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Novel energy crops: an opportunity to enhance the biodiversity of arthropod assemblages in biomass feedstock cultures?

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ABSTRACT

Novel crops for energy production are perceived as a promising option for promoting biodiversity in agrarian landscapes. The biodiversity effects of three novel energy crops on the composition of the carabid beetle and arachnid assemblages at two sites in Northeast Germany were investigated and compared to maize. Species diversity was calculated using different diversity indices to illustrate three aspects of biodiversity: infrequency, heterogeneity, and the dominance structure of the species composition. We also calculated the diversity of habitat preferences of these two animal groups. The number of species and the biodiversity were highest in energy crops and lowest in maize. The vegetation structure explained >50% of the variance in species data. We concluded that the biodiversity effects of the novel energy plants can be attributed to the increased complexity of the vegetation structure. The investigations confirmed that the novel energy plants can contribute substantially to enhance the biodiversity of invertebrate assemblages in biomass feedstock cultures.

Introduction

The increased cultivation of energy plants in recent years is generally assumed to involve decreased biodiversity in the agrarian landscape (Pereira et al. 2010; Robertson et al. 2012). Tscharntke et al. (2005) state that the intensification of land use has led to a worldwide decline in biodiversity. However, the European Union (EU) directive for promoting energy production from alternative resources sets the goal that in the EU, 20% of total energy consumption should be provided by renewable energy by 2020 (EU 2009). Pedroli et al. (2013) concluded from the literature and case studies performed in six EU countries that this directive will lead to an increased conversion of pristine areas into arable fields for energy cropping and the planting of monocultures and may consequently result in a significant decrease in biodiversity. Recent studies proved that the loss of species richness impairs ecosystem functions, e.g. freshwater nutrient cycling (McIntyre et al. 2007).

Opponents of bioenergy cropping complain about the accompanying increasing monocultures associated with maize and winter oilseed rape (Brassica napus L.) cultivation, the increasing use of pesticides, soil degradation, and the reduction in fauna and flora (Karpenstein-Machan 2013). Because of its high yield, maize is currently the crop most frequently grown for biogas production (DBFZ 2012). Moreover, it is the second most cultivated crop plant in Germany (DMK 2014). The cultivation area of maize in Germany increased from approximately 56,000 ha in 1960 to 2.57 M. ha in 2014 ([DMK] Deutsches Maiskomitee 2014). This biased and regionally unbalanced increase in maize cropping has resulted in skepticism from the public toward energy cropping as being potentially competitive to food production. Moreover, the cropping of maize requires an intensive use of pesticides (Altieri 1999). In a study of the impact of Bt-maize on arthropod predators in Spain, Poza et al. (2005) found that the Anthocoridae were reduced temporarily, but no effect was detected for other arthropod predators. In another study on the impact of conventional and Bt-maize on mainly predatory arthropods, Farinós et al. (2008) found a reduction in species richness of rove beetles in maize treated with the neonicotinoid imidacloprid. It remains open whether intensive pesticide spraying affects herbivores that are active on maize plants. Herbivorous arthropods have great importance as prey items for predators (ants, spiders, and birds) and hosts for parasitoids (Büchs 2003). Köhler (1998) emphasizes that the number of individuals of herbivorous species increases when more extensive management (no herbicides and no fertilizers) is performed.

However, energy cropping offers numerous chances for increasing biodiversity, e.g. growing in mixed cultures with other crops, the combination with crops for food production within crop rotations, and the use of perennial cultures or short-rotation coppices (SRCs) (Karpenstein-Machan 2013). Tilman et al. (2009) stressed that the positive effects of energy cropping,
Recent years have observed support for the cropping of alternative, novel energy plants that combine rather high methane yields with properties that will enhance biodiversity (Dieter 2014). Karpenstein-Machan (2013) proposed integrative cultivation concepts for food, fodder, and wildlife. Following these concepts, annual crops for food, feed, and energy are cultivated in a conventional way. The crops are rotated within a period of at least 3 years with the objective of maximum yields. The fields of annual crops are framed by wildflower strips that are not sprayed with pesticides. These wildflower strips would increase the biodiversity of flora and fauna and should reduce pesticide use on the commercial crops. Furthermore, the flowers can be harvested and digested in a biogas plant or remain as straw in the strips. The mixtures of maize, winter triticale, and winter rye as crops for energy production are integrated into the food and fodder crop rotation. An integration of novel energy plants into this crop rotation is also conceivable. One of these novel energy plants is the cup plant (Silphium perfoliatum L.). It is a perennial plant with high yield and may grow for up to 15 years at the same site. Thus, annual plowing may be omitted, and the use of pesticides is limited to the year of planting. The flowering time lasts from the middle of June to the end of August, a period when honeybees usually do not find enough nectar. Another novel energy crop is the very richly structured Szarvasi grass (SZ).

Currently, only a few empirical results on the impact of novel energy plants on biodiversity have been published (Pedroli et al. 2013; Emmerling 2014; Meyer et al. 2014); moreover, the effect on the biodiversity of carabid beetles and arachnids has been sparsely investigated.

Within a research project of the University of Trier, the soil ecological impacts of novel energy plants (cup plant, SZ, and wildflower mixture [WI]) have been investigated and compared to maize since 2011 (Felten & Emmerling 2011). The initial results showed that in soils cropped with novel energy plants, the content of microbial biomass increased by 30–50% compared to maize cultures. Moreover, significantly more species and individuals of earthworms occurred compared to maize (Felten & Emmerling 2011; Emmerling 2014). To date, only Pedroli et al. (2013) and Meyer et al. (2014) provide empirical results for the effects of novel energy plants on biodiversity. Incentive schemes for the cropping of novel energy plants are mostly based on expert opinions about the biodiversity effects of different alternative crops (e.g., substance classes for application).

