to that habitat type (>60%).

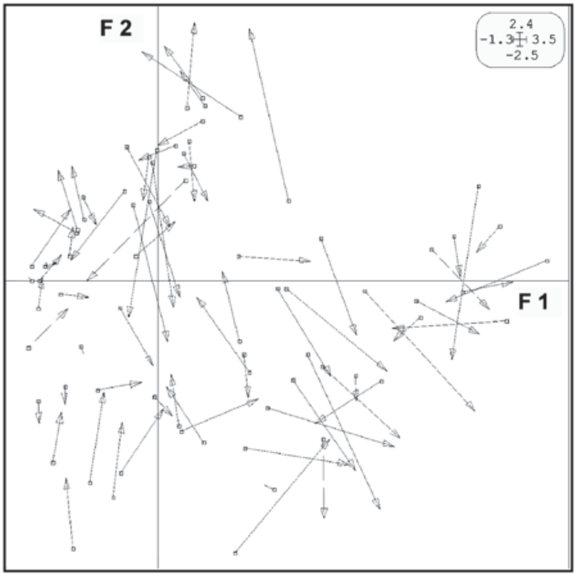

Figure 5. Ordination of plots based on environmental parameters and occurrence of species (co-inertia). Dots describe the ordination of the plots according to their environmental characteristics, whereas arrowheads show the ordination according to species occurrence.

Table 3. Dominance class (classes 3 to 5 based on ENGELMANN 1978) and fidelity (bold >80%; normal >60%) of the indicator species for the clusters of plots. Clustering of plots is based on abiotic parameters. Grey boxes: indicator species only for one cluster (specificity >40%, fidelity >80%); white boxes: Indicator species for a group of clusters (specificity and fidelity >60%). For the description of clusters see Table 2.

Species/ cluster	**1**	**2**	**3**	**4**	**5**
Stenolophus skrimshiranus	**3**				
Bembidion dentellum	**3**				
Agonum versutum	**3**				
Agonum duftschmidi	**4**				
Chlaenius nigricornis	**3**				
Pterostichus nigrita	**3**				
Anthracus consputus	**3**	**3**			
Stenolophus mixtus	**4**	**3**			
Anisodactylus binotatus		**3**			
Epaphius secalis			4		
Agonum fuliginosum	**4**		**3**		
Agonum afrum	**5**		**3**		
Oodes helopioides	**3**		3		
Pterostichus gracilis	**3**		3		
Poecilus cupreus		**4**	3		
Pterostichus vernalis		**3**	**3**		
Bembidion biguttatum	**5**	**3**	3		
Clivina fossor	**4**	**4**	**4**		
Acupalpus exiguus	**3**	**3**	**3**		
Pterostichus anthracinus	**3**	**3**	**3**		
Bembidion guttula	**3**	**3**	**4**		
Pterostichus strenuus	**3**	3	**4**	3	
Amara communis			**4**	4	**3**
Amara lunicollis		3		**4**	**4**
Syntomus truncatellus				4	**5**
Carabus nemoralis					**4**
Carabus auratus					5

Only a few indicator species were revealed for the intermediate meadows. The more dry and elevated plots (cluster 5) are characterised by *Carabus auratus,* whereas the species *Amara communis* and *A. lunicollis* indicate both, the conditions on fresh meadows (cluster 4) as well as those of the dry meadows representing cluster 5.

4. Discussion

In the past carabid beetles were mainly used for the assessment of habitat quality (e.g. MOSSAKOWSKI and PAJE, 1985; ARNDT and PELLMANN, 1996; BRÄUNICKE and TRAUTNER, 2002) or to assess the impact of habitat management/habitat change on species assemblages (e.g. GRANDCHAMP *et al.*, 2005; LATTY *et al.*, 2006), mainly for deriving conservation values or conservation strategies. They have been used scarcely as test organisms for correlating species occurrence with selected environmental parameters (e.g. IRMLER *et al.*, 2002; EYRE *et al.*, 2005). This study shows that carabids are also appropriate organisms for indicating quantifiable environmental variables (compare FOLLNER and HENLE, 2006).