The potential of novel energy plants for the promotion of biodiversity was investigated in the framework of the joint research project ‘Development and Comparison of Optimized Cultivation Systems for the Agricultural Production of Energy Crops under Different Site Conditions in Germany’ (EVA, Phase III) (FNR 2015) in a 2-year field study in two different cultivation regions in Germany. In 2013 and 2014, two fields at the sites Ostprignitz-Ruppin (OPR) and ‘Uckermark’ (UCK) were investigated, and the novel energy plants cup plant (SI), SZ, and a WI were cultivated in each case. On the fourth field, silage maize (SM) was examined as a reference crop. In this paper, the results from 2013 are presented. The investigations in the two regions were not designed as replicates but as a comparison of the effects of novel energy crops on both animal groups under different climates and soil conditions. The aim of these investigations was to determine whether biodiversity (species and habitat preference diversity) of the carabid beetle and arachnid assemblages was significantly higher in the fields cropped with novel energy plants than in fields of SM. We introduced formulae for calculating habitat preference diversity based on the established indices α, Shannon-Wiener, Evenness, and reciprocal Simpson. These indices allow a general view of the structural composition of carabid beetle and arachnid assemblages. The assessment of habitat preference diversity is based on the assumption that the number of species with different habitat preferences is positively correlated with vegetation structure diversity. Richly structured vegetation offers more different living environments, expressed by a mosaic of microclimates and patches of bare and overgrown soil for the carabid beetle and arachnid species. This variety enables colonization for species having more varied habitat requirements compared with a more poorly structured environment (Ysnel & Canard 2000; Schwab et al. 2002; Benton et al. 2003). To interpret the expected differences, the impact of the vegetation structure (of weeds and cultivated plants) on species composition of both animal groups was tested. Based on the aims, we developed the following hypotheses: (1) the stands of novel energy plants will show a significantly higher vegetation structure diversity than the stands of maize, (2) species and preferred habitat diversity will be significantly higher in the fields of novel energy plants than they are in the fields of maize, and (3) the vegetation structure variables of the cultivated plants and the weeds will explain a large proportion of the variance in the species data of the carabid beetle and arachnid assemblages.

**Location, soils, and climate of the sites**

The investigation area Vehlow near Kyritz (52°57′ North, 12°23′ East) is situated in the district OPR in Northeast Brandenburg (Altitude: 40 m N.N.). The pending ground moraine is mostly covered with...
Table 1. Annual average temperature and annual precipitation at the meteorological stations next to the investigation sites (DWD 2014, unpublished, long-term averages 1981–2010).

| Site | Average annual temperature (°C) | Average annual precipitation (mm) | Meteorological station |
|------|---------------------------------|----------------------------------|------------------------|
| OPR  | 9.2                             | 574                              | Kyritz                 |
| UCK  | 8.4                             | 620                              | Feldberg (Mecklenburg) |

drifting sand. Soil types are sands to loamy sands with 13% clay. The predominant soil type throughout the plains area is gley. However, the water content is significantly altered by the deep receiving water (4 m below the ground). The soil quality (Ackerzahl) lies between 25 and 30.

The investigation area Parmen is situated in the district Northwest UCK at a slope of a summit of a ground moraine (100 m N.N.) with an incline of approximately 1.5%. Here, the soil types pallid soil and pseudo-gley are dominant, originating from strong loamy sands and loam of the ground moraine and the top layer, respectively. The soils have a quality (Ackerzahl) of 45. An outline of the long-term averages of temperature and precipitation is shown in Table 1.

Management of the investigation areas

At both sites, the investigations were performed in the second year of standing of the perennial cultures. At OPR, all culture species were fertilized with digestate from the biogas plant. In the maize plot, urea was additionally applied as an inorganic fertilizer. At the UCK site, the energy plants investigated were also fertilized with digestate. In the maize cultures, urea and Kieserite served as additional fertilizers.

The mechanism by which the type of fertilizer directly affects carabid beetle and arachnid conditions is not known, but several investigations clearly demonstrate that organically managed fields (no pesticides and no mineral fertilizers) benefit carabid beetles and arachnids, each of which were stored in 70% ethanol until they were determined at the species level. Carabid beetles were identified according to Müller-Motzfeld (2004), spiders according to Heimer and Nentwig (1991) and Wiehle (1956, 1960), and harvestmen according to Martens (1978). The nomenclature of the carabid beetles followed Köhler and Klausnitzer (2014), while for spiders and for harvestmen, Platnick (2013) and Blick and Komposch (2004) were used as standards for nomenclature, respectively.

At both sides of the pitfall traps, an area of 1 m² was established where plant species composition and vegetation structure were surveyed simultaneously with the changing of the pitfall traps according to the Braun-Blanquet estimation scale (Dierschke 1994). In addition to the coverage of the single plant species, the vegetation structure variables height and coverage of the culture species and the cover values of the herb, grass, moss, and litter layer were surveyed. The percentage of bare ground was calculated as the difference between the total vegetation coverage and 100%.

Data evaluation

Species diversity was characterized by the diversity indices Alpha, Shannon-Wiener, Evenness, and reciprocal Simpson (Magurran 2009), each of which focus on infrequent species, hetero- and homogeneity of the carabid beetle and arachnid assemblages, and the proportion of highly dominant species to different extents. We chose this approach because each index emphasizes a different aspect of the quantitative and qualitative composition of the invertebrate assemblages (Table 2).

A joint interpretation of these indices will give a first impression of the dominance structure. Using the formulae [1]–[4], the diversity indices were calculated for habitat preferences, which may be taken as a measure of the number of potential habitats that may be occupied by species within the cultures. To calculate the diversity of habitat preferences, the number of species was replaced with the number of habitat preferences in the species diversity formulae [1]–[4]. Habitat preferences for carabid beetles were taken from the catalogue of the GAC (2009), while preferences for spiders and harvestmen were taken from Platen et al. (1991). The diversity of vegetation structure was also calculated using the formulae [1]–[4], except that the number of species was replaced by the number of structural variables (cover values of the elements of the vegetation layer and the height of the culture species).

Materials and methods

Data collection

Carabid beetles and arachnids were collected at eight plots using five pitfall traps with an upper diameter of 6.5 cm each (Barber 1931). The traps were placed in a straight line with an intertrap distance of 10 m and filled to one-third with a 4% formaldehyde solution as a preservation fluid. A detergent was added to the solution to reduce the surface tension. The investigation began on 22 April 2013 and ended on 10 October 2013. The traps were changed every fortnight and transported to the laboratory, where they were presorted to carabid beetles and arachnids, each of which were identified according to Müller-Motzfeld (2004), spiders according to Heimer and Nentwig (1991) and Wiehle (1956, 1960), and harvestmen according to Martens (1978). The nomenclature of the carabid beetles followed Köhler and Klausnitzer (2014), while for spiders and for harvestmen, Platnick (2013) and Blick and Komposch (2004) were used as standards for nomenclature, respectively.
Table 2. Definition of species, habitat preferences, and vegetation structure diversity indices, with a description of the scope of their applicability: \(n\); number of individuals of a particular species; \(N\); total number of individuals in a plot; \(p\); relative number of individuals of a particular species (\(n/N\)); \(x\); constant, which is calculated from the quotient \(S/N\) iteratively for every single plot; \(S\); number of species; SHP; number of habitat preferences; HP; habitat preference; SVS; number of vegetation structure elements; vs; relative number of cover values of a particular structural element (\(vs/Cov\text{tot}\)); Cov\text{tot}; total cover value of all vegetation structure elements in a plot; vs: vegetation structure.

| Index | Formula | Focus on |
|-------|---------|----------|
| alpha | \(\alpha = N/(1-x)/x\) \[1\] | Infrequent species |
| Shannon-Wiener | \(H' = -\sum p_i \ln p_i\) \[2\] | Heterogeneity of species composition |
| Evenness | \(E = H'/\ln S\) \[3\] | Equality of the distribution of individuals to the species |
| Reciprocal Simpson | \(D_i = 1/\sum (n_i/(n_i-1-N-1))\) \[4\] | Number of highly dominant species |
| Habitat preference diversity | \(\alpha_{HP}\) \[5\] | Infrequent habitat preferences |
| Shannon-WienerHP | \(H'_{HP} = -\sum p_{i1} \ln p_{i1}\) \[6\] | Heterogeneity of habitat preference composition |
| EvennessHP | \(E_{HP} = H'_{HP}/\ln S_{HP}\) \[7\] | Equality of the distribution of individuals to the different habitat preferences |
| Reciprocal SimpsonHP | \(D_{SP_{HP}} = 1/\sum (n_i/(n_i-1-N-1))\) \[8\] | Number of habitat preferences of a great number of individuals |
| Vegetation structure diversity | \(H'_{VS}\) \[9\] | Heterogeneity of vegetation structure composition |
| Reciprocal SimpsonVS | \(D_{SP_{VS}} = 1/\sum (vs_i/Cov\text{tot}_{vs_i}/Cov\text{tot}_{1-Cov\text{tot}_{1}})\) \[10\] | Number of vegetation structure elements with a great number of high cover values |

As an assessment criterion for the dominance of typical arable field species, we introduced and calculated the Arable Field Affinity-Index (AFAI) based on the Forest Affinity-Index of Allegro and Sciaky (2003). Therefore, the degree of binding to arable fields of carabid beetle and arachnid species was divided into five classes: –1 = no occurrence in arable fields, –0.5 = bound to other habitats but also occurring in arable fields, 0 = eurytopic species, 0.5 = weak binding to arable fields, and 1 = exclusively in arable fields. The class values of the species were then multiplied by the relative activity abundances (\(n_i \times N^{-1}\)) at every single plot and summed afterward. The result is the AFAI, which may take values between –1 = no arable field species are present in the plot and 1 = all species in the particular plot are arable field species.

Computer programs used were EstimateS (Colwell 2013), CANOCO v. 4.5 (Braak & Smilauer 2002), and SPSS v. 22 (IBM Corp., Armonk, NY, USA).

Results

Vegetation structure diversity

The vegetation structure diversity indices for the plots and the two sites are listed in Table 3.

The results demonstrate that the SZ plots at both sites (except for \(\alpha\)) possessed the highest diversity values and consequently had the highest structural diversity. In all cases, the cup plant and the WI plots ranked second. The maize plots had the lowest diversity values and, thus, the poorest vegetation structure.

Biodiversity of the carabid beetle and arachnid assemblages

Alpha diversity

In total, 94 carabid beetle species including 35,077 individuals were found at both sites. The single numbers per plot, the diversity indices, and the AFAI are listed in Table 4. For arachnids, 117 species with 31,749 individuals (111 spider species with 30,326 individuals and 6 harvestmen species with 1423 individuals) were caught (Table 4).

At both sites, the highest numbers of species (with the exception of UCKSI) and the highest diversity indices were calculated for the most richly structured plots, the SZ and WI, while the lowest numbers occurred predominantly in SM. Notably, the AFAI, a measure of the number of typical arable field species, was maximal for carabid beetles in SM only at the UCK site. However, at both sites, the lowest AFAI was calculated at one of the richly structured plots (Table 4).

The effect of the vegetation structure on species composition

Based on the redundancy analysis (RDA), the explanation of the variance in the carabid beetle species data by vegetation structure variables and the cumulative variance explanation on the first four canonical axes are listed in Table 5. For carabid beetles, on the first four axes, 41% of the variance in the species data was explained, and seven vegetation structure variables explained a total of 52% of that variance. The height of the culture plants and the litter coverage had the greatest share, while the proportion of open, uncovered carabid, and the moss coverage contributed only marginally to the variance explanation.

The cumulative percentage variance and the total variance explanation by the vegetation structure variables for arachnids did not differ significantly from the values calculated for carabid beetles. In contrast, the litter cover had the highest share of variance explanation in the carabid beetle species data, while the open, bare ground had the highest value for arachnids. The coverage of the herb layer ranked...
second, while the coverage and height of the crop contributed less to the explanation (Table 5).

The relationship between the vegetation structure variables and the carabid beetle assemblage composition at the plots is shown in Figure 1. The structure-providing variables – the cover values of the herb, grass, moss, and litter layers – were opposite to the poorer structure-providing variables – the coverage of the culture plant and the proportion of open, bare ground. Based on proximity to the first canonical axis and the length of the gradient, the litter cover had the greatest influence in the richly structured plots, whereas the coverage of the culture plant had the maximal influence in the poorly structured plots. In addition, the coverage of the grass layer had minimal influence on species composition (Figure 1).