In most common bioindication-studies only a few easy-to-assess variables, such as temperature or pH-value, have been measured – often without testing whether the variables are relevant for the species' occurrence patterns. Moreover, these data are often surveyed only once or in too coarse intervals, meaning that the temporal change of environmental variables and its impact on species assemblages cannot be correctly assessed.

This is especially true for bioindication in dynamic ecosystems like floodplains. In fact, GUTIÉRREZ *et al.* (2004) and BALLINGER *et al.* (2005) give detailed information about the study-site (habitat-type, vegetation structure, soil type etc.) but do not provide sound data on floodplain typical parameters, such as duration of inundation or groundwater depth. BONN *et al.* (1997) measured both flood height and duration but finally transformed these quantified data to qualitative data. Due to the use of mainly qualitative data (e.g. 'shortly inundated'), there is only limited power of expression to relationships between species and environmental parameters.

An assessment of the relationship between carabid species occurrences and quantified abiotic parameters has been conducted rarely, although its increasing importance during the last years is obvious. KLEINWÄCHTER *et al.* (2005) correlated soil grain size with species occurrence for revealing habitat preferences of carabid species. EYRE *et al.* (2005) derived climate and altitude variables from a climatology data base to detect relationships between the distribution of British carabid beetles and climatic and altitude parameters. VAN LOOY *et al.* (2005) also derived several hydrological indices (e.g. width: depth-ratio of the river, number of summer peaks) from a 10-year average daily discharge and matched these quantified (but derived) data with carabid species occurrence in order to define indicator species for different habitat types.

Nevertheless, there are methodical problems in deriving several environmental variables from only a few data. EYRE *et al.* (2005) recognise that problem as they only "… *assumed* that the values for each parameter were representative of the environment …" (p. 974, italicization ours).

In this study quantified and statistical significant environmental variables were used to reveal species-environment relationships. The results of the Co-Inertia-analysis show a strong relationship between both the flood duration and the groundwater depth and the occurrence of carabid beetles. These results are supported by FOECKLER *et al.* (2006) who assessed a strong relationship between mollusc occurrence and flood duration. DZIOCK (2006) revealed similar correlations, as the occurrence of syrphid species in floodplains can be mainly explained by groundwater depth.

Indicator species for different hydrological site conditions were found and hence, for both environmental variables (duration of inundation and groundwater depth). Plots characterised by a long flood duration were inhabited mainly by strictly hydrophilic species with high dispersal power, such as *Bembidion dentellum*, *Agonum duftschmidi*, and *Stenolophus skrimshiranus* (HUGENSCHÜTT, 1997), this power being essential for settling on sites that are prone to disturbances (e.g. flood events) and are available only for relative short periods of time (HERING and PLACHTER, 1997). GRUBE and BEYER (1997) and BONN *et al.* (1997) considered the species *Bembidion dentellum* and *Stenolophus skrimshiranus* as indicator species for wet conditions as well. However, they also possessed a very high specificity for inundated alluvial forests. MÜLLER *et al.* (2002) caught *B. dentellum* in softwood-forests and considered *St. skrimshiranus* and *A. duftschmidi* as typical species for alluvial forests.

Despite their medium habitat specificity and fidelity species such as *Amara communis*, *A. lunicollis, Pterostichus strenuus* and *Syntomus truncatellus* are still able to indicate environmental conditions in the transition zone from wet to dry habitats ('detector species', *sensu* MCGEOCH *et al.*, 2002). Although *Pt. strenuus* appeared in four of five clusters, its strong fidelity (>80%) to long inundated plots and to the relatively wet *Phalaris* reeds is obvious. This pattern of occurrence shows its 'detection power' from intermediate to wet conditions, with a preference for lightly wet conditions. In contrast, both *Amara* species occurred mainly in meadow plots with intermediate moisture. *A. communis* is associated with the moist plots, whereas *A. lunicollis* shows strong fidelity to the drier plots. Therefore, both species are suitable to indicate the transition from dry meadows to fresh meadows. BONN *et al.* (2002) recorded *A. communis* and *A. lunicollis* in several grasslands types as well, though the specificity of *A. communis* was high in dry meadows, whereas *A. lunicollis* had high specificity for wet meadows, which is contrary to the presented results. Additionally, and similar to this study, *Pt. strenuus* showed a high preference for wet plots, though it only appeared in alluvial forests. GÜNTHER and ASSMANN (2005) showed similar observations, as they considered *S. truncatellus* as non-hygrophilic associated with dry and open grasslands and *A. lunicollis* and *Pt. strenuus* as hydrophilic species associated with open grasslands.

The species *Carabus auratus* and *Carabus nemoralis* both show high specificity for the driest and less disturbed plots. This pattern of occurrence is supported by several studies (FAN *et al.*, 1993; BASEDOW, 2002; DORING and KROMP, 2003), showing that *C. auratus* is a typical species for dry meadows and fields with a relatively low disturbance regime. Although *C. nemoralis* is known for its preference for woodland habitats (LATTY *et al.*, 2006; WELLER and GANZHORN, 2004), this species can occur in several habitats, as long as they are at least lightly shaded and possess moist conditions. A likely reason for its specificity for the elevated meadows in the study plot can be seen in the relatively moist conditions prevailing in the spring.

Epaphius secalis is the only species that clearly separates the *Phalaris*-reed-plots from the surrounding meadow-plots with a high specificity for those habitats, expecting a true indicator species here. But due to a fidelity <80% in the whole cluster, it cannot be considered as an indicator species for a group of plots according to our definition. Nevertheless, this species is well known for its preference to swampy and lush plots (e.g. HUGENSCHÜTT, 1997; GIERS, 2003), although MÜLLER *et al.* (2002) found it only in woodland-habitats.

Although it depends upon the geographical region, several species can occur in different floodplain habitats, and we have to assume that the duration of inundation and the groundwater depth are the main responsible parameters for the occurrence of these species, as wet soil conditions in floodplains are related to inundation and groundwater depth. This likely implies that for the studied carabids in floodplain grasslands, hydrological parameters may be more important than habitat type.

We can assume the quality of our indication of hydrological site conditions as fairly precise, as we could assign selected species to clusters of plots with characteristic values of flood duration and groundwater depth. Indication worked fine especially in the long inundated plots (cluster 1), as we could reveal *Amara communis*, *A. lunicollis, Pterostichus strenuus,* and *Syntomus truncatellus* as species with high specificity and fidelity to plots with low groundwater depth and a long duration of inundation.

On the other hand we assessed *Carabus auratus* as a species with high specificity and fidelity to elevated meadow-plots and thus as a distinct indicator species for a high groundwater depth and relatively short duration of inundation, and thus low disturbance regime.

In contrast, intermediate hydrological conditions are more difficult to indicate by carabid species, as we revealed several species possessing low specificity to only one cluster but high specificity to several clusters. A likely reason for this limited indication power for one cluster is the wide niche breadth of those species, allowing them to cover a broad range of a gradient. Nevertheless, we showed that also several common species such as *Syntomus truncatellus* or *Pterostichus strenuus* still show preferences for certain hydrological conditions and can thus be used for revealing gradients of environmental variables.

We showed that carabid assemblages can serve as efficient indicators of water conditions of floodplain grassland habitats. For this reason, and because carabids are quick and cheap to collect, these insects can be used in environmental follow-up studies on habitat quality and changes, and as tools for landscape and conservation planners. Moreover, carabids may prove useful for the implementation of international environmental regulations, such as the EU Habitat and Water Framework Directives.

5. Acknowledgements

We gratefully thank the numerous technical assistants and trainees helping us in the collecting and sorting of carabid beetles. Additionally, we thank two anonymous referees for their constructive comments, MEIKE KLEINWÄCHTER for giving references and the Federal Ministry of Education and Research (bmbf) for financial support (reference number: 0339579).

6. References

AMOROS, C. and G. E. PETTS, 1993: Hydrosystemes fluviaux. – Collection d'Ecologie **24**.

ARNDT, E. and H. PELLMANN, 1996: Ökologische Charakterisierung von Biotopen im urbanen Raum am Beispiel von Modelltiergruppen. Final report of the research project Naturnahe Biotope im urbanen Raum und ihre Vernetzung. – UFZ-Bericht **6**.