At the arrowheads of the vegetation structure variable axes, representing gradients, a number of characteristic carabid beetle species are aggregated of both richly and poorly structured plots. In quadrants I and IV, these aggregates include meadow and dry grassland species (Amara ssp. and Harpalus ssp.); in

Table 3. VStruc = vegetation structure. a,b,c,d indicate significant differences: Alpha (sVStruc), Shannon-Wiener (sHsVStruc), Evenness (sEveVStruc), and reciprocal Simpson Index (1/sDVStruc) for the single plots.

| Carabid beetles | OPRSI | OPRSM | OPRSZ | OPRWI | UCKSI | UCKSM | UCKSZ | UCKWI |
|-----------------|-------|-------|-------|-------|-------|-------|-------|-------|
| Nspecies        | 56    | 48    | 62    | 60    | 61    | 48    | 52    | 61    |
| Nindividuals    | 5052  | 3448  | 5630  | 3695  | 6206  | 3799  | 2537  | 4710  |
| α               | 8.82  | 7.89  | 9.75  | 10.17 | 9.39  | 7.74  | 9.26  | 9.89  |
| H               | 2.73  | 2.27  | 2.38  | 3.05  | 2.86  | 2.20  | 3.00  | 2.76  |
| Evenness        | 0.68  | 0.59  | 0.58  | 0.74  | 0.70  | 0.57  | 0.76  | 0.67  |
| AFAI            | 0.30  | 0.19  | 0.40  | 0.17  | 0.47  | 0.59  | 0.36  | 0.47  |
| Nsig           | 13    | 13    | 15    | 13    | 15    | 13    | 12    | 17    |
| Hsig            | 1.63  | 1.82  | 1.88  | 1.71  | 1.87  | 1.69  | 1.65  | 2.25  |
| EveVsig         | 1.13  | 1.10  | 1.06  | 1.36  | 1.07  | 0.69  | 1.77  | 0.92  |
| 1/DVsig        | 0.44  | 0.43  | 0.39  | 0.53  | 0.40  | 0.27  | 0.71  | 0.32  |
| NArachnid       | 13    | 13    | 15    | 13    | 15    | 13    | 12    | 17    |
| HArachnid       | 1.63  | 1.82  | 1.88  | 1.71  | 1.87  | 1.69  | 1.65  | 2.25  |
| EveVArachnid    | 1.13  | 1.10  | 1.06  | 1.36  | 1.07  | 0.69  | 1.77  | 0.92  |
| 1/DVArachnid   | 0.44  | 0.43  | 0.39  | 0.53  | 0.40  | 0.27  | 0.71  | 0.32  |

Table 4. Number of carabid beetle and arachnid species (Nspecies), number of individuals (Nindividuals), species diversity indices (α), Shannon-Wiener (Hs), Evenness and reciprocal Simpson 1/D, AFAI, and diversity indices for habitat preferences (HP) at the investigation plots. Five traps per plot.

| Carabid beetles | OPRSI | OPRSM | OPRSZ | OPRWI | UCKSI | UCKSM | UCKSZ | UCKWI |
|-----------------|-------|-------|-------|-------|-------|-------|-------|-------|
| Nspecies        | 56    | 48    | 62    | 60    | 61    | 48    | 52    | 61    |
| Nindividuals    | 5052  | 3448  | 5630  | 3695  | 6206  | 3799  | 2537  | 4710  |
| α               | 8.82  | 7.89  | 9.75  | 10.17 | 9.39  | 7.74  | 9.26  | 9.89  |
| H               | 2.73  | 2.27  | 2.38  | 3.05  | 2.86  | 2.20  | 3.00  | 2.76  |
| Evenness        | 0.68  | 0.59  | 0.58  | 0.74  | 0.70  | 0.57  | 0.76  | 0.67  |
| AFAI            | 0.30  | 0.19  | 0.40  | 0.17  | 0.47  | 0.59  | 0.36  | 0.47  |
| Nsig           | 13    | 13    | 15    | 13    | 15    | 13    | 12    | 17    |
| Hsig            | 1.63  | 1.82  | 1.88  | 1.71  | 1.87  | 1.69  | 1.65  | 2.25  |
| EveVsig         | 1.13  | 1.10  | 1.06  | 1.36  | 1.07  | 0.69  | 1.77  | 0.92  |
| 1/DVsig        | 0.44  | 0.43  | 0.39  | 0.53  | 0.40  | 0.27  | 0.71  | 0.32  |

Table 5. Variance explanation of the carabid beetle (above) and arachnid species data by the vegetation structure variables (relative numbers). Axis 1–4: first to fourth canonical axes; StructVar: vegetation structure variables (Legend: see Figure 1); VarExpl: variance explanation; Cov: cover value; Total: total variance explanation by all structure variables; and cumulative percentage variance of carabid beetle and arachnid species data.

| StructVar | CovCult | HeightCult | CovHerb | CovGrass | CovMoss | CovLitt | Covopen | Total |
|-----------|---------|------------|---------|----------|---------|---------|---------|-------|
| VarExpl   | 0.15    | 0.21       | 0.10    | 0.10     | 0.04    | 0.18    | 0.09    | 0.52  |
| Axis 1    | 0.34    | 0.18       | 0.10    | 0.10     | 0.04    | 0.18    | 0.09    | 0.52  |
| 21.7      | 0.33    | 0.17       | 0.10    | 0.10     | 0.04    | 0.18    | 0.09    | 0.52  |
| StructVar | 0.08    | 0.02       | 0.00    | 0.00     | 0.00    | 0.00    | 0.00    | 0.00  |
| VarExpl   | 0.07    | 0.01       | 0.02    | 0.02     | 0.00    | 0.00    | 0.00    | 0.00  |
| Axis 1    | 0.12    | 0.02       | 0.03    | 0.03     | 0.00    | 0.00    | 0.00    | 0.00  |
| 45.1      | 0.52    | 0.13       | 0.14    | 0.14     | 0.00    | 0.00    | 0.00    | 0.00  |
quadrants II and III, they include predominantly arable field species, such as *Bembidion* ssp., *Agonum muelleri* (Herbst), and *Anchomenus dorsalis* (Pontoppidan).