AVIRON, S., F. BUREL, J. BAUDRY and N. SCHERMANN, 2005: Carabid assemblages in agricultural landscapes: impacts of habitat features, landscape context at different spatial scales and farming intensity. – Agric. Ecosyst. Environ. **108**: 205–217.

BALLINGER, A., R. M. NELLY and P. S. LAKE, 2005: Immediate and longer-term effects of managed flooding on floodplain invertebrate assemblages in south-eastern Australia: generation and maintenance of a mosaic landscape. – Freshw. Biol. **50**: 1190–1205.

BASEDOW, T., 2002: Changes in agriculture in an area in Northern Germany between the years 1971 and 2000, and the reactions of populations of predatory carabids (Col., Carabidae), of other predators, and of cereal aphids, to these changes. – J. Plant Dis. **109**: 1–14.

BONN, A., K. HAGEN and B. HELLING, 1997: Einfluss des Überschwemmungsregimes auf die Laufkäfer- und Spinnengemeinschaften in Uferbereichen der Mittleren Elbe und Weser. – *In*: HANDKE, K. and J. HILDEBRANDT (eds.). Einfluss von Vernässung und Überstauung auf Wirbellose: Referate und Ergebnisse eines Workshops. – Arbeitsber..Landschaftsoekol. Muenster **18**: 177–191.

BONN, A., K. HAGEN and D. WOHLGEMUTH-VON REICHE, 2002: The significance of flood regimes for carabid beetle and spider communities in riparian habitats – a comparison of three major rivers in Germany. – River Res. Applic. **18**: 43–64.

BRÄUNICKE, M. and J. TRAUTNER, 2002: Die Laufkäfer der Bodenseeufer: Indikatoren für naturschutzfachliche Bedeutung und Entwicklungsziele. – Bristol-series **9**, Haupt Publishing.

DÖRFER, K., M. BUSCHMANN and B. GERKEN, 1995: Carabidengemeinschaften (Coleoptera, Carabidae) im Einflussbereich wechselnder Wasserstände an der Oberweser. – *In:* GERKEN, B. and M. SCHIRMER (eds.). Die Weser. – Limnologie aktuell **6**: 191–212.

DOLÉDEC, S. and D. CHESSEL, 1994: Co-inertia analysis: an alternative method for studying species-environment relationships. – Freshw. Biol. **31**: 277–294.

DORING, T. F. and B. KROMP, 2003: Which carabid species benefit from organic agriculture? – A review of comparative studies in winter cereals from Germany and Switzerland. – Agr. Ecosys. Envir. **98**: 153–161.

DUELLI, P., M. K. OBRIST and D. R. SCHMATZ, 1999: Biodiversity evaluation in agricultural landscapes: above-ground insects. – Agric. Ecosyst. Environ. **74**: 33–64.

DUFRÊNE, M. and P. LEGENDRE, 1997: Species assemblages and indicator species: the need for a flexible asymmetrical approach. – Ecol. Monogr. **67**: 345–366.

DZIOCK, F., 2006: Life-history data in bioindication procedures, using the example of hoverflies (Diptera, Syrphidae) in the Elbe floodplain. – Internat. Rev. Hydrobiol. **91**: 341–363.

DZIOCK, F., K. HENLE, F. FOECKLER, K. FOLLNER and M. SCHOLZ, 2006: Biological indicator systems in floodplains – a review. – Internat. Rev. Hydrobiol. **91**: 271–291.

ENGELMANN, H.-D., 1978: Zur Dominanzklassifizierung von Bodenarthropoden. – Pedobiologia **18**: 378–380.

EYRE, M. D., S. P. RUSHTON, M. L. LUFF and M.G. TELFER, 2005: Investigating the relationships between the distribution of British ground beetle species (Coleoptera, Carabidae) and temperature, precipitation and altitude. – J. Biogeogr. **32**: 973–983.

FAN, Y. Q., M. LIEBMAN, E. GRODEN and A. R. ALFORD, 1993: Abundance of carabid beetles and other ground-dwelling arthropods in conventional versus low-input bean cropping systems. – Agr. Ecosys. Environ. **43**: 127–139.

FOECKLER, F. and H. BOHLE, 1991: Fließgewässer und ihre Auen – prädestinierte Standorte ökologischer und naturschutzfachlicher Grundlagenforschung. – *In*: HENLE, K. and G. KAULE (eds.). Arten- und Biotopschutzforschung für Deutschland. – Berichte aus der ökologischen Forschung Bd. **4**: 236–266.

FOECKLER, F., O. DEICHNER, H. SCHMIDT and E. CASTELLA, 2006: Suitability of molluscs as bioindicators for meadow- and flood channels of the Elbe-floodplains. – Internat. Rev. Hydrobiol. **91**: 314–325.

FOECKLER, F., F. DZIOCK, M. SCHOLZ, S. STAB and K. HENLE (eds.), in press: Entwicklung von Indikationssystemen am Beispiel der Elbaue. – Ulmer Verlag, Stuttgart.

FOLLNER, K. and K. HENLE, 2006: The performance of plants, molluscs, and carabid beetles as indicators of hydrological conditions in floodplain grasslands. – Internat. Rev. Hydrobiol. **91**: 364–379.

FOLWACZNY, B., 1959: Bestimmungstabelle der Arten der Untergattung *Acupalpus* s. str.- Ent. Bl. **55**: 175 – 186.

FREUDE, H., 1976: Adephaga 1: Familie Carabidae (Laufkäfer). – *In*: FREUDE, H., K. W. HARDE and G. A. LOHSE: Die Käfer Mitteleuropas 2, Goecke u. Evers Verlag.

GERKEN, B., 1981: Zum Einfluß periodischer Überflutungen auf bodenlebende Coleopteren in Auwäldern am Südlichen Oberrhein. – Mitt. dtsch. Ges. allg. angew. Ent. **3**: 130–134.

GERKEN, B., K. DÖRFER, M. BUSCHMAMN, S. KAMPS-SCHWOB, J. BERTHELMANN and D. GERTENBACH, 1991: Composition and distribution of Carabid-communities along rivers and ponds in the region of Upper Weser (NW/NDS/FRG) – with respect to protection and management of a floodplain ecosystem. – Regulated Rivers **6**: 313–321.

GERKEN, B., 1992a: Fluss- und Stromauen als Ökosysteme – Standortcharakteristika, Lebensgemeinschaften und Sicherungserfordernisse. – *In:* Naturschutz im Elbegebiet. Ber. Landesamt Umweltschutz Sachsen-Anhalt **5**: 2–11.

GERKEN, B., 1992b: La grande plaine germano-polonaise. Plaines, plateaux et collines franco-germaniques. – *In:* BLANDIN, P. (ed.). La Nature en Europe. – Paris, Bordas. pp. 150–157, pp. 176–185.

GIERS, A., 2003: Prognose und Bewertung der ökologischen Folgen wasserbaulicher Maßnahmen am Beispiel einer Talsperrenplanung im Hochsauerland. – PhD-thesis, University Bochum.

GODREAU, V., G. BORNETTE, B. FROCHOT, C. AMOROS, E. CASTELLA, B. OERLI, F. CHAMBAUD, D. OBERTI and E. CRANEY, 1999: Biodiversity in the floodplain of Saône: a global approach. – Biodiv. Conserv. **8**: 839–864.

GRANDCHAMP, A. C., A. BERGAMINI, S. STOFER, J. NIEMELÄ, P. DUELLI and C. SCHEIDEGGER, 2005: The influence of grassland management on ground beetles (Carabidae, Coleoptera) in Swiss montane meadows. – Agr. Ecosyst. Environ. **110**: 307–317.

GREENWOOD, M. T., M. A. BICKERTON, E. CASTELLA, A. R. LARGE and G.E. PETTS, 1991: The use of Coleoptera (Arthropoda: Insecta) for floodplain characterization on the river Trent, U.K. – Regulated Rivers **6**: 321–332.

GREENWOOD, M. T., M. A. BICKERTON and G. E. PETTS, 1995: Floodplain Coleoptera distributions: River Trent, U.K. – Arch. Hydrobiol. (Suppl. 101) Large Rivers **9**: 427–437.