The ordination diagram for arachnids (Figure 2) presents a similar arrangement of the vegetation structure axes and the centroids of the plots to the one for the carabid beetles, but the distance between the plots is shorter in the diagram for the arachnids than for the carabid beetles (Figure 2).

The cover values of litter and the crop had the highest impact on species composition, while grass and moss coverage had the lowest impact (Figure 2). At the arrowheads of the structure-providing variables in quadrants I and IV, a number of lycosid spider species of the genus *Pardosa* and dry grassland species of the genus *Xysticus* are aggregated, while at the arrowheads of the less structure-providing variables in quadrant III, the aggregate includes arable field species among the linyphiid spiders (*Agyneta rurestris* (C.L. Koch), *Bathyphantes gracilis* (Blackwall), *Oedothorax apicatus* (Blackwall), and *Porrhomma* spp. (Figure 2)).

**Discussion**

The results of our investigations showed a clear relationship between the vegetation structure and the composition of the carabid beetle and arachnid assemblages regarding species diversity. Plots with richly structured vegetation, especially the SZ and the WI, showed significantly higher values in nearly all biodiversity indices than the maize and cup plant plots, whose vegetation structure was more simplified. Thus, the richly structured plots possessed not only a higher species richness and a higher number of infrequent species (expressed by the α-value) but also a higher number of dominant species (expressed by the reciprocal Simpson Index) and, thus, a more balanced dominance structure compared to that in maize. Therefore, a positive relationship exists between higher species richness, habitat preference diversity, and vegetation structure. This relationship with habitat preferences primarily indicates that more richly structured vegetation provides more habitats for species with different ecological demands.

One may suppose that an additional risk of decreased biodiversity would result from the cropping of energy plants. However, many recent publications note that both the type and the extent of these effects depend on numerous factors (Dauber et al. 2010; Rowe et al. 2013), including the design of the cultivation practices (Tilman et al. 2009). The effects on biodiversity also vary depending on the use-paths of the biomass. While the production of biodiesel fuel and bioethanol is based on the use of a reduced number of traditional crops (cereals, rape, and palm oil), the
processing of biomass from biogas production provides numerous new options for diversification in agricultural farming. The use of wet biomass for biogas production allows a renaissance for the cultivation of perennial crops (e.g., clover grass, Miscanthus), the introduction of new crops (Sorghum, SZ [Elymus elongatus subsp. ponticus cv. Szarvas-1], and the cup plant [Silphium perfoliatum]), and the cultivation of mixed crops (flowering mixtures and vetch rye). By comparing novel energy plants (amaranth, legume grass, and sun flowers) with maize and SRCs, Mast et al. (2012) found a higher species richness of carabid beetles in novel energy crop cultures. For arthropod assemblages, Meek et al. (2002) identified the reduced management activities (soil tillage, fertilization, and pest control) in perennial cultures as the strongest explanatory variable for the number of species diversity in field margins.

The impact of different farming systems on species diversity was investigated by Östman et al. (2001). They compared the condition expressed by the fat reserves of four polyphagous carabid beetles caught in five farms that were organically managed and five farms that were conventionally managed and found that the condition of one species was significantly better in organically than in conventionally farmed fields, and the three other species showed a similar trend. Dritschilo and Wanner (1980) found twice the number of species and seven times the number of individuals on farms that were organically managed than on conventionally managed farms. In all field studies that compare organic with conventional farming, the organically managed fields were not sprayed with pesticides and no mineral fertilizers were used. Between these two measures, pesticide use seems to be the most responsible for the lower numbers of species and individuals. Basedow (1987) considers pesticides as the main factor responsible for the reduced numbers in species and individuals in conventionally farmed wheat fields. Additionally, an indirect negative impact may originate from the reduction of food supply (especially in Collembola, which is one of the main food resources for smaller carabid beetles and spiders), the reduction of phytophagous insects (Eigenbrode & Pimentel 1988), and the reduction of weeds that cause the loss of food resources for polyphagous carabid beetles as well as the loss of shelter (Piffner & Niggli 1996). On the other hand, organic fertilization may improve saprophagous mesofauna (Purvis & Curry 1984) and thus benefit epigeic predators.

Based on investigations made in meadows, Schwab et al. (2002) highlighted vegetation structure as a key parameter of biodiversity. Ysnel and Canard (2000) found no relationships between vegetation structure in hedgerows and the species diversity of spiders.

The impact of the vegetation structure on quantitative and qualitative features is also illustrated by the results of the RDA. In both animal groups, more than 50 % of the variance in the species data is explained by the vegetation structure variables. This value lies in the upper range of the values provided by Schwab et al. (2002). The largest share of the variance in the carabid beetle species data is explained by the coverage of the litter layer that provides shelter, food resources, and overwintering habitat and the coverage of the crop plants, while the largest share of the variance in the arachnid data is primarily explained by the proportions of bare ground and herb layers that provide web attachment points for web-building species. Benton et al. (2003) emphasized the support of species and individual numbers as well as the nutrition supply for animals through structural diversity on different scales (landscape, farm, and field scale). On the field scale, the density and geometry of the crop species planting improve the nutrition supply for spiders (Harwood et al. 2001; Vickery et al. 2001) and increase the population density of carabid beetles (Thomas et al. 2001).

Büchs (2012) critically asks whether increased structure in crop stands will always have a ‘beneficial effect’ on species composition. He highlighted the problem that, depending on the size of the geographic range, increased structure will indeed increase the numbers of species in many cases, but this gain often means an increase in species with no identifiable preference to abiotic factors only. For instance, in dry arable fields, an artificially induced increase in structure will lead to a decrease in specialists adapted to dry and warm climates. He concluded that an ecologically meaningful assessment of the agrarian landscape cannot be based on species richness alone but must also consider the numbers of specially adapted species. For our investigation sites, we could show that the plots cropped with novel energy plants, and thus were richly structured, not only possess a higher species richness but also promote feeding and habitat specialists among carabid beetles such as Calosoma auripunctatum (Herbst), Carabus auratus (Linné), Dolichus halensis (Schaller), and Poecilus punctulatus (Schaller), but there were strong differences between the regions. This pronounced regionality will become important when examining the composition of the ecological groups. The regional differences can be attributed to the different species inventory, the site characteristics, and the shaping of the vegetation structure of the single energy plant.