GRUBE, R. and W. BEYER, 1997: Einfluss eines naturnahen Überflutungsregimes auf die räumlich-zeitliche Dynamik der Spinnen- und Laufkäferfauna am Beispiel des Deichvorlandes der Unteren Oder. – *In:* HANDKE, K and J. HILDEBRANDT (eds.). Einfluss von Vernässung und Überstauung auf Wirbellose: Referate und Ergebnisse eines Workshops. – Arbeitsber. Landschaftsoekol. Muenster **18**: 209–226.

GUENTHER, J. and T. ASSMANN, 2005: Restoration ecology meets carabidology: effects of floodplain restitution on ground beetles (Coleoptera, Carabidae). – Biodivers. Conserv. **14**: 1583–1606.

GUTIÉRREZ, D., R. MENÉNDEZ and M. MÉNDEZ, 2004: Habitat-based conservation priorities for carabid beetles within the Picos de Europa National Park, northern Spain. – Biol. Conserv. **115**: 379–393.

HANNING, K. and J. DREWENSKUS, 2005: Charakterisierung redynamisierter Flussabschnitte an der Mittleren Ruhr anhand ihrer Laufkäferzönosen. – Hydrologie und Wasserbewirtschaftung **49**: 110–117.

HENLE, K., F. DZIOCK, F. FOECKLER, K. FOLLNER, V. HUESING, A. HETTRICH, M. RINK, S. STAB and M. SCHOLZ, 2006: Study design for assessing species environment relationships and developing indicator systems for ecological changes in flood plains – the approach of the RIVA project. – Internat. Rev. Hydrobiol. **91**: 292–313.

HERING, D. and H. PLACHTER, 1997: Riparian Ground Beetles (Carabidae) preying on aquatic invertebrates: a feeding strategy in alpine floodplains. – Oecologia **111**: 261–270.

HETTRICH, A. and M. RINK, in press: 7.1 Steuerfaktoren und ökologische Muster im Auengrünland des RIVA-Projektes. – *In*: FOECKLER, F., HENLE, K., DZIOCK, F., SCHOLZ, M. and S. STAB (eds.): Entwicklung von Indikationssystemen am Beispiel der Elbaue. – Ulmer Verlag, Stuttgart.

HIEKE, F., 1970: Die paläarktischen *Amara*-Arten des Subgenus Zezea CSIKI (Carabidae, Coleoptera). – Dtsch. Ent. Z., N.F. **17, I – III**: 119–214.

HILDEBRANDT, J., I. LEYER, F. DZIOCK, P. FISCHER and F. FOECKLER, 2005: 5.5 Auengrünland. – *In*: SCHOLZ, M., S. STAB, F. DZIOCK and K. HENLE (eds.). Lebensräume der Elbe und ihrer Auen; Vol. 4 of the series: Konzepte für die nachhaltige Entwicklung einer Flusslandschaft. Weißensee Verlag, Berlin: pp. 234–264.

HUGENSCHÜTT, V., 1997: Bioindikationsanalyse von Uferzonationskomplexen der Spinnen- und Laufkäfergemeinschaften (Arach.: Araneida, Col.: Carabidae) an Fließgewässern des Drachenfelser Ländchens. – Arch. Zool. Publ. **2**.

INGS, T. C. and S. E. HARTLEY, 1999: The effect of habitat structure on carabid communities during the regeneration of a native Scottish forest. – Forest Ecol. Manag. **119**: 123–136.

IRMLER, U., K. HELLER and H. MEYER, 2002: Zonation of ground beetles (Coleoptera: Carabidae) and spiders (Araneida) in salt marshes at the North and the Baltic Sea and the impact of the predicted sea level increase. – Biodiv. Conserv. **11**: 1129–1147.

JESSEL, B., 2005: Der Umgang mit den Auen – ein Prüfstein für die Umsetzung der Wasserrahmenrichtlinie. – *In:* Bundesverband Beruflicher Naturschutz BBN: Neue Horizonte – Zukunftsaufgabe Naturschutz. – Jb. Natursch. Landschaftspfl. **55**: 101–108.

KLEINWÄCHTER, M., T. O. EGGERS, M. HENNING, A. ANLAUF, B. HENTSCHEL and O. LARINK, 2005: Distribution patterns of terrestrial and aquatic invertebrates influenced by different groyne forms along the River Elbe (Germany). – Arch. Hydrobiol. **155**: 319–338.

LATTY, E. F., S. M. WERNER, D. J. MLADENOFF, K. F. RAFFA and T. A. SICKLEY, 2006: Response of ground beetle (Carabidae) assemblages to logging history in northern hardwood-hemlock forests. – Forest Ecol. Manag. **222**: 335–347.

LINDROTH, C. H., 1985: The Carabidae (Coleoptera) of Fennoscandia and Denmark. – Fauna Ent. Scand. **15**: 1–233.

LINDROTH, C. H., 1986: The Carabidae (Coleoptera) of Fennoscandia and Denmark. – Fauna Ent. Scand. **15**: 233–497.

MCGEOCH, M. A., 1998: The selection, testing and application of terrestrial insects as bioindicators. – Biol. Rev. **73**: 181–201.

MCGEOCH, M. A., B. J. VAN RENSBURG and A. BOTES, 2002: The verification and application of bioindicators: a case study of dung beetles in a savanna ecosystem. – J. Appl. Ecol. **39**: 661–672.

METZNER, J., 2004: Dynamische Fließgewässerprozesse am Main und ihre Auswirkungen auf Laufkäferzönosen (Coleoptera, Carabidae). – PhD-thesis, Bayreuther Forum Ökologie **104**, Universität Bayreuth – Institut fuer Terrestrische Oekosystemforschung.

MOSSAKOWSKI, D. and F. PAJE, 1985: Ein Bewertungsverfahren von Raumeinheiten an Hand der Carabidenbestände. – Verh. Ges. Ökol. **13**: 747–750.

MÜLLER, S., J. KALZ-KAPROLAT, U. GRAEFE, A. BEYLICH and H. WILKENS, 2002: Teilprojekt 5: Zoologie – Folgenabschätzung von Auwaldbegründung und Deichrückverlegung auf Biozönosen der Lenzener Elbtalaue mit Hilfe faunistischer Indikatoren. – *In*: NEUSCHULTZ, F., J. PURPS and M. HAPE (eds.). Möglichkeiten und Grenzen der Auenwaldentwicklung und Auenregeneration am Beispiel von Naturschutzgroßprojekten an der Unteren Mittelelbe (Brandenburg). Abschlussbericht des BMBF-Forschungsvorhaben, FKZ 0339517, Landesanstalt für Großschutzgebiete. http://elise.bafg.de/?3819.

NELLES, U. and B. GERKEN, 1990: Zur Carabidenfauna (Coleoptera: Carabidae) einer südfranzösischen Auenlandschaft – zönologische Charakterisierung hochflut-geprägter Standorte und ihre aktuelle Gefährdung. – Acta Bio. Benrodis **2**: 39–56.

OBRDLIK, P. and E. SCHNEIDER, 1994: Analysis of Molluscs and Carabid communities. – Proceedings of the 4th workshop “Funktional Analysis of European Wetland Ecosystems”, EC-STEP project 0084-CT90. Miraflores de la Sierra.