Our investigations demonstrate that biodiversity in all the fields cropped with novel energy plants was significantly higher than in the maize fields. This finding holds not only for different aspects of species diversity but also for the preferred habitat diversity. These increased diversities are connected with the richly structured vegetation, especially in the SZ and wildflower plots. Analogous to the findings of
Emmerling (2014) for soil mesofauna, we may say that novel energy plants with a complex vegetation structure can deliver positive contributions to the promotion of differentiated carabid beetle and arachnid assemblages. However, because of our preliminary results from a 1-year study, we are aware that our findings cannot be generalized or uncritically transferred to other regions or to cropping systems with different energy crops.

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Disclosure statement

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References

Allegro G, Sicaký R. 2003. Assessing the potential role of ground beetles (Coleoptera, Carabidae) as bioindicators in popular stands, with a newly introduced ecological index (FAI). For Ecol Manage. 75:275–284.

Altieri MA. 1999. The ecological role of biodiversity in agroecosystems. Agr Ecosyst Environ. 74:19–31.

Barber HS. 1931. Traps for cave-inhabiting insects. J Elisha Mitchell Scientific Society. 46:259–266.

Basedow T. 1987. Der Einfluss gesteigerter Bewirtschaftungsintensität im Getreidebau auf die Laufkäfer (Col. Carabidae). Auswertung 14-jähriger Untersuchungen (1971-1984). Mitteilungen Der Biologischen Bundesanstalt Berlin-Dahlem. 235:1–123.

Benton TG, Vickery JA, Wilson JJ. 2003. Farmland biodiversity: is habitat heterogeneity the key?. Trends Ecol Evol. 18:182–188.

Blick T, Komposch C. 2004. Checklist of the harvestmen of Central and Northern Europe, (Arachnida: opiliones), version 27, December 2004 [Internet]. Putbus: Arachnologische Gesellschaft; cited 2014 Dec 12. Available from https://arages.de/files/checklist2004_opiliones.pdf

Braak T, Smilauer P. 2002. CANOCO reference manual and canadraw for Windows user’s guide. Software for canonical community ordination [CD-ROM]. Version 4.5. Wageningen and České Budějovice: Biometris. 1. CD-ROM.

Büchs W. 2003. Biodiversity and agri-environmental indicators – general scopes and skills with special reference to the habitat level. Agr Ecosyst Environ. 98:35–78.

Büchs W. 2012. Bewertung der Evertterbraten-Biodiversität landwirtschaftlicher Nutzflächen – Möglichkeiten und Grenzen der Nutzung biotischer Elemente als Indikatoren für Biodiversität der Agrarlandschaft [Evaluation of the invertebrate biodiversity of arable land – potential and limits to use biotic parameters as indicators for the biodiversity of rural areas]. Julius-Kühn-Archiv. 436:44–53.

[DBFZ] Deutsches Biomasseforschungszentrum 2012. Monitoring zur Wirkung des Erneuerbare-Energien-Gesetz (EEG) auf die Entwicklung der Stromerzeugung aus Biomasse. Endbericht für die Periode 2009-2011. [Monitoring for the impact of the renewable energy law (EEG) on the development of the electricity production from biomass. Final report for the period 2009-2011]. [Internet]. [cited 2015 Jan 21]. Available from: http://www.dbfz.de/web/fileadmin/user_upload/Berichte_Projektdatenbank/3330002_Stromerzeugung_auß_Biomasse_Endbericht_Veröffentlichung_FINAL_FASSUNG.pdf; p.1–120.

[DMK] Deutsches Maiskomitee 2014. Maisanbaufläche in Deutschland 2014 [Cultivation area of maize in Germany]. [Internet]. [cited 2015 Jan 21]. Available from: http://www.maiskomitee.de/web/public/Fakten.aspx/Statistik/Deutschland

[EU] European Union. 2009. Directive 09/28/EG of the European Parliament and Council of 23 April 2009 concerning the promotion and use of energy from renewable sources and concerning the alteration and subsequent cancelation of the directives 2001/77/EG und 2003/30/EG 2009.04.23 L140. Brussels: EU. p. 16e62.

[FNR] Specialist Agency for Renewable Raw Materials. 2013. EVA phase III [Internet]. [cited 2015 Feb]. Available from: http://www.eva-verbund.de/home.html

[GAC] Gesellschaft für angewandte Carabidologie 2009. Lebensraumpräferenzen der Laufkäfer Deutschlands. Wissensbasierter Katalog [Habitat preferences of the carabid beetles of Germany. A knowledge based catalogue]. Angewandte Carabidologie. 1–45.Supplement.

Colwell RK 2013. EstimateS: statistical estimation of species richness and shared species from samples (software and user’s guide) [Internet]. Version 9. [cited 2014 Feb 4]. Available from: http://purl.oclc.org/estimates

Dauber J, Jones MB, Stout JC. 2010. The impact of biomass crop cultivation on temperate biodiversity. GCB Bioenergy. 2:289–309.

Dierschke H. 1994. Pflanzensoziologie: grundlagen und methoden [Phytosociology: basic principles and methods]. Stuttgart: Ulmer.

Dieter A. 2014. Agra Europe news [Internet]. [cited 2015 Apr 26]. Available from: http://www.topagrar.com/news/Energie-Energienews-Alternative-Energiepfanzen-ver-dienen-mehr-Bauchtung-1593587.html

Dritschilo W, Wanner D. 2010. Ground beetle abundance in organic and conventional corn fields. Environ Entomol. 9:629–631.

Eigenbrode SD, Pimentel D. 1988. Effects of manure and chemical fertilizers on insect pest populations on clover. Agr Ecosyst Environ. 20:109–125.

Emmerling C. 2014. Impact of land-use change towards perennial energy crops on earthworm population. Appl Soil Ecol. 84:12–15.

Farínós GP, De La Poza M, Hernández-Crespo P, Ortego F, Castañana P. 2008. Diversity and seasonal phenology of...
aboveground arthropods in conventional and transgenic maize crops in Central Spain. Biol Control. 44:362–371.

Felen D, Emmerling C. 2011. Effects of bioenergy crop cultivation on earthworm communities – a comparative study of perennial (Miscanthus) and annual crops with consideration of graded land-use intensity. Appl Soil Ecol. 49:167–177.

Harwood JD, Sunderland KD, Symondson WOC. 2001. Living where the food is: web location by linyphiid spiders in relation to prey availability in winter wheat. J Appl Ecol. 38:88–99.

Heimer S, Nentwig W. 1991. Spinnen Mitteleuropas: ein Bestimmungsbuch [Spiders of Central Europe: an identification book]. Berlin: Parey.

Kapfenstein-Machan M. 2013. Integrative energy crop cultivation as a way to a more nature-orientated agriculture. In: Ruppert H, Kappas M, Ibendorf J, editors. Sustainable bioenergy production – an integrated approach. The Netherlands: Springer; p. 143–180.

Köhler F. 1998. Zur Bestandssituation an Ackerkulturen lebender Blatt- und Rüsselkäferarten in Deutschland (Coleoptera, Chrysomelidae, Curculionidae s.l.). Schriftenreihe Landesanstalt Für Pflanzenbau Und Pflanzenschutz Rheinland-Pfalz. 6:243–254.

Köhler F, Klautzner B 2014. Coleoac. Entomofauna Germanica. Verzeichnis der Käfer Deutschlands [Catalogue of the beetles of Germany] [Internet]. [cited 2015 July 22]. Available from: http://www.coleokat.de/de/ndl/

Magurran AE. 2009. Measuring biological diversity. Oxford: Blackwell.

Martens J. 1978. Weberknechte, Opiliones [Harvestmen, Opiliones]. In: Senglaub K, Hannemann HJ, Schumann H, editors. Die Tierwelt Deutschlands Volume 64 [The fauna of Germany]. Jena: Fischer; p. 1–464.

Mast B, Graeff Hönniger S, Claupein W. 2012. Evaluation of carabid beetle diversity in different bioenergy cropping systems. Sustainable Agric Res. 1:127–140.

McIntyre PB, Jones LE, Flecker AS, Vanni MJ. 2007. Fish extinctions alter nutrient recycling in tropical freshwater. P Natl Acad Sci USA. 104:4641–4646.

Meek B, Loxton D, Sparks T, Pywell R, Pickett H, Nowakowski M. 2002. The effect of arable field margin composition on invertebrate biodiversity. Biol Conserv. 106:259–271.

Meyer S, Hoeber S, Nehring S, Leuschner C. 2014. Konsequenzen des Bioenergiepflanzenanbaus für die Segetalvegetation. Natur Und Landschaft. 89:429–433.

Müller-Motzfeld G. 2004. Vol. 2 Adephyaga 1: carabidae (carabid beetles). In: Freude H, Harde KW, Lohse GA, Klausnitzer B, editors. Die Käfer Mitteleuropas [The beetles of Central Europe], Heidelberg and Berlin: Spektrum Akademischer Verlag.

Östman Ö, Ekholm B, Bengtsson J, Weibull AC. 2001. Landscape complexity and farming practice influence the condition of polyphagous carabid beetles. Ecol Appl. 11:480–488.

Pedroli B Elbersen B, Frederiksen P, Grandin U, Heikkila R, Krogh PH, Iakovichiova Z, Johansen A, Meiresonne L, Spijker J. 2013. Is energy cropping in Europe compatible with biodiversity? Opportunities and threats to biodiversity from land-based production of biomass for bioenergy purposes. Bioenergy Research. 5:73–86.

Pereira HP, Leadley PW, Proença V, Alkemade R, Scharlemann JPW, Fernandez-Manjarrés JR, Araújo MB, Malvaneira P, Biggs R, Cheung WWL, et al. 2010. Scenarios for global biodiversity in the 21st century. Science. 330:1496–1501.

Pfiffner L, Niggli U. 1996. Effects of bio-dynamic, organic and conventional farming on ground beetles (Col. Carabidae) and other epigaic arthropods in winter wheat. Biol Agric Hortic. 12:353–364.

Platen R, Moritz M, Broen B. 1991. Liste der Webspinnen- und Weberknechtarten (Arach.: araneida, Opilionida) des Berliner Raumes und ihre Auswertung für Naturschutzzwecke (Rote Liste) [Checklist of the spiders and harvestmen in the Berlin area and its evaluation for nature conservation purposes (Red List)]. In: Auhagen A, Platen R, Sukkopp H, editors. Rote Liste der gefährdeten Pflanzen und Tiere in Berlin. [Red List of the endangered plants and animals of Berlin]. Landschaftsentwicklung und Umweltforschung S 6. Berlin: Technische Universität; p. 169–205.

Platnick NI. 2013. The World Spider Catalogue. Version 13.5. New York (NY): American Museum of Natural History.

Pozza De La M, Pons X, Farinós GP, Lópe L, Ortego F, Eizaguirre M, Castañera G, Albajes R. 2005. Impact of farm-scale Bt maize on abundance of predatory arthropods in Spain. Crop Prot. 24:677–684.

Purvis G, Curry JP. 1984. The influence of weeds and farmyard manure on the activity of Carabidae and other ground-dwelling arthropods in a sugar beet crop. J Appl Ecol. 21:271–283.

Robertson BA, Porter C, Landis DA, Schemske W. 2012. Agroenergy crops influence the diversity, biomass, and guild structure of terrestrial arthropod communities. Bioenergy Res. 5:179–188.

Rowe L, Coulson D, Doncaster P, Clarke DJ, Taylor G, Hanley ME. 2013. Evaluating ecosystem processes in willow short rotation coppice energy plantations. GCB Bioenergy. 5:257–266.