PALMER, M. W., 1993: Putting things in even better order: the advantages of canonical correspondence analysis. – Ecology **74**: 2215–2230.
RAINIO, J. and J. NIEMELÄ, 2003: Ground beetles (Coleoptera: Carabidae) as bioindicators. – Biodiv. Conserv. **12**: 487–506.
RINK, M., K. HENLE and S. STAB, 2000: Zur Erstellung einer fachlich-statistisch abgestimmten Datenerhebungsstrategie am Beispiel eines synökologisch orientierten Forschungsprojektes in den Elbauen. – Hydrologie und Wasserbewirtschaftung **44**: 184–190.
RINK, M., 2003: Ordinationsverfahren zur Strukturanalyse ökosystemarer Feldinformation und Lebensraumeignungsmodelle für ausgewählte Arten der Elbauen. – UFZ-Berichte **8/2003**: 1–256.
ROBINSON, T. K., K. TOCKNER and J. V. WARD, 2002: The fauna of dynamic Riverine landscapes. – Freshw. Biol. **47**: 661–677.
SCHANOWSKI, A., W. FIGURA and B. GERKEN, in press: 6.3 Laufkäfer als Indikatoren. – *In*: FOECKLER, F., F. DZIOCK, M. SCHOLZ, S. STAB and K. HENLE (eds.). Entwicklung von Indikationssystemen am Beispiel der Elbaue. – Ulmer Verlag, Stuttgart.
SCHMIDT, J., 1994: Revision der mit *Agonum* (s.str.) *viduum* (PANZER, 1797) verwandten Arten (Coleoptera, Carabidae). – Beitr. Ent. **44**: 3–51.
SCHOLZ, M., S. STAB, F. DZIOCK and K. HENLE, 2005: Lebensräume der Elbe und ihrer Auen. – Vol. 4 of the series „Konzepte für die nachhaltige Entwicklung einer Flusslandschaft“, Weißensee Verlag, Ökologie, Berlin.
SCHOLZ, M., U. AMARELL, R. BÖHNKE, J. RINKLEBE, J. GLÄSER and S. STAB, in press: 4.2 Charakterisierung der Untersuchungsgebiete. – *In*: FOECKLER, F., F. DZIOCK, M. SCHOLZ, S. STAB and K. HENLE (eds). Entwicklung von Indikationssystemen am Beispiel der Elbaue. – Ulmer Verlag, Stuttgart.
SIEPE, A., 1989: Untersuchungen zur Besiedlung einer Auen-Catena am südlichen Oberrhein durch Laufkäfer (Coleoptera: Carabidae) unter besonderer Berücksichtigung der Einflüsse des Flutgeschehens. – PhD-thesis, University Freiburg.
SPANG, W., 1996: Die Eignung von Regenwürmern (Lumbricidae), Schnecken (Gastropoda) und Laufkäfern (Carabidae) als Indikatoren für auentypische Standortbedingungen. – Heidelberg. Geograph. Arb. **102**.
THIOULOUSE, J., D. CHESSEL, S. DOLÉDEC and J.-M. Olivier, 1997: ADE-4: a multivariate analysis and graphical display software. – Statistics and Computing **7**: 75–83.
TRAUTNER, J. and K. GEIGENMÜLLER, 1987: Sandlaufkäfer Laufkäfer. Illustrierter Schlüssel zu den Cicindeliden und Carabiden Europas. – Josef Margraf Verlag, Aichtal.
VAN LOOY, K., S. VANACKER, H. JOCHEMS, G. DE BLUST and M. DUFRENE, 2005: Ground beetle habitat templets and riverbank integrity. – River Res. Appl. **21**: 1133–1146.
VAUGHAN, I. P. and S. J. ORMEROD, 2005: Increasing the value of principal components analysis for simplifying ecological data: a case study with rivers and river birds. – J. Appl. Ecol. **42**: 487–497.
WARD, J. V., 1998: Riverine landscapes: biodiversity patterns, disturbance regime and aquatic conservation. – Biol. Conserv. **83**: 269–278.
WELLER, B. and J. U. GANZHORN, 2004: Carabid beetle community composition, body size, and fluctuating asymmetry along an urban-rural gradient. – Basic Appl. Ecol. **5**: 193–201.
WOHLGEMUTH-VON REICHE, D., A. GRIEGEL and G. WEIGMANN, 1997: Reaktion terrestrischer Arthropodengruppen auf Überflutungen der Aue im Nationalpark Unteres Odertal. – Arbeitsber. Landschaftsökol. Münster **18**: 193–207.
WOLFERT, H., P. HOMMEL, A. PRINS and M. H. STAM, 2001: The formation of natural levees as a disturbance process significant to the conservation of riverine pastures. – Landsc. Ecol. **17** (Suppl. 1): 47–57.
YOUNG, W. J., 2001: Rivers as Ecological Systems. The Murray-Darling Basin. Murray Darling Basin Commission, Canberra.
ZULKA, K. P., 1994: Carabids in a Central European floodplain: species distribution and survival during inundations. – *In*: DESENDER, K., M. DUFRENE, M. LOREAU, M.L. LUFF and J. P. MAELFAIT (eds.). Carabid Beetles: Ecology and Evolution. Kluwer Aca. Pupl., Dordrecht: pp. 399 – 405.

Manuscript received March 21st, 2006; revised April 28th, 2006; accepted May 11th, 2006