Schwab A, Dubois D, Fried PM, Edwards P. 2002. Estimating the biodiversity of hay meadows in north-eastern Switzerland on the basis of vegetation structure. Agr Ecosys Environ. 93:197–209.

Thomas CFG, Parkinson L, Griffiths GJK, Fernandez Garcia A, Marshall EJP. 2001. Aggregation and temporal stability of carabid beetle distributions in field and hedgerow habitats. J Appl Ecol. 38:100–116.

Tilmann D, Socolov R, Foley JA, Hill J, Larson E, Lynd L, Pacala S, Reilly J, Searchinger T, Somerville C, et al. 2009. Beneficial biofuels – the food, energy, and environment trilemma. Nature. 325:270–271.

Tschermke T, Klein AM, Krueck A, Steffan-Dewenter I, Thies C. 2005. Landscape perspectives on agricultural intensification and biodiversity–ecosystem service management. Ecol Let. 8:857–874.

Vickery JA, Tallon JW, Feber RE, Asteraki EL, Atkinson PW, Fuller RJ, Brown JK. 2001. The influence of lowland neutral grasslands in Britain: effects of agricultural practices on birds and their food resources. J Appl Ecol. 38:647–664.

Wiehle H. 1956. Linyphiidae-Baldachinspinnen. Die Tierwelt Deutschlands und angrenzender Meeresteile [Linyphiidae-Sheet spiders. The fauna of Germany and adjacent parts of the sea]. Vol. 44. Jena: Fischer.

Wiehle H. 1960. Micryphantidae-Zwergspinnen. Die Tierwelt Deutschlands und angrenzender Meeresteile [Micryphantidae-Dwarf spiders. The fauna of Germany and adjacent parts of the sea]. Vol. 47. Jena: Gustav Fischer.

Ysnel F, Canard A. 2000. Spider diversity in connection with the vegetation structure and the foliage orientation of hedges. J Arachnol. 28:107–114.
Appendix

A1: Key to the abbreviations of the carabid beetles’ species names

Acu meri = Acupalpus meridianus, Ago muell = Agonum muelleri, Ama aeni = Amara aenea, Ama apri = Amara apricaria, Ama auli = Amara aulica, Ama bifr = Amara bifrons, Ama comm = Amara communis, Ama cons = Amara consularis, Ama conv = Amara convexior, Ama fami = Amara familiaris, Ama fulv = Amara fulva, Ama ovat = Amara ovata, Ama pleb = Amara plebeja, Ama simi = Amara similata, Anc dors = Anchomenus dorsalis, Asa flav = Asaphidion flavipes, Asa pall = Asaphidion pallipes, Bem bigu = Bembidion biguttatum, Bem femo = Bembidion femoratum, Bem lampro = Bembidion quadriraculatum, Bro ceph = Broscus cephalotes, Calambi = Calathus ambiguus, Cal cinc = Calathus cinctus, Cal erra = Calathus erratus, Cal fusc = Calathus fuscipes, Cal mel = Calathus melanocephalus, Cal auro = Calosa auropunctatum, Car aura = Carabus auratus, Car gran = Carabus granulatus, Cli foss = Clivina collaris, Cli fusc = Clivina fuscata, Dol hal = Dolichus halensis, Dys glob = Dyschrius globosus, Har affi = Harpalus affinis, Har calc = Harpalus calcagnus, Har dist = Harpalus distinguendus, Har froe = Harpalus froelichii, Har gris = Harpalus griseus, Har latu = Harpalus latus, Har lute = Harpalus luteicornis, Har rubr = Harpalus rubripes, Har rufi = Harpalus rufipes, Har sign = Harpalus signaticornis, Har smar = Harpalus smaragdinus, Har tard = Harpalus tardus, Lim assi = Limodromus assimilis, Lor pilic = Loricer{a} pilicornis, Mic minu = Microlestes minutulus, Neb brev = Nebria brevicollis, Not bigu = Notiophilus biguttatus, Oph rufi = Ophonus rufbarbis, Poe cupr = Pocelius cupreus, Poe lepi = Pocelius lepidus, Poe vers = Pocelius versicolor, Pte mela = Pterostichus melanarius, Pte nigre = Pterostichus niger, Pte vern = Pterostichus vernalis, Syn fove = Symptoma foveatum, Syn viva = Synuchus vivalis, Tre quad = Trechus quadriraculatus, Tre seca = Trechus secalis, Zab tene = Zabrus tenebrioides.

A2: Key to the abbreviations of the arachnid species names

Agy rure = Agyneta rurestris, Alo barb = Alopecosa barbipes, Alo cune = Alopecosa cuneata, Alo pulv = Alopecosa pulverselenta, Ara humi = Araeoncus humilis, Arc peri = Arctosa perifera, Bat grac = Bathyphantes gracilis, Cen sylv = Centromerus sylvaticus, Dip conc = Diplostyla concor, Dip retu = Diplostyla retusus, Lei blac = Leiobunum blackwalli, Mer tril = Mermessus trilobatus, Mic pusi = Microlinyphia pusilla, Oed apic = Oedothorax apicatus, Oed fusc = Oedothorax fuscus, Oed retu = Oedothorax retusus, Pac cler = Pachygnatha clercki, Pac dege = Pachygnatha degeeri, Par agre = Pardosa agrestis, Par amen = Pardosa amentata, Par pal = Pardosa palustris, Par prat = Pardosa pratovagia, Par pul = Pardosa pullata, Pel para = Pelecosus parallelus, Pha opil = Phalangium opilio, Pir pira = Pirata piraticus, Pir conv = Porrhomma convexum, Por micr = Porrhomma microphthalmum, Ril tria = Rilaena triangularis, Rob livi = Robertus lividus, Ste phal = Steatoda phalerata, Ten tenu = Tenuiphantes tenuis, Tro ruri = Trochosa ruricola, Xer mini = Xerolycosa miniata, Xys cris = Xysticus cristatus, Xys koch = Xysticus kochi, Zel petr = Zelotes petrensis.